

1 **Development of selectivity systems**  
2 **for gadoid trawls**



3 **Comparative tests of a well-used and a new flexigrid,**  
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6  
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## 30 **Summary**

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

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

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

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

## 62 **Sammendrag**

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

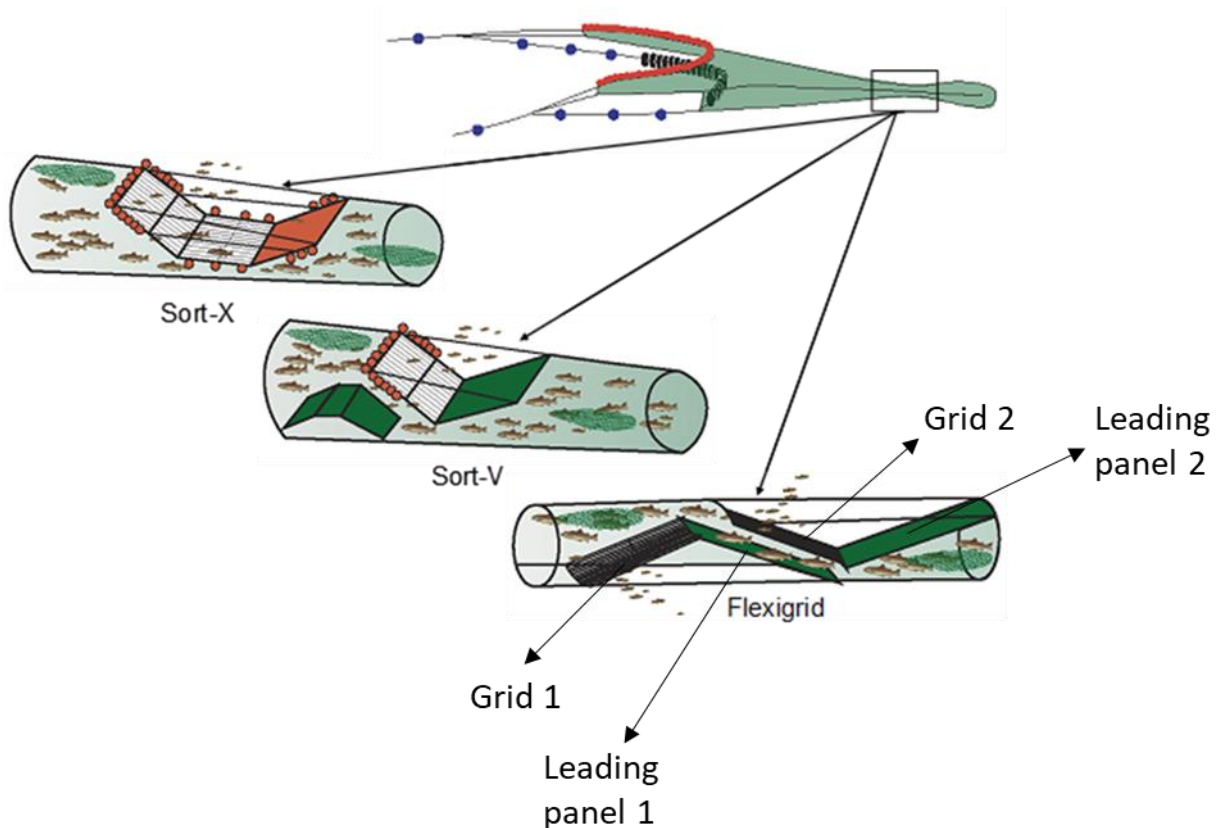
70 For å belyse dette spørsmålet, ble det gjort komparative fiskeforsøk med dobbeltrål der en  
71 sammenlignet fangsten i en trål med ny rist med fangsten i en identisk trål med gammel rist. To  
72 serier med 24 og 10 hal ble gjort hhv med og uten finmasket inner-nett i trålposen. Forsøkene  
73 viste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

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

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

90 **1. Background**

91 Norwegian fishermen targeting gadoid species in the Barents Sea are obliged to use a sorting  
92 grid with a minimum bar spacing of 55 mm and a codend with a minimum mesh size of 130  
93 mm. Three different sorting grid systems are allowed in the Barents Sea: the Sort-X (Larsen  
94 and Isaksen, 1993), the Sort-V (Jørgensen et al., 2006), and the flexigrid (Sistiaga et al.,  
95 2016)., The flexigrid is the most widely used system due to its low weight and  
96 maneuverability, although some vessels employ the Sort-V system. The Sort-X is rarely used  
97 due to its large size and heavy weight.



