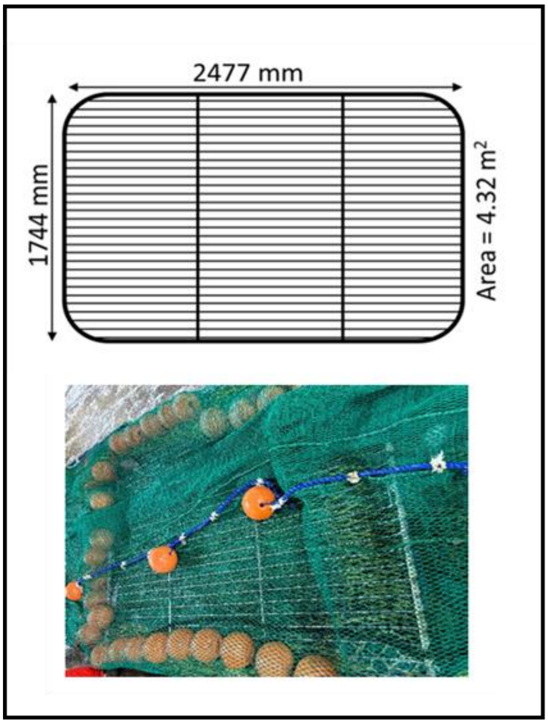
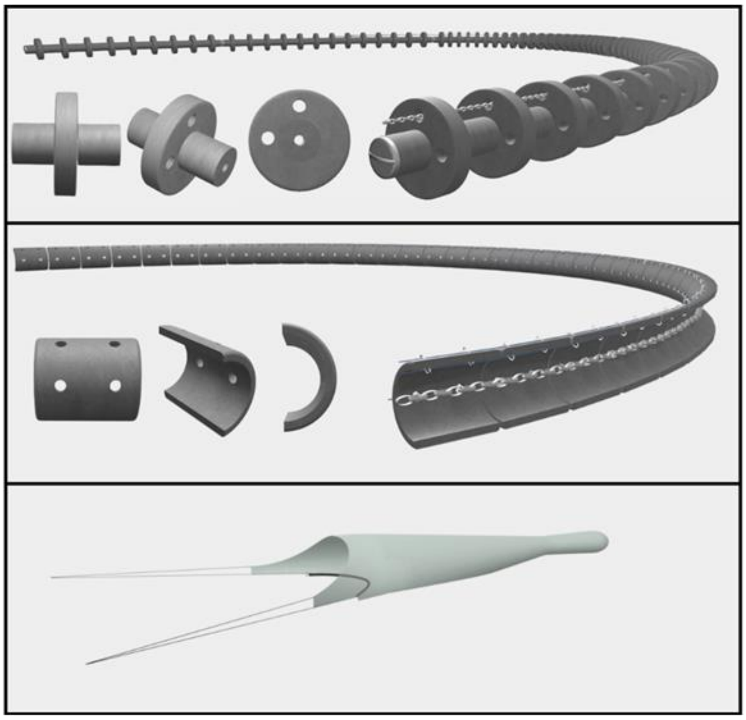
Benign and efficient whitefish trawling (FHF 901754)





Commercial tests with an upscaled sorting grid in a pelagic trawl and a Semi-Circular Spreading Gear in a demersal trawl for gadoids onboard M/Tr "Hermes"

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Summary

For decades the focus in fishing gear technology has been on selectivity. This has led to important contributions like the development of selective sorting grids and codends. However, other important focus areas have emerged in the last decade, i.e., the environmental impact of demersal trawling, and especially its impact on the seabed. A reduction in seabed impact can be achieved by either lifting the trawl from the seabed, i.e., towing pelagic, changing gear components to reduce seabed impact from demersal trawls, or by increasing catch efficiency so that trawling time at the seabed is reduced.

The aim of the present trials was twofold: i) to test whether an upscaled sorting grid can provide good size selectivity in a pelagic trawl targeting gadoids, and ii) to investigate whether a Semi-Circular Spreading Gear (SCSG) results on at least as good catch efficiency for gadoid species as a similar-sized rockhopper (RH) ground gear. Thus, the trials, which were conducted onboard a commercial trawler, were divided into two parts. During the first part of the trials, the performance of an upscaled sorting grid was tested in a pelagic trawl. During the second part of the trials the catch efficiency of a RH gear and a SCSG gear were compared using a twin bottom trawl configuration with both size selective and blinded trawls.

The results from the upscaled sorting grid in the pelagic trawl demonstrated that the grid released cod, haddock and redfish both below and above their minimum size (MS). These results did not include codend size selectivity. When including the selectivity from the codend, meshes the results show that most of the cod and haddock below MS was released. For redfish this result was less clear. However, for all three species significant amounts of fish above their MS's were also released. The results showed that the grid in combination with the selective codend would not violate current by-catch limits in the fishery.

The results from the second part of the study showed that using selective trawls, the trawl equipped with the SCSG captured on average 25.44% more cod, 32.04% more haddock and 64.34% more redfish than the trawl equipped with the RH gear. With blinded trawls, these differences changed to 41.35%, 65.76% and 44.23% for cod, haddock and redfish, respectively. Despite the significant increase in catch efficiency observed for the trawl equipped with the SCSG, it also caught significantly more undersized fish than the trawl equipped with the RH gear. This increase illustrates the importance of size selective devices, especially if the use of the SCSG is widely adopted by industry.

Sammendrag

I flere tiår har fokuset innen fiskeredskapsteknologi vært på selektivitet. Dette har ført til viktige bidrag som utviklingen av seleksjonsrister og selektive trålposer. Det siste tiåret har det imidlertid fokuset skiftet mer og mer over på de miljømessige konsekvensene fra bunntråling, og da spesielt dens påvirkning på havbunnen. En reduksjon i påvirkningen på havbunnen kan oppnås ved enten å løfte trålen fra havbunnen, dvs. taue pelagisk, eller endre ulike komponenter for å redusere påvirkningen på havbunnen, eller ved å øke fangsteffektiviteten slik at tauetiden på havbunnen reduseres.

Målet med forsøkene i denne studien er todelt: i) teste om en oppskalert sorteringsrist kan gi god nok størrelsesseleksjon i en pelagisk trål rettet mot torsk, hyse og uer, og ii) å undersøke om trålgiret Semi-Circular Spreading Gear (SCSG) gir minst like god fangsteffektivitet for som et standard rockhopper gir (RH). Forsøkene ble gjennomført om bord på en kommersiell tråler. I den første delen av forsøkene ble seleksjonsevnen til en oppskalert sorteringsrist testet i en flytetrål. I den andre delen av forsøkene ble fangsteffektiviteten til et rockhopper gir og et semisirkel gir sammenlignet ved bruk av dobbeltrål, både i et kommersielt oppsett (med seleksjonsrist og sekk), samt blindet (uten rist og med småmasket innernett i sekken).

Resultatene fra forsøkene med den oppskalerte sorteringsristen i flytetrålen viste at risten selekterte ut torsk, hyse og uer både under og over minsteminstemål. Disse resultatene inkluderte ikke seleksjon fra trålposen. Når selektiviteten fra trålposen inkluderes, viste resultatene at mesteparten av torsk, hyse og uer under minstemål ble selektert ut. Imidlertid ble også betydelige mengder fisk over minstemål sluppet ut for alle tre artene. Resultatene viste at sorteringsristen i kombinasjon med den selektive trålposen ikke brøt med gjeldende bifangstgrenser i fiskeriet.

Resultatene fra den andre delen av studien viste at bunntrålen (med sorteringsrist og sekk) utstyrt med SCSG fanget i gjennomsnitt 25,44 % mer torsk, 32,04 % mer hyse og 64,34 % mer uer enn trålen utstyrt med rockhoppergiret. For tråloppsettet uten rist og med småmasket innernett i sekken endret disse forskjellene seg til 41,35 %, 65,76 % og 44,23 % for henholdsvis torsk, hyse og uer. Til tross for den betydelige økningen i fangsteffektivitet som ble observert for trålen utstyrt med SCSG, fanget den også betydelig mer undermålsfisk enn trålen utstyrt med rockhoppergiret. Denne økningen illustrerer viktigheten av størrelsesselektive innretninger, spesielt hvis SCSG blir tatt i bruk av trålflåten.

Background

For decades the focus in fishing technology research has been on selectivity. This has led to important contributions like the development of selective sorting grids and codends. However, lately other important focus areas have emerged, i.e., the environmental impact of demersal trawling, and especially, its impact on the seabed (Kaiser et al., 2016; McConnaughey et al., 2020; Mazor et al., 2021). This is because bottom trawling has been widely criticized for its negative physical and biological impact on the seabed (Collie et al., 2000; Hiddink et al., 2017; Sala et al., 2021). Reduction in the seabed impact of bottom trawls can be achieved in different ways including towing pelagic by lifting the trawl and its associated components from the seabed, changing gear components to reduce seabed impact from demersal trawls, or increasing catch efficiency so trawl time is reduced. The text and the results presented below are the basis for two manuscripts that will shortly be submitted to scientific journals and are part of the efforts to reduce the seabed impact of bottom trawls.

