Fisheries Research 170 (2015) 158–165

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Effect of the lifting panel on selectivity of a compulsory grid section (Sort-V) used by the demersal trawler fleet in the Barents Sea cod fishery

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ARTICLE INFO

Article history:
Received 4 November 2014
Received in revised form 26 March 2015
Accepted 29 May 2015
Handling Editor Dr. P. He
Available online 17 June 2015

Keywords:
Lifting panel
Sorting grid
Grid selection
Selectivity
Sort-V
Barents Sea

ABSTRACT

In this study we investigated the effect of the lifting panel on the selectivity of a compulsory grid section (Sort-V) used by the demersal trawler fleet in the Barents Sea cod fishery. Ideally, every fish passing through the grid section of the gear would make contact with the grid and be retained or released depending on size. However, in reality some fish may not be able to make contact with the grid or may actively avoid making contact with it. The purpose of the lifting panel is to make the grid contact probability, C_{grid} (the proportion of fish that contact the grid), as high as possible. We found that the presence of the lifting panel has a significant effect on C_{grid}, as the proportion of fish that came in contact with the grid was reduced from 82% when the lifting panel was present to 67% when the lifting panel was removed. For cod that were making contact with the grid, the mean selectivity parameters, $L50_{grid}$ and SR_{grid}, were 51.06 cm (50.26–51.87 cm) and 7.91 cm (7.33–8.48 cm), respectively, which is in agreement with values estimated for similar grid sections in previous studies. This study highlights the importance of the lifting panel for increasing the effectiveness of the grid section tested.

1. Introduction

In the Northeast Arctic (north from 62°N) gadoid fishery, 2-panel sorting grids sections became mandatory in 1997 as a measure to control size selectivity and to help rebuild the gadoid stocks (Larsen and Isaksen, 1993). Since this measure was introduced, all trawlers fishing in this area have been required to use a grid with a minimum bar spacing of 55 mm. The original Sort-X grid (three sections of steel grid) had handling problems due to its excessive weight and size, thus two more user-friendly grid designs (Sort-V (a single steel grid) and Flexigrid (a plastic and fibreglass grid)) were developed (Fig. 1). A description of each of these grid sections is found at Herrmann et al. (2013). Today, the industry mostly uses the latter two systems.

In recent years, the number of excessively large trawl catches has increased considerably. Large catches can result in reduced fish quality, especially in cases where the catch exceeds the production capacity of the vessel. Large catches also have increased risk of discards, gear damage, and safety problems. The main reasons for the increasing number of large catches are the current high stock biomass of Atlantic cod in the Barents Sea, and difficulties in controlling and limiting the catches in trawls with sorting grid sections. The reason for the latter is the limited sorting area and limited capacity of the sorting grids at high catch rates (>10 t h^{-1}), which leads to a progressive accumulation of fish in front of the grids. Fish also accumulate behind the grids without falling back into the codend until very late in the haul-back operation (Fig. 2). Both effects mean that the catch sensors mounted on the codend fail to give correct information about the catch size (ICES, 2014). More specific, the problems in the Sort-V grid are believed to be partly associated with reduced water flow through the grid section due to the presence of the grid and the diamond mesh lifting and guiding panels in the section. The lifting panel was designed to increase the grid contact probability, C_{grid} (the proportion of fish that contact the grid), while the guiding panel was designed to prohibit escaping fish from re-entering the trawl. In the mandatory Sort-V grid section these panels are made from 60 mm Euroline Premium PE netting (single Ø 3.0 mm twine).

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http://dx.doi.org/10.1016/j.fishres.2015.05.028
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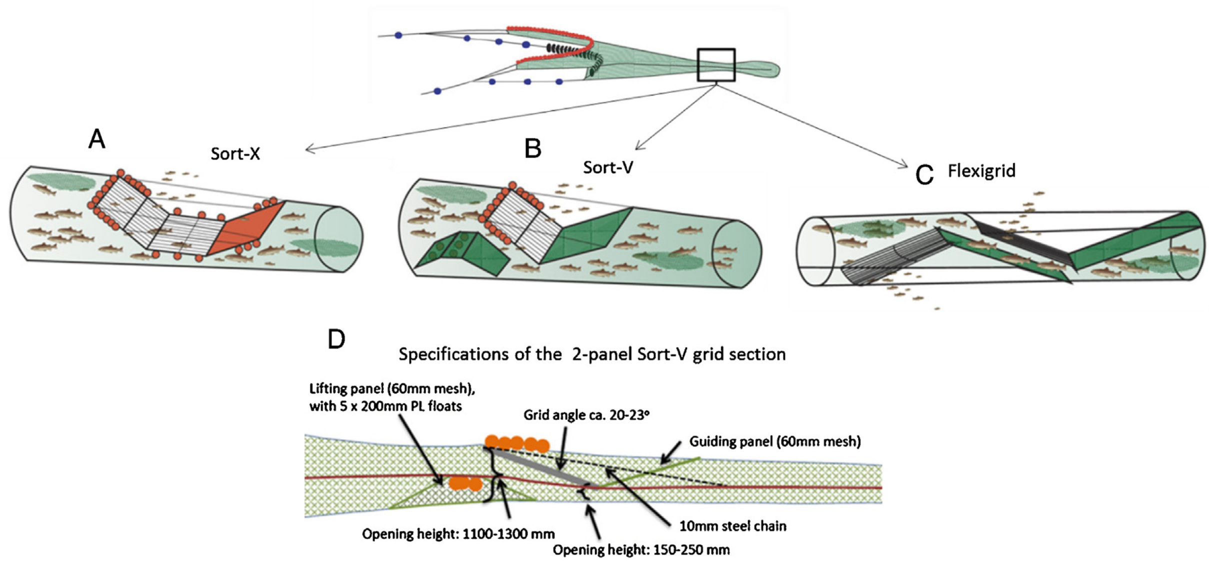

