# Development of selectivity systems for gadoid trawls

## Tests with 45- and 55-mm bar spacing grids onboard M/Tr Hermes, November 2021

## *Note March 2021*

Manu Sistiaga, Jesse Brinkhof, Bent Herrmann, Roger B. Larsen, Eduardo Grimaldo, Neil Anders, Ilmar Brinkhof, Dagfinn Lilleng, Hermann Pettersen and Simon Eliseussen

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## Summary

One of the main objectives in the project "Development of selectivity systems for gadoid trawls" is to "study the effect of using different bar-spacings and meshes for the exploitation pattern of cod, haddock and saithe". In 2020 a research cruise was carried out to compare two Sort-V grids with 45- and 55-mm bar spacing, respectively. The results from that cruise showed that the selectivity for cod and haddock larger than Minimum Legal Size (*MLS*) differed between the grids (i.e. the 45 mm grid retained more fish larger than *MLS*), whereas the selectivity for fish smaller than *MLS* did not. Encouraged by these results, an additional cruise to compare these two grids was carried out onboard the commercial trawler M/Tr Hermes in November 2021.

During the commercial cruise, data were collected in two different fishing grounds, around Bjørnøya and west of Sørøya, and for three different species, cod, haddock and saithe. The results of the cruise showed as in the research cruise of 2020, that the selectivity of the 45- and 55-mm grids differs substantially. For all three species, the 45 mm grid retains in general significantly more fish larger than *MLS* than the 55 mm grid, but in some cases it also retains significantly more fish smaller than *MLS*. In all cases, the difference in retention rate between the grids was larger for fish larger than *MLS* than for fish smaller than *MLS*. The exploitation pattern indicators calculated show that the sorting ability of grids can vary and that catch patterns depend largely on the area and population fished e.g. the discard ratio for haddock increased from <3% to >50% for both grids when the fishery moved from Bjørnøya to the areas west of Sørøya. The results obtained indicate that gear choice including sorting devices other than grids may be necessary in the near future to increase catch efficiency and consequently reduce effort.

Finally, the data analysis in this study was conducted using the paired-gear method and shows the limitations of an indirect data collection method. For future experiments where the size range of the species is expected to be at the edge of the selectivity range of the gear, a direct method like the covered codend method is recommended instead.

## Sammendrag

Et av hovedmålene i prosjektet "Utvikling av seleksjonssystemer i torsketrål" er å "studere effekten av å bruke forskjellige spileavstander og maske-fasonger for beskatningsmønsteret av torsk, sei og hyse". I 2020 ble det gjennomført et forskningstokt for å sammenligne to Sort-V sorteringsrister med henholdsvis 45- og 55-mm spilleavstand. Resultatene viste signifikant forskjell i seleksjonen av torsk og hyse over minstemål (dvs. 45 mm risten fanget mer fisk over minstemål), mens seleksjonen for fisk under minstemål ikke var signifikant forskjellig. På bakgrunn av resultatene fra forskningstoktet ble det gjennomført et oppfølgningstokt-tokt ombord den kommersielle tråleren M/Tr Hermes i november 2021.

I løpet av dette kommersielle toktet ble det samlet data i to forskjellige fiskefelt, rundt Bjørnøya og vest for Sørøya, for tre forskjellige arter: Torsk, hyse og sei. I samsvar med resultatene fra forskningstoktet viser disse resultatene at størrelsesseleksjonen for 45- og 55-mm ristene er signifikant forskjellig. For alle tre artene var tilbakeholdelsen av fisk over minstemål i 45 mm risten generelt høyere enn for 55 mm risten, men i noen tilfeller viste 45 mm risten også høyere tilbakeholdelse for fisk under minstemål. I samtlige tilfeller var forskjellen i tilbakeholdelse mellom ristene høyere for fisk over minstemål enn under minstemål. Fangstsammensetningen er i stor grad er avhengig av populasjonssammensetningen i området man fisker i. For eksempel viste det seg at andelen av fisk under minstemål i forhold til den totale fangsten for hyse økte fra <3% to >50% for både 45- og 55-mm rist når fiskeområdet ble skiftet fra Bjørnøya til Sørøya. Resultatene indikerer at et friere valg av ulike seleksjons-anordninger enn kun rist kan bli nødvendig i fremtiden for å øke fangsteffektivitet og dermed minke innsatsen.

Til slutter det å bemerke atdataene i dette studiet er analyserte ved å benytte dobbeltrål metoden («paired gear method») og analysen viser begrensingene ved denne indirekte datainnsamlingsmetoden. I fremtidige forsøk der størrelsessammensetningen av fisken er forventet å være på grensen til seleksjonsevnen til sorteringsredskapet, anbefales det å bruke direkte innsamlingsmetoder, som dekknett metoden (covered codend method).

## 1. Background

A research cruise carried out onboard R/V "Helmer Hanssen" in December 2020 showed important selectivity differences between a 45 mm steel grid and 55 mm steel grid for cod, haddock and redfish (Sistiaga et al., 2021). For all three species, which have a Minimum Legal Size (*MLS*) of 44, 40 and 32 cm respectively, the retention of most length classes larger than *MLS* was significantly larger for the 45 mm grid, while the differences in retention for the fish smaller than *MLS* between the two grids tested were not significant in any case (Fig. 1).

