Use of selective devices in trawls to support recovery of the Kattegat cod stock: a review of experiments and experience

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The spawning-stock biomass of cod (*Gadus morhua*) in the Kattegat area is at a historically low level. Throughout the past decade considerable efforts have been devoted to research on improving both species and size selectivity of the trawls used in the mixed demersal fishery in the area, because this provides a valuable management tool for reducing the bycatch of cod and reducing mortality, and thus helping to rebuild the depleted stock. Gear research in the area has been focused on devices that allow for continued exploitation of the Norway lobster (*Nephrops norvegicus*) and flatfish, but minimizing the bycatch. We review the results of previous and continuing experiments with various codend mesh sizes, mesh configurations, escape windows, sorting grids, sorting frames, and separator panels, but also changes in whole-trawl designs. Based on our review, we compare and discuss the gear-related technical measures and their effectiveness in maintaining a commercial fishery on viable stocks, yet protecting cod. We discuss the results in relation to changes in legislation and experience with implementation of new selective devices in recent years. We also discuss ways to create stronger incentives for fishers to participate in gear research and to increase acceptance of more selective gears.

Keywords: bycatch, cod, discards, escape window, Kattegat, *Nephrops*, recovery, selectivity, sorting grid, trawl.

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Introduction

Cod (*Gadus morhua*) used to be the most important commercial species in the Kattegat area (Svedäng and Bardon, 2003). However, the spawning-stock biomass has declined steadily during the past 30 years and has reached a historically low level. ICES has recommended a zero catch for several years (ICES, 2008). The main issue is the need to decouple cod catches from those of Norway lobster (*Nephrops norvegicus*), plaice (*Pleuronectes platessa*), and sole (*Solea solea*) in a mixed demersal-trawl fishery. Therefore, considerable efforts have been devoted to research on improving both species and size selectivity of the gears used in the area, with the aim of providing advice on appropriate measures on gear design that could be used as a management tool for rebuilding the depleted cod stock in the Kattegat. Several steps have been taken in recent years to develop and implement selective devices in the fishery. Here, we review continuing and previous studies, and in particular, experience with devices already introduced into the fishery. We discuss future progress regarding research needs and possibilities for further implementation of selective devices that could support the recovery of the Kattegat cod stock.

Our focus is on cod. However, major target species, particularly *Nephrops*, sole, and plaice, are also discussed in relation to maintaining a viable fishery that harvests these species, yet protecting cod. We concentrate on experiments from the Kattegat and Skagerrak. Aside from the resemblance of the two adjacent areas regarding the biological characteristics and fishery practices, the Skagerrak is often preferred as an experimental site, because of its higher catch rates, particularly of cod. We also compare our results with experiments in other areas, if these are relevant.

The Kattegat area is predominantly fished by Danish and Swedish vessels. Main demersal species targeted are *Nephrops*, plaice, sole, and cod. Landings of other demersal species are low. Regarding gear usage, trawls with codends within the mesh-size range of 90–99 mm dominate the share of the total landings (2007: *Nephrops*, 91%; cod, 73%; plaice and sole, 50–60%; STECF, 2008). The entire trawler fleet is effectively a mixed *Nephrops*/fish fishery, though individual fishing operations can target particular species quite effectively. The trawl fishery is characterized by substantial discard rates for several species, including cod (STECF, 2008; Krag *et al.*, 2008; Ziegler and Valentinsson, 2008; Frandsen *et al.*, 2009).

Selectivity experiments

Codend mesh size, form, and material

A general way to improve the selectivity of fishing gear is to increase the mesh size. In the Kattegat, mesh size has increased from 60 mm in 1988 (Kirkegaard *et al.*, 1989) to 90 mm in 2005 (EC Council Reg. 27/2005; Frandsen *et al.*, 2009). These relatively small mesh sizes are used to retain *Nephrops* and sole. As observed in other areas (Madsen, 2007), there was a widespread shift towards thicker twine and from single twine to double twine during this period. In general, both factors are expected to decrease selectivity (Lowry and Robertson, 1995; Tokaç *et al.*, 2004; Herrmann and O'Neill, 2006; Sala *et al.*, 2007). No data exist on the use of attachments, such as round straps (Herrmann *et al.*, 2006), which might also reduce the selectivity.

The selectivity for cod in the Kattegat–Skagerrak area has been assessed in recent experiments for traditional diamond-mesh codends (DMC) made of 4 or 5 mm double-polyethylene twine (Madsen and Stæhr, 2005; Madsen *et al.*, 2008b; Frandsen *et al.*, 2009, 2010), which represent the material most frequently used by commercial fishers. Estimates of the selection factor (SF = L50/mesh size, where L50 is the 50% retention length) were in the range 1.60–2.45 (Table 1, nos 1, 4, and 7–9). Low-catch weights, combined with relatively thick twine, may explain the low values (Table 1, nos 8 and 9) estimated by Frandsen *et al.* (2010). Therefore, when the 90-mm minimum mesh size for diamond meshes is used, the L50 is only 14–22 cm, which is well below the minimum landing size (MLS = 30 cm).

