Development of selectivity systems for gadoid trawls

Comparative tests of a well-used and a new flexigrid, October 2022

Report November 2022

Manu Sistiaga, Terje Jørgensen, Hermann Pettersen, Ilmar Brinkhof, Kristian Skaar, Bent Herrmann, Jesse Brinkhof, Eduardo Grimaldo, Roger B. Larsen

Table of Contents

Summary

Norwegian fishermen targeting gadoid species in the Barents Sea are obliged to use a sorting grid combined with a size selective codend. Among the three allowed grid systems in the fishery, the flexigrid is the most widely used and the only one composed of two flexible grids. Earlier studies conducted to document the fish size sorting properties of the flexigrid system have shown discrepant results. While one study the use of the flexigrid resulted on selectivity results that are comparable to those obtained with the other allowed grid systems, in another study the results obtained are much poorer. It was speculated that the source for this discrepancy is that while in one of the studies the flexigrid system was new, the system used in the other study had been used in commercial fishery for a while.

A direct comparison between a new and a used flexigrid system was carried out using a twin trawl configuration in a commercial vessel. Two series of 24 and 10 hauls were carried out with configurations without and with a size selective codend following the grid system, respectively. The catch comparison / catch ration analyses showed that the used grid retains significantly more cod under 60 cm than the new grid. The results for haddock showed the same trend but were not as conclusive due to lower numbers of fish in the catches. The indicators also showed similar results with a 55% higher and significantly different probability of capture of cod under minimum legal size for the trawl with the used grid compared to the trawl with the new grid. However, combining the grids with a size selective codend eliminated the differences observed between the size selectivity of the grids, demonstrating the importance of the codend in the overall combined grid and codend system when the grid does not perform as expected.

The underwater recordings showed that a steeper angle of the grids and smaller gaps between the grids and the netting section, which would likely increase the contact of the fish with the grids, can be the source for the better selectivity performance of the new grid. It is speculated that the stretching of the section as well as changes in the material properties after heavy use in commercial fisheries are the most likely source for the changes observed in the section. Other issues such as substantial deformation of the grids after commercial use are also identified in the flexigrid system.

This study shows that the use and potential change in material properties of a flexigrid system can significantly change its size-selective properties over time. This issue is also relevant for other gears and illustrates and issue that should not be overlooked by managing authorities and considered by scientists in future trials, where often only new equipment is tested.

Sammendrag

I trålfisket etter bunnfisk i Barentshavet er det påbudt å bruke seleksjonsrist i tillegg til en selektiv trålpose. Av de tre ristene som er godkjent for bruk, er fleksirista den mest benyttede og den eneste som konstruert av to fleksible rister. Tidligere studier av seleksjonsegenskapene for rista har gitt motstridende resultater. Mens en studie viste seleksjon på nivå med de andre ristene, viste en annen studie betydelig dårligere seleksjon for fleksirista. Da rista som ble benyttet i den ene forsøket var ny, mens den andre hadde vært brukt i lengre tid, ble det spekulert i om dette forholdet kunne være årsaken til forskjellen i seleksjonseffektivitet.

For å belyse dette spørsmålet, ble det gjort komparative fiskeforsøk med dobbelttrål der en sammenlignet fangsten i en trål med ny rist med fangsten i en identisk trål med gammel rist. To serier med 24 og 10 hal ble gjort hhv med og uten finmasket inner-nett i trålposen Forsøkene viste at ei gammel rist holder tilbake en signifikant større andel torsk under 60 cm enn ei ny rist. Torsk under minstemål har 55% høyere fangstsannsynlighet ved bruk av gammel vs ny rist. Resultatene for hyse viste samme trend, men er mer usikre grunnet små fangster av hyse. Når det ble bruk en selektiv trålpose i tillegg til rist, var det ikke lenger forskjell i størrelsessammensetningen av fangsten i de to trålene. Dette viser betydningen av maskeseleksjon i trålposen når ristseleksjonen fungerer dårlig.

Undervannsobservasjoner av ristene viste at den nye rista stod med en brattere vinkel enn den gamle. Dermed var det mindre fri passasje mellom de to ristenhetene og notveggen i seksjonen med ny fleksirist, og dette kan være forklaringen på bedre seleksjon ved bruk av ny vs. gammel rist. Det antas at strekk av notlinet i ristseksjonen og endringer i materialegenskapene på rista som følge av store belastninger i kommersielt bruk er hovedårsaken til forskjellen mellom gammel og ny ristseksjon. Samtidig ble det også observert at kommersiell bruk over tid kan gi deformasjon av fleksirista.

Forsøkene har vist at bruk av fleksirist-systemet over tid kan føre til markante endringer i seleksjonsegenskapene til systemet. Slike endringer over tid kan også være relevante for andre redskaper og er et forhold som både forvaltere og redskapsforskere bør hensynta, all den tid forsøk som oftest gjøres med ny redskap.

1. Background

Norwegian fishermen targeting gadoid species in the Barents Sea are obliged to use a sorting grid with a minimum bar spacing of 55 mm and a codend with a minimum mesh size of 130 mm. Three different sorting grid systems are allowed in the Barents Sea: the Sort-X (Larsen and Isaksen, 1993), the Sort-V (Jørgensen et al., 2006), and the flexigrid (Sistiaga et al., 2016)., The flexigrid is the most widely used system due to its low weight and maneuverability, although some vessels employ the Sort-V system. The Sort-X is rarely used due to its large size and heavy weight.

