Size selection of cod by rigid grids; is anything gained compared to diamond mesh codends only?

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Abstract

Size selective grids were introduced into the Barents Sea demersal trawl fishery in 1997. It was believed at the time that in comparison to standard diamond mesh codends, grids had better selective properties, i.e. narrower selection range. Few studies have directly compared the selective properties of the combined grid and codend with that of the codend only. In this study we describe two experiments carried out in 2002 and 2003, where we directly compared the properties of codend selectivity for cod (*Gadus morhua*) with the combined selectivity of a Sort-V grid and a codend. In 2002 we used small-meshed covers, whereas the twin trawl method was used in 2003. In both experiments we compared the selectivity of a 135 mm codend only with that of a trawl fitted with a 135 mm codend and a 55 mm grid, which is the mandatory configuration. In 2003 we also estimated the selectivity of a 155 mm diamond mesh codend, having an L_{50} similar to that of the grid and 135 mm codend combination. The results presented no evidence that the grid and mesh combination had sharper size selection than codend meshes. The introduction of the mandatory use of grid in the fishery in 1997 therefore only increased L_{50}, and corresponded to a mesh size increase of around 20 mm. Mean selection length of the grid was inversely related to catch rates in the 2002 experiment when large catches were taken. Grid selection appeared less affected by seasonal variations in degree of stomach fullness or condition than mesh selectivity. Other situations where grid selection might perform better than mesh selection are discussed.

Key words: cod, grid, mesh, NE Atlantic, selectivity

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Introduction

In most fisheries where the management objective is to minimise the capture of sub-legal fish while minimising losses of marketable fish, a sharp selection, i.e. a narrow selection range (SR; the difference in length between the 25 and 75% capture probabilities), is preferred. Rigid sorting grids were first introduced into shrimp trawl fisheries to reduce the by-catch of turtles (Watson and McVea, 1977) and juvenile fish (Isaksen et al., 1992). Grids were later modified to perform as size selective devices (Larsen and Isaksen, 1993) and a large number of size selective grid designs have been tested in a variety of fisheries (Anon, 1998). Grids are generally assumed to have a sharper size selection than codend meshes and grids have been made mandatory in some fisheries, notably the bottom trawl fisheries in Norwegian waters of the North East Atlantic where the current minimum mesh size is 135 mm.

The Norwegian technical regulations introduced in the early 1980s include a general discard ban and prohibit fishing in areas where cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and redfish (*sebastes spp*) below minimum catch size exceed 15% of the catch composition. As a consequence, the areas available for the fleets to operate in were reduced. This resulted in an incentive to improve the size selective properties of the trawls used. It was believed that the selectivity of traditional diamond mesh codends was poor, resulting in large catches of juvenile fish. Increasing the mesh size to compensate was thought to result in unacceptable losses of large fish, i.e. that codends exhibit a relatively flat selection pattern.

Despite the considerable research effort into grid designs, the grids have not been proven to have better selective properties than codend meshes, as research has tended to focus only on determining the selectivity of the grids *per se* (Anon, 1998). For cod, Larsen and Isaksen (1993) estimated the selection range of a Sort-X grid to be in the range of 4.5 – 8.6 cm, while Isaksen et al. (1996) estimated SRs of 11 and 15 cm for the Sort-X and Sort-V grid respectively. The Sort-V grid (Figure 1) was developed as a user-friendlier version of the Sort-X (see, Larsen and Isaksen (1993) for details) and is now more typically used by the commercial fleets. Both grids had the minimum legal bar spacing of 55 mm. Later comparative studies have shown no difference in the selectivity of the Sort-X and Sort-V grids (B. Isaksen, Institute of Marine Research, Bergen, Norway; pers. comm.).

With the exception of one study, no estimates of the selective properties of the codends typical of the modern fishery in the Barents Sea have been published. When comparing selectivity of Russian and Norwegian style codends, Isaksen et al. (1990), compared the selectivity of Russian and Norwegian style cod-ends with mesh sizes of 141 and 137 mm respectively. The Russian style cod-end had L_{50} and SR of ∼58 and 9 cm, while those of the Norwegian style cod-end were ∼48 and 16cm. Both experiments were done with unsupported covers. Estimates were based on pooled data, and the parameters were

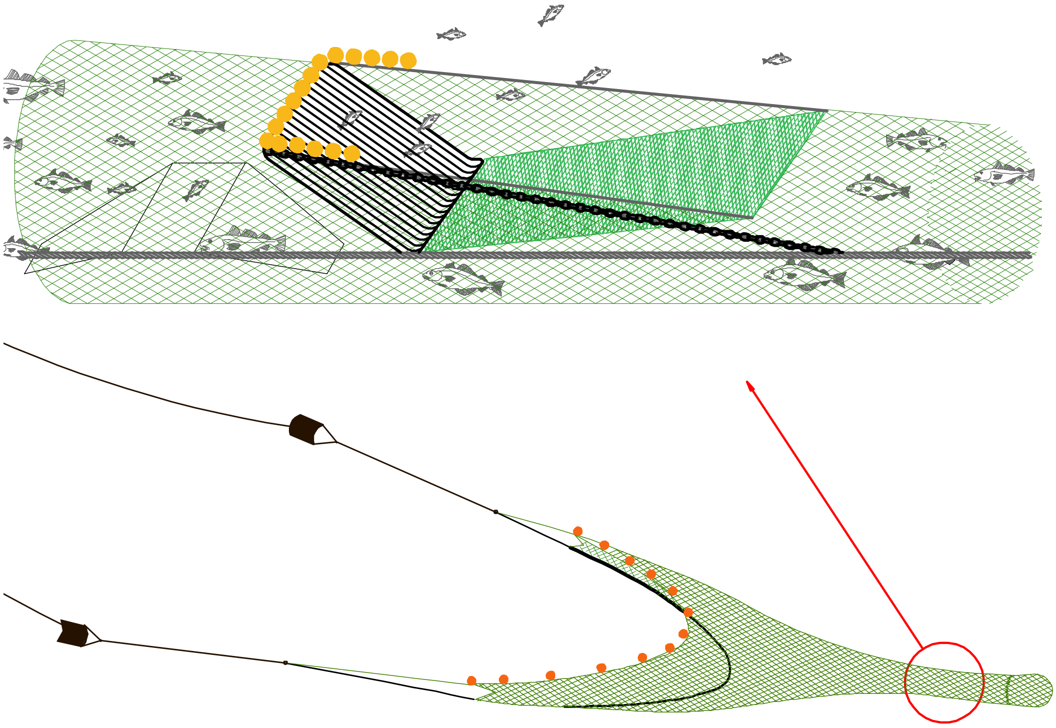

Fig. 1. Single Sort-V grid as used in experiments

obtained from selection curves fitted by eye. The Norwegian data set was subsequently re-estimated by Kvamme and Isaksen (2004), giving L_{50} and SR of 47.1 and 13.4 cm respectively. Unfortunately the Russian data was not available for re-examination, but the estimates were closer to recently obtained data (Kvamme and Isaksen, 2004).

Only a few studies have determined the combined selectivity of grids and codends (Anon, 1998). For the North Sea trawl fishery, Graham et al. (2004) showed an increase in L_{50} for haddock with the inclusion of a 35 mm single (Sort-V) grid in a trawl with a 120 mm codend, but only for low codend catches (< 0.5 tonnes). The SR was approximately 1 cm narrower when the grid was installed. Kvamme and Isaksen (2004) observed that L_{50} for cod increased by approximately 4 cm with the inclusion of a 55 mm Sort-X grid in the Barents Sea cod fishery, with no effect on selection range.