Pelagic trawl targeting gadoids

In the 1960- and -70's a significant amount of the landings of cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and saithe (*Pollachius virens*) in the Barents Sea were caught using pelagic trawls. However, the pelagic trawl fishery for these species suffered from excessive large catches of target-size fish and juvenile fish. This led to the management authorities banning pelagic trawling for gadoid species north of 64^o N in 1979 (Jørgensen et al.,2011). This ban has persisted, except for redfish (*Sebastes mentella*), which can be targeted in certain areas of the Barents Sea using pelagic trawls. Since the ban on pelagic trawls, fish stock population dynamics as well as the available gear technology have changed substantially. In the last three decades, fishing gear research in the Barents Sea has to a large extent focused on developing selective devices to avoid by-catch of unwanted species and/or juvenile fish. This is particularly true for demersal trawls (Kennely and Broadhurst, 2021), which are often criticized for high levels of discards (Gilman et al., 2020). Until the 1990s selectivity studies mainly focused on improving selectivity in diamond meshed codends. However, early in the 1990s, rigid size sorting grids were developed, first in the fishery for deepwater shrimp, and then for the demersal trawl fishery for gadoids (Larsen and Isaksen, 1993; Sistiaga et al., 2016; Brinkhof et al., 2020). Thus, the application of both devices significantly reduced the by-catch of juvenile fish in their respective fisheries. Current regulations do not allow catches containing a more 15% of fish below minimum size (MS), which are 44, 40, and 30 cm for cod, haddock and redfish, respectively (Ministry of Trade, Industry and Fisheries, 2020). Applying size selective sorting grids in pelagic trawls could potentially solve the previously reported issues with retention of juvenile gadoids in pelagic trawls. One major difference in the construction of pelagic trawls compared to demersal trawls is the size of the nets, with the former being much larger than the latter. Larger trawls can lead to higher catch rates, which may have implications for the capacity in the sorting grid section. Clogging of the grid section has already been reported in demersal trawls under extraordinarily high catch rates (Sistiaga et al., 2010; 2016; Brinkhof et al., 2022). However, this issue could be solved by increasing the sorting capacity of the grid compared to those used in the current fishery (Sistiaga et al., 2016; Brinkhof et al., 2020;2022).

Therefore, the purpose of the pelagic trawl trials conducted here was to investigate whether the use of an upscaled rigid sorting grid could solve the bycatch issues that led to the ban of this type of gear in 1979.

The semicircular spreading gear

The seabed impacts of demersal trawls are a long-known and well-acknowledged problem (Jones, 1992; Clark et al., 2016; Eigaard et al., 2017; Hiddink et al., 2020; Willer et al., 2022) and the number of theoretical and practical work conducted to reduce these impacts have been substantial in the last decades (e.g. Ball et al., 1999; 2003; Sterling and Eayrs, 2006; Esmaeili and Ivanovic 2014; Broadhurst et al., 2015; O'Neill and Ivanovic, 2016).

Ground gears are attached to the fishing line in demersal trawls for protection against the seabed and ensure proper contact with the seabed. They can vary a lot in size and shape, depending on the type of substrate in the fishing grounds, the nature of the target species in the fishery, and the dimensions of the trawl it is attached to (Broadhurst et al., 2015, 2021; McHugh et al., 2017; Fakıoğlu et al., 2023). In the Barents Sea demersal trawl fishery targeting cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) for example, rockhoppers (RH) substituted rubber bobbins and during the late 80s, as they proved to be more efficient at capturing fish herded in front of the trawl. However, later studies showed that substantial numbers of fish still escape underneath the trawl (Ingolfsson and Jørgensen, 2006). Also, RH gears can be heavy (i.e. > 4 tons in a large whitefish or shrimp trawls) meaning that they can inflict substantial impacts to the seabed substrate and the animals and flora associated to it (Watling and Norse, 1998; Grabowski et al., 2014). As part of the global efforts to reduce the impacts of bottom trawling, Grimaldo et al. (2014) presented for the first time a new ground gear concept based on semicircular HDPE modules: the semicircular spreading gear (SCSG).

During the initial testing, the gear showed a 7 % higher spreading and somewhat higher catch efficiency than an equivalent RH gear. However, the number of hauls performed was too small to draw any conclusions regarding catch efficiency. Further, due to that the SCSG tested weighed approximately one third of an equivalent RH gear (Brinkhof et al., 2017), it was assumed that it would lead to reduced seabed impact. However, no scientific trial has tested the magnitude of the seabed impact infringed by SCSGs yet.

Brinkhof et al. (2017) and Larsen et al. (2018) conducted sea trials to estimate potential differences in the loss of respectively cod and haddock underneath the trawl between size-equivalent SCSG and RH gears. The studies concluded that the loss of both species under the ground gear was reduced when the SCSG was used, resulting in a higher catch efficiency compared to an equivalent RH gear. Brinkhof et al. (2017) and Larsen et al. (2018) studied the selectivity (probability that a fish enters the trawl body) of the trawls with the two gears, but they did not evaluate the overall length-dependent retention of the gears including undersized fish. Hence, they could not consider the implications of other potential effects of using the SCSG (e.g. changes in catch efficiency due to differences in trawl geometry (Grimaldo, 2014). Further, their trials were based on individual assessments of the efficiency of the ground gears rather than a direct comparison of the length-dependent retention.

The use of the SCSG is spreading fast among fishers operating demersal trawlers in the north Atlantic (Knut Steffen Solvåg, Selstad AS, personal communication). However, no study has compared these two gears directly in an experimental design that can evaluate the magnitude of the potential length-dependent differences in retention between these two gears. Therefore, the aim for this part of the trials was to conduct commercial scale sea trials that directly compared the catch efficiency of two equivalent SCSG and RH gears. The final goal was to determine whether these two ground gears can lead to differences in the exploitation patterns of demersal trawls.

Materials and methods

Fishing trials

The sea trials were conducted in November 2024 onboard the commercial trawler "Hermes" (Length - 70 m, gross tonnage - 3400 tons). The fishing grounds were in the Barents Sea (74°14'N 23°11'E – 74°19'N 23°05'E). The vessel has four separate trawl lanes for demersal trawls and a net drum for a pelagic trawl. The trawl doors used during the sea trials were of the type Rock Seamaster (4800 kg, 11.5 m^2).

Gear configuration for the tests with an upscaled grid in a pelagic trawl

The length of the sweeps between the trawl doors and the pelagic trawl was 100 m (40 m of chain and 60 m of wire. Between the sweeps and the trawl net a chain clump weighing 1500 kg was attached on each side. The trawl employed was an Egersund 720 pelagic trawl. The length of the headline was 175 m, and the length of the fishing line, which was made from 22 mm ML chain was 171.8 m. The mesh size in the wings was 8000 mm, and was gradually reduced towards the codend, which had a mesh size of 133.5 mm (SD ± 2.9 mm). The total length of the codend was 30 m. In front of the codend we mounted the section with an upscaled sorting grid (Fig. 1). The grid was 1.74 m wide and 2.47 m long, resulting in an area of 4.32 m^2, which is double as large as the steel-made single grid used in the demersal trawl fishery today (Sistiaga et al., 2023). The bar spacing was according to the legislation, i.e., 55.17 mm (SD ± 0.66 mm), which establishes a minimum bar spacing of 55 mm.

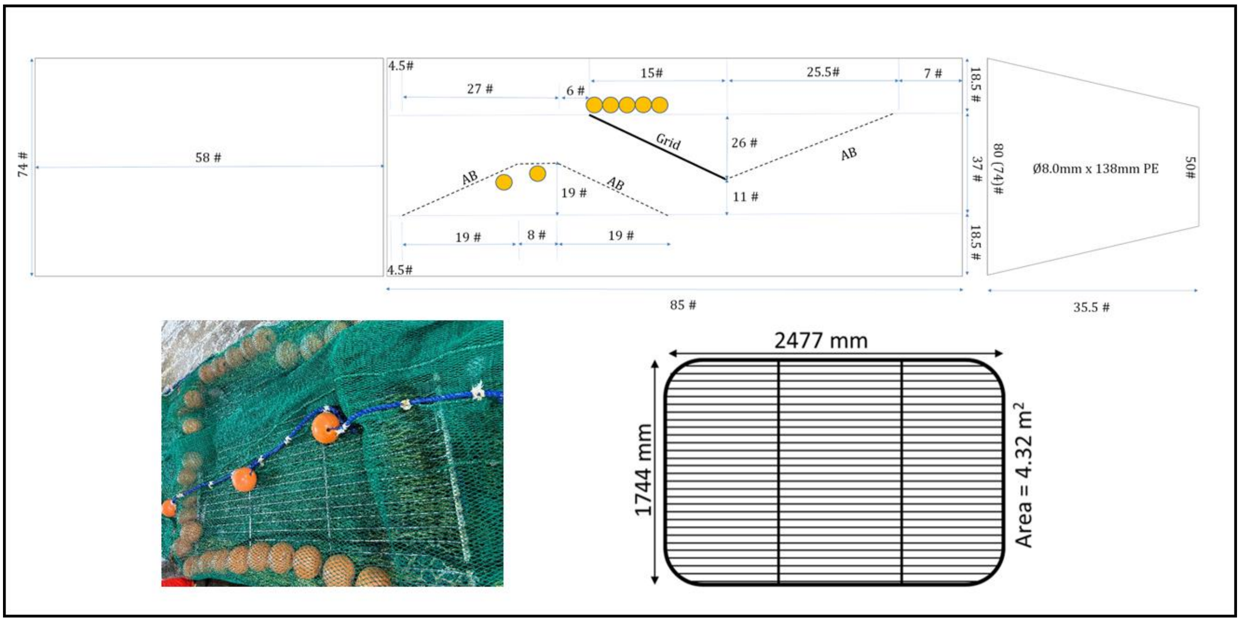

Figure 1. Illustration and schematics of the upscaled grid section.

