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Broadening the horizon of size selectivity in trawl gears

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ABSTRACT

The discussion of alternative harvest patterns in commercial fisheries has been raised by stock assessment and fishery modelers, especially in the wider context of balanced harvesting. But often, these theoretical approaches propose alternative exploitation patterns that are difficult to achieve within the current limitations in the selectivity characteristics of fishing gears, such as trawl gears. The aim of the present study is to broaden the horizon for size selectivity in trawl gears by demonstrating the feasibility of alternative selectivity patterns for trawls. As a case study, we combined two well-known selection devices to obtain a bell-shaped selectivity curve in trawls with low catch ability of both small and large individuals from the target species. We have successfully tested this gear in the Baltic Sea cod fishery. The results revealed that completely different exploitation patterns for trawl gears can be achieved by means of gear technology.

1. Introduction

Selectivity can be defined as the dependence of a fishing gear's capture efficiency on factors such as size, age, and species (MacLennan, 1992). Adapting the selectivity of fishing gears is the most important strategy used in many fisheries around the world to achieve the desired exploitation patterns. So far, a widely accepted paradigm is that "Improving selectivity leads to a more efficient exploitation of the stock's growth potential" (Macher et al., 2008), and that good fishery management requires fishing gears to catch large adult fish while allowing small juveniles to escape (Armstrong et al., 1990). According to classical theory, length at first catch is the key parameter to optimizing a stock's yield. (Armstrong et al., 1990; Beverton and Holt, 1957).

The size selection of fishing gears is described by selectivity curves, which quantify the probability that a given length class of a given fish species will be caught, assuming that it is available to the gear. Selectivity curves differ between gear types and configurations of gears (Dickson et al., 1995; Hovgård and Lassen, 2000; Wileman et al., 1996). Passive gears, such as gillnets, have size selection properties usually described as bell-shaped curves (Dickson et al., 1995; Hovgård and Lassen, 2000; Huse, 2000; Millar and Fryer, 1999; Millar and Holst, 1997). They are characterized by low retention probabilities at small length classes, as well as at large length classes, with the result that gillnets catch primarily medium-sized length classes.

Historically, the selective properties of trawls and other active gears were adapted by altering the size selection in the codend (Glass, 2000). This strategy assumes that most fish entering the gear drift toward the codend, where a simple size-selection process occurs: smaller fish with specific morphological characteristics have a greater probability of passing through the meshes and escaping, whereas larger fish have a greater probability of being retained in the codend. In contrast to passive gears, the selection curve in trawl gears is S-shaped. Thus, the retention probability increases with the size of fish (Dickson et al., 1995; Gulland, 1983; Huse, 2000; MacLennan, 1995; Millar and Fryer, 1999; Reeves et al., 1992; Wileman et al., 1996). To reduce unwanted bycatch, the classical codend selection is often supplemented with additional selectivity approaches, such as grids (He and Balzano, 2012; Sistiaga et al., 2010), escape windows (Armstrong et al., 1998; Bullough et al., 2007; Catchpole and Revill, 2008; Madsen, 2007), and other strategies (Herrmann et al., 2015). Currently, the selective properties of these types of devices are optimized by changing the S-shaped selectivity curve, resulting in a change in the position of the curve along the length range of the species (often described as the L50-value, length of 50% rejection/retention) and/or in the steepness of the curve often described as the SR-Value, L25–L75; (Dickson et al., 1995; Wileman et al., 1996). A good example of such a limited approach is the development of gear regulations for cod-

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directed fisheries in the Baltic Sea (Feekings et al., 2013; Madsen, 2007). Since 1999, fishery management and fishery science have tried repeatedly to adapt the size selectivity of legal codends to accomplish specific management goals. This effort, mostly limited to discard reduction, has been carried out without considering a broader set of fishery management objectives, such as optimal population dynamics and healthy population structure. Nevertheless, owing to a lack of alternative selectivity options, the standard S-shaped trawl selectivity curve was “only” moved left and right (Fig. 1).

The lack of possible alternatives to the S-shaped trawl selectivity curves also narrows the range of potential exploitation patterns to be investigated in fishery models, in the search for optimal harvest strategies. Typically, such studies only considered S-shaped selectivity scenarios (Kronbak et al., 2009; Macher et al., 2008). With the debate about balanced harvesting (Garcia et al., 2012; Jacobsen et al., 2013; Zhou et al., 2010), additional selectivity patterns are being discussed and used for modeling purposes (Jacobsen et al., 2013). However, it often remains unclear how the alternative harvest patterns could be implemented technically in the fisheries.

