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# Size selective capture of Atlantic cod (*Gadus morhua*) in floating pots

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ABSTRACT

Little is known about the size selectivity of cod in static fishing gears such as pots and traps. In this field study, floating fishing pots were equipped with 40, 45 and 50 mm square mesh escape windows in order to estimate the size selectivity of cod at different mesh sizes. Relationships between selectivity parameters and mesh size, as well as an optimal mesh size for the escape window with respect to current minimum landing size of cod in the Baltic Sea were sought. The results show that the floating pot is not only species selective when used in the Baltic Sea cod fishery, the implementation of an escape window reduced the proportion of undersized bycatch in the pots by more than 90%. The estimated length at 50% retention was found to be a direct function of fish body length (girth) and mesh size of the escape window, while the estimated selection range remained unchanged regardless of mesh size. Optimal mesh size, with respect to the length at 50% retention and current minimal landing size of 38 cm in the Baltic, was determined to be 45 mm. Strong indications (significant on the 0.01 probability level in the case of 50 and 40 mm escape windows) suggested that the relative fishing power of the pots increased with the implementation of an escape window. This result could be explained as a “saturation effect”, i.e. the probability of cod entering the pot is likely to be negatively dependent on cod density in the pot. The high species selectivity and the low catch rate of undersized fish have consolidated the floating pots position as a highly benign fishing method and the foremost alternative gear for the future coastal cod fishery in the Baltic Sea.



## 1. Introduction

Commercial fishing with static fishing gears are found all around the Swedish coastline and are of great economical importance in many coastal villages (Waldo et al., 2010). In recent years, these fisheries have been suffering from diminishing stocks and increasing damage caused by seals (Swedish Board of Fisheries, 2009). The fishery for Atlantic cod (*Gadus morhua*) in the Baltic Sea is one of the fisheries that are particularly affected by these problems (Königson et al., 2009).

In an attempt to find a solution to the growing conflict between the coastal cod fishery and the seals the Swedish Board of Fisheries is currently evaluating alternative, potentially seal-proof, fishing gear. One of the gears considered is a baited portable fish trap, i.e. a pot (FAO, 1990). Pots have an obvious advantage by enclosing the catch in a chamber where the seals cannot reach, compared to gillnets and longlines where the catch is easily available to seals. Moreover, the recently developed floating pot has significantly higher species selectivity and catch rate of cod than the standard bottom-set pot (Furevik et al., 2008).

However, 45–60% of the cod caught in the commercially available floating pot consists of fish below legislated minimum landing size and has to be discarded (Furevik et al., 2008; Ovegård unpubl. data, 2009). Although the pot retains the catch alive, observations from commercial fishing vessels testing the floating pot suggests that the frequency of fish with eversion of the gut through the mouth is high and the survival of the discarded fish is low (Ovegård pers. obs.). The rapid reduction in pressure experienced by the fish while being mechanically hauled towards the surface is likely inflicting irreversible damage to the swim bladder (Tytler and Blaxter, 1973; Stewart, 2008). High discard rates of caught and thereby possible fatally injured fish are not only a threat to the productivity of the stock; they are also a highly time-consuming problem for the fishermen (Kelleher, 2005). Consequently, if the floating pot is to be a valid alternative to other static fishing gears the proportion of undersized bycatch must be reduced.

Although the problem with high discard rates of undersized fish is well known and several studies (e.g. Jørgensen et al., 2006; Grimaldo et al., 2007; Sistiaga et al., 2008) have focused on improving the escape of undersized cod from fishing gear, little is known of the selectivity patterns of escape windows for cod in static fishing gears. The only fully satisfactory method for describing the size selectivity of a static fishing gear is to compare selection curves for different mesh types (Wileman et al., 1996). Studies which only

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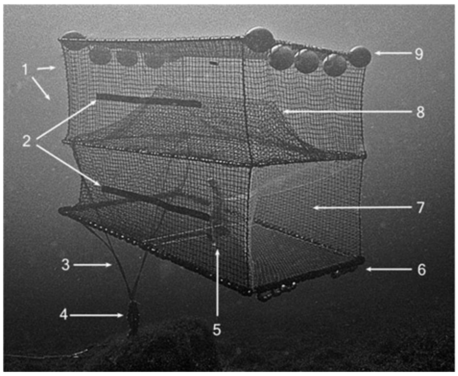


