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Escape mortality of trawl caught Baltic cod (*Gadus morhua*) — the effect of water temperature, fish size and codend catch

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Abstract

Experiments were conducted in the Baltic Sea to measure mortality of cod that escape through trawl codend meshes under commercial fishing conditions. Three codend types were tested: a 120 mm diamond mesh codend, a Danish type 105 mm escape window codend, and a 105 mm square mesh top-panel codend (Bacoma-window). In total, 30 tows were carried out in three different experiments. Mean tow duration was 3 h and average codend catch 536 kg (range 47–2592 kg). Escapees were collected during the last 20 min of each haul by a caging method. These fish were then held in cages anchored on the seabed and checked daily by divers. Average number of escapees in cage was 133. Average caging duration was 9.5 days. The mortality of escapees was low in normal water temperatures (<10 °C) in all codend types. Higher mortalities were observed when cages were held in temperatures above 15 °C. The majority of these deaths occurred during the first day after the tow. Apparently, these fish experienced strong thermal stress when they were towed to the cage release site through the thermal stratification layer. In commercial trawling the tow is usually not directed to shallow waters. A somewhat higher mortality was predicted for larger fish that escaped from the 120 mm diamond mesh codend while in the 105 mm escape window codend the effect was reverse. In the Bacoma-window codend the number of dead escapees was very low in all length groups. We did not find any clear difference in skin injury between the three codend types. The predicted escape mortality was somewhat higher with higher codend catches. We conclude that the mortality of Baltic cod codend escapees is low in the normal water temperature (3–9 °C).

Keywords: Baltic cod; *Gadus morhua*; Escape window; Bacoma-codend; Codend escapees; Mortality; Temperature; Fish length; Codend catch; Skin injury

1. Introduction

Improving trawl selectivity is based on the fundamental assumption that escaping fish survive. The question of survival is becoming increasingly important because there is a tendency among fisheries managers to increase the minimum allowed mesh size. For instance, in the Baltic cod (*Gadus morhua*) trawl fishery the minimum mesh size has been increased three times during the last decade. A larger mesh size means that a larger part of the fish population will swim through the trawl meshes. If the survival of these fish is poor,

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there may be no advantages of increasing the mesh size (e.g. Kuikka et al., 1996; Breen and Cook, 2002). In the worst case the effect of this type of unaccounted mortality may be negative on fish stocks because the overall mortality caused by the exploitation is underestimated. For the effective management of fishery, the mortality associated with escape should be known.

Most survival experiments carried out so far have not fully simulated commercial fishing conditions in terms of tow duration, depth, catch size, and season (e.g. Main and Sangster, 1990; Soldal et al., 1993; Sangster et al., 1996; Suuronen et al., 1996a, 1996b). Hence, these experiments may not reflect the full range of possible sources of injury and mortality encountered by trawl codend escapees under normal commercial fishing conditions. For instance, Suuronen et al. (1996a) observed a low mortality among Baltic cod escapees but they typically assessed the mortality in relatively shallow water during summer months under short trawl tows and low catches.

Furthermore, the escapee-capture methods used in the past experiments may have been detrimental to the escapees, e.g., by causing additional damage and stress for instance due to the towing of escapees in the collection cover (e.g. Suuronen et al., 1996b). Breen et al. (2002) reported that the escapees captured in the codend cover are exposed to a continuous flow of water and suspected that depending on the length of time spent in the cover (cover exposure time) this may cause injury and fatalities among fish. In most survival experiments the sampling period typically has been from the beginning to the end of the tow because there has been no adequate technique available to take samples during the tow. This has effectively restricted the duration of the experimental tows (typically only 10–30 min), whereas commercial trawl tows usually take 3–6 h. Clearly, the duration of the tow and codend catch volume should not be restricted by the method used to collect escapees. A technique is needed that permits collection of fish escaping from the codend during any chosen interval during a tow so that survival can be assessed for realistically long commercial tows with commercial catch quantities. In addition, the injury induced by the collection technique should be minimized.

The first objective of this study was to develop a method for measuring the mortality of cod escaping through trawl codend meshes under commercial fishing conditions. A technique was developed by which we can collect a sample of escaping fish during any moment of a haul and minimize injury caused by cover exposure (Lehtonen et al., 1998). With this technique, the sampling period can be controlled more precisely and can be kept substantially shorter than in previous experiments (e.g. Suuronen et al., 1996a). Hence, the sampling duration is not dependent on the tow duration. Survival can be assessed for short and long tows and for small and large catch quantities.

The objective of this study was (a) to assess the survival of Baltic cod under commercial fishing conditions and (b) to examine the degree of damage of fish due to the trawling and escape process by using the new collection technique. This paper describes survival experiments that were conducted in 1997–1998 in the Baltic Sea.

2. Material and methods

2.1. Escapee-collection technique

A cage system that was attached to the terminal end of a codend cover with gates that open and close was designed (for more details, see Lehtonen et al., 1998). The cage system was made of two sections. The front section (release unit) was fixed to the rear part of the codend cover and carries three timers that are operated with rechargeable batteries. The detachable rear section (collection unit) consists of front gate, cage body and rear gate. Gate frames were connected to the cage body with hinges. The collection unit was ca. 5 m^3 (1.7 m per side) and webbed with black 26 mm (stretched mesh) square mesh knotless PA netting.