Apart from the fundamental concept of balanced harvesting and underlying aims, other rationales offer themselves as alternative harvest strategies for trawl fisheries: Although the importance of age structure for recruitment success is still under discussion (Brunel, 2010; Morgan et al., 2011), there are arguments for a healthy age structure, including large and old individuals (Berkeley et al., 2004; Hixon et al., 2014; Law et al., 2015). For several stocks, the positive influence on population dynamics caused by older individuals has been postulated, with varying driving factors, including parental effects (Cardinale and Arrhenius, 2000; Cerviño et al., 2013; Marteinsdottir and Begg, 2002; Trippel et al., 2005) and enhanced resilience against excessive fishing pressure and against climate variation (Ottersen et al., 2006). The extent of such effects is still being debated (Marshall et al., 2010; O'Farrell and Botsford, 2006). In addition, age-structure indices are also important to ecosystem-based fishery management.

In line with the above arguments, we aim in this study to reduce the catchability of trawl gears for both tails of the length distribution (juveniles and older fish) for a given target species. Achieving this through fishing technology would require finding ways to shift the traditional S-shaped trawl selection curves toward bell-shaped selection curves, commonly associated with passive gears such as gillnets (Dickson et al., 1995). The strategy adopted here emulates gillnet-like bell-shaped selectivity by adding the rejection of larger individuals during the selectivity process in a standard trawl gear. The technological approach is simple and is based on the combination of two well-known and widely used selection devices. The proof of concept was carried out in the Baltic Sea cod-directed fishery.

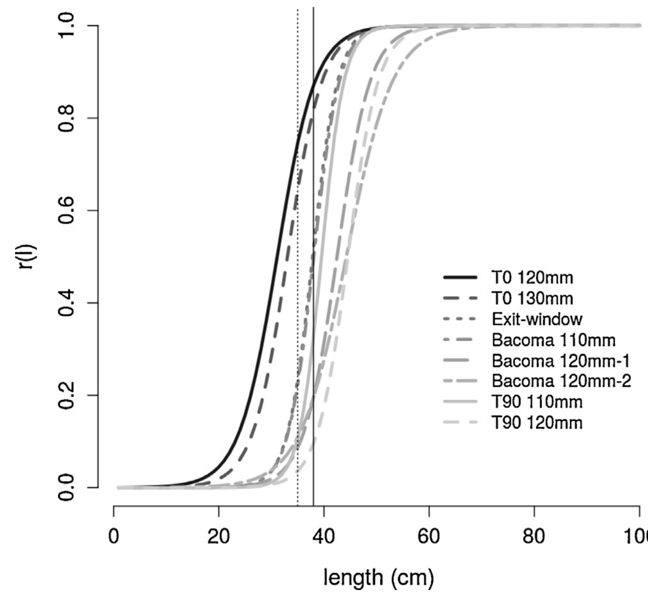

Fig. 1. Selection curves of legalized codends for the Baltic cod trawl fishery, 1999–2015. Vertical lines represent the corresponding minimum landing/reference sizes (MLS; 35 cm, 1999–2002 and 2015; 38 cm, 2003–2014). Codends are (a) T0 120 mm (1999–2001); (b) T0 130 mm (2002–2003); (c) Exit-window (1999–2001); (d) Bacoma 110 mm (2003–2009); Bacoma 120 mm (2001–2003 and 2010–2015); T90 110 mm (2006–2009); T90 120 mm (2010–2015). Selectivity curves were derived from personal, unpublished selectivity experiments conducted between 1999 and 2010. A description of the legislative development can be found in Feekings et al. (2013).