Increasing the nominal codend mesh size from 90 to 120 mm (as prescribed for the North Sea) resulted in a 59% reduction for cod <40 cm (Table 2, no. 3). However, catches of legal-sized (≥40 mm) *Nephrops* were reduced by approximately one-third and the catches of most other commercial species were reduced (Krag *et al.*, 2008). Madsen *et al.* (2008b) estimated that 43% of all undersized cod escaping got away during towing and 57% during haul back. A high haul-back escape has also been reported recently from other areas (Madsen *et al.*, 2008a; Grimaldo *et al.*, 2009).

Herrmann *et al.* (2009) measured the morphological parameters of Skagerrak cod that determine the physical potential to penetrate different mesh types. Based on simulations for diamond, square, rectangular, and hexagonal meshes, they found that hexagonal meshes yield the highest L50 for a given mesh size. To improve selectivity in diamond meshes, they suggested diminishing the initial stretching tension on the codend netting

Table 1. Selectivity estimates (L50, length at 50% retention; SR, selection range = L75–L25; SF, selection factor based on codend mesh size; SRA, selection ratio = SR/L50) for cod according to experiments (*n*, number of hauls) using a variety of mesh sizes (in mm; DMC, diamond-mesh codend; SMC, square-mesh codend; T90, meshed turned by 90°), escape windows (BW, bottom window; BA, BACOMA window; SMW, square-mesh window), and a sorting box (SB).

Codend type[a]	*n*	L50 (cm)	SR (cm)	SF	SRA	Reference
(1) 104DMC	8	25.5	4.2	2.45	0.16	Madsen and Stæhr (2005)
(2) 104DMC + 85BW	10	29.9	4.2	3.50	0.14	Madsen and Stæhr (2005)
(3) 103DMC + 85BA	12	29.9	4.2	3.53	0.14	Madsen and Stæhr (2005)
(4) 99DMC	16	23.7	13.1	2.38	0.55	Madsen *et al.* (2008b)
(5) 99T90	16	32.2	7.8	3.25	0.24	Madsen *et al.* (2008b)
(6) 93DMC + 127SMW(6–9 m)	18	27.1	10.9	2.92	0.40	Frandsen *et al.* (2009)
(7) 96DMC	18	23.0	7.0	2.39	0.30	Frandsen *et al.* (2009)
(8) 94DMC	18	15.0	3.3	1.60	0.22	Frandsen *et al.* (2010)
(9) 95DMC	6	18.9	6.3	1.99	0.33	Frandsen *et al.* (2010)
(10) 71SMC	18	26.9	4.4	3.80	0.16	Frandsen *et al.* (2010)
(11) 68SMC	6	26.3	6.3	3.85	0.24	Frandsen *et al.* (2010)
(12) 99DMC + SB + 382SMW	11	97.2	39.9	9.80	0.41	Madsen *et al.* (2010b)

[a]Mesh-size measurements with ICES 4 kg gauge or Omega wedge (Fonteyne *et al.*, 2007) were converted to EEC wedge (5 kg hanging weight) values by adding 3.9% (Ferro and Xu, 1996) or 3.7% (Frandsen *et al.*, 2009), respectively.

Table 2. Reduction in cod catch (C in number), discards (D in weight), or landings (L in weight) estimated from experiments using twin trawl rigs for comparing two gears simultaneously (least selective gear up front; *n*, number of hauls; statistics if available: $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$; n.s.: non-significant).

Comparison	*n*	Reduction	Reference
(1) CT + 111DMC: LMT + 133SMS + 111DMC	21	C: <40 cm, 59%***; ≥40 cm, n.s.	Madsen *et al.* (2006)
(2) 81DMC: 80DMC + 97SMW	19[a]	C: <40 cm, n.s.; ≥40 cm, n.s.	Krag *et al.* (2006)
(3) 93DMC: 124DMC	24	C: <40 cm, 59%***; ≥40 cm, n.s.	Krag *et al.* (2008)
(4) 80#DMC + 90#SMW (6–9 m): 80#DMC + 90#SMW (3–6 m)	20	C: <40 cm, n.s.; ≥40 cm, 11%*	Krag *et al.* (2008)
(5) 80#DMC: 80#DMC + 97SMW	24	C: <40 cm, n.s.; ≥40 cm, n.s.	Krag *et al.* (2008)
(6) 80#DMC + 97SMW: 80#DMC + 120SMW	21	C: <40 cm, n.s.; ≥40 cm, n.s.	Krag *et al.* (2008)
(7) 73DMC: 35#SG + 73DMC	15	D: 68***; L: 100%***	Valentinsson and Ulmestrand (2008)
(8) 71DMC: 35#SG + 71SMC	7	D: 73%*; L: 100%*	Valentinsson and Ulmestrand (2008)
(9) 91DMC + 116SMW: 70SMC + 35#SG	9	D: 76%**; L: 100%**	Valentinsson and Ulmestrand (2008)
(10) 68SMC + 35#MG3: 69SMC + 35#SG	14	D: 48%*; L: 100%*	Valentinsson and Ulmestrand (2008)
(11) 70SMC + 35#FG: 70SMC + 35#SG	10	D: n.s.; L: NA	Valentinsson and Ulmestrand (2008)
(12) 68SMC: 69SMC + 35#MG3	6	D: 66%*; L: 64%*	Valentinsson and Ulmestrand (2008)
(13) 83DMC: 71SMC + 35#HBG	10	D: 77**; L: 100%*	Valentinsson and Ulmestrand (2008)
(14) CT: RTP	24	C: <30 cm, n.s.; ≥30 cm, 41%***	Krag and Madsen (2010)