During the first part of the trials all escapees were retained by covering the grid outlet with a cover and blinding the codend with a small meshed liner built of 45 mm meshes (Fig. 2). Both the grid cover and the codend liner were removed during the second part of the trials to mimic commercial practice (Fig. 2). Besides estimating the size selectivity of the grid, these two configurations enabled the estimation of i) cumulative catch distributions without any selectivity (*GC & BC*), ii) cumulative catch distributions when the contribution of the grid was added (*G & BC*), and iii) cumulative catch distributions when the contribution of the codend was added (*G & C*).

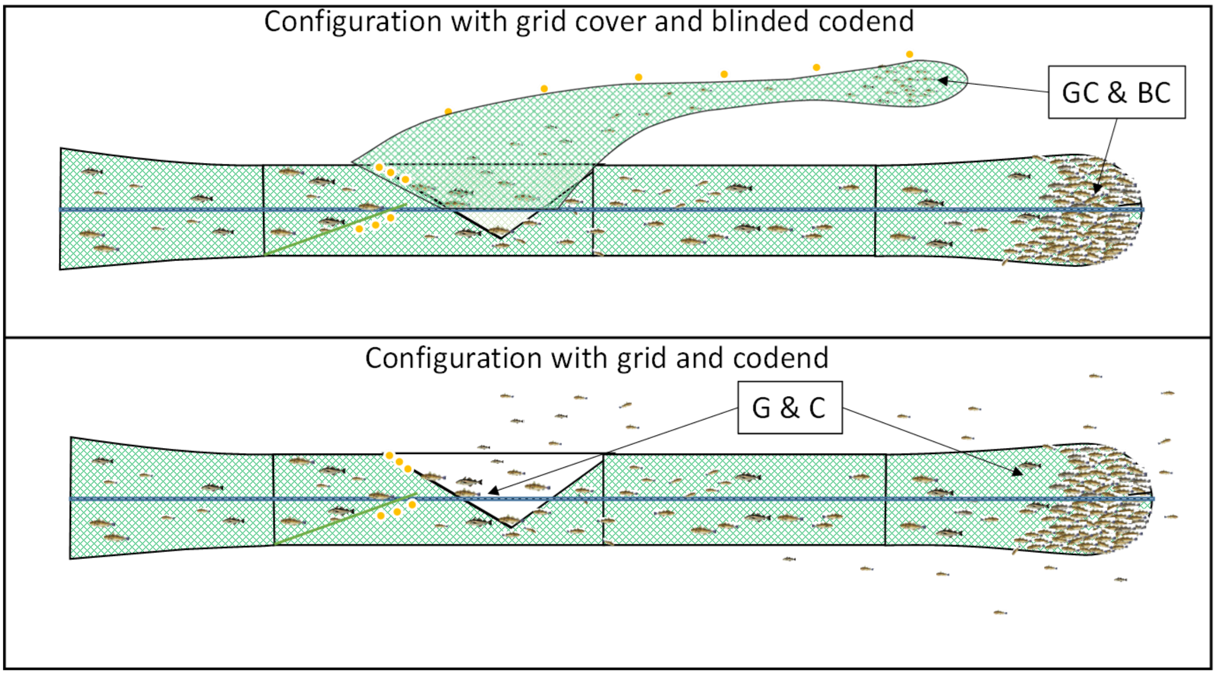

Figure 2. Schematics of the two configurations fished during the sea trials. Upper: Grid with grid cover followed by a blinded codend. Lower: Commercial configuration with uncovered grid and selective codend.

Gear configuration for the tests with the SCSG

During the trials we used a twin trawl configuration with trawl doors and a roller clump. The trawl doors were of the type Rock Seamaster (4800 kg, 11.5 m^2) and the roller clump of the type Injector (7500 kg). The doors and roller clump were joined with the ground gears of the trawls by 105 m sweeps. The ground gear in each trawl was composed by 15 m chains in each side with two steel and four rubber bobbins. The center part of the ground gears was a 30.25 m RH gear in one of the trawls and a 30.0 m SCSG in the other trawl. The RH was composed by five 6.05 m long sections. The one in the middle had a diameter of 61.0 cm whereas the other four had a diameter of 53.3 cm. The SCSG was composed by 7 sections: a 4.3 m section in the middle followed by a 4.55 m section on each of the sides, and two 4.14 m sections in each of the sides after that. The diameter of the SCSG was 44.1 cm for all seven sections (Fig. 3). We used two identical Mørenot #634 trawls with a headline of 51.2 m, a fishing line of 31.1 m and constructed entirely of 155 mm meshes. The extension pieces attached to each of the trawls were 75.5 meshes long, built of 145 mm euroline netting. The codends were 138.5 meshes long, 86 free meshes around, and were built of 10 mm knotless PE twine.

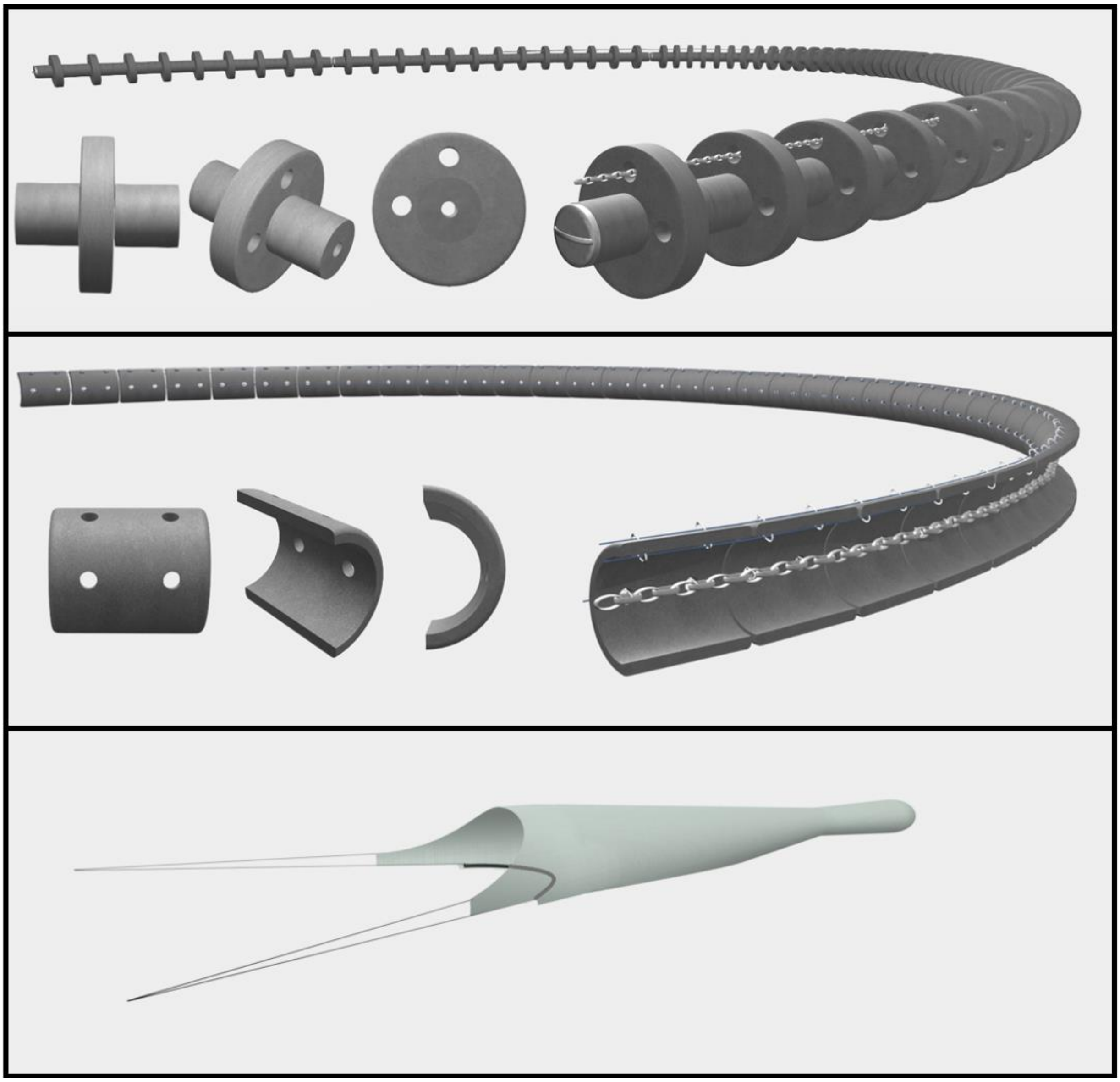

Figure 3. Schematics of the RH gear and the semicircular spreading gear.

