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Size-related mortality of herring (*Clupea harengus* L.) escaping through a rigid sorting grid and trawl codend meshes

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Studies on herring, *Clupea harengus* (L.), were conducted in the northern Baltic to assess whether the mortality of herring escaping through a rigid sorting grid (12 mm bar spacing) placed in front of the codend was different from that of herring escaping from a 36 mm diamond mesh codend. Escapees were collected into netting cages, and subsequently transferred into large holding cages (85 m^3) where they were held for up to two weeks to assess mortality. 76–100% of small (<12 cm) and 44–83% of large (12–17 cm) escapees were dead after 7 days. The 14-day mortalities were 96–100% and 77–100% for small and large escapees, respectively. In the spring experiments, survival of large herring that escaped through the grid was 7–18% higher than that of codend escapees and, in the autumn experiments, was 2–7% higher. Survival of small escapees was not improved by the use of a sorting grid. Observations on escapees suggested that they suffered considerable loss of scales during capture, and that injured skin areas were often seriously infected within a few days of escape. Herring caught by seine and handline, used as controls, were generally in good condition, but they also experienced mortality. After two weeks their cumulative mortality reached 9% in spring and about 55% in the autumn. On the basis of our results, we argue that a considerable part of the mortality observed in herring escapees may be attributed to mechanical contacts with the trawl netting and exhaustion during the capture process, and that damage can occur in the net long before fish reach the codend.

Key words: pelagic trawl, sorting grid, codend mesh, herring, escape mortality, experimental design.

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Introduction

Poor trawl selectivity is one of the current concerns in fisheries management. In order to improve the selective characteristics of trawl nets, codend modifications are currently under investigation worldwide. One fundamental aspect of this research is to ensure that fish which pass out of the trawl net survive, and thus help to build up the future stock. Treschev *et al.* (1975) and Efanov (1981) found that about 90% of Baltic herring (*Clupea harengus* L.) survived after escaping from codends of 24–32 mm mesh sizes, although mortality of the smallest juveniles was higher. Suuronen *et al.* (1996), however, suggested that survival of herring escaping from trawl codends was 10–40%, and that survival did not depend on the codend mesh size. They argued that skin injuries and exhaustion while herring are inside the trawl are mostly responsible for this high mortality.

The use of rigid grids for sorting undersized fish out of trawls has been developed recently in Scandinavia (e.g. Larsen and Isaksen, 1993). According to numerous underwater observations, the passage of herring through a rigid sorting grid appears much easier than swimming through diamond or square meshes (Suuronen, 1991; Suuronen *et al.*, 1993). The loss of scales of mesh-selected small haddock (*Melanogrammus aeglefinus*) was found to be significantly higher than that of grid-sorted

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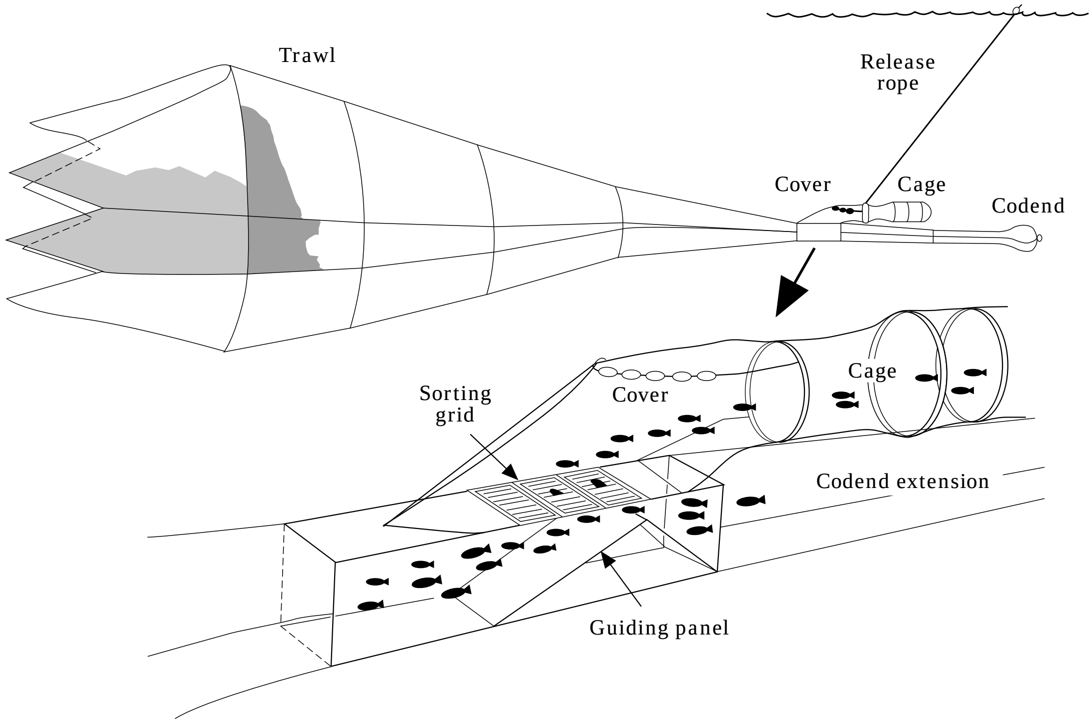

Figure 1. General design of a herring midwater trawl with rigid sorting grid and collecting cover and cage. The sorting grid was mounted at the front upper panel of the codend extension parallel to the netting.

fish (Soldal *et al.*, 1991). Furthermore, a sorting grid placed in front of the codend may have better selective performance at higher catch rates because it is not easily blocked by catch (Suuronen *et al.*, 1993). Thus, given the differences between both sorting processes, the frequency and degree of injuries in escapees, and their subsequent mortality, might be expected to be lower for grid-sorted fish. Thus, sorting grids might be an alternative to conventional mesh selection for fragile and easily injured fish such as herring.

