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Short communication

Survival of juvenile herring (*Clupea harengas membras*) after passing through a selection grid in a pontoon trap

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ABSTRACT

A common problem in the Baltic Sea and Gulf of Bothnian herring trap fishery is the bycatch of undersized Baltic herring (*Clupea harengus membras*). By equipping a pontoon trap with a rigid grid with vertical bars, a substantial proportion of the undersized herring can escape from the gear by swimming through the grid. However, it has not been clear whether or not the young fish are injured by their passage through a grid and what their fate is. The purpose of this study was to investigate the short term mortality of herring after passage through a grid. To capture young herring, a selection grid was mounted at the entrance to the fish chamber of a pontoon trap, so that only young herring (approximately 12–18 cm in length) could swim in. The trap was then closed and the herring were confined in the fish chamber for seven days before assessing survival rates. The same procedure was performed with control herring which were trapped without passing through any grid. The whole trial was repeated three times. On average about 7% of the young herring selected through a sorting grid died during the experiment. The results demonstrated that passing through a rigid grid did not affect the short term mortality of young herring during the seven days in captivity. The highest mortality (45%) was in fact observed in one of the control groups presumably in connection with extreme temperature fluctuations.

1. Introduction

Several studies have been conducted to examine the survival rates of fish released from fishing gear. (e.g. Chopin and Arimoto, 1995; Suuronen et al., 1996a,b; Suuronen and Erickson, 2010). Most of these studies have been on active gear such as trawls and the mortality among escapees has in general been variable and highly species dependent (Suuronen, 2005). One of the species showing the highest mortalities is the herring (*Clupea harengus membras*). In a study by Suuronen et al. (1996b) as many as 70–100% of herring less than 12 cm in length and 44–83% of herring in the range 12–17 cm selected from the codend of a pelagic trawl died. Suuronen et al. (1996a,b) argued that the high mortality of herring escaping from trawls is largely due to the exhaustion and physical damage experienced inside the trawl. The passage through a selection device was not the primary cause of injury and death.

Apart from trawling, a common fishing method for herring in the Gulf of Bothnia is the use of traps (Parmanne, 1989; Tschernij et al., 1993). A recently developed trap for this type of fishery is the pontoon trap (Hemmingsson et al., 2008), also called the push-up trap (Suuronen et al., 2006). Since the introduction of the pontoon trap, damages to gear and catch losses caused by grey seals (*Halichoerus grypus*) have significantly decreased (Lunneryd et al., 2003; Suuronen et al., 2006; Lehtonen and Suuronen, 2010).

However, a problem with herring traps, including the pontoon trap, is that they catch herring of all sizes indiscriminately (Tschernij et al., 1993). By equipping the pontoon trap with rigid grids, an effective exclusion of small herring from the catch can be achieved (Lundin et al., 2011a). But in order to ensure a sustainable fishery, the question must still be resolved as to whether allowing the escape of undersized herring in this way is enough. Are they then in a fit state to survive and grow to maturity?

There are few studies on the survival of fish escaping or released from traps. Siira et al. (2006) showed an average of only 7% mortality among adult Atlantic salmon released from large floating salmon traps along the northern Baltic coast. Fish are not forced to swim into or out of the traps, as both capture and any possible escape requires active behaviour. Therefore, it is unlikely that these fish sustain as much damage and stress during the capture and escape processes as fish that are forced to struggle in order to escape (e.g.

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from a trawl).A general problem in survival studies of fish escaping from fishing gear is how to measure their mortality rates after escapement and how to collect them without causing any further injury. In the present study, these problems were solved by allowing herring to pass through a grid into a fish chamber where they were kept captive for seven days.

In a stationary trap, caught fish are exposed to environmental stressors before they may escape through a selection device, and it may take them some time to find their way out. A key environmental stressor is temperature, which directly influences the metabolic rates of the organism (Hirst and Bunker, 2003; Folkvord, 2005) and plays a critically important role in the mortality rates of escapees (Suuronen, 2005; Gale et al., 2011).

The aims of the present study were to assess the survival of grid-selected herring in a pontoon trap and to evaluate the effect of ambient temperature variations on mortality rate.

2. Materials and methods

2.1. Trials and gear

The study was conducted in the Swedish inshore waters of the Bothnian Sea (61°57′N, 17°22′E). Six trials were performed between the 7th July and the 6th September 2010 with experimental trials using a selection grid alternated with control trials (Table 1).