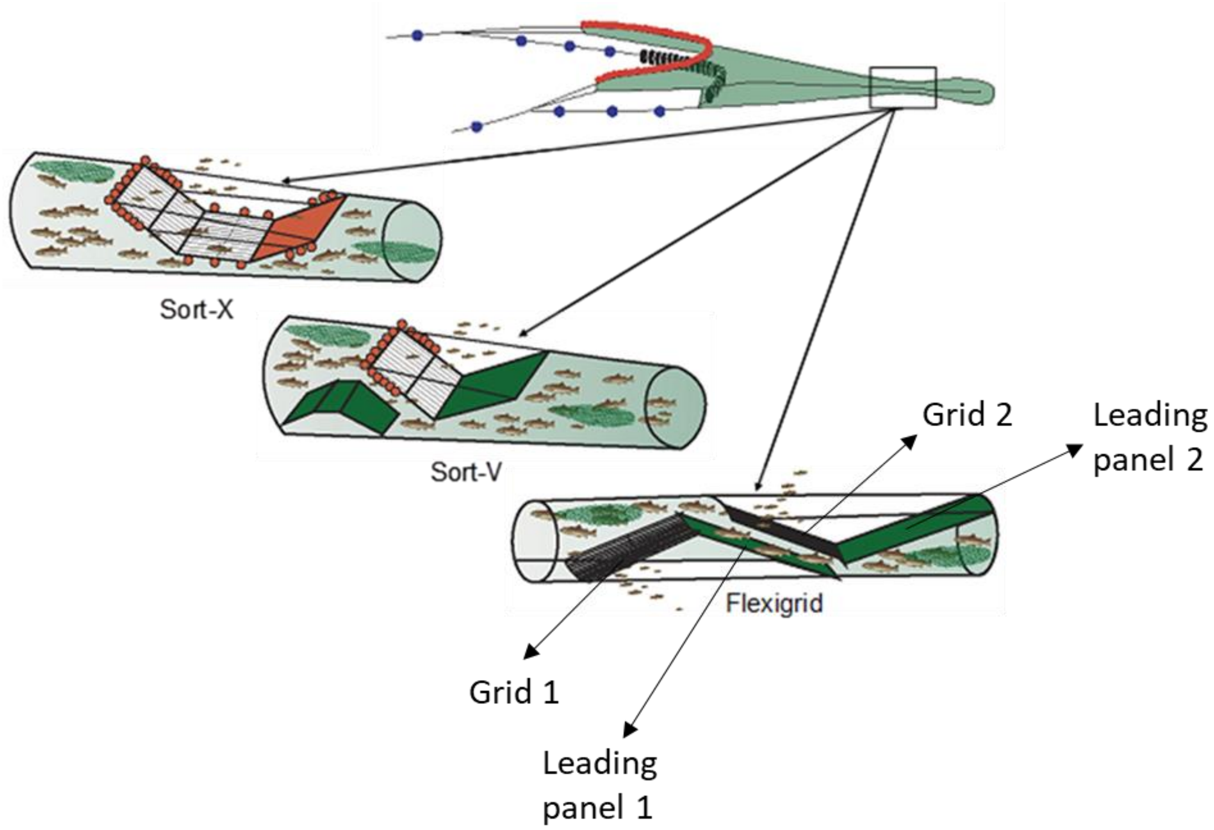

Fig. 1: Illustration of the three different sorting grid systems permitted in the Barents Sea gadoid trawl fishery.

The flexigrid is the only one of the three systems that is composed of two grids (Fig. 1). In addition to providing a first escape possibility for the fish entering the section, the first grid also acts as a lifting panel for the second grid, an important element for the sorting efficiency in these types of sorting devices (Grimaldo et al., 2015).

Several studies have focused on the sorting properties of the flexigrid both before its implementation in the technical regulations in 2002 (e.g. Angell et al., 2001) and after (Sistiaga et al., 2009, 2016; Brinkhof et al., 2020) . Studies have also compared the sorting properties of the flexigrid with the Sort-V. In principle, the two grids should have similar sorting properties, but the results show that this is not always the case (Sistiaga et al., 2009).

It has long been speculated that although the flexigrid has advantages from a handling point of view, it is less effective at sorting undersized fish than the Sort-V grid. Earlier studies show inconsistency in the results, and while the flexigrid can provide similar selectivity results as the Sort-V (Brinkhof et al., 2020), other studies have shown that the selectivity results can be unsatisfactory (Sistiaga et al., 2016). The source for this variability in the results and why the flexigrid at times retains substantial quantities of undersized fish is not well-understood, but it is likely that in certain circumstances the lack of contact of the fish with the grids in the flexigrid system is low. Flexigrids with low inclination angles can lead to higher likelihood of fish passing through the grid section without contacting the grid because the spaces between the netting panels in the section and the grids become larger. As Brinkhof et al. (2020) already pointed out, it has been speculated that the flexigrid can lose its sorting properties with use: "*a common claim amongst fishers is that well-used flexigrid sections (as the one applied in Sistiaga et al. (2016)) release less fish than new flexigrid sections. A possible mechanism for this is that hauling large catches onboard will cause the meshes in the flexigrid section to stretch, which will result in a permanently larger mesh size and length. A minor increase in mesh length size would cause a lower grid angle than the intended 25°, subsequently reducing contact probability and the release efficiency for fish.*".

It is common practice that the gear tested in research cruises is new and/or has not been exposed to extended commercial use. This was for example the case for the selectivity trials carried out with the flexigrid by Brinkhof et al. (2020). Therefore, potential flaws that could appear in the equipment with time are not captured by the results obtained. If the physical properties of the grid section and consequently its size selection properties change with use, and the differences between a new and a well-used flexigrid can be as large as the differences observed between the results obtained by Sistiaga et al. (2016) and Brinkhof et al. (2020), the merits of such a grid system in the fishery could be questioned. The problem could also be extrapolated to other types of gear whose properties may also change with time and use.

The size selection system in the Barents Sea demersal gadoid fishery is a dual selection system because the first selection process of the grid is complemented by a subsequent size selection process in the codend. Both Sistiaga et al. (2010) and Brinkhof et al. (2020) demonstrated that in such a dual system, most escapes occur in the grid. However, it is possible that the selective role of the codend becomes more important in scenarios where, for whatever the reason, the sorting capacity of the grid is reduced.

The aim of the present study was to compare the size sorting properties of a well-used flexigrid section with those of a new flexigrid section. But, in addition, the comparison of the size sorting properties of the grid section was also compared in combination with a size selective codend to investigate to what extent the codend can contribute to selectivity in cases where the grid may not be working as expected.