**Fig. 1.** The floating pot (length: 150 cm, width: 100 cm, height: 120 cm) at 15 m of depth. The ability to float above the bottom allows the pots to orient themselves in the direction of the water current, which enables the odour plume of the bait to always go through the downstream entrance of the pots (Furevik et al., 2008).

compare catch rates between pots with different mesh sizes (e.g. Brothers and Hollett, 1991; Robichaud et al., 1999) do not describe the size selectivity of the gear, but rather their fishing efficiencies at the time and place tested. The few studies that have modelled the selectivity of escape windows in static fishing gears (e.g. Shepherd et al., 2002; Stewart and Ferrell, 2003) have been conducted on other species of round fish, and their results cannot be applied to the fishery for cod in the Baltic Sea.

In this study, we compare the effect of three different mesh sizes on the size of cod captured in floating pots. Furthermore, relationships between selectivity parameters and mesh size, and optimal mesh size for the escape window (with respect to current minimum landing size of cod in the Baltic Sea) were determined.

## 2. Materials and methods

### 2.1. Sea trials and gear

The study was conducted in the southern Baltic Sea. Fishing trials were performed in collaboration with two local professional fishermen in the Bay of Hanö (between 55°50′–56°00′N and 14°35′–15°05′ E) from the 22nd of April 2009 to the 19th of January 2010.

The pots used were a similar version of the standard bottom-set two-chamber collapsible pot as used in the study by Furevik et al. (2008). In addition to modifying the standard pot to float above the bottom (40–60 cm) (Furevik et al., 2008) one of the potsĭ entrances and the net above this entrance, on the same side as the holdfast (upstream in current water), was removed and replaced by either a net with large mesh size (escape window) or a net with small mesh size (control) (Fig. 1). Escape window coverage of one entire vertical short side allowed undersized fish to exit from both the upper and lower chamber of the pot. The placement, opposite to the remaining entrance and at the same side as the holdfast, was designed to maximize the selectivity with as little modification of the original design as possible (Stewart and Ferrell, 2003) and minimize the chance of fish getting lost through the escape window when the pot was hauled (Fig. 1). Three different lengths of mesh side (Wileman et al., 1996) (40, 45 and 50 mm; all square mesh netting constructed of black 3/4 380-denier polyethylene twine) were used for the escape windows in order to evaluate the effect of mesh size. The same type of net, assumed to retain fish of all sizes encountered, as the net covering the remaining sides of the pot (square 27 mm length of mesh side, black 1.5 mm polyethylene twine) were used for the control pots. A square mesh net was used for the escape windows since it has been shown to retain fewer small fish (Brothers and Hollett, 1991) and has a better capacity to keep the meshes of the window fully open (Grimaldo et al., 2007) compared to circular and diamond mesh nets.

### 2.2. Experimental setup

A "paired gear" comparative fishing experiment was used to evaluate the selection properties of the escape windows. Four pots with identical mesh size in the escape window and four control pots were deployed along the same connecting nylon rope, henceforth defined as one string. The pots were set randomly in the strings, 50 m apart, making each string approximately 400 m. All pots in each string were equally baited with 300–350 g of fresh fine-cut Baltic herring (*Clupea harengus*), the bait proven to be most effective for attracting cod in a previous study by the Swedish Board of Fisheries (Ljungberg unpubl. data, 2007). Under the assumption that the Bay of Hanö constitutes a homogenous habitat and that the physical properties and behaviour of the fish affecting the selectivity remained unchanged over the sampling period, the experimental fishing started with the 50 mm window and finished with the 40 mm window. Soak-time ranged from one to 14 days, randomly distributed between strings and during the experimental fishing period. Due to high catch variability between strings, and gear setup paired for selectivity and not catch comparison, possible effects of prolonged soak-time were not considered. However, during the data analysis it became clear that only one day of soak-time was not enough time for allowing the fish that could exit through the escape window to actually leave the pots. Hence, all strings with only one day of soak-time were later removed from all analysis. Pots were hauled and handled one at a time on the string and individual length of all cod was measured to the nearest full cm.