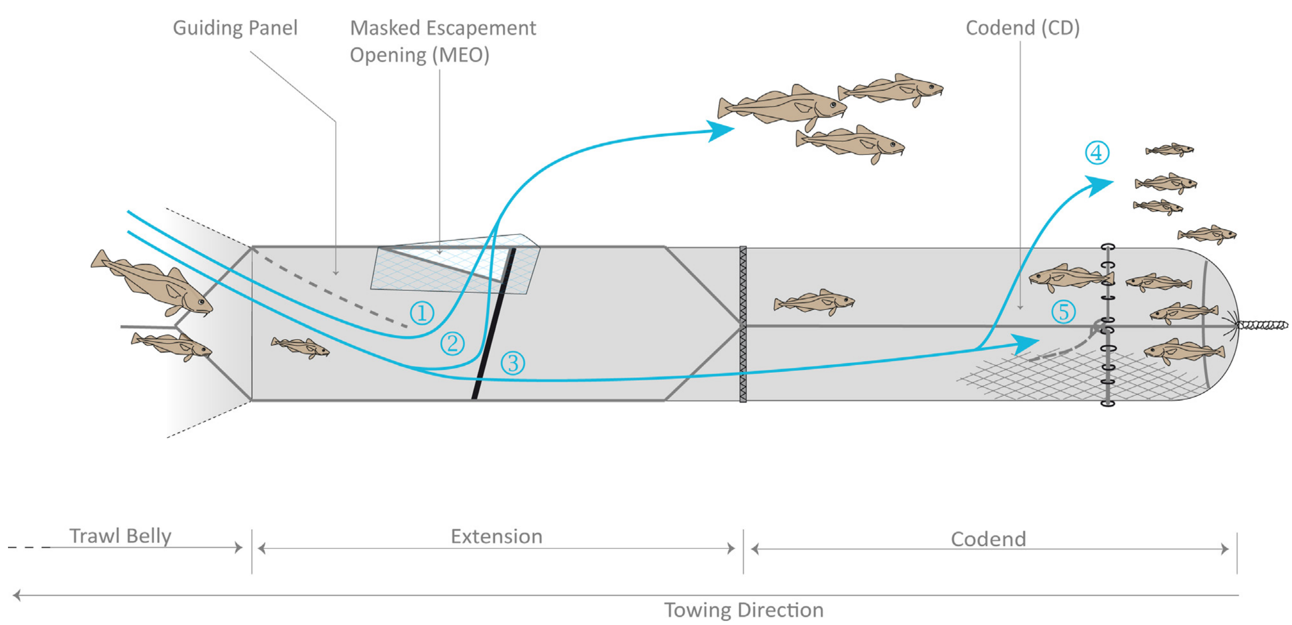

Fig. 2. Illustration of the grid and codend selection system used to obtain bell-shaped trawl selectivity. In addition to technical details, the different traits of fish entering the extension piece are illustrated: (a) fish not contacting the grid and escaping through the MEO; (b) fish contacting the grid, but not able to pass through; (c) fish contacting the grid, passing through, and entering the codend; (d) fish escaping through the codend meshes; (e) fish finally caught within the test codend.

The overall aim of the study is to demonstrate the feasibility of alternative selectivity patterns for trawls in general. Based on this demonstration, it is hoped that the study will stimulate further discussion and development that will broaden the scope of fishery management.

2. Material and methods

2.1. Selectivity concept

To achieve a bell-shaped size selectivity pattern for a target species in trawl fisheries, two selection devices —a grid system and a standard codend—were mounted sequentially (Fig. 2). The first selection device, a steel grid, was mounted in the extension piece between the belly section of the trawl and the codend. The purpose of the grid was to change the population structure entering the codend by rejecting large fish and allowing small and medium-sized fish to pass through it and continue the selection process. Large fish unable to pass through the grid would be excluded from the gear through the escape outlet placed in the upper panel in front of the grid. Ideally, all fish should contact the grid in their normal swimming orientation and be sorted according to size by the grid. However, not all fish entering the gear will necessarily contact the grid, and some may subsequently escape through the outlet, regardless of their size (Millar and Fryer, 1999; Sistiaga et al., 2010). Consequently, this study faced the challenge of ensuring that a large proportion of fish made proper contact with the grid to be sorted by size before encountering the escape outlet. To stimulate grid contact, we attached a rectangular piece of netting at the front of the escape outlet. The netting was mounted over the outlet to make the outlet less visible to fish (Fig. 2). The resulting masked escape outlet is denoted hereafter as MEO.

The small and medium-sized fish not rejected in the grid zone are sorted by the second size-selection process determined by the selectivity properties of the codend. At this stage, only small fish have any probability of escaping by passing through the codend meshes. The profile of the resulting catch is therefore determined by the combination of two size-selection processes, differing in purposes and acting sequentially along the gear. Because codend size selection acts only on fish that contact and pass through the grid in the first selection process, the second selection process is conditioned by the first.

2.2. Experimental setup

To estimate the individual and combined selectivity properties of both selection devices, it is helpful to use a three-compartment setup (Jørgensen et al., 2006; Kvamme and Isaksen, 2004; Sistiaga et al., 2010 (Fig. 3) to directly quantify fish escaping through the MEO (fish rejected by the grid or fish that did not contact the grid), fish retained in the codend, and fish that passed through the codend meshes. We used an experimental design based on the cover method (Wileman et al., 1996) to collect the experimental data. In addition to the common setup, based on covering the codend with a small mesh net cover, this experimental setup uses a top cover to collect the fish using the MEO to escape from the gear. Consequently, the experimental design includes three compartments:

(a) TC = top cover to collect all individuals escaping through the MEO ($n_{TC,l}$)
(b) CD = codend, containing the gear's final catch ($n_{CD,l}$)
(c) CC = cover codend to collect all individuals escaping through the codend meshes ($n_{CC,l}$)

2.3. Model for describing bell-shaped selection curves

The probability that a fish will be caught (*r(l), overall retention probability of the gear*) upon entering the experimental gear depends on the probability that it passes through the grid ($p_{grid}(l)$, *passage probability through the grid*) toward the codend, and that it is subsequently retained in the codend through size selection there ($r_{codend}(l)$, *retention probability in the codend conditioned entry*). The overall size selection of the gear can be described by the following model:

$$r(l) = p_{grid}(l, C_{grid}, L50_{grid}, SR_{grid}) \times r_{codend}(l, L50_{codend}, SR_{codend}) \quad (1)$$