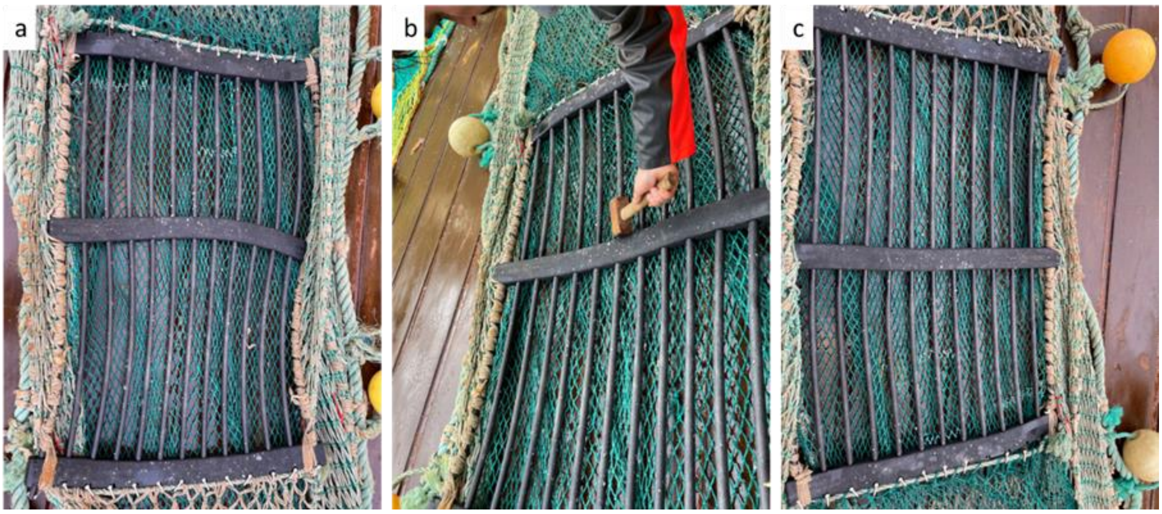

Fig. 2: Deformations that can appear in the flexigrid with prolonged use (a). The shape of the grid needs to be continuously corrected by means of a hammer (b) to return the grid to a shape closer to the expected (c).

2. Materials and methods

2.1. Fishing trials

Fishing trails were conducted in the Barents Sea, around Bear Island between the 20th of October and the 3rd of November 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 (9m^2 ca. 4,400 kg each), a central clump (Thyborøn 2700 mm 6,500 kg) and 100 m sweeps. The door distance was typically 220-250 m depending on the operational depth.

One of the trawls was rigged with a flexigrid section that had been fished (UG) for ca. 20,000 hours 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 *Forskrift om gjennomføring av fiske, fangst og høsting av viltlevende marine resurser (Høstingsforskriften)*. The bar spacing of the grids and the mesh openings of the codends was measured following Wileman et al. (1996). The mean bar spacing of the grids in the new grid section was (55.87 ± 1.73 mm) (Mean ± SD), whereas the mean bar spacing of the grids in the used grid section was (55.90 ± 4.86 mm). Each grid section was followed by a 22 m long extension piece. The codends following the extension pieces in each of the trawls were #90 meshes long x #80 free meshes around, built of knotless meshes in 130 mm nominal mesh size (nms) (10 mm twine). The mesh size of the codend used with the NG was 136.48 ± 3.08 mm, whereas the mesh size of the codend used with the UG was 137.88 ± 1.94 mm. The difference in the average mesh size measured for the two codends was not significant. During the first series in the experiments (Hauls 1-24) the codends were completely blinded with 45 mm nominal mesh size inner-nets, which ensured that no cod or haddock under 10 cm could escape from the codends (Sistiaga et al., 2011). In series 2 (Hauls 25-35), the inner-nets were removed to evaluate the implications of adding subsequent codend selectivity to the selectivity of the grid sections (Fig. 3). To account for potential differences in the fishing power of the trawls, each grid section was mounted half the number of hauls on the starboard and port side trawls respectively. (Table 1).