All herring in the experiment were caught in a herring trap of the same type as used by Lundin et al. (2011a). A single-walled pontoon fish chamber was attached to the trap and used as a fish-holding cage (Fig. 1). The material for the netting was knotted green Dyneema® with 0.5 mm twine thickness and 24 mm stretched mesh size. The volume of the fish chamber was 31.8 m^3. The entrance to the middle chamber was equipped with a large mesh netting panel (500 mm stretched mesh size) to prevent grey seals from entering. A Mini Current Meter Sensordata SD-6000 measuring water currents and temperature every 30 min (Fig. 2) was placed next to the pontoon fish chamber.

2.2. Herring pontoon trap equipped with interchangeable entrance hatches

The entrance to the fish chamber was surrounded by a steel frame (480 mm × 480 mm). The frame was equipped with two hatches, both hung from the top edge of the frame like a ‘cat-flap’: hatch A: square frame with a grid consisting of vertically mounted 2 mm stainless steel rods with 14 mm gaps between. Hatch B: square frame equipped with a closing net (24 mm stretched mesh size). The system with the two hatches provided for three different modes of operation: both hatches open allowed herring of all sizes to pass through; hatch A closed and hatch B open allowed only under-sized herring to pass through; and both hatches closed prevented any fish from passing through. The different positions of the hatches were controlled by ropes from the top of the fish chamber.

2.3. Experiments

A total of six trials were conducted; three using grid-selected herring (hatch A closed and hatch B open) and three using non-selected herring as a control (both hatches open) (Table 1). Trials were run every other week. When a sufficient number of herring (>100) were estimated to have entered the fish chamber, both hatches were closed. This took between 24 h and 48 h. The number of herring enclosed at one time varied between 172 and 2170. To prevent additional herring from entering the trap during the experiments and being kept in a “holding bay” between the wings, the leading net was lifted from the seabed to the surface at several points.

During each trial, the fish were held in captivity for seven days. Any deaths due to injuries received are likely to occur within a couple of days (Suuronen et al., 1996b). Observation periods longer

Table 1
Trial number, selection mode, trial time period, numbers of dead and live herring and temperature data for each trial.

Trial	Mode	Start	End	Total herring (No.)	Dead (No.)	Alive (No.)	Mortality (%)	Maximum temperature (°C)	Minimum temperature (°C)	Temp difference (°C)	Mean temperature (°C)
1	Grid	7 July	14 July	1883	103	1780	5.5	15.5	13.0	2.5	14.6
2	Control	16 July	23 July	2170	978	1192	45.1	17.2	6.0	11.2	13.4
3	Grid	29 July	5 August	715	90	625	12.6	14.8	11.7	3.1	12.9
4	Control	9 August	16 August	301	21	280	7.0	18.8	15.8	3.0	17.1
5	Grid	19 August	26 August	172	5	167	2.9	17.2	16.0	1.2	16.5
6	Control	30 August	6 September	1886	218	1668	11.6	15.7	14.7	1.0	15.2

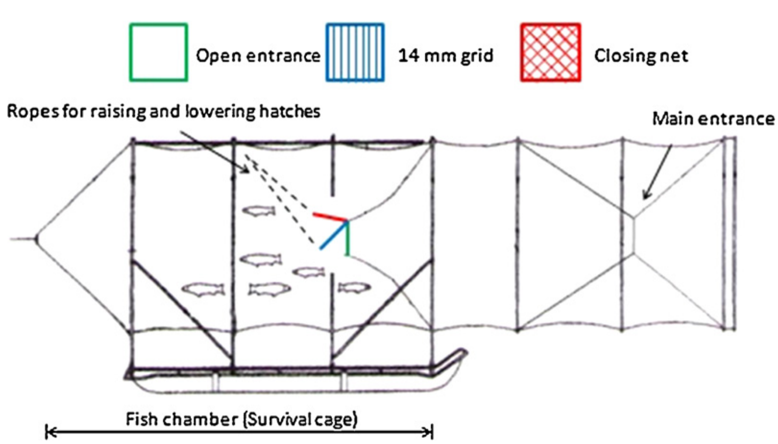

Fig. 1. Pontoon fish chamber equipped with interchangeable entrance hatches, allowing either grid-selected or non-selected (control) herring to enter the fish chamber before closing.