Mesh sizes and grid bar distances are indicated in front of the gear type (#nominal values; otherwise measured values). CT, conventional trawl; FG, flexigrid; HBG, horizontal bars grid (Figure 2); LMT, large-mesh top panel (Figure 3); MG3, modified grid 3 (Figure 2); NA, not available; RTP, reduced top panel; RF, raised fishing line; SG, standard grid; SMC, square-mesh codend; SMS, square-mesh section (Figure 1); for other abbreviations and mesh-size measurement conversion, see Table 1.

[a]Excluding one haul with bulk catch.

by shortening the selvedge ropes or by reducing the number of meshes in the circumference. Frandsen *et al.* (2010) found a relatively high selection factor for cod with a square-mesh codend (SMC; Table 1, nos 10 and 11), but also a relatively high selection factor of *Nephrops*, whereas the selectivity of plaice was unchanged compared with a DMC.

Codends with the diamond meshes turned 90° (T90; Table 1, no. 5) are expected to ensure a larger mesh opening, because the knots determine the initial mesh-bar angle. This simple way to improve selectivity (because standard conventional netting can be used) was introduced in the legislation for the Baltic Sea from 2006 on (Herrmann *et al.*, 2007; Madsen, 2007). Compared with traditional diamond meshes (Table 1, no. 4), the selection factor was considerably higher. Madsen *et al.* (2008b) have demonstrated that this was specifically caused by a higher escape rate during haul back. The retention of *Nephrops* above MLS (≥40 mm carapace length) was also reduced considerably, especially during haul back, whereas selectivity of plaice was comparable.

Escape windows

An escape window is a panel with a mesh shape and/or mesh size different from the remaining part of the codend. The principle is that a window placed in a top panel offers an escape possibility for fish, whereas *Nephrops* are expected to pass underneath. A chief benefit is that the method is simple and cheap. The application of windows is not a recent invention, but was tested in the Kattegat 95 years ago by Ridderstad (1915). Many recent studies on *Nephrops* fisheries in other areas (Briggs, 1992; Thorsteinsson, 1992; Armstrong *et al.*, 1998; Madsen *et al.*, 1999; Catchpole and Revill, 2007; Revill *et al.*, 2007) and in the Kattegat–Skagerrak area (Ulmestrand and Larsson, 1991) have established improved selectivity for whiting and haddock, but also for cod in the North Sea (Madsen *et al.*, 1999; Revill *et al.*, 2007).

Krag *et al.* (2008) assessed the performance of a 97-mm square-mesh window (SMW; Figure 1, no. 5) in the Kattegat–Skagerrak *Nephrops* fishery. Such a window installed in a DMC and 6–9 m from the codline had no significant effect on the catch of cod (Table 2, no. 2). However, when placed 3–6 m from the codline (Figure 1, no. 4), catches of cod >40 cm were reduced (Table 2, no. 4), but this introduced a statistically significant ($p < 0.05$) 12% loss of legal-sized *Nephrops*. Experiments from other fisheries also indicate that the location of the window is important, particularly if it is positioned backwards (Graham and Kynoch, 2001; Graham *et al.*, 2003). Increasing the mesh size in the window from 97 to 120 mm had no significant effect (Table 2, no. 6).

Frandsen *et al.* (2009) reported a higher selection factor for a codend with a window as currently specified in the legislation (Figure 1, no. 5; Table 1, no. 6) than with a conventional codend (Figure 1, no. 1; Table 1, no. 7), but the difference was not significant.

Madsen and Stæhr (2005) tested the Bacoma window concept (BA: Figure 1, no. 7; implemented by legislation in the Baltic Sea cod fishery; Madsen, 2007) and the application of bottom windows (BW) as used formerly (Figure 1, no. 8) and reported a significant increase in L50 and a substantial increase in the selection factor for both (Table 1, nos 2 and 3) compared with a conventional DMC (Table 1, no. 1).

Madsen *et al.* (2010a, b) developed a codend with a four-panel section named the sorting box (SB: Figure 1, no. 6). The box was placed 3–6 m from the codline to provide better stability in the codend, to enhance escape of cod, and to avoid the possible loss of *Nephrops* (Krag *et al.*, 2008). When using a 382-mm SMW, the selectivity of cod was improved considerably (Table 1, no. 12), whereas the selection curve of *Nephrops* was not different from a standard DMC, although the possibility that some *Nephrops* escaped through the window could not be excluded (Madsen *et al.*, 2010b). A sizeable escape of plaice was also observed.