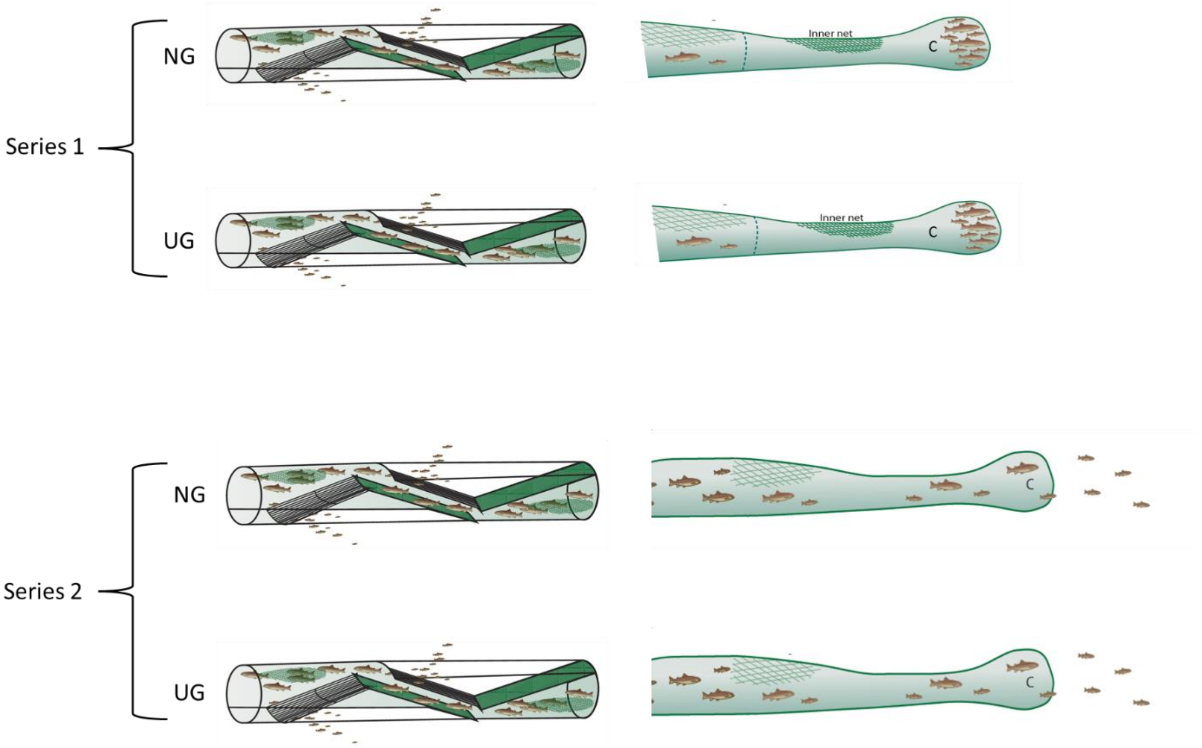

Fig. 3: Illustration of the gear configurations employed in series 1 and series 2. In series 1 the codends were blinded while in series 2 the codend were selective.

The catch from both trawls was kept separated. Cod (Minimum Legal Size (*MLS*) = 44 cm) and haddock (*MLS* = 40 cm) were measured to the nearest cm below. For each haul, all specimens of these two species were measured, except for those hauls where for practical reasons 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.

2.2. Data analysis

During the cruise the new and used flexigrid sections were fished simultaneously in a pair 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 new (Test1) and old (Test2) grids respectively, we studied potential differences in the catch efficiency between the gears averaged over hauls. Further, we investigated whether these differences could be length-dependent. Specifically, to assess the relative length-dependent catch efficiency difference between the new and old grid, 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 sets:

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

where $nTest1_{lj}$ and $nTest2_{lj}$ are the numbers of individuals of each species caught in each length class l in the test and the control trawls, respectively. h is the number of hauls carried out in that specific cruise, while $qTest1_j$ and $qTest2_j$ are subsampling factors that quantify the fraction of the caught individuals being length measured for each species 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:

$$-\sum_l\left\{\sum_{j=1}^{h}\left\{\frac{nTest1_{lj}}{qTest1_j}\times ln\big(CC(l,v)\big)+\frac{nTest2_{lj}}{qTest2_j}\times ln\big(1.0-CC(l,v)\big)\right\}\right\} \tag{2}$$

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 new grid and the old grid 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:

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

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... v_4 led to 31 additional models that were also considered as potential models for the catch comparison $CC(l,\mathbf{v})$. 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 $CC(l, \mathbf{v})$ we obtained the relative catch efficiency (also named catch ratio) $CR(l, \mathbf{v})$ between the two trawls with the two different grids by the following relationship:

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

The catch ratio represents the ratio between the catch efficiency of the trawl with the new grid and the trawl with the old grid. 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 new grid is catching 50% more individuals of size *l* of that specific species than the control trawl configuration. Contrary, if $CR(l, \mathbf{v}) = 0.7$ 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 Test1 and Test2 gears, 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:

$$
\begin{aligned}
CR_{average-} &= \frac{\sum_{l<ml}\sum_{j=1}^{h}\left\{\frac{nTest1_{lj}}{qTest1_{j}}\right\}}{\sum_{l<ml}\sum_{j=1}^{h}\left\{\frac{nTest2_{lj}}{qTest2_{j}}\right\}} \\
CR_{average+} &= \frac{\sum_{l\geq ml}\sum_{j=1}^{h}\left\{\frac{nTest1_{lj}}{qTest1_{j}}\right\}}{\sum_{l\geq ml}\sum_{j=1}^{h}\left\{\frac{ntest2_{lj}}{qTest2_{j}}\right\}}
\end{aligned}
\qquad (5)
$$

where the outer summations include the size classes in the catch during the experimental where the outer summations include the size classes in the catch during the experimental fishing period respectively under (for $CR_{average-}$) and over (for $CR_{average+}$) the minimum legal size (*MLS)* for cod and haddock.

2.3. Underwater recordings

To inspect the functioning of the grid section while fishing, we conducted underwater recordings by means of two simple camera rigs attached at different positions in the grid section. The camera rigs were composed of one GoPro 9 camera (San Mateo, California, USA) inserted on stainless-steel housings, 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 recent research indicates that light affects fish behaviour and therefore may also affect the performance of grids (Personal communication, Jesse Brinkhof, University of Tromsø, Norway).

3. Results

During the cruise we carried out a total of 34 hauls, 24 in series 1 and 10 in series 2. During the cruise, a total of 44851 cod and 7762 haddock were measured (Table 1).

Table 1: Overview of the hauls conducted during the experimental sea trials and the numbers of cod and haddock measured and captured in each of the gears. NGM: n New Grid Measured; NGT: n New Grid Total; UGM: n Used Grid Measured; UGT: n Used Grid Total.