Each of the partial selectivity functions on the right side of Eq. (1) has a specific structure and therefore must be described separately. The first is the probability that a fish will pass through the grid toward the codend ($p_{grid}(l)$). This is the combined probability that a fish efficiently contacts the grid (C_{grid}, *contact probability with grid*) and, once it contacts the grid, it is small enough not to be rejected by the selective properties of the grid ($1-r_{grid}(l)$); therefore:

$$p_{grid}(l, C_{grid}, L50_{grid}, SR_{grid}) = C_{grid} \times (1 - r_{grid}(l, L50_{grid}, SR_{grid})) \quad (2)$$

Second, $r_{codend}(l)$ in Eq. (1) refers to the probability that a fish will be retained in the codend, presupposing that it enters the codend.The probabilities $r_{grid}(l)$ and $r_{codend}(l)$ can be described by standard S-shaped size-selection models for trawl gears. We considered four different S-shaped models: *Logit*, *Probit*, *Gompertz*, and *Richard*. Details of these functions and the respective calculations of the selectivity parameters L50 (length of 50% rejection/retention) and SR (L75–L25) can be found in Wileman et al. (1996).

2.4. Model estimation and selection

The values for the parameters for the overall selection model (1) – C_{grid}, $L50_{grid}$, SR_{grid}, $L50_{codend}$, and SR_{codend} — were obtained using maximum likelihood estimation based on the experimental data, pooled over hauls *j* (1 to *m*) by minimizing:

$$-\sum_{l}\sum_{j=1}^{m}\left\{n_{TC,l,j} \times ln\left(1.0 - p_{grid}\left(l, C_{grid}, L50_{grid}, SR_{grid}\right)\right) + \left(n_{CC,l,j} + n_{CD,l,j}\right) \times ln\left(p_{grid}\left(l, C_{grid}, L50_{grid}, SR_{grid}\right)\right) + n_{CC,l,j} \times ln(1.0 - r_{codend}\left(l, L50_{codend}, SR_{codend}\right)) + n_{CD,l,j} \times ln\left(r_{codend}(l, L50_{codend}, SR_{codend})\right)\right\} \quad (3)$$

In total, 16 models were considered to describe the overall size selectivity in the trawl, based on the number of combinations of the four different S-shaped functions considered for both $r_{grid}(l)$ and $r_{codend}(l)$ (Section 2.3). The 16 competing models were evaluated based on their AIC-values (Akaike, 1974); the model with the lowest value was selected. The diagnosis of goodness-of-fit of the selected model to describe the experimental data was based on the *p*-value, model deviance vs. degree of freedom, and finally the inspection of the model curve's ability to reflect the length-based trends in the data.

The maximum likelihood estimate using Eq. (3) with Eq. (1) and (2) and requires the aggregation of the experimental data over

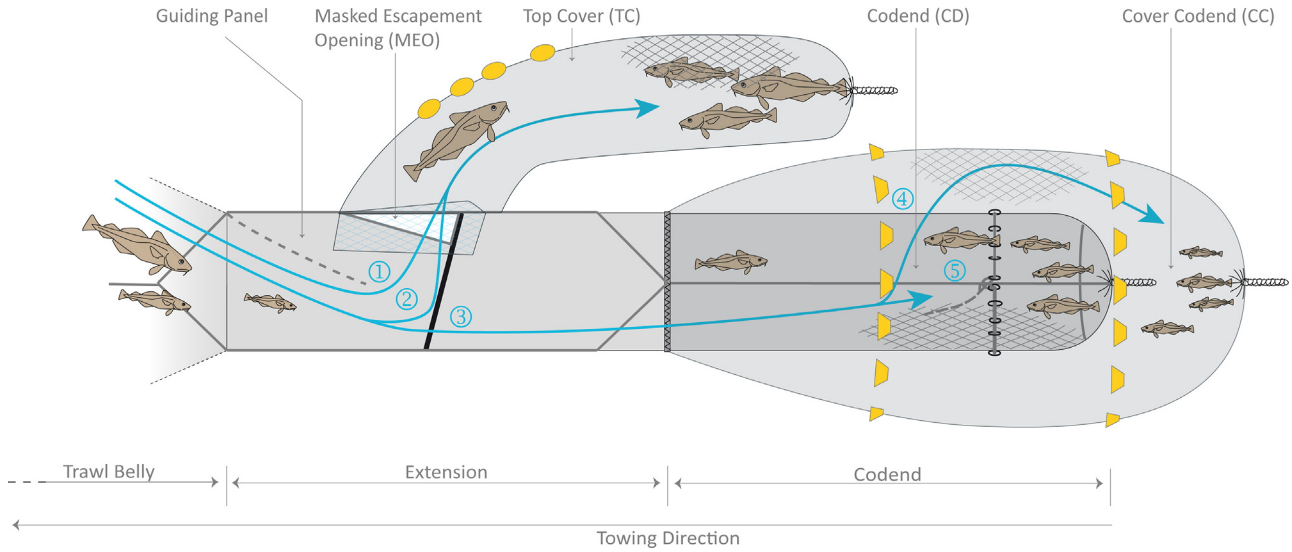

Fig. 3. Illustration of the experimental setup with three compartments. For a description of different numbers, see Fig. 2.

