Survival and injuries of cod, haddock and saithe that escape through codends and sorting grids in a commercial fishery

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Abstract

Survival rates and injuries of haddock (*Melanogrammus aeglefinus*), cod (*Gadus morhua*) and saithe (*Pollachius virens*) were studied after they escaped from codends and grids in full-scale trials in the Barents Sea. Escaped fish were collected in a cage connected to a hooped codend cover for the codend escapees, or a grid cover for the grid escapees. Trawl-caught controls were sampled by removing the codend and attaching the cage to the trawl extension. Acoustic release devices were used to time the sampling. Due to technical problems, the replicates were fewer than planned. Control fish were also sampled in fish traps. Survival rates of cod and saithe were 100%. Haddock survival was lower (50–98%) and in some cases related to fish length. Haddock survival could not be shown to depend upon the selectivity device, but the number of replicates does not allow us to draw a firm conclusion. Scale loss of haddock decreased as fish length increased in all experimental groups. Cod and saithe suffered fewer skin and fin injuries than haddock.

Key words: survival, cod, haddock, trawl, injuries, saithe

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Introduction

For the efficient management of any fishery, the overall mortality associated with the exploited fish stocks needs to be taken into account. If this is not done, the estimates of the potential yield of the stocks will be biased, with the degree of inaccuracy depending on the extent of the unknown mortality (Cook, 2003). To date, conservation regulations for trawls have focused on improving the size selectivity of codends, for example by increasing mesh size, modifying the shape of codend meshes, or introducing sorting grids or selectivity panels into the trawl (e.g. Valdemarsen and Suuronen 1993. The selective devices sort out small fish, which are usually of less value or illegal to catch, and it is important for the development of the fish stocks that escaping fish survive. Several studies have shown that although this may be the case for some species, it is definitely not so for all.

In one of the most studied groups of fish, the gadoids, low mortality rates have been observed in cod and saithe (Soldal et al., 1993; Suuronen et al., 2005). Haddock tend to be more vulnerable, with escape mortality estimates ranging from 0 to 30% (Soldal et al., 1993; Sangster et al., 1996; Soldal and Engås, 1997). Some studies have shown an inverse relationship between survival rates of haddock and their length (Sangster et al., 1996). The highest mortality seems to occur during the first 24 hours after escape and declines with time. Smaller escapees have been observed to die sooner than larger individuals (Sangster et al., 1996).

Most survival studies carried out so far have not reflected true commercial fishing conditions. In the late 80s and early 90s gadoid survival was studied in the Norwegian bottom trawl fisheries north of 62°N (Soldal et al., 1993; Soldal and Engås, 1997). Ten years later, fishermen's organisations criticised the experiments as being unrealistic as regards towing times and choice of fishing grounds. As in other early survival studies, escapees were sampled only at the beginning of each trawl haul. In addition, repeated contact with gear in an area of high fishing intensity could potentially increase the mortality of fish to beyond the levels observed in the experiments. In response to the criticism, a new set of experiments, reflecting the commercial conditions, was carried out on an active fishing ground in the Barents Sea in 2000 and 2001, employing a new experimental technique. The new method enabled us to perform trawl hauls of commercial length while keeping the sampling time short, by timing both the start and end of the escapee-sampling period by means of acoustic releases.

Materials and methods

Two separate survival experiments were carried out: one in August 2000 (trial 1) and one in August 2001 (trial 2). Both took place in the Barents Sea off the Varanger Peninsula in Northern Norway (Figure 1). In order to simulate fishing intensity on active fishing grounds, three trawlers with 745–1790 kW engines, rigged with their own bottom trawls and Sort-X sorting grids, fished within a specified area for a week before the experiments started. About 70 hauls were made in each trial.

The trawlers that performed the experimental hauls had 1790 kW main engines, and were rigged with their own commercial bottom trawls (Alfredo no. 3 and Cotesi no. 3). The codend was made of 2 × 5 mm braided Magnet-PE twine with a nominal mesh size of 135 mm (measured to 138 mm, SE = 0.7 mm). The overall length of the codend was 9.4 m and its circumference was 62 meshes (including selvedges). The tapered extension between the trawl and codend was 14 m long. To collect grid escapees, a Sort-X stainless steel sorting grid (Larsen and Isaksen, 1993) with 55 mm bar spacing was fitted to the trawl. Escaping fish were collected in cages attached to cover nets, either covering the codend in order to catch codend escapees and control fish (Figure 2, B and C) or the opening of the sorting grid (Figure 2, A) to catch grid escapees.

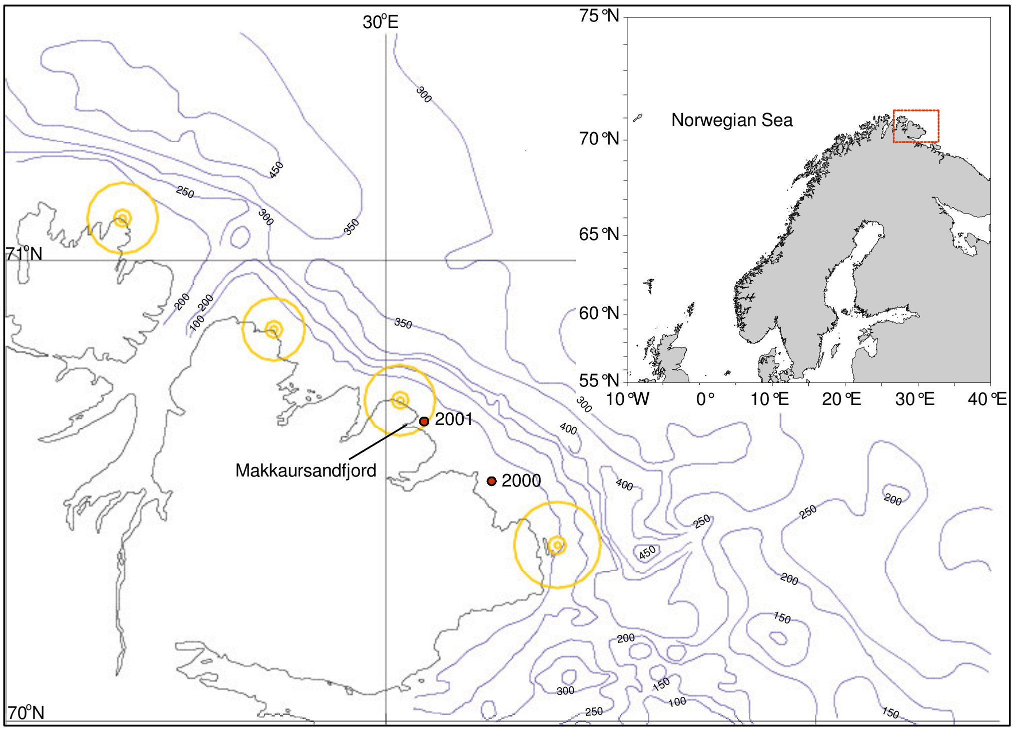

Fig. 1. The location of the experiments.