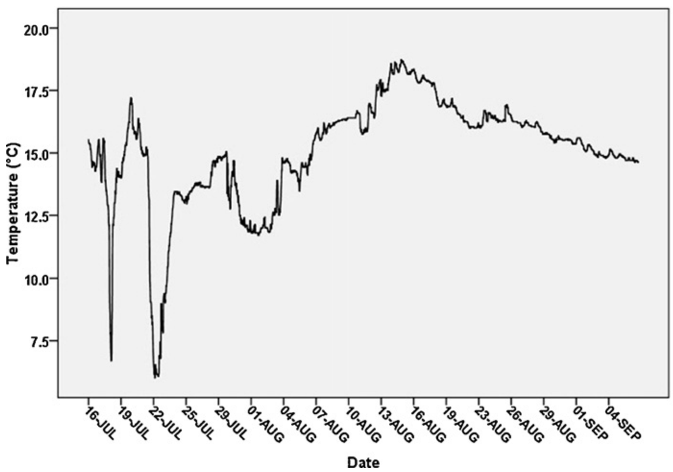

Fig. 2. Ambient water temperatures during the period of the trials. Data set started at 14:20 on the 16th July and ended at 10:20 on the 7th September. Interval time was 30 min. The severe drops in temperature corresponds to the 18th and 23rd July.

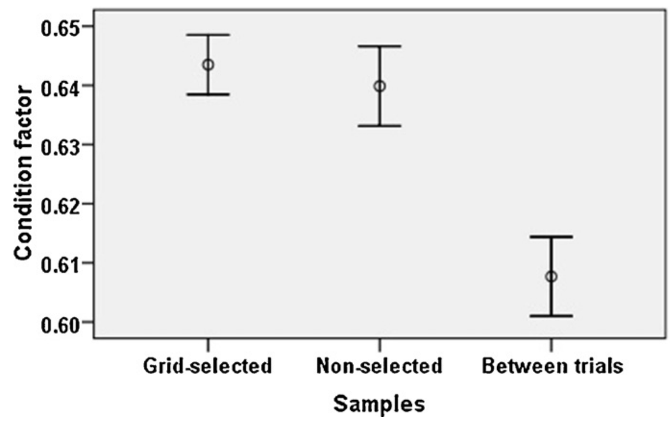

Fig. 3. Condition factors of herring in experiments and of herring taken in samples between trials. Error bars represents the 95% CI.

than one week may not be meaningful because at this point in time secondary infections and stress connected to the captivity become the prime factors leading to fatalities (Suuronen, 2005). To further avoid using herring which had been inside the wings of the trap during the trials and which had possibly already become stressed and injured, the entrance to the fish chamber was left open for 24 h between all trials so that the herring could enter and then be released. When releasing these herring from the fish chamber, samples of between 30 and 169 individuals were taken for measurement. Between trials, a water pump was used to clean the fish chamber of scales and seaweed.

2.4. Measurements

After seven days, the fish chamber was emptied. The catch was promptly sorted in the boat into two groups, dead or alive. Most of the dead herring had extensive scale loss with exposed muscles, presumably by being rubbed on the fish chamber bottom netting. They were thus easy to recognize. Caudal fin abrasions were common among both dead and live herring. All herring in the two groups were counted. Samples of herrings from both groups were measured in length and weighed, rounding down to the nearest 0.5 cm and whole grams. For all trials except for trial 5, sub-samples of between 104 and 386 herrings were taken for the measurements. Due to abrasions, caudal fins were not included in the length measurements. Lengths were instead measured to the end of the caudal peduncle. To estimate the total lengths of these herring, a conversion factor was calculated by measuring the caudal fins of herring in the sub-samples taken between trials. In total 1537 herring were measured.

2.5. Analysis

Mortality was measured for each trial by comparing the number of dead herring with the number of live herring. To determine the statistical effects of grid passage and of water temperature on the mortality rates, a generalized linear model (GLM) (Liang and Zeger, 1986) was used to analyse the data.

The effect of grid passage on the degree of well-being among herring was examined by using the Fulton's Condition Factor K, given by $K = 100 \times W/L^3$, where W is the weight of the herring in grams and L is the length of the herring in centimetres (Bagenal and Tesh, 1978). The condition factor was compared between grid-selected herring, non-selected herring and herring sampled between trials.

Bycatch of stickleback (*Gasterosteus aculeatus aculeatus*) and a few small whitefish (*Coregonus lavaretus*) was inevitable. These species occurred at about the same amount in all trials and were believed not to have affected the results and were therefore not included in the analysis.

3. Results

The mortality of grid-selected herring varied between 2.9% and 12.6%, and the average mortality was 7.0% (Table 1). In the control groups the mortality varied between 7.0% and 45.1%, and the average mortality was 21.2%. Mortality was high in particular in the control sample (no. 2) where there was an abrupt drop in water temperature (Table 1; Fig. 3). Linear regression shows that herring in the control groups had a significantly higher mortality rate ($p < 0.001$) (Tables 2 and 3).