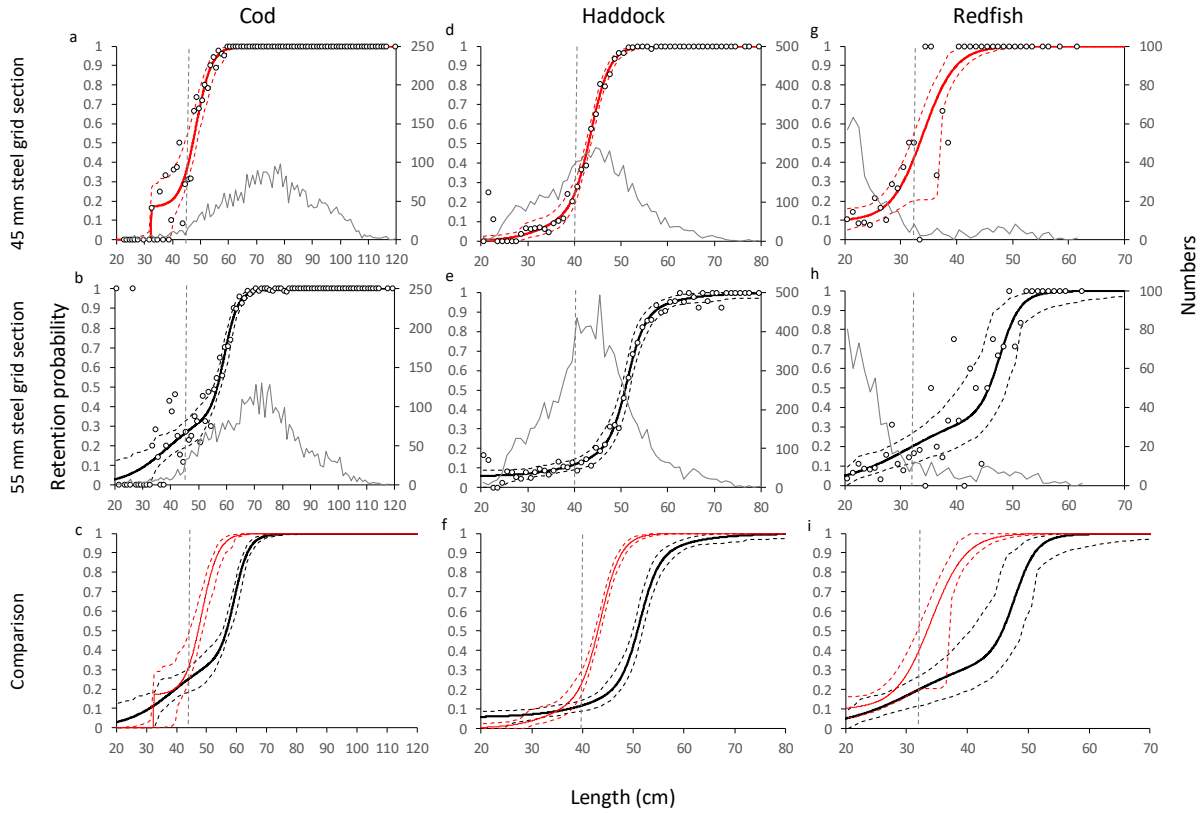


Fig. 1: Retention probability with the 45 mm steel grid and the 55 mm steel grid for cod (a-c), haddock (d-f) and redfish (g-i) in the research cruise carried out onboard R/V Helmer Hanssen in December 2020. In the comparison, the standard Sort-V section with a 45 mm steel grid in red and the standard Sort-V section with a 55 mm steel grid in black.

Encouraged by the results obtained in the research cruise in December 2020, the project group decided to compare the performance of the Sort-V steel grid with these two different bar spacings, 45- and 55-mm, in purely commercial fishing conditions.

## 2. Materials and methods

*2.1. Fishing trials*

Fishing trails were conducted in the Barents Sea, around Bear Island (73° 58' 139" / 74° 31' 071" N – 18° 11' 733" / 25° 02' 314" E), and off the coast of Norway, west of Sørøya (70° 53' 291" / 71° 13' 818" N – 21° 33' 966" / 21° 57' 379" E), between the 9th and 21st of November 2021. The commercial vessel "M/Tr Hermes" (55 m LOA, 1572 Gross Tonnage) was chartered for the trials. The vessel operates two Mørenot 634# trawls (headline height ca. 7m) in a twin setup with a pair of Scorpion injector doors (10.5 m, 4700 kg each), a central clump and 100 m sweeps. The door distance was typically 220-250 m.

One of the trawls was rigged with either a 55 mm or 45 mm steel grid sorting section (Sort-V type) in front of the extension piece and a blinded codend (test gear), whereas the other trawl was rigged without grid section and with a blinded codend (control gear). The codends used were built of 133 mm meshes (#100 meshes long and 80 free meshes around) and were blinded by means of liners built of 45 mm nominal size meshes, which ensured that no fish under 10 cm can escape from the codend (Sistiaga et al., 2011). The test and control gears were alternated between the starboard and port sides every 5 to 8 hauls (Table 1).