hauls. This results in stronger data to estimate the average size selectivity, at the expense of not considering explicit variation in selectivity between hauls (Fryer, 1991). To account correctly for the effect of between-haul variation in estimating uncertainty in size selection, we used a double bootstrap method to estimate the Efron percentile Confidence Intervals for both the estimated parameters in Equation (1) and the resulting curves for $p_{grid}(l)$, $r_{codend}(l)$, and $r(l)$. We used the software tool SELNET (Herrmann et al., 2012) for the analysis and applied 1000 bootstrap iterations to estimate the confidence intervals.

2.5. Specific setup of the trawl

The experimental trawl was a TV300/60 (300 meshes circumference behind the square with a 120 mm mesh opening in the belly and 60 mm in the extension piece), a standard trawl used in the Baltic cod-directed trawl fishery. The trawl and the codend were two-panel constructions, whereas the extension piece was a four-panel construction (Fig. 3). The extension piece included small transition sections that allowed the two-panel (belly and codend) and four-panel (extension piece) constructions to be joined.

To achieve the intended bell-shaped selection curve by using the proposed sequential selection system, it was necessary to define the grid's bar spacing and codend characteristics, considering the length structure of the population available at the moment of the experiment (obtained from Baltic International Trawl Survey, ICES SD24, first quarter 2014). The information about the population structure revealed very low abundance of large cod (above 50 cm, Fig. 4). We used SELNET's built-in parametric simulation facilities to predict the selection curves of a grid combined with a codend. This simulation (Fig. 4 left) indicated that it would probably not lead to sufficient coverage of the bell-shaped selection curve when combining a highly selective grid (for example with bar spacing of 70 mm) and a codend (for example the mandatory T90 120 mm codend). Therefore, it was proposed to combine a grid with reduced bar spacing (50 mm) and a less-selective codend (T90 105 mm). The grid was installed at an angle of 75° and a guiding panel was installed in front of the grid to further encourage fish contact with the grid, in addition to the use of MEO (Fig. 3). The codend was made of 4 mm PE double twine with an actual mesh size of 107 mm and 50 meshes along and 50 meshes around.

The top cover and cover codend were designed following recommendations of Wileman et al. (1996) (Fig. 3). The cover codend and the last part of the top cover were made of PE single twine 2.5 mm netting with a mesh size of 60 mm. The cover codend dimensions were 570 meshes in circumference and 275 meshes in length. The top cover construction followed the design guidelines from Wileman et al.(1996), therefore it comprises the assembly of net pieces with different dimensions and cutting edges. To avoid masking effects, 11 floats with a buoyancy of ~800 g each were attached to the top cover, while the combination of 5 kites with lead weights were used to separate the cover codend from the codend.

To understand the operation of the selectivity devices and the behavior of fish near such devices, we used GoPro cameras (GoPro Hero 3HD cameras without artificial light), installed at several positions on the trawl.

3. Results

The experimental fishing was conducted on board the German Fishery Research Vessel (FRV) “Solea” (total length = 42 m, 950 kW, stern trawler) over a period of 3 days (21–23 March 2014) in the Western Baltic Sea (Table 1). The water depth varied between 14 and 46 m. The average towing speed was 3 knots. The haul duration was either 90 or 120 min.

In all, eight valid hauls were achieved by the experimental fishing (Table 1). All cod observed in the different compartments were measured to the nearest half centimeter below their total length.

A total of 12 514 cod (5371.28 kg) were caught in experimental hauls used in the analysis (Table 1). All three compartments contained enough cod for proper analysis.

The 16 different models (Section 2.4) were successfully estimated, and the best model (considering the AIC-value) was determined to be the one that used the Gompertz function to describe both the grid and the codend selectivity (Table 2). The estimated curves for grid passage probability, conditioned codend retention, and overall selection together with their 95% confidence intervals are shown in Fig. 5 (left). Inspecting the *p*-values and deviance vs. DOF-from-the-fit statistics (Table 2) could have indicated lack of fit for the model. But inspecting the ability of the model curves to reproduce the trends in the experimental data revealed no systematic pattern of deviances for any of the curves (Fig. 5). Therefore, we consider the poor fit statistics a result of overdispersion in the data and, based on this, we are confident in applying the model to describe the trends in the data. The probability that a fish efficiently contacted the grid was estimated as $C_{grid} = 0.73$ (Table 2),