The ambient water temperature varied between 6.0 °C and 18.8 °C during the experiment. The trial with the greatest fluctuations in temperature was trial no. 2 on 18th July 2010. The temperature dropped from 15 °C to 6 °C in the course of 15 h and increased to 14 °C over a further 11 h (Fig. 3). Four days later in the trial there was an even greater but not as sudden dip in temperature.

When taking the temperature differences for each trial into consideration in the GLM-analysis, no significant difference could

Table 2
Generalized linear model (GLM), showing the *p*-values of selection modes and their effect on the herring mortality for each trial.

Parameter estimates							
Parameter	B	Std. error	95% Wald confidence interval		Hypothesis test		
			Lower	Upper	Wald Chi-Square	df	Sig.
Intercept	0.540	0.0725	0.398	0.682	55.517	1	0.000
Mode = grid	−2.467	0.0903	−2.644	−2.290	745.689	1	0.000
Mode = control	0	–	–	–	–	–	–
Trial	−0.395	0.0197	−0.433	−0.356	399.536	1	0.000

Table 3
Estimated marginal means of selection mode in the generalized linear model.

Estimates				
Mode	Mean	Std. error	95% Wald confidence interval	
			Lower	Upper
Grid	0.04	0.003	0.03	0.04
Control	0.30	0.008	0.29	0.32

be demonstrated between grid-selected herring and non-selected (control) herring ($p = 0.729$) (Tables 4 and 5).

There was no significant difference in condition factor between grid-selected herring and non-selected (control) herring (Mann–Whitney *U*-test, $p = 0.430$). There was however a significantly higher condition factor in herring in the trials, than in herring sampled between trials (Kruskal–Wallis test, $p < 0.001$) (Fig. 3).

The size range of herring was 9–20 cm in the grid trials and 7–21 cm in the control trials. The herring in the grid trials were on average smaller (mean length 15.5 cm) than the herring in the control trials (15.9 cm, Independent sample *t*-test, $p < 0.05$). The mean length of live herring sampled was 15.6 cm, while the mean length of dead herring was 16.0 cm (Fig. 4). When grid-selected groups and control groups were combined, the dead herring were significantly longer (independent sample *t*-test, $p < 0.05$).

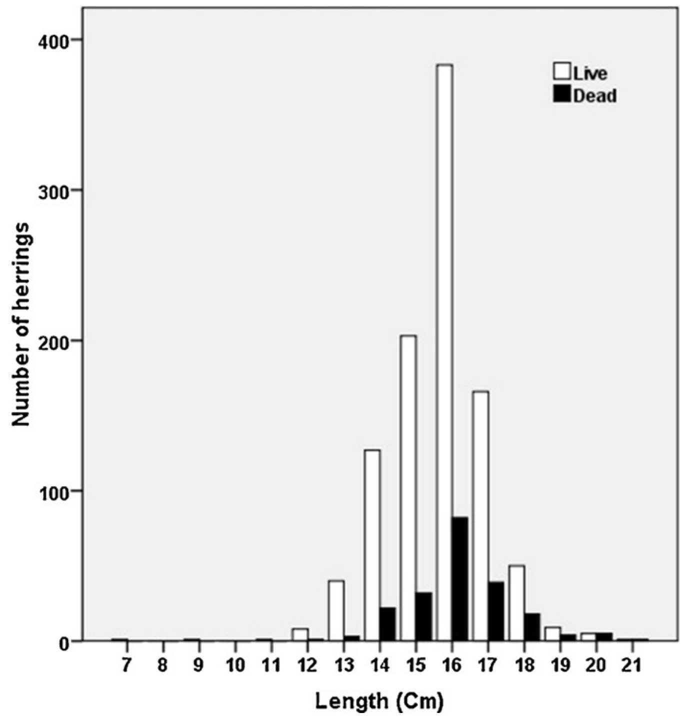

Fig. 4. Lengths of live and dead herring in trials.

4. Discussion

This study strongly indicates that a passage through a rigid grid does not in itself affect the short term mortality of herring. It is therefore deemed highly probable that herring would survive an escape from a pontoon trap under commercial fishing conditions.

The most important factor for the short term mortality in the holding period was the ambient water temperature. By far the highest mortality rate was reached during the trial with the greatest temperature fluctuations. During this trial the temperature dropped rapidly from 15 °C to 6 °C on two occasions. Severe temperature drops have been shown to be fatal in other studies. Edsall and Colby (1970) found that lake herring (*Coregonus artedii*) transferred from 20 °C to 2 °C generally died within 24 h. High mortality may also be caused by severe temperature increase (Suuronen et al., 2005). Herring prefer temperatures in the range of 10–13 °C and 14 °C is assumed to be the upper limit (Neuman, 1982). When caught in a stationary trap, there is an obvious risk of being exposed to temperatures well above and below this range.