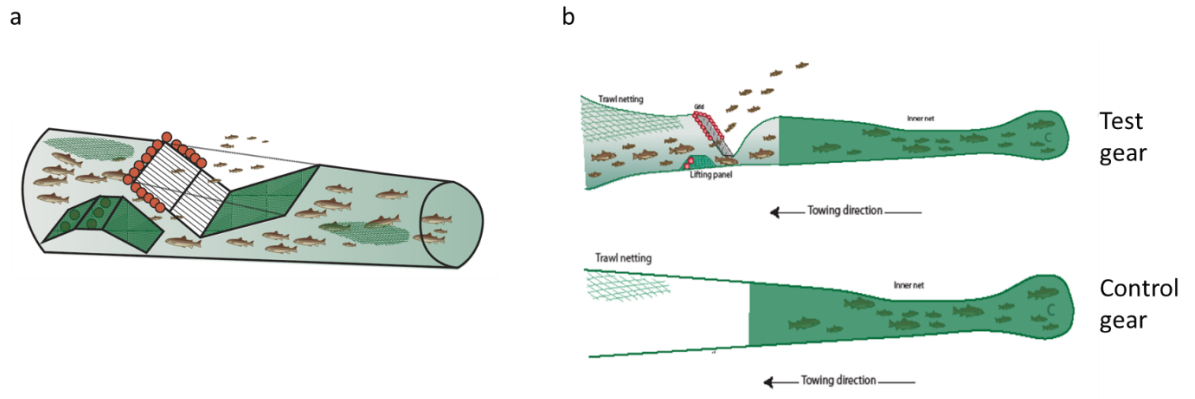


Fig. 2: Illustration of a Sort-V type grid section used during the fishing trials.

The catch in the test and control gear was kept separated. All cod, haddock and saithe (*MLS* = 45 cm) were measured to the nearest cm below except for those hauls where for practical issues the catch had to be subsampled. In the hauls where the catch had to be subsampled, all fish in the fraction that was not measured were counted and the subsampling factor calculated.

*2.2. Data analysis*

The length measurements were used as paired-gear data to estimate the selectivity of the two grid sections for cod, haddock and saithe. The selectivity analysis was carried out following the

procedure described in Wileman et al., 1996 for paired gear data analysis. We used the software tool SELNET (Herrmann et al. 2012) for the analysis. Eight different models were considered: Logit, Probit, Gompertz, Richard, CLogit, CProbit, CGompertz and CRichard (Lomeli et al., 2019). The model with the lowest AIC value (Akaike, 1974) was chosen for further analysis. Once the specific size-selection model was identified for each species and codend configuration, the double bootstrap method implemented in SELNET was used to obtain the confidence limits for the size selection curve and the corresponding parameters. This bootstrapping approach is identical to the one described in Millar (1993) and takes into consideration both within-haul and between-haul variation. For each species analyzed, 1000 bootstrap repetitions were conducted. Each bootstrap run resulted in a set of data that was pooled and then analyzed using the identified selection model. Thus, each bootstrap run resulted in an average selection curve. The Efron percentile 95% confidence limits for the average selection curve were obtained based on the same 1000 bootstrap repetitions (Efron 1982; Herrmann et al. 2012).

To investigate how the different codend configurations affected the capture pattern for each species separately, we estimated the value of three exploitation pattern indicators, nP-, nP+, and nDiscard (discard ratio). nP- represents the probability for fish under *MLS* to be retained, nP+ is the probability for fish larger than *MLS* to be retained, and the discard ratio is the ratio between the number of fish smaller than *MLS* retained and the total number of fish retained in the test codend. These indicators, which are dependent on the entry population in the gear, are often used in fishing gear size selectivity studies to supplement assessment solely based on selectivity curves (Santos et al. 2016; Sala et al. 2017; Cheng et al. 2019; Kalogirou et al. 2019; Melli et al. 2020). The indicators were calculated using the procedure described in Wienbeck et al. 2014:

$$
\begin{aligned}
nP- &= 100 \times \frac{\sum_j \sum_{l<MLS} (nTestC_{jl})}{\sum_j \sum_{l<MLS} (nControlC_{jl})} \\
nP+ &= 100 \times \frac{\sum_j \sum_{l>MLS} (nTestC_{jl})}{\sum_j \sum_{l>MLS} (nControlC_{jl})} \qquad (1) \\
* DiscardRatio &= 100 \times \frac{\sum_j \sum_{l<MLS} (nTestC_{jl})}{\sum_j \sum_{l} (nTestC_{jl})}
\end{aligned}
$$

* Regarding discard ratio it is important to bear in mind that discards are not allowed in Norway, and that the name of the indicator was only chosen because it is the most commonly used term in literature.

## 3. Results

During the cruise we carried out a total of 46 hauls that were used for selectivity analysis, 24 in the area of Bjørnøya and 22 in the are west of Sørøya. The species captured in sufficient numbers to be included in the selectivity analysis were cod and haddock in Bjørnøya, and cod, haddock and saithe west of Sørøya (Table 1). During the cruise, a total of 28190 cod, 42987 haddock and 50325 saithe were measured.

Table 1: Overview of the hauls conducted during the experimental sea trials and the numbers of cod, haddock, and saithe retained in the test and control gears. BØ: Bjørnøya. SØ: Sørøya. SF: subsampling fraction applied to each compartment.