Sorting grids, separator panels, and frames

Grid systems utilizing mechanical sorting by size have been developed for sorting out fish from shrimp (Isaksen *et al.*, 1992; Madsen and Hansen, 2001) and are used in commercial fisheries worldwide. Grid systems tested in the North Sea *Nephrops* fishery demonstrated a 100% reduction in cod ≥35 cm (Catchpole *et al.*, 2006).

Valentinsson and Ulmestrand (2008) reported on a series of comparative experiments with sorting grids in the Kattegat and Skagerrak. Most of the experiments compared a standard ("Swedish") grid (SG) with DMC or SMC, but other types were also used (Figure 2). All experiments using the SG showed markedly reduced catches of cod of all sizes (Table 2, nos 7 and 8), as well as strongly reduced catches of legal-sized plaice, whereas the average loss of *Nephrops* ≥40 mm was not significant.

A comparative test has also been made between a SG and a flexigrid (FG) made of rubber with composite bars (Table 2, no. 11). The FG caught significantly less marketable *Nephrops* than the SG, and the results for fish selectivity were inconclusive. The observed variability of fish selectivity may indicate that bar spacing was less stable for the FG than for the standard aluminium grid, and the water-flow characteristics may also differ. Moreover, the FG was difficult to handle, because it did not bend on the drum properly because of low drag caused by low catches (Valentinsson and Ulmestrand, 2008).

Another experiment (Valentinsson and Ulmestrand, 2008) compared a grid with horizontal bars (Figure 2, no. 2) with a conventional DMC. These horizontal bars were intended to increase the retention of flatfish. However, this gear appeared to be inefficient for *Nephrops* retention, whereas retention of cod (Table 2, no. 13) and plaice was similar to the SG.

Two experiments by Valentinsson and Ulmestrand (2008) compared a modified grid with a 15-cm opening in the lower part (MG3: Figure 2, no. 5) with an SG and a 70-mm SMC. The modified grid caught more cod (Table 2, no. 10) and small plaice than an SG and fewer cod of all sizes (Table 2, no. 12) than with an SMC.

Frandsen *et al.* (2009) tested a modified grid system (MG1: Figure 2, no. 3) with increased bar spacing in the top to retain larger *Nephrops*. This gear reduced catches of cod significantly, catching less than 5 and 1% below and above MLS (30 cm), respectively, and very few cod passed through the larger spaces at the top (<0.2%). However, this modified grid also had a lower selectivity of cod <MLS than a DMC and a 120-mm SMW codend (Figure 1, no. 5), which might be explained by the small catches influencing the mesh opening. Furthermore, 17% of marketable *Nephrops* were lost and the percentage loss increased with size.

Madsen *et al.* (2008b) investigated the possibilities for increasing the retention of larger *Nephrops* by increasing the bar distance (to 40 mm), having a section at the bottom with larger bar spacing

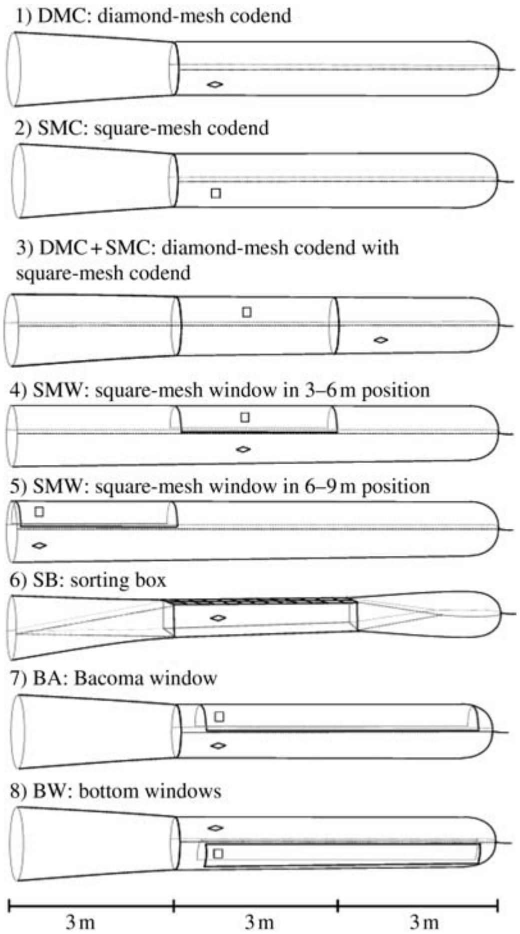

Figure 1. Various codends with SBs and windows tested (Tables 1 and 2).

(90 mm) and a hole cut posterior to the upper edge of the grid in the top panel (to allow *Nephrops* rejected by the grid to fall back into the codend; MG2: Figure 2, no. 4). Approximately 13 and 2% of cod <MLS and >MLS, respectively, passed through the grid. Very few cod passed through the hole in the bottom of the grid (<2%) or through the hole in the top panel (<1%). Approximately 19% of *Nephrops* above MLS passed through the hole in the bottom section of the grid, 55% passed through the rest of the bars and 5% fell back through the hole, giving a total of 20% that were lost.