The reduced catch of juveniles observed when fishing with a grid installed, may thus be the result of a higher mean selection length of grids compared to the codend mesh size used and not caused by narrower selection range of grids. In this paper we describe the results from two experiments conducted in 2002 and 2003 where the selective properties of conventional diamond mesh codends were compared with those of a Sort-V grid and codend combination to assess if there are any benefits to using one system over another. Specifically for the 2003 experiments, comparisons included a diamond mesh codend made of a mesh size corresponding to the mean selection length of the grid.

Table 1. Station information for the valid selectivity hauls taken during the 2002 experiments

Exp.	Net	Haul	Date	Time	Latitude (North)	Longitude (East)	Depth (m)	Duration	Catch (kg) Cod	Haddock	Other*	Total
S-I	135 mm PE	3	04.05	14:30	70°33’	30°56’	114	0:15	1836	256	0	2092
		4	04.05	22:35	70°35’	30°48’	138	0:30	3240	860	0	4100
		7	04.06	17:50	70°52’	30°22’	306	0:45	1980	0	20	2000
		8	04.06	19:40	70°51’	30°30’	343	2:55	7380	0	60	7440
		9	04.07	03:55	70°51’	30°37’	309	2:10	1332	0	60	1392
		10	04.07	07:10	70°54’	30°18’	315	1:50	1548	0	20	1568
		29	04.12	19:10	71°02’	29°17’	325	1:20	5616	0	460	6076
		30	04.13	00:55	71°03’	29°19’	319	1:05	4500	0	480	4980
		31	04.13	06:25	70°57’	29°45’	365	1:50	3744	0	70	3814
		32	04.13	11:15	71°02’	29°24’	334	1:45	4824	0	454	5278
		33	04.13	16:20	71°02’	29°25’	340	1:15	2016	0	360	2376
		34	04.13	20:00	71°02’	29°35’	324	2:05	2988	0	208	3196
		35	04.14	00:55	70°59’	29°28’	333	2:05	1872	0	730	2602
		36	04.14	04:00	71°03’	29°17’	315	2:15	2088	0	1360	3448
S-II	55 mm Sort-V	11	04.07	16:10	70°51’	30°41’	325	3:20	2232	0	20	2252
	&	12	04.08	00:40	70°56’	29°50’	334	1:40	9432	0	170	9602
	135 mm PE	13	04.08	09:35	70°56’	29°55’	312	1:25	10512	0	60	10572
		14	04.08	16:55	70°59’	29°43’	328	1:05	5184	0	40	5224
		15	04.08	22:05	70°58’	29°45’	323	1:15	4104	0	70	4174
		16	04.09	03:40	70°59’	29°50’	310	1:55	2232	0	70	2302
		17	04.09	10:40	70°56’	29°58’	321	1:15	4212	0	70	4282
		18	04.09	15:55	70°59’	29°40’	328	1:30	5724	0	30	5754
		19	04.09	22:35	70°58’	29°46’	320	1:30	8100	0	110	8210
		20	04.10	06:10	70°56’	30°02’	309	0:50	4320	0	50	4370
		21	04.10	10:55	71°01’	29°47’	325	0:50	1692	0	50	1742
		22	04.10	13:05	70°56’	29°56’	309	1:15	1656	0	60	1716
		23	04.11	14:10	70°52’	30°22’	310	1:30	504	0	20	524
		24	04.11	16:55	70°53’	30°07’	303	1:30	3276	0	40	3316
		26	04.12	00:30	71°01’	29°30’	321	3:15	4932	0	60	4992
		27	04.12	08:25	70°59’	29°48’	332	1:45	4896	0	130	5026
		28	04.12	11:20	71°02’	29°20’	319	1:05	3996	0	1350	5346

*) includes catches of saithe, redfish and wolffish

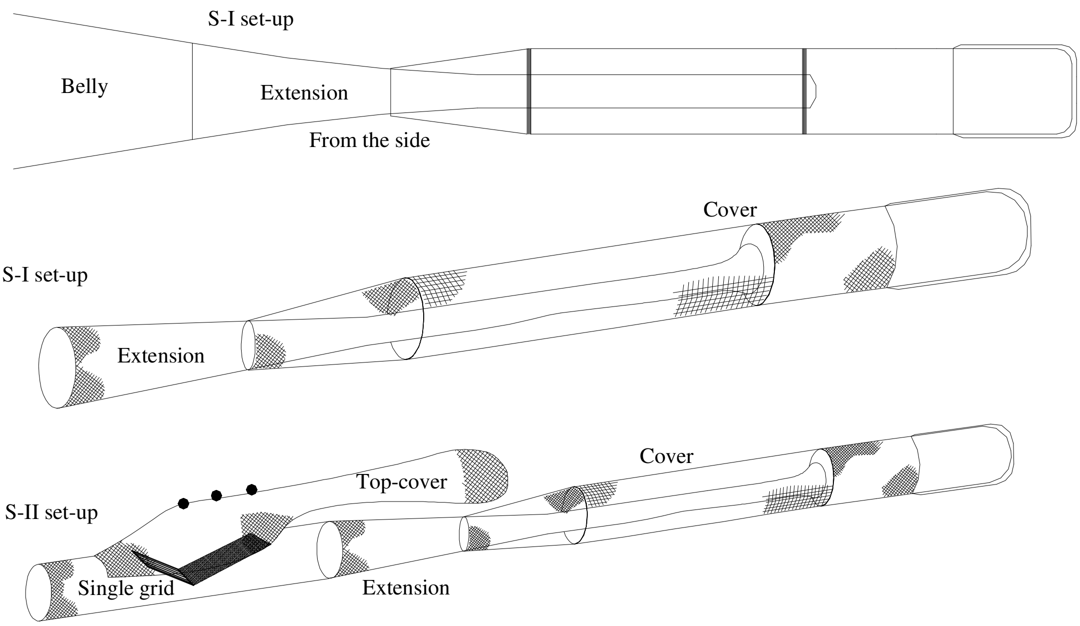

Fig. 2. The experimental setup for the 2002 experiment

Materials and methods

All the experiments were made onboard fishing vessels operating their own commercial trawls and fishing as in commercial mode. Choice of fishing areas was done in collaboration with the captains. Two different methods to determine the selectivity of the gear configurations were used. In the 2002 experiment, a small-mesh cover supported by plastic hoops was used to retain the fish escaping from the codend and where appropriate, this was combined with a small-mesh cover attached to the escape outlet of the grid to retain those fish escaping from the grid (Wileman et al., 1996). In 2003, the twin trawl technique was used. Here the population estimate of the fish entering the test net is obtained from the catch retained in the small mesh codend of the other net making up the twin trawl.