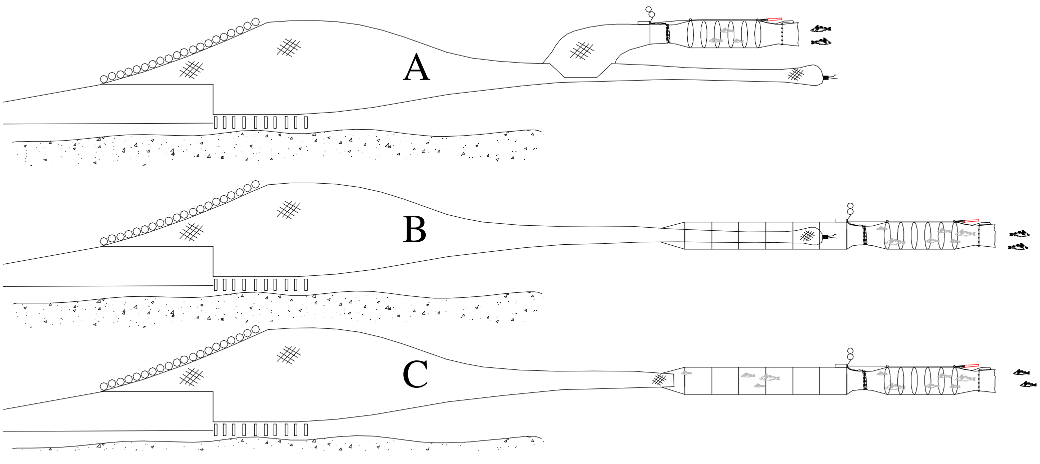

Fig. 2. Cover nets and cages; A: Sampling of grid escapees, B: Sampling of mesh escapees, and C: Sampling of control fish where codend has been removed.

A total of nine cages were used to collect fish during each experiment. In the first trial, they were collapsible, with a large volume and designed to be positioned mid-water. They were cylindrical; 5 m long, 2 m in diameter with hoops made of 25 mm plastic tubing. However, the vertical transport of fish and placement of cages mid-water later raised some concerns about being potential sources of mortality. Therefore, in the second trial, square cages ($5 \times 2 \times 2$ m) constructed of 70 mm aluminium tubing frames were used and placed on the seabed. The frames were lined with knotted square mesh netting (50 mm stretched mesh, twine diameter 1.8 mm Polyethylene). The rear end of the cages (the closing net) was made of 19.6 mm Polyamide netting. Two acoustic releases (AR 661 B2S from Oceano Technologies) were mounted on the cover net in front of the cage.
Fish were sampled from grid and mesh escapees plus a control haul, for which the codend was removed. To minimize variation in fish density over time, the categories(grid, mesh, control) were dispensed throughout the experimental period. The trawlers towed for approximately 1 h at a speed of 1.8 to 2 ms^{-1} (3.5 to 4 knots) with the cage open at the rear, allowing all the fish to pass through it. To start sampling escapees, a signal was sent to the first release unit, which released a sea anchor that closed the rear end of the cage. Some difficulties with this closing method were encountered in our experiment (see Discussion). The cage was then monitored by a towed underwater vehicle with a light sensitive camera, and released and closed when 100-200 individuals were estimated to have entered the cage, which was released from the cover net with the second acoustic releaser. Floats rose to the surface, maintaining tension at the front end of the cage and keeping it closed (see Figure 3 for chronological order of grid-cage release). Sampling time was defined as the time between the first and the second release, and varied from 5 to 15 minutes.

Following release in trial 1, the cages were raised to a depth of 40-50 m and anchored on the fishing grounds where they were released. The towing depths

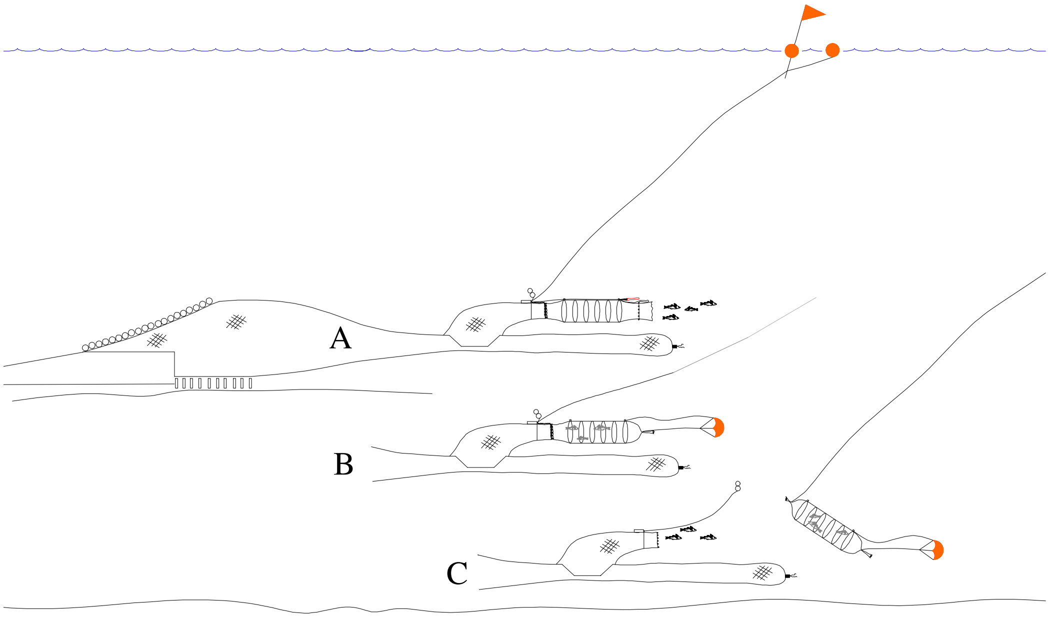

Fig. 3. A: Trawl towed with cage open; cover net encloses the Sort-X grid, B: Sea anchor released by acoustic release closes the cage and fish sampling begins, C: Cage released and closed in front by acoustic release.

were 70 to 90 m. A depth limit of 100 m for fishing and releasing of the cages was pre-set in order to avoid violating a safety limit of max 50% pressure reduction (Tytler and Blaxter, 1973). An active radar buoy was attached to each surface buoy in order to facilitate tracking during the next few days.
In trial 1 some anchors did not grasp properly due to strong currents, and some of the cages drifted several km during the observation period, which complicated the tracking process. Therefore, in trial 2, after towing from depths of 40 to 70 m to depths less than 30 m, the cages were released and towed by an auxiliary vessel into a sheltered area and anchored on the bottom at 20 to 30 m depth close to the shoreline. The towing speed was max 0.5 ms^{-1} (1 knot) and towing time 50 to 85 min. The current speed was 0 to 0.3 ms^{-1}, as measured by a current meter anchored close to the cages. The water temperature at the anchorage in trial 2 was 8.6 to 9.1°C (not measured in trial 1).
The cages were inspected by underwater video immediately after release in order to estimate the quantity of fish and to check that they were properly closed. Thereafter, when weather permitted, they were inspected every second day until recovered. In trial 1 a camera was rigged on the lower end of a metal bar and lowered to the cage along the buoy rope. In trial 2 a remotely operated vehicle was used.
A second control group of trap-caught fish was included in trial 2. Three fish traps (1.8 × 1.8 × 2.2 m) baited with mackerel were set out at the anchoring sites and observed daily by underwater video. When sufficient numbers of fish had entered, the traps were closed and left on the seabed.