Fig. 1. Sorting grid sections that are mandatory in the Norwegian Sea (north of 62°N) and Barents Sea demersal fishery: (A) Sort-X, (B) Sort-V, and (C) Flexigrid. (D) Shows the specifications of a 2-panel Sort-V grid section.

Experiments with full-scale versions of Sort-V grid sections in the flume tank in Hirtshals (Denmark) revealed important geometry problems and also documented significant water flow reduction in the mandatory sorting grids (Gjøsund et al., 2013). The lifting panel was observed to be over-sized and to have an excessive amount of slack net material, which blocked almost the entire cross-section and grid surface. In addition, there was virtually no free opening below the sorting grid for fish to pass towards the codend (Fig. 3). These problems may affect the C_{grid} value by forcing fish to make contact with the grid, but they also imply reduced sorting capacity and reduced water flow. The flow measurements in the flume tank experiments showed that the velocity was reduced by more than 50–60% behind the grid compared to the velocity at the inlet of the section for the mandatory 2-panel Sort-V grid section. Flow conditions were slightly improved for a modified 4-panel Sort-V section, likely due to less slack netting, use of square mesh lifting and guiding panels and reduced influence of the boundary layer in the larger cross-section of a 4-panel section. When the lifting panel was removed, however, the flow conditions were significantly improved. Hence, better balance among grid contact, water flow, and sorting capacity is needed.

The aim of the present study was to assess the effect of the lifting panel on cod selectivity in order to determine if the lifting panel can be excluded from grid sections without significantly reducing the proportion of fish making physical contact with the grid. We directly compared the selectivity of a 4-panel sorting grid section (Sort-V) with and without the lifting panel under commercial conditions.

2. Materials and methods

2.1. Sea trials and data collection

Data collection was carried out onboard the commercial trawler “Ramoen” (66.7 m LOA, 5170 HP) from 28 October to 13 November 2013 in the Hopendjupet Basin (between 77°05′–77°15′N and

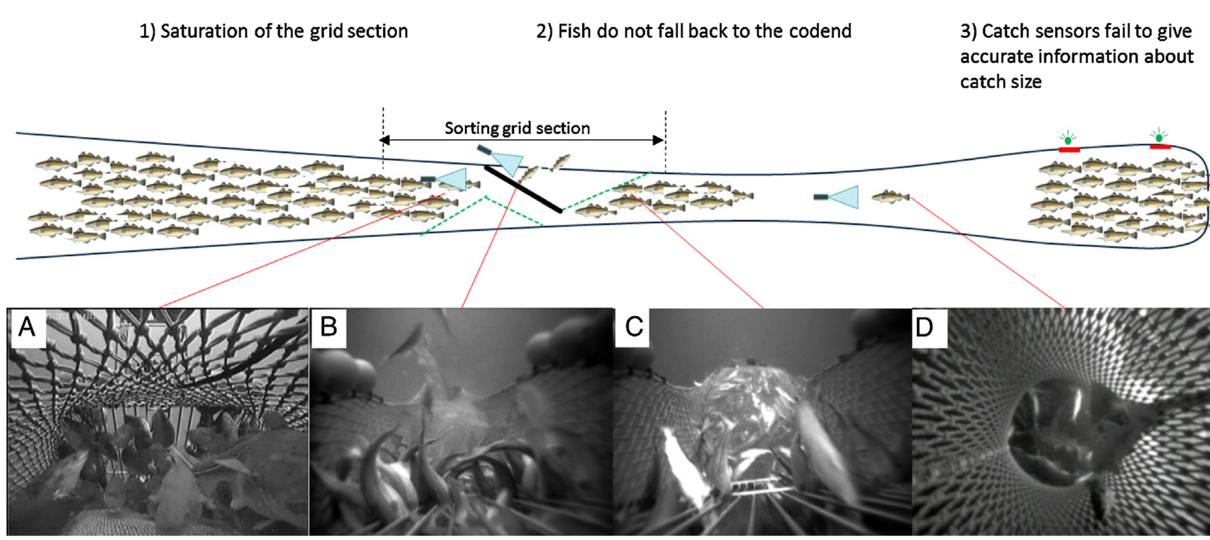

Fig. 2. Problems associated with current mandatory sorting grids during the fishing operation: (1) Saturation of the Sort-V grid section. Image (A) shows lots of fish swimming in front of the grid; image (B) shows lots of fish blocking the grid. (2) Fish do not fall back to the codend: Image (C) shows lots of fish swimming behind the guiding panel; image (D) shows few fish falling back to the rear most part of the codend. All images are from the tow process at 70 m depth in natural light.

