Development of selectivity systems for gadoid trawls (FHF- 901633)

Benign and efficient whitefish trawling (FHF 901754)

Commercial tests with an upscaled sorting grid and a Semi-Circular Spreading Gear onboard M/Tr Ramoen

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Summary

The Barents Sea whitefish trawl fishery is one of the most important and valuable fisheries in the world. However, despite being a well-developed fishery, it faces challenges especially related to selectivity and seabed impact.

Regarding size selectivity, the compulsory gear in the area is composed of a sorting grid and a subsequent size selective codend. Even though the size and capacity of the trawlers participating in the fishery have increased substantially during the last three decades, the size of the grids have remained the same creating capacity problems in the gear that can lead to clogging and ultimately gear damage. Regarding seabed impact, rockhoppers, which are the standard ground-gear used by the trawler fleet, have been shown to be one of the main components of trawls inflicting seabed disturbance. A Semi-Circle Spreading Gear (SCSG) that can substitute the rockhopper gear has shown promising results in scientific trials, but its catch efficiency has not been tested commercially yet. This gear weighs approximately one third of the equivalent rockhopper gear and the weight is spread over a larger surface. Therefore, it is assumed to be gentler to the seabed than a rockhopper.

The sea trials presented in this report had two main objectives: to test whether an upscaled sorting grid can provide better size selectivity results compared to the standard-sized grid used by the fleet, and to investigate whether a SCSG results on at least as good catch efficiency as an equivalent rockhopper ground gear.

The comparisons between the two sorting grid configurations tested showed that the upscaled grid significantly increased the sorting efficiency of the grid for both cod and haddock resulting overall in better size selectivity results. This additional sorting capacity exhibited by the upscaled grid is expected to play an important role in situations where the fish entry densities in the trawl are high e.g. using pelagic trawls for gadoid species. The upscaled grid did not imply any additional work or challenge for the crew during its operation.

The SCSG showed significantly higher catch efficiency for both undersized and commercial-sized cod meaning that in combination with efficient size selectivity devices this ground-gear would improve the efficiency of the fishery. Because the SCSG is assumed to have lower seabed impact and higher catch efficiency than the rockhopper gear, its implementation in the fleet can be an important step in the race towards more environmentally friendly fishing gear.

Sammendrag

Trålfisket etter hvitfisk i Barentshavet er en av de viktigste og mest verdifulle fiskeriene i verden. Til tross for å være et stort og effektivt fiske, står det overfor sentrale utfordringer, som selektivitet og negativ påvirkning på havbunnen. Når det gjelder størrelsesselektivitet, er det påbudt med bruk av sorteringsrist og en påfølgende selektiv trålpose. Selv om størrelsen og kapasiteten til trålnøtene som brukes i fisket har økt betydelig de siste tre tiårene, har størrelsen på ristene forblitt den samme, noe som skaper kapasitetsproblemer i ristseksjonene, som igjen kan føre metning av risten og til slutt skade på utstyret. Når det gjelder påvirkning på havbunnen, har rockhopper-giret, som er det standard giret brukt av trålerflåten, vist seg å være en av de viktigste delene av trålen som forårsaker forstyrrelser på havbunnen. Et nytt gir kalt Semi-Circle Spreading Gear (SCSG), har vist lovende resultater i vitenskapelige forsøk, men dens fangsteffektivitet har ennå ikke blitt testet i kommersielt fiske. Det nye giret veier omtrent en tredjedel av et tilsvarende rockhopper gir, og vekten er fordelt over en større overflate. Derfor antas det nye giret å være mer skånsomt mot havbunnen enn rockhopper giret.

Hensikten med forsøkene i denne rapporten var todelt: å teste om en oppskalert sorteringsrist kan gi bedre resultater for størrelsesselektivitet sammenlignet med den standard størrelsen på risten som brukes av flåten, og å undersøke om en SCSG gir minst like god fangsteffektivitet som et tilsvarende rockhopper-gir.

Sammenligningene mellom de to sorteringsristkonfigurasjonene viste at den oppskalerte risten økte sorteringskapasiteten betydelig for både torsk og hyse, noe som resulterte i bedre størrelsesseleksjon. Den økte sorteringskapasiteten i den oppskalerte risten forventes kan være av stor betydning i situasjoner der fisketetthetene er store, for eksempel ved bruk av pelagisk trål i torskefisket. Den oppskalerte risten medførte ikke noe ekstra arbeid eller utfordring for mannskapet under skyting og hiving.

SCSG viste betydelig høyere fangsteffektivitet for torsk både over og under minstemålet. I kombinasjon med effektiv størrelsesseleksjon vil dette giret kunne forbedre fiskeriets fangsteffektivitet. Fordi det antas at SCSG har mindre negativ påvirkning på havbunnen og høyere fangsteffektivitet enn rockhopper-giret, kan implementeringen av det nye giret i trålflåten være et viktig skritt i retning av et mer miljøvennlig trålfiske.

1 Background

In the Barents Sea demersal trawl fishery, fishermen are obliged to use a size sorting grid in the extension piece of the trawl followed by a size selective codend (Fig. 1). The grid must have a minimum bar spacing of 55 mm, while the codend mesh size needs to be at least 130 mm. The working principle of the grid is such that the if fish contacts the grid and can physically pass through it will escape the trawl, whereas the fish that do not contact the grid or are physically not able to pass through it will drift towards the codend, where they will get an additional escape possibility through the codend meshes. Earlier studies carried out with sorting grids have identified capacity issues, meaning that at high fish entry densities grids can show reduced size sorting efficiency. In some cases, the entry densities of fish are so high the grid can clog and consequently completely stop sorting (Sistiaga et al., 2016). Further, if catch starts accumulating in front of the grid due to that the grid is clogged, the whole grid section can burst resulting in loss of catch and serious gear damage for the fishermen. In other fisheries, increasing the size of the grid has shown improved sorting efficiency (Larsen et al., 2018) and it is speculated whether an increase in size could be beneficial for size discrimination of key target species in this fishery as well. Since the introduction of the grid in 1997, the size of the vessels operating in the fishery as well as their capacity and size of the gear used have increased substantially. However, the size of the grid have remained the same.