Valentinsson and Ulmestrand (2008) investigated the potential of using an inclined separator panel (ISP: Figure 2, no. 7; Rihan and McDonnell, 2003) to separate cod from *Nephrops*. The results varied substantially between hauls and vessels, but indicated that the ISP displayed species-selective properties. However, the average loss of *Nephrops* (27%) was considered too high for acceptance by the industry.

Krag *et al*. (2009a, b) found in two experiments that 18 and 13%, respectively, of the cod enter the lower 25% part of a frame when inserted in the trawl extension (at a 50° angle). Moreover, bars helped to guide the cod upwards (Krag *et al*., 2009a). Following these principles, Madsen *et al*. (2008b) tested a 30-cm high sorting frame with two guiding bars (Figure 2, no. 6) and found that 88% of the marketable *Nephrops* and ~40% of the cod passed through the frame.

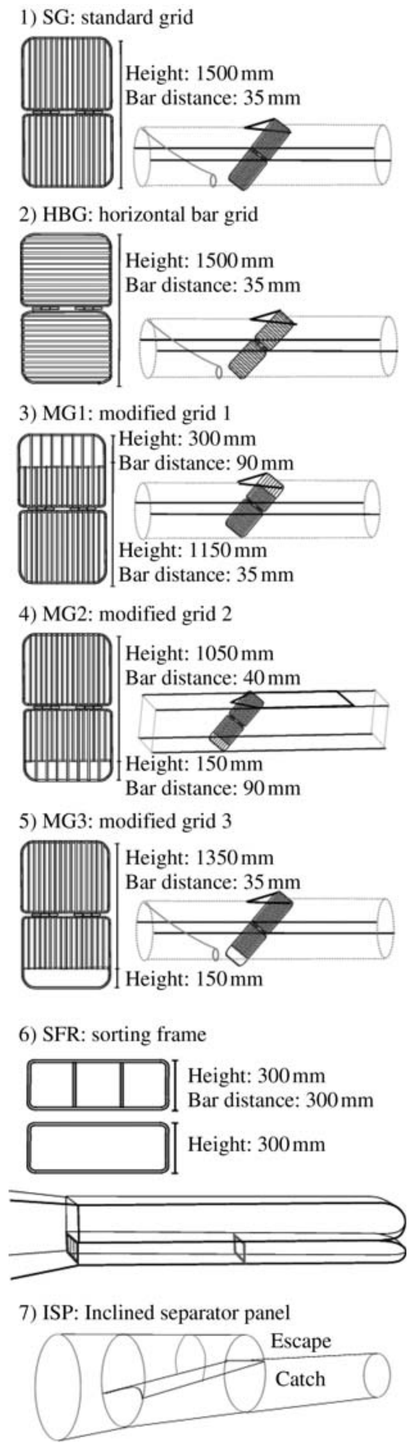

Figure 2. Various forms of sorting grids, separator panels, and frames tested (text, Tables 1 and 2).

Whole-trawl selectivity

Over the past decades, there has been a tendency in the Kattegat fishery to develop dual-purpose trawls for targeting both *Nephrops* and fish. In contrast, recent work has been aimed at developing trawls with increased catch rates of *Nephrops* and reduced catch rates of fish by reducing the distance between doors and using longer wings, lower trawl heights and large-mesh

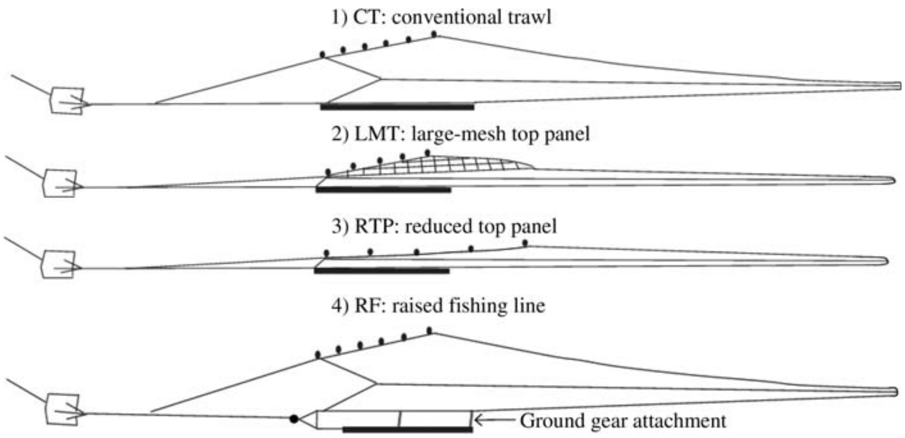

Figure 3. Conventional and modified trawls (text, Table 2).

top panels (LMT), although as yet it has not been technically possible to assess the effects (Madsen *et al.*, 2008b). Because doors and sweeps have no effect on the catchability of *Nephrops* (Main and Sangster, 1985; Thorsteinsson, 1986; Newland and Chapman, 1989), reducing the swept area by 50% might reduce cod catches by the same amount.