Haul Nr	Date	Time start (hh:mm)	Towing time (hh:mm)	Position start	Depth (m)	Side new grid	Cod (*n*)				Haddock (*n*)				
							NGM	NGT	UGM	UGT	NGM	NGT	UGM	UGT	Total Catch
1	21.10.2022	16:12	05:05	73°53'821'' / 19°45'115'' Ø	209	Starboard	524	840	643	808	15	22	27	35	3534
2	22.10.2022	22:24	05:03	74°00'976'' / 20°29'545'' Ø	198	Starboard	748	757	752	720	19	19	20	25	2769
3	22.10.2022	04:30	05:06	73°57'056'' / 20°23'421'' Ø	233	Starboard	933	1557	932	1499	11	15	7	11	8879
4	22.10.2022	10:38	04:49	73°55'944'' / 20°11'453'' Ø	216	Starboard	949	1962	941	1438	14	24	15	27	13096
5	22.10.2022	16:28	05:15	73°56'675'' / 20°16'556'' Ø	216	Starboard	1007	1076	920	1060	24	26	31	31	7474
6	22.10.2022	22:33	05:05	73°58'748'' / 20°01'962'' Ø	175	Starboard	624	624	703	703	35	35	50	50	1648
7	23:10.2022	04:36	04:51	74°01'407'' / 20°24'263' Ø	171	Starboard	959	1377	1047	1155	6	13	17	18	6848
8	23.10.2022	20:13	03:10	74°51'186'' / 16°41'345' Ø	303	Starboard	654	654	508	508	3	3	2	2	5277
9	24.10.2022	01:06	03:08	75°03'631'' / 15°44'815' Ø	276	Starboard	850	1392	642	969	3	3	5	5	6791
10	24.10.2022	05:14	04:59	75°15'597'' / 15°40'536' Ø	169	Starboard	868	868	683	683	42	42	51	51	3828
11	24.10.2022	12:44	03:07	75°43'846'' / 17°43'233' Ø	205	Starboard	387	387	412	412	55	55	68	68	3339
12	24.10.2022	23:16	04:00	75°51'010'' / 18°18'808' Ø	127	Starboard	470	470	443	443	143	143	119	119	4837
13	25.10.2022	09:16	04:57	75°56'728'' / 18°10'899' Ø	124	Port	490	490	664	863	881	881	934	1157	5156
14	25.10.2022	15:14	04:22	74°54'037'' / 19°02'947' Ø	76	Port	442	442	476	476	1296	1296	1048	1048	5990
15	25.10.2022	20:30	04:57	74°48'998'' / 19°38'256' Ø	74	Port	162	162	252	252	808	808	829	829	3298
16	26.10.2022	03:14	04:09	74°43'134'' / 20°20'032' Ø	56	Port	298	298	601	601	252	252	361	361	1656
17	26.10.2022	08:23	04:46	74°28'566'' / 20°49'378' Ø	164	Port	394	394	826	826	75	75	185	185	3424
18	26.10.2022	14:03	04:24	74°24'178'' / 20°43'070' Ø	171	Port	576	576	957	957	54	54	74	74	2600
19	26.10.2022	21:49	04:42	73°57'871'' / 18°36'687' Ø	150	Port	344	344	595	595	21	21	41	41	1432
20	27.10.2022	03:28	04:56	73°46'092'' / 18°15'027' Ø	244	Port	780	780	1027	1027	5	5	12	12	3941
21	27.10.2022	15:26	04:32	73°43'946'' / 19°09'396' Ø	296	Port	296	296	312	312	4	4	5	5	2998
22	27.10.2022	20:51	05:31	73°43'316'' / 18°05'924' Ø	273	Port	1251	1990	1109	2257	3	6	5	5	9928
23	28.10.2022	03:21	05:11	73°49'167'' / 17°55'008' Ø	226	Port	1055	1055	1340	1340	14	14	10	10	5197
24	28.10.2022	09:20	05:16	73°47'042'' / 18°15'787' Ø	230	Port	1085	1298	1029	1640	20	20	43	43	8139
25	28.10.2022	15:37	06:09	73°45'537'' / 18°25'687'' Ø	266	Port	559	658	586	881	*	*	*	*	3328
26	28.10.2022	22:49	04:17	73°47'997'' / 17°46'448'' Ø	262	Port	587	1789	584	2207	*	*	*	*	11471
27	29.10.2022	04:09	05:38	73°51'424'' / 17°54'930'' Ø	213	Port	575	1343	560	1919	*	*	*	*	6823
28	29.10.2022	17:37	04:58	73°46'835'' / 18°05'345'' Ø	256	Port	587	2581	579	3193	*	*	*	*	13998
29	29.10.2022	23:36	05:54	73°46'847'' / 18°09'976'' Ø	228	Port	527	877	560	1011	*	*	*	*	4747
30	30.10.2022	05:49	04:26	73°48'240'' / 17°40'162'' Ø	260	Starboard	507	1256	521	995	*	*	*	*	7211
31	30.10.2022	11:15	05:24	73°49'480'' / 17°46'172'' Ø	235	Starboard	522	991	529	838	*	*	*	*	5250
32	30.10.2022	17:36	05:49	73°48'227'' / 17°36'847'' Ø	274	Starboard	555	1036	512	928	*	*	*	*	3624
33	31.10.2022	00:14	04:45	73°55'625'' / 18°50'990'' Ø	150	Starboard	510	1163	514	772	*	*	*	*	5128
34	31.10.2022	05:58	05:51	73°54'188'' / 19°08'813'' Ø	169	Starboard	508	963	509	901	*	*	*	*	6693

3.1. Catch Comparison (CC) and Catch Ratio (CR)

Despite the low p-values obtained for cod and haddock in the analysis, the deviance and DOF in both cases were of the same magnitude and the models showed to represent the trend in the data fine. This was the case especially for cod, where the data were much more abundant 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 (Fig. 4; Table 2).

Table 2: Fit statistics for cod and haddock, and series 1 and 2.

		Series 1	Series 2
Cod	P-value	<0.001	<0.001
	Deviance	192.93	162.63
	DOF	119	87
Haddock	P-value	0.002	*
	Deviance	108.9	*
	DOF	69	*