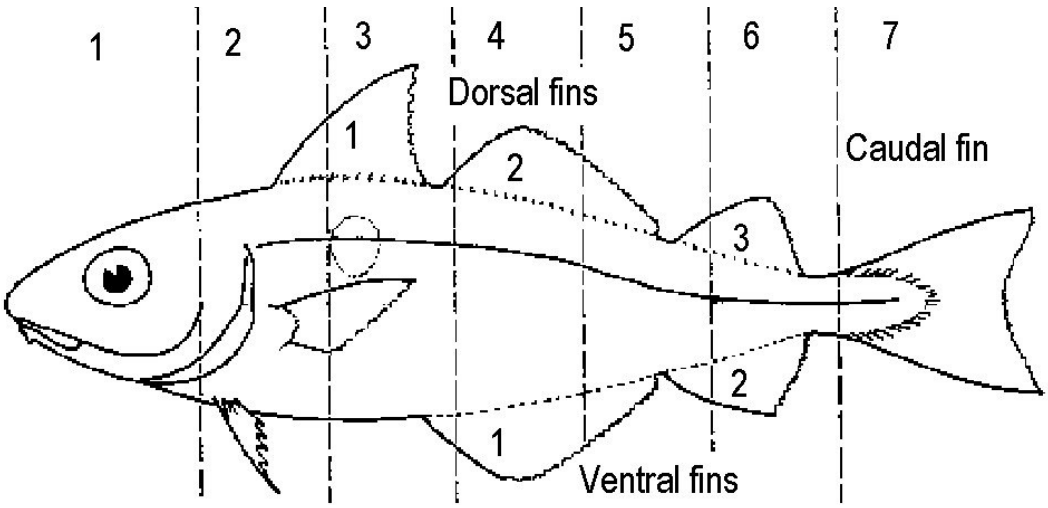

Fig. 4. The flank was divided into seven vertical sections for injury analysis. Dorsal and ventral fins were numbered as shown in the figure.

After an observation period of seven days, the cages and traps were brought to the surface and live and dead fish were counted. The total lengths of the live cod, haddock and saithe were measured to the nearest cm and the extent of injuries recorded. When registering injuries, each flank was divided into seven areas (Figure 4). Dorsal, ventral and caudal fins were also defined as registration units. In trial 1, fin split (cleft in fins), tissue loss, fin and skin bruises (blood visible but epidermis not ruptured), skin lesions (epidermis ruptured) and infections (purulence visible) were recorded. In trial 2, skin bruises, lesions and scale loss were recorded and classified as small (<1 cm^2), medium (1-4 cm^2) and large (>4 cm^2). Fin split, bruises, lesions and tissue loss were also registered.

Data analysis

For investigating length dependent mortality, the logit model, belonging to the binomial family of Generalized Linear Models (GLM) was used. In cases of subsampling, a model for retrospective sampling was used (McCullagh and Nelder, 1989). The equation for the logit link function is $g(l) = a + bl$, where l is fish length. The length of fish with a 50% chance of survival (LS_{50}) can be calculated with 95% confidence intervals as (Wileman et al., 1996):

$$\frac{-a}{b} \pm 1.96 \times \sqrt{\frac{var(a) + 2 \times LS_{50} \times cov(ab) + {LS_{50}}^2 \times var(b)}{b^2}}$$

For the data analysis of injuries, the seven vertical sections on each flank were further divided into upper and lower parts by an imaginary horizontal line running from head to tail, thus dividing each section into 4 sub-sections

(left/right flank; upper/lower section). Injuries in each sub-section were then denoted as absent or present. The presence of injuries per section then becomes multinomial, with five possible outcomes (0,1,...,4). For visual presentation, the mean number of injuries on each skin area was calculated and 95% error limits estimated by simulations, using a random number generator for multinomial probability distribution, while the mean number of injuries per fin (dorsal, ventral and caudal fins) was calculated and approximate 95% error limits estimated as ± 2 binomial SE (standard error).
When testing for differences in frequency of injuries between categories (mesh, grid, control), a reference point m was defined as the median value of frequency of injury, excluding fish with no injuries. Categories of 'None' (no injuries at all), 'Moderate' (number of injuries per fish = 1 to m) and 'High' (number of injuries per fish $> m$) were arranged in contingency tables and tested for homogeneity using the χ^2-test. The p-value was computed by Monte Carlo simulation with 10000 replicates. This was done by random sampling from the set of all contingency tables with given marginals. A C translation of the algorithm of Patefield (1981) was used.
Differences in injuries between species were tested pairwise. Numbers of fish for each paired specimen in a given cage with none, moderate and high numbers of injuries were arranged in a 2×3 contingency table. χ^2-tests with simulated p-values were then performed for all recorded injuries.
The number of injuries per fish was modelled as a function of length and cages:

$$E(I_j) = a_j + b_j l$$

where I_j corresponds to total number of specified injuries per fish of length l in cage $j = 1, 2, \ldots, n$. a and b are the parameters to be estimated. Where differences in the slope parameters b_j occurred, they were within, as well as between categories. The data were therefore adequately fitted with the simpler model:

$$E(I_j) = a_j + bl$$

In the tables that present the results of the analysis, we have chosen to show the a-values for the cages that were the only valid cages in their categories (mesh cage in trial 1 and grid cage in trial 2). For the remaining cages we show the values for $(a_j - a_1)$ and whether that difference is significantly different from zero. In the cases where the residuals tended to have a skewed distribution or kurtosis, a square root transformation was applied to conform with the assumption of normality. All statistical analysis and figures were done in R (R Development Core Team, 2004)

Results

Survival and catch composition

Mesh- and grid-selected cod and saithe suffered no mortality in the experiments. During the two field experiments, only one dead individual of each species was found, both in a control cage in trial 2. Only one trap-caught control fish, a saithe, died, probably as the result of a parasite infection.
Haddock mortality ranged from 2 to 50% (Table 1). In trial 1, the average mortality of grid-selected haddock was 12% and of mesh-selected haddock 50% (one cage only). The mortality of trawl-caught controls was 9% and length-dependent mortality was apparent in two of the cages (Figure 5). In trial 2, the mortality of haddock was length-related in all cages (Figure 6, Table 2). The length at 50% survival did not differ significantly between control, mesh and grid cages. Nor did the slope parameter b for the control differ significantly from the mesh and grid curves, suggesting that there was no difference in curve steepness between categories.