This paper describes the technique and results from the survival experiments conducted in spring and autumn 1993 to assess and compare the mortalities of herring escaping through rigid sorting grids and codend meshes.

Materials and methods

Survey area, fishing trials, and sorting devices

Experiments were conducted from 18 May to 10 June (spring) and from 6 October to 25 November (autumn) of 1993, in 35–60 m-deep waters in the Archipelago Sea, northern Baltic Proper, where salinity is approximately 0·6‰. Hauls were performed with a standard herring midwater trawl (see Suuronen and Millar, 1992). During the spring, the trawl was towed by the stern trawler "Harengus" (300 hp), and in autumn it was towed by the "Mia", a traditional side trawler of 850 hp. The headline height of the trawl during towing ranged from 18–20 m and average towing speed was 3.0 knots (± 0.3 knots). In spring, the tows were made in the evening and at night, and in autumn during the late afternoon and evening, at depths where most of the herring were concentrated (usually 10–40 m). The duration of tows was restricted to 2–10 min to prevent potential injury induced by the cage after escape (see Suuronen, 1991; Suuronen *et al.*, 1996). Due to the short towing times, catches were low (around 30–50 kg). Catches consisted almost entirely of herring.

We examined the mortality of herring escaping from a 36 mm diamond mesh codend (mesh opening 33–34 mm, 250 meshes in circumference) made of polyamide (PA) twine (210/30) and through a rigid sorting grid made of anodised aluminum. The grid consisted of three rectangular parts (50 × 80 cm each; bar diameter = 12 mm, between-bar distance = 12 mm) to ease its bending on the net drum. It was mounted in the front upper panel of the codend extension piece parallel to the netting (Fig. 1) only during those tows aimed to collect herring escaping through it. The selectivity performance of the 36 mm diamond mesh codend and the 12 mm grid have been discussed by Suuronen and Millar (1992) and Suuronen *et al.* (1993).

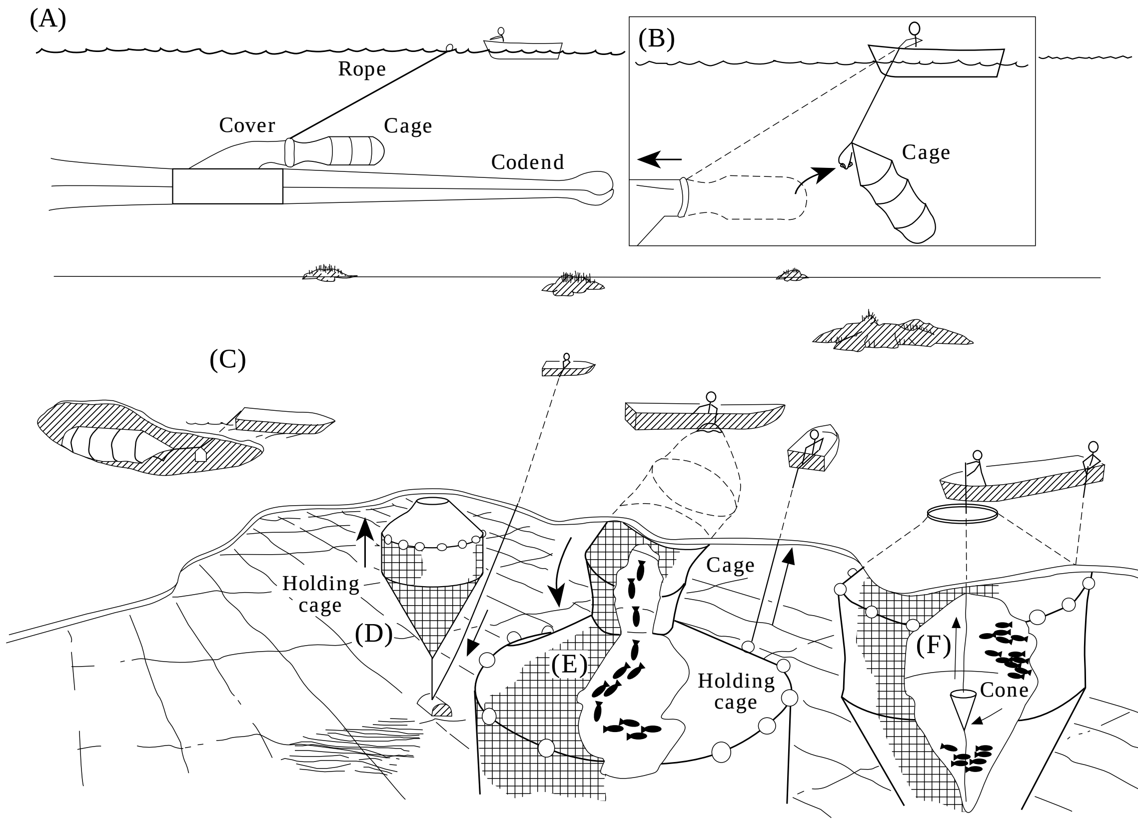

Figure 2. Schematic representation of the experimental procedures used during towing (A), release (B) and transport of collection cage (C), and during transferring of fish from collection cage to large holding cage (E), adjusting the depth of holding cage (D), and collecting of dead fish with a netting cone (F).