The trials were carried out in the Barents Sea, where it is obligatory to use a sorting grid with a minimum bar spacing of 55 mm combined with a size selective codend with a minimum mesh size of 130 mm. The first series of hauls was conducted with the trawls mimicking a commercial configuration, i.e., both trawls had a 55 mm flexigrid and a size selective codend. The meshes in the codends were measured to be 134.8 ± 3.3 mm (mean ± STD) and 136.7 ± 3.1 mm, respectively. Conversely, during the second series the grids were removed from the trawls and the codends were blinded through their whole length with 45 mm nominal mesh size inner nets making the trawls non-selective. Halfway through each series the ground gears and trawls changed side to account for potential differences in the fishing power of the trawls and minimize any potential trawl effect in the evaluation of the ground gears.

Data analysis

After each tow the catch form the codend and the cover were kept in separate holding tanks. Cod, haddock, and redfish above 20 cm were length measured to the nearest centimeter below. For those hauls where it was not possible to measure all the fish, the catch was subsampled. For those cases, the fraction of fish that was not measured was counted, enabling calculation of the subsampling factor.

Data analysis for the tests with an upscaled grid in a pelagic trawl

The size selectivity data of the grid was modelled by traditional (Wileman et al., 1996) and more advanced s-shaped selection curves using the approach described in Jacques et al. (2024). In these models the retention is estimated based in three main parameters, L50, SR, and the contact parameter C. L50 represents the length at which a fish that has a 50% probability of being retained in the gear, the selection range (SR) is the selection range defined as the difference between L75 and L25, whereas C represents the fraction of fish entering the grid section that contacts the grid in a way that provides it with a length-dependent probability to pass through the grid. The models tested were logit, Clogit, Dlogit and Tlogit. All the models are described in detail in Jacques et al. (2024). The confidence intervals (CIs) for the size selection models used were estimated by the double bootstrapping method presented in Herrmann et al. (2017), which accounts for between-haul variation in the sampling process in the outer loop and within-haul variation in the inner loop of each bootstrap repetition.

In addition to the size selectivity analysis, the performance indicators *nP-*, *nP+* and *nDiscardRatio* were also estimated (Cuende et al., 2022). *nP-* is the percentage of fish below minimum entering the gear that was captured, *nP+* is the percentage of the fish above minimum size entering the gear that was captured, whereas *nDiscardRatio* is the percentage of fish below MS captured by the gear with respect to the total catch. These vary between trials and cannot be extrapolated to other fishery situations because they depend on the fish population present in the fishing area at the time the trials were conducted. However, indicators provide an example of the performance of the gear and are valuable to understand the results of the trials. A detailed description of the indicators and how to estimate them is given in Cuende et al. (2022). The CIs for the indicators were also estimated by a double bootstrap approach.

Data analysis for the tests with the SCSG

The aim of the data analysis for this part of the trials was to study potential length-dependent differences in catch efficiency between the RH gear and the SCSG averaged over hauls. A catch comparison ratio analysis was conducted using the number of individuals caught for each length class in each of the gears. The analysis was carried out for cod, haddock and redfish separately. The method applied here is identical to that used by Herrmann et al. (2017), Olsen et al. (2012), and more recently by Sistiaga et al. (2024). Using the catch comparison rates, the catch ratios between the SCSG and the RH gear were estimated for the different length classes using equation 4 in Sistiaga et al. (2024). The CIs for the catch ratio were estimated by a double bootstrap approach as described in Herrmann et al., 2017.

In addition to the catch comparison analysis, performance indicators $CR_{average}$, $CR_{average-}$ and $CR_{average+}$ were also estimated. These show the probability of capture for fish of all sizes, fish below minimum size and fish above minimum size in the SCSG with respect to the RH gear, respectively. A detailed description of the indicators and how to estimate them is given in Cuende et al. (2022). For the indicators also the CIs were also estimated using the bootstrap procedure described above.

Results

Results for the tests with an upscaled grid in a pelagic trawl

During the sea trials a total of 18 valid hauls were conducted with the pelagic trawl configuration. Eight hauls were conducted with the grid cover and blinded codend, and eight hauls were conducted with a commercial configuration with no grid cover and a selective codend (Table 1). In total, the length of 10,662 cod, 4,253 haddock, and 5,723 redfish were measured in this part of the trials.

Table 1. Overview over the hauls conducted during the sea trials showing date, the trawl configuration with the grid covered and blinded codend (GC&BC), and the configuration with the grid and codend (G&C), time start, towing time, depth, and number of cod, haddock and redfish that where measured in either the codend or cover with the corresponding subsampling factor (S.F.).

					Cod				Haddock				Redfish			
Date	**Trawl**	**Time start (hh:mm)**	**Towing time (hh:mm)**	**Depth (m)**	***n* Codend**	**S.F.**	***n* Cover**	**S.F.**	***n* Codend**	**S.F.**	***n* Cover**	**S.F.**	***n* Codend**	**S.F.**	***n* Cover**	**S.F.**
21.11.2024	GC&BC	19:37	03:23	240	1016	0.29	1001	0.38	74	0.26	498	0.49	441	0.23	180	0.11
22.11.2024	GC&BC	10:38	01:00	230	403	1.00	1123	0.61	50	1.00	97	1.00	220	1.00	177	1.00
22.11.2024	GC&BC	13:01	01:03	223	304	1.00	1017	0.70	208	1.00	462	0.16	423	1.00	596	1.00
22.11.2024	GC&BC	15:32	00:53	221	181	1.00	910	1.00	157	1.00	709	0.43	407	1.00	485	1.00
23.11.2024	GC&BC	11:24	01:10	245	296	1.00	1103	1.00	12	1.00	170	1.00	94	1.00	83	1.00
23.11.2024	GC&BC	13:47	01:08	240	27	1.00	407	1.00	38	1.00	517	1.00	24	1.00	48	1.00
23.11.2024	GC&BC	16:53	01:26	259	40	1.00	542	1.00	51	1.00	224	0.41	13	1.00	105	1.00
23.11.2024	GC&BC	20:13	02:18	150	220	1.00	1121	1.00	71	1.00	458	1.00	245	1.00	447	1.00
24.11.2024	G&C	00:27	03:01	190	196	1.00	-	1.00	22	1.00	-	1.00	243	1.00	-	1.00
24.11.2024	G&C	04:22	01:47	190	221	1.00	-	1.00	18	1.00	-	1.00	287	1.00	-	1.00
24.11.2024	G&C	07:06	03:30	222	280	1.00	-	1.00	19	1.00	-	1.00	293	1.00	-	1.00
24.11.2024	G&C	11:42	?	168	67	1.00	-	1.00	4	1.00	-	1.00	33	1.00	-	1.00
24.11.2024	G&C	14:55	03:23	187	55	1.00	-	1.00	45	1.00	-	1.00	42	1.00	-	1.00
24.11.2024	G&C	19:09	02:31	218	93	1.00	-	1.00	195	1.00	-	1.00	805	1.00	-	1.00
24.11.2024	G&C	22:39	?	255	19	1.00	-	1.00	99	1.00	-	1.00	19	1.00	-	1.00
25.11.2024	G&C	01:31	02:28	202	20	1.00	-	1.00	55	1.00	-	1.00	13	1.00	-	1.00

Based on the lowest AIC-value the TLogit model resulted on the lowest AIC and therefore the preferred fit for all three species (Table 2 and 3).

Table 2. AIC-values for the models considered.

	AIC		
Model	**Cod**	**Haddock**	**Redfish**
Logit	15644.29	5222.66	6622.73
Probit	15721.22	5235.68	6629.39
Gompertz	16044.33	5246.31	6697.26
Richards	15409.21	5185.59	6564.70
Dlogit	15373.95	5128.30	6559.91
Tlogit	**15367.41**	**5124.44**	**6542.84**
Clogit	15389.66	5135.24	6585.59
DSLogit	15378.02	5130.50	6561.71

Table 3. The fit statistics showing the model chosen (based on lowest AIC) with the corresponding p-value, degrees of freedom (DOF), and deviance.

Species	**Cod**	**Haddock**	**Redfish**
Model	TLogit	TLogit	TLogit
p-value	0.1156	0.0008	0.0001
DOF	74	48	32
Deviance	88.79	84.82	69.69

The size selectivity curves showed a relatively low retention of fish below the MS of 44- and 40 cm for cod and haddock, respectively (Fig. 4). Contrary, for redfish there was a relatively high probability for retention of fish below the MS of 30 cm. However, for all three species there was a significant loss of fish above their respective MS's (Fig. 4). This was corroborated by the exploitation pattern indicators, which show that 47.32% (CI: 27.03-62.46) of cod, 57.79% (CI: 30.37-78.45) of haddock, and 71.47% (CI:60.73-78.08) above MS are retained in the codend. Simultaneously, 17.42% (CI:4.08-29.75) of cod, 9.53% (CI: 6.54-15.13) of haddock, and 9.62% (CI: 4.95-12.55) of redfish below were retained. It is important to consider that the exploitation pattern indicators are dependent on the population structure of fish encountered during the sea trials, and that the results may differ under different conditions. Also, both the results in Fig. 4 and Table 3 refer solely to the selectivity for the grid, without considering the potential selectivity contribution of the codend. Combining the results from Fig. 4 (with cover grid) with the data from the hauls conducted with the commercial configuration (without cover over the grid and without blinded codend) shows that the codend would release most of the fish below MS if they were not released by the grid (Fig. 5). Fig. 5. shows the cumulative catch distribution for a non-selective configuration (dark grey), configuration considering only selectivity in the grid (grey), and configuration when considering selectivity in both grid and codend. The corresponding quantiles for the cumulative catch distribution are presented in Table 4.