Experience with beam trawls in the North Sea, as well as trawls tested around the Faroe Islands and in the Baltic Sea (Thomsen, 1993; Madsen *et al.*, 2006; Mieske, 2008), has demonstrated that an LMT (Figure 3, no. 2) or a reduced top panel (RTP; Figure 3, no. 3) combined with a low headline height can help to reduce the cod catch in targeted flatfish fisheries. Madsen *et al.* (2006) tested an LMT with a low height (0.8–1.1 m) and 400 mm meshes in the upper panel in combination with a square-mesh section (SMS; Figure 1, no. 3). This trawl exhibited a large reduction in the catch of cod <40 cm (Table 2, no. 1), but a higher catch of large cod. It also caught more plaice. A recent experiment with a RTP yielded a reduction in larger cod (Table 2, no. 14), an increase in plaice and sole, and a reduction in *Nephrops* (Krag and Madsen, 2010). In contrast, Revill *et al.* (2006) did not detect any significant effect on cod when testing a trawl with a RTP in the North Sea.

Krag *et al.* (2010) tested a trawl with a raised (60 cm) fishing line (Figure 3, no. 4) in the Skagerrak and obtained a 65% reduction in the catch of cod (all sizes). The plaice catches were also reduced, whereas haddock and saithe catches were largely maintained. Because the commercial catches of the latter species are limited in the Kattegat, this design is not relevant to the fishery.

Legislation and experience with implementation

Legislation

Over the past 20 years, the minimum diamond-mesh size in codends used in the Kattegat has successively been increased from 60 to 70 mm in 1989 and further to 90 mm in 2005, unless an SG is used in combination with a 70-mm SMC (EC Council Reg. 27/2005). A 120-mm SMW (6–9 m position) inserted in a 90-mm codend was introduced in the legislation from 2005 (Krag *et al.*, 2008). Despite the regulatory measures taken by the European Commission for the recovery of the Kattegat cod (drastic cuts in TACs and number of days at sea, and the gear regulations), these have largely been unsuccessful so far (EC COM SEC 386/2008). Therefore, Sweden and Denmark made a bilateral agreement on complementary technical measures in December 2008, including the mandatory use of either a modified SB (named the SELTRA trawl) with a 300-mm window or an SG with a 70-mm SMC in the major spawning and nursery areas in combination with closed areas and seasons (Figure 4). These measures will be in effect for at least 3 years, after which a first evaluation will be done.

Figure 5 provides the estimated selection curves for various gears in relation to current and past legislation in the Kattegat, as well as in the North Sea (120 mm diamond mesh). Cod selectivity appears to have been improved only marginally by the mesh-size increases and the implementation of the 120-mm SMW and a substantial proportion of undersized cod (20–30 cm) will be retained by these gears.

Practical experience with implementation

When the 120-mm SMW was introduced, a problem experienced by fishers and netmakers was the elongation of the window after the net had been used for a while, which influenced trawl performance. To overcome this problem, netmakers developed methods for reinforcing the joins between the standard netting and the window. Having noted this, fishery inspectors consulted scientists and they verified that the performance of the window was not affected in a negative way. The SB implemented by legislation from 2009 has been modified from 120 (Madsen *et al.*, 2010a, b) to 100 open meshes in circumference (SELTRA trawl) to conform to EU legislation (EC Council Reg. 850/1998). The consequence of the reduced height might increase the escape of *Nephrops* through the window.

The use of the SG by Swedish fishers has gradually increased since its introduction in 2004. In 2009, *Nephrops* landings in the Skagerrak and Kattegat by vessels using the grid reached 50% of the total. The grid is now being used by most demersal trawlers at some time of the year (109 out of 137 vessels with grid permits in 2009). Its use has been promoted by incentives, such as an increased quota share, access to commercially important *Nephrops* areas that are closed to other trawls, and an unlimited number of fishing days, because of documented low cod catches [Council Reg. (EC) no. 43/2009]. Although its use has become widespread, problems are still being reported by the industry, particularly regarding blockage of the grid, safety issues related to on-board handling, and a loss of large *Nephrops*. Moreover, inspectors uncovered several cases of suspected circumvention of

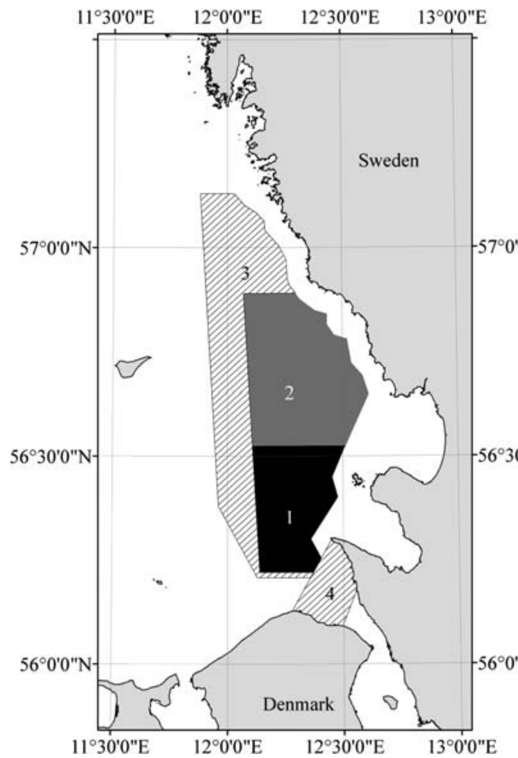

Figure 4. Map of closed areas in the Kattegat since 2009: (1) permanently closed for all fisheries; (2) permanently closed for fisheries targeting cod and closed for all fisheries during the first quarter; (3) seasonally closed (1 January–31 March) for fisheries targeting cod; and (4) seasonally closed (1 February–31 March) for fisheries targeting cod. Demersal trawls equipped with a SG, or a 300-mm SB, are allowed unless the closure applies to all fisheries.