2002 experiment

The 50.7 m, 1790 kW, stern trawler 'Anny Kræmer' was chartered for the purposes of the experiment. The vessel is equipped for single rig trawling, and is a traditional Norwegian trawler operating in the Barents Sea. The trawl used was an Alfredo 3, a two-panel bottom trawl with 36.5 m headline and 18.9 m fishing line, and a stretched circumference of 66.9 m. The fishing grounds were located off the coast of Finnmark, Northern Norway. A total of 31 valid hauls were taken from 5 to 14 April, mainly at depths from 300 to 350 metres (Table 1). Two hauls were rejected due to operational irregularities like debris

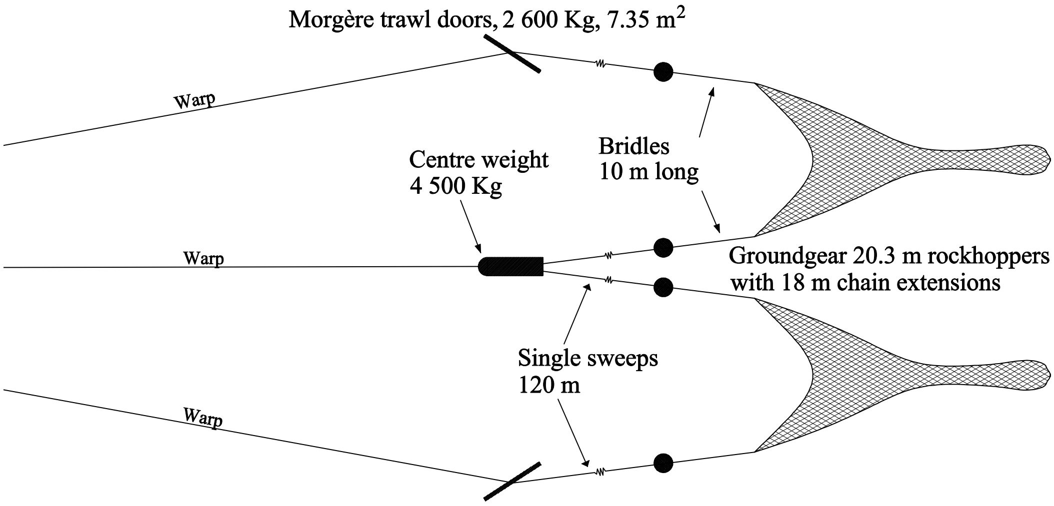

Fig. 3. Twin trawl rig used during the 2003 sea trial

(e.g. an oil barrel) blocking the grid extension in front of the grid. Fish (especially cod) caught during the experiment were observed to feed intensively on spawning aggregations of capelin (*Mallotus villosus*).
Two experimental set-ups with the single trawl were used (Figure 2):

S-I (Codend mesh selection): Trawl without grid mounted. Hoop-supported cover over codend.

S-II (Simultaneous estimates of grid and codend as well as the combined selection): Trawl with grid mounted. Small-meshed (40 mm) top cover over fish outlet of the grid and hoop-supported cover over codend.

The codend was made of double 5 mm braided and knotted PE (Magnet), 9.9 m long, and 60 meshes wide (48 open meshes). The mesh size of the codend (137.2 ± 4.0 mm) was measured wet during the experiment using an ICES gauge. Two rows of 20 meshes were measured, starting at five meshes in front of the codline.

2003 experiments.

The twin-rig fishing vessel 'Comet' (40 m, 1600 kW) was hired for the experiments. This vessel normally operates a twin-rig system for both shrimp and fish trawling. The vessel was fishing two identical Maxi 400 trawls. In comparison to the Alfredo trawl used the previous year, they are of similar design and with 73.1 m stretched circumference, 20.3 m fishing line and 33.2 m headline. Rigging details are given in Figure 3.
In addition to grid selectivity, the selectivity of a 155 mm codend was assessed to ascertain whether this mesh size provided similar selection characteristics, in terms of both L_{50} and SR, as the combination of a grid with 55 mm bar

space and a 135 mm codend. The choice of 155 mm mesh size was based on the selection factor (L_{50}/mesh size = 3.6) from the 135 mm codend obtained in 2002 experiments and the L_{50} from the grid/codend combination.
The fishing took place at depths of 170 to 280 m, mainly in the areas west of Bear Island and in the SE Barents Sea. A total of 26 valid hauls were taken in the period from 28 July to 11 August (Table 2).

Three experimental setups with twin trawl were used:

T-I (Selectivity of 135 mm codend meshes): Starboard side was fished with a fine-meshed (40 mm) inner liner and port side with a 135 mm codend.

*T-II (Combined selection of grid and 135 mm codend meshes):*Starboard side was fished with a fine-meshed (40 mm) inner liner and port side with a 55 mm grid and a 135 mm codend.

T-III (Selectivity of 155 mm codend meshes): Starboard side was fished with a 155 mm codend and port side with a 135 mm codend with fine-meshed inner liner.

Both large-mesh codends were constructed as trouser cod-ends. The 135 mm codend was made of double 5 mm braided and knotted PE and 9.3 m long. Each trouser leg had a circumference of 60 meshes (48 open meshes). The 155 mm codend was made of impregnated double 6 mm braided and knotted PA, 9.8 m long and each bag had a circumference of 56 meshes (44 open meshes). The actual mesh sizes of the codends were measured (mean ± sd) using an ICES gauge and were 134.9 ± 2.5 mm for the 135 mm PE codend and 152.5 ± 2.5 mm for the 155 mm PA codend. One series of measurements was taken after a few hauls with the codend, another at the end of the trials. Each series consisted of two rows of 20 meshes, four meshes to the left and right of the middle mesh, starting five meshes in front of the codline.

Statistical analyses

Exploratory data analysis showed the selectivity to be adequately modelled with the logistic curve.

$$r(l) = \frac{exp(a + bl)}{1 + exp(a + bl)} \tag{1}$$

where $r(l)$ is the probability that a fish of length l will be retained in the test codend. a and b are the two generic selection parameters determining the

Table 2. Station information for the valid selectivity hauls taken during the 2003 experiments

Exp.	Net	Haul	Date	Time	Latitude (North)	Longitude (East)	Depth (m)	Duration	Catch (kg)			
									Cod	Haddock	Other*	Total
T-I	135 mm PE	1	07.26	00:15	74°09’	17°57’	168	4:00	1105	0	0	1105
		2	07.26	05:45	74°12’	17°15’	221	4:00	3488	368	0	3856
		3	07.26	11:15	74°00’	17°17’	225	4:00	2475	268	0	2743
		4	07.26	17:30	74°09’	17°03’	222	4:00	2700	401	342	3443
		5	07.26	22:40	73°59’	17°20’	218	4:00	3900	635	494	5029
		6	07.27	08:00	74°11’	17°07’	226	4:15	1686	301	722	2709
		8	07.27	23:45	74°12’	17°02’	218	4:45	1650	602	228	2480
		10	07.28	11:45	74°10’	17°06’	221	4:15	1650	0	0	2136
		11	07.28	17:15	73°59’	17°21’	223	4:00	1538	368	0	4007
T-II	55 mm Sort-V	41	08.09	21:25	74°00’	17°17’	205	4:50	5925	368	464	6757
	&	42	08.10	06:20	74°00’	17°48’	195	4:10	1110	67	99	1276
	135 mm PE	43	08.10	12:55	74°15’	17°15’	202	2:45	4087	635	76	4798
		44	08.10	21:30	74°26’	16°58’	184	4:05	1231	301	152	1684
		45	08.11	04:00	74°35’	16°34’	225	3:30	7200	535	103	7838
		46	08.11	13:30	74°35’	16°36’	215	4:10	1368	468	95	1931
		47	08.11	18:40	74°43’	16°38’	212	4:35	4390	2408	285	7083
T-III	155 mm PA	13	07.30	11:15	71°30’	34°26’	227	4:00	3338	33	38	3409
		14	07.30	16:30	71°45’	34°27’	245	4:05	405	67	171	643
		15	07.30	21:45	71°55’	33°48’	229	4:30	10633	167	1980	12780
		16	07.31	11:50	71°48’	33°54’	254	2:40	6968	33	491	7492
		17	07.31	20:20	71°53’	33°32’	239	2:10	3325	33	65	3423
		18	08.01	01:30	71°49’	33°51’	280	4:30	3447	167	181	3795
		19	08.01	07:00	71°50’	33°42’	254	5:00	3017	134	181	3332
		20	08.01	14:45	71°49’	33°52’	236	4:10	3070	234	343	3647
		21	08.02	08:30	71°21’	26°22’	269	3:00	2544	635	1097	4276
		22	08.02	12:00	71°20’	25°45’	279	5:00	3018	1070	2398	6486