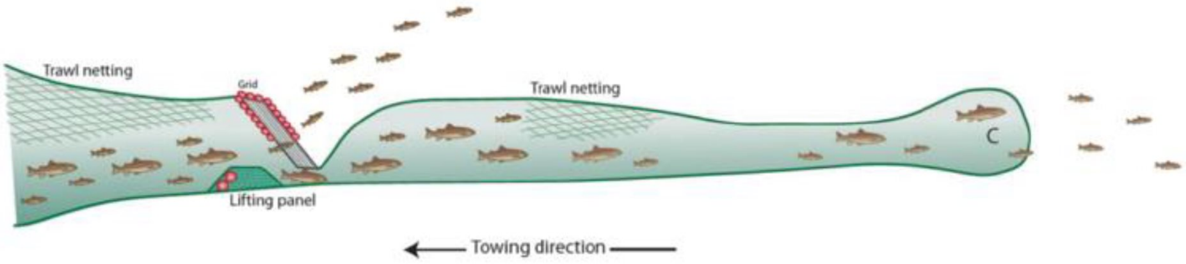

Fig. 1: Illustration of the working principle of the grid and codend configuration used in the Barents Sea demersal trawl fishery.

Norwegian whitefish trawl fishery, like many other trawl fisheries around the globe, has become increasingly controversial in the last decade due to the environmental impact attributed to trawls (Løkkeborg, 2005). In many bottom trawls, the ground gear is one of the main components contributing to the overall seabed impact of the gear, and particularly in fisheries targeting bottom-dwelling species can be heavy. Trawlers fishing for cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) in the Norwegian and Barents Sea use almost exclusively rockhoppers. Rockhoppers are known to inflict damage to the seabed (Watling and Norse, 1998) and have also been reported to contribute to low catch efficiencies as substantial quantities of fish can escape under the ground gear during the fishing operation (Ingolfsson and Jørgensen, 2006). In an attempt to reduce seabed impact and improve catch efficiency, a Semi-Circle Spreading Gear (SCSG) has earlier been tested on scientific basis. Regarding catch efficiency the results were encouraging. Further, the gear is hydrodynamically designed to reduce friction with the seabed (Fig. 2) and weighs approximately 1/3 of an equivalent rockhopper spread over a larger surface, therefore, it is assumed that its bottom impact is lower than that of rockhoppers (Brinkhof et al., 2017; Larsen et al., 2018). This, however, needs further documentation. Despite the promising results obtained on a research vessel, the SCSG has never been commercially tested.

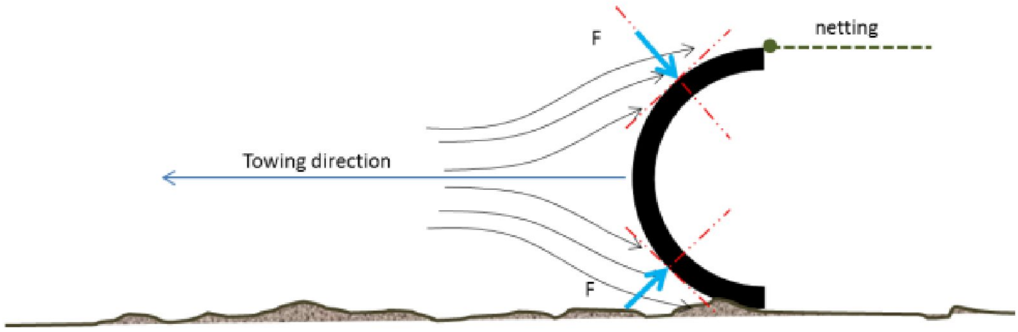

Fig. 2: Illustration of the forces acting on the semi-circular plates (Source: Grimaldo et al., 2013).

Thus, the aim of the present trials is twofold:

1) Test whether an upscaled sorting grid can provide better size selectivity results than an equivalent grid of standard size.

2) Test whether a SCSG results on at least as good catch efficiency as an equivalent rockhopper ground gear.

2 Materials and methods

2.1. Fishing trials

Fishing trials were conducted in the Barents Sea and more specifically in the fishing grounds around Bear Island (73° 48' 405" / 76° 00' 619" N – 15° 40' 766" / 22° 55' 537" E) between the 14^{th} and 27^{st} of November 2023. A commercial trawler, "M/Tr Ramoen" (75.1 m LOA, 3723 Gross Tonnage), was chartered for the experiments. The vessel is a modern whitefish trawler in the Barents Sea that operates with a twin-trawl configuration. It employs two Selstad

630# trawls (headline height ca. 7 m), a pair of Thyborøn type 26 VFG doors (9 m^2, ~4400 kg each), a central clump (Thyborøn 2700 mm, ~6500 kg) and 100 m sweeps. The door distance is typically 220-250 m depending on the fishing depth.

2.1.1 Gear configuration for the tests with an upscaled grid

During the first trials, both trawls were rigged identically to the belly of the trawl. In the aft of one of the trawls, we installed a standard Sort-V grid section built of 135 mm mesh size (nominal) netting with a steel standard-size grid. The bar spacing of the grid was measured to be 55.17 ± 0.36 mm (mean ± SD). This section, including the grid, which has an effective sorting area of 2.16 m^2, was identical to the one used by the commercial fleet today (Fig. 3a).

In the other trawl, we installed an upscaled version of the standard grid section currently used by the fleet, which was also built of 135 mm (nominal) mesh size netting. The effective sorting area of the grid in this case was 4.32 m, double as large as that of the standard grid. The bar spacing of the grid was measured to be 55.19 ± 0.67, which was practically the same as that of the standard grid with a somewhat larger variation. For structural reasons, the upscaled grid had two transversal steel bars compared to the single transversal steel bar in the standard grid. The length and height of the netting section were upscaled accordingly so that the grid could be installed in the section with the same angle as in the standard section (approx. 25° (Larsen ad Isaksen, 1993)). This resulted in the section of the upscaled grid being 25.5 meshes longer and 22 meshes higher than the standard grid section.

Both grid sections had a 58-mesh extension piece in front and 35 mesh extension behind (Fig. 3) before the codend. The codends in each of the trawls were built of knotless netting and were #90 meshes long with a circumference of #80 free meshes around. Both codends were blinded with liners built of netting with 32.90 ± 0.74 mm mesh size, which ensured that no cod or haddock under 10 cm would be able to escape from the codend (Sistiaga et al., 2011).

The upscaled grid was defined as the Test1 gear during the experiments whereas the standard grid section was defined as the Test2 gear. The Test1 and Test2 gears were alternated during the trials to avoid any influence due to potential differences in the fishing power of the two trawls employed (Fig. 4; Table 1). The catches from both trawls were kept in separate bins onboard. All cod and haddock were measured to the nearest cm below except for those hauls where for practical issues the catch had to be subsampled. In the hauls where the catch had to be subsampled, all fish in the fraction that was not measured were counted and the subsampling factor calculated (Table 1).