Table 1
Number of fish and mortality arranged by experimental categories

			Haddock			Cod		Saithe	
	Cage		Number		Mortality	Number		Number	
Year	Type	No.	Total	Dead	%	Total	Dead	Total	Dead
	Mesh	5	139	70	50	15	0	4	0
	Grid	1	64	1	2	4	0	8	0
2000	Grid	6	85	17	20	16	0	36	0
	Control	3	194	23	12	20	0	3	0
	Control	4	74	3	4	3	0	0	0
	Control	9	133	11	8	3	0	3	0
	Mesh	2	1700	546	32	320	0	56	0
	Mesh	8	2470	646	26	139	0	14	0
2001	Grid	6	887	34	4	31	0	54	0
	Control	3	601	129	22	404	1	30	0
	Control	9	1780	471	27	103	0	68	1
	Traps		62	0	0	25	0	6	1

In trial 1, the total number of fish caught (valid cages only) was 804. Of these, 689 were haddock, 61 cod and 54 saithe. The length distributions of haddock are shown in Figure 5. The length of the cod ranged from 30 to 59 cm, (mean = 44.1 cm, SD = 5.9), and of saithe from 32 to 50 cm (mean = 38.6 cm, SD = 4.9). Two mesh cages and one control cage did not close properly and were therefore excluded from the survival analysis, leaving only one valid cage in the mesh group. This cage was accidentally released at a depth of more than 100 m. Although this exceeded the pre-set depth limit, we have chosen to include the cage in our analysis.

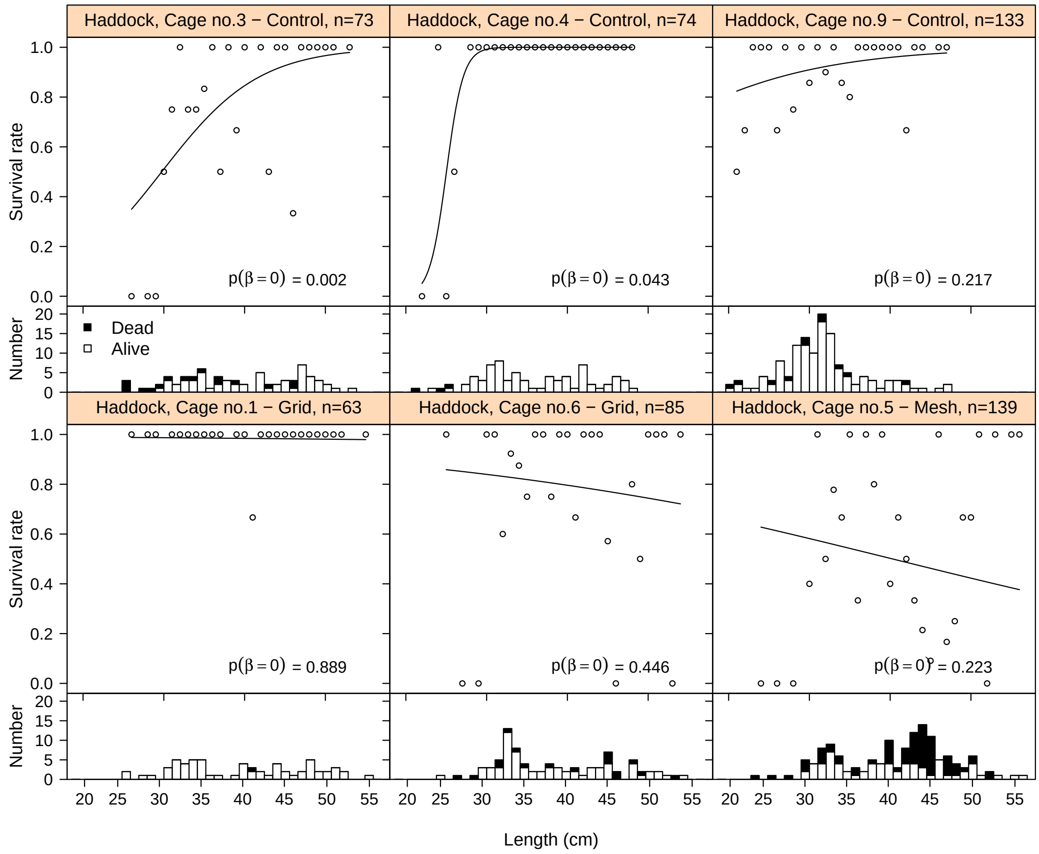

Fig. 5. Survival by length groups and length distribution of alive and dead haddock from the trial in 2000 (trial 1). The p-values correspond to testing length dependence.

Table 2
Lower and upper 95% confidence intervals for length (cm) of 50% haddock survival (LS_{50}) and slope parameter b for the logistic model in trial 2.

		LS_{50}		b	
Category	Cage no.	lower	upper	lower	upper
Control	3	26.3	31.8	0.17	0.28
Control	9	28.9	31.5	0.31	0.43
Mesh	2	25.2	32.3	0.20	0.40
Mesh	8	24.4	29.5	0.09	0.18
Grid	6	16.3	26.8	0.14	0.22

A total of 8663 fish were caught in the valid cages in trial 2. Of these, 7442 were haddock, 998 cod, and 223 saithe. The length distributions of haddock are shown in Figure 6. The length of the cod ranged from 18 to 63 cm (mean = 30.7 cm, SD = 7.2), and of saithe from 21 to 45 cm (mean = 31.5 cm, SD = 4.4). In the fish traps, a total of 62 haddock, 25 saithe and six cod were caught. The length of the haddock ranged from 25 to 49 cm, with an average length of 33.1 cm (SD = 5.1). The length of the cod caught in the fish traps ranged from 26 to 52 cm (mean = 4.7, SD = 9.4), and that of saithe from 18 to 38 cm,