Survival experiments

Collection of escapees and caging techniques

A hooped netting cage (diameter 2 m, length 7.5 m, volume approximately 20 m^3) was attached to a cover fitted over the codend or the sorting grid (Figs 1, 2A). Fish that escaped from the codend or sorting grid were guided by the cover aft into the cage. The cover and the cage were made of unimpregnated knotless (14 mm stretched mesh length) nylon netting except for the rearmost panel of the cage which was made of 6 mm stretched netting. The meshes were hung in a square orientation. During tows, the cover was held away from the codend meshes by means of three hoops (diameter 2 m) giving the cover a cylindrical form. After 2–10 min of towing, the cage was remotely released from the trawl and closed (Fig. 2B), and slowly transported at $\frac{1}{2}$ knot speed in about 5–10 m depth to the large holding cages (Fig. 2C). The towing direction and release position were chosen to minimise transport time to the cage site. Transport time varied from 5–35 min.

The 85 m^3 underwater holding cages were also made of unimpregnated 14 mm (stretched length) knotless nylon meshes hung in a square. Holding cages had a diameter of 4 m and a total height of 10 m (Fig. 2D). Figure 2e illustrates the technique used when transferring the fish from the towing cage into the large holding cage. The mouths of the two cages were connected together by zippers and the whole system was carefully pulled down so that the fish could swim freely from the upper towing cage to the lower holding cage. Finally, the system was lifted, and the upper cage was detached from the large cage which was then closed and lowered to the chosen depth.

Usually, escapees from two successive hauls were transferred into a holding cage to get enough fish in all size-classes and to reduce inter-haul variation. A total of seven holding cages (three for codend escapees, four for grid escapees) were deployed in spring, while eleven cages (eight for codend escapees, three for grid escapees) were used in autumn. The duration of the caging period was usually about two weeks (Table 1, T).

Holding cages were anchored in sheltered areas to reduce the risk of storm damage. However, in autumn, occasional strong sea currents tipped some cages into almost-horizontal orientation. To minimise possible

Table 1. Starting day of experiment, treatment, tow duration, cage depth (uppermost part), caging period (T), observations (n), initial number of small (N_S) and large (N_L) fish kept in holding cage and subset code. (C=coded, G=grid, H=hook and line, S=seine, Sp=spring, A=autumn, Sm=small herring, Lg=large herring).

Cage	Date	Treatment	Tow time (min)	Depth (m)	T (day)	n	N_S	N_L	Subset	
1	18/5/93	Grid	11.5	7	6.8	3	76	89	GSmSp	GLgSp
2	19/5/93	Codend	10	7	12	5	359	341	CSmSp	CLgSp
3	25/5/93	Grid	10.5	7–8	15.3	4	58	78	GSmSp	GLgSp
4	27/5/93	Grid	10	7–8	13.9	4	287	808	GSmSp	GLgSp
5	1/6/93	Codend	10	7–9	14.9	5	60	200	CSmSp	CLgSp
6	7/6/93	Hook	—	8–13	24.1	12	—	259	HLgSp	
7	9/6/93	Grid	11	8–10	14.4	8	49	89	GSmSp	GLgSp
8	10/6/93	Codend	11.5	8–10	13.5	6	85	287	CSmSp	CLgSp
9	10/6/93	Seine	—	5	14	5	758	—	SSmA	
10	10/7/93	Seine	—	0	13.1	5	560	—	SSmA	
11	14/10/93	Codend	10	5	13.8	8	196	133	CSmA	CLgA
12	15/10/93	Grid	10	5	14	7	18 896	286	GSmA	GLgA
13	21/10/93	Codend	5	0	13	7	44	3	CSmA	CLgA
14	22/10/93	Codend	5	2	12.1	6	136	18	CSmA	CLgA
15	28/10/93	Codend	5	2	13.9	9	158	86	CSmA	CLgA
16	29/10/93	Codend	5	0–2	16.9	10	468	48	CSmA	CLgA
17	3/11/93	Codend	5	0	8.9	6	68	10	CSmA	CLgA
18	3/11/93	Codend	5	2	12	6	43	231	CSmA	CLgA
19	11/11/93	Hook	—	2	19.9	10	—	161	HLgA	
20	18/11/93	Grid	5	2	12.9	7	40	307	GSmA	GLgA
21	24/11/93	Grid	3.5	2	13.9	8	5	34	GSmA	GLgA
22	25/11/93	Codend	2	2	12.9	8	48	4	CSmA	CLgA

differences in environmental conditions during the observation period, cages were anchored close to each other. In the spring, cage depth was chosen so that the mid-section of the cage was always in waters of 10°C (± 1°C). Usually, the uppermost part of the cage was at 7–10 m depth (Table 1). In the autumn, temperature of the upper water layer (0–30 m) varied from 3–5°C. Nevertheless, cage depth was varied so that the fish of three cages were allowed access to the surface (Table 1). Predation of fish by sea birds was prevented by a framed netting roof.

Dead and moribund fish were removed and counted, on average, every second day after capture (Table 1, n). Each time, after lifting the cage near to the surface, these fish were collected with a netting cone mounted in the cage (Fig. 2F). The total length of each fish was measured to the nearest half cm, and a visual inspection for superficial injuries was performed. On completion of each survival experiment, the whole cage was lifted to the surface, all dead and live fish were counted and measured, and their injuries inspected. The pooled length distributions of codend and grid herring escapees from the spring and autumn experiments are shown in Figs 3a, 3c, respectively. With the exception of the spring grid escapees, the distributions were markedly bimodal.

Gear performance during towing and fish behaviour during transport and caging was occasionally observed by an underwater camera.