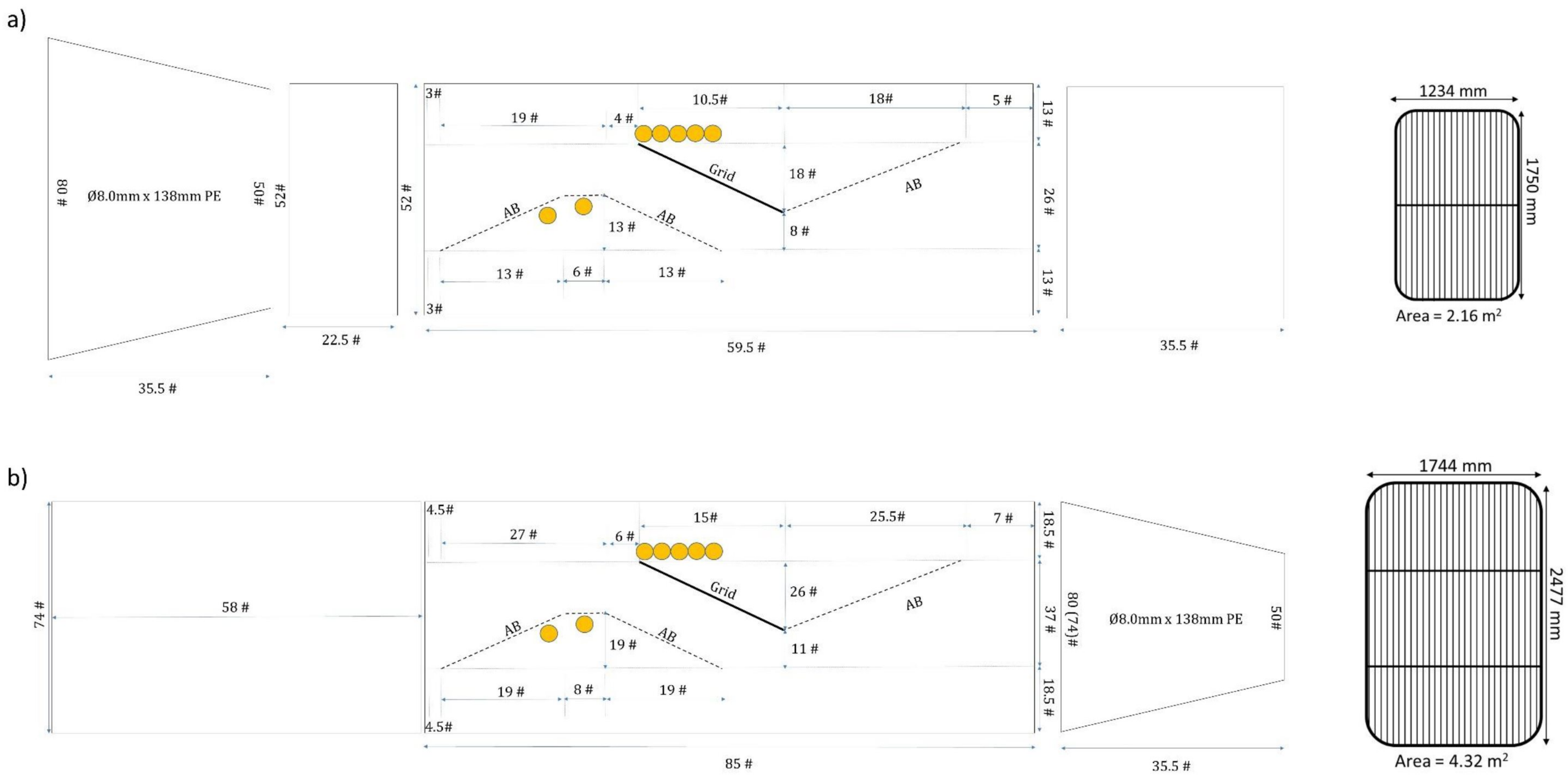

Fig. 3: Drawings of the two grid sections tested during the sea trials. a) Standard Sort-V grid and b) Upscaled Sort-V grid.

All trials included in this study followed normal commercial fishing practice and the animals were not exposed to any additional harm. Therefore, this study did not require any specific permits from the authorities regarding animal rights. Further, the trials did not involve any endangered or protected species.

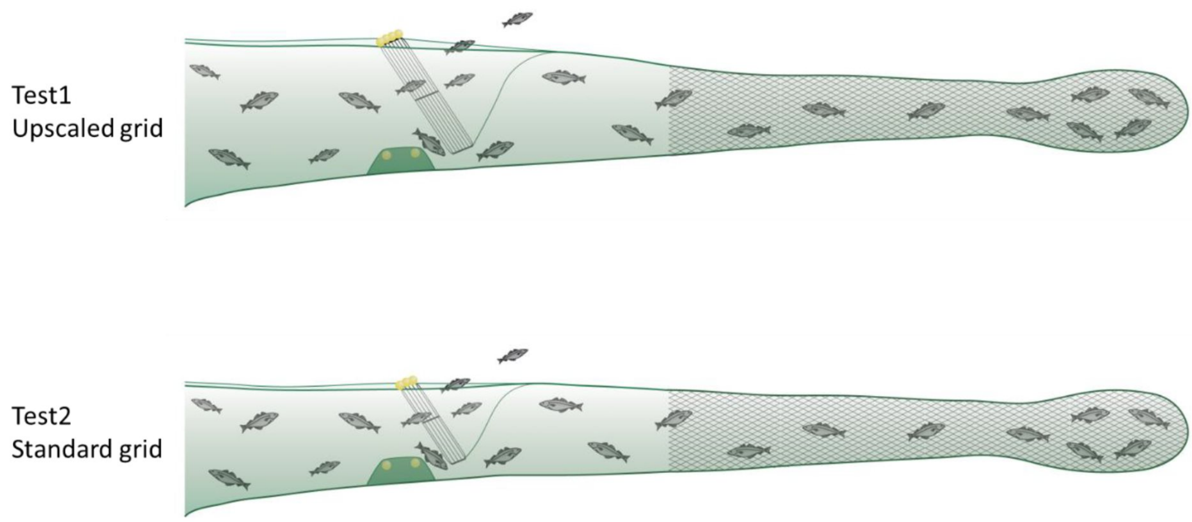

Fig. 4: Illustration of the gear configuration used during the trials with the upscaled and standard grids.