98  
99

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

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

105 Several studies have focused on the sorting properties of the flexigrid both before its  
106 implementation in the technical regulations in 2002 (e.g. Angell et al., 2001) and after (Sistiaga  
107 et al., 2009, 2016; Brinkhof et al., 2020) . Studies have also compared the sorting properties of

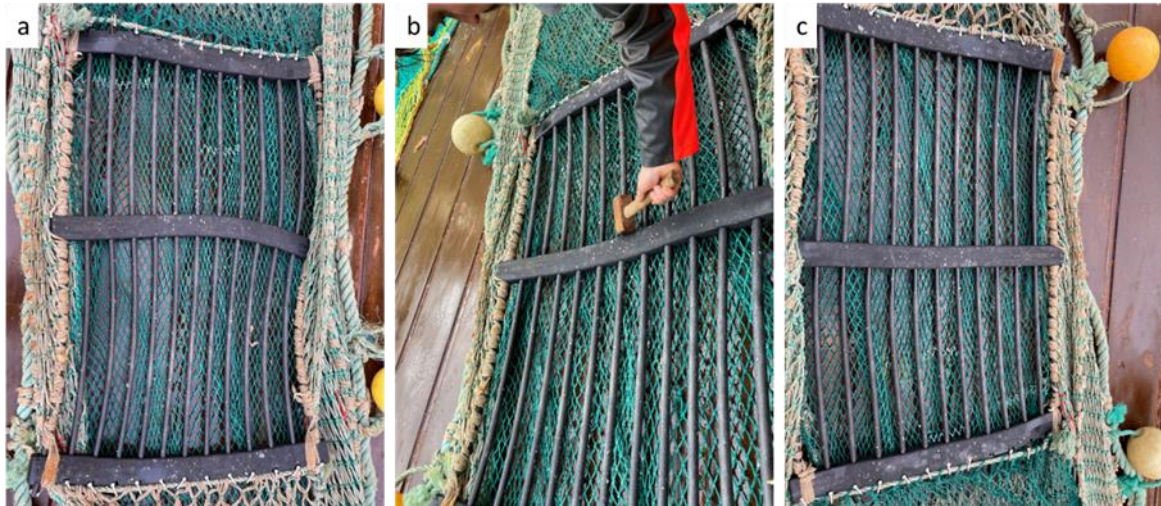
108 the flexigrid with the Sort-V. In principle, the two grids should have similar sorting properties,  
109 but the results show that this is not always the case (Sistiaga et al., 2009).

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

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

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

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



147  
148 Fig. 2: Deformations that can appear in the flexigrid with prolonged use (a). The shape of the grid needs to be  
149 continuously corrected by means of a hammer (b) to return the grid to a shape closer to the expected (c).

