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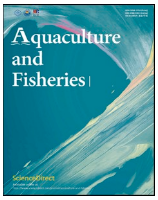

Original research article

Used vs. new: Does it have consequences for the performance of fishing gear?

Manu Sistiaga [a,b,*], Terje Jørgensen [a], Ilmar Brinkhof [b], Bent Herrmann [b,c,d], Jesse Brinkhof [b,c]

[a] *Institute of Marine Research, Postbox 1870 Nordnes, Bergen, N-5817, Norway*
[b] *The Arctic University of Norway, UiT, Breivika, Tromsø, N-9037, Norway*
[c] *SINTEF Fisheries and Aquaculture, Brattørkaia 17C, Trondheim, N-7010, Norway*
[d] *DTU Aqua, Technical University of Denmark, Hirtshals, 9850, Denmark*

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ABSTRACT

Sea trials to test size selectivity equipment in trawls are often limited in time because they are costly, and the results can be influenced by multiple factors that are often overlooked. In the Barents Sea gadoid trawl fishery, the use of a size sorting grid in front of the codend is compulsory. The flexigrid, a netting section containing two flexible grids, is the most widely used grid section in this fishery. However, earlier selectivity studies with this device have shown inconclusive results. It has been speculated that the differences observed resulted from the difference in age and usage of the grid sections in the studies compared. To reveal whether potential changes in the device construction over time can lead to differences in size selection properties, we performed comparative fishing trials where we compared a brand new flexigrid section and a well-used flexigrid section used continuously by a commercial trawler for approximately four years. The results showed that the new flexigrid released significantly more cod below ~60 cm than the used flexigrid. However, when the grids were fished with a subsequent diamond mesh codend, there was no difference in the overall selectivity of the two gears, meaning that the size selectivity in the codend compensates for the potential reduction in selectivity performance of the grids. This study shows the importance of considering the age and earlier use of size selection devices like sorting grids before they are compared with other devices, as their size selection properties can change significantly over time and with use.

1. Introduction

Studies in fishing gear technology are frequently motivated by industrial and management challenges of diverse nature e.g., environmental impact, catch efficiency or selectivity issues. These types of studies can be diverse ranging from small scale laboratory or flume tank experiments on land, to sea trials with commercial scale gear. Sea trials are costly, which often limit their duration, and conditions at sea vary constantly e.g., weather, species composition and availability of fish. Therefore, mimicking the conditions experienced by the commercial fleets can be difficult.

The management regulations for most fish stocks harvested worldwide comprise minimum catch sizes or contain laws that regulate the sizes of fish that can legally be caught (FAO, 1995, p. 41). Therefore, size selectivity in fishing gear, and especially in towed fishing gear like trawls or demersal seines, is one of the most widely studied topics within fishing gear technology (Kennelly & Broadhurst, 2021).

In the Barents Sea gadoid fishery, cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) are the main target species and have Minimum Legal Sizes (*MLS*s) of 44 cm and 40 cm, respectively. The size selectivity of whitefish trawls in this region is based on a dual size selection system comprising a sorting grid with a minimum bar spacing of 55 mm and a codend with a minimum mesh size of 130 mm. Thus, undersized fish that do not escape through the grid can get additional escape opportunities in the codend. There are three different sorting grid systems permitted in the Barents Sea: the Sort-X (Larsen & Isaksen, 1993), the Sort-V (Jørgensen et al., 2006), and the flexigrid (Sistiaga et al., 2016). The flexigrid, which contains two grid panels i.e., grid 1 and grid 2, is the most widely used system today due to easier handling compared to the other two systems (Sistiaga et al., 2016). In the grid and codend dual selection system utilized in the Barents Sea, the first size selection process in the grid section is complemented by a subsequent

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[*] Corresponding author. Institute of Marine Research, Postbox 1870 Nordnes, Bergen, N-5817, Norway.
E-mail address: manu.sistiaga@hi.no (M. Sistiaga).

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mesh size selection process in the codend. Both Sistiaga et al. (2010) and Brinkhof et al. (2020) demonstrated that in such a dual system, most escapees occur in the grid. The grid is the first selection device in the sequential process and a grid bar spacing of 55 mm is equivalent to a diamond mesh size of approximately 155 mm (Jørgensen et al., 2006). However, the selective role of the codend may become more important in scenarios where the sorting capacity of the grid is reduced e.g., due to clogging.

The size selectivity of sorting grids in whitefish fisheries has been widely studied since they were implemented in Norway in the 90s (Larsen et al., 2018; Larsen & Isaksen, 1993). The research spans from studies of changes in grid design (Grimaldo et al., 2015) to consequences of using different bar spacings (Sistiaga et al., 2008). Some of the results obtained in these grid studies illustrate a recognized problem in fisheries technology science; that gear performance studies carried out with the same gear can provide different results or are not able to mimic the results obtained by the fishing industry. Sistiaga et al. (2016) and Brinkhof et al. (2020) presented size selectivity results for flexigrid sections that significantly differed from each other. In the latter study it was speculated that the poorer performance of the grid section experienced in Sistiaga et al. (2016) resulted from the grid section in that study having suffered from potential structural changes due to “rough handling and forces from large catches”, which resemble scenarios often meet during commercial fishing practice. Similar differences in selectivity performance have also been experienced for other types of sorting grid sections e.g., Sistiaga et al. (2010) vs Larsen et al. (2018). In a review of bycatch reduction devices in fishing gear, Kennelly and Broadhurst (2021) identified a number of important issues that can compromise sea trial results in size selectivity studies, and specifically mentioned biological, environmental and operational factors like sea state (Somerton et al., 2018), towing speed (Sala et al., 2007) or catch weight (O’Neill et al., 2008). These factors can potentially lead to different outcomes when performing similar studies and have often been overlooked in the literature.

