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Size selection of herring (*Clupea harengus membras*) in a pontoon trap equipped with a rigid grid

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ABSTRACT

A sustainable fishery in the Baltic and Bothnian Seas requires the development and introduction of fishing gear which fishes selectively and at the same time excludes raiding seals. The purpose of this study was twofold: firstly to test and evaluate rigid grids as a method for retaining only larger herring in a pontoon trap, and secondly to analyze which factors were influencing the selection process. The results demonstrate that it is indeed possible to sort herring by size in a pontoon fish chamber. The efficiency of excluding undersized herring was at best 27%, using a selection grid covering just over 0.1% of the fish chamber wall. The factors which have most effect on the selection were the quantity of fish in the trap, the season of the year, the time of day and the presence of seals.

1. Introduction

The herring fishery in the Bothnian Sea has been an important regional fishery, but the increasing population of grey seals (*Halichoerus grypus*) over the last 20 years has caused serious problems for its viability (Kauppinen et al., 2005; Westerberg et al., 2006). Most severely affected has been the inshore fishery using gill nets and traps. Seals plunder fish from the fishing gear and cause extensive material damage (Lunneryd and Westerberg, 1997; Lehtonen and Suuronen, 2004; Fjälling, 2005; Königson et al., 2007; He and Inoue, 2010). Therefore, there has been and remains a compelling need to develop seal-safe fishing gear.

A successful and now commonly used device developed for the Bothnian Sea salmonid fishery in response to this need is the pontoon fish chamber. A fish trap using this type of chamber, which is raised to the surface for emptying using compressed air, is referred to as a pontoon trap (Hemmingsson et al., 2008) or push-up trap (Suuronen et al., 2006). (For a detailed description, see Suuronen et al., 2006; Hemmingsson et al., 2008). Pontoon traps for salmonids have proven to be more effective than traditional traps in the presence of seals (Lunneryd et al., 2003; Suuronen et al., 2005; Lehtonen and Suuronen, 2010). The Baltic herring trap fishery started in Finland at the beginning of the nineteenth century (Parmanne, 1989). It has since then become one of the most common fishing methods for spring spawning herring. As a possible solution to the problem of raiding seals, development of a seal safe pontoon trap for herring began in 2009.

However, a known problem with all herring traps is that they catch herring indiscriminately. It is important to minimize the bycatch of undersized herring. Their capture wastes a valuable natural resource and also increases the sorting work which the fishermen have to do.

Several studies of selection by fish size have been done for active fishing gear (Suuronen et al., 1996a,b; Armstrong et al., 1998; Madsen and Stær, 2004; Herrman and O'Neill, 2006; Bahamon et al., 2007). In trawl fisheries, the survival of young herring selected from the trawl cod-end is low (Suuronen et al., 1996a,b). Suuronen et al. (1996a,b) argued that the high mortality of young herring in this case is largely due to the exhaustion and physical damage experienced in the trawl.

Only a few studies on selective release have been done for fixed gear such as larger size traps and pound-nets (Laarman and Ryckman, 1982; Brothers and Hollet, 1991; Tschernij et al., 1993; He and Inoue, 2010). In a trap, herring are not forced to