| Area | Grid | Haul Nr | Test side | Towing time | Depth (m) | Cod | | | | Haddock | | | | Saithe | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Test | SF | Control | SF | Test | SF | Control | SF | Test | SF | Control | SF |
| BØ | 45 mm | 2 | BB | 02:45 | 112 | 246 | 1.000 | 476 | 1.000 | 1739 | 0.863 | 2487 | 0.604 | – | – | – | – |
| BØ | 45 mm | 3 | BB | 03:17 | 105 | 237 | 1.000 | 201 | 1.000 | 1066 | 1.000 | 823 | 1.000 | – | – | – | – |
| BØ | 45 mm | 4 | BB | 03:39 | 127 | 190 | 0.926 | 287 | 0.833 | 840 | 1.000 | 729 | 1.000 | – | – | – | – |
| BØ | 45 mm | 5 | BB | 03:04 | 116 | 200 | 1.000 | 275 | 1.000 | 1510 | 1.000 | 1633 | 0.980 | – | – | – | – |
| BØ | 45 mm | 6 | BB | 03:12 | 130 | 160 | 1.000 | 196 | 1.000 | 1082 | 1.000 | 1210 | 1.000 | – | – | – | – |
| BØ | 45 mm | 7 | SB | 04:58 | 130 | 97 | 1.000 | 195 | 1.000 | 407 | 1.000 | 482 | 1.000 | – | – | – | – |
| BØ | 45 mm | 8 | SB | 04:58 | 125 | 293 | 1.000 | 260 | 1.000 | 3399 | 0.442 | 3644 | 0.412 | – | – | – | – |
| BØ | 45 mm | 9 | SB | 02:53 | 135 | 207 | 1.000 | 173 | 1.000 | 1194 | 1.000 | 1323 | 1.000 | – | – | – | – |
| BØ | 45 mm | 10 | SB | 02:56 | 111 | 96 | 1.000 | 112 | 1.000 | 290 | 1.000 | 340 | 1.000 | – | – | – | – |
| BØ | 45 mm | 11 | SB | 03:00 | 111 | 136 | 1.000 | 350 | 1.000 | 73 | 1.000 | 333 | 1.000 | – | – | – | – |
| BØ | 55 mm | 12 | SB | 03:59 | 135 | 99 | 1.000 | 203 | 1.000 | 80 | 1.000 | 204 | 1.000 | – | – | – | – |
| BØ | 55 mm | 13 | SB | 03:57 | 68 | 187 | 1.000 | 153 | 1.000 | 133 | 1.000 | 142 | 1.000 | – | – | – | – |
| BØ | 55 mm | 15 | SB | 03:54 | 132 | 402 | 1.000 | 592 | 1.000 | 4229 | 0.357 | 6107 | 0.247 | – | – | – | – |
| BØ | 55 mm | 16 | SB | 03:41 | 130 | 436 | 1.000 | 686 | 1.000 | 2422 | 0.619 | 3920 | 0.383 | – | – | – | – |
| BØ | 55 mm | 17 | SB | 06:10 | 130 | 599 | 1.000 | 885 | 1.000 | 5675 | 0.264 | 6795 | 0.221 | – | – | – | – |
| BØ | 55 mm | 18 | SB | 07:42 | 132 | 440 | 1.000 | 947 | 1.000 | 2079 | 0.722 | 5053 | 0.297 | – | – | – | – |
| BØ | 55 mm | 20 | BB | 02:05 | 125 | 32 | 1.000 | 178 | 1.000 | 75 | 1.000 | 381 | 1.000 | – | – | – | – |
| BØ | 55 mm | 21 | BB | 02:54 | 135 | 19 | 1.000 | 228 | 1.000 | 36 | 1.000 | 129 | 1.000 | – | – | – | – |
| BØ | 55 mm | 22 | BB | 03:14 | 120 | 73 | 1.000 | 338 | 1.000 | 13 | 1.000 | 370 | 1.000 | – | – | – | – |
| BØ | 55 mm | 23 | BB | 03:41 | 280 | 1065 | 1.000 | 2013 | 0.745 | – | – | – | – | – | – | – | – |
| BØ | 55 mm | 24 | BB | 03:36 | 300 | 1339 | 1.000 | 2659 | 0.572 | 1 | 1.000 | 14 | 1.000 | – | – | – | – |
| BØ | 55 mm | 25 | BB | 02:48 | 295 | 1528 | 0.987 | 2690 | 0.565 | 4 | 1.000 | 14 | 1.000 | – | – | – | – |
| BØ | 55 mm | 26 | BB | 04:11 | 290 | 1784 | 0.841 | 3764 | 0.399 | 1 | 1.000 | 10 | 1.000 | – | – | – | – |
| BØ | 55 mm | 27 | BB | 03:46 | 300 | 850 | 1.000 | 1721 | 0.871 | 5 | 1.000 | 15 | 1.000 | – | – | – | – |
| SØ | 55 mm | 28 | BB | 01:03 | 220 | 24 | 1.000 | 70 | 1.000 | 8 | 1.000 | 186 | 1.000 | 972 | 1.000 | 5093 | 0.295 |
| SØ | 55 mm | 29 | BB | 02:40 | 190 | 15 | 1.000 | 95 | 1.000 | 14 | 1.000 | 987 | 0.412 | 325 | 1.000 | 4766 | 0.315 |
| SØ | 55 mm | 30 | BB | 03:08 | 186 | 47 | 1.000 | 144 | 1.000 | 56 | 1.000 | 1107 | 1.000 | 1201 | 1.000 | 4747 | 0.319 |
| SØ | 55 mm | 31 | BB | 04:30 | 200 | 14 | 1.000 | 150 | 1.000 | 8 | 1.000 | 1728 | 0.429 | 120 | 1.000 | 3479 | 0.431 |
| SØ | 55 mm | 32 | BB | 03:34 | 185 | 23 | 1.000 | 122 | 1.000 | 12 | 1.000 | 1509 | 0.333 | 402 | 1.000 | 4858 | 0.313 |
| SØ | 55 mm | 33 | SB | 03:07 | 180 | 25 | 1.000 | 116 | 1.000 | 32 | 1.000 | 861 | 0.333 | 938 | 1.000 | 7286 | 0.207 |
| SØ | 55 mm | 34 | SB | 04:34 | 195 | 26 | 1.000 | 168 | 1.000 | 12 | 1.000 | 1206 | 0.222 | 167 | 1.000 | 2029 | 0.739 |
| SØ | 55 mm | 35 | SB | 02:58 | 200 | 42 | 1.000 | 194 | 1.005 | 18 | 1.000 | 817 | 0.400 | 197 | 1.000 | 2776 | 0.540 |
| SØ | 55 mm | 36 | SB | 03:29 | 220 | 30 | 1.000 | 167 | 1.000 | 16 | 1.000 | 662 | 0.285 | 580 | 1.000 | 3962 | 0.381 |
| SØ | 55 mm | 37 | SB | 03:05 | 200 | 23 | 1.000 | 133 | 1.000 | 10 | 1.000 | 406 | 0.500 | 706 | 1.000 | 5703 | 0.264 |
| SØ | 45 mm | 38 | SB | 03:14 | 200 | 88 | 1.000 | 121 | 1.000 | 107 | 1.000 | 1241 | 0.267 | 3184 | 0.474 | 4201 | 0.357 |
| SØ | 45 mm | 39 | SB | 04:59 | 200 | 78 | 1.000 | 153 | 1.000 | 105 | 1.000 | 1345 | 0.200 | 3902 | 0.404 | 4581 | 0.322 |
| SØ | 45 mm | 40 | SB | 03:21 | 205 | 85 | 1.000 | 143 | 1.000 | 59 | 1.000 | 1419 | 0.333 | 1213 | 1.000 | 2844 | 0.526 |
| SØ | 45 mm | 41 | SB | 03:22 | 195 | 102 | 1.000 | 121 | 1.000 | 82 | 1.000 | 873 | 0.444 | 1859 | 0.807 | 2720 | 0.555 |
| SØ | 45 mm | 42 | BB | 04:07 | 200 | 62 | 1.000 | 131 | 1.000 | 157 | 1.000 | 1205 | 0.182 | 2277 | 0.663 | 4215 | 0.358 |
| SØ | 45 mm | 43 | BB | 03:55 | 220 | 39 | 1.000 | 137 | 1.000 | 26 | 1.000 | 1180 | 0.200 | 647 | 1.000 | 1114 | 1.000 |
| SØ | 45 mm | 44 | BB | 01:37 | 210 | 53 | 1.000 | 78 | 1.000 | 185 | 1.000 | 532 | 0.250 | 2127 | 0.705 | 2940 | 0.510 |
| SØ | 45 mm | 45 | BB | 02:09 | 195 | 9 | 1.000 | 17 | 1.000 | 14 | 1.000 | 547 | 1.000 | 315 | 1.000 | 695 | 1.000 |
| SØ | 45 mm | 46 | BB | 01:19 | 200 | 30 | 1.000 | 60 | 1.000 | 33 | 1.000 | 473 | 1.000 | 281 | 1.000 | 323 | 1.000 |
| SØ | 45 mm | 47 | BB | 01:50 | 225 | 70 | 1.000 | 114 | 1.000 | 43 | 1.000 | 491 | 1.000 | 1346 | 1.000 | 1402 | 1.000 |
| SØ | 45 mm | 48 | SB | 02:02 | 210 | 108 | 1.000 | 65 | 1.000 | 853 | 1.000 | 55 | 1.000 | 1430 | 1.000 | 1352 | 1.000 |
| SØ | 45 mm | 49 | SB | 01:29 | 200 | 38 | 1.000 | 32 | 1.000 | 313 | 1.000 | 34 | 1.000 | 1401 | 1.000 | 1557 | 1.000 |