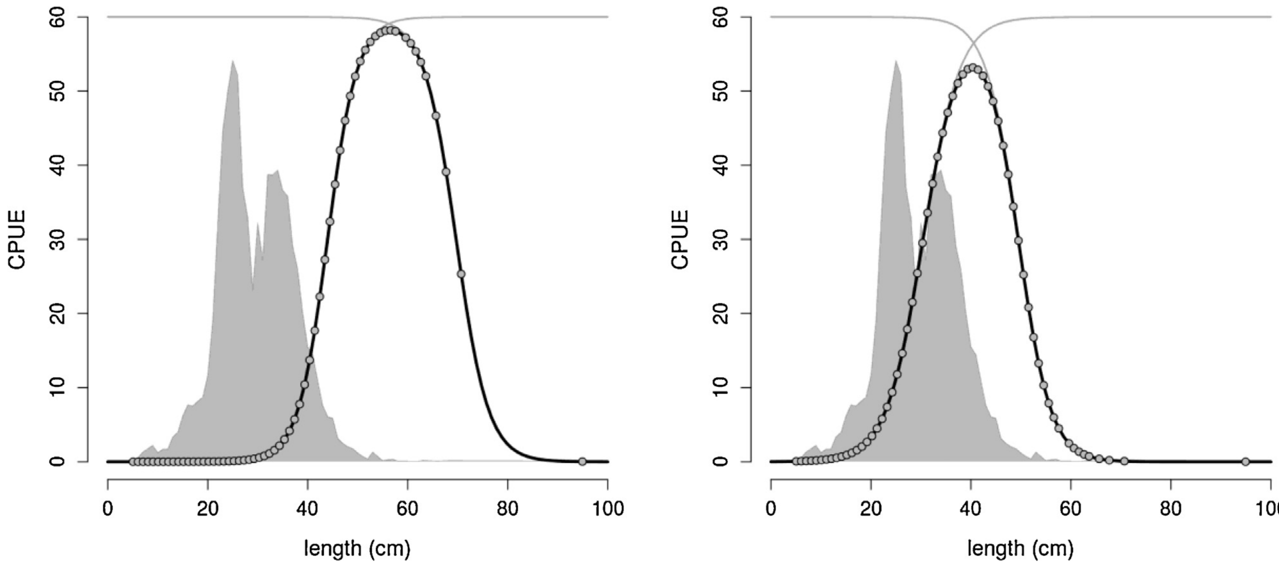

Fig. 4. A priori simulation of expected selectivity of the sequential selectivity system to be used during experimental fishing. Grey shaded area: expected length distribution for cod in the fishing area (derived from Baltic International Trawl Survey, ICES SD24, first quarter 2014). Grey lines: simulated selectivity curves for grid and codend (assuming 100% contact probability with the grid). Black line: resulting retention probability of the entire trawl. Dots indicate the distribution of length classes in population along the simulated retention curve. Left: combination of grid spacing 70 mm with T90 120 mm codend; right: combination of grid spacing 50 mm and T90 105 mm codend.

Table 1
Operational information of the experimental fishing hauls. TC = top cover, CC = cover codend, CD = codend.

Haul	Tow duration(min)	Latitude	Longitude	Depth (m)	Cod catch in different compartments Number (Catch weight in kg)		
					TC	CD	CC
1	120	54°12,227N	012°00,860E	14	321 (137.65)	835 (402.33)	657 (202.11)
2	120	54°12,568N	011°47,101E	23	375 (396.62)	1151 (433.63)	751 (246.03)
3	90	54°12,254N	012°00,422E	15	953 (176.15)	839 (526.22)	741 (238.89)
4	90	54°45,378N	013°29,785E	41	38 (16.40)	364 (148.26)	138 (32.09)
5	120	54°50,315N	013°27,635E	46	608 (239.47)	966 (418.59)	396 (115.05)
6	120	54°52,660N	013°15,529E	45	197 (80.44)	649 (254.39)	634 (147.39)
7	120	54°52,610N	013°15,166E	45	742 (331.47)	424 (167.88)	268 (63.46)
8	120	54°52,540N	013°30,885E	47	647 (225.76)	487 (266.01)	333 (104.99)
				Total	3881 (1608.44)	4715 (2617.31)	3918 (1150.01)

meaning that 73% of fish entering the trawl effectively contacted the grid and were sorted by it, based on size. Therefore, a number of individuals that could have passed through the grid escaped through the MEO and were released to the top cover (Fig. 5, top left). The underwater video recordings revealed that many fish hit the grid soon after entering the trawl, while others were actively swimming in front of the grid and not making immediately use of it. For those fish, the chances increased to find the way out through the escapement opening above the grid—even when covered by a net panel. This grid-avoidance response by cod could have contributed to the reduction in C_{grid}.