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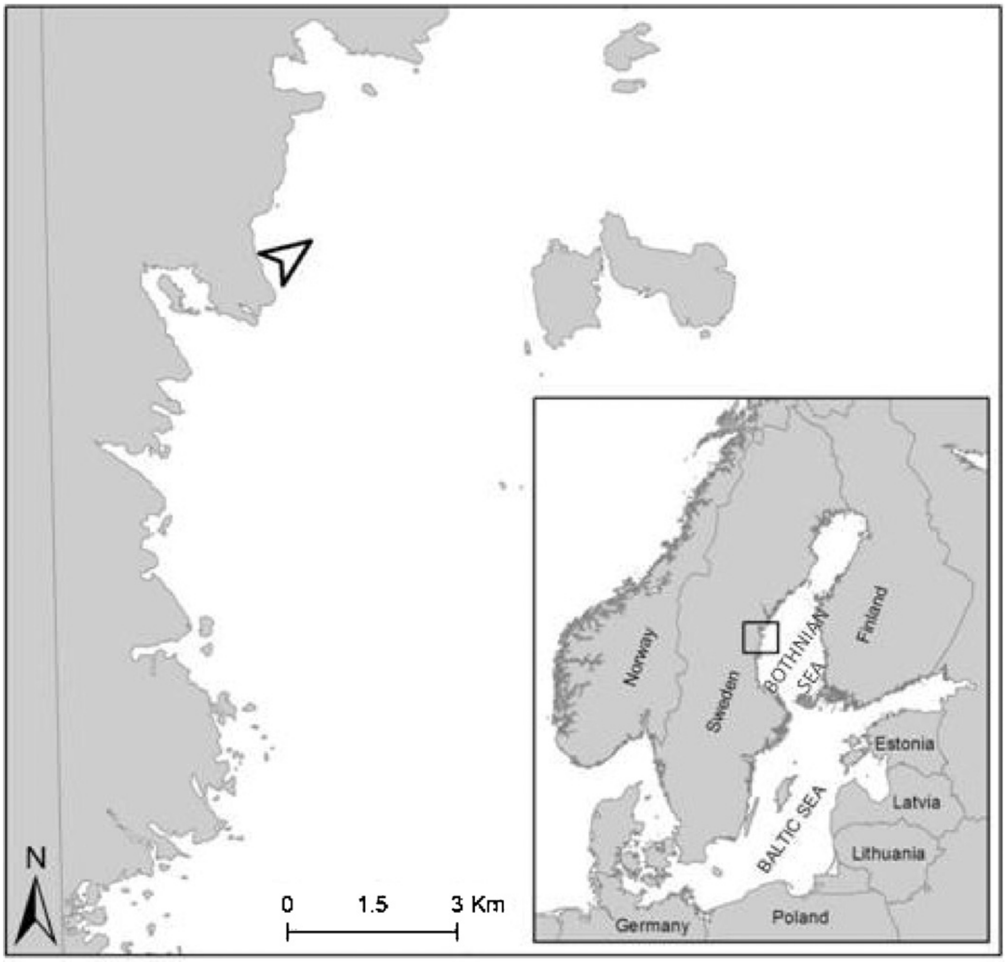

Fig. 1. Map of the Baltic and Bothnian Sea, showing the location for the experiment. The arrow shows the placement and orientation of the trap, with the entrance towards land.

swim into or out of the trap, as any capture or possible escape requires active behaviour. Therefore, it is highly 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. from a trawl).There are several factors which can be assumed to affect the degree of selection: (1) environmental conditions, such as currents, light intensity and temperature; (2) behavioural characteristics of the fish, such as flight disposition, school cohesion, boldness/shyness and reactions to predators; and (3) physical characteristics of the fish, such as visual acuity and tactile sense.

Experiments with pontoon traps for salmonids have demonstrated that it is possible to selectively release unwanted fish from the catch. Lundin (unpublished data) demonstrated that 78% of undersized whitefish (*Coregonus lavaretus*) succeeded in escaping through a selection device fitted to a pontoon trap. Achieving the same result with herring is expected to be more difficult, as herring have a strong school cohesion, forming highly synchronized and polarized schools.

In previous trawl studies (Suuronen, 1991; Suuronen et al., 1993) it has been demonstrated that it is easier for young herring to escape through a rigid sorting grid than through a mesh. Loss of scales for haddock (*Melanogrammus aeglefinus*) selected by a mesh was significantly higher than for fish selected by a grid (Soldal et al., 1991, cited in Suuronen et al., 1996b). Taking these observations into account, a rigid grid was chosen as the selection device in our experimental herring trap.

The aim of the present study was to evaluate the efficiency of size-selection by means of a grid in a herring pontoon trap. A special focus was to investigate which factors influence the selection process.