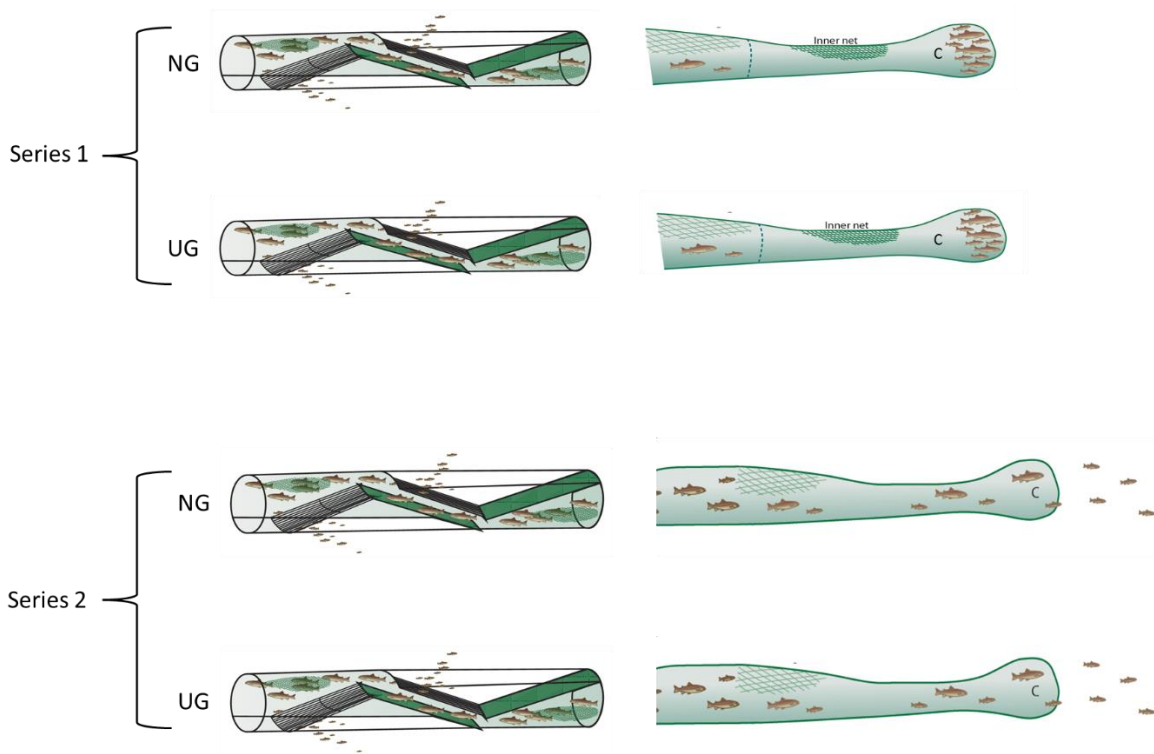
## 150 2. Materials and methods

### 151 2.1. Fishing trials

152 Fishing trials were conducted in the Barents Sea, around Bear Island between the 20<sup>th</sup> of  
153 October and the 3<sup>rd</sup> of November 2022. The commercial vessel “M/Tr Ramoen” (75.1 m LOA,  
154 3723 Gross Tonnage) was chartered for the trials. The vessel operates two Selstad 630# trawls  
155 (headline height ca. 7m) in a twin setup with a pair of Thyborøn type 26 VFG doors (9m<sup>2</sup> ca.  
156 4,400 kg each), a central clump (Thyborøn 2700 mm 6,500 kg) and 100 m sweeps. The door  
157 distance was typically 220-250 m depending on the operational depth.

158 One of the trawls was rigged with a flexigrid section that had been fished (UG) for ca. 20,000  
159 hours over four years, whereas the other trawl was rigged with a new flexigrid section (NG).  
160 Both the construction of the sections and the grids in the sections were identical and built  
161 following the guidelines in the Fisheries Directorate directive *Forskrift om gjennomføring av*  
162 *fiske, fangst og høsting av villlevende marine resurser (Høstingsforskriften)*. The bar spacing  
163 of the grids and the mesh openings of the codends was measured following Wileman et al.  
164 (1996). The mean bar spacing of the grids in the new grid section was (55.87 ± 1.73 mm) (Mean  
165 ± SD), whereas the mean bar spacing of the grids in the used grid section was (55.90 ± 4.86  
166 mm). Each grid section was followed by a 22 m long extension piece. The codends following

167 the extension pieces in each of the trawls were #90 meshes long x #80 free meshes around, built  
 168 of knotless meshes in 130 mm nominal mesh size (nms) (10 mm twine). The mesh size of the  
 169 codend used with the NG was  $136.48 \pm 3.08$  mm, whereas the mesh size of the codend used  
 170 with the UG was  $137.88 \pm 1.94$  mm. The difference in the average mesh size measured for the  
 171 two codends was not significant. During the first series in the experiments (Hauls 1-24) the  
 172 codends were completely blinded with 45 mm nominal mesh size inner-nets, which ensured  
 173 that no cod or haddock under 10 cm could escape from the codends (Sistiaga et al., 2011). In  
 174 series 2 (Hauls 25-35), the inner-nets were removed to evaluate the implications of adding  
 175 subsequent codend selectivity to the selectivity of the grid sections (Fig. 3). To account for  
 176 potential differences in the fishing power of the trawls, each grid section was mounted half the  
 177 number of hauls on the starboard and port side trawls respectively. (Table 1).



178

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

181 The catch from both trawls was kept separated. Cod (Minimum Legal Size (*MLS*) = 44 cm) and  
 182 haddock (*MLS* = 40 cm) were measured to the nearest cm below. For each haul, all specimens  
 183 of these two species were measured, except for those hauls where for practical reasons the catch  
 184 had to be subsampled. In the hauls where the catch had to be subsampled, all fish in the fraction  
 185 that was not measured were counted and the subsampling factor calculated.



186 2.2. Data analysis

187 During the cruise the new and used flexigrid sections were fished simultaneously in a pair trawl  
 188 configuration. Therefore, the data can be treated as paired. We used the statistical analysis  
 189 software SELNET (Herrmann et al., 2012, 2017) to analyze catch data and to conduct size-  
 190 dependent catch comparisons and catch ratio analyses. Using the number of individuals caught  
 191 for each length class in the trawls with the new (Test1) and old (Test2) grids respectively, we  
 192 studied potential differences in the catch efficiency between the gears averaged over hauls.  
 193 Further, we investigated whether these differences could be length-dependent. Specifically, to  
 194 assess the relative length-dependent catch efficiency difference between the new and old grid,  
 195 we applied the method described in Herrmann *et al.* (2017) and Olsen et al. (2019). This method  
 196 models the size-dependent catch comparison ratio (proportion caught in test trawl,  $CC_i$ )  
 197 summed over sets:

$$198 \quad CC_l = \frac{\sum_{j=1}^h \left\{ \frac{n^{Test1}_{lj}}{q^{Test1}_j} \right\}}{\sum_{j=1}^h \left\{ \frac{n^{Test1}_{lj}}{q^{Test1}_j} + \frac{n^{Test2}_{lj}}{q^{Test2}_j} \right\}} \quad (1)$$