The cover was initially deployed with the gates open so any fish escaping from the codend were allowed to swim freely through the cage system and into the open sea. This allowed a realistic catch to collect in the codend before sampling of the escapees began. Collection of the sample began when a pre-set timer activated the closure of the rear gate. Following a 20 min sampling time, the front gate was closed using a second timer, confining sampled escapees inside of the collection unit. Shortly after the front gate was closed, a third timer activates the separation of the collection unit from the release unit. The collection unit then drops to the sea bed and a float rises to the surface indicating cage position.

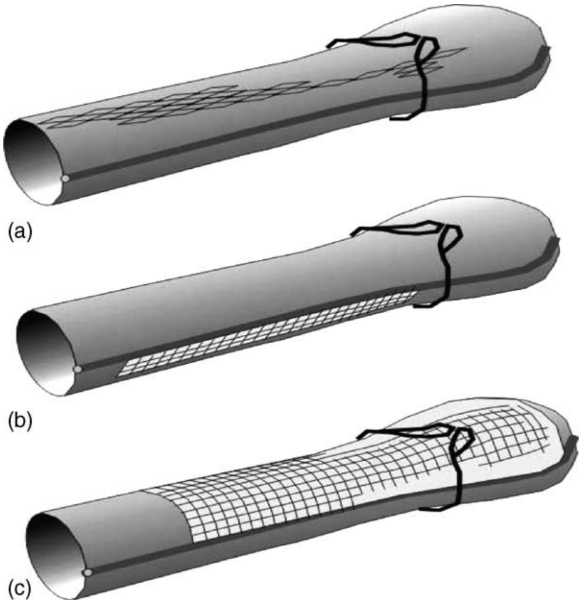

Fig. 1. Three codend types that were tested in the cod survival experiments in 1997–1998 in the Baltic Sea: (a) standard 120 mm diamond mesh codend (D120), (b) Danish type of 105 mm PET escape window codend (E105), and (c) 105 mm square mesh knotless ultra-cross top-panel codend (UC105; Bacoma-window).

2.2. Experimental codends

Three codend types (Fig. 1) were tested in the experiments: (a) standard 120 mm diamond mesh codend (D120), (b) Danish type of 105 mm PET escape window codend (E105), and (c) 105 mm square mesh knotless ultra-cross top-panel codend (UC105). The presented mesh sizes are nominal. D120 and E105 were the codend types that were most commonly used in the Baltic cod fishery during the time of this study. UC105 was chosen as a third test codend because this type of codend had shown promising selectivity characteristics during the preliminary selectivity trials (e.g. Madsen et al., 2002; Tschernij and Suuronen, 2002) and was considered as a candidate for a future codend type in the Baltic cod fishery. This type of window codend has since 2002 been the only allowed window codend type in the Baltic cod trawl fishery (so-called Bacoma top window codend). Since October 2003, the minimum mesh opening of the Bacoma-window has been 110 mm (EC Council Regulation No. 1754/2003).

The D120 standard codend was a commercial diamond mesh codend measuring 100 open meshes in circumference. The E105 escape window codend was a standard 105 mm diamond mesh codend that was equipped with 105 mm square mesh escape window panels (double 4 mm twisted PET knotted netting) on both sides of the codend (for more details, see EC Council Regulation No. 3362/94). The 3.5 m window panels were mounted just below the side seams 1.8 m ahead from the end of codend. The UC105 codend was made of a 105 mm standard codend that was equipped with a 105 mm knotless square mesh ultra-cross top-panel (braided single 4.9 mm twine, black) attached four meshes in front of the codline. The length of the panel was 60 meshes and width 24 meshes.

The selectivity characteristics of the codends tested here have been described in Lowry et al. (1995), ICES (1996), Tschernij et al. (1996), Tschernij and Holst (1999), Madsen et al. (2002) and Tschernij and Suuronen (2002). According to these sources, the 50% retention length (L_{50}) of E105 is ca. 32 cm, D120 ca. 35 cm, and UC105 ca. 37 cm. Hence, the codends tested in this survival study did not have exactly similar selectivity characteristics.

2.3. Survival experiments

Experiments were conducted in the southern Baltic Sea on commercial fishing grounds off Simrishamn in the Bay of Hanö, Sweden (ICES subdivision 25) with a chartered commercial stern trawler “Kungsö” (GRT 166, 22 m, 661 kW) using a conventional commercial bottom trawl (380 mm × 120 mm) and trawl rigging. The first experiment was made in August–September 1997 (Experiment 1), the second in March–April 1998 (Experiment 2) and the third one in August–September 1998 (Experiment 3).

In total, 30 technically successful trawl tows were conducted, 14 tows with the E105 codend, 12 tows with the D120 codend and four tows with the UC105 codend. It is notable that during Experiment 2 there were very few young fish in the survey area and we were not able to collect enough escapees from the E105 codend. To obtain at least some escapees into the collection cages, we were forced to use the D120 codend that has a somewhat higher L_{50} (six out of seven tows).