2.1.2 Gear configuration for the tests with the SCSG

The trawls used for the tests with the SCSG were the same as those used in the trials with the upscaled grid (Section 2.1.1). The SCSG was installed in one of the trawls while in the other trawl one of the rockhoppers used by the commercial vessel was installed. For these trials the grid sections and liners in the codends were removed. Thus, the mesh size of the codend used together with the SCSG was 130.67 ± 3.33 mm (mean ± SD) whereas the codend used together with the rockhopper as ground-gear had a mean mesh size of 133.92 ± 2.59 mm.

The SCSG was composed of seven sections; a section of 4.3 m in the middle, two sections of 4.7 m at the sides, and four sections of 4.14 in between (Fig. 5a). Each section was built of seven or eight semi-circle modules of 50 cm. The tube used to build these modules had an external diameter of 50 cm and internal diameter of 44 cm (Fig. 5a). The different sections were joined together and to the rest of the ground gear of the trawl by 12 cm locks. The total length of the SCSG was 31 m. The rockhopper used was also 31 m and composed of 50 cm high rubber discs alternated with metal and rubber spacers (Fig. 5b).

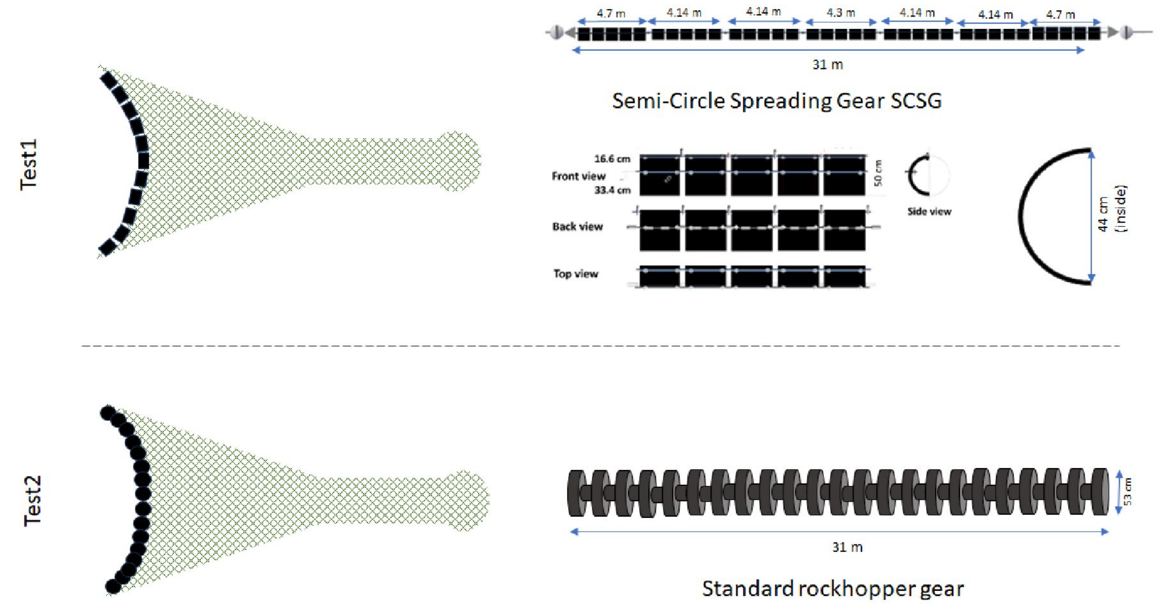

Fig. 5: Illustration of the SCSG (a) and Rockhopper gear (b) used during the sea trials.

Once the tow was finished the catch was handled following the same procedure as in the trials with the upscaled grid (section 2.1.1).

2.2 Data analyses

The data collected to compare the upscaled grid (Test1) versus the standard grid (Test2) in the first part of the trials, and the SCSG (Test1) versus the rockhopper gear (Test2) trials carried out in the second part of the trials, were analyzed separately.

In both experiments, the data could be analyzed as paired because they were collected with a twin trawl configuration. We carried out a catch comparison (*CC*) / catch ratio (*CR*) analysis to study the potential length-dependent differences in the catch efficiency between the gears averaged over hauls. The catch *CC*/*CR* analysis carried out was identical to that used by Sistiaga et al. 2023 to investigate potential differences between a new and a used grid.

This method models the size-dependent catch comparison ratio (proportion caught in Test1 trawl, CC_l) summed over hauls:

$$CC_l = \frac{\sum_{j=1}^{h}\left\{\frac{nTest1_{lj}}{qTest1_j}\right\}}{\sum_{j=1}^{h}\left\{\frac{nTest1_{lj}}{qTest1_j}+\frac{nTest2_{lj}}{qTest2_j}\right\}} \qquad (1)$$

where $nTest11_{lj}$ and $nTest2_{lj}$ are the numbers of individuals of the species caught in length class l in the Test1 and Test2 trawls, respectively for haul j. h is the number of hauls carried out in that specific cruise, while $qTest1_j$ and $qTest2_j$ are the subsampling factors for each specific haul j, i.e. the fraction of fish measured from the total number of individuals caught of the species being length measured in the respective trawl.

The functional form for the catch comparison rate $CC(l, \boldsymbol{v})$ was obtained using maximum likelihood estimation by minimizing the following expression:

$$-\sum_l \left\{ \sum_{j=1}^{h} \left\{ \frac{nTest1_{lj}}{Test1} \times ln\big(CC(l,v)\big) + \frac{nTest2_{lj}}{qTest2_j} \times ln\big(1.0 - CC(l,v)\big) \right\} \right\} \qquad (2)$$

where $\boldsymbol{v}$ represents the parameters describing the catch comparison curve defined by $CC(l, \boldsymbol{v})$. The outer summation in expression (2) is the summation over the length classes l. When the catch efficiency of the Test1 and the Test2 is equal, the expected value for the summed catch comparison rate would be 0.5. Therefore, this baseline can be applied to judge whether there is a difference in catch efficiency between the two gears. The experimental CC_l was modelled by the function $CC(l, \boldsymbol{v})$, on the following form:

$$CC(l,v) = \frac{exp\big(f(w,v_0,\ldots,v_s)\big)}{1+exp\big(f(w,v_0,\ldots,v_s)\big)} \qquad (3)$$

where f is a polynomial of order t with coefficients v_0 to v_s. The values of the parameters $\boldsymbol{v}$ describing $CC(l, \boldsymbol{v})$ are estimated by minimizing expression (2), which are equivalent to maximizing the likelihood of the observed catch data. We considered s of up to an order of 4 with parameters v_0, v_1, v_2, v_3 and v_4. Leaving out one or more of the parameters $v_0 \ldots v_4$ led to 31 additional models that were also considered as potential models for the catch comparison $CC(l,\boldsymbol{v})$. Among these models, estimations of the catch comparison rate were made using multi-model inference to obtain a combined model (Burnham and Anderson, 2002; Herrmann *et al.*, 2017).