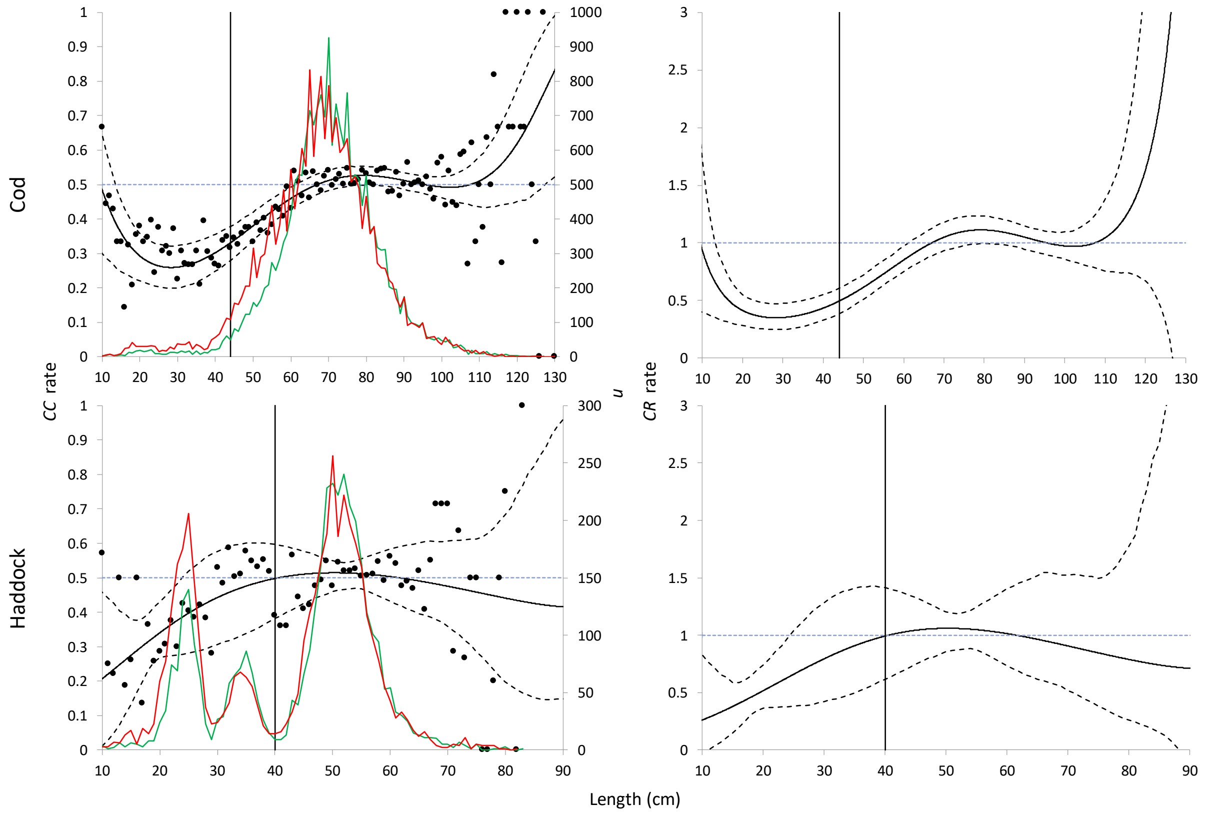

Figure 4: Catch comparison rate (left panels) and catch ratios (right panels) for the trawl configuration with NG versus the configuration with the UG in series 1, with blinded codends. In the catch comparison plots the circles show the experimental catch comparison ratios, whereas the solid line and 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. 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.

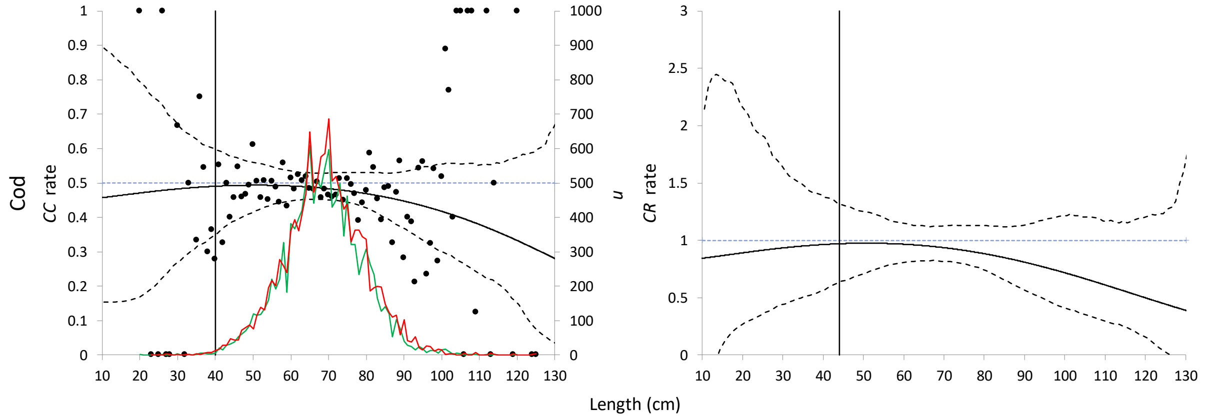

Figure 5: Catch comparison rate (plot left) and catch ratios (plot right) for the trawl configuration with NG versus the configuration with the UG in series 2, with selective codends. In the catch comparison plot the circles show the experimental catch comparison ratios, whereas the solid line and the 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. 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.

The plots for cod in Fig. 4 clearly show that the new grid retains significantly less fish under 60 cm than the used grid. Further, the difference in retention is largest for fish under *MLS*. The catch ratio curve shows that the new grid retained less than 50% of individuals below *MLS* compared to used grid. For cod above 60 cm, which would be on the upper limit of the the selective range of a flexigrid section with a 55 mm grid bar spacing (Sistiaga et al., 2016; Brinkhof et al., 2020), the retention of both configurations tested in Series 1 is very similar. 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 were 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 (Fig. 4).

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. 5). Thus, the selectivity in the codend likely compensated for the differences in sorting efficiency of the new and the used grids.

3.2. Indicators

The size-integrated average values for the catch ratio showed that during series 1, there was no difference between the trawl with the new grid and the old grid regarding the probability for a cod over *MLS* to be captured in either trawl. However, for fish under *MLS*, the probability of capture was 55% higher and significantly different for the trawl with the used grid compared to the trawl with the new grid. The results for haddock followed the same pattern and while the probability of catching fish above *MLS* was practically equal for both trawls, the trawl with the used grid caught almost 30% more fish under *MLS* than the trawl with the new grid. This difference, however, was non-significant (Table 3).

For series 2, $CR_{average}$- is not significantly different from 100% meaning that the difference observed for fish under *MLS* between the gear with the new grid and the used grid disappears when selective codends are applied subsequent to the grid (Table 3).

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.