Owing to the value obtained for C_{grid}, which implies the loss of some fish belonging to the desired length classes, the bell-shaped selection curve did not reach the full catchability (retention probability) at the targeted mid-sized length classes. Nevertheless, the overall gear selectivity curve (Fig. 5, bottom left) clearly demonstrates the possibility of obtaining bell-shaped size selectivity in trawls.

Table 2
Selectivity parameters for the best models describing the size selections of the two selective devices in the test gear during the experimental sea trials; 95% confidence limits shown in parentheses; DOF: degree of freedom.

Selection device	Model	Parameter	Value
Grid	Gompertz	C_{grid}	0.73 (0.64–0.83)
		$L50_{grid}$	47.93 (46.45–49.46)
		SR_{grid}	8.40 (5.72–12.14)
Codend	Gompertz	$L50_{codend}$	29.70 (28.22–30.94)
		SR_{codend}	11.05 (10.17–11.82)
		p-Value	0.0093
		Deviance	217.57
		DOF	171
		Number of hauls	8
		AIC	27060.56

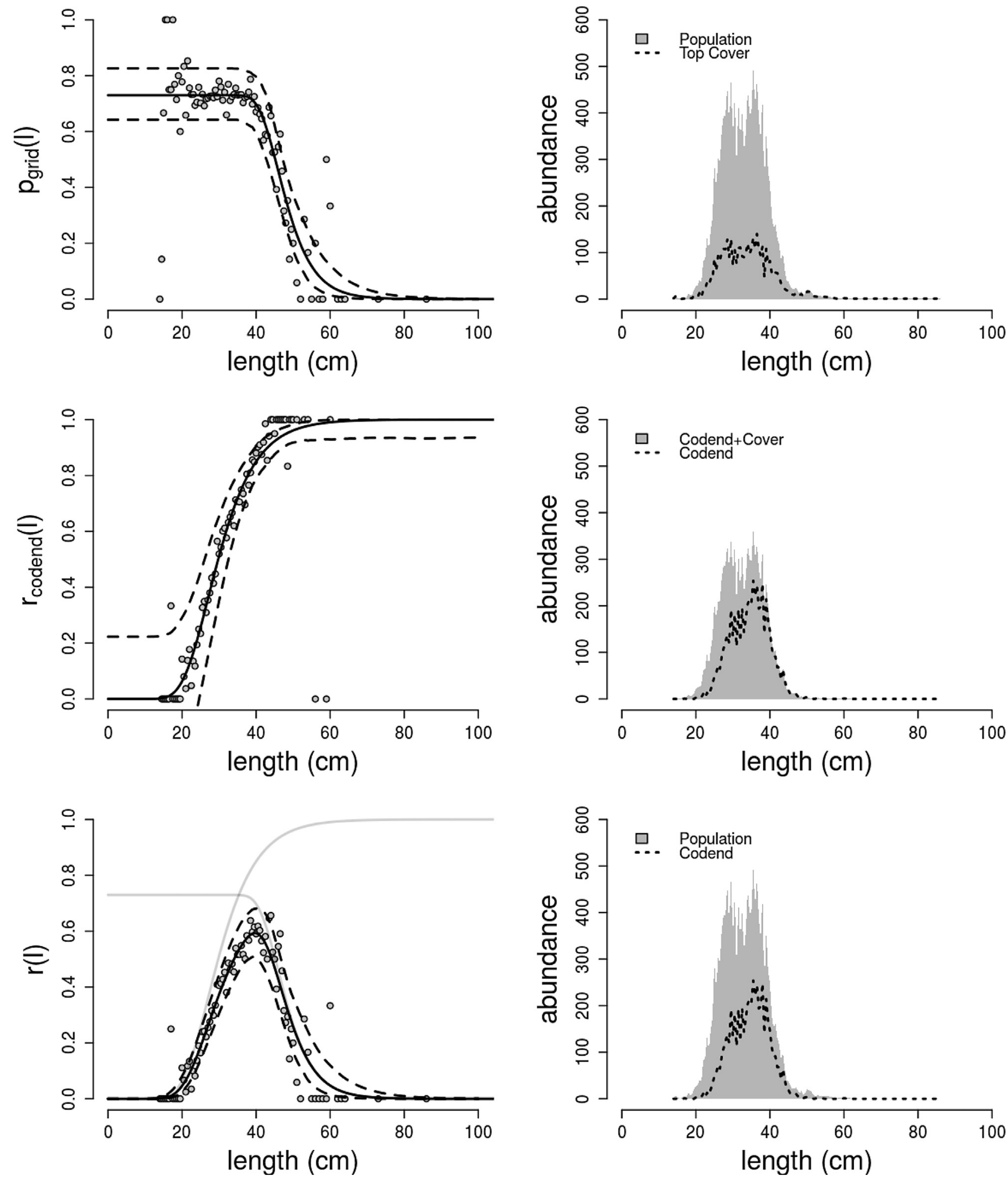

Fig. 5. Left: size selection curves of cod in different selectivity devices (including experimental data (points) and 95% confidence limits). Top: grid with vertical bars and 50 mm bar distance; Middle: T90 105 mm codend; Bottom: selectivity curves of grid and codend (grey lines) and resulting combined selectivity curve. Right: catch within a given compartment (stippled curve) in relation to the length distribution encountering the relevant selection device (grey shaded area).