### 2.3. Data analysis

The catch from all pots with or without an escape window from respective type of string (40, 45 or 50 mm length of mesh side in the escape windows) was combined and analysed with the SELECT (Share Each LEngth Catch Total) method (Millar and Walsh, 1992). This is the most widely used method for paired gear selectivity experiments analysis (e.g. Shepherd et al., 2002; Jørgensen et al., 2006; Grimaldo et al., 2007; Sistiaga et al., 2008), and includes a measurement of the relative fishing power ($p$) of the test gear. A logistic (symmetric about the length of 50% retention ($l_{50}$)) selection curve was fitted to the data sets with both the assumption of equal fishing power ($p = 0.5$) and $p$ estimated. The logistic model can be written as

$$r(l) = \frac{\exp(\alpha + \beta l)}{1 + \exp(\alpha + \beta l)} \tag{1}$$

where $r(l)$ is the probability that a fish of length $l$ is retained (given that it has entered one of the pots in the string) and $\alpha$ and $\beta$ are parameters to be estimated. Given that a fish is retained in the string, $p$ defines the probability of a fish entering a pot with an escape window. The parameter $\varphi(l)$ will therefore, based on $p$ and $r(l)$, provide a retention probability for a fish of size $l$ entering a pot with an escape window as

$$\varphi(l) = \frac{p \cdot r(l)}{p \cdot r(l) + (1 - p)} \tag{2}$$

which gives the log-likelihood function for the data, with consideration to $p$, as

$$\sum_{l} (n_{l_1} \log_e \varphi(l) + n_{l_2} \log_e (1 - \varphi(l))) \tag{3}$$

where $n_{l_1}$ and $n_{l_2}$ is the number of fish at length $l$ per string in pots with and without an escape window. The $l_{50}$ and selection range (SR), the difference between the lengths of 75% and 25% retention,

**Table 1**
Parameter estimates and model deviance (MD) of the logistic selection curve $r(l)$ with equal ($p = 0.5$) and unequal (estimated) relative fishing power assumptions. Deviance values for the hypotheses of equal relative fishing power are also given. L.C.: length classes, Date: first haul–last haul, SE: standard errors, df: degrees of freedom.

| | 40 mm windows | | | | 45 mm windows | | | | 50 mm windows | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. L.C. | 31 | | | | 31 | | | | 31 | | | |
| No. fishes | 730 | | | | 1008 | | | | 501 | | | |
| No. Strings | 13 | | | | 23 | | | | 18 | | | |
| Date | 2009/10/29–2010/01/19 | | | | 2009/06/24–2009/12/08 | | | | 2009/04/22–2009/10/06 | | | |
| | $p = 0.5$ | SE | $p =$ est. | SE | $p = 0.5$ | SE | $p =$ est. | SE | $p = 0.5$ | SE | $p =$ est. | SE |
| $\alpha$ | −24.20 | 3.32 | −21.58 | 4.63 | −28.58 | 2.85 | −25.78 | 3.98 | −34.38 | 5.49 | −31.79 | 6.63 |
| $\beta$ | 0.76 | 0.10 | 0.66 | 0.15 | 0.75 | 0.08 | 0.67 | 0.11 | 0.86 | 0.14 | 0.76 | 0.17 |
| $p$ | 0.5 | | 0.57 | 0.02 | 0.5 | | 0.54 | 0.02 | 0.5 | | 0.66 | 0.03 |
| $l_{50}$ (cm) | 32.0 | 0.24 | 32.9 | 0.68 | 38.0 | 0.20 | 38.6 | 0.60 | 40.2 | 0.27 | 41.6 | 0.74 |
| SR (cm) | 2.9 | 0.40 | 3.4 | 0.76 | 2.9 | 0.29 | 3.3 | 0.54 | 2.6 | 0.41 | 2.9 | 0.64 |
| MD | 32.94 | | 23.66 | | 35.45 | | 32.85 | | 54.24 | | 30.44 | |
| df | 29 | | 28 | | 29 | | 28 | | 29 | | 28 | |
| $p$-Value | 0.28 | | 0.70 | | 0.19 | | 0.24 | | <0.01 | | 0.34 | |
| $H_0$: $p = 0.5$ | | | | | | | | | | | | |
| Deviance | | | 9.28 | | | | 2.6 | | | | 23.08 | |
| df | | | 1 | | | | 1 | | | | 1 | |
| $p$-Value | | | <0.01 | | | | 0.11 | | | | <0.01 | |