In sea trials designed to test fishing gear, it is common that the gears used in the tests are new and unused. However, if the characteristics of the device change with its use, and consequently its size selection properties, it could have serious implications for the outcomes and conclusions from the trials. An example that illustrates this issue is the use of T90 meshes (meshes turned by 90°) in the codend. T90 mesh panels have long been suspected to change their size selection properties after prolonged use and exposure to large loads. Several studies have speculated that as T90 meshes stretch, they lose their intended shape and acquire more diamond mesh-like size selection properties (ICES, 2011). This is also potentially the case for the flexigrid, which is mounted in a netting section and built of rubber and plastic, materials that can change their properties with time. The meshes in the flexigrid section can stretch due to exposure to large loads over time, likely resulting in lower grid angles than initially intended and deformation of the grids. As illustrated by Brinkhof et al. (2020), these structural deformations can lead to the flexigrid acquiring a tunnel-like shape with lower likelihood for fish to interact with the grids, consequently resulting in poorer size sorting properties.

The present investigation compares the size selectivity of a flexigrid section exposed to large loads over time and the size selectivity of a brand new flexigrid section, with the aim of evaluating the potential implications of employing used or new equipment in size selectivity studies. Specifically, the study aimed at answering the following research questions.

- Do a well-used flexigrid section exposed to large loads over time and a new flexigrid have equal size sorting properties?
- What are the potential differences in size selection properties between a well-used flexigrid section exposed to large loads over time and a new flexigrid section?
- To what extent does the codend compensate for the overall size selectivity in cases where the size sorting properties of the grid have been reduced?

2. Materials and methods

2.1. Fishing trials

Fishing trials were conducted in the Barents Sea, around Bear Island (73°43′316 N - 75°56′728′′ N and 15°40′536′ E - 20°49′378′ E), from the 21st to the 31st of October 2022. The commercial vessel “M/Tr Ramoen” (75.1 m LOA, 3723 Gross Tonnage) was chartered for the trials. The vessel operates two Selstad 630# trawls (headline height ca. 7m) in a twin setup with a pair of Thyborøn type 26 VFG doors (9 m^2, ca. 4400 kg each), a central clump (Thyborøn 2700 mm, 6500 kg) and 100 m sweeps. The distance between the doors with such a configuration is typically 220–250 m, depending on the operational depth.

One of the trawls was rigged with a used flexigrid section (UG) fished commercially for ca. 20000 h over four years, whereas the other trawl was rigged with a new flexigrid section (NG). Both the construction of the sections and the grids in the sections were identical and built following the guidelines in the Fisheries Directorate directive (Norwegian Directorate of Fisheries, 2022). The bar spacing of the grids and the mesh sizes in the grid sections and codends were measured following the procedure in Wileman et al. (1996). In the NG the mean bar spacing of the grids was 55.87 ± 1.73 mm (Mean ± SD), whereas in the UG the mean bar spacing of the grids was 55.90 ± 4.86 mm. Each grid section was followed by a 22 m long extension piece in 155 mm nominal mesh size. The codends following the extension pieces in each of the trawls were #90 meshes long x #80 free meshes around, built of knotless meshes. The mesh size of the codend used in combination with the NG was 136.48 ± 3.08 mm, whereas the mesh size of the codend combined with the UG was 137.88 ± 1.94 mm, meaning the average mesh sizes for the two codends were not significantly different.

The sea trials consisted of two different series. In the first series (hauls 1–24) the codends were completely blinded with 45 mm nominal mesh size inner-nets, which ensured that no cod or haddock above 10 cm could escape from the codends (Sistiaga et al., 2011). In series 2 (hauls 25–34), the inner-nets were removed to evaluate the implications of adding subsequent codend selectivity to the overall selectivity in the aft of the trawl (Fig. 1). To account for potential differences in the fishing power of the trawls, the grid sections were mounted half the number of hauls on the starboard side trawl and half the number of hauls on the port side trawl, respectively (Table 1).

The catches from both trawls were kept separated. Cod and haddock were measured to the nearest cm below. For each haul, all specimens of these two species were measured, except for those hauls where the catches were too large and for practical reasons had to be subsampled. In the hauls where the catch was subsampled, all fish in the fraction that was not measured were counted and the subsampling factor calculated.

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.