Our results do not indicate any bias resulting from cover selection, because the model we applied was able to describe the full range of the data without any systematic pattern of deviation.

4. Discussion

The discussion of alternative harvest patterns in commercial fisheries has been raised by stock assessment scientists and fishery modellers, especially in the wider context of balanced harvesting

(Garcia et al., 2012; Jacobsen et al., 2013; Zhou et al., 2010). These theoretical approaches often propose alternative exploitation patterns, which cannot be achieved under the currently assumed paradigm for size-selection characteristics for target species with active fishing gears, such as trawl gears.

The aim of the present study was to broaden the horizon for size selectivity in trawl gears by demonstrating the feasibility of alternative size-selection patterns for trawls, in addition to the traditional S-shaped pattern.

Therefore, we have chosen one example to demonstrate that completely different exploitation patterns can be achieved in trawl fisheries to accomplish alternative fishery-management objectives. The practical exercise was to simultaneously obtain low catch probability of the smaller and larger individuals available in the targeted fish population. The underlying idea is based on the hypothesis that, in addition to short- and medium-term effects of the loss of reproductive potential of older and larger fish, size selectivity of trawls also has a long-term effect. It is known that the fishing pressure in combination with traditional S-shaped selectivity patterns of trawls can result in fishery-induced evolution (Andersen and Brander, 2009; Jørgensen et al., 2007; Kuparinen and Merilä, 2007; Law, 2000). Although the rate of evolution is assumed to be lower than previously published (Andersen and Brander, 2009), an alternative harvest pattern—targeting not only large individuals—may help to reduce the evolutionary effects of trawl selectivity.

The technological strategy adopted to achieve our goal was the combination of two well-known size-selection devices in fishing-gear technology, integrated sequentially in the trawl to establish a dual selection system. This has been tested for the cod-directed trawl fishery in the Baltic Sea. We used a grid to specifically sort out the large individuals of the target species, while allowing smaller fish to enter the codend. The use of a grid for this purpose is new for the target species. Until now, grids have been used to supplement codend size selectivity by allowing small individuals to escape (He and Balzano, 2012; Herrmann et al., 2013; Jørgensen et al., 2006; Kvamme and Isaksen, 2004; Sistiaga et al., 2010; Wileman et al., 1996) or to exclude the entire length range of specific bycatch species from the catch (He and Balzano, 2011; Isaksen et al., 1992; Sala et al., 2011). In some cases, both grid applications are combined in the same gear (He and Balzano, 2013).

In excluder-grid-based selectivity systems, it is also likely that selectivity patterns can be found that differ from the standard S-shape trawl selectivity curve. Possible examples are shrimp fisheries, where trawls are used to avoid catch of unwanted roundfish species (He and Balzano, 2011; Isaksen et al., 1992). If the grid-bar spacing allowed the passage of individuals of roundfish species within the length range, which is also relevant to codend selectivity, it may also be possible to find bell-shaped selectivity for these species. This bell-shaped selectivity curve releases the large individuals in front of the grid and the small individuals in the codend. In contrast to the design used in this study, this potential bell-shaped selectivity curve is derived by accident and is not obtained on purpose, and certainly not for the target species.

The experimental results presented here demonstrate that it is possible to obtain completely different exploitation patterns for trawl gears by means of gear technology.

Based on the length distribution of cod available during the experiments, the selective properties of the selection devices used did not necessarily result in an optimized harvest pattern for cod in the Baltic Sea, but were chosen based on experimental considerations (see Section 2.5) and, following the aim of this study, to act as a feasibility study. Optimal combinations of grid and codend selectivity for a variety of fisheries can be identified in future modelling studies. To improve the proposed selectivity pattern, attention has to be paid to increasing the probability of contact with the grid by specimens entering the trawl.

As mentioned above, the use of multiple selection devices gives more flexibility to obtain desired harvest patterns. On the other side, the complexity of the trawl has effects on costs and handling of the gear. Such aspects also have to be taken into account when identifying optimal harvest strategies to obtain a sustainable use of a population and a sustainable fishery.

It was shown that it is possible to achieve a bell-shaped selectivity in trawl fisheries, which is similar to the selectivity curve of gill-nets. Nevertheless, it is not clear whether the population effect of both fisheries is identical when using bell shaped curves. For instance, it could be influenced by potential differences in survival of escapees in both fisheries.

We hope this study will initiate further discussion and development that will broaden the scope and possibilities of fishery management. Modelers are encouraged to enlarge the scope of their models to include alternative selectivity patterns and to discuss with fishing gear technologists how to bring them into practice.

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