*) includes catches of saithe, redfish and wolffish

mean selection length and the selection range by the relationships:

$$L_{50} = -\frac{a}{b} \quad , \quad SR = \frac{ln(9)}{b} \tag{2}$$

The logistic selectivity curves were fitted by maximizing the log-likelihood of the binomial probability function.

The covered codend case

In the case of covered codend, the logistic model reduces to

$$logit(r(l)) = ln\frac{r(l)}{1-r(l)} = a + bl \tag{3}$$

which is a generalized linear model. When subsampling, the model was fitted to unraised data and $ln(q_{1l}/q_{2l})$ set as an offset variable, where q_{1l} and q_{2l} denote the sampling proportions for size class l in the test gear and small mesh control codend, respectively. The inclusion of subsampling fractions as an offset is equivalent to the binomial model for data obtained from retrospective sampling (McCullagh and Nelder, 1989), introduced for selectivity analysis by Millar (1994). For the combined grid- and mesh selectivity, the total selection of the gear was better described by modelling the combined selection of grid and codend meshes by a single logistic function, rather than as a product of two logistic curves (Kvamme and Isaksen, 2004). The product model is more complex, with higher number of parameters and gives worse fit (higher deviance). When data for the combined selection were obtained from the two small-mesh covers with different sampling proportions, the catches were raised and then scaled down to the number of measured fish to avoid underestimating the variances by raising the data.

The twin trawl case

For experiments performed with twin trawl, the model becomes (Holtrop, 1998):

$$\tilde{r}(l) = \frac{pr(l)}{q_{1l}pr(l) + q_{2l}(1-p)} \tag{4}$$

Where q_{1l} and q_{2l} denote the sampling proportions for the trawls with the test codend and the small mesh control codend, respectively. p is the estimated split factor that measures the relative fishing power of the two nets and gives

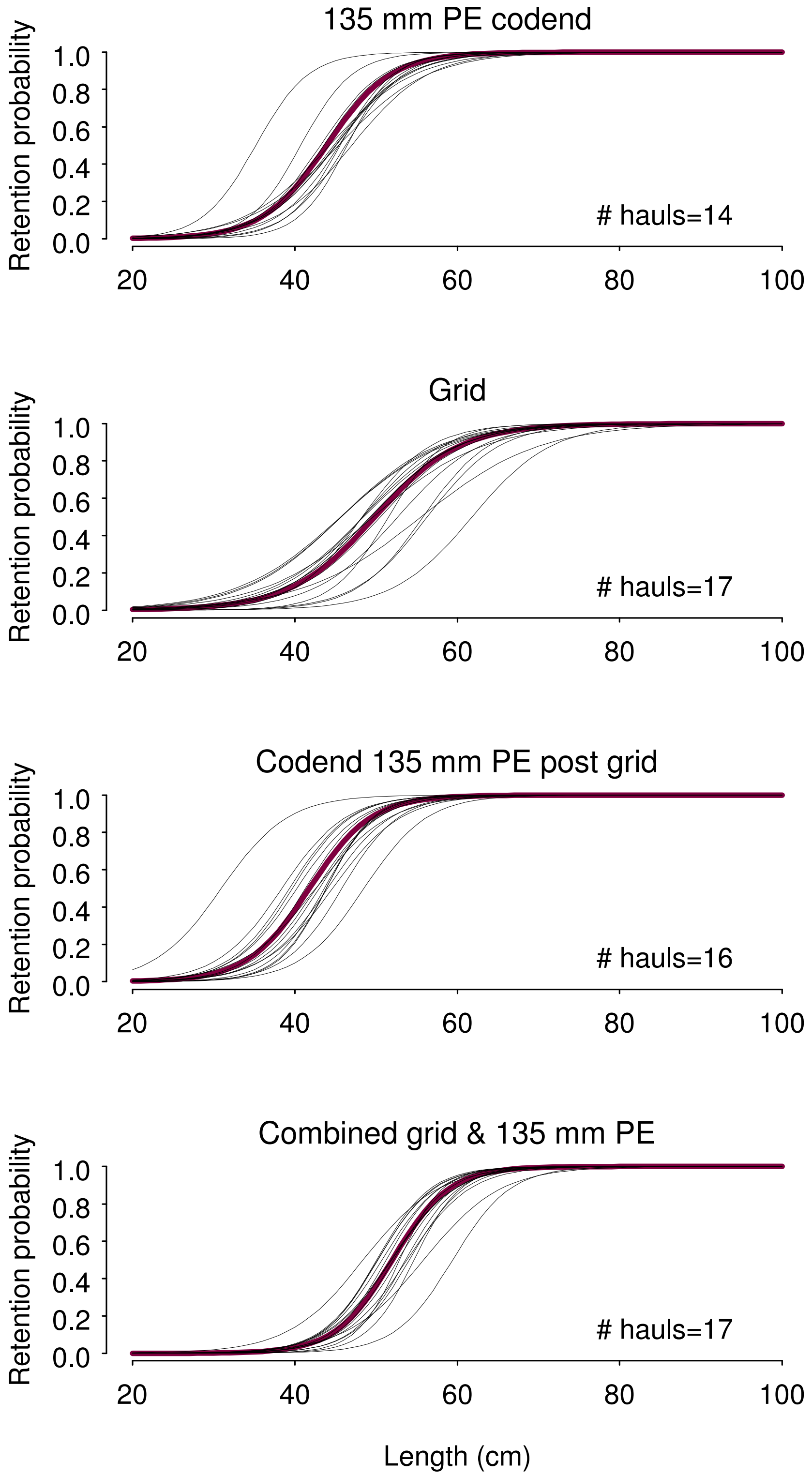

Fig. 4. Estimated selection curves for individual hauls in the 2002 experiments. Mean selection curves are also shown (bold line)

the conditional probability that a fish will enter the test net given that it has entered one of the two nets of the twin trawl.

Model choice was based on minimum AIC values:

AIC = -2 log-likelihood + 2 # parameters

Between haul variation

To model mean selectivity curves, the between-haul model of Fryer (1991) was used, based on restricted maximum likelihood (REML). The selection parameters a and b were assumed to be linearly related to catch rate (kgh^{-1}). Logarithmic transformed values were used to reduce the influence of a few extreme catches.
A stepwise procedure was used to decide the final model specification, based on minimum AIC values. For identical AIC values the simplest model was chosen. Maximum likelihood estimation was used for model selection, while parameter estimates were based on REML estimates (Graham et al., 2004).
To test the null hypothesis of no difference in measured selectivity of trawl gear with and without grid fitted, grid presence was included as an explanatory variable in the model, implemented by an indicator variable. Otherwise the model and procedure were identical to those for selectivity modelling above. The computer software programs CC2000 and EC (Constat, www.constat.dk) were utilized for model fitting and between haul analyses.