2.2. Data analysis

During the cruise the new and used flexigrid sections were fished simultaneously in a twin trawl configuration. Therefore, the data can be treated as paired. We used the statistical analysis software SELNET (Herrmann et al., 2012, 2017) to analyze catch data and to conduct size-dependent catch comparisons and catch ratio analyses. Using the number of individuals caught for each length class in the trawls with the NG and UG respectively, we studied potential length-dependent differences in the catch efficiency between the gears averaged over hauls. To

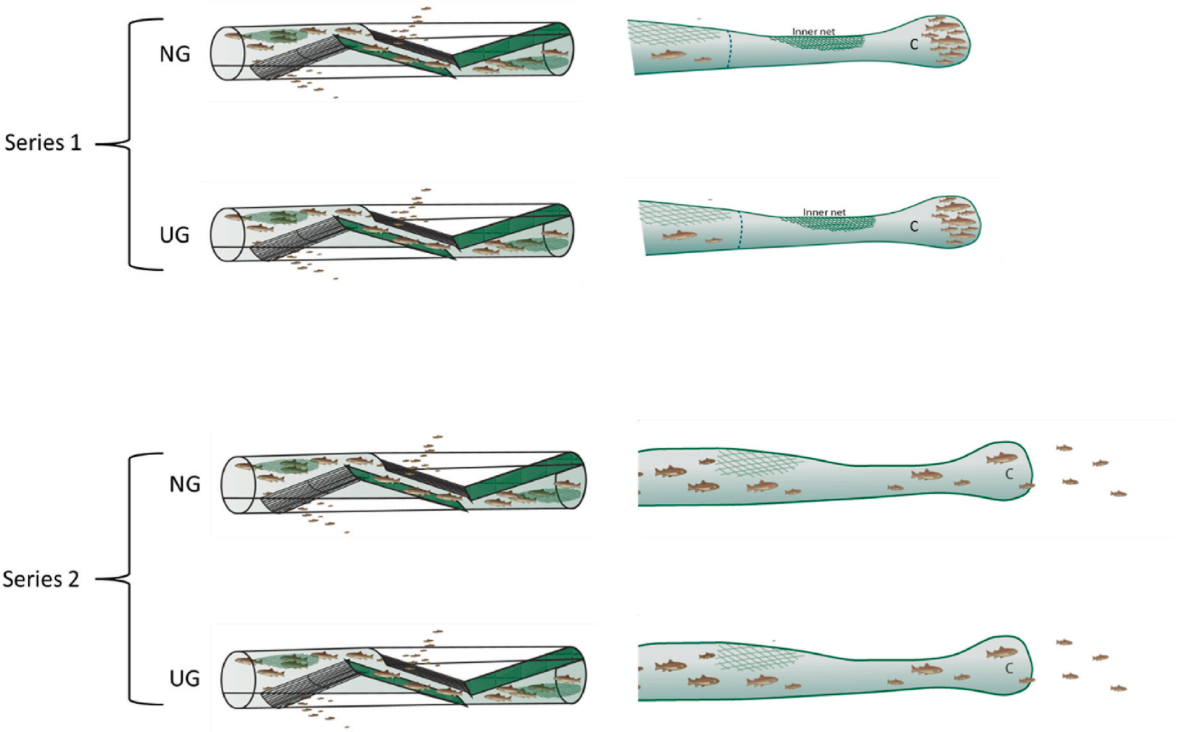

Fig. 1. Illustration of the gear configurations employed in series 1 and series 2. In series 1 the codends were blinded while in series 2 the codends were selective.

Table 1
Overview of the hauls conducted during the experimental sea trials. In addition to haul number, date, towing start time (UTC), towing time, position, depth, the side at which the *NG* was placed and the total catch, the numbers (*n*) of cod and haddock measured and the subsampling factor (*q*) for each of the gears are provided.