Fish caught by handline and seine

As controls, cumulative mortalities of non-trawled herring held in similar caging conditions were also estimated. On two occasions (7 June and 11 November), herring were caught by handline fitted with barbless hooks (non-baited) at depths of 5–10 m at dusk, and caged in large holding cages for 20–24 d (Table 1). Fish which were hooked cleanly on the lips and showed no apparent signs of physical damage were immediately released into the holding cage that had been secured along-side the boat. These fish did not experience any transport, neither were they touched by hand. Only herring larger than 12 cm were caught by hook and line (Fig. 3b, 3d). In autumn, herring were also caught by a small purse seine made of small mesh knotless nylon netting. These were primarily small herring (Fig. 3d) which were transferred to two large holding cages and held for 13–14 d (Table 1).

Data analysis

Given the bimodality shown by herring length frequencies (Fig. 3) and the knowledge of possible differences between mortality rates for small and large herring (Suuronen *et al.*, 1996), we calculated cumulative mortalities for two length groups. One, subsequently termed "small", consisted of all herring smaller than 12 cm, while the "large" group included fish of 12–17 cm. Fish larger than 17 cm were excluded from the analysis.

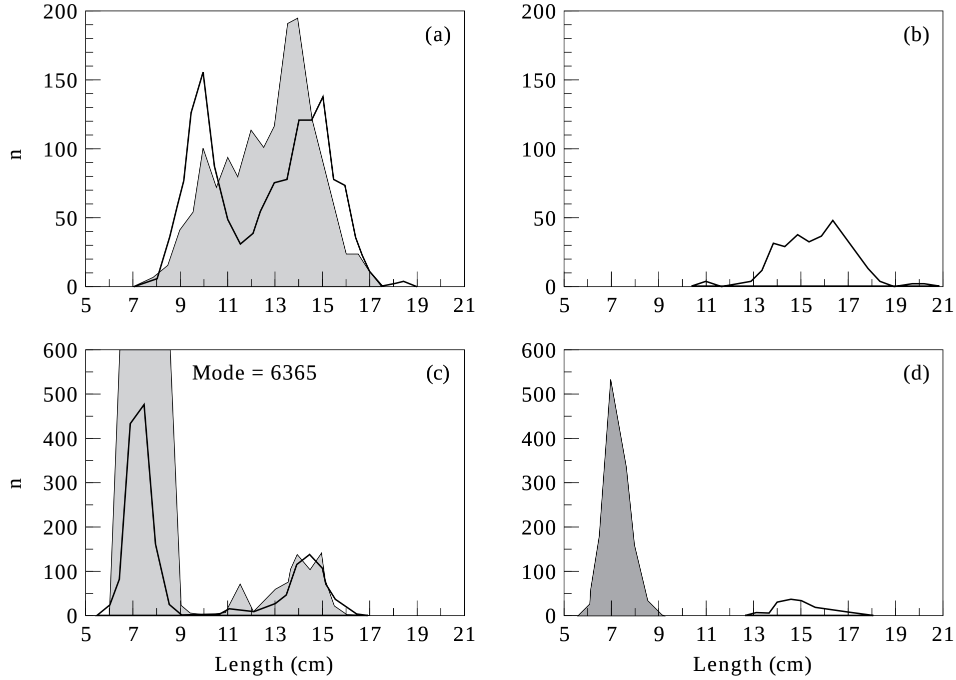

Figure 3. Length frequency distributions for herring mortality spring (a and b) and autumn (c and d) data. For (a) and (c): ▩=grid; □=codend. For (b) and (d): ▩=seine; □=hook.

Cumulative mortalities at each observation time t for length group g and experimental cage i were calculated as $M_{g,i}(t)=d_{g,i}(t)/N_{g,i}$, where $N_{g,i}$ is the total number of fish of size group g initially placed in holding cage i (Table 1, N_S and N_L), and $d_{g,i}(t)$ is the cumulative number of dead fish at observation time t. Observation time t was measured as decimal fractions of days, counted from the start of the caging period (t=0).

For our analysis, cumulative mortalities were classified into 11 subsets (Table 1) according to sorting devices or catching technique (C=codend, G=grid, H=hook and line, and S=seine), season (Sp=spring and A=autumn), and fish size group (Sm=small and Lg=large). For example, CSmA is the subset of all cumulative mortalities estimated at each observation time for each of the eight cages deployed in autumn that contained small herring that had escaped through codend meshes.

Observations and collection of dead fish from holding cages had been planned to occur every 24 h, counted from the time at which cages were deployed. Unfortunately, the long distance between cage locations and the harbour and weather conditions did not allow us to keep such a strict schedule. Thus, observation time t varied considerably among experimental cages, creating a design with many empty cells. To avoid this problem and still be able to assess cumulative mortality after one and two weeks of caging, we decided to treat observation time t as a continuous explanatory variable and model cumulative mortality M as a logistic function:

$$M(t)=\frac{\alpha}{1+\exp(\beta-\gamma\times t)}$$

where α, β, and γ are parameters such that $\alpha \leqslant 1$, $\beta>0$, and $\gamma>0$. Model fits for each of the 11 subsets were obtained by non-linear least squares using available software.

We produced 1000 bootstrap replicates for each subset by resampling from the ordered residuals of the original fits. Bootstrap replicates were also fitted to the logistic model, and predicted cumulative mortalities at time t=7 and 14 days ($\hat{M}(7)$ and $\hat{M}(14)$) were calculated. The 2.5 and 97.5 percentiles of the sorted distributions of $\hat{M}(7)$ and $\hat{M}(14)$ were used as 95% confidence interval limits. Standard errors for the parameter estimates were also based on the bootstrap samples.