		$CR_{average}-$	$CR_{average}+$
Series 1	Cod	45.10 (33.38 - 58.11)	95.62 (85.34 - 107.78)
	Haddock	72.96 (41.26 - 113.13)	101.30 (78.88 - 113.55)
Series 2	Cod	77.52 (34.49 - 145.14)	92.93 (80.93 - 111.30)

3.3. Observations on deck and underwater recordings

Observations of the grids during the cruise revealed that the shape of the grids in the new and used flexigrid sections were different (Fig. 6 a,c). It seems that the tension created in the grid section due to the catch load as well as the squeezing forces to which they are exposed to on deck (Fig. 6b), contribute to the observed deformations of the grids over time (Fig. 6c).

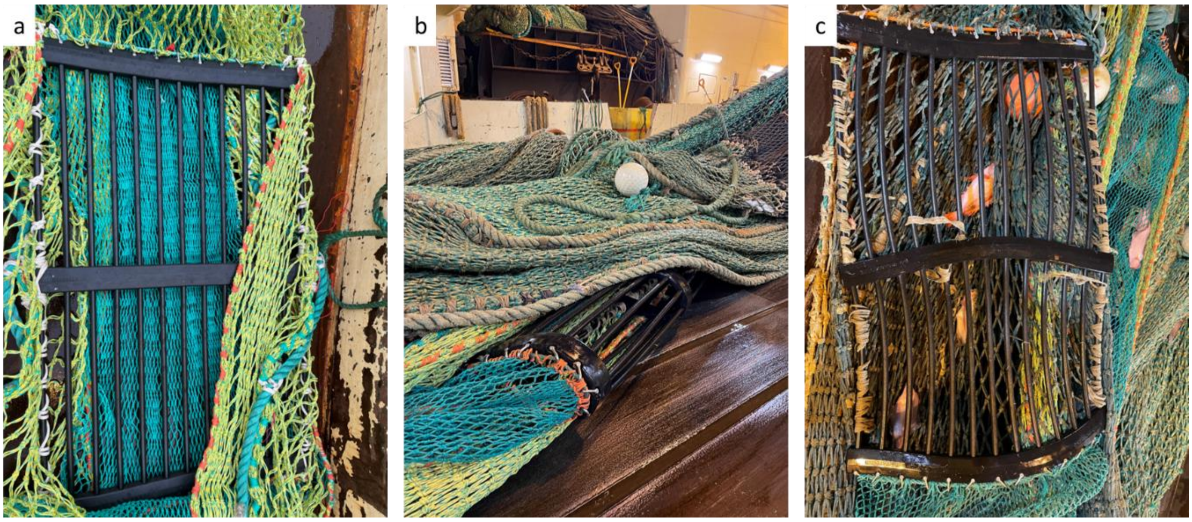

Fig. 6: Pictures of a grid in the new flexigrid section (a), a grid in the old flexigrid section squeezed on deck (b), and a grid in the old Flexigrid section laying on deck (c), taken through the trials.

The underwater recordings showed that the grids in the new section seemed to have a steeper angle than the grids in the used section, which likely results in a higher contact probability of fish with the grids. The recordings also showed that the gaps between the grids and the netting panels in the section were larger, resulting probably in a larger proportion of fish simply passing through the section without being subjected to a size selection process by any of the two grids (Fig. 7).

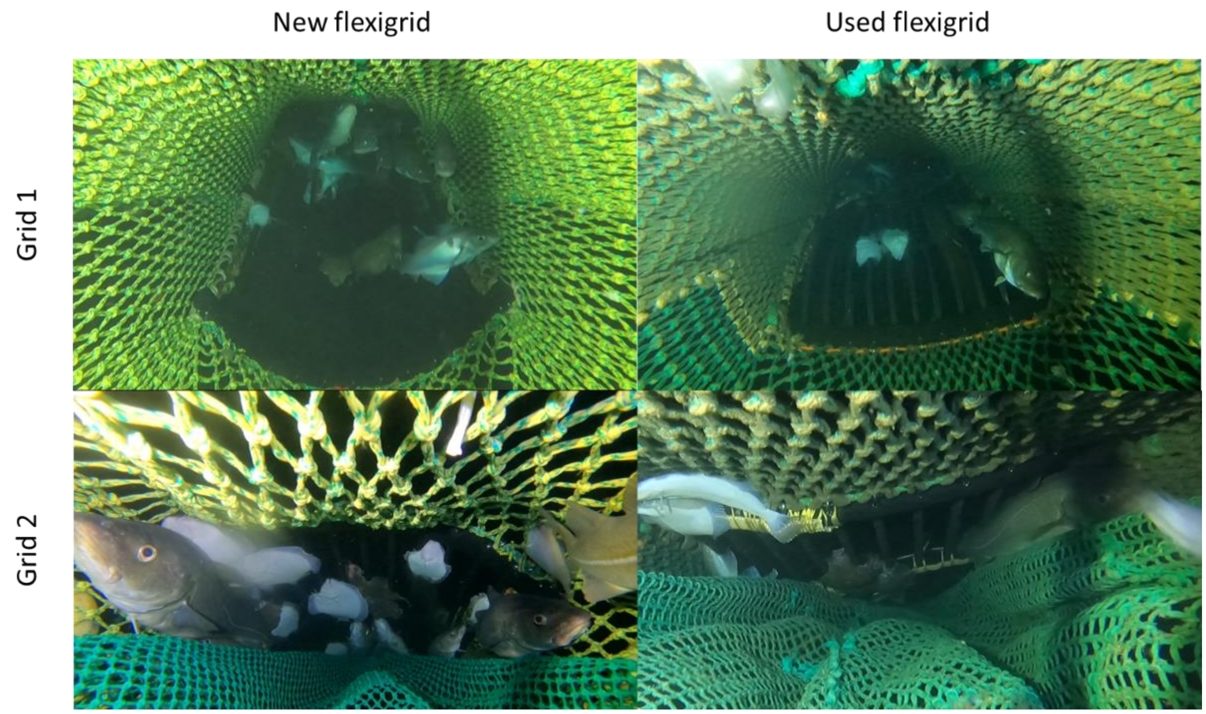

Fig. 7: Pictures of grid 1 and grid 2 in the new flexigrid section (left) and pictures of grid 1 and grid 2 in the used flexigrid (right) during the fishing trials.