Table 3. The selectivity parameters L50, SR and Contact, and the exploitation indicators *nP+*, *nP-* and *nDiscardRatio*.

Species	**Cod**	**Haddock**	**Redfish**
L50 (cm)	53.93 (48.77-59.61)	46.99 (42.67-50.47)	27.24 (25.73-36.77)
SR (cm)	14.36 (9.22-25.03)	4.89 (1.14-23.56)	13.78 (5.77-15.84)
***nP+* (%)**	47.32 (27.03-62.46)	57.79 (30.37-78.45)	71.49 (60.68-78.16)
***nP-* (%)**	17.42 (4.08-29.75)	9.53 (6.54-15.13)	9.34 (5.25-11.94)
***nDiscard Ratio* (%)**	25.54 (12.63-29.39)	89.52 (81.29-96.14)	7.05 (4.20-9.16)

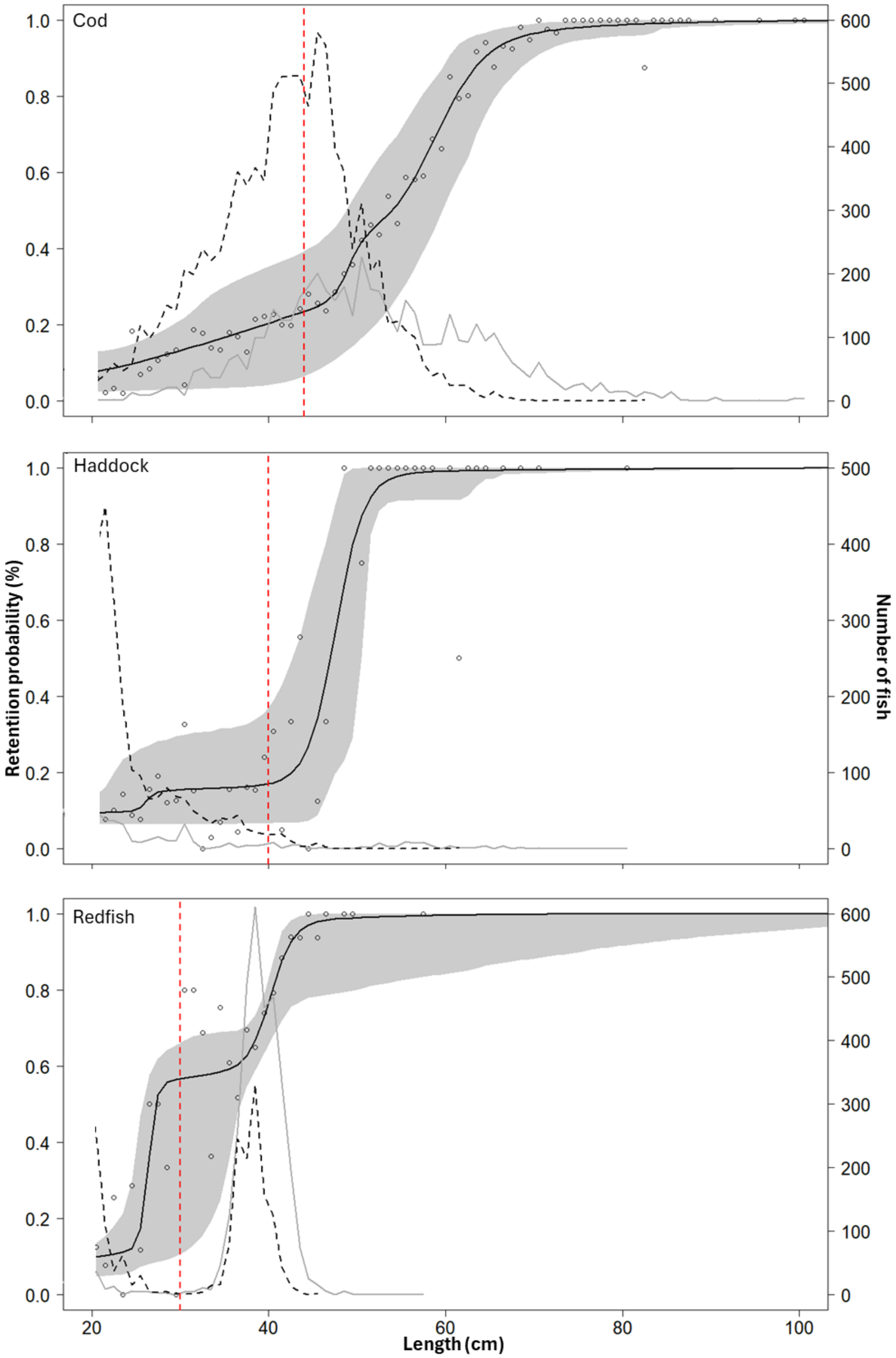

Figure 4. Size selectivity curves (black curve) for cod (upper), haddock (middle) and redfish (lower) with corresponding 95% confidence bands (gray area). The black circles denote the experimental data, the black stippled line the catch in the cover, the gray solid line the catch in the codend, and the vertical stippled line the MS for the respective species.

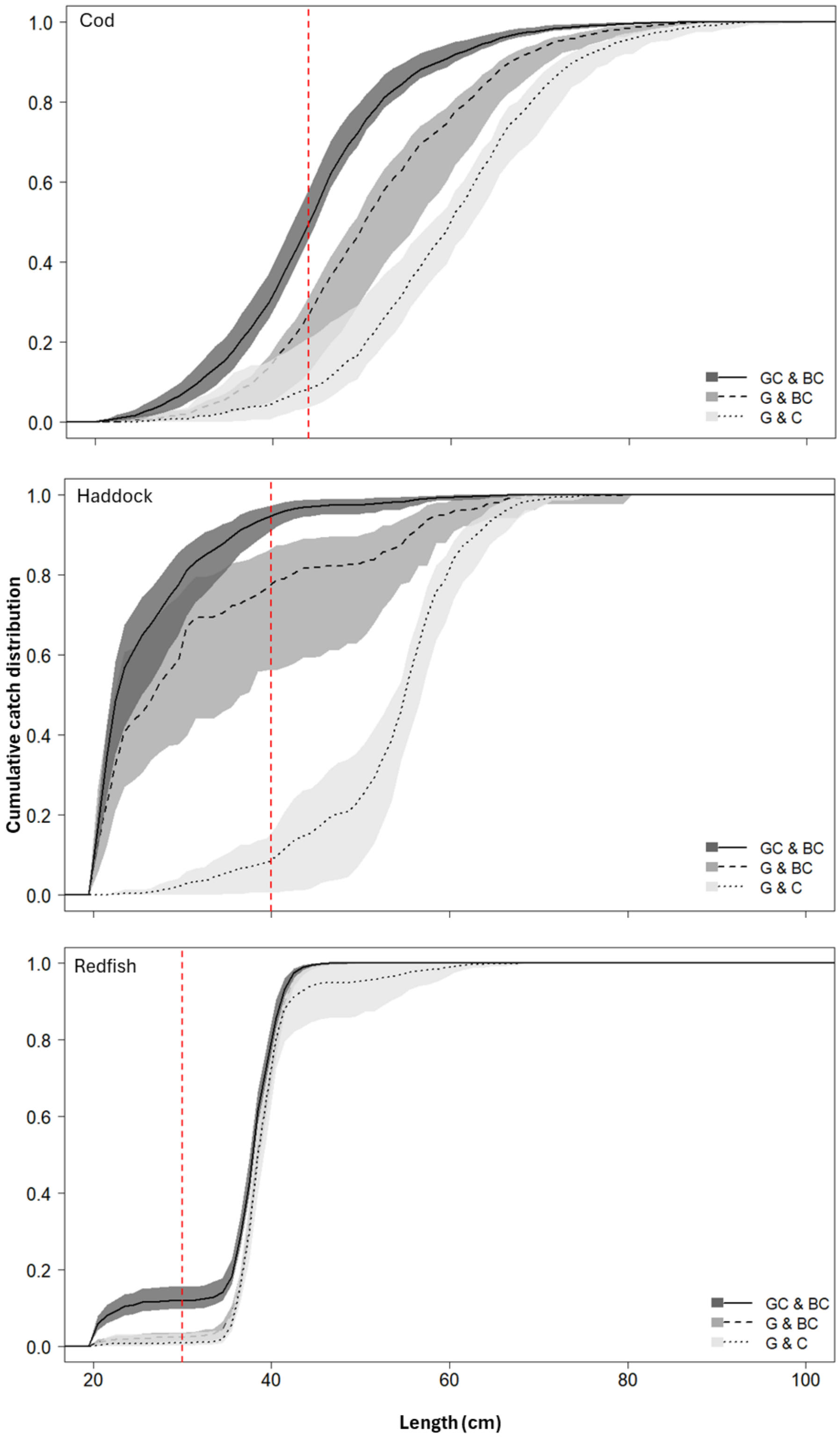

Figure 5. Cumulative catch distribution curves for cod (upper), haddock (middle) and redfish (lower) with 95% confidence bands (gray shaded areas). The solid curve with CI's in dark grey represent the total catch distribution caught, i.e., catch in grid cover and blinded codend (GC&BC), the stippled curve with the CI's in grey represent the catch distribution in blinded codend without the grid cover (G&BC), and the dotted curve with CI's in light grey represent the cumulative catch distribution in the non-blinded codend and without a grid cover (G&C). The red vertical stippled line denotes the MS.