199 where  $n^{Test1}_{lj}$  and  $n^{Test2}_{lj}$  are the numbers of individuals of each species caught in each length  
 200 class  $l$  in the test and the control trawls, respectively.  $h$  is the number of hauls carried out in that  
 201 specific cruise, while  $q^{Test1}_j$  and  $q^{Test2}_j$  are subsampling factors that quantify the fraction of  
 202 the caught individuals being length measured for each species in the respective trawl.

203 The functional form for the catch comparison rate  $CC(l, \nu)$  was obtained using maximum  
 204 likelihood estimation by minimizing the following expression:

$$205 \quad - \sum_l \left\{ \sum_{j=1}^h \left\{ \frac{n^{Test1}_{lj}}{q^{Test1}_j} \times \ln(CC(l, \nu)) + \frac{n^{Test2}_{lj}}{q^{Test2}_j} \times \ln(1.0 - CC(l, \nu)) \right\} \right\} \quad (2)$$

206 where  $\nu$  represents the parameters describing the catch comparison curve defined by  $CC(l, \nu)$ .  
 207 The outer summation in expression (2) is the summation over the length classes  $l$ . When the  
 208 catch efficiency of the new grid and the old grid is equal, the expected value for the summed  
 209 catch comparison rate would be 0.5. Therefore, this baseline can be applied to judge whether  
 210 there is a difference in catch efficiency between the two grids. The experimental  $CC_l$  was  
 211 modelled by the function  $CC(l, \nu)$ , on the following form:

$$212 \quad CC(l, \nu) = \frac{\exp(f(w, \nu_0, \dots, \nu_s))}{1 + \exp(f(w, \nu_0, \dots, \nu_s))} \quad (3)$$

213 where  $f$  is a polynomial of order  $t$  with coefficients  $\nu_0$  to  $\nu_s$ . The values of the parameters  $\nu$   
 214 describing  $CC(l, \nu)$  are estimated by minimizing expression (2), which are equivalent to  
 215 maximizing the likelihood of the observed catch data. We considered  $s$  of up to an order of 4

216 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  
217 31 additional models that were also considered as potential models for the catch comparison  
218  $CC(l, \mathbf{v})$ . Among these models, estimations of the catch comparison rate were made using multi-  
219 model inference to obtain a combined model (Burnham and Anderson, 2002; Herrmann *et al.*,  
220 2017).

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

$$228 \quad CR(l, \mathbf{v}) = \frac{CC(l, \mathbf{v})}{(1 - CC(l, \mathbf{v}))} \quad (4)$$

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

235 The confidence limits for the catch comparison and catch ratio curves were estimated using a  
236 double bootstrapping method (Herrmann *et al.*, 2017). This technique accounts for uncertainty  
237 due to between-haul variation by selecting  $m$  hauls with replacement from the  $m$  hauls available  
238 during each bootstrap repetition. Within each resampled haul, the data for each length class are  
239 resampled in an inner bootstrap to account for the uncertainty in the haul due to a finite number  
240 of cod and haddock. To correctly account for the increased uncertainty due to subsampling, the  
241 data were raised by sampling factors after the inner resampling. However, contrary to the double  
242 bootstrapping method described in Herrmann *et al.* (2017), the outer bootstrapping loop in the  
243 current study that accounted for the between-haul variation was performed pairwise for the  
244 Test1 and Test2 gears, reflecting the experimental design in which both gears were deployed  
245 simultaneously. Moreover, by using multi-model inference in each bootstrap iteration, the  
246 method also accounted for the uncertainty in model selection. We performed 1000 bootstrap  
247 repetitions and calculated the Efron 95% confidence limits (Efron, 1982). To identify the sizes

248 of the different species with significant differences in catch efficiency, we checked for size  
 249 classes in which the 95% confidence limits for the catch ratio curve did not contain 1.0.  
 250 Indicators in the form of size-integrated average values for the catch ratio ( $CR_{average}$ ) were  
 251 estimated directly from the experimental catch data by:

$$\begin{aligned}
 CR_{average-} &= \frac{\sum_{l < ml} \sum_{j=1}^h \left\{ \frac{n_{Test1lj}}{q_{Test1j}} \right\}}{\sum_{l < ml} \sum_{j=1}^h \left\{ \frac{n_{Test2lj}}{q_{Test2j}} \right\}} \\
 CR_{average+} &= \frac{\sum_{l \geq ml} \sum_{j=1}^h \left\{ \frac{n_{Test1lj}}{q_{Test1j}} \right\}}{\sum_{l \geq ml} \sum_{j=1}^h \left\{ \frac{n_{Test2lj}}{q_{Test2j}} \right\}}
 \end{aligned}
 \tag{5}$$

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

### 257 2.3. Underwater recordings

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

264 The hauls used for the underwater recordings were not included in the data analysis because  
 265 recent research indicates that light affects fish behaviour and therefore may also affect the  
 266 performance of grids (Personal communication, Jesse Brinkhof, University of Tromsø,  
 267 Norway).