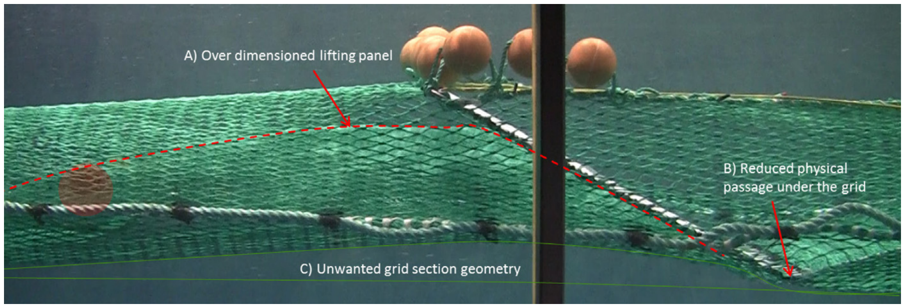

Fig. 3. Grid section (2-panel Sort-V) showing the over-dimensioned lifting panel that blocks the grid (A), the grid blocking the passage towards the codend (B), and the unwanted grid section's geometry as a result of using low density PE netting in the lower panel (C).

28°17′–30°45′E). The towing speed was 4 knops and the fishing depth varied between 180 and 227 m.

Data were collected using the alternate haul technique (Wileman et al., 1996). Two identical 2-panel SELSTAD-628 bottom trawls were used, each of them with a sorting grid section. The trawls were made from 155 mm (mesh opening) Euroline Premium polyethylene (PE) netting (single Ø 3.0 mm twine), had 628 meshes of circumference in the mouth, a 31.1 m long fishing line, and a 48.9 m long headline. The trawls were rigged with five sections of rockhopper gear made of 54 cm rubber discs and 20 cm spacers, attached 1–1 in the central section and 1–2 in the side sections; 100 m long sweeps (22 mm wire); and a pair of Scorpion Injector bottom trawl doors (9.5 m^2 and 4400 kg each). Transitional diamond mesh sections were made to connect the 2-panel trawl bellies to the 4-panel grid sections. They were made from 138 mm (mesh opening) Euroline Premium PE netting (single Ø 8.0 mm twine), and were 44.5 meshes long.

Two identical 4-panel grid sections, each with a 55 mm single grid (Sort-V), were attached to the aft section of the trawl bellies. These sections were made from 138 mm (mesh opening) Euroline Premium PE netting (single Ø 8.0 mm twine), were 44.5 meshes long, and had 104 meshes of circumference. One of the grid sections had a squared-mesh lifting panel that was made of 80 mm Euroline Premium PE netting (single Ø 3.0 mm twine). The other section did not have a lifting panel.

We used small-mesh grid covers (GCs) to assess the selectivity of the sorting grids. The GCs were made of 60 mm (mesh opening) Euroline Premium PE netting (single Ø 2.2 mm twine) and had a total length of approximately 23 m (Larsen and Isaksen, 1993). The entire GC was reinforced with double 155 mm (mesh opening) Euroline Premium PE netting (single Ø 4.0 mm twine). The installation of the GC was done following standard procedures described by Larsen and Isaksen (1993) and Wileman et al. (1996).

Two identical 2-panel diamond mesh codends were attached to the grid sections. These were made from 138 mm (mesh opening) Euroline Premium PE netting (double Ø 6.0 mm twine), were 200 meshes long, and had 96 meshes of circumference. Round straps (Ø 24 mm PE) were attached on the codend at intervals of 1.2 m. The codends (C) were blinded by attaching 14 m long inner nets (CC) constructed of 60 mm (mesh opening) Euroline Premium PE netting (single Ø 2.2 mm twine) (Fig. 4).

Between 600 and 1200 cod from the codend and a similar number from the GC were measured to the nearest cm and weighed. The rest of the cod in the catch were counted, the subsample fractions were calculated and later incorporated to the analysis.

Underwater video observations were made to monitor the correct operation of the GC, and obtain information of fish behaviour respect to the grid section. Since artificial light could affect fish behaviour, these hauls were excluded from the analysis. We used a Simrad Konsberg OE1324 enhanced SIT low light camera with a sensitivity of 2×10^{-4} lx and a 9 W halogen lamp connected to a self-contained recorder unit and battery package. The camera unit was fixed 2 m in front of the grid (facing backwards).

2.2. Modelling size selection for individual hauls

The fish that escaped through the grid were collected in the small-meshed GC. The fish that did not escape thought the grid were collected in the codend blinded with the CC. The experimental grid selection r_l was expressed as:

$$r_l = \frac{nCC_l \times qCC}{nCC_l \times qCC + nGC_l \times qGC} \tag{1}$$

where nGC_l is the number of fish of length l measured in the *GC* and nCC_l is the number of fish of length l collected in the codend with the *CC*. *qGC* and *qCC* are the proportions of the catch measured in the two compartments (subsampling factor), respectively.