of the different models was determined by the selection parameters $\alpha$ and $\beta$ such that

$$l_{50} = -\frac{\alpha}{\beta} \tag{4}$$

$$\mathrm{SR} = l_{75} - l_{25} = \frac{2\log_e(3)}{\beta} \tag{5}$$

The add-on program SOLVER in Microsoft Office Excel was used to fit the selection models through maximization of the log-likelihood function with respect to parameter $p$ and the parameters specifying the selection curve $r(l)$ (Tokai and Mitsuhashi, 1998). When a satisfactory fit was achieved of the selection curve the standard errors of the estimated selection parameters were obtained by standard maximum likelihood theory (Wileman et al., 1996). Goodness of fit of the models was checked with Model Deviance (MD) (Millar and Fryer, 1999), and plotting of the deviance residuals (Millar and Fryer, 1999). Deviance residuals evenly distributed and <2 in amplitude indicates a satisfactory fit (Millar and Fryer, 1999). The model with the lowest MD was used when comparing the $l_{50}$ and SR of the escape windows. The MD was also used to test the hypotheses of equal relative fishing power ($H_0$: $p = 0.5$) (Millar and Fryer, 1999). To avoid large variance in the proportion of retained fish in pots with an escape window, due to insufficient number of individuals, only length class 25–55 cm was used when fitting the model (catch per length class ≥ five individuals in all three types of strings). Proportion of discarded fish was calculated from the catch in all length classes. All tests and calculations were based on number of individuals, and only complete and fully functional strings were used in the analysis (some strings had missing and/or damaged pots, likely inflicted by trawls).

## 3. Results

Overall, 54 strings with a total catch of 2446 fish were used in the statistical analysis (Table 1). Of the total catch, which consisted of 100% cod, 2239 individuals were between 25 and 55 cm in length and used for determining the parameters of the selection curves (Fig. 2). A satisfactory fit of the logistic model was obtained, with $p$ estimated, for all 3 types of strings (Fig. 3, Table 1). The length at $l_{50}$ increased significantly with increased mesh size, while the SR remained unchanged regardless of mesh size (Table 1, Fig. 4). The increased size selectivity with increased mesh size was also evident when comparing the selection curves for the escape windows (Fig. 5). The relative fishing power $p$ of pots with an escape window was significantly ($p < 0.01$) higher than 0.5 in strings with 40