2. Materials and methods

2.1. Location and time period

The location of the experiment was in the Bothnian Sea, in inshore waters at 61°57′N, 17°22′E (Fig. 1). The trap was placed with a compass heading of 67°N and was in the sea from 24th April until 27th July 2009. No experiments were carried out between 1st and 22nd June, as a gale dislocated and damaged some parts of the gear, necessitating repairs and replacement.

2.2. Herring trap with a pontoon fish chamber

The herring trap used for this study consisted of a leading net, wings and adapter (Fig. 2). Stretched mesh length was 24 mm. A single-walled pontoon fish chamber with 32 mm stretched mesh length was attached to the trap. The pontoon fish chamber consisted of two parts, the middle chamber and the fish chamber (Fig. 3). Seals could swim into the middle chamber, but were prevented from swimming into the fish chamber by a steel rod fixed across the middle of the entrance. The trap was emptied once or twice a week, depend-

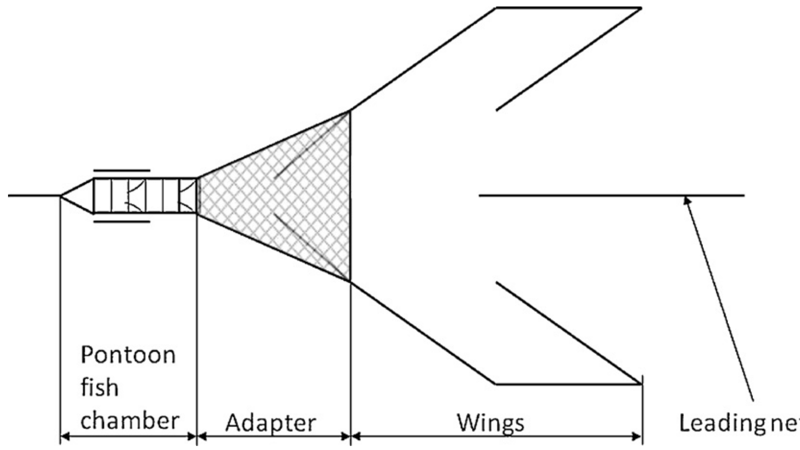

Fig. 2. Complete pontoon trap, including leading net, wings, adapter and pontoon fish chamber.

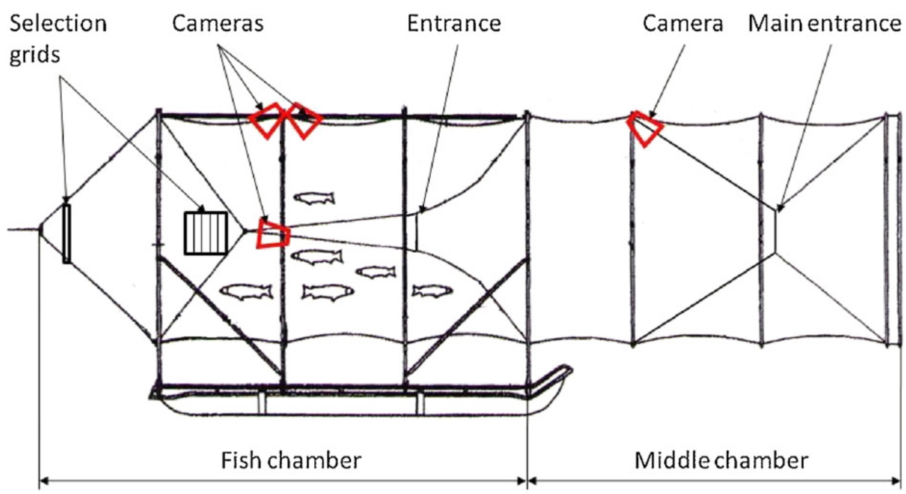

Fig. 3. Pontoon fish chamber, showing placement of cameras and selection grids.

ing on weather conditions and the amount of fish in the trap.