Haul Nr	Date	Time start (hh: mm)	Towing time (hh: mm)	Depth (m)	Side NG	Cod (*n*)				Haddock (*n*)				Total Catch (kg)
						NG	qNG	UG	qUG	NG	qNG	UG	qUG	
1	October 21, 2022	16:12	05:05	209	Starboard	524	0.62	643	0.80	15	0.68	27	0.77	3534
2	22.10.2022	22:24	05:03	198	Starboard	748	0.99	752	1.04	19	1.00	20	0.80	2769
3	22.10.2022	04:30	05:06	233	Starboard	933	0.60	932	0.62	11	0.73	7	0.64	8879
4	22.10.2022	10:38	04:49	216	Starboard	949	0.48	941	0.65	14	0.58	15	0.56	13096
5	22.10.2022	16:28	05:15	216	Starboard	1007	0.94	920	0.87	24	0.92	31	1.00	7474
6	22.10.2022	22:33	05:05	175	Starboard	624	1.00	703	1.00	35	1.00	50	1.00	1648
7	23:10.2022	04:36	04:51	171	Starboard	959	0.70	1047	0.91	6	0.46	17	0.94	6848
8	23.10.2022	20:13	03:10	303	Starboard	654	1.00	508	1.00	3	1.00	2	1.00	5277
9	24.10.2022	01:06	03:08	276	Starboard	850	0.61	642	0.66	3	1.00	5	1.00	6791
10	24.10.2022	05:14	04:59	169	Starboard	868	1.00	683	1.00	42	1.00	51	1.00	3828
11	24.10.2022	12:44	03:07	205	Starboard	387	1.00	412	1.00	55	1.00	68	1.00	3339
12	24.10.2022	23:16	04:00	127	Starboard	470	1.00	443	1.00	143	1.00	119	1.00	4837
13	25.10.2022	09:16	04:57	124	Port	490	1.00	664	0.77	881	1.00	934	0.81	5156
14	25.10.2022	15:14	04:22	76	Port	442	1.00	476	1.00	1296	1.00	1048	1.00	5990
15	25.10.2022	20:30	04:57	74	Port	162	1.00	252	1.00	808	1.00	829	1.00	3298
16	26.10.2022	03:14	04:09	56	Port	298	1.00	601	1.00	252	1.00	361	1.00	1656
17	26.10.2022	08:23	04:46	164	Port	394	1.00	826	1.00	75	1.00	185	1.00	3424
18	26.10.2022	14:03	04:24	171	Port	576	1.00	957	1.00	54	1.00	74	1.00	2600
19	26.10.2022	21:49	04:42	150	Port	344	1.00	595	1.00	21	1.00	41	1.00	1432
20	27.10.2022	03:28	04:56	244	Port	780	1.00	1027	1.00	5	1.00	12	1.00	3941
21	27.10.2022	15:26	04:32	296	Port	296	1.00	312	1.00	4	1.00	5	1.00	2998
22	27.10.2022	20:51	05:31	273	Port	1251	0.63	1109	0.49	3	0.50	5	1.00	9928
23	28.10.2022	03:21	05:11	226	Port	1055	1.00	1340	1.00	14	1.00	10	1.00	5197
24	28.10.2022	09:20	05:16	230	Port	1085	0.84	1029	0.63	20	1.00	43	1.00	8139
25	28.10.2022	15:37	06:09	266	Port	559	0.85	586	0.67	*	*	*	*	3328
26	28.10.2022	22:49	04:17	262	Port	587	0.33	584	0.26	*	*	*	*	11471
27	29.10.2022	04:09	05:38	213	Port	575	0.43	560	0.29	*	*	*	*	6823
28	29.10.2022	17:37	04:58	256	Port	587	0.23	579	0.18	*	*	*	*	13998
29	29.10.2022	23:36	05:54	228	Port	527	0.60	560	0.55	*	*	*	*	4747
30	30.10.2022	05:49	04:26	260	Starboard	507	0.40	521	0.52	*	*	*	*	7211
31	30.10.2022	11:15	05:24	235	Starboard	522	0.53	529	0.63	*	*	*	*	5250
32	30.10.2022	17:36	05:49	274	Starboard	555	0.54	512	0.55	*	*	*	*	3624
33	31.10.2022	00:14	04:45	150	Starboard	510	0.44	514	0.67	*	*	*	*	5128
34	31.10.2022	05:58	05:51	169	Starboard	508	0.53	509	0.56	*	*	*	*	6693

assess the relative length-dependent catch efficiency difference between the NG and UG, we applied the method described in Herrmann et al. (2017) and Olsen et al. (2019). This method models the size-dependent catch comparison ratio (proportion caught in test trawl, CC_l) summed over hauls:

$$CC_l = \frac{\sum_{j=1}^{h}\left\{\frac{nNG_{lj}}{qNG_j}\right\}}{\sum_{j=1}^{h}\left\{\frac{nNG_{lj}}{qNG_j}+\frac{nUG_{lj}}{qUG_j}\right\}} \tag{1}$$

where nNG_{lj} and nUG_{lj} are the numbers of individuals of the species caught in length class l in the test and the control trawls, respectively for haul j. h is the number of hauls carried out in that specific cruise, while qNG_j and qUG_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:

$$-\sum_{l}\left\{\sum_{j=1}^{h}\left\{\frac{nNG_{lj}}{qNG_j}\times ln(CC(l,v))+\frac{nUG_{lj}}{qUG_j}\times ln(1.0-CC(l,v))\right\}\right\} \tag{2}$$

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 NG and the UG 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 grids. The experimental CC_l was modelled by the function $CC(l, \boldsymbol{v})$, on the following form:

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

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 & 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 overdispersion (Herrmann et al., 2017; Wileman et al., 1996). 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 grids by the following relationship:

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

The catch ratio represents the ratio between the catch efficiency of the trawl with the NG and the trawl with the UG. Thus, if the catch efficiency of both trawls for that given species is equal, $CR(l,\boldsymbol{v})$ should always be 1.0. Similarly, $CR(l, \boldsymbol{v}) = 1.5$ would mean that the trawl with the new grid is catching 50% more individuals of size l of that specific species than the control trawl configuration. Contrary, if $CR(l, \boldsymbol{v}) = 0.7$ would mean that the trawl with the new grid 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, contrary to the double bootstrapping method described in Herrmann et al. (2017), the outer bootstrapping loop in the current study that accounted for the between-haul variation was performed pairwise for the NG and UG 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.

Indicators in the form of size-integrated average values for the catch ratio ($CR_{average}$) were estimated directly from the experimental catch data by:

$$\begin{aligned} CR_{average-} &= 100 \times \frac{\sum_{l<MLS}\sum_{j=1}^{h}\left\{\frac{nNG_{lj}}{qNG_j}\right\}}{\sum_{l<MLS}\sum_{j=1}^{h}\left\{\frac{nUG_{lj}}{qUG_j}\right\}} \\ CR_{average+} &= 100 \times \frac{\sum_{l\geq MLS}\sum_{j=1}^{h}\left\{\frac{nNG_{lj}}{qNG_j}\right\}}{\sum_{l\geq MLS}\sum_{j=1}^{h}\left\{\frac{nUG_{lj}}{qUG_j}\right\}} \end{aligned} \tag{5}$$

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 NG and UG were estimated by:

$$\begin{aligned} nDiscardRatioNG &= 100 \times \frac{\sum_{l<MLS}\sum_{j=1}^{h}\left\{\frac{nNG_{lj}}{qNG_j}\right\}}{\sum_{l}\sum_{j=1}^{h}\left\{\frac{nNG_{lj}}{qNG_j}\right\}} \\ nDiscardRatioUG &= 100 \times \frac{\sum_{l\geq MLS}\sum_{j=1}^{h}\left\{\frac{nUG_{lj}}{qUG_j}\right\}}{\sum_{l}\sum_{j=1}^{h}\left\{\frac{nUG_{lj}}{qUG_j}\right\}} \end{aligned} \tag{6}$$

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 (Melli et al., 2020; Wienbeck et al., 2014).