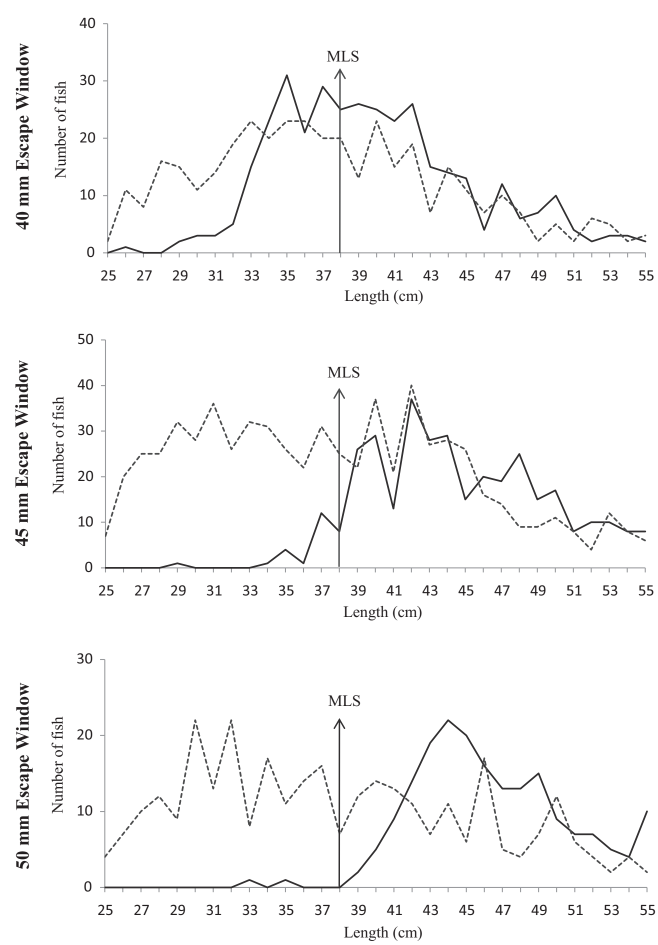


**Fig. 2.** Distribution of cod retained in pots with 40, 45 and 50 mm escape windows (solid line) and control pots (dashed line) in length class 25–55 cm. Minimum landing size (MLS) for cod in the Baltic is also indicated with an arrow in each chart.