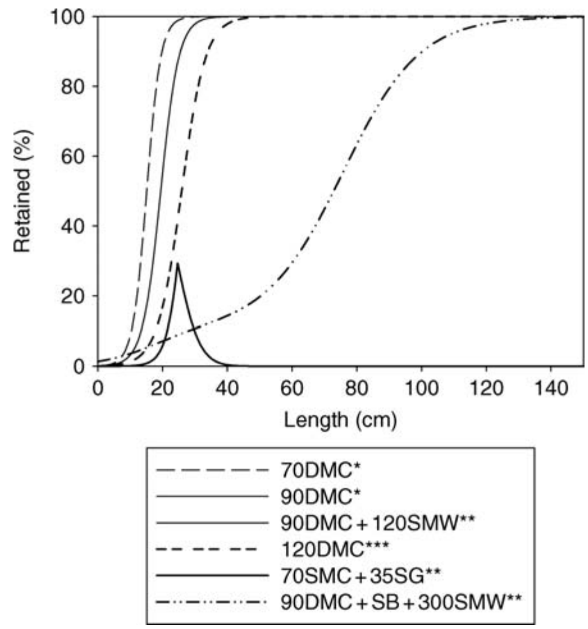

Figure 5. Cod selection curves for different gears according to minimum allowed mesh/bar size specified in previous (asterisk) or current (double-asterisks) legislation for the Kattegat and in current legislation for the North Sea (triple asterisks): 70DMC, 90DMC, and 120DMC refer to diamond-mesh codends (estimates based on the average for DMC codends in Table 1); 90DMC + 120SMW: a diamond-mesh codend with 120-mm square-mesh window in 6–9 m position that does not differ significantly from the 90DMC (Frandsen *et al.*, 2009); 70SMC + 35SG: square-mesh codend (Table 1, nos 10 and 11) and a 35-mm grid (Frandsen *et al.*, 2009); and 90DMC + SB + 300SMW: a diamond-mesh codend with a sorting box having a square-mesh window (Table 1, no. 12). All estimates are based on assuming a constant selection factor and a selection ratio.

the rules, mostly regarding the fastening of the grid in the extension piece and the choice of grid material. However, after consultations among inspectors, vessel owners, and scientists, most questions as to how to interpret the rather flexible wording of the legislation (Appendix 2 to Annex III of Council Reg. (EC) no. 43/2009) apparently have been resolved. Other issues raised after the introduction related to decreasing selectivity for *Nephrops* over time and poor selectivity for flatfish in the SMC.

Discussion

Table 3 summarizes the ability of the most relevant gear types to reduce the catch of cod, as well as their efficiency for *Nephrops* and flatfish. Because some estimates are based on extrapolations and assumptions, they should not be interpreted as absolute estimates, but rather as an indication of the general tendencies. The table clearly illustrates that if gear-related technical measures are used to retain a commercial fishery on the viable stocks, yet protecting cod as much as possible, the direction of development has to be changed from trying to optimize the current mixed fishery to developing directed fisheries towards specific target species. Therefore, more effort should be devoted to research into the effect of specific devices on target species, in combination with spatial and temporal closures. For instance, experiments focusing on devices tested in the economically important fishery targeting sole are few, because most experiments have been conducted in the directed *Nephrops* fishery outside the sole fishing season. The major challenge is to find solutions allowing fishers to maintain an economically viable fishery without catching cod.

A sorting grid that can be adjusted by changing the bar distance has the advantage of permanently blocking cod larger than a given size. This distance is also easy to control by fishery inspectors. Recent investigations indicated that the grid might be modified to reduce the loss of *Nephrops* at the cost of more cod being caught. Nevertheless, the reduction in cod catches appears to remain much higher than for most alternatives investigated so far. Testing other construction materials than aluminium (Loaec *et al.*, 2006) is also important, because this may help to improve working conditions and the safety of fishers. Continuing research on the SG is particularly addressing issues of *Nephrops* selectivity and discards of flatfish.

Development of the sorting-box concept has demonstrated that the selectivity of an SMW can be improved considerably, but the current design is not yet as selective as the SG. The SB avoids a major loss of *Nephrops*, but the loss of flatfish remains large. More tests are needed to optimize this concept.