The average towing duration was 3 h 4 min (range 2 h 53 min–3 h 24 min). Typical towing depth was 30–55 m. However, tows were directed at the very final phase from normal fishing depths to somewhat shal-

Table 1
General information of survival tows and caging carried out in 1997 and 1998 in the Baltic Sea: Experiment 1 (August–September 1997), Experiment 2 (March–April 1998) and Experiment 3 (August–September 1998)

Experiment/date	Codend type	Codend catch (kg)	Caging duration (days)	Cage depth (m)	Temperature (°C)	Number of escapees	Number of dead escapees	Escape mortality (%)
Experiment 1								
August 14	E105	2590	7	21	17.7	239	40	16.7
August 15	E105	1296	7	22	18.3	655	79	12.1
August 15	E105	795	7	23	17.8	424	73	17.2
August 19	D120	792	7	24	18.6	588	49	8.3
August 19	D120	1620	7	25	18.6	140	35	25.0
August 20	D120	2592	7	22	18.1	284	137	48.2
August 29	E105	807	5	22	16.2	89	67	75.3
August 29	D120	162	5	23	16.2	84	49	58.3
August 30	D120	514	5	23	16.4	36	5	13.9
August 30	E105	287	5	21	16.4	69	28	40.6
August 31	E105	420	5	22	17.4	83	13	15.7
August 31	D120	254	5	27	14.2	83	0	0
September 4	E105	323	7	34	8.4	231	0	0
September 4	E105	184	7	34	8.8	97	2	2.1
September 5	E105	198	7	35	8.0	89	0	0
Experiment 2								
March 24	E105	182	12	21	3.3	13	0	0
March 24	D120	47	12	18	3.3	137	2	1.5
March 25	D120	122	12	17	3.5	46	3	6.5
March 25	D120	82	12	23	3.5	69	1	1.4
March 25	D120	95	12	19	3.5	38	0	0
March 26	D120	123	12	16	4.1	56	1	1.8
March 28	D120	69	12	25	3.9	57	0	0
Experiment 3								
August 7	E105	532	12	28	5.4	21	0	0
August 7	E105	195	12	28	5.6	26	0	0
August 17	UC105	144	14	29	5.9	67	1	1.5
August 17	UC105	341	14	27	6.0	29	0	0
August 18	E105	422	14	26	5.7	27	2	7.4
August 18	UC105	315	13	31	5.4	114	0	0
August 20	E105	390	13	31	5.8	73	6	8.2
August 20	UC105	183	13	29	5.8	26	1	3.8

Temperature (°C) is indicated as the temperature measured in Day 1 at the cage site at the cage depth.

lower grounds to release the cage in depths where scuba divers were able to monitor the cages (Table 1).

Sampling of codend escapees took place during the last 20 min of each haul. On the basis of pilot tests (Lehtonen et al., 1998), this sampling duration was considered long enough to collect sufficient number of escapees in each tow but short enough for not causing severe additional damage and stress for them. After 20 min sampling the front gate was closed and the collection cage was released from the trawl. The float that came up to the surface indicated the position of the cage. Cages were then anchored separately on the seabed to the site where they were detached from the trawl. No transportation of cages was conducted and cages were held at bottom throughout the experiment (i.e., live cod were not raised to the surface until the end of the study). Divers made daily visits to seabed cages to count the number of fish and to remove the dead escapees from each cage. Holding depths of cages ranged from 16 to 35 m. The bottom at cage site was flat and consisted mainly of sand. In the first experiment, the caging duration averaged 6 days (range 5–7 days), and in the second and third experiments 13 days (range 12–14 days). The average fish density in cage was 26.6 fish/m^3 (range 2.6–131 fish/m^3).

To assess the performance of the gear during the tow and the release process, and to monitor the behavior of escapees in the codend cover and collection cage, a towed underwater video camera system was used during the tows in Experiments 1 and 3. In addition, a fixed underwater video camera was attached in the lower corner of the releaser unit to observe the release process and fish behavior at that particular location of the gear. In Experiment 2 no underwater observations were made due to harsh conditions.

During Experiment 1 fish were daily fed with fresh slices of herring and sprat by the divers. Fish did not show any interest to fresh herring and sprat. Therefore, fish were not fed during second and third experiments. Divers recorded cages with a hand-held underwater video camera to obtain information of fish behavior in cages. Water temperature at the cage site was measured daily. Table 1 shows water temperatures at the cage site during the first caging day. It is notable that during Experiment 1, the water temperature at cage site was markedly lower in depths below 30 m compared to depths of 20–25 m. Usually the temperature did not vary much during the consecutive caging days at a particular depth (less than 1 °C). Water temperature was not measured during the actual trawl tows.

Before completing the caging, all dead escapees were removed from the cage by divers to ensure that only alive escapees remained in the cage. This procedure was important in order to separate the fish that may have died during the last monitoring day from the escapees that may have died while the cage was slowly (3–4 m/min) raised to surface. Fish behavior during the ascent was documented with an underwater video camera held by a diver. The cage was kept near the surface until all fish were transferred with a small dip net into seawater filled container placed on the rear deck of the research boat.

2.4. Documentation of skin injury in fish

Documentation of skin injury in escapees was conducted immediately after the fish were transferred to the surface. The type of injury was registered into two categories: scale loss and net marks (for methodological details, see Suuronen et al., 1996a). Scale loss (cm^2) was quantitatively determined with a measurement ruler. Net marks were assessed only on the basis of their existence (injury/no injury). The damaged skin areas were recorded for later analysis using photography and a video camera.

2.5. Capture of control fish

To evaluate whether the cage holding procedure caused additional injury and mortality to escapees, a substantial effort was allocated to catch control fish. During the first experiment, eel-traps, hand lining and bottom gillnetting were used but caught few fish and caused unacceptable injuries. During the second experiment, the harsh weather conditions made the capture of controls impossible.