2.3. Underwater recordings

To inspect the functioning of the grid section while fishing, we conducted underwater recordings by means of two camera rigs attached at different positions in the grid sections. The camera riggs were composed of one GoPro 9 camera (San Mateo, California, USA) inserted in a stainless-steel housing, and two white-light scuba dive flashlights with batteries (Brinyte®, DIV01C–V and type CREE XPE R5; Shenzhen Yeguang Technology Co., Ltd., China) per rig fixed to a steel frame.

The hauls used for the underwater recordings were not included in the data analysis because of concerns regarding the possible influence of light on fish behavior and therefore, potentially also on the performance of the grids.

3. Results

During the cruise a total of 34 hauls, 24 in series 1, where the codends were blinded, and 10 in series 2, where the codends were not blinded, were carried out. A total of 44851 cod and 7762 haddock were length-measured (Table 1). The numbers of haddock caught in series 2 were too low to perform any type of selectivity analysis and therefore, the species was not included in the series.

3.1. Catch comparison (CC) and catch ratio (CR)

Despite the low p-values obtained for cod and haddock in the analysis, the models represented well the trend in the data. This was the case especially for cod, where the data were stronger than for haddock. Thus, the low p-values were considered a result of overdispersion of the data and the models used in the analyses adequate (Figs. 2 and 3; Table 2).

The plots for cod in Fig. 2 demonstrate that the NG retains significantly less cod below under 60 cm than the UG. Further, the difference in retention is largest for fish below *MLS*. The catch ratio curve shows that for fish below *MLS* the NG retained less than 50% of individuals compared to the UG. For cod above 60 cm, which would be on the upper limit of the selective range of a flexigrid section with a 55 mm grid bar spacing (Brinkhof et al., 2020; Sistiaga et al., 2016), the retention of both configurations tested in series 1 was similar i.e., the *CR* curve above 60 cm was not significantly different from 1.0. Since the retention for fish in the non-selective size range were equal, and the trawls were alternated during the trials, the observed differences in size composition between the two trawls during series 1 can only be due to the differences in the selectivity performance of the grids. The pattern in the data for haddock was similar to that observed for cod, but the numbers of fish of this species captured during the trials were lower and the results are therefore not as conclusive due to wider CIs (Fig. 2).

When the inner-nets were removed from the codends in series 2, the catch ratio was no longer significantly different for any of the size classes of cod (Fig. 3). Thus, the selectivity in the codend likely compensated for the differences in sorting efficiency of the NG and the UG. During series 2, the catches of haddock were not large enough to allow a similar analysis.

3.2. Indicators

The size-integrated average values for *CR* showed that during series 1, there was no difference between the trawl with the NG and the UG regarding the probability for a cod over *MLS* to be captured in either trawl. However, for fish under *MLS*, the probability of capture with the NG with respect to the UG was 45.10%, which was significantly lower. The results for haddock followed the same pattern and while the probability of catching fish above *MLS* was practically equal for both trawls, the NG only captured 72.96% of the haddock below *MLS* that was captured with the UG. However, this difference was not significant. The discard ratio was higher for both species with the UG but the differences between the configurations were not significant (Table 3).

For series 2, the size-integrated average value for *CR* under *MLS* was not significantly different from 100% meaning that the difference observed for fish under *MLS* between the gear with the NG and the UG