2.3. Selection grids and placement

Two sets of selection grids were used in trials. The first was a square grid, with each side measuring 25 cm and 16 mm spacing between bars. The square grid was placed on one side of the fish-chamber, between the foremost rings, and was continuously monitored by an underwater camera (Fig. 3). The small size enabled an excellent overview of activity through the grid. The second grid was circular, with a diameter of 53 cm and 14 mm bar spacing; this was placed in the cone-shaped end of the fish chamber. A 15 m long collection bag was attached to the circular grid to collect escapees. The purpose of this configuration was to obtain a controlled measure of selection efficiency and size composition. The circular grid was only filmed during one 48-h period, to investigate whether herring swam back through the grid. Both grids were manufactured using smooth steel bars.

The 16 mm grid was in place from 25th May to 1st June and from 22nd June to 1st July. The 14 mm grid was in place from the 1st to the 27th of July.

2.4. Camera system

The camera system consisted of four underwater videocameras manufactured by Watec®. The model was the WAT – 902H monochrome camera. The video footage was saved on a CamDisc Recorder with exchangeable hard disks of 80-120 GB, powered by a 72 Ah battery. The software used to adjust the recording settings was Camtel® Windows software v.3.26. The recorder was set to film at a speed of 3–4 frames per second and with a time and date stamp included. For viewing the recorded material, CamControl player v.3.29 was used.

The cameras were aimed at the fish-chamber, the entrances, the square grid and for one period at the circular grid (Fig. 3). Footage from various angles allowed us to study herring behaviour in response to different stimuli.

2.5. Current meter

A current meter, model Mini Current Meter Sensordata SD-6000, was used for measuring temperature, velocity and direction of current. These parameters were measured at 30-min intervals throughout the whole study period.

3. Analysis

3.1. Selection efficiency

When using the 16 mm grid, the catch from two periods was landed and weighed, firstly between 28th May and 1st June and secondly between 22nd and 24th June. These data were used to cal-

Table 1
The different catch periods and the total seasonal catch in the pontoon trap (kg). Numbers within parentheses were estimated, as occasionally it was not possible to land the catch.

Catch period	Herring (Est)	European sprat (Est)	White fish	Perch	Trout	Salmon	Three spined stickleback	Other (roach, eel, pike, flounder, burbot, smelts, plaice, lumpsucker, bleak, garfish)
24 Apr 2009 to 8 Jul 2009	15,246 (12,500)	0	65	41	1	0	0.4	10
22 Jun 2009 to 24 Jul 2009	6630 (3800)	255 (160)	28	17	4	10	10	3.5

Table 2
Numbers of selected herrings, number of herrings left in the trap and selection efficiencies at different trails with open and closed entrance using 14 mm and 16 mm grids.

Trail	Time	Grid	Selected herrings	Left in trap	Left in trap (<threshold)	Selection efficiency (%)	Entrance
1	28 May–1 Jun	16 mm	7680	28,439	21,045	26.7	Open
2	22–24 Jun	16 mm	4752	35,215	28,841	14.1	Open
3	2–3 Jul	14 mm	1991	6906	6078	24.7	Open
4	6–7 Jul	14 mm	1115	2837	2837	28.2	Closed
5	14–15 Jul	14 mm	53	1271	1271	4.0	Closed
6	16–17 Jul	14 mm	703	2581	2261	23.7	Closed
7	20–21 Jul	14 mm	154	661	661	18.9	Closed
8	23–24 Jul	14 mm	130	756	756	14.7	Closed

culate the selection efficiency by counting escapees during a 5-min sequence every 30 min. In May there were 95 such 5-min sample periods and in June 39. Samples were also taken from the catches and measurements taken of the herrings' lengths and weights. From these, mean values for the whole catch were calculated.

The mean number of escapees per 5 min was multiplied by the total number of 5-min periods during the entire study period and then related to the amount of potential escapees remaining in the trap. On numerous occasions, it was observed that herring actually squeezed themselves through the bars, and it was judged that herring with a dorsal width of up to 17 mm could escape through the 16 mm bars. This width correlated with an average length of 18.5 cm and resulted in the definition of a potential escapee as a fish under 18.5 cm in length.