*3.1. Selectivity analysis*

The size selectivity analysis results showed primarily that although the models chosen fitted the data well (Fig. 3-4), the p-values obtained for fit of the model were generally low and below 0.05 in 6 out of the 10 cases (Table 2). In the case of cod and saithe, these low p-values were most likely consequence of overdispesion of the data and the precission of the paird-gear sampling methodology used, which is substantially lower than for the covered codend method (Herrmann et al., 2016). For haddock, in addition to the lack of precission implicit in an indirect method, the lack of fish of sizes over the selective range of the gear contributed to the dificulty to fit a model to the data. For haddock captured in the area west of Sørøya with the 55 mm grid, the lack of fish that was large enough to define the whole selection curve led to that the split parameter (fishing power of the test gear with respect to the overall fishing power of both gears, i.e. a split of 0.5 means that both gears have equal fishing power) was manually fixed at 0.5, which seemed adequate considering that in most other cases the split was estimated to be close to 0.5.

In four out of the ten cases, the model with the lowest AIC value did not contain the parameter contact (*C*), which represents the fraction of fish that is subjected to a size selection process at the grid, e.g. a contact value of 0.8 would indicate that 80% of the fish entering the grid section was size selected by the grid. Considering that the contact parameter values estimated in the cases where the contact parameter was present in the chosen model was in all cases >0.95, it seems natural that in four cases the best fit was given by models with $C = 1$ (the parameter does not need to be considered in the model).