During the third experiment, the capture of control fish was conducted with two-chamber pots made of 26 mm (stretched mesh) square mesh knotless PA netting (same netting material as in collection cages). The length and height of the pots was 1.2 m and the width 0.8 m (2.6 m^3). Small pieces of herring, sprat and shrimp were placed in a small netting bag inside the pots as bait. In total, 47 fish were caught with 10 pots and anchored in the vicinity of the cage site at the same depths as the trawling cages (25–30 m). Fish were held in these pots and monitored in the same area, depth, and temperature as the trawl escapees. The average stocking density in pot was 1.8 fish/m^3. Divers closed the entrances in the pots before the eventual monitoring started to prevent new entries. Fish were not transferred into holding cages because it was considered technically too difficult and very risky for the escapees. The pots were assumed to mimic the holding cages. Control cages were not towed 20 min.

2.6. Statistical analysis of escapee mortality and skin injury data

Logistic regression analysis (binary logit with multiple predictors, rem logit, SYSTAT, 2002) was used in modelling escapee mortality and skin injury (1/0, response variables). The mortality of codend escapees was modelled with continuous explanatory factors that were water temperature, fish length, codend catch (kg) and fish density in cage (fish/m^3). The statistical examination of UC105 codend mortality's explanatory factors was excluded because the total number of dead escapees was very low (n = 2). When estimating the relative importance of each explanatory factor to D120 and E105 codend mortality, the response variable was weighted by the number of fish in cage by each tow, i.e. each tow was treated as a single case. When comparing the escape mortality and skin injury of the three codend types, the response variable was weighted by the number of fish in cage by each codend type, i.e. each codend type was treated as a single case. The escape mortality and skin injury probability (P) were calculated as

$$P = \frac{\exp(\alpha + \beta_1 \times x_1 + \beta_2 \times x_2 + \delta_1(x_1 \times x_2) + \cdots + \beta_n \times x_n + \delta_n(x_{n-1} \times x_n))}{(1 + \exp(\alpha + \beta_1 \times x_1 + \beta_2 \times x_2 + \delta_1(x_1 \times x_2) + \cdots + \beta_n \times x_n + \delta_n(x_{n-1} \times x_n)))} \quad (1)$$

where α, β and δ are estimated parameters and x is an explanatory factor. The term $\exp^{(\text{parameter estimate})}$ is commonly known as the odds ratio. The odds ratios were evaluated when estimating the relative importance of each explanatory factor to escape mortality and skin injury. Interaction terms, ($\delta(x \times x)$), were applied for assessing interactions between the explanatory factors. In mortality analysis, the least significant term was removed one at a time until all parameters were significant (95% criterion). The final model-based results are from the reduced versions of the complete models. Deviances, degrees of freedom and Hosmer–Lemeshow statistics were taken into consideration when selecting the model. Hosmer–Lemeshow statistics are used to assure that the results are not unduly influenced by a handful of unusual observations (SYSTAT, 2002). The influence of the unusual observations cannot be evaluated by the deviance/degrees of freedom ratio.

3. Results

3.1. Fish behavior during escape, sampling and caging

Underwater observations showed that the trawl codend was most of the time enveloped by a sand and mud cloud generated by the ground gear of the trawl. On a few occasions when visibility allowed observation, cod were seen swimming inside the extension piece and codend, maintaining their position in relation to the gear and keeping some distance to the netting walls. Smaller (<30 cm) cod appeared more exhausted than the larger ones, and were occasionally observed to pass rapidly towards the rear part of the codend. Fish within the catch bulge were often pressing against each other and the codend wall. Only a few active attempts to swim through the codend or window meshes were observed. On the other hand, cod were often seen squeezing slowly through a mesh; this behavior appeared passive and could take several minutes. Larger individuals sometimes became stuck (gilled) in the meshes of the standard diamond mesh codend and remained impinged between the bars. Too few observations were obtained to make reliable comparisons about the escape behavior of cod in relation to various codend types. It is also notable that these observations were made when the codend was covered by the cover.

Escapees were seen freely swimming through the cover and the cages when the gates were open. Fish maintained some distance from the codend cover. Once activated, the gates closed slowly. Fish remained at some distance from the gates during this closing process. No evidence of a panic response was observed during this process. During the daily underwater observations at cage site, caged fish were swimming slowly in shoals avoiding the netting walls. No observations, however, were made during night. No panic response was observed during the lifting of cages to the surface.

3.2. Codend catch

The average codend catch of cod was 536 kg (range 47–2592 kg). In general, codend catch was markedly lower in the second and third experiment than in the first experiment (Table 1). In Experiment 1, the fish length in codend catch ranged from 15 to 70 cm and showed the highest peak in the 40–47 cm length classes. The length distribution of catch in both codend types was similar but E105 retained substantially more cod in size groups below 35 cm than D120. In Experiment 2, the length of fish in codend catch ranged from 14 to 91 cm and showed the highest peak in the 28–45 cm. Note that six out of seven tows in Experiment 2 were made with D120. The average size of fish caught in codend was substantially smaller (ca. 10 cm) in Experiment 2 than in Experiment 1 indicating different cod length distribution in the study area. In Experiment 3, the fish