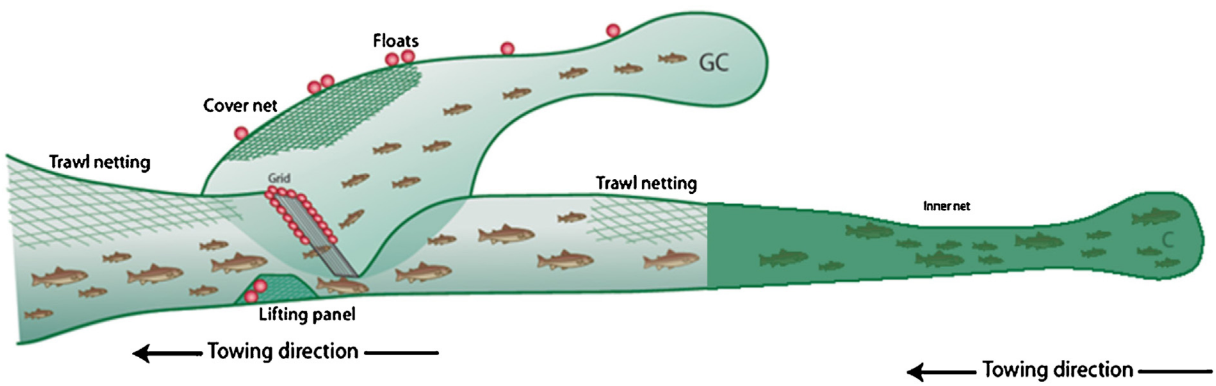

Fig. 4. Grid and codend setup: A grid cover (GC) collects the fish escaping through the grid, and the codend (C) is blinded with an inner net (CC).

The size selection $r(l, v)$ for the individual hauls was estimated by minimizing the negative log likelihood function (1) with respect to the parameter v as follows:

$$-\sum_l \left\{ nGC \times \ln\left(\frac{qCC \times r_a(l,v)}{qCC \times r_a(l,v) + qGC \times (1 - r_a(l,v))}\right) + nCC \times \ln\left(\frac{qGC \times (1 - r_a(l,v))}{qCC \times r(l,v) + qGC \times (1 - r(l,v))}\right)\right\} \quad (2)$$

This summation (Eq. (2)) was performed over the range of length classes, and a suitable model for size selection $r_a(l, v)$ then was chosen.

It is possible that not all cod were able to contact the grid and therefore had a length-dependent possibility for escape. Therefore, each individual haul was analysed using a model (Clogit) that explicitly accounts for C_{grid}:

$$\begin{aligned} r_a(l, \boldsymbol{v}) &= \text{Clogit}\left(l,\ \ L50_{grid},\ \ SR_{grid},\ \ C_{grid}\right) \equiv \\ &1.0 - C_{grid} \times \left(1.0 - \text{logit}\left(l,\ \ L50_{grid},\ \ SR_{grid}\right)\right) \end{aligned} \quad (3)$$

The value of C_{grid} ranges from $0 < C_{grid} < 1$. If $C_{grid} = 1$, every fish entering the grid area will contact the grid and will therefore have a real chance to escape. $L50$ is defined as the size at which a fish has 50% chance of being retained by the gear given that it entered the gear. SR is the difference between $L75$ and $L25$. Thus, $L50_{grid}$ and SR_{grid} are the selection parameters that express the size selection for the proportion of fish that come in contact with the grid.

For the present investigation, we needed a model such as Clogit that explicitly considers grid contact. The aim of the study was to study the effect of removing the lifting panel from the grid section, and the main purpose of the lifting panel is to direct fish towards the grid and improve the probability of contact (C_{grid}). Previous studies of similar grid sections used the Clogit model successfully (Sistiaga et al., 2010; Herrmann et al., 2013) to investigate size selection properties.

Since C_{grid} was expected to have a value close to one of the boundaries (0 or 1) in some of the individual hauls application of the standard analytical method for estimating the parameter covariance matrix for individual hauls (denoted the R-matrix according to Fryer (1991)) based on the calculation of the Fisher Information Matrix (Wileman et al., 1996) would not be valid (Collins and Lanza, 2010). Therefore, we estimated the 3 × 3 covariance matrix for $L50_{grid}$, SR_{grid}, and C_{grid} for each individual haul by applying the bootstrap procedure introduced for such situations by Herrmann et al. (2013). Thus, estimation of 95% confidence limits for $L50_{grid}$, SR_{grid}, and C_{grid} was also based on this bootstrap method using the "Efron 95 percentile" (Efron, 1982; Chernick, 2007). To estimate the selectivity of each individual haul, we carried out a total of 10,000 bootstrap repetitions.

2.3. Modelling the effect of the lifting panel on size selection

Based on Eq. (3), the size selection in the individual hauls is described by three parameters: $L50_{grid}$, SR_{grid}, and C_{grid}. The size selection process is expected to be affected by two factors: the presence or absence of the lifting panel in the grid section and between-haul variation (Fryer, 1991). We were interested in determining whether the presence of the lifting panel would affect the C_{grid} parameter and consequently the selection process. Thus, in the analysis we included the presence or absence of the lifting panel as a fixed effect and also accounted for between-haul variation by applying the method developed by Fryer (1991). Other factors that may affect selectivity (i.e., catch rate, catch size, etc.) were considered as random effects that vary randomly, and they were uncontrolled among the hauls carried out with the two setups. In addition to values for the three selection parameters from individual hauls, the method requires the 3 × 3 covariance matrix for the selection parameters from the individual hauls as input.