Table 2: Selection model, selectivity parameters, and fit statistics for the two grids tested during the sea trials.

| | | | Model | *L50* | *SR* | Contact (*C*) | *CL50* | *CSR* | *D* | Split | Deviance | DOF | P-Value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BJØRNØYA | Cod | 45 mm | CRichard | 44.02 (40.64 - 47.70) | 9.20 (5.18 - 13.62) | 0.99 (0.85 - 1.01) | 44.10 (40.69 - 48.00) | 8.97 (3.88 - 13.51) | 0.011 (-0.162 - 99.827) | 0.502 (0.432 - 0.572) | 90.9 | 93 | 0.542 |
| | | 55 mm | Richard | 57.39 (54.13 - 61.67) | 20.78 (15.97 - 28.61) | – | – | – | 0.084 (0.025 - 0.414) | 0491 (0.448 - 0.550) | 126.71 | 97 | 0.023* |
| | Haddock | 45 mm | Richard | 39.01 (35.95 - 41.33) | 13.02 (8.83 - 17.74) | – | – | – | 0.010 (-0.026 - 0.244) | 0.502 (0.457 - 0.547) | 102.04 | 63 | 0.001** |
| | | 55 mm | Probit | 58.69 (48.45 - 76.94) | 25.27 (19.54 - 33.67) | – | – | – | – | 0.689 (0.528 - 0.849) | 111.03 | 65 | 0.003** |
| SØRØYA | Cod | 45 mm | Logit | 43.44 (40.24 - 47.08) | 12.16 (8.97 - 15.58) | – | – | – | – | 0.510 (0.450 - 0.572) | 92.79 | 87 | 0.316 |
| | | 55 mm | CRichard | 58.56 (55.91 - 61.09) | 7.54 (4.59 - 11.84) | 0.98 (0.94 - 0.99) | 58.72 (56.02 - 61.23) | 7.10 (4.32 - 11.26) | 0.035 (0.016 - 100.002) | 0.389 (0.317 - 0.465) | 82.98 | 83 | 0.48 |
| | Haddock | 45 mm | CLogit | 47.92 (43.29 - 52.59) | 10.40 (7.00 - 13.92) | 0.99 (0.95 - 0.99) | 48.06 (43.54 - 52.75) | 10.20 (6.68 - 13.69) | – | 0.569 (0.393 - 0.698) | 81.91 | 53 | 0.007** |
| | | 55 mm | CLogit | 58.78 (54.27 - 65.15) | 10.90 (4.74 - 17.35) | 0.99 (0.99 - 0.99) | 58.88 (54.30 - 65.28) | 10.76 (4.69 - 17.14) | – | 0.500 (0.500 - 0.500) | 61.14 | 46 | 0.067 |
| | Saithe | 45 mm | CLogit | 46.31 (44.17 - 47.80) | 7.30 (0.70 - 12.55) | 0.89 (0.60 - 0.99) | 47.01 (44.59 - 49.30) | 6.11 (4.16 - 8.74) | – | 0.479 (0.422 - 0.537) | 99.02 | 76 | 0.039* |
| | | 55 mm | CRichard | 60.82 (58.76 - 64.82) | 6.86 (5.28 - 11.23) | 0.95 (0.88 - 0.99) | 61.10 (59.23 - 65.16) | 6.21 (4.53 - 10.85) | 0.328 (0.117 - 2.160) | 0.470 (0.378 - 0.616) | 72.4 | 51 | 0.026* |

Comparisons of the selectivity curves obtained with the 45- and 55-mm grids around Bjørnøya show clear differences between the grids for both cod and haddock. Compared to the 55 mm grid the curves show that the 45 mm grid will catch significantly more cod larger than *MLS* without significantly increasing the catch of fish smaller than *MLS* when fishing in the same fish population (Fig. 3c). For haddock on the other hand, the diffreence between the

selection curves is larger for fish larger than *MLS*, but the 45 mm grid will also catch more fish under *MLS* than the 55 mm grid when fishing on the same population (Fig. 3f).