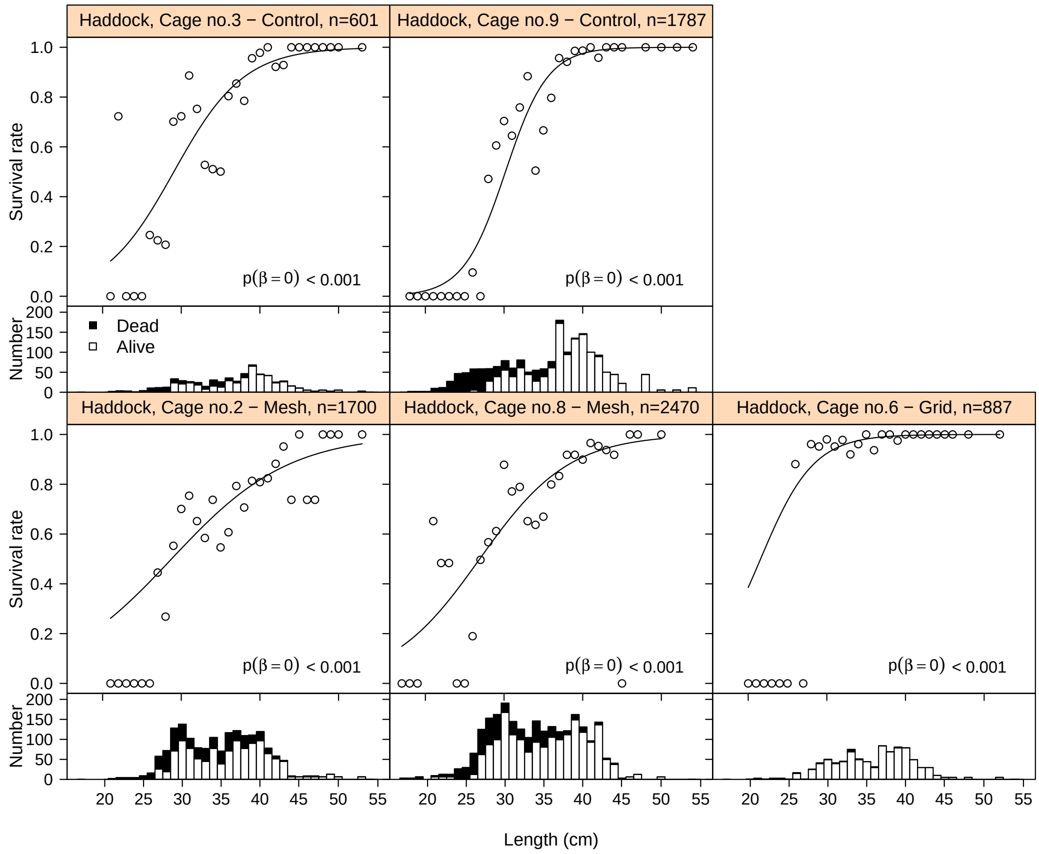

Fig. 6. Survival by length groups and length distribution of alive and dead haddock from the trial in 2001 (trial 2). The p-values correspond to testing length dependence.

(mean = 26.9, SD = 5.1).

In trial 2, four cages (one control cage, one mesh cage and two grid cages) were excluded due to insufficient numbers of fish being taken or unsuccessful closing of the cages. The only remaining cage in the grid escape group was also observed to be inadequately closed, but to a lesser degree than those excluded, with an opening diameter of about 30 cm, so that some fish may have escaped during towing. However, at the anchoring site the net lay under the cage preventing escapes after anchoring. It was closed by a diver before it was hauled up.

Haddock injuries

The injuries were predominantly small, and medium and large injuries occurred independently of cage category. To simplify the analysis, small, medium and large injures were therefore merged.

The majority of the haddock had no or few lesions, infections or bruises on the skin. Scale losses were more frequent. The fin injuries were more severe

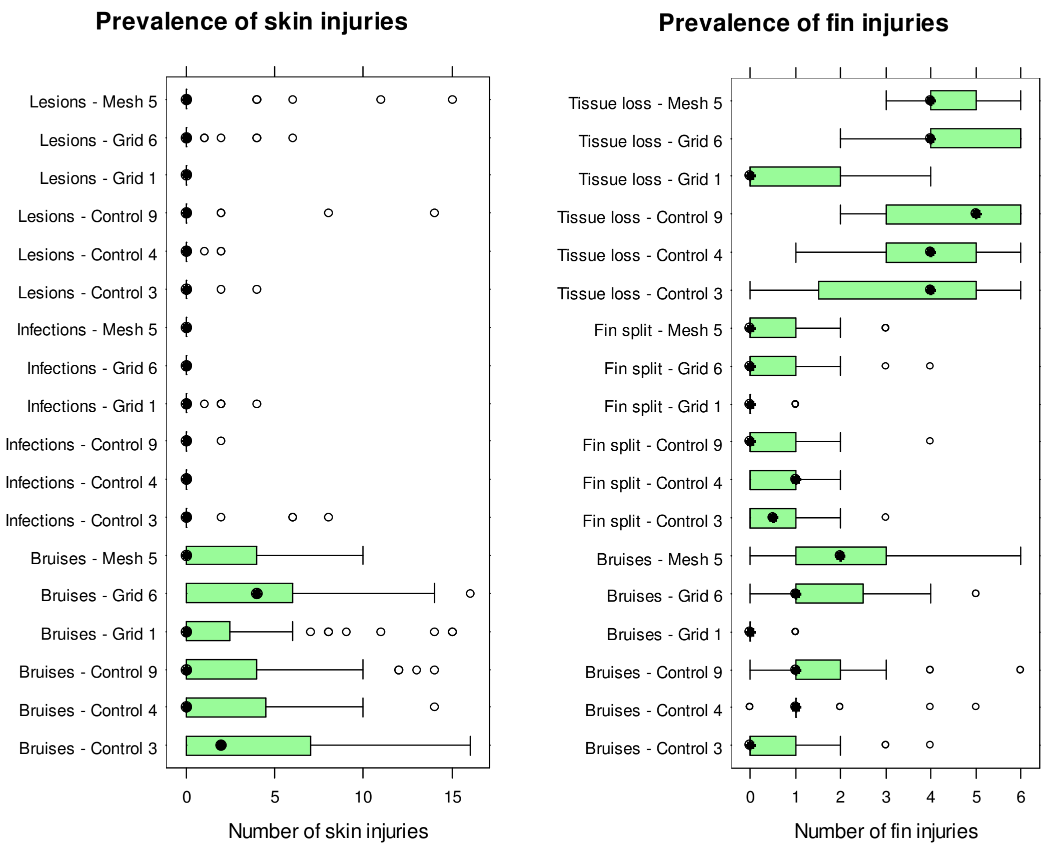

Fig. 7. Prevalence of haddock fin and skin injuries in trial 1. The boxes show lower and upper quantiles, filled dots (•) show median values and the whiskers stretch to 1.5 interquantile distance or the extreme values of the data, whichever is less. Data points outside the whiskers may be outliers and are indicated as open dots (○).

than skin injuries in both trials (Figures 7 and 8).

Skin bruises and skin lesions did not differ significantly between cages ($p>0.05$). Although some of the other injuries, predominantly fin injuries, differed between cages, the differences within categories were as large as between them. The number of bruises and lesions as well as the extent of scale loss increased from snout to tail in all categories, with the highest mean number in flank areas 4 to 6 (Figures 9 and 10). Infections in grid-selected haddock were found only in flank areas 6 and 7 (five fish infected).

The dorsal and caudal fins in all categories were most liable to suffer tissue loss, while ventral fins had the lowest frequency in all cases (Figures 11 and 12). The caudal fin had the highest occurrence of fin bruises and splits in all categories.