## 268 3. Results

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

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

274

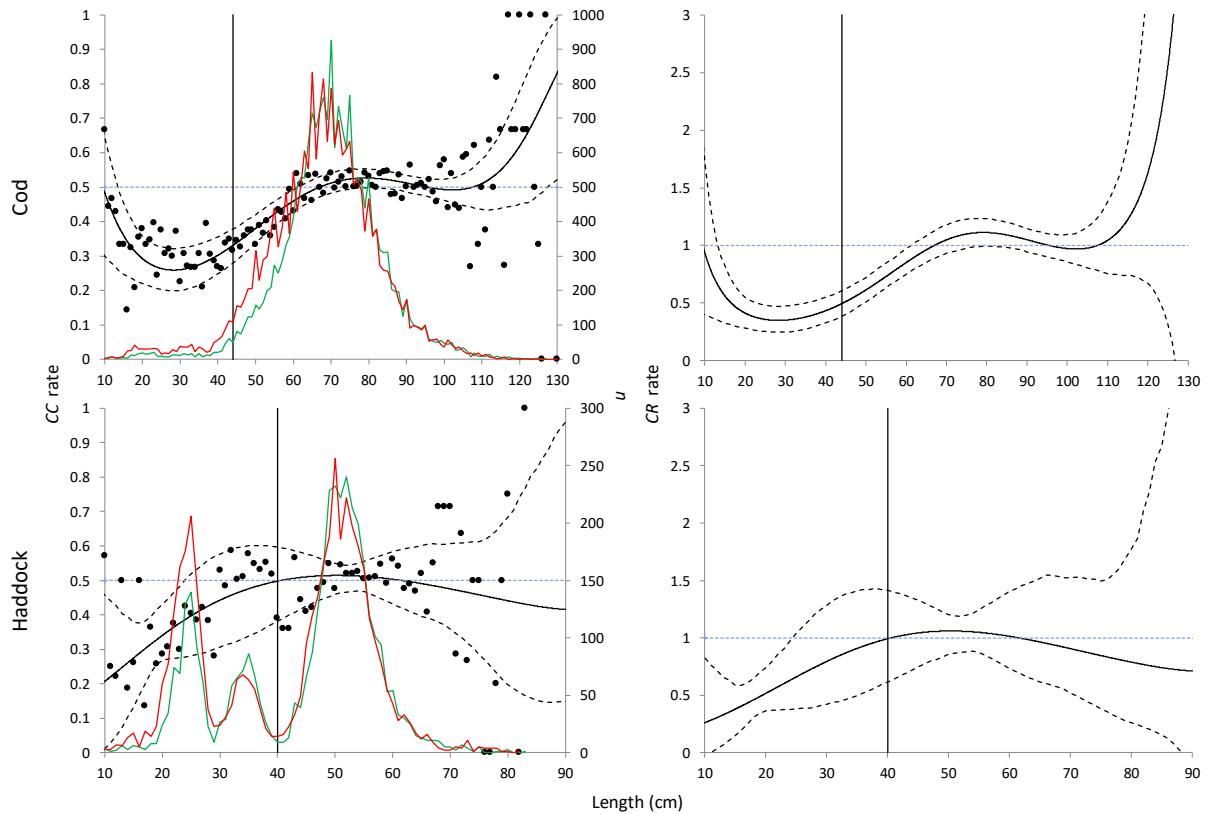
### 275 3.1. Catch Comparison (CC) and Catch Ratio (CR)

276 Despite the low p-values obtained for cod and haddock in the analysis, the deviance and DOF  
277 in both cases were of the same magnitude and the models showed to represent the trend in the  
278 data fine. This was the case especially for cod, where the data were much more abundant than  
279 for haddock. Thus, the low p-values were considered a result of overdispersion of the data and  
280 the models used in the analyses adequate (Fig. 4; Table 2).