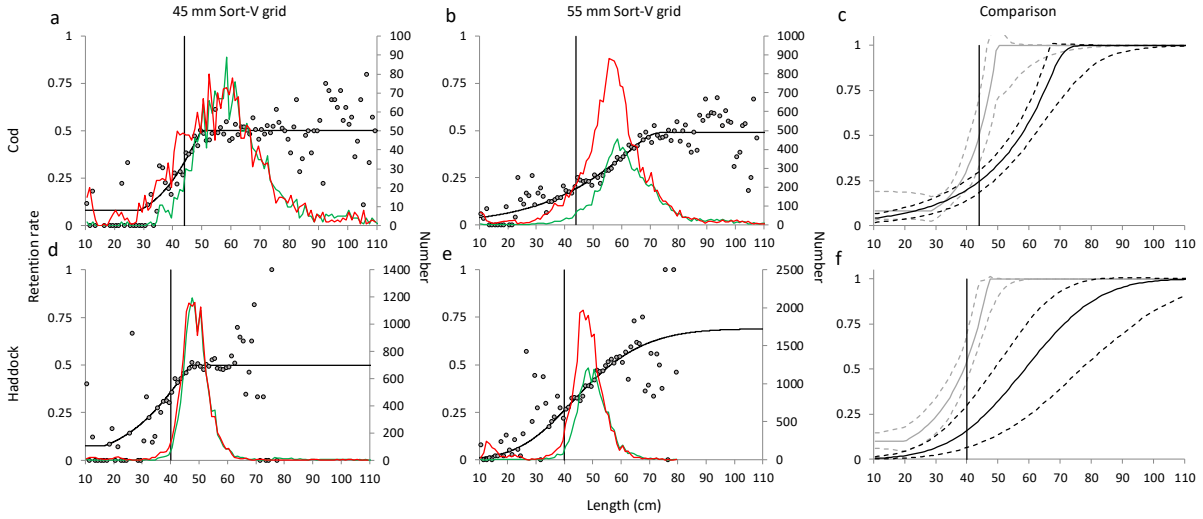


Fig. 3: Plots a-b and d-e show length-dependent retention probabilities for cod and haddock with the 45- and 55-mm grids in the Bjørnøya area. In each plot, the circles represent the experimental observations, the solid curve represents the model fitted to the data, and the dashed curves represent the 95% CIs. The red line represents the population caught by the control gear whereas the green line represents the population caught by the test gear. Plots c and f show comparisons between the selectivity curve obtained with the 45 mm grid (grey) and the 55 mm grid (black) for each species. Dashed curves represent the 95% CIs.

Comparisons of the selectivity curves obtained with the 45- and 55-mm grids in Sørøya show also clear differences between the selection properties of the grids, specially for cod and saithe. For cod, the results show that the 45 mm grid will catch significantly more fish larger than *MLS* than the 55 mm grid, however, unlike the results obtained in Bjørnøya, the 45 mm grid would also catch significantly more fish smaller than *MLS* (Fig. 4c). For haddock, the 45 mm grid would catch significantly more fish between ca. 40 and 53 cm catching little more fish smaller than 40 cm (Fig. 4g). Finally, the results for saithe show that the grid with 45 mm bar spacing would catch significantly more fish larger than *MLS* than the grid with a 55 mm bar spacing, and only significanty more fish of a few length classes smaller than its *MLS* of 45 cm (Fig. 4j).

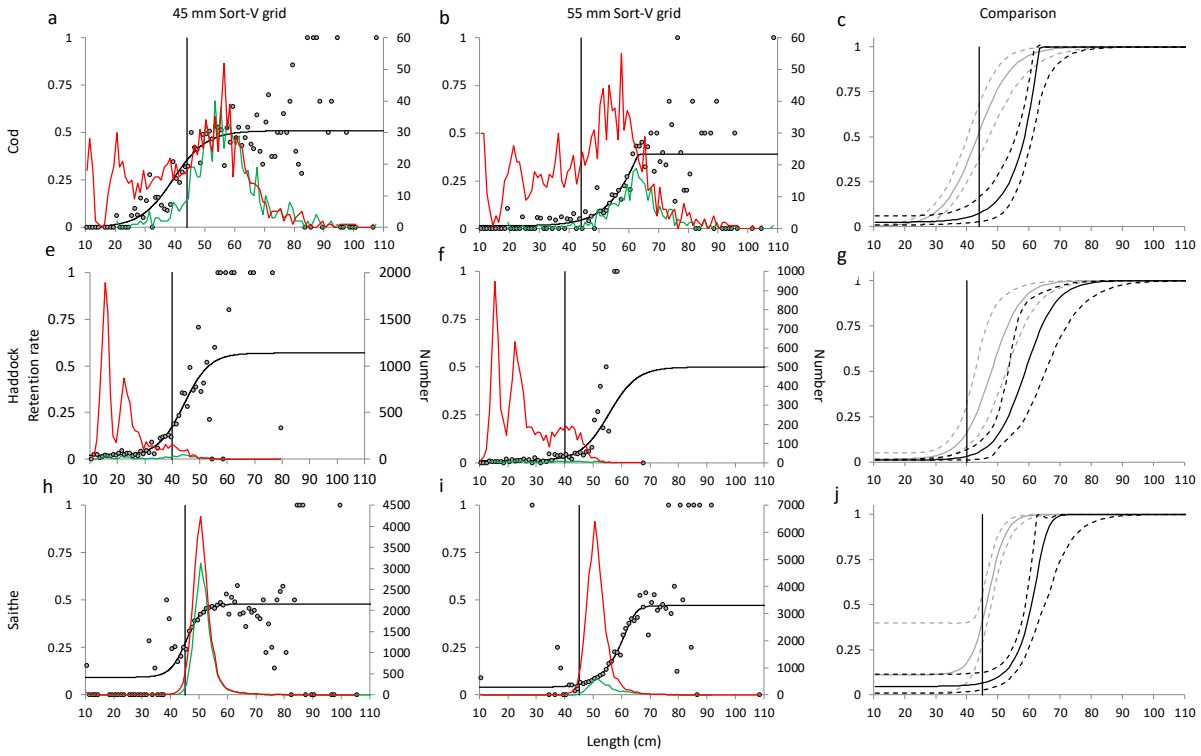


Fig. 4: Plots a-b, d-e and g-h show length-dependent retention probabilities for cod, haddock and saithe with the 45- and 55-mm grids in the Sørøya area. In each plot, the circles represent the experimental observations, the solid curve represents the models fitted to the data, and the dashed curves represent the 95% CIs. The red line represents the population caught by the control gear whereas the green line represents the population caught by the test gear. Plots c, f and i show comparisons between the selectivity curve obtained with the 45 mm grid (grey) and the 55 mm grid (black) for each species. Dashed curves represent the 95% CIs.

### *3.2. Exploitation pattern indicators*

Regarding the exploitation pattern indicators, the results showed that in general, the probability to catch fish smaller than *MLS* was significantly higher for the 45 mm grid than for the 55 mm grid, whereas the probability to catch fish larger than *MLS* was significantly higher for the 45 mm grid than for the 55 mm grid. In all cases except for haddock in Sørøya, the discard ratio was significantly lower than the 15% in numbers allowed by the authorities today.