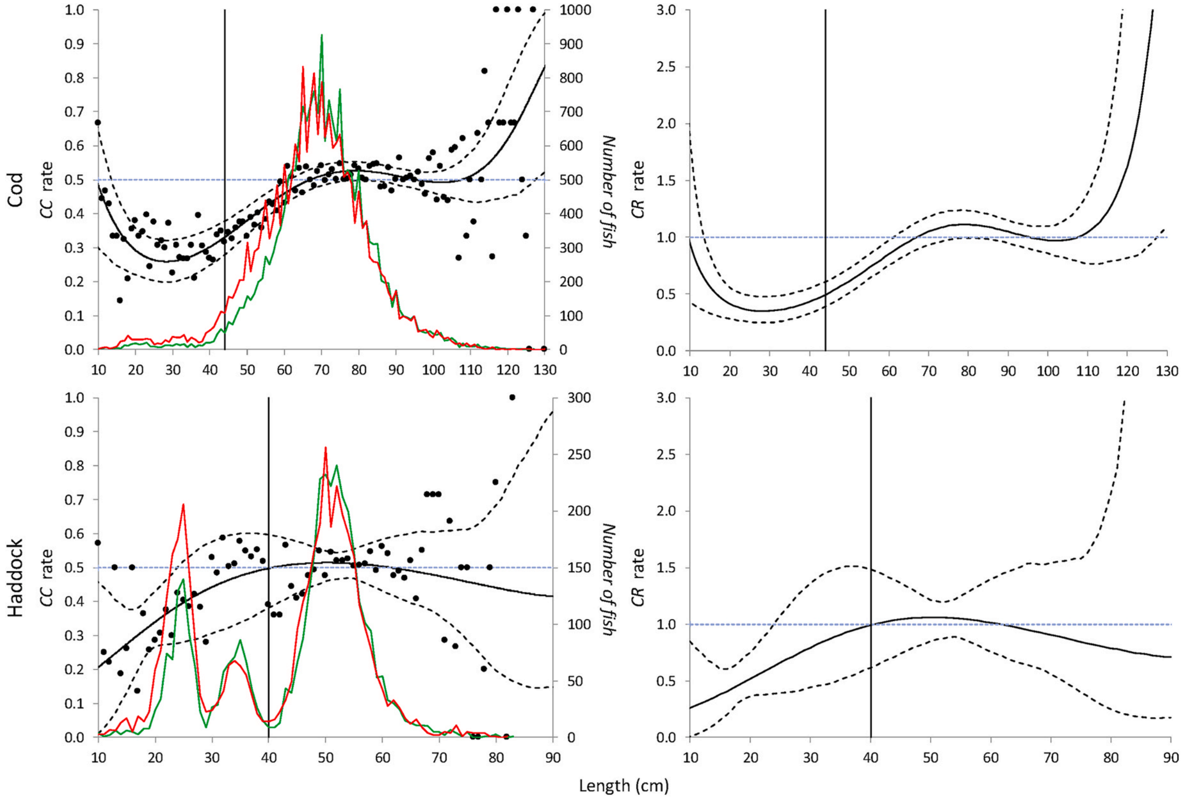

Fig. 2. Catch comparison rate (left column) and catch ratios (right column) for the trawl configuration with NG versus the configuration with the UG in series 1, with blinded codends. In the catch comparison plots the circles show the experimental catch comparison ratios, whereas the solid line and the dotted lines show the modelled catch comparison ratio and the corresponding 95% confidence intervals. The green lines show the catch distribution in the NG configuration whereas the red lines show the catch distribution in the UG configuration, both with scale in the right axis. In the catch ratio plots the solid black curve is the catch ratio curve, and the dotted curves are the corresponding 95% confidence intervals. The vertical black line represents the *MLS* in every case.

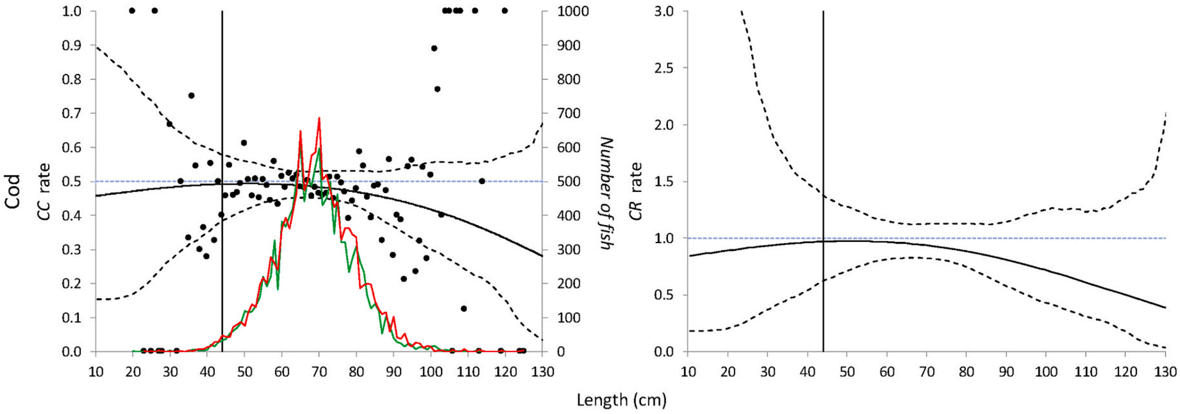

Fig. 3. Catch comparison rate (plot left) and catch ratios (plot right) for the trawl configuration with NG versus the configuration with the UG in series 2, with selective codends. In the catch comparison plot the circles show the experimental catch comparison ratios, whereas the solid line and the dotted lines show the modelled catch comparison ratio and the corresponding 95% confidence intervals. The green line shows the catch distribution in the NG configuration whereas the red line shows the catch distribution in the UG configuration, both with scale in the right axis. In the catch ratio plot the solid black curve is the catch ratio curve, and the dotted curves are the corresponding 95% confidence intervals. The vertical black line represents the *MLS* in every case.

Table 2
Fit statistics for cod and haddock in series 1 and 2, including *p* – value, deviance, and degrees of freedom (DOF).

Species	Series	*p* - value	Deviance	DOF
Cod	1	<0.001	192.93	119
	2	<0.001	162.63	87
Haddock	1	0.002	108.90	69
	2	*	*	*

disappears when selective codends are applied subsequent to the grid. As in series 1, the discard ratio for the UG was higher than for the NG, but the differences between the configurations were not significant (Table 3).