The ability of the combined model to describe the experimental data was evaluated based on the p-value. This p-value, which was calculated based on the model deviance and the degrees of freedom, should not be <0.05 for the combined model to describe the experimental data sufficiently well, except for cases where the data were subjected to over-dispersion (Wileman et al., 1996; Herrmann et al., 2017). Based on the estimated catch comparison function $CC(l, \boldsymbol{v})$ we obtained the relative catch efficiency (also named catch ratio) $CR(l, \boldsymbol{v})$ between the two trawls with the two different gears by the following relationship:

$$CR(l,v) = \frac{CC(l,v)}{(1-CC(l,v))} \qquad (4)$$

The catch ratio represents the ratio between the catch efficiency of the trawl with the Test1 gear and the trawl with the Test2 gear. Thus, if the catch efficiency of both trawls for that given species is equal, $CR(l,\mathbf{v})$ should always be 1.0. Similarly, $CR(l, \mathbf{v})$ = 1.5 would mean that the trawl with the Test1 gear is catching 50% more individuals of size l of that specific species than the trawl with the Test2 gear. Contrary, if $CR(l, \mathbf{v})$ = 0.7 would mean that the trawl with the Test1 gear is only catching 70% of the individuals of length l for the specific species investigated.

The confidence limits for the catch comparison and catch ratio curves were estimated using a double bootstrapping method (Herrmann et al., 2017). This technique accounts for uncertainty due to between-haul variation by selecting m hauls with replacement from the m hauls available during each bootstrap repetition. Within each resampled haul, the data for each length class are resampled in an inner bootstrap to account for the uncertainty in the haul due to a finite number of cod and haddock. To correctly account for the increased uncertainty due to subsampling, the data were raised by sampling factors after the inner resampling. However, the outer bootstrapping loop in the current study that accounted for the between-haul variation was performed pairwise for the Test1 and Test2 gear configurations, reflecting the experimental design in which both gears were deployed simultaneously. Moreover, by using multi-model inference in each bootstrap iteration, the method also accounted for the uncertainty in model selection. We performed 1000 bootstrap repetitions and calculated the Efron 95% confidence limits (Efron, 1982). To identify the sizes of the different species with significant differences in catch efficiency, we checked for size classes in which the 95% confidence limits for the catch ratio curve did not contain 1.0.

In addition to the CC/CR, indicators in the form of size-integrated average values for the catch ratio ($CR_{average}$) were estimated directly from the experimental catch data. The size classes in the catch during the experimental fishing period respectively under ($CR_{average-}$) and over ($CR_{average+}$) Minimum Legal Size (*MLS)* were estimated for cod and haddock. The *MLS* for cod in the Barents Sea is 44 cm whereas for haddock it is 40 cm. In addition to the $CR_{average}$, the discard ratios for the upscaled grid (Test1) and standard grid (Test1) in one study, and the SGSG (Test1) and rockhopper gear (Test2) in the other study were estimated. The indicators were estimated following the exact same procedure as in Sistiaga et al., 2023.

$$CR_{average-} = 100 \times \frac{\sum_{l<MLS}\sum_{j=1}^{h}\left\{\frac{nTest1_{lj}}{qTest1_{j}}\right\}}{\sum_{l<MLS}\sum_{j=1}^{h}\left\{\frac{nTest2_{lj}}{qTest2_{j}}\right\}}$$
$$CR_{average+} = 100 \times \frac{\sum_{l\geq MLS}\sum_{j=1}^{h}\left\{\frac{nTest1_{lj}}{qTest1_{j}}\right\}}{\sum_{l\geq MLS}\sum_{j=1}^{h}\left\{\frac{nTest2_{lj}}{qTest2_{j}}\right\}} \quad (5)$$

where the outer summations include the size classes in the catch during the experimental fishing period respectively under (for $CR_{average-}$) and over (for $CR_{average+}$) MLS for cod and haddock. In addition to the $CR_{average}$, the discard ratios for the Test1 and Test2 gears were estimated by:

$$nDiscardRatioTest1 = 100 \times \frac{\sum_{l<MLS}\sum_{j=1}^{h}\left\{\frac{nTest1_{lj}}{qTest1_{j}}\right\}}{\sum_{l}\sum_{j=1}^{h}\left\{\frac{nTest1_{lj}}{qTest1_{j}}\right\}}$$
$$nDiscardRatioTest2 = 100 \times \frac{\sum_{l\geq MLS}\sum_{j=1}^{h}\left\{\frac{nTest2_{lj}}{qTest2_{j}}\right\}}{\sum_{l}\sum_{j=1}^{h}\left\{\frac{nTest2_{lj}}{qTest2_{j}}\right\}} \quad (6)$$

Note that discards are not allowed in the Barents Sea and that fish under *MLS* captured must be processed onboard. The naming used here is only justified by the terminology earlier used for this parameter in literature (Wienbeck et al., 2014; Melli et al., 2020).

We used the statistical analysis software SELNET (Herrmann et al., 2012, 2017) to conduct size-dependent *CC* and *CR* analyses and to estimate the indicator values. Results

3 Results

3.1 Upscaled grid versus standard grid

During the first part of the cruise comparing the upscaled and the standard sorting grids, a total of 21 hauls that had sufficient numbers of cod and/or haddock to be included in the data analysis were carried out. (Table 1). During the cruise, a total of 24,384 cod and 12,520 haddock were measured.

Table 1: Overview of the hauls conducted during the experimental sea trials with the upscaled grid and the standard grid. LGM is the number of fish measured in the trawl with the upscaled grid, LGT is the total number of fish in the trawl with the upscaled grid, SGM is the number of fish measured in the trawl with the standard grid and SGT is the number of fish in the trawl with the standard grid. Data for cod and haddock. SF: subsampling fraction applied to each compartment.