Because the $L50_{grid}$ and SR_{grid} are the selection parameters for the fish that actually contact the grid and because the grid used in both setups was the same, we expected that these two parameters would not be affected by the presence or absence of the lifting panel (lp). In contrast, we expected that the presence or absence of the lifting panel could affect C_{grid}. However, to test for a potential effect of the lifting panel on $L50_{grid}$ and SR_{grid}, we used the following model as a starting point for the analysis:

$$\begin{aligned} L50_{grid}(lp) &= p01 + p11 \times lp \\ SR_{grid}(lp) &= p02 + p12 \times lp \\ C_{grid}(lp) &= p03 + p13 \times lp \end{aligned} \quad (4)$$

$p01$, $p02$, and $p03$ represent the intercepts in model (4). lp is either 0.0 (for the hauls without the lifting panel) or 1.0 (for the hauls with the lifting panel). Thus, $p11$, $p12$, and $p13$ model the effect of the lifting panel on the selection parameters. In addition to model (4), we also considered all of the simpler models that can be derived by eliminating either one or more of the terms at a time following a backward elimination (until all the parameters in the specific model were found to be significant).

The entire analysis was performed using the software SELNET (Sistiaga et al., 2010; Wienbeck et al., 2011; Herrmann et al., 2012). Further information about how to apply SELNET for the type of analysis described in this section can be found in Herrmann et al. (2013).

3. Results

3.1. Catch data

A total of 31 hauls were carried out during the sea trials, 15 with the lifting panel mounted in the grid section and 16 hauls without the lifting panel. Catch rates were relatively high, with rates greater than 1000 kg h^{-1} in 28 out of the 31 hauls. The highest catch rate recorded was 9658 kg h^{-1}. Because of the large catches obtained during the cruise (average total catch = 9392 kg), the fish populations in the codend and grid cover were subsampled for most of the hauls. The subsampling factors during the cruise varied between 0.065 and 1.000 for the codend and 0.122 and 1.000 for the grid cover (Table 1).

Underwater video observations were performed in six hauls (three with the lifting panel and three without the lifting panel). The videos showed that most fish could not keep swimming in front or behind the sorting grid in any of the grid sections (with or without lifting panel) and that small fish were rapidly sorted out of the trawl while large fish passed under the grid towards the codend. Underwater video observations also showed a large number of fish swimming in the anterior part of the codend and not falling back until very late in the haul-back process. Late entrance of fish into the aft section of the codend meant that the catch sensors did not activate, which often led to unexpected large catches.

3.2. Model fit and selectivity estimates

Inspection of the p-values and the deviance values versus the degrees of freedom (DOF) indicated that the *Clogit* model was able to describe the data sufficiently well for all individual hauls. Only in 1 out of the 31 hauls was $p < 0.05$ (Haul nr. 2). A more detailed analysis of this haul showed that the low p-value obtained was a consequence of over-dispersion of the data. That the experimental data were well modelled based on a model with a length-independent value for C_{grid} was further supported by the

Table 1
Haul data summary: *n* fish is the number of fish measured in each compartment, and sampling is the sampling ratio.

Haul nr.	Date	Position		Lifting panel	Tow time (min)	Total catch (kg)	Catch rate	Codend		Grid cover	
							($kg\,h^{-1}$)	*n* Fish measured	Sampling	*n* Fish measured	Sampling
1	30-10-13	77°04′N	28°54′E	Yes	159	2191	827	489	1.000	149	1.000
2	31-10-13	76°13′N	25°27′E	No	90	1335	890	557	0.758	484	1.000
3	31-10-13	75°45′N	23°59′E	No	113	3261	1732	652	0.422	361	0.597
4	31-10-13	76°13′N	19°57′E	Yes	200	9690	2907	577	0.287	419	1.000
5	31-10-13	76°12′N	19°36′E	Yes	246	8722	2127	470	0.218	379	0.443
6	1-11-13	76°13′N	19°39′E	No	249	9047	2180	542	0.234	841	1.000
7	1-11-13	76°16′N	19°39′E	No	252	7937	1890	535	0.260	374	0.448
8	1-11-13	76°14′N	20°01′E	Yes	274	7477	1637	421	0.245	881	1.000
9	1-11-13	76°18′N	19°49′E	Yes	278	4481	967	407	0.534	233	1.000
10	2-11-13	76°41′N	23°01′E	No	265	6982	1581	498	0.221	606	0.657
11	2-11-13	76°43′N	22°53′E	No	260	7514	1734	688	0.481	680	0.408
12	2-11-13	76°44′N	23°02′E	Yes	265	7433	1683	729	0.193	480	0.136
13	2-11-13	77°06′N	27°47′E	Yes	108	7192	3996	543	0.170	413	0.750
14	3-11-13	77°11′N	28°06′E	No	107	17,224	9658	767	0.121	442	0.428
15	3-11-13	77°15′N	28°11′E	No	133	5183	2338	469	0.179	596	1.000
16	3-11-13	77°06′N	28°13′E	Yes	181	10,963	3634	634	0.205	316	0.345
17	3-11-13	70°00′N	28°30′E	Yes	229	7724	2024	522	0.158	480	0.424
18	3-11-13	77°10′N	28°21′E	No	245	14,681	3595	490	0.084	552	0.384
19	3-11-13	77°17′N	28°20′E	No	250	9944	2387	680	0.134	436	0.232
20	4-11-13	77°12′N	28°24′E	Yes	210	6780	1937	579	0.174	770	0.961
21	4-11-13	76°49′N	28°41′E	Yes	285	10,407	2191	568	0.172	408	0.613
22	4-11-13	76°36′N	29°18′E	No	248	7046	1705	502	0.160	574	0.614
23	4-11-13	76°51′N	28°36′E	No	257	13,150	3070	745	0.108	449	0.122
24	5-11-13	76°59′N	28°24′E	Yes	277	9726	2107	745	0.148	718	0.299
25	5-11-13	77°01′N	28°26′E	Yes	249	10,995	2649	521	0.102	597	0.234
26	5-11-13	77°08′N	28°15′E	No	192	16,518	5162	691	0.094	390	0.337
27	5-11-13	76°16′N	28°11′E	No	147	18,969	7742	537	0.065	531	0.391
28	5-11-13	77°18′N	28°11′E	Yes	132	16,250	7386	495	0.068	441	0.225
29	6-11-13	77°12′N	28°17′E	Yes	113	9578	5086	552	0.152	796	0.623
30	6-11-13	77°15′N	28°21′E	No	178	13,013	4386	429	0.074	481	0.210
31	6-11-13	77°18′N	26°16′E	No	262	9729	2228	632	0.139	632	0.403