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

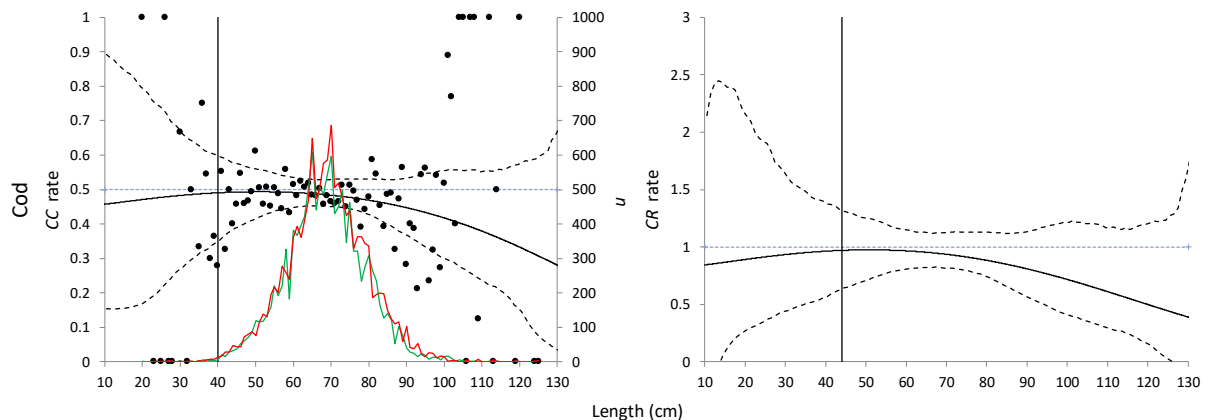
		Series 1	Series 2
Cod	P-value	<0.001	<0.001
	Deviance	192.93	162.63
	DOF	119	87
Haddock	P-value	0.002	*
	Deviance	108.9	*
	DOF	69	*

282



283

284 Figure 4: Catch comparison rate (left panels) and catch ratios (right panels) for the trawl configuration with NG  
 285 versus the configuration with the UG in series 1, with blinded codends. In the catch comparison plots the circles  
 286 show the experimental catch comparison ratios, whereas the solid line and the dotted lines show the modelled  
 287 catch comparison ratio and the corresponding 95% confidence intervals. The green lines show the catch  
 288 distribution in the NG configuration whereas the red lines show the catch distribution in the UG configuration. In  
 289 the catch ratio plots the solid black curve is the catch ratio curve, and the dotted curves are the corresponding  
 290 95% confidence intervals. The vertical black line represents the *MLS* in every case.



291

292 Figure 5: Catch comparison rate (plot left) and catch ratios (plot right) for the trawl configuration with NG  
 293 versus the configuration with the UG in series 2, with selective codends. In the catch comparison plot the circles  
 294 show the experimental catch comparison ratios, whereas the solid line and the dotted lines show the modelled  
 295 catch comparison ratio and the corresponding 95% confidence intervals. The green line shows the catch  
 296 distribution in the NG configuration whereas the red line shows the catch distribution in the UG configuration. In  
 297 the catch ratio plot the solid black curve is the catch ratio curve, and the dotted curves are the corresponding 95%  
 298 confidence intervals. The vertical black line represents the *MLS* in every case.

299 The plots for cod in Fig. 4 clearly show that the new grid retains significantly less fish under  
300 60 cm than the used grid. Further, the difference in retention is largest for fish under *MLS*.  
301 The catch ratio curve shows that the new grid retained less than 50% of individuals below  
302 *MLS* compared to used grid. For cod above 60 cm, which would be on the upper limit of the  
303 the selective range of a flexigrid section with a 55 mm grid bar spacing (Sistiaga et al., 2016;  
304 Brinkhof et al., 2020), the retention of both configurations tested in Series 1 is very similar.  
305 Since the retention for fish in the non-selective size range were equal, and the trawls were  
306 alternated during the trials, the observed differences in size composition between the two  
307 trawls during series 1 can only be due to the differences in the selectivity performance of the  
308 grids. The pattern in the data for haddock were similar to that observed for cod, but the  
309 numbers of fish of this species captured during the trials were lower and the results are  
310 therefore not as conclusive (Fig. 4).

311 When the inner-nets were removed from the codends in series 2, the catch ratio was no longer  
312 significantly different for any of the size classes of cod (Fig. 5). Thus, the selectivity in the  
313 codend likely compensated for the differences in sorting efficiency of the new and the used  
314 grids.