Haul Nr	Date	Time start (hh:mm)	Towtime (hh:mm)	Depth (m)	Side LG	Cod (*n*)						Haddock (*n*)						Total Catch (kg)
						LGM	LGT	SF	SGM	SGT	SF	LGM	LGT	SF	SGM	SGT	SF	
1	14.nov	04:00	03:56	232	port	826	826	1.000	662	662	1.000	186	175	1.000	153	321	1.000	2735
2	14.nov	09:30	05:04	221	Port	927	927	1.000	1170	1170	1.000	278	250	1.000	44	385	1.000	4063
3	15.nov	15:37	05:24	201	Port	636	636	1.000	533	533	1.000	294	248	1.000	292	264	1.000	3396
4	15.nov	21:30	04:52	216	Port	537	537	1.000	607	607	1.000	552	595	1.000	653	664	1.000	4600
5	15.nov	03:23	05:09	227	Port	680	680	1.000	774	774	1.000	369	290	1.000	414	346	1.000	4530
6	15.nov	09:45	05:23	228	Port	959	959	1.000	938	938	1.000	238	181	1.000	205	192	1.000	3463
7	16.nov	15:41	05:10	230	Port	722	1204	0.600	677	1216	0.557	256	212	1.000	276	191	1.000	5000
8	16.nov	21:26	02:16	270	Port	245	236	1.000	255	256	1.000	532	536	1.000	631	633	1.000	3011
9	17.nov	03:14	04:34	240	Port	478	478	1.000	493	493	1.000	276	276	1.000	582	582	1.000	3429
10	17.nov	09:02	05:02	203	Port	256	256	1.000	293	293	1.000	167	167	1.000	433	433	1.000	1168
11	17.nov	20:56	03:39	300	Port	328	328	1.000	392	392	1.000	354	354	1.000	593	593	1.000	2509
13	18.nov	04:41	05:07	266	starboard	541	528	1.000	506	500	1.000	328	307	1.000	326	304	1.000	3437
14	18.nov	10:33	04:44	355	starboard	522	673	0.776	500	618	0.809	387	500	0.774	495	635	0.780	3747
15	18.nov	16:29	04:40	259	starboard	651	1211	0.538	524	1131	0.463	546	917	0.595	478	786	0.608	9579
16	18.nov	21:26	04:46	305	starboard	567	991	0.572	626	833	0.752	385	647	0.595	390	545	0.716	5079
17	19.nov	03:14	04:53	274	starboard	534	719	0.743	499	700	0.713	389	525	0.741	394	607	0.649	4267
18	19.nov	09:02	02:21	290	starboard	142	142	1.000	95	95	1.000	292	292	1.000	332	332	1.000	1844
19	19.nov	20:56	01:42	216	starboard	678	2037	0.333	533	2017	0.264	*	*	*	*	*	*	7201
20	19.nov	23:31	04:18	235	starboard	700	2469	0.284	794	2469	0.322	*	*	*	*	*	*	9752
23	20.nov	16:29	04:49	234	starboard	585	3161	0.185	641	3288	0.195	*	*	*	*	*	*	10056
24	20.nov	22:13	04:51	244	starboard	667	3246	0.205	691	3487	0.198	*	*	*	*	*	*	12825

3.1.1 CC/CR analysis

The *CC* analysis shows that despite the *p*-values being <0.05 in the fit statistics, the resulting models represented the trends in the data well for both cod and haddock. Thus, the low *p*-values are assumed to be a result of overdispersion in the data and not unadequate fit. (Table 2; Fig. 6).

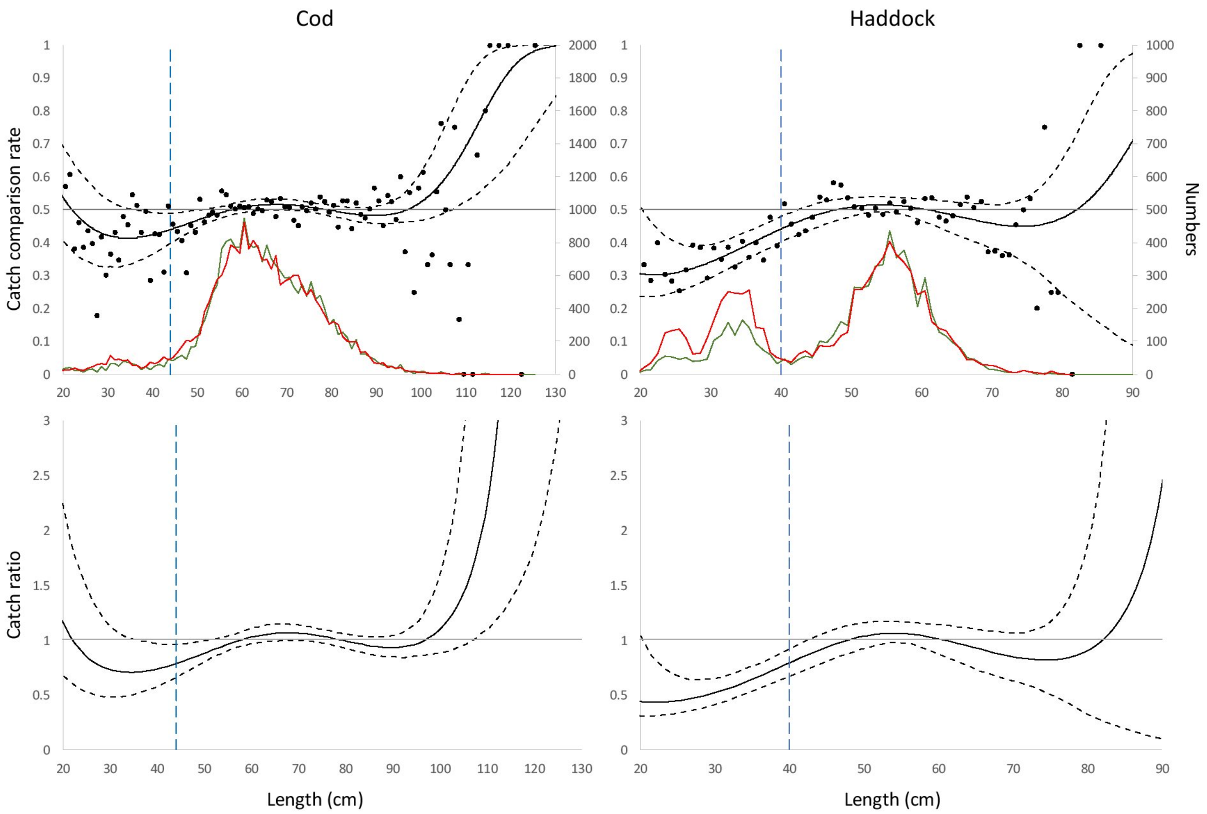

Fig. 6: Catch comparison rate (top row) and catch ratio (lower row) for the trawl configuration with the upscaled grid versus the standard sorting grid. In the catch comparison plots the circles show the experimental catch comparison ratios, whereas the solid line and the stippled lines show the modelled catch comparison ratio and the corresponding 95% confidence intervals. The green lines show the catch distribution in the upscaled grid configuration gear whereas the red lines show the catch distribution in the standard grid configuration gears, both with scale in the right axis. In the catch ratio plots the solid black curve is the catch ratio curve, and the stippled curves are the corresponding 95% confidence intervals. The horizontal grey lines represent the line for equal fishing power in each of the comparisons, whereas the vertical stippled blue line represents the *MLS* in every case.