Results

Fish behaviour and condition during experiments

Observations of the escapees during transportation (Fig. 2C) to the cage site revealed that most of them swam calmly within the cages. Some fish showed occasional bursts of swimming. However, fish were not seen to have vigorous contacts with the cage. When herring were transferred from the towing cage to the

Table 2. Parameter estimates and standard errors (between parentheses) for logistic mortality curves. Average percent cumulative mortality ($\hat{M}$) after 7 and 14 days of cage confinement and corresponding 95% confidence intervals. Average cumulative mortalities, standard errors, and confidence intervals are based on 1000 bootstrap samples.

Subset	α	β	γ	$\hat{M}(7)$	$\hat{M}(14)$
CSmSp	0.9974	1.5255	0.3777	76.33	97.76
	(0.0075)	(0.3133)	(0.0518)	70.88–82.31	95.71–99.05
CLgSp	0.8387	8.8286	1.2669	43.72	89.94
	(0.0202)	(1.5764)	(0.2216)	35.27–51.87	85.62–92.86
CSmA	0.9856	2.5515	1.6221	99.81	99.84
	(0.0021)	(0.2346)	(0.1527)	99.29–99.99	99.32–100.00
CLgA	1.0000	3.2092	0.6594	82.69	99.57
	(0.0031)	(0.4616)	(0.0756)	77.09–88.65	98.63–99.91
GSmSp	0.8888	8.8990	2.4983	94.94	96.40
	(0.0324)	(3.7468)	(1.1458)	83.34–99.99	88.90–100.00
GLgSp	0.7170	4.5937	0.8572	54.66	77.43
	(0.0489)	(0.6552)	(0.1449)	43.43–65.81	68.47–86.10
GSmA	0.9832	2.3323	1.1789	99.30	99.74
	(0.0041)	(1.0855)	(0.3661)	98.03–99.94	98.91–100.00
GLgA	1.0000	2.5820	0.3979	57.69	95.33
	(0.0120)	(0.2926)	(0.0434)	52.96–62.69	91.79–97.67
HLgSp	0.1075	4.2699	0.4217	2.36	8.93
	(0.0022)	(0.2780)	(0.0283)	1.97–2.70	8.59–9.27
HLgA	0.7068	4.9366	0.4521	11.70	56.13
	(0.0302)	(0.4976)	(0.0501)	7.84–14.95	51.64–59.87
SSmA	0.4765	6.5988	1.0466	31.84	55.31
	(0.1290)	(8.3586)	(1.2384)	21.95–43.60	44.18–65.44

large holding cages (Fig. 2E), their behaviour was calm and they did not attempt to escape. Occasionally, however, some fish were seen to be trapped by the netting folds of the upper cage, but later they swam into the lower cage. Some skin abrasion may have occurred on these occasions. No dead herring were observed during transfer.

While in the large holding cages, most trawl-escapees kept swimming within the middle parts of the cages, usually forming loose shoals. Some fish swam lethargically away from the main school. Generally, the activity of fish appeared low, and no aggressive behaviour was observed. No observations were conducted at night and during the conditions of strong currents. In spring, after the third or fourth day of captivity, many live fish were observed with parts of their skin covered by white mucus. In autumn, severe skin infections were also observed, usually a few days later than in spring.

Underwater observations demonstrated that during emptying (Fig. 2F), the netting cone mounted inside the cages collected all the dead and moribund fish lying on the bottom of the cage without causing any observable harm to those alive. Visual examination of the fish removed at the periodic visits to the cages showed various degrees of external injury and decomposition. Some moribund and recently dead fish had much of their skin infected and covered by mucus, and some others had part of their skin swollen or peeled off revealing the muscle. Skin damage generally increased towards the caudal peduncle, and in many cases fish had lost the caudal fin. Often 20–40% of the skin of these fish was abraded. Usually, larger fish had substantially more visible injuries than the smaller ones. Living fish removed at the end of the caging period often displayed small local skin infections, and in some cases had red sores on their flanks.

Contrary to the condition displayed by trawl-caught herring, fish caught by handline were usually in good condition during the three weeks of observation. The skin of those fish still alive at the end of the caging period did not display white mucus or injuries; only minor local infections, mainly on the snout, were occasionally observed. The dead fish displayed various levels of decomposition. Small herring caught in autumn by seine were also in good condition during the two weeks of confinement, and only a few live fish had local skin infections.

Mortality of cage-kept herring

The scatter plots and fitted curves in Figure 4 (see Table 2 for parameter estimates) show distinct patterns for the cumulative mortalities of trawl-escapees. While mortalities were generally low on the first caging day, they increased dramatically after a few days, approaching the asymptote value, α, which represents approximate maximum cumulative mortality (Table 2). This value was 1 or very close to 1 for all the small trawl escapees (with the only exception of GSmSp, α=0.89) and for the large escapees of the autumn experiments. Asymptotes for the