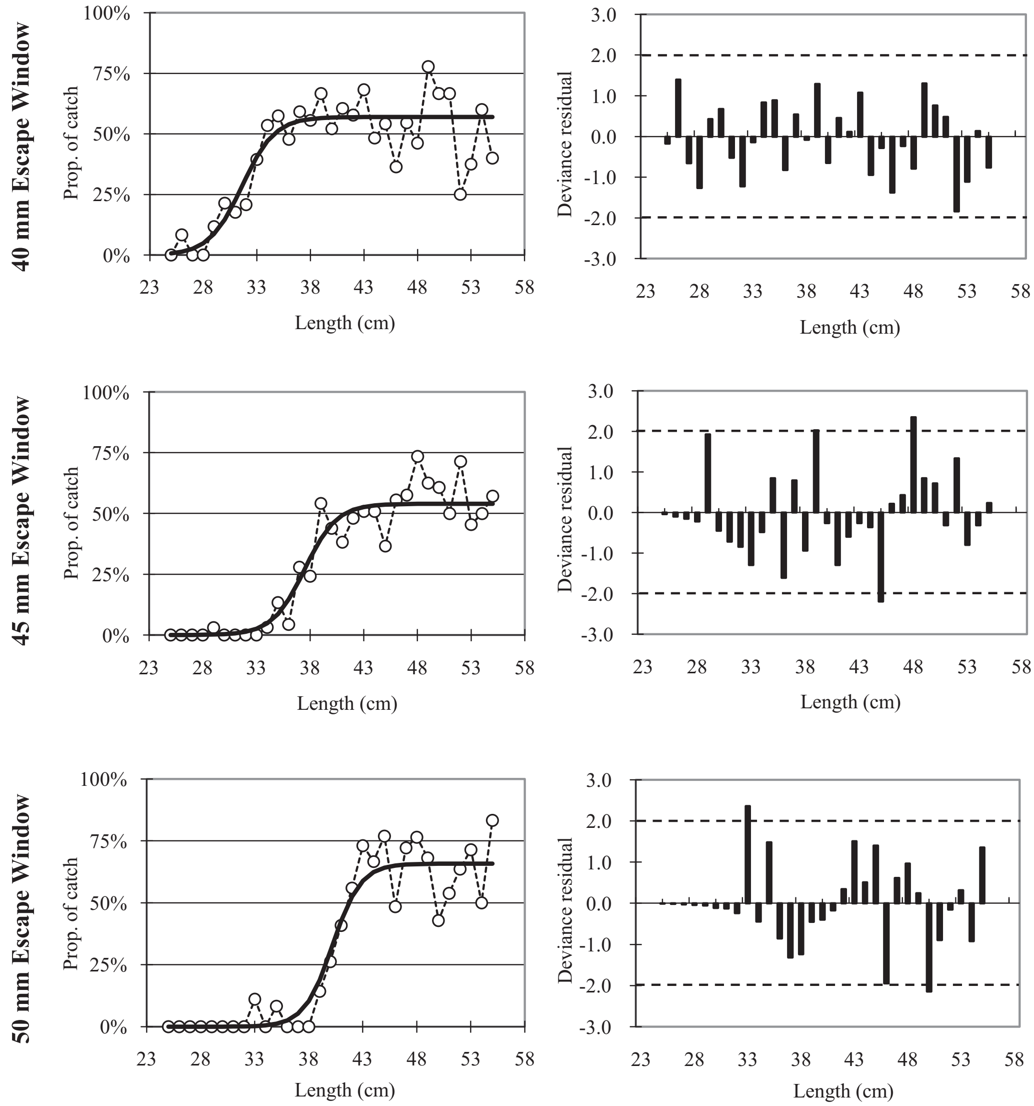


**Fig. 3.** Proportion of catch in pots with 40, 45 and 50 mm escape windows at length class 25–55 cm. Dots represent original data [catch escape pots/(catch escape pots + catch control pots)], solid line is the fitted logistic retention probability function $\varphi(l)$ with the parameter $p$ estimated. The deviance residuals, of the probability function $\varphi(l)$ with $p$ estimated, indicate a satisfactory fit (minor exceptions) of the logistic model in all cases.

and 50 mm windows, however, not in strings with 45 mm windows (Table 1). The 45 mm mesh window provided optimal retention of cod, with respect to $l_{50}$ and current minimum landing size of 38 cm, and reduced the proportion of bycatch of cod < 38 cm in length with 94% (from 48.8% to 5.6% bycatch of total catch).

## 4. Discussion

The results demonstrate that the floating pot was not only species selective when used in the Baltic Sea cod fishery, the escape window reduced the proportion of undersized bycatch in the pots

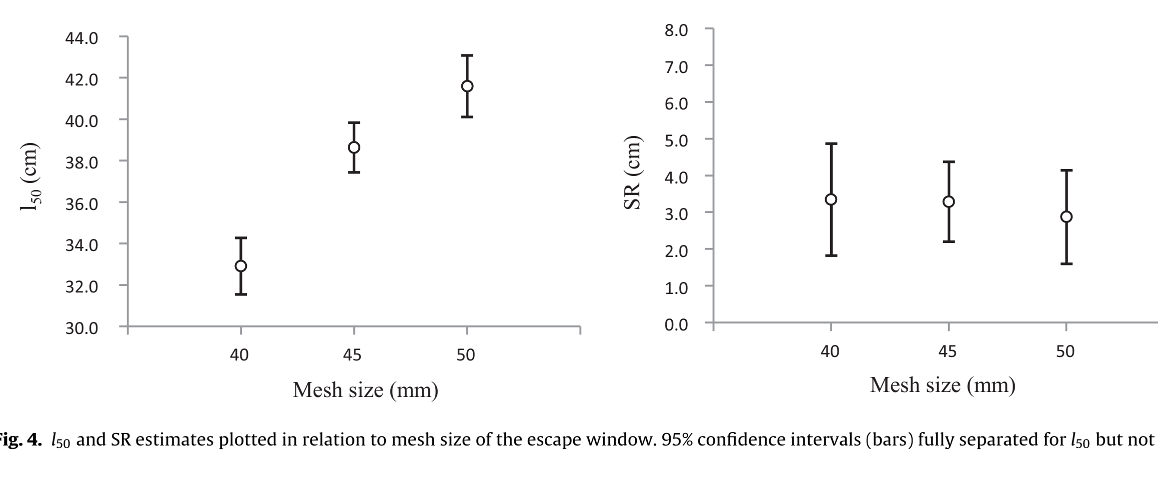


**Fig. 4.** $l_{50}$ and SR estimates plotted in relation to mesh size of the escape window. 95% confidence intervals (bars) fully separated for $l_{50}$ but not for SR.