Results

2002 experiment

Cod made up the bulk of the catches (median 97% by weight). Catch rates were generally high with a median catch rate of 2670 kgh^{-1} (range 350 to 8400 kgh^{-1}). Towing times varied from 15 min to 3 h 20 min with a median value of 1 h 30 min (Table 1).
Estimates of selectivity parameters for individual hauls are given in Table 3 and the by-haul selection curves are shown in Figure 4. The modelled mean selectivity of the 135 mm PE codend was independent of catch rate for both generic parameters (Table 4). For grid, catch rate affected the mean selection length, but not the selection range (Table 4, Figure 5). For the modelled combined selectivity of mesh and grid, catch rate affected both L_{50} and SR (Figure 5).
The installation of a grid into a trawl with standard 135 mm codend significantly changed the selectivity of the trawl (Table 5, Figure 6). L_{50} and SR

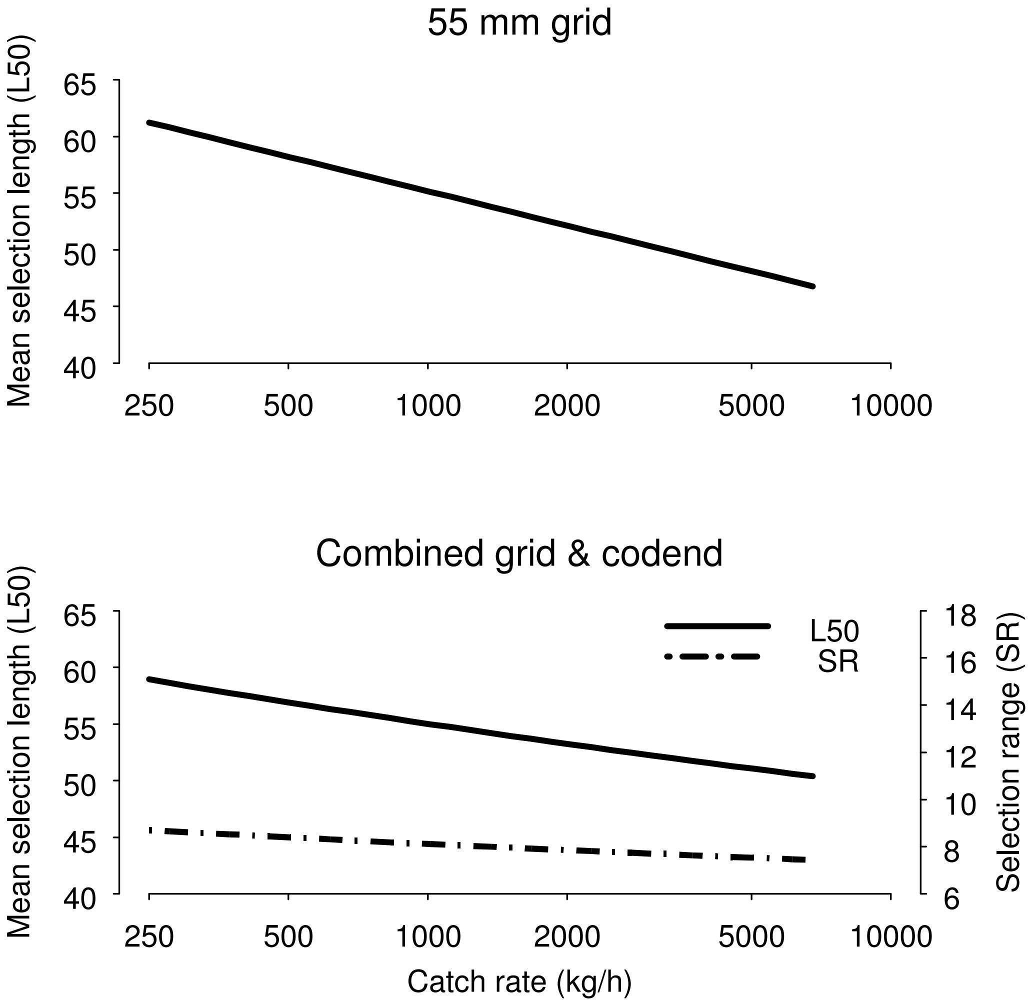

Fig. 5. Catch rate dependency of the estimated grid (upper graph) and combined grid and codend selection parameters (L_{50} and SR) as estimated from the 2002 experiments

for the grid only were higher than for the 135 mm codend (Table 4), but the post-grid codend contributes to reduce the SR, resulting in a similar SR for the grid-codend combination as that for the 135 mm mesh codend only. Model predictions specify an increase of L_{50} by approximately 9 cm, and a decrease of SR by 1 cm by installing a grid into a trawl with a 135 mm codend.

Table 3: 2002 experiment. The estimates of the selection parameters a and b and their associates variances and estimates of mean selection length (L_{50}) and selection range (SR) (derived from a and b)

Device	Haul	a	b	var(a)	var(a,b)	var(b)	L_{50}	SR
Codend	3	-12.86	0.316	1.871	-0.0402	0.00088	40.71	6.96
135mm PE	4	-15.64	0.337	2.516	-0.0520	0.00108	46.43	6.52
	7	-10.83	0.308	3.365	-0.0679	0.00138	35.17	7.13
	8	-9.98	0.212	0.890	-0.0166	0.00031	47.00	10.34
	9	-13.98	0.307	2.096	-0.0423	0.00086	45.56	7.16
	10	-10.04	0.224	1.080	-0.0209	0.00041	44.78	9.80
	29	-11.35	0.261	1.816	-0.0341	0.00065	43.52	8.42
	30	-12.02	0.265	1.628	-0.0304	0.00057	45.41	8.30
	31	-11.15	0.259	2.156	-0.0409	0.00078	43.13	8.50
	32	-12.85	0.278	1.726	-0.0323	0.00061	46.24	7.91
	33	-8.44	0.191	1.200	-0.0225	0.00043	44.26	11.52
	34	-10.29	0.229	1.430	-0.0268	0.00051	44.99	9.61
	35	-8.21	0.181	0.759	-0.0145	0.00028	45.36	12.15
	36	-10.13	0.225	1.054	-0.0205	0.00040	45.07	9.78
Grid	11	-7.60	0.137	0.814	-0.0151	0.00028	55.54	16.06
	12	-7.32	0.147	0.497	-0.0094	0.00018	49.66	14.90
	13	-7.10	0.156	0.508	-0.0098	0.00019	45.63	14.12
	14	-11.47	0.238	1.116	-0.0208	0.00039	48.30	9.25
	15	-9.13	0.185	1.117	-0.0211	0.00040	49.27	11.85
	16	-10.29	0.195	0.746	-0.0137	0.00025	52.68	11.25
	17	-9.04	0.187	1.513	-0.0284	0.00054	48.39	11.76
	18	-7.66	0.168	0.845	-0.0155	0.00029	45.69	13.10
	19	-7.40	0.162	0.683	-0.0128	0.00024	45.72	13.57
	20	-9.98	0.206	1.251	-0.0232	0.00043	48.36	10.65
	21	-9.57	0.189	1.271	-0.0236	0.00044	50.52	11.60
	22	-12.69	0.225	1.776	-0.0325	0.00060	56.31	9.75
	23	-12.62	0.204	1.675	-0.0277	0.00047	61.81	10.76
	24	-13.75	0.247	1.875	-0.0343	0.00063	55.79	8.91
	26	-8.46	0.175	0.710	-0.0132	0.00025	48.48	12.59
	27	-14.90	0.289	1.418	-0.0260	0.00048	51.53	7.60
	28	-9.10	0.184	0.871	-0.0160	0.00030	49.33	11.91
Codend	11	-11.16	0.262	3.239	-0.0638	0.00127	42.62	8.39
(post-grid)	12	-12.48	0.257	1.636	-0.0304	0.00057	48.52	8.54
	13	-7.55	0.244	1.446	-0.0273	0.00052	30.95	9.00
	14	-10.96	0.276	4.811	-0.0921	0.00177	39.70	7.96
	15	-9.34	0.219	1.724	-0.0321	0.00060	42.57	10.02
	16	-15.15	0.345	7.188	-0.1422	0.00283	43.86	6.36
	17	-10.65	0.271	3.496	-0.0680	0.00133	39.34	8.12
	18	-9.74	0.254	4.480	-0.0851	0.00163	38.40	8.66
	19	-13.06	0.285	1.591	-0.0293	0.00054	45.79	7.70