### 315 **3.2. Indicators**

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

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

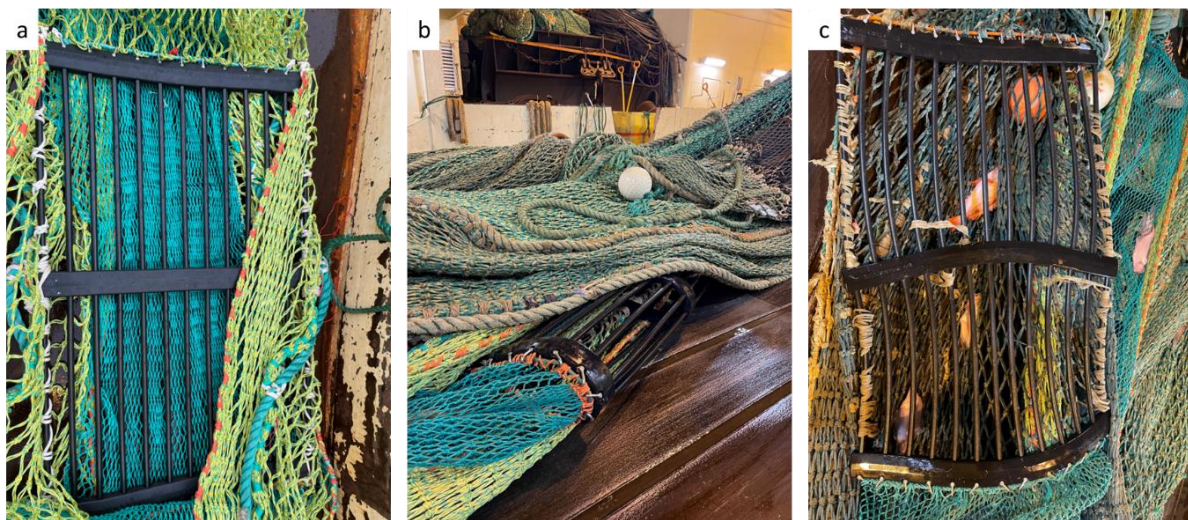
327 Table 3: Size-integrated average values for the catch ratio under ( $CR_{average-}$ ) and over  
328 ( $CR_{average+}$ ) the *MLS* for cod (44 cm) and haddock (40 cm); 95% confidence intervals are  
329 provided in brackets.

		$CR_{average^-}$	$CR_{average^+}$
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)

330

### 331 **3.3. Observations on deck and underwater recordings**

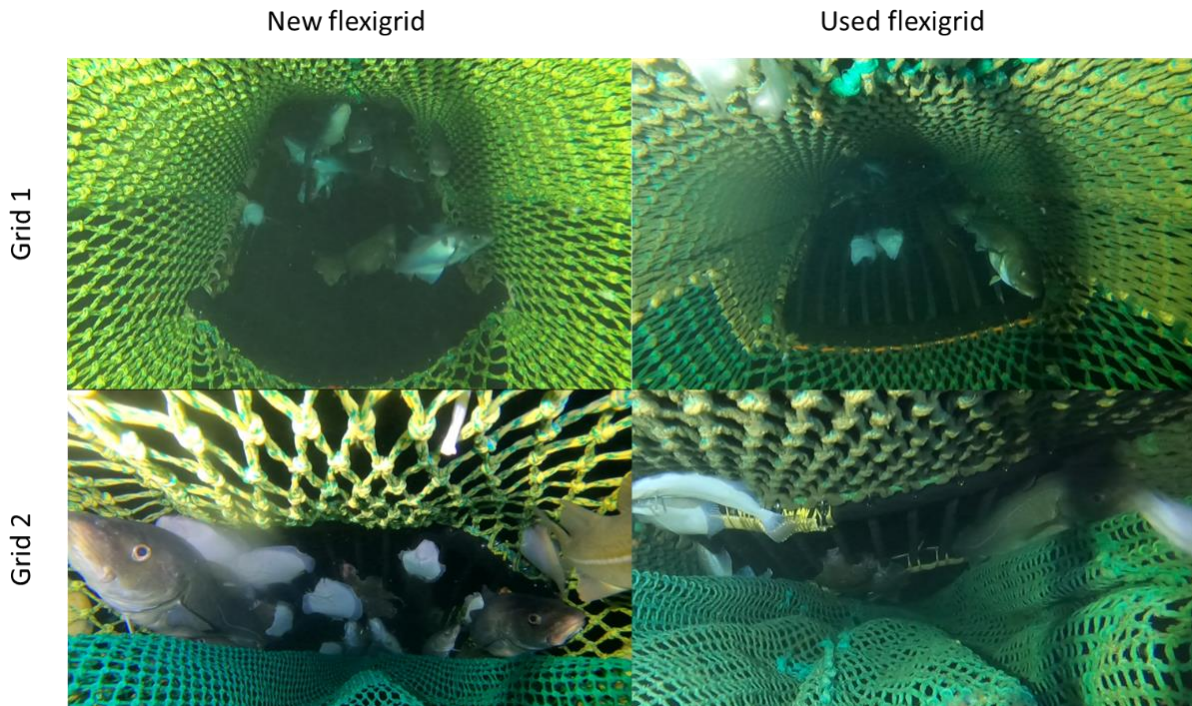
332 Observations of the grids during the cruise revealed that the shape of the grids in the new and  
 333 used flexigrid sections were different (Fig. 6 a,c). It seems that the tension created in the grid  
 334 section due to the catch load as well as the squeezing forces to which they are exposed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



336

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

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



345

346 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  
 347 flexigrid (right) during the fishing trials.