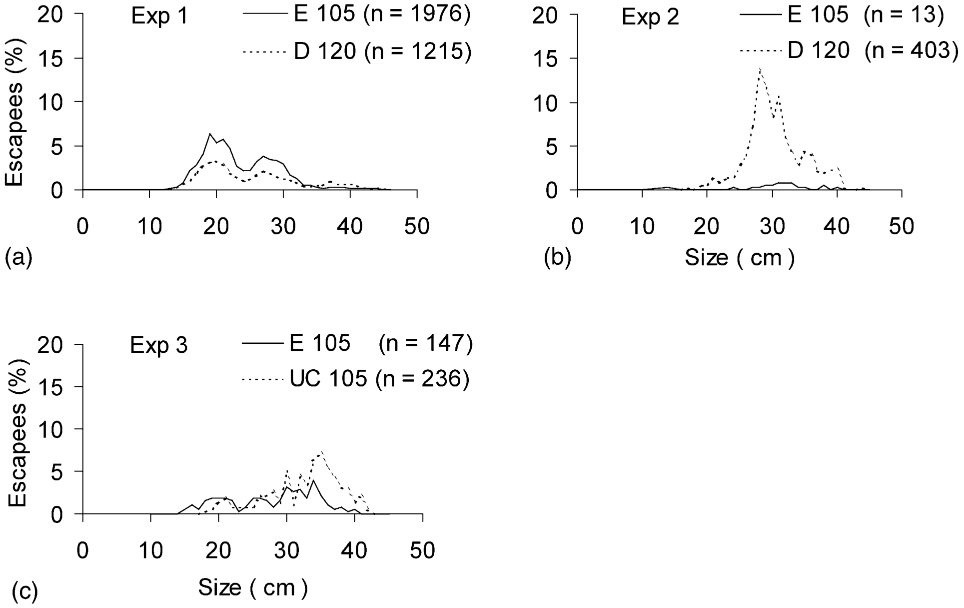

Fig. 2. Pooled percentage length frequency distributions of escapees in 120 mm diamond mesh codend (D120), 105 mm Danish escape window codend (E105) and in 105 mm UC codend (UC 105) in Experiments 1–3.

length in codend catch ranged from 12 to 98 cm peaking at 28–48 cm. E105 caught markedly more fish below 30 cm compared to UC105 suggesting better selectivity of the UC105.

3.3. *Escape mortality*

There was a substantial variation in number of escapees caught in cage within and between the three experiments (Table 1). The average number of fish in cage was 133 (range 13–655).

In Experiment 1, a total of 3191 escapees were held in cages (average 213/cage). The length distributions of escapees in E105 and D120 were very similar (Fig. 2a). Few escapees were larger than 40 cm. Total number of survivors was 2614. The number of dead escapees was 577. The average size of dead escapees was 25.3 cm and that of surviving escapees 24.0 cm. Large differences in mortality were observed between hauls in Experiment 1 (Table 1) but the average mortality was at the same level in both codend type. In general, a substantially higher mortality took place during the first 11 hauls (on average 26.2%) than during the four last hauls (<1%) when the cages were released and anchored in deeper and colder water. It is noteworthy that 92% of deaths occurred during the first day after the trawling. It is also notable that during those first 11 hauls the water temperature at cage site was exceptionally high: on the average 17.4 °C (range 16.2–18.6 °C).

In Experiment 2, a total of 416 escapees were held in cages (average 60/cage) and most escapees were 25–35 cm (Fig. 2b). The total number of survivors was 409, while the number of dead escapees was seven. The mean length of survivors was 30.3 cm and that of dead 31.9 cm. The average water temperature at cage site was 3.8 °C (range 3.3–4.1 °C), which is typical for winter.

In Experiment 3, a total of 383 escapees were held in cages (average 48/cage). There were relatively more escapees above 35 cm in UC105 than in E105 (Fig. 2c). The total number of survivors was 373. The total number of dead escapees was 10; eight of them in E105. The mean length of survived fish was 31.1 cm. All dead fish were small; their mean length was 19.7 cm (range 16–25 cm). The average water temperature at cage site was 5.7 °C (range 5.4–6.0 °C).

All 47 control fish in Experiment 3 survived the whole monitoring period. Their lengths ranged from 17 to 43 cm; most were from 31 to 35 cm. There were no controls in Experiments 1 and 2.

3.4. Factors affecting mortality

Fig. 3 presents the cumulative mortality of escapees in each cage shown (a) in high water temperature and (b) in low temperature. Clearly, in normal water temperatures (<10 °C), low mortality was observed in all codend types. At higher temperature, the mortality increased dramatically. Further, the variation in mortality increased with increasing temperature. It is noteworthy that most deaths took place in the very beginning of the monitoring period (Fig. 3). Clearly, the caging duration used in this study was long enough to show the cumulative mortality of cod.

The model suggests that water temperature was the most important factor in determining the mortality of escapees (Table 2 and Fig. 4). The higher the water temperature the higher the mortality (odds 1.574, 1.263). It is notable that odds ratio values farther away from value one reflect larger relative effect on mortality. The statistical significance in Table 2 ($P < 0.05$) does not inevitably indicate large relative effect of an explanatory factor in determining escapee mortality (unlike large or small odds ratios). The interaction terms shown in Table 2 are statistically significant ($P < 0.05$). Their relative effect in determining escapee mortality in E105 and D120, however, was small (small deviation from value 1 in odds ratio). The interaction terms "temperature (°C) × catch (kg)" and "temperature (°C) × length (cm)" were statistically insignificant ($P > 0.05$) in D120 and were excluded in the model.