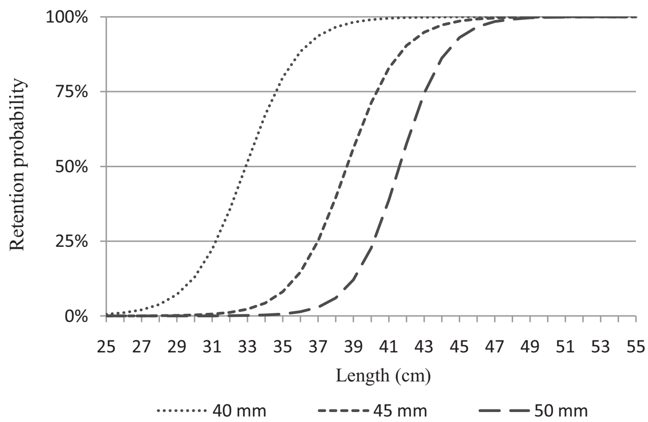


**Fig. 5.** Retention probability of cod, length class 25–55 cm, in floating pots with 40, 45 and 50 mm escape windows.

with more than 90%. The reduction in catch of small cod did not reduce the catch rate of larger cod. On the contrary, our results indicate that the escape windows increase the fishing power of the pots. The estimated length at 50% retention ($l_{50}$) of the escape windows was found to be a direct function of fish body length (girth) and mesh size, while the estimated selection range remained unchanged regardless of mesh size. Based on these results, and with respect to current minimal landing size of cod in the Baltic, optimal mesh size for a 3/4 380-denier polyethylene twine escape window was determined to be 45 mm.

To be able to compare the results obtained with the different escape windows, the analysis of the individual observations has to be consistent concerning the model used. The logistic model provided an adequate fit for all three types of strings, and was for this reason used to analyse all the combined-hauls. The combined-haul analysis method can be regarded as an estimation of the mean selection curve over the entire fishery (Wileman et al., 1996). The normally used (in combined-hauls analysis of selectivity experiment with trawls) standard errors correction procedure for mean selection curves (Wileman et al., 1996), could not be calculated due to insufficient numbers of individuals per haul. However, between-haul variation is mainly a problem with towed gear, particularly in alternative gear experiments and has not yet been reported for static gear experiments (such as traps or pots) (Millar and Fryer, 1999). Although both soak-time, fishing position and date varied considerably between the different strings during the entire fishery, the SR of these mean selection curves for each mesh size was similar (Fig. 5). This does not only strengthen the validity of the estimated selectivity parameters, it also indicates that there was likely no major between-hauls variation of the selectivity.

The clear relationship found between size selection of cod and mesh size (Fig. 4) has also been shown in previous experiments with trawls. However, the trawl experiments have revealed a much wider SR (Madsen, 2007; Sistiaga et al., 2008). Our results are in line with previous experiments on pot selectivity and other species of round fish (Shepherd et al., 2002; Stewart and Ferrell, 2003), indicating that pots have more “knife-edged” size selectivity than active gear. The short selection range of the pots compared to other types of gear was also evident in the proportion of discarded fish. The 45 mm windows, which had a $l_{50}$ only 6 mm above the minimum landing size of 38 cm, had a discard rate of no more than 5.6%. Moreover, although the proportion discarded fish was reduced with more than 90% the relative reduction in mortality of undersized fish was probably even larger. Stomach content examinations (Ovegård unpubl. data) showed that the frequency of cannibalism was several times higher in pots without an escape window compared to pots with an escape window.

In contrast to previous size selectivity studies of escape windows in pots (Robichaud et al., 1999; Shepherd et al., 2002; Stewart and Ferrell, 2003), our results show that the catch of fish above the length at $l_{50}$ increased in pots with an escape window relative to pots without an escape window. Although this effect was not significant in the case of the 45 mm window, and is a clear subject of possible bias in the experimental setup (no pot is an exact replica of another and they are spatially separated in the strings), we still consider it viable. Cod territorial behaviour (Brown, 1961) and previous results of pot catch rate being density dependent (High and Beardsley, 1970) suggests that there might be a “saturation effect”. That is the probability of cod entering the pot is likely to be negatively dependent on cod density in the pot. Another possibility is that the larger meshes of the escape window could make the floating pot distributing the bait odour more effectively, either by directly influencing the width of the active space of the odour, or by enhancing the pots ability to direct itself according to the water current. Whatever the reason, and regardless if it is a biological or environmental effect, our result clearly shows that the implementation of an escape window does not reduce the fishing efficiency of the floating pot.

We have shown that the implementation of an escape window in the floating pot has both environmental and economical advantages. It reduces the discard of undersized fish, decreases the workload for the fishermen and maintains (possibly increases) the catch rate of large fish. Although the floating pot needs to be further tested, especially the pots potential to be seal-proof, the improved qualities of the pot has further consolidated the potsĭ position as the foremost alternative gear for the future coastal cod fishery in the Baltic Sea.

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