In trial 1, numbers of skin bruises, fin bruises, and fin splits increased slightly with increasing fish length, while the number of fin tissue losses decreased. An inconsistency within cage categories was seen in the covariance analysis. For instance, the prevalence of fin injuries in control cage no. 3 deviates from that of the mesh cage, but also from control cage no. 9. A similar inconsistency

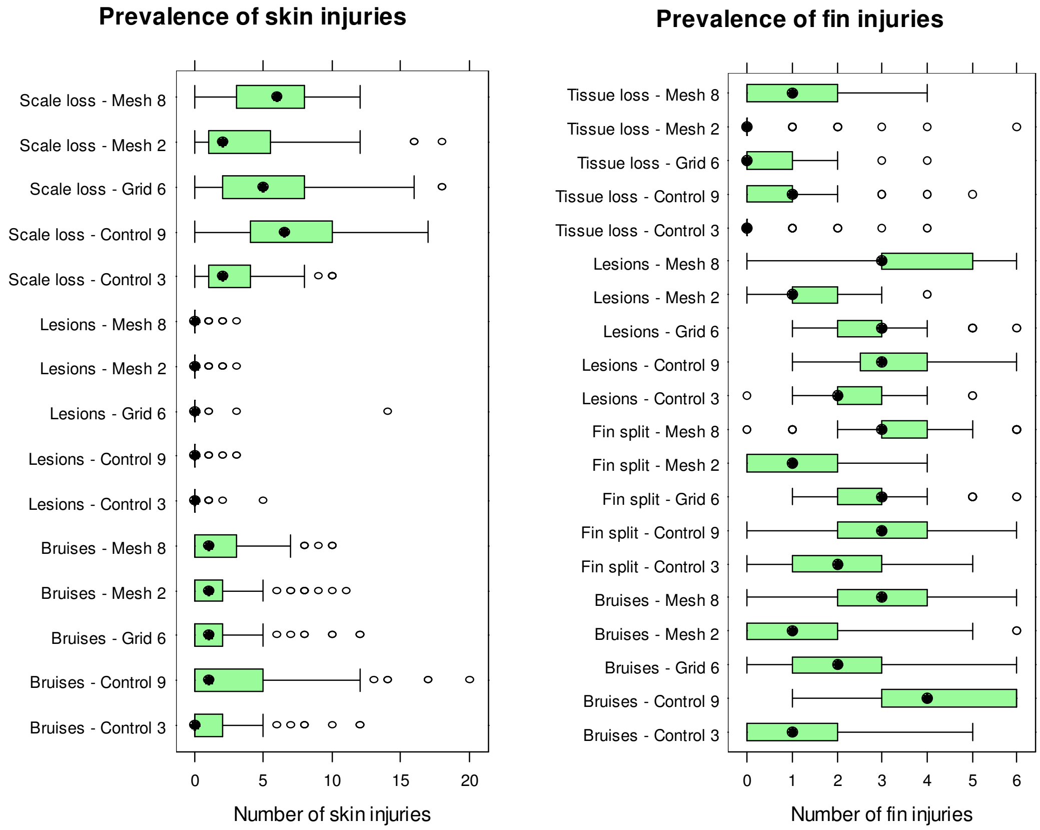

Fig. 8. Prevalence of haddock fin and skin injuries in trial 2.

was also found for the grid cages. In trial 2, both numbers of scale losses and fin lesions declined with increasing length, but length dependence was more profound for scale loss. As in trial 1, a covariance analysis revealed differences within categories, i.e. no difference between categories could be detected.
Thirty haddock from two fish traps were examined to quantify injuries. Fewer scale losses, fin bruises and fin lesions were found in haddock taken by traps than by trawl. Injuries were not related to fish length. No fin lesions were observed and injuries were primarily small. Unlike in the trawl groups, skin bruises and skin lesions were predominantly found on the snout. Fin splits were most common on the tail, while fin bruises and fin rot were more evenly distributed over the fins.

Cod and saithe injuries

Cod suffered in general less severe injuries than saithe, which in turn suffered less severe injuries than haddock (χ^2-test, α=0.05). In cod, skin bruises, scale losses and fin splits were inversely related to fish length, and no differences between categories were detected. No fin lesions were found in cod. Contrary to the haddock, where the frequency of bruises increased towards the tail, most skin bruises on cod were found in flank areas 1 and 2. Lesions were only

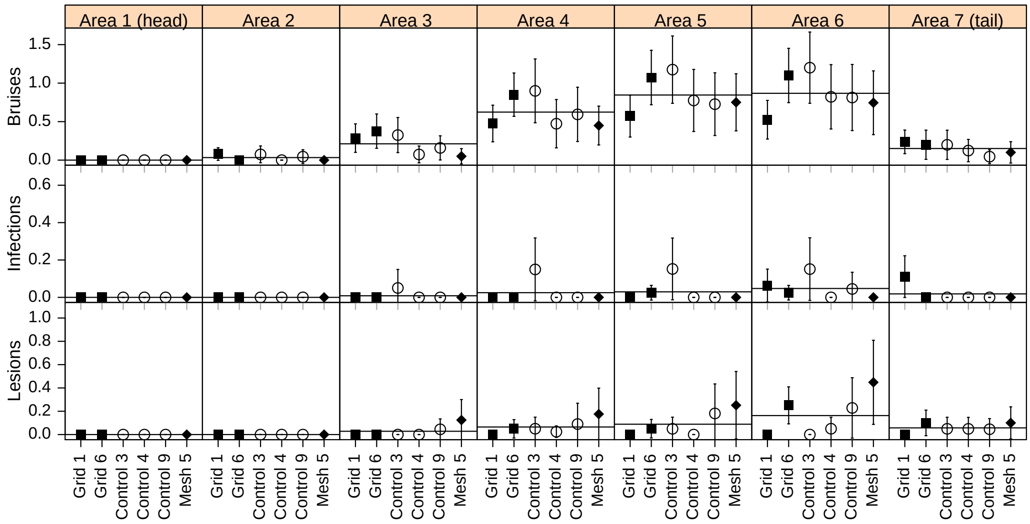

Fig. 9. Mean number of skin injuries in different areas of haddock in trial 1. Error bars show approximate 95% confidence intervals (multinomial, simulated). The horizontal lines show means for all cages.

observed on two fish (grid and mesh categories), in both cases on the head. Fin bruises were most frequent on the foremost dorsal fin. Fin splits were most frequently found on the caudal fin and the rearmost dorsal and ventral fins.

The injuries of saithe were not length related and differences between cage categories were not detected. Flank areas 3 - 5 showed the highest frequencies of scale loss in both categories. No fin splits were found in the caudal fins of mesh-selected saithe and in only one out of 20 saithe from the grid group.

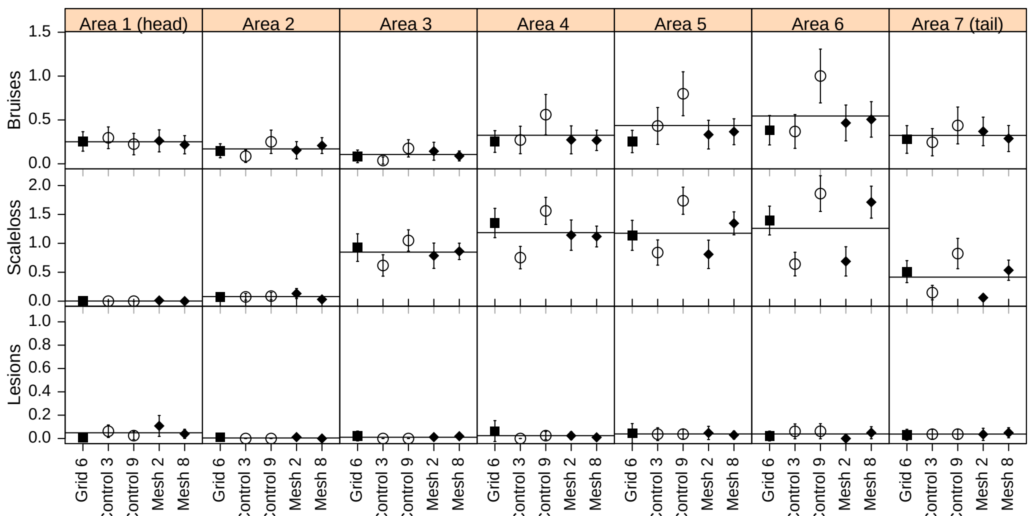

Fig. 10. Mean number of skin injuries in different areas of haddock in trial 2. Error bars show approximate 95% confidence intervals (multinomial, simulated). The horizontal lines show means for all cages.