In general, low mortality was observed in all length classes in normal temperatures, with no apparent length-effect (Fig. 4). However, in E105 a somewhat higher mortality was predicted in small length classes (odds 0.887, Table 2) while in D120 the length-effect was reverse (odds 1.109). In E105 and D120, the predicted escapee mortality was somewhat higher with higher codend catches (in kg). Codend catch had the smallest relative effect on escapee mortality within the significant factors (odds 1.026, 1.001).

Fish density in cage was insignificant in determining E105 codend escape mortality ($P = 0.15$) and was removed from the final model. Fish density was significant ($P < 0.05$) in determining escape mortality in D120 codend but the relative effect to the overall escape mortality was negligible (odds 0.99). Due to insignificance of the Hosmer–Lemeshow probability value, fish density in cage was removed from the final model (Table 2).

The statistics suggested reasonably good model fit in all mortality analysis because the deviances were smaller than their degrees of freedom values and because the Hosmer–Lemeshow probability values showed significance.

In normal water temperatures (<10 °C) the escape mortality did not differ statistically (E105, $P = 0.971$; UC105, $P = 0.205$) between the three codend types when the D120 codend mortality was used as a reference (Table 3).

3.5. Skin injury

Figs. 5 and 6 show the scale loss and net mark length distributions of escapees by trawl codend type and by fish length groups in each three experiments. The skin injury length distributions are scaled to the total number of skin injuries by each codend type, i.e. the figures do not show the absolute numbers of skin

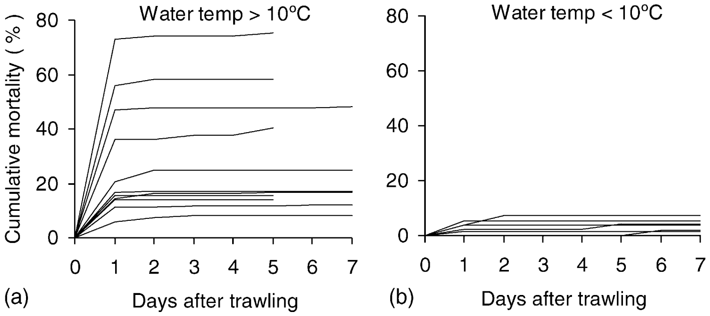

Fig. 3. Cumulative mortality by trawl tow for cod that escaped through trawl codend meshes and held in cages (a) at high water temperature and (b) at low temperature (all experiments included).

Table 2
The parameter estimates and odds ratios of the mortality analysis. It is notable that odds ratio values farther away from value 1 reflect larger relative effect on escapee mortality

Codend type/parameter	Estimate	S.E.	*t*-Ratio	*P*-value	Odds ratio	Upper 95%	Lower 95%	d.f.
E105								
Constant	−10.858	0.714	−15.191	0.000				
Temperature (°C)	0.454	0.043	10.511	0.000	1.574	1.714	1.447	
Length (cm)	−0.118	0.028	−4.218	0.000	0.887	0.938	0.840	
Catch (kg)	0.026	0.001	39.992	0.000	1.026	1.027	1.025	
Catch × length	−0.000	0.000	−15.421	0.000	0.999	0.999	0.999	
Temperature × length	0.012	0.001	7.388	0.000	1.012	1.016	1.009	
Temperature × catch	−0.001	0.000	−39.049	0.000	0.998	0.998	0.998	
Hosmer–Lemeshow	262.929			0.000				3
D120								
Constant	−7.966	0.300	−26.553	0.000				
Temperature (°C)	0.233	0.008	26.438	0.000	1.263	1.285	1.241	
Length (cm)	0.104	0.008	12.259	0.000	1.109	1.128	1.091	
Catch (kg)	0.001	0.000	9.855	0.000	1.001	1.001	1.001	
Catch × length	−0.000	0.000	−8.413	0.000	0.999	0.999	0.999	
Hosmer–Lemeshow	62.066			0.000				5

injuries by codend type. They only show the relative length distributions of skin injuries in each codend type. There appears to be no clear differences in skin injury length distributions between the three codend types. In the control fish in Experiment 3, two fish (4%) had net marks and no scale loss was observed (47 fish in total).

The model faintly suggest that in normal water temperatures D120 caused more skin injuries (scale loss + net marks) than E105 codend, and an increase in

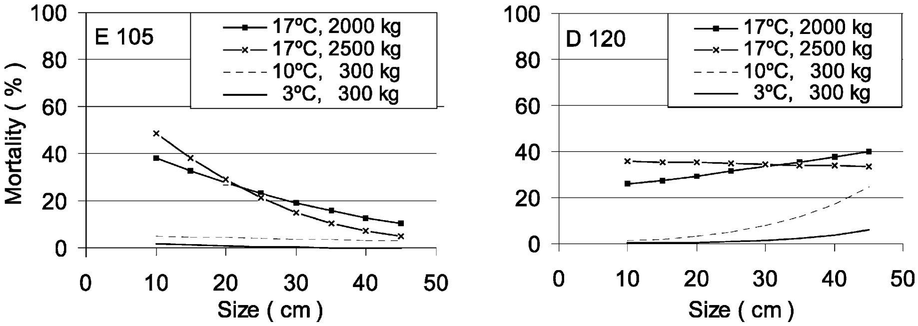

Fig. 4. Effect of water temperature, fish size and codend catch on escape mortality in E105 and D120 codends based on logistic regression model.