Table 4. Quantiles (%) with 95% confidence limits in brackets for the cumulative catch distribution presented in Fig. 5 for the following configurations: non-selective configuration (grid cover &blinded codend, GC&BC), configuration considering only selectivity in the grid (grid and blinded codend, G&BC), and configuration when considering selectivity in both grid and codend (grid and codend, G&C).

Sp.	Conf.	Q05	Q10	Q25	Q50	Q75	Q90	Q95
Cod	GC & BC	28.14 (26.05-30.53)	31.65 (29.63-33.98)	38.00 (35.89-39.24)	44.12 (42.28-44.89)	51.98 (47.94-51.28)	58.71 (54.94-60.46)	64.44 (60.46-65.71)
	G & BC	33.69 (32.23-39.68)	37.77 (36.33-42.79)	43.48 (42.31-48.31)	50.31 (49.06-56.22)	59.61 (57.29-64.01)	66.77 (65.39-71.00)	71.89 (70.19-76.70)
	G & C	40.23 (30.99-45.56)	45.65 (34.61-48.77)	52.16 (46.60-54.52)	60.00 (57.93-62.43)	66.92 (65.45-70.66)	73.81 (71.95-77.86	78.79 (77.22-82.96)
Haddock	GC & BC	19.80 (19-74-19.95)	20.11 (19.97-20.39)	20.97 (20.69-21.52)	22.69 (21.99-25.48)	28.70 (25.74-32.43)	35.84 (32.19-39.37)	40.30 (36.50-45.96)
	G & BC	19.89 (19.69-20.39)	20.28 (19.88-21.10)	21.72 (20.44-23.08)	26.78 (22.35-36.50)	38.44 (29.71-53.69)	55.63 (50.10-60.12)	59.74 (55.70-67.88)
	G & C	34.30 (30.03-48.73)	40.70 (34.63-50.59)	50.23 (43.00-53.63)	54.98 (53.70-56.77)	58.39 (57.27-60.79)	63.02 (61.04-65.90)	65.60 (63.90-68.19)
Redfish	GC & BC	20.36 (20.14-20.89)	23.19 (21.22-31.89)	36.17 (35.74-36.43)	37.90 (37.57-38.06)	39.61 (39.21-39.84)	41.09 (40.47-41.34)	41.95 (41.33-42.27)
	G & BC	34.59 (33.78-35.50)	35.68 (35.35-36.12)	37.05 (36.86-37.31)	38.45 (38.18-38.73)	40.19 (39.69-40.45)	41.51 (40.92-41.94)	42.33 (41.75-42.84)
	G & C	35.34 (34.66-35.61)	35.96 (35.60-36.30)	37.19 (36.80-37.64)	38.56 (38.04-39.17)	40.16 (39.39-40.89)	42.14 (40.70-53.32)	49.71 (41.49-58.58)

Results for the tests with the SCSG

During the hauls where where the trawls were fished with size selective grids and codends, a total of ten hauls were conducted. In these hauls a total of 17,420 cod, 420 haddock and 1,475 redfish were captured and length measured. During the hauls where the grids were removed and codends were blinded using inner nets, a total of eight hauls containing 12,589 cod, 2,918 haddock and 1,248 redfish were captured and length measured. The towing duration within the 18 hauls conducted varied between 61 and 302 min and the total catches between 1026 and 7307 kg (Table 5).

Table 5: Series, date, haul number, time the tow started, tow duration, depth, side of the SCSG and RH, and numbers of cod, haddock and redfish caught with each of the gears in each haul for the 18 hauls conducted during the sea trials.

Series	Date	Haul nr	Time start (hh:mm)	Tow duration (mm)	Depth (m)	Starboard	Port	Catch (Kg)	SCSG			RH		
									n Cod	*n* Haddock	*n* Redfish	*n* Cod	*n* Haddock	*n* Redfish
1	19.11.20	1	09:41	204	209	RH	SCSG	4311	164	0	10	148	2	12
1	19.11.20	2	14:12	242	219	RH	SCSG	5807	900	9	651	612	4	362
1	19.11.20	3	19:42	259	228	RH	SCSG	6632	1509	10	74	1126	11	75
1	20.11.20	4	01:17	191	202	RH	SCSG	5027	1422	17	50	851	10	40
1	20.11.20	5	05:26	216	191	RH	SCSG	5786	1496	25	58	1045	13	28
1	20.11.20	6	21:58	213	170	SCSG	RH	4355	1101	67	10	1018	50	6
1	21.11.20	7	02:24	221	176	SCSG	RH	4044	1202	63	4	1010	43	0
1	21.11.20	8	06:59	172	185	SCSG	RH	2549	626	29	1	776	28	5
1	21.11.20	9	10:51	179	229	SCSG	RH	2377	454	17	12	407	15	7
1	21.11.20	10	14:43	190	244	SCSG	RH	3639	819	2	47	734	5	23
2	25.11.20	11	05:28	61	239	SCSG	RH	1026	290	28	41	211	17	56
2	25.11.20	12	11:38	302	184	SCSG	RH	7307	742	112	7	684	55	3
2	26.11.20	13	16:10	126	194	SCSG	RH	3764	1268	196	14	1082	145	11
2	26.11.20	14	19:11	173	200	SCSG	RH	6127	1734	599	20	1252	356	17
2	27.11.20	15	01:02	120	243	RH	SCSG	1724	505	60	576	338	51	364
2	27.11.20	16	04:28	123	154	RH	SCSG	2066	892	286	37	691	187	40
2	27.11.20	17	07:46	103	166	RH	SCSG	2194	1151	324	34	542	170	12
2	27.11.20	18	10:17	90	150	RH	SCSG	3035	791	215	8	416	117	8

Trials with selective trawls

Independent of the type of ground gear employed, the retention of cod, haddock and redfish below 30 cm was low when the trawls were fished with a 55 mm bar spacing size sorting grid and a size selective codend with a mesh size of ~135 mm (Fig. 6). This led to increased binominal noise in the data and wider confidence intervals for undersized fish in general. The fit statistics for cod and redfish show that the polynomial models used in these cases were good representations of the data as the p-values were 0.3177 and 0.1974, respectively (Table 6). For haddock, the p-value was 0.0083. However, the modelled curves represented the main trends in the data even though it was challenging to visually evaluate the fit of the data due to the limited number of haddock caught. Therefore, the small p-value was considered caused by overdispersion in the experimental data and we were confident in using the estimated curves to describe the length dependent catch comparison rate and catch ratio

For cod, the *CR(l,v)* plot shows that practically all length classes up to 67 cm differ significantly from the baseline (Fig. 6b). This demonstrates that the trawl equipped with the SCSG is more efficient at capturing cod both above and below its MS. For haddock, the length classes between 52 and 63 cm showed to be significantly different from the baseline, whereas for redfish the interval with length classes that were significantly different from the baseline were between 28 and 39 cm (Fig. 6d, f). In all cases, the length classes that showed significant differences between the gears showed higher catch efficiency for the trawl equipped with the SCSG.

Table 6: Fit statistics for the *CC(l, v)* curves for cod, haddock and redfish shown in Fig. 6 and 7.