Table 2: Fit statistics for the *CC* ratio curves for both cod and haddock. DOF = Degrees of Freedom.

	p - value	Deviance	DOF
Cod	<0.001	196.29	104
Haddock	0.0313	92.44	69

The *CC*/*CR* analysis shows that the trawl with the upscaled grid captured significantly less cod between 36 and 50 cm than the trawl with the standard grid configuration. However, these differences dissapeared for fish above 50 cm and to 100 cm, meaning that both trawls were catching fish of these sizes with equal efficiency. There was barely any cod above 100 cm, which is anyway well above the selective range of any grid with a 55 mm bar spacing (Sistiaga et al., 2011). The data for haddock showed a similar trend, but the differences were more marked for this species. The gear configuration with the upscaled grid captured significantly less undersized fish, fish between 20 and 41 cm, than the gear cnfiguration with the standard grid. For fish above 41 cm, which is just above the *MLS* for haddock, there were no differences in the catch efficiency between the gears compared.

The exploitation pattern indicators showed that for cod, the probability for fish both above and below MLS to be captured in either trawl was not significantly different from 100% in any of the two cases. Further, the discard ratio estimated for the upscaled grid configuration was not significantly different of that of the standard grid for cod (Table 3). For haddock, the results showed that the probability for a fish under *MLS* to be caught when the upscaled grid configuration was used was ca. 45% lower than when the standard grid was used. For haddock above *MLS* on the other hand the differences were not significant, which led probably to that the discard ratio between the configurations was not significantly for haddock either (Table 3).

Table 3: Exploitation pattern indicators for the trials comparing the upscaled grid configuration (LG) and the standard grid configuration (SD).

	$CR_{average-}$ (%)	$CR_{average+}$ (%)	*n* Discard ratio LG (%)	*n* Discard ratio SD (%)
Cod	78.30 (54.03 - 115.80)	100.83 (96.14 - 106.96)	5.39 (4.11 - 7.01)	6.84 (4.78 - 8.78)
Haddock	55.41 (45.01 - 71.08)	101.98 (93.41 - 111.74)	23.95 (15.58 - 36.07)	36.69 (23.49 - 53.44)

3.2 SCSG vs Rockhopper

For the comparison between the SCSG and the rockhopper gear, only data for cod could be collected in sufficient numbers. A total of nine hauls were included in the analysis.

Table 4: Overview of the hauls conducted during the experimental sea trials with the SCSG and the Rockhopper gear. SCSGM is the number of fish measured in the trawl with the SCSG, SCSGT is the total number of fish in the trawl with the SCSG, RHGM is the number of fish measured in the trawl with the rockhopper gear and RHGT is the number of fish in the trawl with the rockhopper gear. Data for cod and haddock. SF: subsampling fraction applied to each compartment.

Haul Nr	Date	Time start (hh:mm)	Towing time	Depth (m)	Side Test1	Cod (*n*)						Total
						SCSGM	SCSGT	SF	RHGM	RHGT	SF	Catch (Kg)
32	24.nov	19:04	04:04	196	starboard	609	5175	0.118	660	2477	0.266	12155
33	25.nov	00:06	05:03	145	starboard	601	7569	0.079	561	5229	0.107	18420
34	25.nov	09:54	04:18	138	starboard	559	4329	0.129	516	2000	0.258	9206
36	25.nov	19:59	04:06	164	starboard	510	3668	0.139	609	2379	0.256	7860
37	26.nov	00:42	04:48	143	starboard	593	7430	0.080	579	3457	0.167	16794
38	26.nov	06:29	05:22	163	starboard	511	4888	0.105	514	2391	0.215	10436
40	27.nov	18:31	05:33	163	starboard	531	5224	0.102	520	2636	0.197	8256
41	27.nov	00:46	05:05	138	starboard	514	5581	0.092	529	3509	0.151	15205
42	27.nov	06:52	05:37	137	starboard	508	5284	0.096	540	2717	0.199	11473

3.2.1 CC/CR analysis

The *CC* analysis shows that the *p*-value is <0.05 for the model applied. However, the model represented the trends in the data well and therefore, we assumed that this low *p*-value is just a result of overdispersion in the data (Table 5; Fig. 7).

Table 5: Fit statistics for the *CC* ratio curve for cod. DOF = Degrees of Freedom.

	p - value	Deviance	DOF
Cod	<0.001	138.63	81

The *CC*/*CR* size distribution cuves showed that the trawl with the SCSG captured significantly more cod between 23 and 88 cm than the trawl with the rockhopper gear. The size distribution of the fish captured through the whole cruise (pooled) with the SCSG and the rochopper gear were clearly different, supporting the *CC*/*CR* results obtained (Fig. 7).

The exploitation pattern indicators showed that the SCSG had on average a probability to catch cod under *MLS* that was 116% higher than the rockhopper gear and a 82% higher capture probability for fish above *MLS*. In both cases, the differences between the catch efficiency of the gears is significant. The discard ratio for the SCSG was 1.3% higher than that for the rockhopper gear, but this difference was not significant (Table 6).