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

#### 353 4. Discussion and conclusion

354 The results of the present study clearly showed that the size selectivity performance of the  
 355 new flexigrid section and the used flexigrid section tested here differ. The used flexigrid  
 356 sorted out significantly less fish under 60 cm while the retention of fish over this size was the  
 357 same for both sections. However, this difference between the grid sections disappeared when  
 358 the grid sections were operated in combination with size selective codends. This result  
 359 emphasizes the importance of combining grids with size selective codends, as the codend  
 360 seems to contribute substantially to the overall size selectivity when the grid is not working as  
 361 expected. Earlier studies have shown that in such combined selectivity systems, the grid is the  
 362 main contributor to the overall selectivity of the gear (Sistiaga et al., 2010; Brinkhof et al.,  
 363 2020). However, grids can be blocked by seaweed, flatfish and other marine animals, and it is  
 364 important to document that in those cases a selective codend seems to contribute much more



365 importantly to the overall selectivity. It should be pointed out however that mesh size of the  
366 codend both exceeded the minimum legal mesh size of 130 mm.

367 From the underwater recordings and the grid section mesh measurements taken onboard, it  
368 seems like, as Brinkhof et al. (2020) pointed out earlier, the meshes in the grid section stretch  
369 with use reducing the angle of the grids, increasing the free space between the edge of the grid  
370 and the netting panels of the section and consequently reducing the probability for fish to  
371 contact the grids. The view though the grid becomes more of a "tunnel-like" passage where  
372 where the probability for fish to be subjected to a size selection process by any of the grids  
373 is low. The netting material used in both sections here was the same, so given that the mesh  
374 size was the same before both grids were used in the fishery, the used flexigrid section  
375 showed signs of having stretched, which would lead to the flatter grid angles observed. We  
376 have no measurements of the original mesh size in the used grid section, so we cannot be  
377 certain that the meshes have been stretched and were not like that originally. However, the  
378 angles of the grids observed indicate that this is the case.

379 In addition to the contact probability issue observed in the underwater recordings,  
380 observations of the used grid on deck showed clear signs of deformation, which could not be  
381 observed in the new grid. As the new grid, the used grid showed an average bar spacing of ca.  
382 55 mm, however, the standard deviation as a result of the variability in the bar spacing was  
383 substantially higher for the used grid (1.73 mm vs. 4.86 mm). On top of the contact issue, the  
384 increased variability in the grid bar spacing observed in the used grid will lead to an increased  
385 variability in the selectivity, which opposes the purpose of inserting a sorting grid in the gear.  
386 Grids have earlier been claimed to provide more stable size selection results than diamond  
387 mesh codends due to that they are more rigid than codend meshes.

388 The results of the current study also bring up an issue that can often be overseen by scientists  
389 and, as demonstrated in the present study, can lead to puzzling results. Fishing gear tests are  
390 usually conducted with new equipment and the results are assumed to represent how the  
391 equipment would perform under commercial conditions. However, the performance  
392 documented in scientific trials carried out with new equipment do not always represent the  
393 performance observed by fishermen with the same equipment exposed to heavy duty. The  
394 results obtained by Sistiaga et al. (2016) and Brinkhof et al. (2020) with the flexigrid section  
395 exemplifies this situation. The selectivity results obtained in the former study with a well-used  
396 grid section were substantially poorer than in the latter study with a new grid section.

397 Brinkhof et al. (2020) already brought the potential differences between used and new grid  
398 section as a potential source for the differences observed, but this could not be demonstrated  
399 at the time. The issue observed between the grids here may also have been the source for  
400 discrepancies in the results obtained between other studies that have tested equipment that a  
401 priori is the same or very similar but differ in the time it has been used. It is obvious that as  
402 the properties of materials change with use, so do the selectivity properties of the equipment  
403 built with these materials, especially equipment built with flexible materials like the flexigrid.  
404 This is something to account for in the future and it should have implications for the extent to  
405 which specific units of certain fishing gear should be allowed to use in commercial activities.

406 Establishing the extent to which a specific type of gear should be allowed or used in  
407 commercial duty can be complicated because the gear can be operated in very different ways  
408 by different users and consequently, its properties over time could change differently.  
409 However, it is important to realize that the changes in properties over time can be a  
410 determining issue for the performance of a gear and results of scientific tests. Although  
411 complicated and time demanding, it would be interesting in the future to explore if, how and  
412 when the properties of fishing gear change with time.

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