Continued on Next Page…

Table 3 – Continued

Device	Haul	a	b	var(a)	var(a,b)	var(b)	L_{50}	SR
	20	-13.52	0.310	4.315	-0.0823	0.00158	43.61	7.09
	21	-10.48	0.260	4.953	-0.0965	0.00190	40.26	8.44
	22	-11.57	0.280	8.082	-0.1591	0.00318	41.31	7.84
	24	-11.19	0.254	4.076	-0.0757	0.00142	44.01	8.64
	26	-10.55	0.236	2.098	-0.0381	0.00070	44.64	9.30
	27	-14.71	0.335	5.766	-0.1080	0.00204	43.84	6.55
	28	-11.67	0.271	3.848	-0.0721	0.00136	42.99	8.10
Combined grid & codend	11	-11.74	0.210	0.916	-0.0169	0.00032	55.86	10.46
	12	-16.03	0.296	1.378	-0.0253	0.00047	54.10	7.41
	13	-14.83	0.295	1.369	-0.0258	0.00049	50.24	7.45
	14	-15.18	0.303	1.641	-0.0304	0.00057	50.09	7.25
	15	-15.43	0.296	1.408	-0.0261	0.00049	52.15	7.42
	16	-13.95	0.259	1.174	-0.0214	0.00039	53.81	8.48
	17	-14.37	0.283	1.445	-0.0270	0.00051	50.74	7.76
	18	-10.47	0.216	1.172	-0.0213	0.00039	48.43	10.17
	19	-14.49	0.289	1.563	-0.0288	0.00053	50.20	7.61
	20	-15.75	0.307	1.625	-0.0297	0.00055	51.26	7.15
	21	-13.32	0.257	1.323	-0.0245	0.00046	51.93	8.56
	22	-16.50	0.308	1.792	-0.0327	0.00060	53.64	7.14
	23	-16.83	0.283	3.255	-0.0570	0.00101	59.44	7.76
	24	-19.11	0.350	2.221	-0.0403	0.00074	54.68	6.29
	26	-15.04	0.285	1.571	-0.0284	0.00052	52.70	7.70
	27	-19.98	0.378	2.276	-0.0413	0.00075	52.90	5.82

2003 experiment

The number of hauls for each of the experimental setups T-I to T-III were nine, seven and 10 respectively (Table 2). Due to technical problems, the number of hauls with mesh (setup T-I) and grid (setup T-II) was below the target of at least 10 hauls for each setup. Catch rates were considerably lower in 2003 than in 2002, with a median of 870 kgh^{-1} (range 157 to 2840 kgh^{-1}). Catches were generally dominated by cod (median value 83%), but a few hauls had less than 50% cod. Towing time varied from 2 h 10 min to 5 h, with a median of 4 h 15 min (Table 2).

The by-haul selection parameter estimates are given in Table 6 and the corresponding selection curves are shown in Figure 7. Both the L_{50} and SR estimates

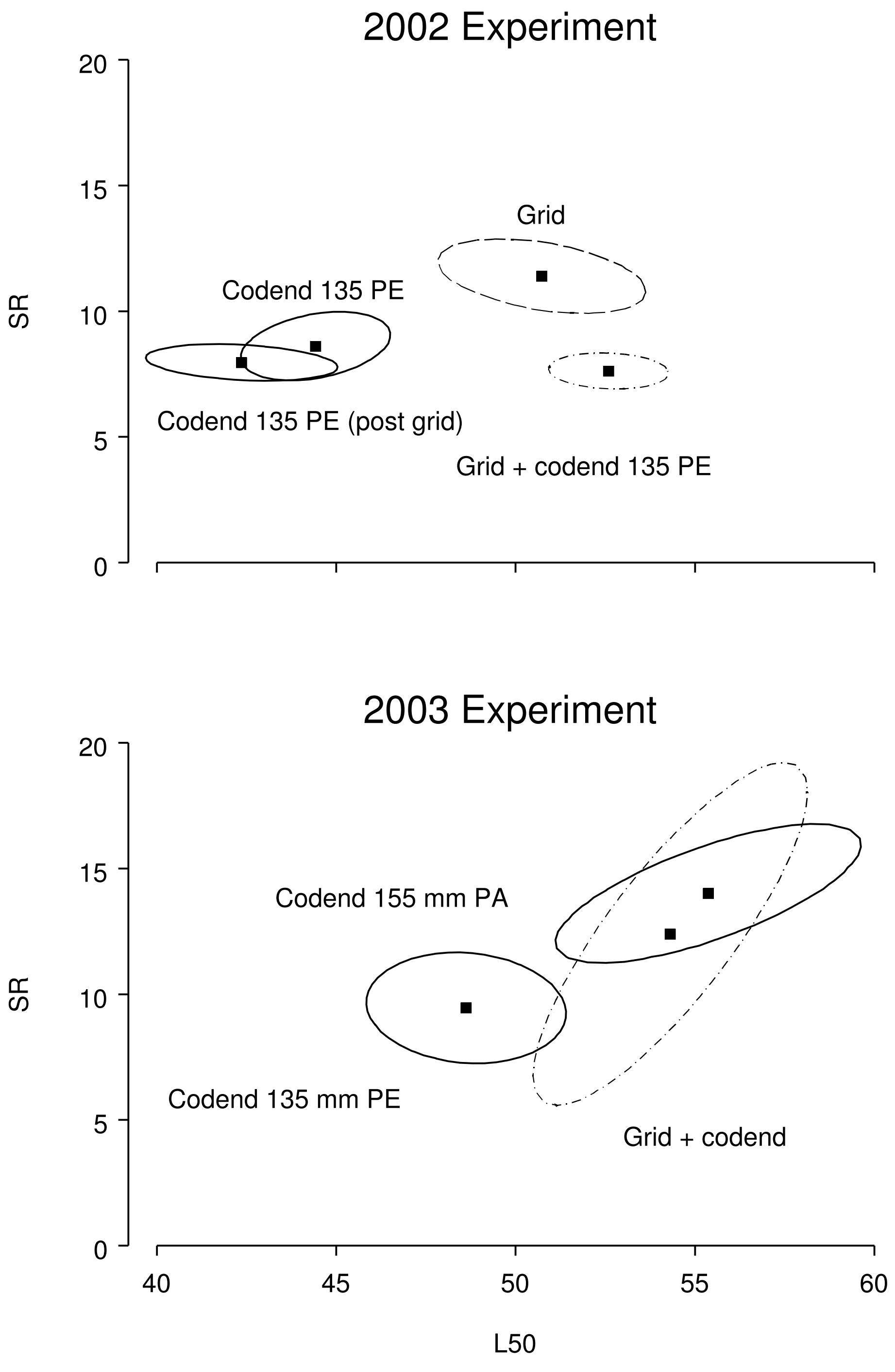

Fig. 6. Estimated 95% confidence regions for the estimated selection parameters for each of the selectivity experiments