Survival of cod escaping through codend meshes during towing is generally high (Soldal *et al.*, 1993; Suuronen *et al.*, 1996, 2005). Escape during hauling causes additional stress and physical damage; therefore, the mortality is expected to be higher (Madsen *et al.*, 2008a, b). Selective devices, such as sorting grids and windows, are more likely to facilitate escapement at depth than changes in mesh size or mesh configuration (Madsen *et al.*,

Table 3. Assessment of the average effect (for numbers) of different gear types in respect of catch reduction for cod (below and above MLS) and efficiency for catching *Nephrops* and flatfish (P, plaice; S, sole) above MLS using the 90DMC as the baseline.

	Cod (%)			Flatfish (%)		
Selective device	**<MLS**	**≥MLS**	***Nephrops* (%)**	**P**	**S**	**Comments**
90DMC: baseline	0[a]	0[a]	100[b]	100[c]	100[c]	Low selectivity of cod
120DMC	48[a]	3[a]	86[b]	79[c]	29[c]	Only catch of small cod reduced
70SMC	62[a]	1[a]	78[d]	100[d]	>100[c]	Only catch of small cod reduced
120SMC	99[a]	55[a]	24[d]	89[d]	34[c]	Only relevant when targeting plaice
90DMC + 120SMW	0[a]	0[a]	100[e]	100[e]	NA	No effect
90DMC + SG	60[b]	99[b]	70 or 100[f]	8 or 27[f]	NA	Loss of flatfish
90DMC + SFR	59[g]	62[g]	88[g]	47[g]	NA	More research needed
90DMC + 300SB	65[a]	82[a]	100[h]	11[h]	NA	Research on improving flatfish efficiency
90DMC + RTP	0[i]	41[i]	81[i]	>100[i]	>100[i]	Only catch of large cod reduced
90DMC + 50% reduced swept area	50[j]	50[j]	100[j]	50[j]	50[j]	Option worthwhile considering

SFR, sorting frame; for other abbreviations see Tables 1 and 2. MLS: cod = 30 cm, *Nephrops* = 40 mm carapace length, plaice = 27 cm, and sole = 24 cm. NA: not available; Use of selectivity parameters is based on assuming a constant selection factor and selection ratio and combined with population estimates for cod, *Nephrops* and plaice obtained from the control codend used by Frandsen *et al.* (2009) and sole from the Danish sole survey in Kattegat and Skagerrak using commercial vessels and a 55-mm mesh size (8509 ≥ MLS).

[a]Same selectivity parameters as used in Figure 5.

[b]Selectivity parameters from Frandsen *et al.* (2009).

[c]Mean selectivity parameters for beam trawls estimated from Fonteyne and M'Rabet (1992) assuming no difference in selectivity compared with otter board trawls.

[d]Mean selectivity parameters estimated from Frandsen *et al.* (2010).

[e]No statistical significant difference compared with 90DMC (Frandsen *et al.*, 2009).

[f]First value represents total number retained relative to that with 90DMC (Frandsen *et al.*, 2009) and the second value represents landings relative to gear test 1 in Valentinsson and Ulmestrand (2008; 100% where the difference was not significant).

[g]Madsen *et al.* (2008b) assuming that all individuals passing above the SFR escapes.

[h]No statistical significant difference in selectivity parameters of *Nephrops* and selectivity parameters used for plaice assuming that a reduction in window mesh size from 382 to 300 mm will not influence the selectivity (Madsen *et al.*, 2010b).

[i]Krag and Madsen (2010).

[j]Theoretical estimate (see text).

2008a, b; Grimaldo *et al.*, 2009). More attention should be paid to this aspect in future when evaluating gear performance.

Some experimental results presented are based on comparisons of test gear and conventional gear. The estimated retention in the test gear is therefore a measure of relative selectivity, not of absolute selectivity. Comparisons of individual catch-comparison experiments must be done carefully, because differences in the size structure of the populations fished may affect observed differences in catches. Similarly, the estimates of percentage catch reduction from selectivity experiments provided in Table 3 should also be interpreted with caution, because they also depend on the size structure of the population that encounters the experimental gear. Furthermore, several other variables, such as the catch weight, can influence the performance and selectivity of the tested gears (Wileman *et al.*, 1996; Madsen, 2007).

Experiences in the adjacent Baltic Sea have established that enhancing the motivation of fishers to adopt new fishing gear may greatly help the implementation of legislation (Tschernij *et al.*, 2004; Suuronen *et al.*, 2007). Rewards through unrestricted effort, extra quota, and exclusive access to valuable areas are examples of incentives that facilitate a faster shift in gear use and greater acceptance of selective gears (Krag *et al.*, 2008; Valentinsson and Ulmestrand, 2008; Catchpole and Gray, 2010).

To encourage fishers to participate in the development of selective fishing gear, a form of legislation should be considered that makes it easier to switch to test devices during certain periods without further commitments. When complicated devices are used during commercial operations, technical problems often arise that had not been encountered or addressed in scientific experiments. Such problems should be resolved quickly to find appropriate solutions, before they become prescribed. One proposal could be to issue temporal derogations to vessels willing to test a new gear, when catch composition and operational aspects are closely monitored by observers or documented by fishers themselves. In this particular case, where the goal is to protect cod, it is also very important to assess whether the gear regulations have had the expected effect and the stock has actually benefited from them.

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