Table 3
The probability values suggest that the escapee mortality of three codends did not differ statistically

Codend type/parameter	Estimate	S.E.	*t*-Ratio	*P*-value	Odds ratio	Upper 95%	Lower 95%	d.f.
D120 (reference)								
Constant	−3.342	0.272	−12.291	0.000				
UC105	−0.727	0.573	−1.268	0.205	0.484	1.486	0.157	
E105	−0.013	0.355	−0.036	0.971	0.987	1.978	0.493	
Hosmer–Lemeshow	0.000			0.000				0

The D120 codend was used as a reference. The Hosmer–Lemeshow statistics show significance.

Table 4
The parameter estimates and odds ratios of the three skin injury analysis

Codend type/parameter	Estimate	S.E.	*t*-Ratio	*P*-value	Odds ratio	Upper 95%	Lower 95%	d.f.
(a) D120 vs. E105								
Constant	−0.806	0.604	−1.335	0.182				
E105	−2.778	0.708	−3.922	0.000	0.062	0.249	0.016	
Length (cm)	0.046	0.020	2.323	0.020	1.047	1.088	1.007	
Length × codend	0.100	0.025	4.026	0.000	1.105	1.160	1.052	
Hosmer–Lemeshow	10.388			0.168				7
(b) E105 vs. UC105								
Constant	−3.584	0.370	−9.679	0.000				
UC105	3.303	0.975	3.389	0.001	27.186	183.693	4.023	
Length (cm)	0.146	0.015	9.787	0.000	1.157	1.191	1.123	
Length × codend	−0.067	0.032	−2.063	0.039	0.935	0.997	0.878	
Hosmer–Lemeshow	4.934			0.668				7
(c) D120 vs. UC105								
Constant	−0.806	0.604	−1.335	0.182				
UC105	0.525	1.085	0.484	0.629	1.690	14.180	0.201	
Length (cm)	0.046	0.020	2.323	0.020	1.047	1.088	1.007	
Length × codend	0.033	0.035	0.942	0.346	1.033	1.107	0.965	
Hosmer–Lemeshow	3.413			0.491				4

fish length increased the probability of skin injury (Table 4a). The model also suggest that UC105 codend caused more skin injuries than E105 codend (Table 4b). However, UC105 codend did not differ statistically from D120 codend in respect to skin injury ($P = 0.629$, Table 4c). In the skin injury analysis the constants show insignificance and the Hosmer–Lemeshow statistics suggest large influence of few unusual observations (Table 4, $P = 0.168$, $P = 0.668$ and $P = 0.491$). That is, the skin injury analysis does not give us any statistically significant effects.

4. Discussion

The results obtained in this study support the earlier findings of low mortality of cod escaping trawl codend in normal (<10 °C) seawater temperatures (Soldal et al., 1993; Suuronen et al., 1996a). The mortality was on average less than 3%. In high temperatures (>15 °C), a substantially higher mortality (up to 75%) was observed with high variation between hauls. Atlantic cod prefers temperatures between 2 and 10 °C (Swain and Kramer, 1995). That is very likely the temperature range that cod prefers also in the Baltic Sea.

The fact that most deaths in Experiment 1 took place during the first caging day indicates strong trauma in the beginning of the caging. Several stressors may have affected simultaneously but water temperature at cage site appeared the most important single factor in determining the mortality. These fish were apparently exposed to a relatively abrupt change in temperature during the last moment of the tow when the tow was directed from normal 35 to 50 m fishing depths to more shallow waters to release the cage. Although we did not measure the water temperature during the eventual trawl tows, water temperatures at cage site at various depths provide some idea of the water temperatures at fishing grounds in late summer 1997. The temperature was around 15–19 °C at caging depths of 21–25 m and ca. 8 °C at depths of 34–35 m (see Table 1). Apparently, fish were in most cases captured in water temperatures below 8 °C and were towed at the final phase of the haul through the thermal stratification layer that was exceptionally strong in late summer 1997. Thus, the rise of temperature may have been up to 8–10 °C during the last minutes of the tow. An abrupt and several degrees of rise in temperature induced high mortality in adult sablefish, *Anoplopoma fimbria* (Olla et al., 1998).

The high mortality of codend escapees in our 1997 experiment (Experiment 1) was likely due to exceptionally high water temperature at cage site. From the

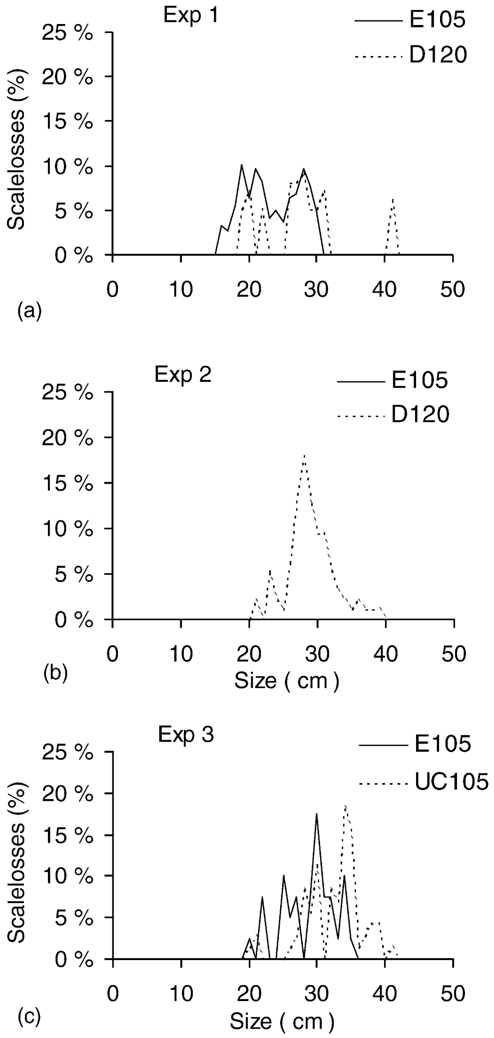

Fig. 5. The scale loss length distributions of escapees (scaled) in three codend types in Experiments 1–3. Size groups with less than five escapees are excluded from the figures.