Table 4. Estimated selection parameters for different gear configurations. Natural logarithm of catch rates was used as explanatory variable and the estimates refer to a catch rate of 1000 kgh^{-1}.

Year	Methodology	Experiment	Intcpt(a)	Intcpt(b)	ln($cpue_a$)	ln($cpue_b$)	a	b	L_{50}	SR
2002	Single trawl with covers	135mm PE	-11.058	0.252			-11.058	0.252	43.89	8.72
		Grid	-16.338	0.191	0.83858		-10.545	0.191	55.17	11.49
		Grid+135mm PE	-14.894	0.181		0.0130	-14.894	0.271	55.02	8.12
		135 PE (post grid)	-10.935	0.262			-10.935	0.262	41.79	8.40
2003	Twin trawl	135mm PE	-10.647	0.215			-10.647	0.215	49.52	10.22
		155mm PA	-8.686	0.157			-8.686	0.157	55.37	14.01
		Grid+135mm PE	-10.235	0.188			-10.235	0.188	54.35	11.67

Table 5. Modelling of selectivity with catch rate and grid as explanatory variables. Only coefficients of the final models are given

Year	Experiment	Intcpt(a)	Intcpt(b)	ln(cpue$_a$)	ln(cpue$_b$)	grid$_a$	grid$_b$	a	b	L$_{50}$	SR
2002	135 PE &	-10.949	0.157		0.012	-3.950	0.032	-10.949	0.251	43.55	8.74
	Grid + 135 PE							-14.899	0.284	52.54	7.75
	135 PE &	-11.047	0.258					-11.047	0.258	42.79	8.51
	135 PE (post grid)										
2003	135 PE &	-10.338	0.208				-0.017	-10.338	0.208	49.77	10.58
	grid + 135 PE								0.191	54.21	11.52
	155 PA &	-9.409	0.172					-9.409	0.172	54.80	12.80
	Grid+135 PE										

were generally higher than in the 2002 experiment (covered codend). The selectivity parameters were independent of catch rate for all setups (Table 4). Based on the twin trawl trials, the installation of grid into a trawl with 135 mm codend was found to increase the L_{50} by 6 cm and the SR by 1 cm. There was no significant difference in selectivity between the 155 mm mesh codend and the grid-135 mm codend combination. The confidence regions were in general wider than those for the 2002 experiment (Figure 5). The results of the combined modelling of the selectivity data for the 155 mm codend trawl and the trawl with standard 135 mm codend with grid installed, presented no evidence of a grid-related difference in selectivity (Table 5).

Discussion

This study found no consistent evidence that the Sort-V grid had sharper size selection than a conventional diamond mesh codend. The SR determines the steepness of the selection curve and thereby how selective the gear is. If it is the objective of managers to minimise capture of juveniles while maintaining catches of legal sized fish, the selective device with the smallest SR is preferable, because it, with a proper choice of L_{50}, meets this objective. The analysis of our data, supported by the results of Kvamme and Isaksen (2004), indicate that in this respect there is no significant difference between grids and traditional diamond mesh codends. Moreover, modelling of the stock effects of changes in fleet selectivity has shown changes in SR to have smaller impact on long-term yield than a change in L_{50} (Kvamme and Frøysa, 2004). Another management objective could be to minimise yield variability froma given stock (MacLennan, 1995). In that case it is better to have a comparatively wider SR, typically equating to half the L_{50}. This, however, would result in capture of more juveniles.

The introduction of grids in the bottom trawl fisheries in the Barents Sea should therefore not have resulted in sharper selection but an increase of the mean selection length (L_{50}) of the target species by 4-5 cm, corresponding to an increase in mesh size by 20 mm, from 135 to 155 mm. By shifting the location of the selection curve to the right, the catch of undersized fish was considerably reduced and trawlers fishing with grid could legally fish in areas otherwise closed due to by-catch of juveniles exceeding the upper legal by-catch limit of 15% (Norwegian regulations).

The comparison of the selectivity of a 135 mm codend with that of the combined grid and 135 mm codend was made with identical codends and any differences in selectivity are therefore primarily due to the presence of the grid. However, the 2003 comparison of the grid system (grid and 135 mm codend) with a 155 mm mesh codend might be confounded by the fact that the 155 mm codend was made of 6 mm double PA while the 135 mm codend was