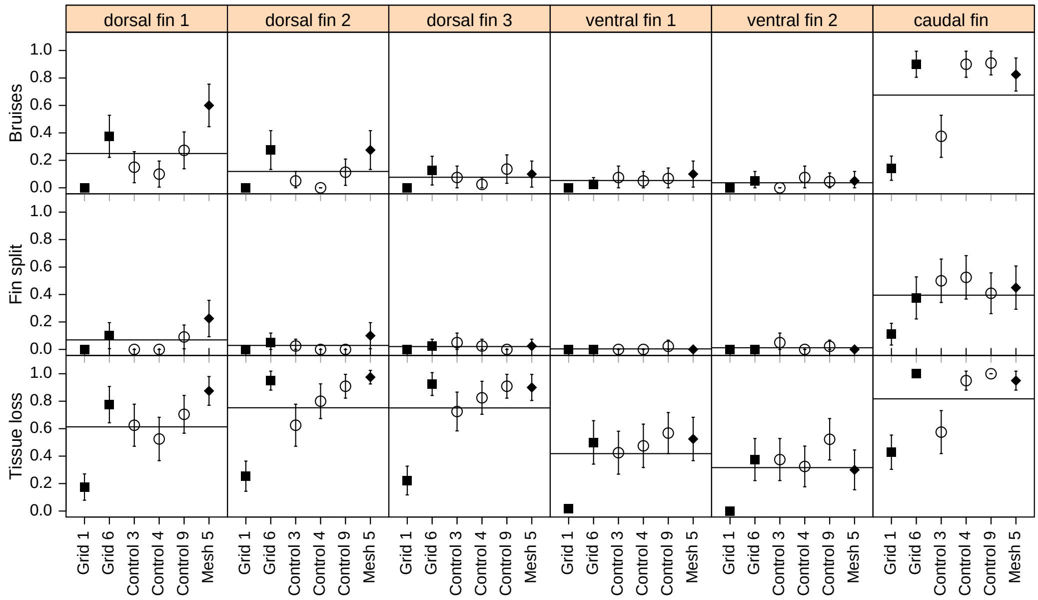

Fig. 11. Mean number of injuries on different fins of haddock in trial 1.Error bars show approximate 95% confidence intervals (binomial). The horizontal lines show means for all cages.

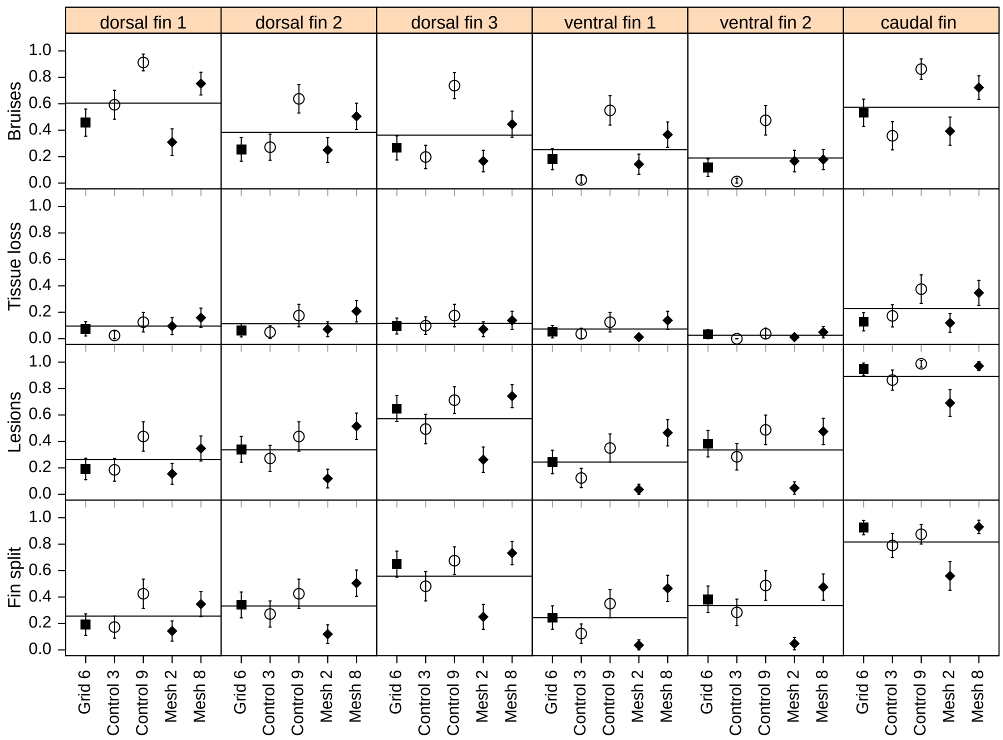

Fig. 12. Mean number of injuries on different fins of haddock in trial 2. Error bars show approximate 95% confidence intervals (binomial). The horizontal lines show means for all cages.

Discussion

Mortality

These experiments have shown that cod and saithe are robust survivors, and that neither mesh nor grid penetration have a direct impact on their survival probabilities. These results are in agreement with those of previous experiments (DeAlteris and Reifsteck, 1993; Soldal et al., 1993; Suuronen et al., 2005).

The mortality of haddock was higher than in cod and saithe, consistent with what has been documented in other experiments (Soldal et al., 1993; Sangster et al., 1996; Soldal and Engås, 1997), and also higher than that of haddock observed in previous experiments carried out in the same fishery (Soldal et al., 1993). There was no difference in mortality rates between the trawl-caught controls and the mesh and grid groups in either of the trials. The lowest and highest mortalities in our experiments were for grid (2%) and mesh (50%) escapees in trial 1. Similarly, the lowest and highest mortalities in trial 2 were 4% in grid and 32% in mesh cages. However, the high mortality observed in the mesh cage in trial 1 may have been caused by a rapid pressure reduction, and the low mortality rate in the grid cage in trial 2 may have been affected by incomplete closing of the cage.

Although the control fish avoided the mesh and grid escape process, they did not suffer less mortality and injury rates than fish in the escape groups. This suggests that the escape event *per se* is not the main cause of mortality in a trawl capture process. Fish often swim in front of the trawl until they become fatigued and are overtaken by the trawl (e.g. Wardle 1986). Exhausted fish may find it difficult to maintain their distance from the net walls in the trawl, and are more likely to be hit and injured by a trawl. Also, physical exhaustion caused by intensive exercise may cause mortality, probably by intracellular acidosis (Wood et al., 1983). Physical injuries may also lead to mortality due to stress and disturbed osmotic balance (Eddy, 1981; Smith, 1993). No mortality was observed among trap-caught haddock. This suggests that the mortalities observed in the other haddock groups are related to the trawling process and/or the sampling technique, but not to captivity in cages as such. This has also been suggested by Sangster et al. (1996).