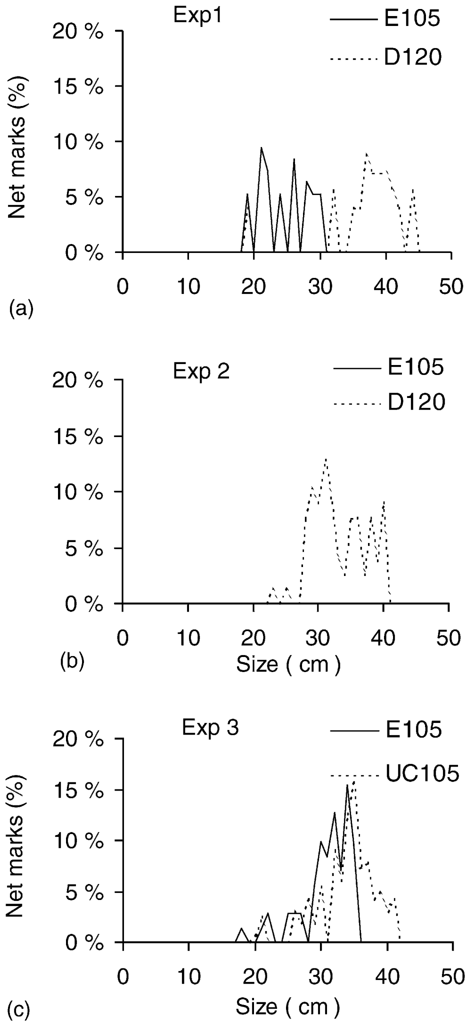

Fig. 6. The net mark distributions of escapees (scaled) in three trawl codend types in Experiments 1–3. Size groups with less than five escapees are excluded from the figures.

management point of view, the high mortality of escapees in high temperatures is not a relevant concern as long as fishery is not taking place at such temperatures. According to the long-term data of the Swedish Meteorological Institute, the mean water temperature in late August 1970–1995 at 35–50 m depths in our research area varied between 6 and 9 °C. This data further supports our argument that our experimental set-up to a large extent induced the high mortality in Experiment 1. However, in commercial trawling a trawl may in some special cases visit shallower and warmer waters. For example, during a turn a trawl may occasionally drift to a shallower bank. Furthermore, at the end of a tow when the codend is lifted through thermal layers towards surface there may still be marked escape of fish from the codend (e.g. Tschernij and Suuronen, 2002). Very little is known of the fate of these fish but apparently, the warm surface water is not a favorable feature from the survival point of view.

During a normal commercial fishing, codend escapees have a possibility to swim immediately after the escape to they normal environment to recover. Being enclosed in a cage, often in non-favorable conditions, is likely to cause additional stress and mortality. It is notable, however, that in normal water temperatures the holding of fish in a cage was not a critical mortality factor in our experiments—fish exhibited almost no mortality. On the other hand, our caging experiments may have shown mortality values that are too low, as they do not account for escapees that may have experienced greater predation mortality. Ryer (2002) showed under laboratory conditions that walleye pollock (*Theragra chalcogramma*) subjected to capture and escape stress were more likely to encounter predators than a control group.

We did not find any clear relationship between fish length and mortality. In E105, larger escapees appeared more tolerant to the damage while in D120, a higher mortality was observed in larger fish. This may be due to more difficult escape process through the diamond codend mesh, due to its smaller relative mesh opening. Other studies conducted on gadoid escapee survival have been somewhat inconclusive regarding the relation of mortality and fish size but the general observation has been that mortality decreases with length (e.g. Soldal et al., 1993; Sangster et al., 1996). Clearly, more data is needed in this area.

Codend catch appeared not to affect mortality in temperatures below 10 °C. Most of the hauls conducted in low temperatures, however, had fairly small catches. It is noteworthy that Pikitch et al. (2002) found no significant relationship between codend catch and escape mortality of pollock, however, there are no formally published reports of similar work on other species. Clearly, the effect of codend catch on mortality requires further studies.

We did not find any clear difference in skin injury between the three codend types and between different size groups. Clearly, we remain highly uncertain regarding our skin injury analysis. Several other studies conducted on gadoid survival have been inconclusive regarding the relation of skin injury and fish size (e.g. Sangster et al., 1996; Suuronen et al., 1996a; Ingolfsson et al., 2002; Pikitch et al., 2002).

In conclusion, our results indicate that the mortality of Baltic cod codend escapees is low in the water temperature that is normally encountered in the trawling grounds in the Baltic Sea (3–9 °C). The observed high mortality of codend escapees in 1997 experiment was likely due to exceptionally high water temperature at the cage site. Further, our results suggest that other factors than codend design are important in determining the mortality of cod escapees.

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