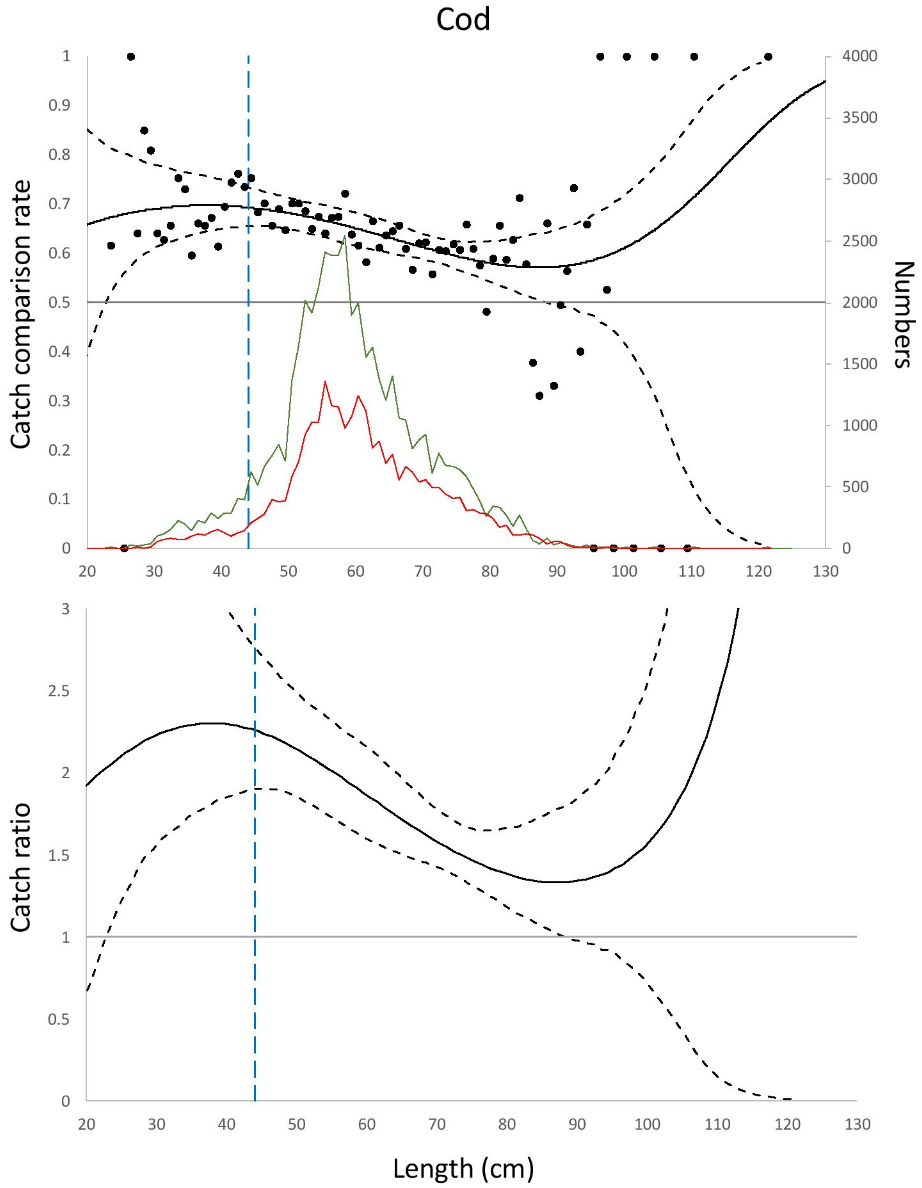

Fig. 7: Catch comparison rate (top) and catch ratio (down) for the trawl configuration with the SCSG versus the trawl with the rockhopper gear. In the catch comparison plot the circles show the experimental catch comparison ratios, whereas the solid line and the stippled lines show the modelled catch comparison ratio and the corresponding 95% confidence intervals. The green line shows the catch distribution in the SCSG whereas the red line shows the catch distribution in the trawl with the rockhopper gear, both with scale in the right axis. In the catch ratio plot the solid black curve is the catch ratio curve, and the stippled curves are the corresponding 95% confidence intervals. The horizontal grey line represents the line for equal fishing power in each of the comparisons, whereas the vertical stippled blue line represents the *MLS* for cod.

Table 6: Table 3: Exploitation pattern indicators for the trials comparing the SCSG and the rockhopper gear.

	$CR_{average-}$ (%)	$CR_{average+}$ (%)	*n* Discard ratio SCSG (%)	*n* Discard ratio Rockhopper (%)
Cod	226.47 (167.12 - 319.27)	181.75 (161.69 - 204.11)	6.91 (6.05 - 7.98)	5.63 (4.19 - 7.46)

4 Discussion and conclusion

The aim of the present trials was twofold: to test whether an upscaled sorting grid can provide better size selectivity results than an equivalent grid of standard size, and to investigate whether a SCSG results on at least as good catch efficiency as an equivalent rockhopper ground gear.

The results from the trials showed that increasing the size of the grid enhances its size sorting properties, especially when the fish entry densities in the trawl are high. For haddock, the upscaled grid significantly reduced the probability for capture of individuals below *MLS* without reducing the probability for capture of individuals above *MLS*. This would be largely beneficial for the fishing industry as it would contribute to maximizing the value of their quotas and at the same time reducing the environmental impact and inconveniences linked to catching fish under *MLS*. The results for cod showed the same tendency as for haddock and were also slightly significant for a range of length classes, however, the difference between the grids was not as clear in this case. Haddock has earlier been reported to be a more active species than cod in the trawl with a higher ability to contact and be size sorted by sorting grids (Sistiaga et al., 2010). Thus, it is likely that haddock can take more advantage than cod of the increase in grid area in the upscaled grid, increasing its chances for escape when it can physically pass between the bars in the grid.

In the past three decades, the size of the vessels and the trawls employed in the Barents Sea demersal trawl fishery have increased substantially. Further, pelagic trawls, which can be very effective and capture high densities, have been considered implemented in the fishery. However, the grid sections employed by the fleet have remained the same since they were implemented in 1993. During the trials, using the upscaled sorting grid did not imply any additional work or maneuverability challenge for the crew compared to the standard sorting grid. But, due to its size, the risk for the bars in the upscaled grid to bend is higher than that of the standard grid and therefore, the grid needs to be tested over longer periods and its structural strength further improved.

The results of the second part of the sea trials showed that using a SCSG as ground gear instead of a traditional rockhopper gear led to substantially higher catch efficiency for cod. The results showed that the probability for the SCSG to capture fish above and below MLS was significantly higher for the SCSG, however, considering the distribution of fish in the fishing grounds, it is clear that the increase in retention of fish above *MLS* exceeds the increase in retention of fish below *MLS*. Further, it needs to be considered that these comparison trials were carried out without sorting grids, which most likely would have reduced the numbers of undersized cod in both trawls and potentially reduce the differences observed for these sizes of fish. The differences observed for the fish above *MLS* show that the use of the SCSG vs the rockhopper gear results in a major increase in catch efficiency. If this difference is upscaled to the whole whitefish trawler fleet operating in the Barents Sea, it could have a major impact for the fishery. Due to time constraints, in the present experiments only nine hauls could be carried out and the ground gears could not be shifted from starboard to port side and vice versa. Thus, despite the encouraging results obtained during this trial, the SCSG needs to be further tested over a larger number of hauls alternating its position in a twin trawl configuration, and in areas with different size distributions of fish and different seabed substrates.

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