3.3. Observations on deck and underwater recordings

Observations of the grids during the cruise revealed that the shape of the grids in the NG and UG were different (Fig. 4 a,c). It seems that the tension created in the grid section due to the catch load as well as the deforming forces to which they are exposed to on deck (Fig. 4b), contribute to the observed deformations of the grids over time (Fig. 4c).

Table 3
Size-integrated average values for the catch ratio under ($CR_{average^-}$) and over ($CR_{average+}$) the *MLS* for cod (44 cm) and haddock (40 cm); 95% confidence intervals are provided in brackets.

Series	Species	$\mathrm{CR}_{\mathrm{average}}$- (%)	$\mathrm{CR}_{\mathrm{average}}$+ (%)	nDiscard ratio NG (%)	nDiscard ratio UG (%)
1	Cod	45.10 (33.38–58.11)	95.62 (85.34–107.78)	2.43 (1.27–3.98)	5.02 (2.90–7.26)
	Haddock	72.96 (41.26–113.13)	101.30 (78.88–113.55)	30.93 (13.71–47.75)	38.34 (21.58–50.08)
2	Cod	77.52 (34.49–145.14)	92.93 (80.93–111.30)	0.79 (0.18–1.63)	0.95 (0.14–2.24)

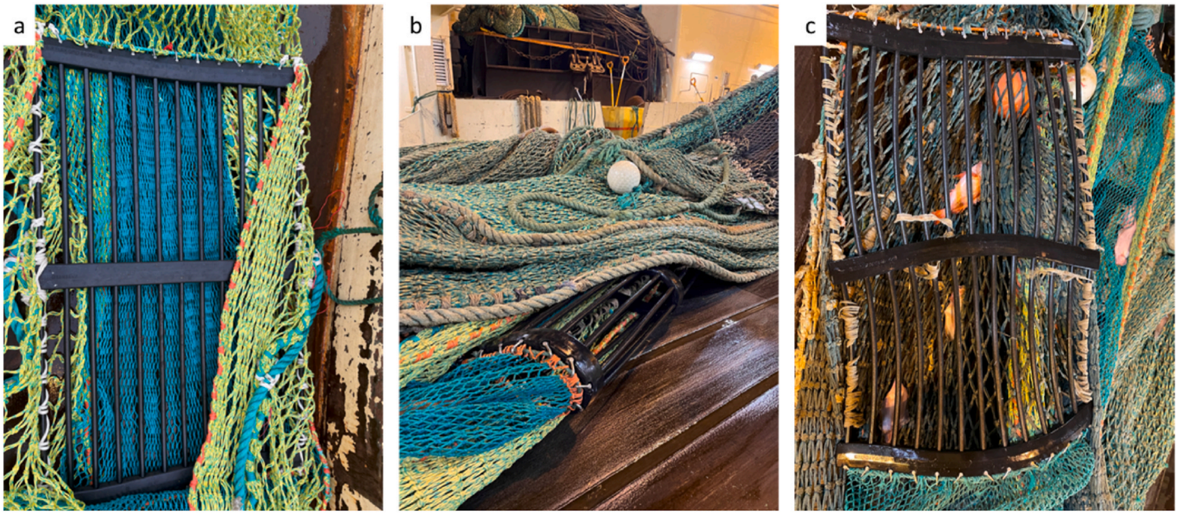

Fig. 4. Pictures of a grid in the new flexigrid section (a), a grid in the used flexigrid section deformed on deck (b), and a grid in the used flexigrid section laying on deck (c).

The underwater recordings showed that the grids in the NG had a steeper angle than the grids in the UG, which likely results in a higher contact probability for fish with the grids. The recordings also showed that the lumen between the grids and the netting panels in the section were larger, probably resulting in a larger proportion of fish passing through the UG without being subjected to a size selection process by any of the two grids (Fig. 5).

During the cruise, there was no possibility to measure the grid angle of the four grids in the sections. However, to understand why the grids in the used section seem to lie flatter, the size of the meshes in the grid section were measured following the procedure in Wileman et al. (1996). The average mesh size in the NG was (138.08 ± 0.31 mm) (Mean ± SE) whereas in the UG it was (140.2 ± 0.50 mm), meaning that the mesh size was significantly larger in the latter.

4. Discussion

The results in the present study show that the size selectivity performance of the NG and the UG tested differ. The UG sorted out significantly less cod below 60 cm while the retention of cod above this size was the same for both sections. However, this difference between the grid sections disappeared when the grid sections were operated in combination with size selective codends. This result emphasizes the importance of combining grids with size selective codends, as the codend sems to contribute substantially to the overall size selectivity when the grid is not working as intended. Earlier studies have shown that in such combined selectivity systems, the grid is the main contributor to the overall selectivity of the gear (Brinkhof et al., 2020; Sistiaga et al., 2010). However, grids can become clogged by litter, seaweed, flatfish and other marine animals, and it is important to document that in those cases a selective codend can contribute substantially to the overall selectivity. It should be pointed out that the mesh size of the both codends used exceeded the minimum legal mesh size of 130 mm, and that using smaller mesh sizes would likely reduce the contribution of the codend to the overall escape.