When using the 14 mm grid, a total of six experiments with previously caught herring were carried out. In one trial, the entrance to the fish chamber was left open and in the remaining five the entrance was closed. In the latter cases, additional herring were prevented from entering the fish chamber. A fixed time limit of 24 h selection was used to arrive at a controlled measurement of escapees. During each experiment with the 14 mm grid, 50–100 herrings were randomly sampled from the trap and collection bag. Length, width, height and weight were measured.

3.2. Influencing factors

A total of 463 sets of data from the current meter were collected during two separate periods, 26th to 30th May and 23rd June to 1st July, with values recorded at half-hourly intervals. For the 5-min time period following each current reading, the film from the 16 mm selection grid was studied and escapees were counted. To estimate the amount of fish in the trap during each 5-min period, a linear rate of increase was assumed, using data from the size of the catch and the length of the catch period. To determine which factors were significant for the selection, a generalized estimating equation (GEE) (Liang and Zeger, 1986) was used to analyze the data.

To put selection in relation to seal presence, film recorded from the middle chamber was analyzed and seal observations were noted. Seal presence was defined as from when the seal had its head inside the entrance of the middle chamber until it had completely exited.

4. Results

4.1. General

The total catch of herring during the trials was approximately 22 tonnes (Table 1). Bycatches consisted most commonly of sprat (*Sprattus sprattus*), whitefish (*Coregonus laveretus*) and perch (*Perca fluviatilis*), but also of salmon (*Salmo salar*) and trout (*Salmo trutta*) which are both potential predators of herring. Additionally, one small seal forced its way into the fish chamber and expired there. Herring from the subsamples were found to be between 11 and 25 cm in length ($n = 1247$).

4.2. Selection efficiency

In the May trials, the average number of escapees per 5-min period was 6.4 individuals. The total number of fish swimming through the grid over the entire period was thus estimated at 7680 individuals (almost 250 kg, based on the mean weight of herrings with <17 mm dorsal width remaining in the trap). Remaining in the trap were 28,439 individuals (1170 kg), of which 21,045 (889 kg) were of selectable size. Hence, the selection efficiency was 27% (Table 2).

In the June trials, the average number of escapees was 8.8 individuals per 5-min period. Total selection during the trial period was 4752 individuals (152 kg). There remained 35,215 herring (1260 kg) in the trap, of which 28,841 (922 kg) were selectable. Hence, the selection efficiency was 14% (Table 2).

The selection efficiency in July with the 14 mm grid varied between 4.0% and 28.2%. The highest apparent degree of efficiency was reached when the entrance was open and the catch was abundant (Table 2). Almost all of the herring caught in July were of selectable size. However, the average lengths of the escapees and remaining herrings differed significantly (independent sample t-test: $p < 0.01$) (Fig. 4).

4.3. Influencing factors

4.3.1. Quantities of herring and presence of seals

There was a significant positive correlation between the number of fish in the trap and the number of fish escaping (Spearman rank correlation coefficient $r_s = 0.430$, $p < 0.01$) (Fig. 5).

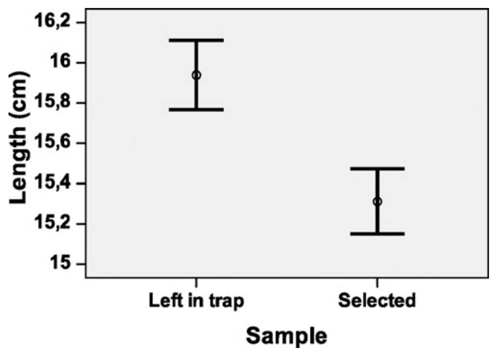

Fig. 4. Average length difference between escaped and retained herring with 14 mm grid ($N = 1028$).