Table 2
Results from analysis of individual hauls. Values were estimated using the Clogit model; the values in brackets are 95% confidence limits.

Haul	lp	$L50_{grid}$ (cm)	SR_{grid} (cm)	C_{grid}	p-Value	Deviance	DOF
1	1.0	50.47 (47.34–53.33)	8.32 (5.03–10.73)	0.93 (0.84–1.00)	1.00	32.86	77
2	0.0	48.06 (44.33–50.57)	14.33 (11.56–17.99)	0.72 (0.63–0.86)	0.03	93.17	63
3	0.0	53.89 (52.44–55.18)	5.37 (3.80–7.22)	0.42 (0.38–0.46)	0.99	36.50	59
4	1.0	53.08 (50.57–55.48)	7.12 (4.32–9.92)	0.88 (0.83–0.95)	0.96	52.56	72
5	1.0	50.34 (47.23–53.46)	9.76 (6.97–12.55)	0.91 (0.83–0.99)	0.93	56.10	73
6	0.0	49.10 (45.15–53.04)	8.77 (4.61–12.93)	0.71 (0.55–0.86)	1.00	41.65	78
7	0.0	49.05 (44.98–53.11)	9.94 (4.73–15.15)	0.72 (0.59–0.85)	1.00	39.08	73
8	1.0	50.10 (48.05–52.15)	8.22 (5.97–10.47)	0.80 (0.73–0.88)	1.00	35.19	74
9	1.0	48.57 (42.43–54.70)	8.95 (3.26–14.65)	0.75 (0.59–0.89)	0.98	54.94	78
10	0.0	53.50 (50.72–56.28)	9.25 (5.50–12.99)	0.47 (0.41–0.58)	1.00	32.83	65
11	0.0	52.45 (50.24–54.17)	11.98 (8.95–15.63)	0.76 (0.70–0.86)	0.99	35.28	58
12	1.0	55.85 (53.75–57.59)	9.95 (6.21–14.37)	0.62 (0.56–0.70)	0.49	54.57	55
13	1.0	49.84 (45.96–51.35)	6.22 (5.14–8.93)	0.68 (0.58–0.99)	0.87	49.70	62
14	0.0	50.62 (46.05–52.27)	7.82 (6.46–11.00)	0.66 (0.57–0.92)	0.86	49.19	61
15	0.0	50.92 (47.99–52.71)	7.05 (5.47–9.36)	0.62 (0.52–0.80)	1.00	32.32	63
16	1.0	53.89 (51.49–55.75)	6.84 (4.94–9.08)	0.77 (0.67–0.91)	1.00	33.53	70
17	1.0	49.82 (48.78–50.92)	7.85 (6.81–9.28)	1.00 (0.97–1.00)	1.00	29.60	64
18	0.0	49.82 (47.90–51.69)	8.73 (7.39–10.65)	0.91 (0.79–0.99)	0.58	61.19	64
19	0.0	51.05 (49.16–52.35)	6.96 (5.46–9.14)	0.63 (0.57–0.74)	1.00	29.76	63
20	1.0	48.70 (45.71–50.15)	7.57 (6.36–9.86)	0.68 (0.59–0.87)	1.00	25.52	61
21	1.0	51.18 (48.95–52.89)	6.64 (5.10–8.99)	0.92 (0.84–0.99)	0.97	49.27	70
22	0.0	49.56 (46.09–51.14)	9.06 (8.01–12.37)	0.86 (0.77–0.99)	0.96	46.11	65
23	0.0	52.72 (50.96–54.07)	7.80 (5.79–10.06)	0.68 (0.62–0.77)	0.92	49.59	65
24	1.0	52.48 (50.00–53.61)	6.31 (4.79–9.34)	0.65 (0.60–0.79)	0.94	48.05	65
25	1.0	52.12 (49.79–53.44)	7.41 (5.66–10.17)	0.80 (0.72–0.96)	1.00	38.53	64
26	0.0	46.74 (42.97–48.78)	8.72 (7.20–11.28)	0.73 (0.61–0.99)	1.00	37.41	63
27	0.0	50.30 (46.06–52.51)	7.70 (6.21–10.73)	0.71 (0.59–0.99)	0.73	53.77	61
28	1.0	51.85 (49.71–53.53)	7.59 (5.79–9.52)	0.74 (0.66–0.86)	1.00	32.71	59
29	1.0	51.92 (48.10–53.28)	6.88 (5.42–10.67)	0.81 (0.74–0.99)	0.92	46.46	61
30	0.0	51.40 (46.77–53.47)	7.99 (6.41–11.96)	0.78 (0.71–0.99)	0.70	53.73	60
31	0.0	46.29 (43.90–47.86)	10.80 (9.71–12.77)	0.91 (0.79–1.00)	0.80	51.58	61

estimated values for the grid contact likelihood (C_{grid}) for individual hauls. For several hauls, C_{grid} was considerably less than 1.0 (Table 2).