Caging may protect escaping fish from predation, and potentially increase post-escape survival rates. Injuries and/or exhaustion caused by the capture and escape process have been shown to result in behaviour impairments in sablefish (*Anoplopoma fimbria*) and walleye pollock (*Theragra chalcogramma*), making individuals more vulnerable to predation (Ryer, 2004; Ryer et al., 2004). The predation mortality may therefore add to the overall mortality but remains unknown.

External injuries

The injuries on cod and saithe tended to be less than on haddock, and the level of damage varied within experimental categories. The species difference in vulnerability to injuries is in agreement with earlier experiments with gadoid species (Soldal et al., 1993; Sangster et al., 1996; Soldal and Engås, 1997). Since there were no clear differences in injuries between categories, the injuries do not seem to be related to the penetration through meshes or grids. Mortality rates in the cages cannot be explained by the level of injuries.
The injuries of the trap-caught haddock were significantly less serious than those of the trawl-caught groups, suggesting that the trawling process and/or the sampling technique and not captivity as such caused the injuries.

Length dependent survival and injuries

Haddock survival was related to fish length in trial 2, and haddock smaller than 30 cm had a probability of survival of less than 50%. Difference between categories could not be detected. In trial 1, length-related survival was only found in two control cages. Since there was no size-related survival in the experimental categories in trial 1, the most likely reason for the size-dependence in trial 2 is that the smaller fish became exhausted and ceased swimming during towing of the cages to the anchoring sites, suffering physical injuries and stress. Suuronen et al. (2005) could not document any clear relationship between fish length and survival in Baltic cod.
Scale loss in trial 2 (not recorded in trial 1) was negatively correlated with length for all cages. Apart from that, there was no consistent relationship between fish injuries and body length, except for a weak length relationship in injuries in trial 1. Scale loss may therefore have a causal connection to mortality. The smallest fish presumably tire first and may not be able to maintain their position in the cage during trawling and towing of cages; they become pinned against the net wall of the trawl or cage where the scales are scraped off. The degree of scale loss was lower and independent of fish length in haddock caught in traps, where there was no mortality. Nevertheless, it should be borne in mind that only haddock that survived until the end of the experiment, and not dead fish, were examined for injuries. Therefore, implications of connections between mortality and injuries of live fish must be done with precaution. The results regarding length-related scale loss and mortality of mesh-selected haddock are in agreement with previous experiments (Soldal et al., 1991; Sangster et al., 1996). A similar relationship has also been observed in other species, such as herring (*Clupea harengus* L.) (Suuronen et al., 1996).
Most skin injuries were found on the rear part of the body. Tail beating when pressed against net walls of the trawl during towing is one likely cause of the skin injuries. In addition, the smallest individuals may not have been able to

maintain their position in the cage during towing, adding to the size-related mortality effects. Injuries caused by the fish squeezing through the codend meshes would tend to be most evident at the location of maximum girth, while random collisions with the net panels would have led to injuries being more evenly distributed over the flank area.

Experimental procedure

Care was taken to simulate commercial fishing practices as far as possible. Both experiments were carried out on board commercial stern trawlers towing their own fishing gears, but choice of fishing grounds, length of towing time and experimental technique were revised.

Both experiments were performed in an area that was closed to commercial trawling to protect the released cages from being overrun and damaged by fishing gear. Moreover, the fish population in the area, a mixture of cod, haddock and saithe, was typical of a fishing ground in the Barents Sea. The sampling technique used was similar to that developed by Lehtonen et al. (1998), with a double set of acoustic releasers, enabling us to keep the towing time at commercial lengths, and at the same time sample escapees at any desired period during the tow. We therefore consider that these experiments imitated commercial fishing practice well. Since we observed a higher mortality of haddock than in the previous experiments (Soldal et al., 1993), it cannot be ruled out that the changes in experimental procedure may be one reason for this increase.

The mortalities observed in survival experiments are easily influenced by the methods used to collect, transport and monitor escapees (Suuronen et al., 1996), and the variability in our results indicates that methodological errors affected our results. Breen et al. (2002) demonstrated that haddock mortality correlated with time spent in the cover/cage during towing (cover exposure time). It is therefore of great importance to keep the sampling time as short as possible, and to design the codend cover and cage in a manner that reduces the interior water flow.

The cover exposure time in our experiments varied between trials. The sampling time was 5 to 15 min in both trials, but in trial 2 the cages were towed slowly (< 0.5 ms^{-1}) after release for 50 to 85 min into sheltered water before being anchored. Current speed at the sites was of moderate magnitude and the fish was easygoing in the cages. The variability in mortality and injury levels between cages, however, was high in both trials. Ideally the number of parallels within each category should have been increased to compensate for the high variability in results. This was not easily done as the number of parallels is a compromise between the cost of full-scale trials and the degree of confidence in the results.

A single cage in trial 1 (cage 5) was released at a greater depth (between 100 and 130 m) before it floated up to 50 m depth where it was anchored. This

was the only valid mesh cage in trial 1 and it had 50% haddock mortality. The ascent from 110 to 50 m depth in a few minutes is close to the tolerance limit of cod (Tytler and Blaxter, 1973), which need three hours to adapt to a 50% pressure reduction (Harden Jones and Scholes, 1985). The results obtained by Tytler and Blaxter indicate that haddock have a lower tolerance to pressure reduction than cod, and this may explain the high haddock mortality in cage 5. No mortality of cod or saithe was observed.
During trial 2 sea turbidity was high (visibility approximately 1 m). As a result we have no documentation regarding the number of fish or of fish behaviour in the cages during the towing and monitoring period, or of the functionality of the caging technique during the experiments. Problems with the closing of the cages occurred, either due to a failure in the locking mechanism or the drag from the sea anchors was unsufficient to contract the netting. In particular, cage 6, the only valid grid cage in trial 2, was seen to be inadequately closed towards the end of the observation period and was therefore closed by a diver before being brought to the surface. The inner diameter of the opening was approximately 25 - 30 cm. If the cage was open already during sampling, dead fish may have leaked out, causing the observed survival rate to be overestimated.

Concluding remarks

Our experiments, carried out under virtual commercial fishing conditions, showed that cod and saithe tolerate selection through meshes and grid without their survival being affected. Escape mortality of haddock was found to be higher than in earlier experiments carried out in the same fishery, a fact that may partly be due to changes in fishing practice and the experimental procedure. Mortality was independent of selectivity device. Escaping through meshes or grids is therefore not believed to be the main cause of the observed mortality. Scale loss was size-related in the same way as mortality, and is suspected to have a causal connection to mortality. Swimming ability is regarded as a critical factor, and the observed mortality may be caused by the strain inflicted on the fish as they pass through the trawl, or by the sampling procedure. Before further studies are carried out, it is important to evaluate the possible mortality-inducing effects of the experimental procedure.

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