Also, the presence of grey seals had a significant impact, increasing the effectiveness of the selection (Mann–Whitney *U*-test: $p < 0.05$). During the period in question, the trap was visited by seals a total of 307 times, with seal presence totalling 4 h 8 min. Of these visits, 94.5% occurred during the May trials and the remaining 5.5% during the June trials. Looking at how much of the day there was a seal present, during a 5-day period in May, the range in percentage was between 0.52% and 6.87%. In June, the trap was visited on 2 days, with 0.37% and 1.25% seal presence, respectively.

4.3.2. Diurnal, season and current effect

Diurnal time periods were defined as morning (03:01 to 09:00), day (09:01 to 15:00), evening (15:01 to 21:00) and night (21:01 to 03:00). There was a significant difference in escape rates between the different times of day (Kruskal–Wallis test: $p < 0.01$) (Fig. 6a), namely that most herring escaped during the night. Furthermore, there was a significant difference in escaping herring in relation to season, such that the later period (June) on average had a higher number of escapees than the earlier (May), (Mann–Whitney *U*-test: $p < 0.01$) (Fig. 6b). As mentioned previously, no experiments were carried out between the 1st and 22nd June, as the area was affected by a gale.

There was a significant negative correlation between escaping herring and current velocity ($r_s = -0.262$, $p < 0.01$) (Fig. 6c). Also, when the current direction data was divided into four quadrants (0–90°, 91–180°, 181–270° and 271–360°), it was found that a significantly larger proportion of herring escaped within the range 91–180° (Kruskal–Wallis test: $p < 0.05$), i.e. into the direction of the prevailing current.

4.3.3. Generalized estimating equation (GEE)

In the loglinear regression with all variables included, that is, quantity of herring, presence of seals, time of day, season, current velocity and direction, and water temperature, all factors except current velocity had a significant influence on the selection of herring (Table 3). The most significant factor was the quantity of herring in the fish chamber, followed by season, time of day, presence of seal, temperature and current direction in that order.

Pair-wise comparisons in the GEE show that May and June differed significantly concerning selection ($p < 0.01$). Also, the diurnal time periods were significantly different from each other as regards selection ($p < 0.05$), apart from the pairs 'day and evening' ($p = 0.569$) and 'day and morning' ($p = 0.061$).

Temperature had a significant effect on selection in the GEE. However, there was no significant linear correlation. Rather, there was a marked increase in selection between 10 and 13 °C compared with lower and higher temperature ranges.

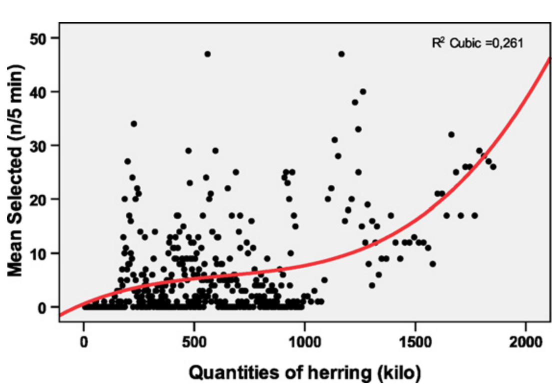

Fig. 5. Selection of herring in relation to quantity of herring.