During the cruise, there was no possibility to measure the grid angle of the four grids in the sections. However, in an attempt to understand why the grids in the used section seem to lay flatter, the size of the meshes in the grid section were measured. The mesh size in the new grid section was (138.08 ± 0.31 mm) whereas in the used section it was (140.2 ± 0.50 mm), meaning that the mesh size was significantly larger in the used section.

4. Discussion and conclusion

The results of the present study clearly showed that the size selectivity performance of the new flexigrid section and the used flexigrid section tested here differ. The used flexigrid sorted out significantly less fish under 60 cm while the retention of fish over 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 expected. Earlier studies have shown that in such combined selectivity systems, the grid is the main contributor to the overall selectivity of the gear (Sistiaga et al., 2010; Brinkhof et al., 2020). However, grids can be blocked by seaweed, flatfish and other marine animals, and it is important to document that in those cases a selective codend seems to contribute much more importantly to the overall selectivity. It should be pointed out however that mesh size of the codend both exceeded the minimum legal mesh size of 130 mm.

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 reducing the angle of the grids, increasing the free space between the edge of the grid and the netting panels of the section and consequently reducing the probability for fish to contact the grids. The view though the grid becomes more of a ”tunnel-like” passage where where the probability for fish to be subjected to a a size selection process by any of the grids is low. The netting material used in both sections here 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 used grid section, 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.

In addition to the contact probability issue observed in the underwater recordings, observations of the used grid on deck showed clear signs of deformation, which could not be observed in the new grid. As the new grid, the used grid showed an average bar spacing of ca. 55 mm, however, the standard deviation as a result of the variability in the bar spacing was substantially higher for the used grid (1.73 mm vs. 4.86 mm). On top of the contact issue, the increased variability in the grid bar spacing observed in the used grid 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.

The results of 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 puzzling results. Fishing gear tests 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 heavy duty. The results obtained by Sistiaga et al. (2016) and Brinkhof et al. (2020) with the flexigrid section exemplifies this situation. The selectivity results obtained in the former study with a well-used grid section were substantially poorer than in the latter study with a new grid section.

Brinkhof et al. (2020) already brought the potential differences between used and new grid section as a potential 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 tested equipment that a priori is the same or very similar but differ 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 use in commercial activities.

Establishing the extent to which a specific type of gear should be allowed or used in commercial duty can be complicated because the gear can be operated in very different ways by different users and consequently, its properties over time could change differently. 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. Although complicated and time demanding, it would be interesting in the future to explore if, how and when the properties of fishing gear change with time.

References

Angell, S., Lilleng, D., Vollstad, J., Grimaldo, E. 2001. Selectivity experiments with 55 and 60 mm Flexigrid in the bottom trawl fishery for cod. Experiments on board “Bliki” 11– 23 June 2001. SINTEF Fisheries and Aquaculture. SINTEF Fisheries and Aquaculture., STF80 A013, 19 (in Norwegian).

Brinkhof, J., Larsen, R.B., Herrmann, B., and Sistiaga, M. 2020. Size selectivity and catch efficiency of bottom trawl with a double sorting grid and diamond mesh codend in the North-east Atlantic gadoid fishery. Fish. Res. 231, 105647.

Efron, B., 1982, The jackknife, the bootstrap and other resampling plans. In: SIAM Monograph No. 38, CBSM-NSF Regional Conference Series in Applied Mathematics, Philadelphia. ISBN: 978–0-89871–179-0.

Grimaldo, E., Sistiaga, M., Herrmann, B., Gjøsund, S.H., Jørgensen, T., 2015. Effect ofthe lifting panel on selectivity of a compulsory grid section (Sort-V) used by the demersal trawler fleet in the Barents Sea cod fishery. Fish. Res. 170, 158–165.

Herrmann, B., Sistiaga, M., Nielsen, K.N., Larsen, R.B., 2012. Understanding the size selectivity of redfish (*Sebastes* spp.) in North Atlantic trawl codends. J. Northwest Atl. Fish. Sci. 44, 1–13.

Herrmann, B., Sistiaga, M., Rindahl, L., Tatone, I., 2017. Estimation of the effect of gear design changes on catch efficiency: methodology and a case study for a Spanish longline fishery targeting hake (*Merluccius merluccius*). Fish. Res. 185, 153–160.

Jørgensen, T., Ingolfsson, I.A., Graham, N., and Isaksen, B. 2006. Size selection of cod by rigid grids — Is anything gained compared to diamond mesh codends only? Fish. Res. 79: 337–348.

Larsen, R.B., and Isaksen, B. 1993. Size selectivity of rigid sorting grids in bottom trawls for Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). ICES Mar. Sci. Symp. 196: 178–182.

Olsen, L., Herrmann, B., Grimaldo, E., Sistiaga, M., 2019. Effect of pot design on the catch efficiency of snow crabs (*Chionoecetes opilio*) in the Barents Sea fishery. PLoS ONE 14 (7), e0219858.

Sistiaga, M., Brinkhof, J., Herrmann, B., Grimaldo, E., Langård, L., and Lilleng, D., 2016. Size selective performance of two flexible sorting grid designs in the Northeast Arctic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) fishery. Fish. Res. 183: 340–351.

Sistiaga, M., Herrmann, B., Grimaldo, E., Larsen, R.B., 2010. Assessment of dual selection in grid based selectivity systems. Fish. Res. 105, 187–199.

Sistiaga, M., Herrmann, B., Larsen, R.B., 2009. Investigation of the paired-gear method in selectivity studies. Fish. Res. 97, pp. 196–205.

Sistiaga, M., Herrmann, B., Nielsen, K.N., Larsen, R.B., 2011. Understanding limits to cod and haddock separation using size selectivity in a multispecies trawl fishery: an application of FISHSELECT. Can. J. Fish. Aquat. Sci. 68, 927–940.

Wileman, D., Ferro, R.S.T., Fonteyne, R., Millar, R.B., (Eds.), 1996. Manual of methods of measuring the selectivity of towed fishing gears. ICES Cooperative Research report No. 215.