The $L50_{grid}$ and SR_{grid} values estimated for the hauls conducted with and without the lifting panel were similar, but the estimated C_{grid} values generally were slightly lower for the hauls without the lifting panel compared to those with the panel (Table 2). For several hauls, C_{grid} was significantly less than 1.0, which demonstrates the importance of analyzing the data with a model that explicitly considers grid contact.

3.3. Mean selectivity parameters and effect of the lifting panel

The mean $L50_{grid}$ and SR_{grid} values for the cod actually making contact with the grid were 51.06 cm (50.26–51.87 cm) and 7.91 cm (7.33–8.48 cm), respectively. The parameter "*lp* (lifting panel)", which was included as a fixed effect in the model, had a significant effect on C_{grid} ($p < 0.001$), whereas it was non-significant for the mean $L50_{grid}$ and SR_{grid} values. Thus, as expected, the final model had the following form:

$$L50_{grid}(lp) = p01$$
$$SR_{grid}(lp) = p02 \tag{5}$$
$$C_{grid}(lp) = p03 + p11 \times lp$$

Table 3 summaries the details for model (5).

The individual curves for the hauls conducted with and without the lifting were described well by the mean curve estimated for each of the cases (Fig. 5A and B). From the values in Table 3 are the following observations made. When the lifting panel was present, the mean C_{grid} value was 0.819 (0.758–0.881); when the lifting panel was not present, the mean value was 0.665 (0.605–0.726). Thus, the presence of the lifting panel increased the grid contact probability by 23% (CI: 11 to 38%).

The mean selection curve for the grid section without the lifting panel hits the y-axis at around 0.33, which means that one-third of the fish entering the section never actually contact the grid. In contrast, the mean curve for the grid with the lifting panel hits the y-axis at around 0.18, meaning that 18% of the fish don't come in contact with the grid. Thus, when the lifting panel is not present, the number of fish that do not contact the grid is increased by 45% (Fig. 5C).

4. Discussion

The results showed that the presence of the lifting panel had a significant effect on C_{grid} and therefore on the opportunity for fish to be sorted out. The proportion of fish that came in contact with the grid was reduced from 82% ($C_{grid} = 0.82$) when the lifting panel was present to 67% ($C_{grid} = 0.67$) when the lifting panel was removed. This means that the portion of fish that do not come in contact with the grid is almost doubled when the lifting panel is absent. Hence the lifting panel has a significant positive effect on the selectivity performance of a Sort-V grid section. Because the lifting panel has a significant negative effect on the water flow through the Sort-V grid section designs (Gjøsund et al., 2013), further work should focus on either improving the lifting panel design or replacing it with another kind of device, such as stimulator devices (Herrmann et al., 2014), that can achieve good grid contact probability.

In the present study, the mean $L50_{grid}$ and SR_{grid} values estimated for the 4-panel Sort-V grid section were in line with previous results for a similar 2-panel grid section (Sistiaga et al., 2010). The mean C_{grid} estimate for the 4-panel Sort-V section with the lifting panel (0.819; 0.758–0.881) also was consistent with values obtained by Sistiaga et al. (2010) for the two earlier experiments with 2-panel Sort-V sections (0.759; 0.647–0.858 and 0.846; 0.733–0.959). These results illustrate that the selectivity properties of the grid itself for the cod that actually make contact with it are stable.