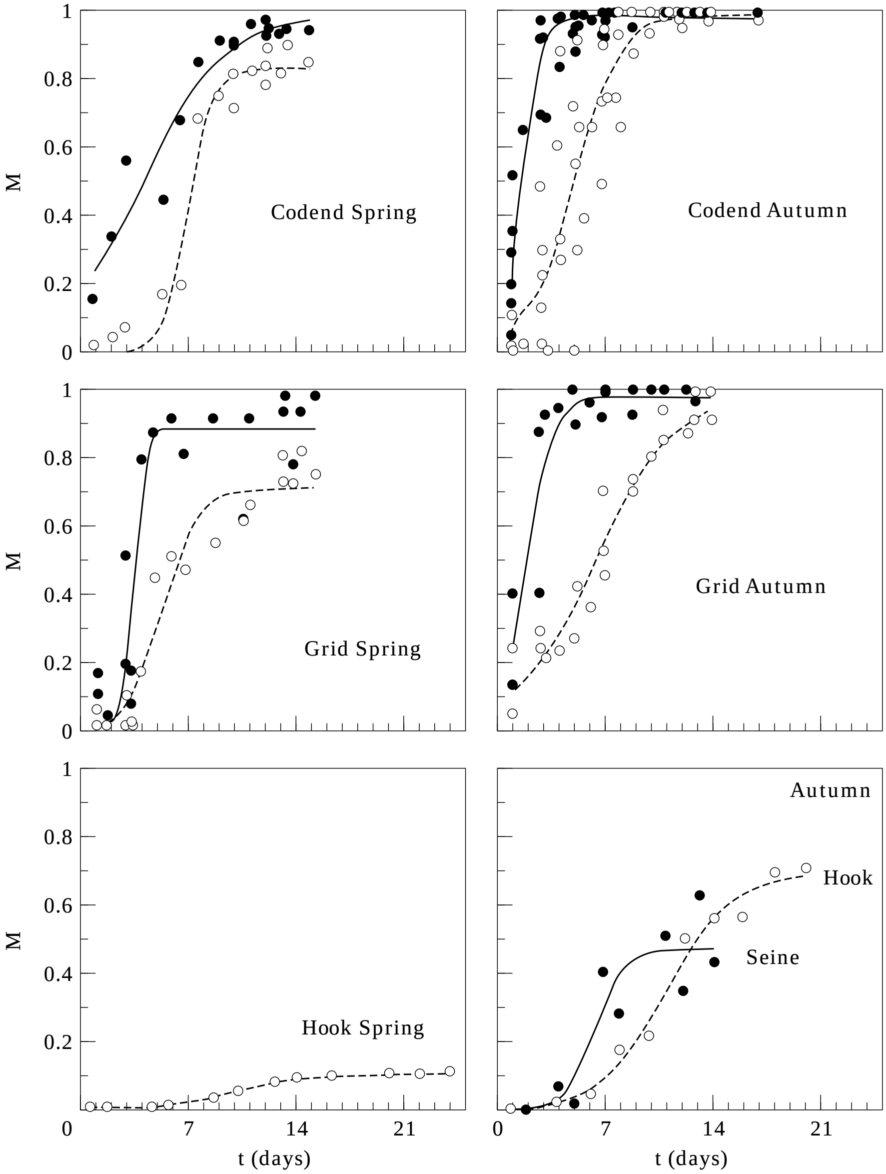

Figure 4. Final fits for cumulative mortalities of small (solid circles) and large herring (open circles).

large escapees of the spring experiments were lower than 1 (α=0.84 and α=0.72 for CLgSP and GLgSP, respectively). Moreover, with the exception of the spring codend experiments, small escapees died faster than large escapees (Fig. 4; compare the steeper slopes of the curves for small escapees to those for large escapees). Curve asymptotes for the large fish were approached at t ⩾ 7 days while those for the small herring were reached in four to seven days (Fig. 4).

Cumulative mortalities for herring caught by seine and hook showed a different pattern. On the first caging days they were as low or lower than those for trawl-escapees, remaining low on following days. Asymptotes α were considerably lower than those for trawl-escapees, especially for the herring caught by hook in the spring experiments (Fig. 4, Table 2, HLgSp, HLgA, and SSmA).

We estimated cumulative mortalities after one and two weeks of caging ($\hat{M}(7)$ and $\hat{M}(14)$) from the 1000 bootstrap replicates of each subset to provide a good assessment of the variation of mortality estimates. Most of the bootstrap distributions for $\hat{M}(7)$ and $\hat{M}(14)$ were skewed. Those for $\hat{M}(7)$ were either slightly positive or negatively skewed with only two symmetric distributions (those for HLgSp and CLgA). Those for $\hat{M}(14)$ were negatively skewed with the exception of HLgSp. Table 2

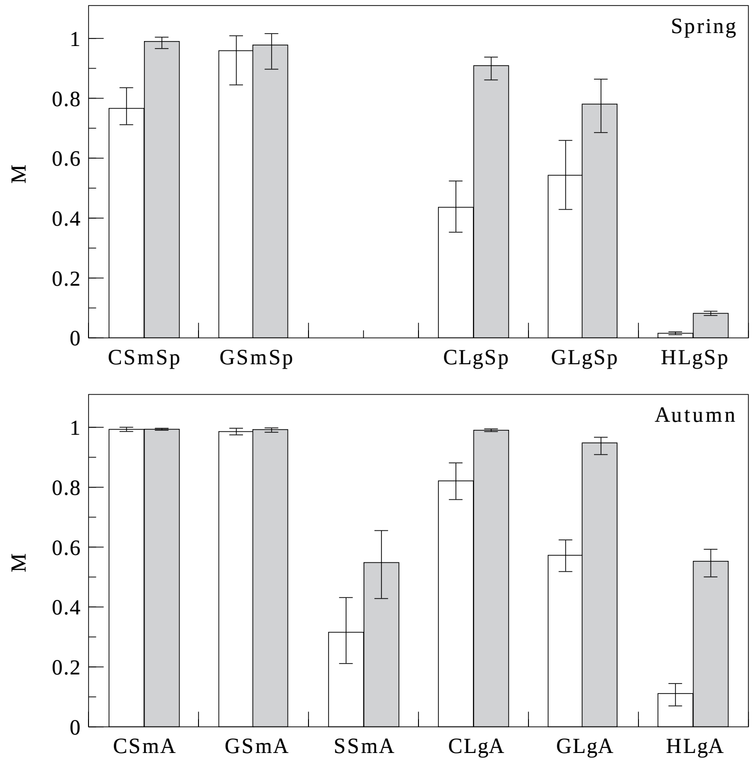

Figure 5. Average predicted mortalities at times t=7 and 14 days, and corresponding 95% confidence limits for bootstrap samples. □: M(T=7); ▩: M(T=14).