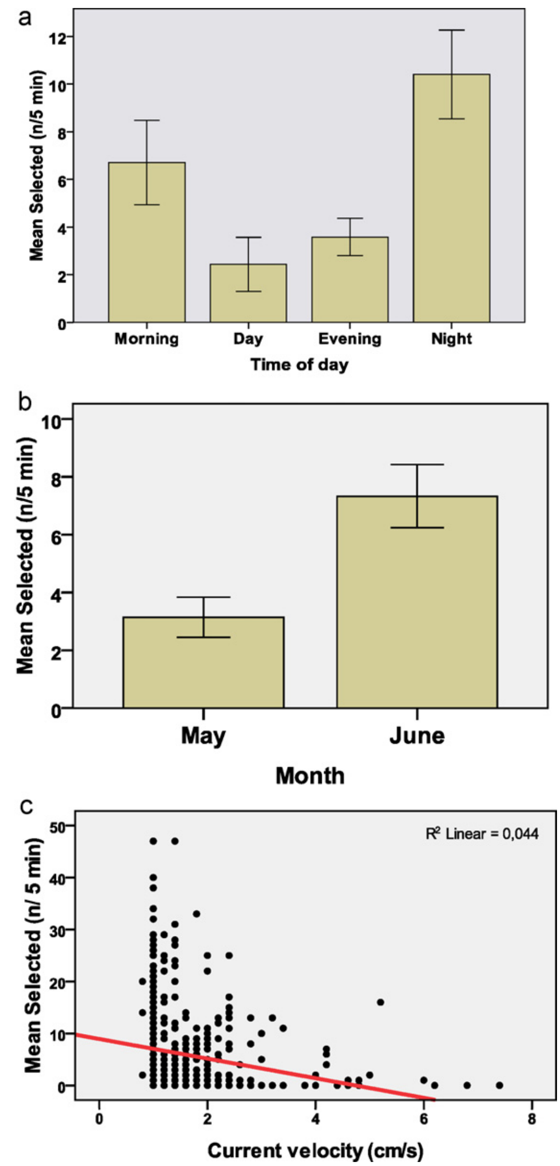

Fig. 6. Selection of herring: (a) in relation to time of day, (b) in relation to month and (c) in relation to current velocity.

5. Discussion

This study demonstrates that effective selection of small herring through a selection grid installed in a herring pontoon trap is achievable. Up to 27% selection efficiency was reached with a pro-

Table 3
Generalized estimating equation (GEE) and the *p*-values of different factors affecting the degree of selection of herring.

Parameter estimates							
Parameter	*B*	Std. Error	95% Wald confidence interval		Hypothesis test		
			Lower	Upper	Wald chi-square	df	Sig.
(Intercept)	1.995	0.3811	1.248	2.742	27.403	1	0.000
Period = June	1.339	0.1973	0.952	1.726	46.054	1	0.000
Period = May	0						
Seal = Absent	−1.162	0.2208	−1.595	−0.729	27.677	1	0.000
Seal = Presen	0						
Timeperiod = Day	−0.709	0.2489	−1.197	−0.222	8.127	1	0.004
Timeperiod = Evening	−0.852	0.1292	−1.105	−0.599	43.519	1	0.000
Timeperiod = Morning	−0.289	0.1257	−0.535	−0.042	5.273	1	0.022
Timeperiod = Night	0						
Temperature	−0.050	0.0217	−0.093	−0.008	5.350	1	0.021
Current velocity	−0.140	0.0784	−0.294	0.013	3.198	1	0.074
Current direction	0.002	0.0010	6.265E−5	0.004	4.101	1	0.043
Quantities of fish	0.001	0.0001	0.001	0.001	59.988	1	0.000
(Scale)	1						

totype grid covering only about 0.1% of the chamber's total area. It is probable that a significantly better efficiency could be attained with a larger grid and more advanced designs.

The 14 mm bar spacing gave a size selection equivalent to a manual sorting for the local commercial market. The largest escapees were 16 mm wide and had a mean weight of 42.4 g. This corresponds to a size 'four' (24–32 herrings/kg = max weight 41.7 g per herring) as defined by the EU (Council Regulation 2406/96, 1996). These fish are not marketable and should be avoided in a catch.

Using the 14 mm grid enabled an accurate sampling of escapees as they were captured in the collecting bag. However, on several occasions it was noted that fish swam back and forth through the grid, which they would not have done in actuality without the collecting bag, so any calculations of efficiency could be inaccurate.

When using the 16 mm grid it was not possible to take a sample of the escapees as they swam out into the open sea. However, the accuracy in calculating the selection efficiency of the 16 mm grid was high, as each escapee could be counted visually. The number and total weight of the potential escapees left in the trap was estimated by sampling the catch.