	Species	P-value	Deviance	DOF
Selective trawls	Cod	0.3177	95.82	90
	Haddock	0.0083	68.33	43
	Redfish	0.1974	32.99	27
Non-selective trawls	Cod	0.0015	143.56	97
	Haddock	0.0430	83.49	63
	Redfish	0.3764	37.01	35

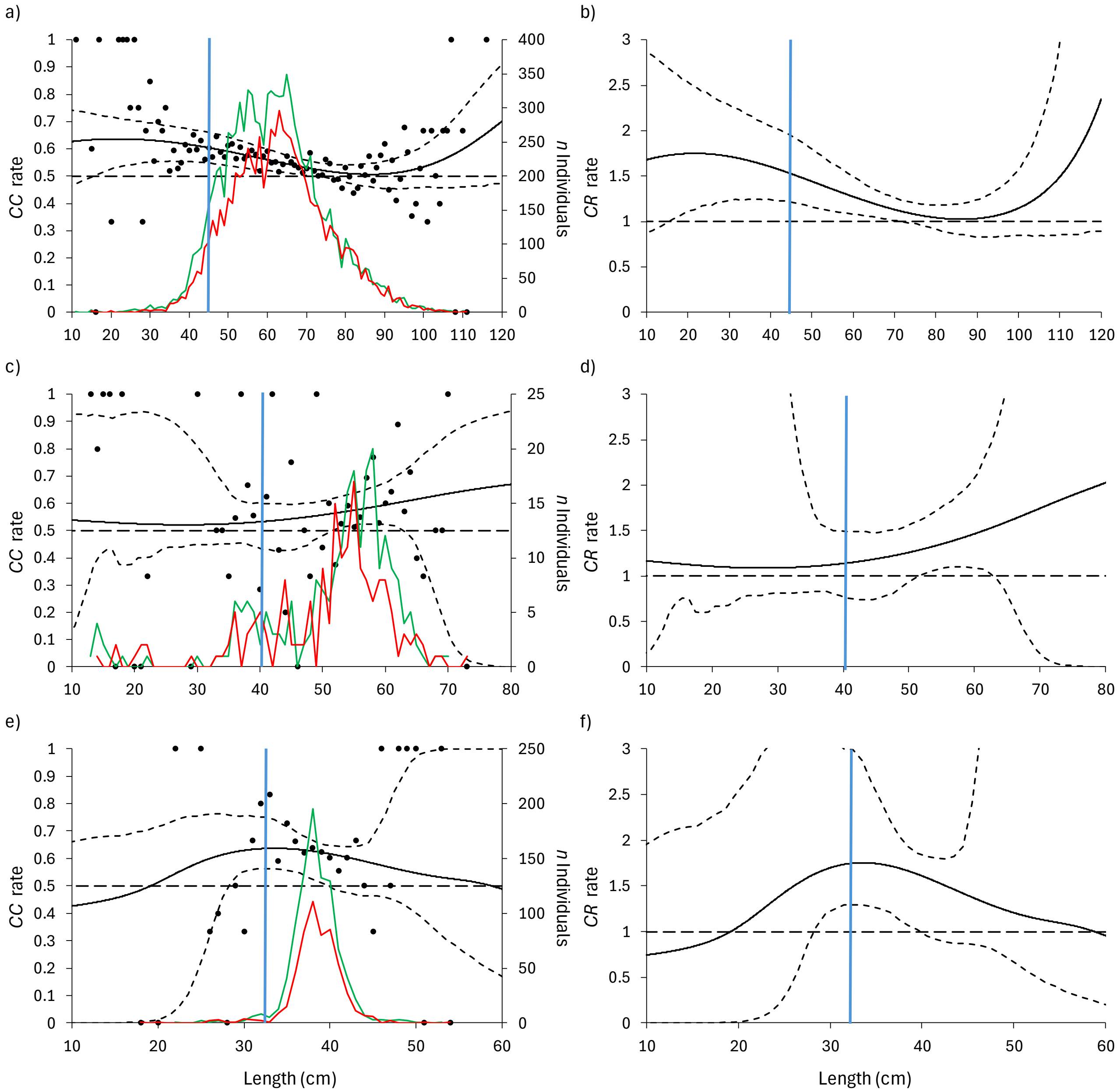

Fig. 6: *CC* (left) and *CR* (right) results for the hauls conducted with selective trawls comparing the SCSG with the RH gear. In the CC plots the black circles are the experimental catch comparison rates, the solid and stippled lines are the *CC(l,* $\boldsymbol{v}$*)* and its corresponding 95% confidence intervals, respectively, and the green and red lines show the size distribution captured by the trawls with the SCSG and RH respectively. In the CR plots the solid and stippled lines are the *CR(l,* $\boldsymbol{v}$*)* and its corresponding 95% confidence intervals, respectively. The vertical blue lines show the MS for each of the species.

Trials with non-selective trawls

The fit statistics for cod and haddock resulted in p-values <0.05. However, in both cases the *CC(l,***v***)* models used showed to represent the data well and therefore, the low p-values are assumed to be a consequence of overdispersion in the data (Table 6; Fig. 7a, 7c). For redfish, despite the low numbers of individuals above 25 cm, the p-value obtained was >0.05 and the model represented the data well (Table 6; Fig. 7e).

The use of trawls that were non-selective for fish above 10 cm increased the catch of fish below 30 cm substantially when compared to the catches in the hauls conducted with selective trawls (Fig. 6, 7). For cod, all length classes from 10- to 88 cm differed significantly from the baseline meaning that the SCSG captured significantly more fish than the RH gear for all these length classes. For length classes between 10- and 80 cm, the SCSG captured approximately 20-40% more cod than the RH gear (Fig. 7b). The SCSG also captured significantly more haddock than the RH gear for length classes between 10 and 70 cm. For haddock at the minimum size (40 cm), the catch efficiency of the SCSG was approximately 50% higher than for the RH gear (Fig. 7d). For redfish the catches were lower than for cod and haddock and the results were therefore not as conclusive. The *CR(l,* ***v****)* curve was over the baseline for all redfish length classes represented in the catches. However, only the length classes between 24- and 32 cm differed significantly from the baseline and could prove higher catch efficiency for the SCSG than the RH gear (Fig 7f).

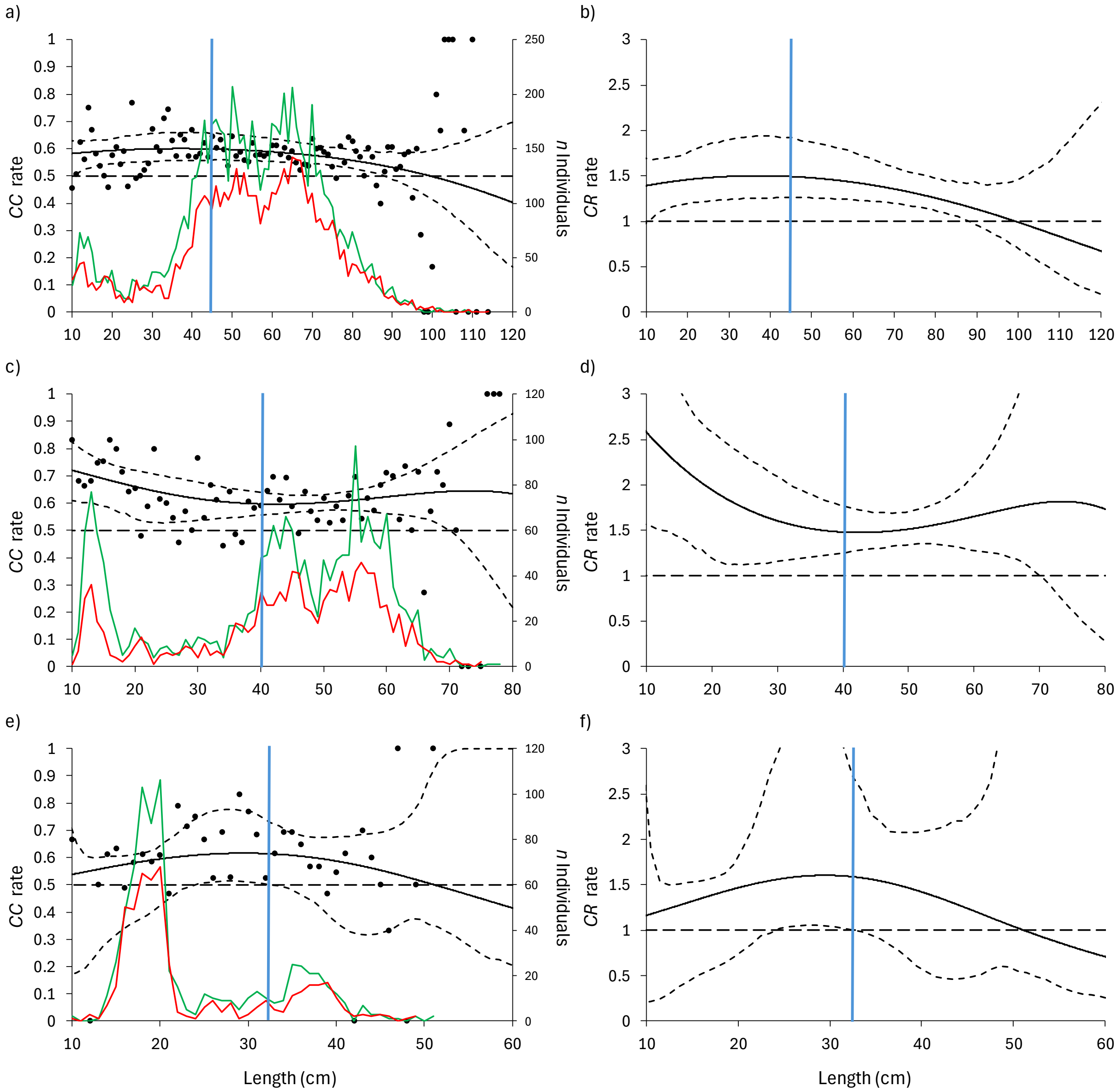

Fig. 7: *CC* (left) and *CR* (right) results for the hauls conducted with the non-selective trawls comparing the SCSG with the RH gears. In the CC plots the black circles are the experimental catch comparison rates, the solid and stippled lines are the *CC(l,* **v***)* and its corresponding 95% confidence intervals, respectively, and the green and red lines show the size distribution captured by the trawls with the SCSG and RH respectively. In the CR plots the solid and stippled lines are the *CR(l,* **v***)* and its corresponding 95% confidence intervals, respectively. The vertical blue lines show the MS for each of the species.