and Figure 5 show the average and 95% confidence limits for these distributions. The average mortalities $\hat{M}(7)$ and $\hat{M}(14)$ were higher for the autumn experiments (Fig. 5). Those for herring caught by seine or by handline were noticeably lower than those for codend or grid escapees. Moreover, average mortalities were lower for the large escapees, for both the spring and autumn experiments. Finally, $\hat{M}(14)$ averages were smaller for grid escapees than for codend escapees, and this pattern was consistent across fish size and season. $\hat{M}(7)$ averages, on the other hand, showed an inconsistent pattern (Fig. 5).

Discussion

The results of the present study suggest that (a) most of the small (<12 cm) herring escapees will die due to the trawl capture process, (b) large (12–17 cm) escapees have a better chance of survival, and (c) survival of escapees is not markedly improved by the rigid sorting grid mounted in front of the codend.

Based upon our direct and underwater observations of herring escapees which showed considerable loss of scales and skin infections, characteristics that were almost totally absent in seine or handline caught fish, we argue that these injuries are mainly trawl-related, and that they greatly contributed to the observed mortality of escapees. Numerous underwater observations (e.g. Suuronen and Millar, 1992; Suuronen *et al.*, 1993) have shown frequent and vigorous contacts of herring with the net, particularly along the top panels of the funnelling rear part of the trawl, during the catching process, resulting in heavy skin abrasion and scale loss. Skin damage in turn may account for mortality by facilitating invasion of infectious agents and making the fish more susceptible to disease (e.g. Efanov, 1981; Lockwood *et al.*, 1983; Hay *et al.*, 1986; Main and Sangster, 1990; Sangster and Lehmann, 1994). The muscular exhaustion caused by the herding of the trawl may also contribute to mortality (Beamish, 1966; Wardle, 1981; Suuronen *et al.*, 1996), particular within the smaller size group. Moreover, damage to skin and severe exhaustion may both cause disturbance of the osmotic balance which in due time may cause death (e.g. Roald, 1980; Borisov and Efanov, 1981; Rosseland *et al.*, 1982; Milligan and Wood, 1986). However, given the low salinities of the Baltic Sea, osmotic stress may have had a smaller effect on mortality than if the experiments had been conducted in the North Sea (Wardle, 1981).

Small herring escapees died substantially faster than the larger ones, although one would expect lower mortality in small fish because it should be easier for them to pass through meshes or sorting grids. Several other studies have also indicated higher mortalities for smaller escapees (e.g. Borisov and Efanov, 1981; Soldal *et al.*, 1993; Sangster and Lehmann, 1994; Suuronen *et al.*, 1996). Underwater observations have clearly shown that, during trawling, small fish, including small herring, are usually forced to swim beyond the limits of their stamina (e.g. Main and Sangster, 1981; Suuronen and Millar, 1992; Suuronen *et al.*, 1996). Furthermore, disturbance of the osmotic balance may be more acute among small fish because of their higher surface/volume ratios.

Light conditions during trawling may have influenced our mortality results since most of the hauls were conducted during the evening or at night. It is fairly well documented that the behaviour of fish in relation to moving netting is primarily determined by their reaction to visual stimuli. As visibility range decreases during darkness, herding becomes reduced and, below a threshold level, fish are unable to react in an ordered pattern (e.g. Blaxter and Parrish, 1966; Blaxter and Batty, 1985; Glass and Wardle, 1989; Walsh and Hickey, 1993). Thus, one may expect that herring swimming in the net during darkness will suffer more abrading contacts with the netting and find it increasingly difficult to escape through the meshes or the grid. For example, Suuronen *et al.* (1995) observed that the highest mortality of 5–10 cm vendace (*Coregonus albula*) escaping from a 24 mm square mesh codend was associated with hauls conducted during darkness.

Herring escapees died faster in autumn than in spring. This difference suggests some seasonal effect on escape survival. However, herring caught by handline also showed a similar mortality pattern. Reasons for this seasonal difference can only be guessed. For example, the possible adverse effects of cage confinement could have been amplified by less than optimal autumn weather conditions. It is also possible that the substantially longer nights in autumn (at latitude 60°N, the average night span is 15 h in the beginning of November, but only 5.5 h in late May) increased the probability of unintentional encounters between fish and cage, causing increased skin abrasion and induced mortality. An additional factor, particularly in the case of small escapees, could have been the different body size (see Fig. 3) and physiological condition of fish. On the basis of our results, it is not clear how much of the increased mortality in autumn trials can be attributed to trawl-related factors.

The advantage of implementing sorting grids over more traditional codend mesh size regulations is not that obvious from our study. Although previous underwater observations showed that the passage of herring through rigid sorting grids was easier than if they swim through codend meshes (Suuronen, 1991; Suuronen *et al.*, 1993), the present experiments suggest that the survival of herring escapees will not be greatly improved by the use of a rigid sorting grid mounted in the front part of the codend. Only large herring may benefit somewhat from grid sorting; the average predicted mortality was 13% lower for grid escapees in spring, and 4% lower in autumn. Among small herring, differences were minimal. It is questionable whether such small reductions in the mortality of herring may have a real impact on the future of the fishery. However, there might still be good opportunities to improve the design and placement of grids, and thus attain greater survival of fish escaping through it. For instance, if the grid was placed before the rear funnelling part of the trawl, where most of the trawl-induced damage is likely to occur, the survival of escapees might improve substantially.