From the underwater recordings and the grid section mesh measurements taken onboard, it seems like, as Brinkhof et al. (2020) pointed out earlier, the meshes in the grid section stretch with use. This reduces the angle of the grids, increases the free space between the edge of the grid and the netting panels of the section and consequently reduces the probability for fish to contact the grids. The view though the grid becomes more of a ”tunnel-like” passage, where the probability for fish to be subjected to a size selection process by any of the grids is low. The netting material in both grid sections was the same, so given that the mesh size was the same before both grids were used in the fishery, the used flexigrid section showed signs of having stretched, which would lead to the flatter grid angles observed. We have no measurements of the original mesh size in the UG, so we cannot be certain that the meshes have been stretched and were not like that originally. However, the angles of the grids observed indicate that this is the case. When netting panels for the grid sections are built, each knot is tightened firmly by machine or hand, but not exposed to heavy loads. The grids are subsequently mounted in the netting section with the intended angle, but when they are used in commercial fishery, they are exposed to heavy loads of up to 40–50 tons. These loads cause each mesh and knot to stretch maximally, slightly increasing the mesh size and consequently reducing the angles of the grids.

In addition to the contact probability issue observed in the underwater recordings, observations of the UG on deck showed clear signs of deformation, which could not be observed in the new grid. The NG and the UG both had an average bar spacing of ca. 55 mm, but the UG had a substantially higher standard deviation than the NG (4.86 vs 1.73 mm). On top of the contact issue, the increased variability in the grid bar spacing observed in the UG will lead to an increased variability in the selectivity, which opposes the purpose of inserting a sorting grid in the gear. Grids have earlier been claimed to provide more stable size selection results than diamond mesh codends due to that they are more rigid than codend meshes (Jørgensen et al., 2006).

The results in the current study also bring up an issue that can often be overseen by scientists and as demonstrated in the present study, can lead to confusing results. Fishing gear trials are usually conducted with new equipment and the results are assumed to represent how the equipment would perform under commercial conditions. However, the performance documented in scientific trials carried out with new equipment do not always represent the performance observed by fishermen with the same equipment exposed to commercial conditions. The results obtained by Sistiaga et al. (2016) and Brinkhof et al. (2020) with the flexigrid section exemplifies this issue. The selectivity results obtained in the former study with a well-used grid section used under commercial conditions were substantially poorer than in the latter study with a new grid section used during scientific trials. Brinkhof et al. (2020) already brought attention to the potential differences between used and new grid sections as a plausible source for the differences observed, but this could not be demonstrated at the time. The issue observed between the grids here may also have been the source for discrepancies in the results obtained between other studies that have

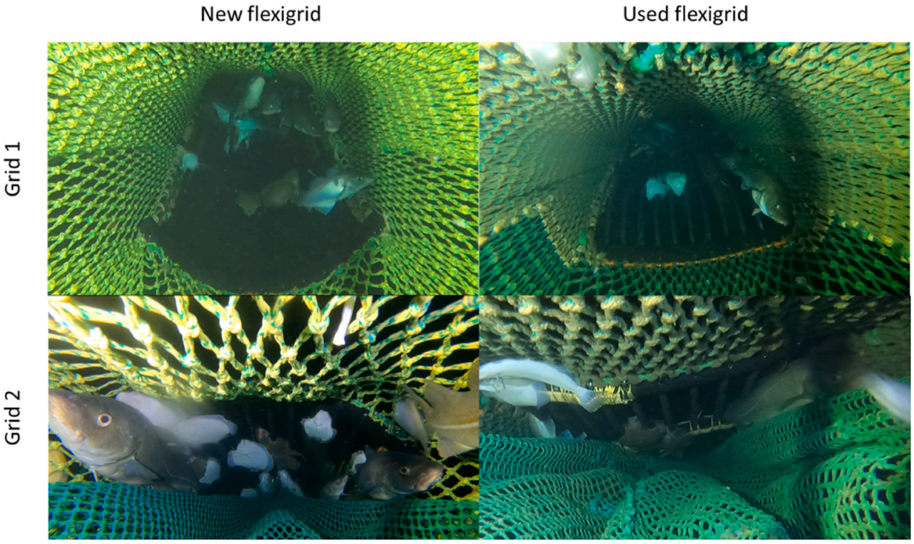

Fig. 5. Pictures of forward and aft grid panels in the NG (left) and in the UG (right) during towing.

tested equipment that a priori is the same or very similar but differs in the time is has been used. It is obvious that as the properties of materials change with use, so do the selectivity properties of the equipment built with these materials, especially equipment built with flexible materials like the flexigrid. This is something to account for in the future and it should have implications for the extent to which specific units of certain fishing gear should be allowed to be used in commercial activities.

Establishing the extent to which a specific type of gear should be allowed or used in commercial fishing can be complicated because the gear can be operated in very different ways by different users and consequently, the change in its properties over time could differ. However, it is important to realize that the changes in properties over time can be a determining issue for the performance of a gear and results of scientific tests. In the future, it would be interesting to explore, how and when the properties of different fishing gear change with time and use.

CRediT authorship contribution statement

Manu Sistiaga: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Roles/Writing - original draft, Writing – review & editing. **Terje Jørgensen:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Roles/Writing - original draft, Writing – review & editing. **Ilmar Brinkhof:** Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Roles/Writing - original draft, Writing – review & editing. **Bent Herrmann:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Resources, Software, Validation, Visualization, Roles/Writing - original draft, Writing – review & editing. **Jesse Brinkhof:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Resources, Validation, Visualization, Roles/Writing - original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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