Under normal conditions herring avoid unfavourable circumstances such as rapid temperature drops. Rapid temperature drops in the Gulf of Bothnia are a well known phenomena among commercial fishermen. The drops are caused by wind blowing offshore, taking the warm surface water with it and replacing it with cold water from below. In a commercial fishing situation the fisherman would be aware of this and would most probably empty the trap as soon as possible to avoid finding dead herring in the trap. In a real life fishing situation, the herring trap is emptied from several times per day up to a minimum of every other day.

The herring released from the trap between the trials had a significantly lower condition factor then the herring in the trials. The released herring had probably been waiting inside the wings or the adapter for a longer period. Since these parts are accessible to predators such as grey seals, there might have been a very high stress level among these herring, leading to a lower condition factor. The seals were distanced from the fish chamber by the netting panel at the entrance of the middle chamber. Hence, the mortality rates would probably not be affected by the presence of seals.

The mortality of fish escaping from fishing gear has in previous studies been shown to be size dependent. Suuronen et al. (1996a) found that among herring released from a trawl codend through a rigid grid, 76–100% of small (<12 cm) and 44–83% of large (12–17 cm) escapees were dead after 7 days. Suuronen et al. (1996b) argued that smaller herring are less able to withstand physical and physiological stress caused by the trawling process. In the present study only 8 herring out of 1537 were under 12 cm in length and all of them were alive. Moreover, the mean length of dead herring was slightly more than that of live ones. Therefore, there appears to be no size-dependent mortality among herring escaping from a trap. This is likely connected to the fact that there is no forced swimming involved in the process, contrary to that in the trawling process.

Table 4
Generalized linear model (GLM), showing the *p*-values of selection modes, trials and temperature differences and their effect on the herring mortality rates.

Parameter estimates							
Parameter	B	Std. Error	95% Wald confidence interval		Hypothesis test		
			Lower	Upper	Wald Chi-Square	df	Sig.
Intercept	−3.619	0.3483	−4.302	−2.937	107.970	1	0.000
Mode = grid	0.072	0.2073	−0.334	0.478	0.120	1	0.729
Mode = control	0						
Trial	0.230	0.0539	0.124	0.336	18.247	1	0.000
Temp difference	0.272	0.0226	0.228	0.316	144.356	1	0.000

Table 5
Estimated marginal means of selection mode in the generalized linear model including the temperature differences during the trials.

Estimates				
Mode	Mean	Std. Error	95% Wald confidence interval	
			Lower	Upper
Grid	0.14	0.016	0.11	0.17
Control	0.13	0.011	0.11	0.16

In all probability a newly escaped herring can be considered to be both stressed and confused. It has just made a choice by leaving the relative safety of the school. It was noted on a few occasions in previous studies that escapees turned and swam back through the grid into the trap (Lundin et al., 2011a,b). The time immediately after escape is most probably a very vulnerable moment as the herring is seeking other herring to become part of a new school. As herring are a schooling fish, they are probably subject to stress when not in a school.

The herring traps are normally placed in the water during the spring spawning period, approximately from the end of April until the end of June. During this period the catches are considerable and can be measured in tonnes. To get an adequate amount of herring in the trials, the experimental season was set after the major spawning season, but before the herring migration from the fishing grounds. This resulted in a limited time window. It was estimated that there would be enough time for six replicates with time to adjust for potential problems.

Getting an adequate number of herring in the fish chamber for each trial was faced by one major problem; when to close the hatch. If the number of herring was small it was not possible to wait longer, as the fish already in the fish chamber would then be subject to an even longer period of captivity.

The difference in sample size is another source for potential bias. The number of herring in the different trials varied from 172 to 2170. These numbers corresponds to 5.4 fish/m^3 or 68.2 fish/m^3. In Lundin et al. (2011a) it was demonstrated that the number of escapees augmented drastically after about 1 tonne. This corresponds to a density of 943.4 fish/m^3. Behaviour of fish in the trap is density dependant, but the densities need to be considerable before any major behavioural changes occur. In the current trials it is probable that the densities were not high enough to initiate any changes in behaviour.

In conclusion, this study demonstrated that passage through a rigid selection grid did not affect the short term mortality or the condition factor of the herring. The mortality rate was however shown to be highly influenced by temperature fluctuations in the water. The result represents an important argument for introducing selection grids in the Baltic Sea herring trap fishery.

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