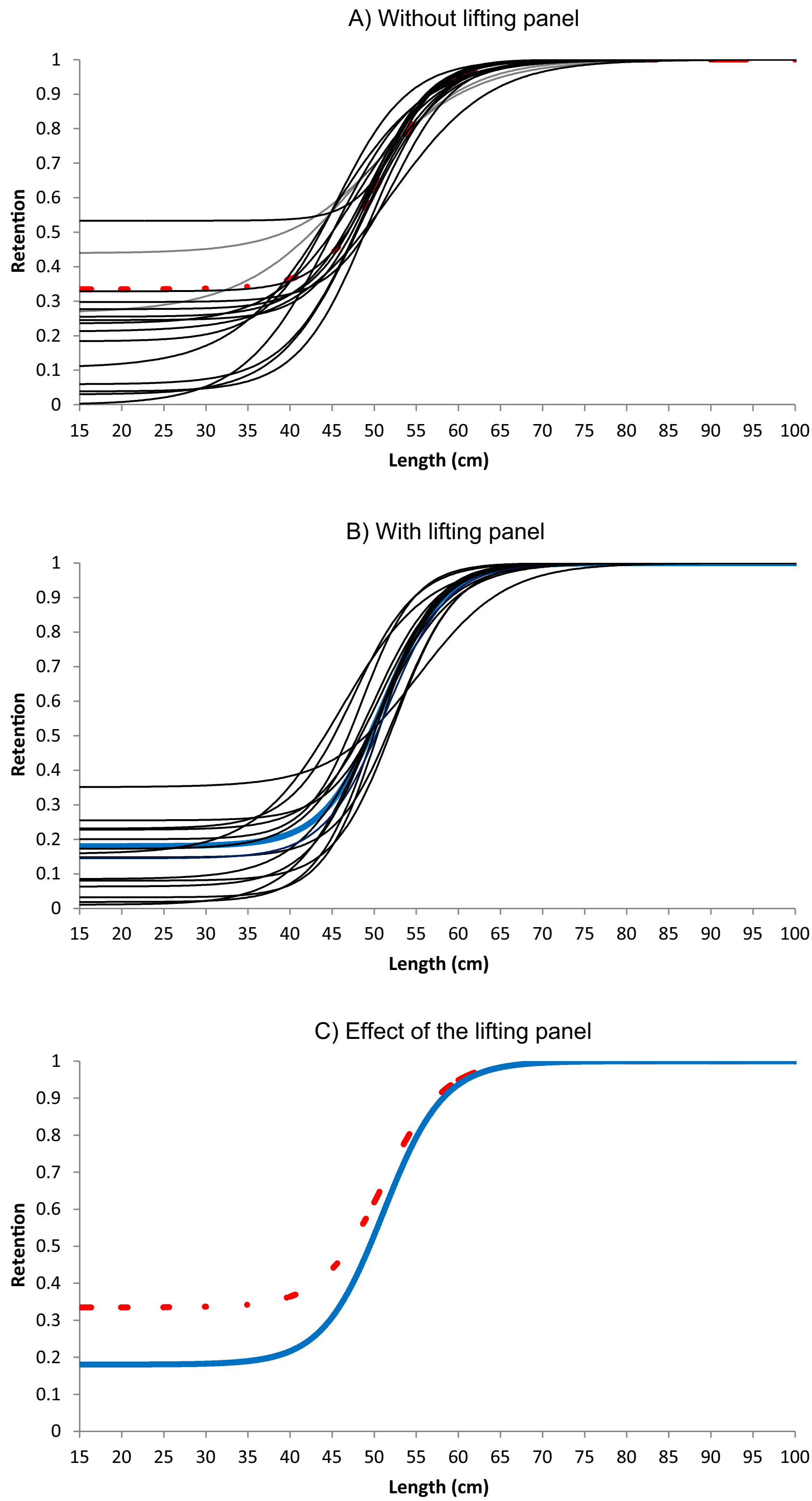

Fig. 5. Panels (A) and (B) show the selection curves estimated for all individual hauls and the mean selection curve (thick line) without and with the lifting panel, respectively. Panel (C) illustrates the effect of the lifting panel on the estimated mean selection curve: The solid line represents the curve for the setup with the lifting panel and the dashed line represents the curve for the setup without the lifting panel.

In contrast to typical observations of traditional 2-panel sorting grid sections, fish did not accumulate in front of any of the 4-panel grid sections (with or without lifting a panel) tested in these trials. Small fish were rapidly sorted out of the trawl, whereas large fish easily passed below the grid towards the codend. This suggests that the new 4-panel grid section together with the modified lifting panel (made of 80 mm squared meshes instead of 60 mm diamond meshes) provides improved flow conditions compared to the traditional 2-panel section with a standard lifting panel (as found in flume tank experiments). Underwater video observations also showed that fish did not accumulate just behind the grid. However, the catch sensor still failed to give correct information about

Table 3
Details for the model (5) (consult Fryer, 1991 for details about this type of modelling).

	Parameter	Multiplier	Value	SE	95% CI	*p*-Value
$L50_{grid}$	*p*01	None	51.0639	0.4029	50.2633–51.8644	8.86E – 97
SR_{grid}	*p*02	None	7.9054	0.2895	7.3301–8.4807	3.12E – 43
C_{grid}	*p*03	None	0.6651	0.0305	0.6046–0.7257	3.86E – 36
	*p*13	*lp*	0.1544	0.0367	0.0814–0.2273	0.0000662
Between-haul variation						
D_{11}	3.5929		D_{12}	−0.8714	D_{13}	−0.1313
D_{22}	1.2384		D_{23}	0.0788	D_{33}	0.0156

the catch size, suggesting that fish accumulate somewhere further downstream from the grid before falling back into the codend. This indicates that the grid section design and flow conditions should be improved further to ensure that fish fall directly back into the codend.

In March 2015, the use of the 4-panel Sort-V grid section was legalized by the Norwegian management authorities as an alternative selection system for the in the Barents Sea demersal trawl fishery.

Acknowledgements

We would like to thank the crew of the trawler “Ramoen”, Jóan Karl Joensen from the University of Tromsø, and Sarah Pötter and Dagfinn Lilleng from the Norwegian Directorate of Fisheries for their help and support during the sea trials. Thanks also are extended to the Norwegian Seafood Research Fund (FHF) and the Norwegian Directorate of Fisheries for financial support to conduct the experiment at sea. This work was conducted as part of the research project “Development of catch control devices for trawls” funded by the Research Council of Norway through the program HAVKYST (project number 216515/E40).

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