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References

Beamish, F. W. H. 1966. Muscular fatigue and mortality in haddock, *Melanogrammus aeglefinus*, caught by otter trawl. Journal of the Fisheries Research Board of Canada, 23: 1507–1521.

Blaxter, J. H. S. and Parrish, B. B. 1966. The reaction of marine fish to moving netting and other devices in tanks. Marine Research, 1. 15 pp.

Blaxter, J. H. S. and Batty, R. S. 1985. Herring behaviour in the dark: responses to stationary and continuously vibrating obstacles. Journal of the Marine Biological Association UK, 65: 1031–1049.

Borisov, V. M. and Efanov, S. F. 1981. To the problem of natural and traumatical mortality of Baltic herring. ICES C.M. 1981/J:13. 10 pp.

Efanov, S. F. 1981. Herring of the Gulf of Riga: the problem of escapement and mechanical impact of the trawl. ICES C.M. 1981/J:7. 16 pp.

Glass, C. W. and Wardle, C. S. 1989. Comparison of the reactions of fish to a trawl gear, at high and low light intensities. Fisheries Research, 7: 249–266.

Hay, D. E., Cooke, K. D., and Gissing, C. V. 1986. Experimental studies of Pacific herring gillnets. Fisheries Research, 4: 191–211.

Larsen, R. and Isaksen, B. 1993. Size selectivity of rigid sorting grids in bottom trawls for Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). ICES Marine Science Symposia, 196: 178–182.

Lockwood, S. J., Pawson, M. G., and Eaton, D. R. 1983. The effects of crowding on mackerel (*Scomber scombrus* L.)—physical condition and mortality. Fisheries Research, 2: 129–147.

Main, J. and Sangster, G. I. 1981. A study of the fish capture process in a bottom trawl by direct observation from a towed underwater vehicle. Scottish Fisheries Research Reports, 23. 24 pp.

Main, J. and Sangster, G. I. 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 Fisheries Research Reports, 46. 28 pp.

Milligan, C. L. and Wood, C. M. 1986. Intracellular and extracellular acid-base status and H^+ exchange with the environment after exhaustive exercise in the rainbow trout. Journal of Experimental Biology, 123: 93–121.

Roald, S. O. 1980. Net marks on Atlantic salmon (*Salmo salar* L.) in Norwegian coastal areas. Preliminary report on gross histological, serological and bacteriological signs. ICES C.M. 1980/M:34, 6 pp.

Rosseland, B. O., Trygve, B. L., and Hansen, L. P. 1982. Physiological effects and survival of Carlin-tagged and descaled Atlantic salmon, *Salmo salar* L., in different water salinities. ICES C.M. 1982/M:30, 23 pp.

Sangster, G. I. and Lehmann, K. 1994. Commercial fishing experiments to assess the scale damage and survival of haddock and whiting after escape from four sizes of diamond mesh codends. ICES C.M. 1994/B:38. 24 pp.

Soldal, A. V., Isaksen, B., Marteinsson, J. E., and Engås, A. 1991. Scale damage and suvival of cod and haddock escaping from a demersal trawl. ICES C.M. 1991/B:44, 7 pp.

Soldal, A. V., Isaksen, B., Marteinsson, J. E., and Engås, A. 1993. Survival of gadoids that escape from a demersal trawl. ICES Marine Science Symposia, 196: 122–127.

Suuronen, P. 1991. The effects of a rigid grating on the selection and survival of Baltic herring – preliminary results. ICES Fish Capture Committee C.M. 1991/B:17, 22 pp.

Suuronen, P. and Millar, R. B. 1992. Size-selectivity of diamond and square mesh codends in pelagic herring trawls: only small herring will notice the difference. Canadian Journal of Fisheries and Aquatic Sciences, 49: 2104–2117.

Suuronen, P., Lehtonen, E., and Tschernij, V. 1993. Possibilities to increase the size selectivity of a herring trawl by using a rigid sorting grid. Paper presented at the Symposium on Gear Selectivity/Technical Interactions in Mixed Species Fisheries hosted by NAFO, Dartmouth, Nova Scotia, Canada, 13–15 September 1993. NAFO SCR Doc. 93/119, Serial no. N2313, 12 pp.

Suuronen, P., Erickson, D. L., and Orrensalo, A. (1996). Mortality of herring escaping from pelagic trawl codends. Fisheries Research, 25: 305–321.

Suuronen, P., Turunen, T., Kiviniemi, M., and Karjalainen, J. (1995). Survival of vendace (*Coreogonus albula*) escaping from a trawl codend. Canadian Journal of Fisheries and Aquatic Sciences, 52: 2527–2533.

Treschev, A. I., Efanov, S. F., Shevtsov, S. E., and Klavsons, U. A. 1975. Die Verletzung und die überlebenschancen des Ostseeherings nach dem Durchdringen durch die Maschen des Schleppnetzsteerts. Fischerei Forschung, 13: 55–59.

Walsh, S. J. and Hickey, W. M. 1993. Behavioural reactions of demersal fish to bottom trawls at various light conditions. ICES Marine Science Symposia, 196: 68–76.

Wardle, C. S. 1981. Physiological stress in captive fish. *In* Aquarium Systems, pp. 403–414. Ed. by A. D. Hawkins, Academic Press, London.