The factor which had the greatest impact on the selection was the amount of herring in the trap. As more fish were enclosed in the trap, more fish escaped. There appeared to be a non-linear relationship between the numbers of escaped fish and the numbers in the trap. After about 1 tonne of herring was caught, there was a stronger correlation and a larger proportion of escapees. Higher quantities are presumed to have led to higher stress levels in the fish as they were observed to swim markedly faster. Additionally, with more fish in the trap, the surface area of the school increases, resulting in more herring being in the proximity of the fish chamber walls and the grid.

The second most significant factor was the season of the year, with more herring escaping from the trap in June than in May. The minor differences in the amount and sizes of herring caught between May and June were not enough to explain this increase. Moreover, fewer seals were present in June. At the same time, by-catches of trout and salmon were higher in June than in May. Their presence could be the possible explanation for the increase in selection pressure, as salmonids are potential predators of herring. Pitcher et al. (1996) showed that herring have adaptive responses to different kinds of predatory attacks.

The third most significant factor affecting selection by size was the time of day, where selection at night was significantly higher than in the morning, day or evening. There are several possible explanations as to why there was a higher degree of selection during the hours of darkness: (1) in this study the majority of herrings swam into the trap at night. It might be that herring are more active immediately after capture and therefore more prone to escape. (2) The escape grid might appear to be brighter than the mesh wall, making it easier to see. At night, herrings searching for zooplankton orient themselves by swimming towards a lighter background (Batty et al., 1990). (3) It is also possible that herring are disorientated in darker waters, and therefore simply swim through the grid randomly.

This study demonstrates that seal presence in the trap had a significant effect on the selection. Herring escapes increased when seals were in the middle chamber. Video footage showed that the herring formed tighter schools, with an increase in swimming speed. This is supported by Wilson and Dill (2002) where pacific herring responded to attacks by predators by increasing their swimming speed and depth.

An increase in current velocity had a significant negative effect on the selection. One possible explanation could be that herring consume more energy to maintain their position in the water when swimming against the current, thereby reducing their chances of detecting the grid. The current velocity at the trap was measured to be between 0 and 8 cm/s, which is considered to be normal for the area. In a study by Harden Jones (1963), currents of 1–2 cm/s were sufficient to influence the herring to position themselves with their heads into the current, i.e. rheotaxis. Rheotaxis might be the behaviour to facilitate feeding.

When dividing the current direction data into four quadrants (0–90°, 91–180°, 181–270° and 271–360°), the 91–180° quadrant differed significantly from the others. When the current originated from a direction of between 91° and 180°, a higher proportion of escaping herring was observed. In this quadrant, the current was going straight towards the grid, thereby simplifying discovery of the grid.

In the GEE there was a significant effect of temperature on selection. There was a marked increase of selection at 10–13 °C, which according to Neuman (1982) is the optimal temperature range for herring. In this temperature window, there was most likely a higher activity level which led in turn to an increased number of escapees.

Video recordings showed that herring could squeeze through the grid. This might mean scale loss and reduced survival rates (Suuronen et al., 1996a). However, lost scales were not seen on the video footage in this study. To prevent larger herring from escaping by squeezing their way out, the bars in the grid should be rigid.

It is uncertain whether a successful escape was the result of a behavioural decision to leave or a product of chance grid encounters. Herring have a strong school cohesion (Partridge et al., 1980) whereby safety is in numbers. If escape is a result of a behavioural choice, then herring which escape could be termed ‘bold’ as they have ventured away from the safety of the school, while herring remaining inside the fish chamber could be labelled ‘shy’. The shy–bold continuum, which Sneddon (2003) refers to, is a fundamental axis of behavioural variation. On the one hand it might pay to be bold, searching for new ways out of a predicament. On the other hand, it could be beneficial to be timid and sociable by staying with the school.

More studies are needed to evaluate which external stimuli and behavioural characteristics of the herring are important for the degree of selection. In addition, further improvements in the design and location of the selection grid are required to increase the efficiency of the selection.

In conclusion, this study demonstrated that selective release of small herring from a pontoon trap is possible and that several factors affect selection efficiency. The optimum conditions for selection according to this study were when catches were large, at the end of June, at night, when seals were present and when current velocities were low and directed towards the grid.

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