Table 2: Exploitation pattern indicator values for the two areas, two different grids tested, and three species sampled during the sea trials. Values are given in %.

| | | | Probability below *MLS* | Probability above *MLS* | Discard ratio |
|---|---|---|---|---|---|
| BJØRNØYA | Cod | 45 mm | 24.24 (17.31 - 32.21) | 96.68 (74.59 - 100.00) | 6.32 (4.73 - 8.26) |
| | | 55 mm | 17.07 (11.03 - 22.90) | 55.38 (51.30 - 61.36) | 3.54 (1.73 - 7.18) |
| | Haddock | 45 mm | 27.24 (16.43 - 40.37) | 93.68 (82.17 - 100.00) | 1.38 (1.06 - 1.74) |
| | | 55 mm | 15.70 (7.29 - 22.59) | 67.77 (47.77 - 82.69) | 2.40 (1.36 - 4.30) |
| SØRØYA | Cod | 45 mm | 12.70 (8.00 - 18.52) | 91.53 (73.87 - 100.00) | 9.12 (5.70 - 13.54) |
| | | 55 mm | 2.40 (0.98 - 4.57) | 31.41 (24.23 - 39.25) | 4.83 (2.02 - 8.39) |
| | Haddock | 45 mm | 3.12 (1.99 - 4.29) | 45.21 (33.90 - 59.68) | 50.45 (42.54 - 58.12) |
| | | 55 mm | 1.25 (0.70 - 2.00) | 6.29 (2.82 - 11.32) | 54.84 (47.38 - 64.48) |
| | Saithe | 45 mm | 25.24 (12.88 - 40.63) | 72.67 (61.08 - 84.96) | 1.04 (0.61 - 1.47) |
| | | 55 mm | 3.58 (1.56 - 6.81) | 12.74 (9.12 - 16.72) | 0.59 (0.25 - 1.04) |

## 4. Discussion and conclusion

The results of this study show that in general, the use of a 45 mm grid significantly increases the proportion of fish larger than *MLS* caught by the gear with little increase of the proportion of fish smaller than *MLS*. This result is very similar to the result obtained for the research cruise carried out onboard R/V "Helmer Hanssen" in December 2020 (Fig. 1), where the comparison of both grids showed a significant increase of catches of cod, haddock and redfish larger than *MLS* with no significant increase in the catches of fish smaller than *MLS*. Thus, it can be concluded that in relation to the *MLS* of cod, haddock redfish and saithe in the Barents Sea today, 45 mm could be a more adequate bar spacing to use in the grid. However, it needs to be considered that Norwegian fishermen have in multiple occasions expressed their lack of interest for fish just larger than *MLS*, making in most cases would make a grid in 50- or 55-mm a more adequate choice. This conclusion is based on the selection curves i.e. proportion of fish expected to be retained at each length class, and the catches will of course depend on the size distribution of the population in the fishing area. If it is dominated by large quantities of fish smaller than *MLS* for example, it may be more adequate to use larger bar spacing, as a marginal difference in the selection curve at those sizes may have large implications. Contrary, if the numbers of fish smaller than and/or around *MLS* are low, it may be more beneficial to lower the bar spacing in the grid to increase the efficiency of the catches of commercial sizes of fish.

The implications of the population structure in the fishing area for the catch composition are well illustrated by haddock in this study. The retention curves obtained for haddock in Bjørnøya

show higher retention rates than in Sørøya, however, the discard ratios calculated for the species with both grids are much higher for haddock in Sørøya than in Bjørnøya. The discard ratio was >50% in Sørøya vs <3% in Bjørnøya for both grids. This result is consequence of the high numbers of haddock under *MLS* present in the fishing ground outside Sørøya at the time the trials were carried out (Fig. 4e-f), and shows that flexibility in gear choice including sorting devices other than grids may be necessary in the near future to increase catch efficiency, reduce effort and make whitefish trawl fisheries more cost-efficient and rational. It must also be bear in mind that in mixed fisheries like the Barents Sea whitefish fishery, achieving satisfactory selectivity results with a universal gear for species with different morphology, behavior and *MLS*s implemented today is very difficult (only possible with very specific and seldom met population structures). In this context, adapting the *MLS*s of the species involved to realistic limits with the selectivity gear in force may also be necessary.

Another issue that the results of the present trials bring up, are the limitations of the paired-gear method for selectivity studies. The paired-gear method is a convenient method when the use of covers is challenging for practical issues, which is often the case on trials carried out on commercial vessels. It is indirect method, i.e. the fish retained by the gear is directly estimated from the fish retained by the test codend, whereas the population fished on is indirectly estimated from a small meshed control gear that is towed simultaneously, requiring a substantially larger amount of fish to be measured to provide the same precision (Herrmann et al., 2016). The numbers of fish measured in these trials were high (>120000 individuals), however, the lack of large numbers of length classes above the selective range, especially for haddock and saithe, created scatter in the data increasing the diversity of models suitable to describe the data and the uncertainty of the model finally fitted to explain the results. This is well illustrated by the haddock caught in Sørøya with the 55 mm grid (Fig. 4f), where the numbers of fish within the selective range of the grid (e.g., 50-60 cm) were so low that the upper part of the selection curve was difficult to define. For future experiments where the size range of the species is expected to be at the edge the selectivity range of the gear, it is recommended to use the covered codend method instead.

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