The size-integrated performance indicators showed that the SCSG captured 38.93 % more cod above MS than the RH gear with the non-selective trawl, but the difference was reduced to 23.99 % in the hauls conducted with the selective trawl. The difference in catch efficiency was larger for undersized cod. The SCSG captured on average 49.70% and 59.94 % more undersized cod than the RH gear with the non-selective and selective trawls, respectively (Table

7; Fig. 8). On average, the SCSG showed to catch significantly more haddock over MS than the RH gear. Specifically, the SCSG captured 59.39 % and 30.13% more haddock over MS than the RH gear with the non-selective and selective trawls, respectively. Regarding undersized haddock, the SCSG captured 82.30 % more fish than the RH gear with the non-selective trawl, but the difference between the gears became non-significant in the series with the selective trawl (Table 7; Fig. 8). For redfish, none of the size-integrated average values were significantly different from the baseline at 100 %, neither when the selective nor when the non-selective trawls were used. Thus, based on the indicators, no difference in the catch efficiency between the SCSG and the RH gear could be determined for this species (Table 7; Fig. 8).

The differences in discard ratio between the SCSG and the RH gear were small for all three species in both the series with the selective and non-selective trawls (< 3 % in every case). When the selective trawl was employed, the discard ratios for cod and redfish were significantly lower than 15%, which is the maximum allowed discard ratio in the Barents Sea demersal trawl fishery. For haddock, the discard ratios were close to 15% both with the SCSG and the RH gears were used. When the non-selective trawls were used on the other hand, the discard ratios were significantly higher than 15% for all three species and both the SCSG and RH gears. For all three species and both gears, the discard ratio was significantly higher when the non-selective trawls were used than when the selective trawls were used (Table 7; Fig. 8).

Table 7: Size-integrated average values for the *CR* under ($CR_{Average-}$) and over ($CR_{Average+}$) the MS for cod, haddock and redfish estimated separately for the trials with the selective and non-elective trawls. Discard ratios for the SCSG and the RH gears are also provided for all three species and both series. Numbers in brackets represent the lower and upper CIs respectively.

		Cod	Haddock	Redfish
Selective trawl	*CRAverage-* (%)	159.94 (118.29 - 203.85)	144.00 (90.00 - 225.00)	93.75 (37.50 - 228.57)
	CRAverage+ (%)	123.99 (107.63 - 137.87)	130.13 (103.00 - 160.41)	166.42 (113.51 - 195.63)
	n Discard Ratio SCSG (%)	5.15 (3.92 - 6.27)	15.06 (10.33 - 20.16)	1.64 (0.72 - 7.74)
	n *DiscardRatio RH* (%)	4.04 (3.27 - 4.81)	13.81 (8.82 - 19.49)	2.87 (1.07 - 13.54)
Non-Selective trawl	*CRAverage-* (%)	149.70 (126.52 - 179.24)	182.30 (134.63 - 227.48)	144.87 (82.88 - 176.58)
	CRAverage+ (%)	138.93 (120.53 - 171.03)	159.39 (140.37 - 176.81)	142.15 (76.23 - 213.33)
	n Discard Ratio SCSG (%)	23.82 (18.46 - 29.71)	30.55 (23.25 - 40.92)	76.66 (45.71 - 81.70)
	n DiscardRatio RH (%)	22.49 (17.64 - 28.90)	27.78 (22.71 - 36.34)	76.32 (45.45 - 85.03)

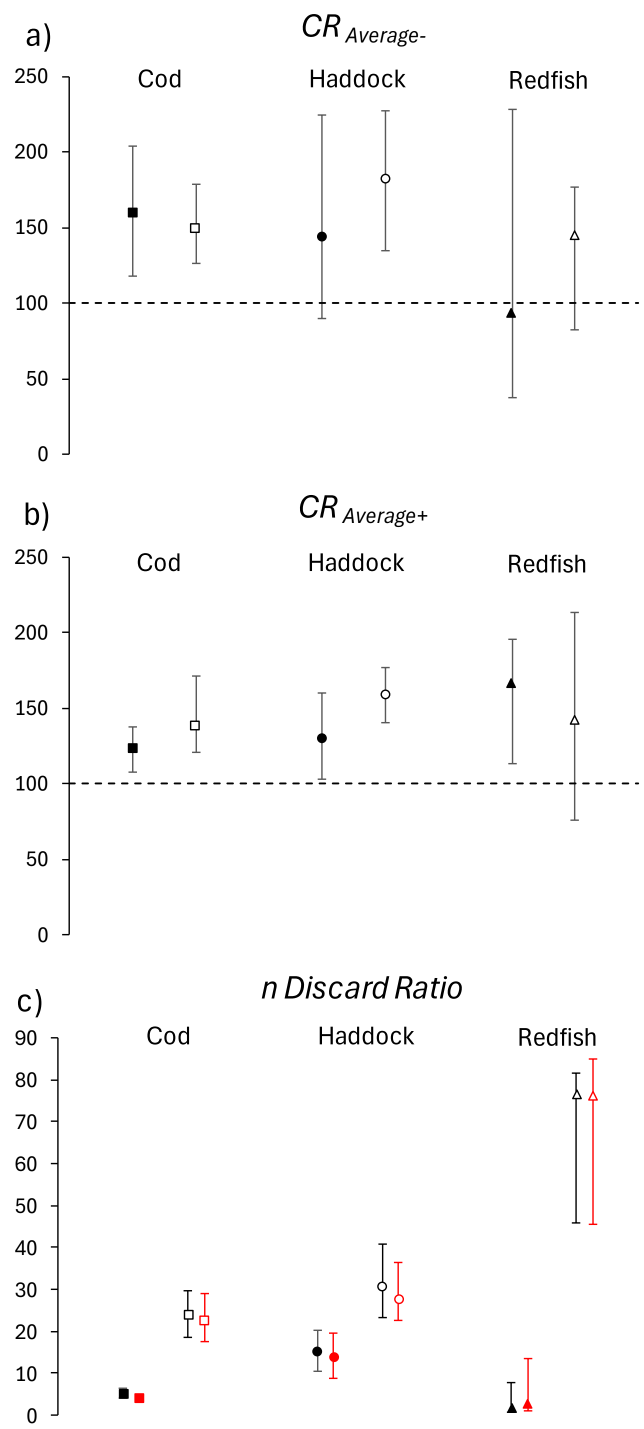

Fig. 8: a) Size-integrated average values (%) for the catch ratio between the SCSG and RH gears for undersized ($CR_{Average-}$) cod (squares), haddock (circles) and redfish (triangles) captured with size selective trawls (solid fill) and non-selective trawls (no fill). b) Size-integrated average values (%) for the catch ratio between the SCSG and RH gears for cod (squares), haddock (circles) and redfish (triangles) above MS ($CR_{Average+}$) captured with size selective trawls (solid fill) and non-selective trawls (no fill). c) n Discard Ratio (%) for cod (squares), haddock (circles) and redfish (triangles) captured with the SCSG (black) and RH gear (red) using size selective trawls (solid fill) and non-selective trawls (no fill). The horizontal stippled line in plots a) and b) represents the baseline for equal size-integrated catch efficiency between the SCSG and RH gear.

Discussion and conclusion

The aim of the present trials was twofold: to test whether an upscaled sorting grid can provide good size selectivity in a pelagic trawl targeting gadoids, and to investigate whether a SCSG results in catch efficiency comparable to a similar-sized RH gear.

The results from the trials with the upscaled grid in the pelagic trawl demonstrated that the grid released cod, haddock and redfish both below and above their MS's. These results did not consider potential selectivity in the codend meshes because it was blinded. When codend selectivity was also considered, the results showed that most cod and haddock, and redfish below MS was released. However, for all three species substantial numbers of fish above their MS's were also released. The results showed that the grid in combination with a selective codend would not violate the by-catch limits in the regulation of catches containing a maximum 15% of fish below MS in numbers (Ministry of Trade, Industry and Fisheries, 2020). It is important to take into account that the trials were conducted during a time of year where pelagic densities of gadoid species are low in the Barents Sea. These densities are expected to be higher during spring and summer.

The trials with the SCSG gear showed that for cod and haddock the catch efficiency of the SCSG was significantly higher than for the RH gear for length classes between 10 - 88 cm and 10 - 70 cm, respectively. However, the range of length classes with significant differences in catch efficiency was substantially reduced in the trials conducted with selective trawls. The results for redfish were less conclusive than for cod and haddock due to the numbers and limited size range of the individuals caught. Size-integrated performance indicators showed that on average, the trawl equipped with the SCSG captured 25.44% more cod, 32.04% more haddock and 64.34% more redfish than the trawl equipped with the RH gear. With blinded trawls, these differences changed to 41.35%, 65.76% and 44.23% for cod, haddock and redfish, respectively. However, the SCSG also caught significantly more undersized fish than the trawl equipped with the RH gear. This increase illustrates the importance of size selective devices, especially if the use of the SCSG is widely adopted by industry.

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