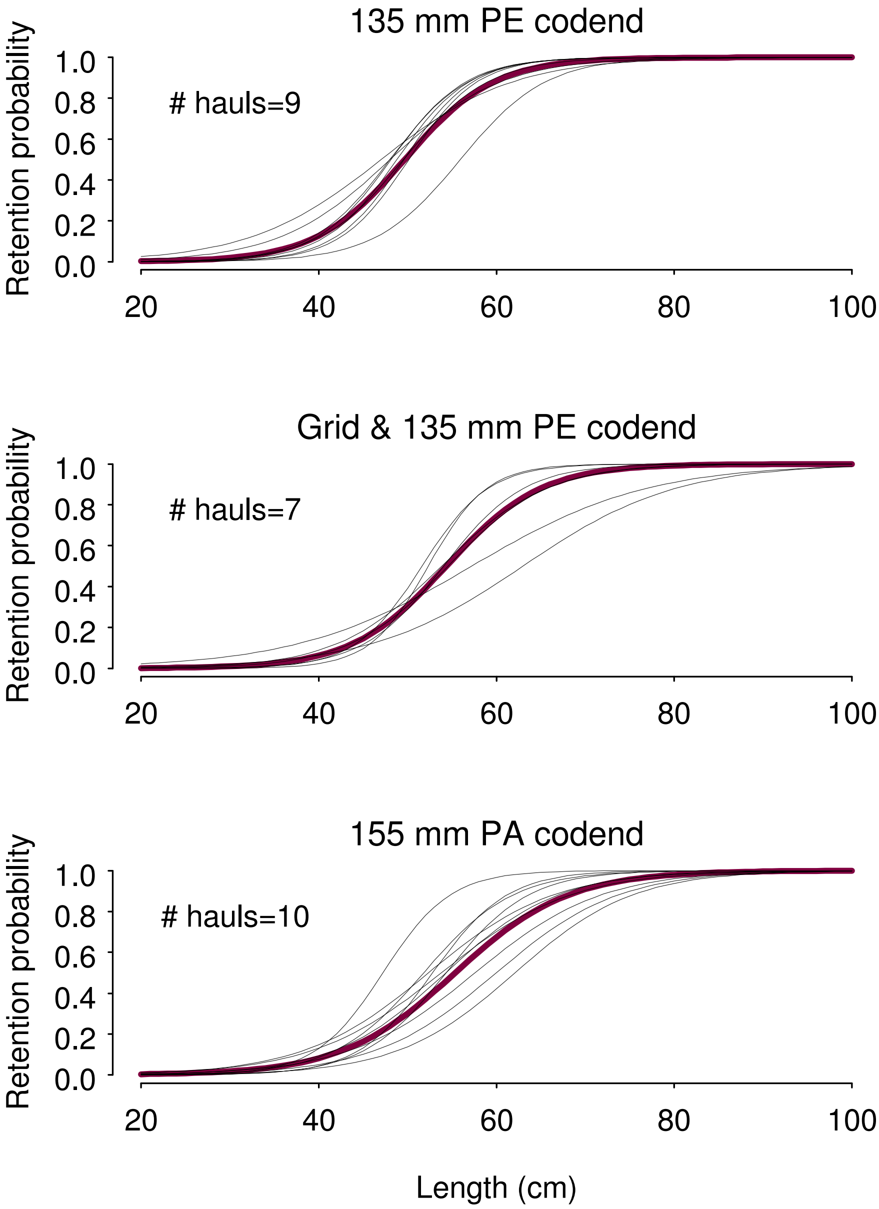

Fig. 7. Estimated selectivity curves for individual hauls in the 2003 experiments. Mean selection curves are also shown (bold line)

made of double 5 mm PE (the difference due to logistic reasons). Material type and twine thickness have both been found to affect L_{50} for diamond meshes (Ferro and O'Neill, 1994; Lowry and Robertson, 1996; Kynoch et al., 1999). If the 155 mm codend had been made of a different material (e.g. PE) and twine thickness (e.g. double 5 mm), the mesh size corresponding to the L_{50} of the grid system would therefore likely be somewhat different. However, of the limited published data available, there is no evidence that SR is affected

Table 6
2003 experiment. The by-haul estimates of the selection parameters a and b and their associates variances, the split parameter p and estimates of mean selection length (L_{50}) and selection range (SR) (derived from a and b)

Device	Haul	a	b	p	var(a)	var(a,b)	var(b)	L_{50}	SR
Codend	1	-11.42	0.237	0.39	1.145	-0.0296	0.00081	48.15	9.26
135mm PE	2	-11.66	0.208	0.60	4.312	-0.0959	0.00218	55.94	10.54
	3	-7.68	0.160	0.49	1.730	-0.0412	0.00103	48.03	13.74
	4	-10.44	0.211	0.57	3.130	-0.0683	0.00153	49.53	10.43
	5	-6.35	0.135	0.56	1.957	-0.0540	0.00155	47.03	16.27
	6	-12.77	0.258	0.44	3.001	-0.0677	0.00157	49.58	8.53
	8	-12.98	0.259	0.46	3.035	-0.0687	0.00159	50.12	8.48
	10	-11.98	0.246	0.49	2.320	-0.0542	0.00130	48.80	8.95
	11	-10.90	0.227	0.43	2.039	-0.0496	0.00124	48.02	9.68
Codend	13	-10.32	0.199	0.46	1.190	-0.0292	0.00074	51.81	11.03
155mm PA	14	-12.63	0.239	0.43	4.275	-0.0980	0.00230	52.82	9.19
	15	-9.39	0.151	0.53	0.965	-0.0209	0.00048	62.09	14.53
	16	-12.46	0.264	0.35	7.108	-0.1686	0.00404	47.21	8.32
	17	-7.39	0.137	0.49	0.947	-0.0227	0.00058	53.79	16.00
	18	-8.74	0.146	0.59	0.721	-0.0174	0.00046	59.99	15.07
	19	-8.59	0.158	0.46	0.837	-0.0206	0.00054	54.29	13.89
	20	-8.13	0.141	0.44	0.474	-0.0108	0.00028	57.60	15.57
	21	-7.44	0.142	0.49	1.537	-0.0330	0.00075	52.35	15.47
	22	-11.72	0.216	0.43	5.293	-0.1051	0.00212	54.33	10.18
Grid &	41	-5.81	0.102	0.60	0.848	-0.0221	0.00072	57.21	21.63
codend	42	-7.32	0.116	0.57	0.137	-0.0031	0.00017	62.97	18.91
135mm PE	43	-13.82	0.268	0.47	2.681	-0.0625	0.00149	51.61	8.21
	44	-9.82	0.180	0.49	0.540	-0.0130	0.00034	54.55	12.21
	45	-15.88	0.303	0.44	3.785	-0.0810	0.00176	52.32	7.24
	46	-12.00	0.222	0.58	0.743	-0.0185	0.00049	54.05	9.90
	47	-9.08	0.169	0.46	2.007	-0.0411	0.00087	53.82	13.02

by material and twine thickness (Kynoch et al., 1999; Tokaç et al., 2004). The conclusion (no evidence of sharper selection of grids than diamond mesh codend) should therefore also be valid for the comparison of the grid system with the 155 mm mesh codend, despite the differences in material and twine thickness.

In the 2002 experiment and in the study by Kvamme and Isaksen (2004), the SR of the grid system was only compared to that of a 135 mm codend. However, the mean selection length of the 55 mm bar spaced grid system is higher than that of the 135 mm codend. If SR increases with increasing mesh size as indicated in the review of selectivity experiments for cod by Halliday et al. (1999), the difference in SR of the grid system and a codend with equal L_{50} would likely be somewhat underestimated.

The L_{50} estimates for grid and for grid and codend combined showed consistent values across surveys. For codend selectivity, however, the estimated L_{50} was significantly higher (6 cm) in 2003 than in 2002. The fish caught in 2002 were foraging on spawning aggregations of capelin and most fish had extended stomachs, while no intensive feeding was observed in 2003. Extended stomachs increase girth and because it is the girth and not the length of a fish that determines the probability of mesh penetration, L_{50} was lower for the given mesh size in the 2002 experiment. The penetration of a grid on the other hand, is determined by the inter-bar distance in relation to the maximum width of the fish. Maximum width of cod is reached around the location of the pectoral fins (B. Isaksen, unpublished data), and the belly region is to some extent laterally compresssible, resulting in a ventral distension of the abdomen. However, this would not hamper grid passage since the grid slots allow for ample space both dorsally and ventrally. Degree of stomach fullness and seasonal variations in condition therefore seem to affect mesh selectivity more than grid selectivity. This conclusion is supported by the similarity of the selectivity results obtained in the 2001 (Kvamme and Isaksen, 2004) and 2003 experiment, both performed in summer and for similar feeding regimes. It should nevertheless be kept in mind, that the experimental setup differed between the 2002 and 2003 experiments, the main difference being the use of single trawl in 2002 and twin trawl in 2003. The twin trawl method has been shown to give higher variances (Madsen and Holst, 2002), and the confidence regions for L_{50} and SR were larger in 2003 than in 2002. The twin trawl method may also give systematically lower estimates than the covered codend method (Shephard, 2000). Comparisons should therefore be interpreted with care.

In the 2002 experiment, both L_{50} and SR of the combined grid and 135 mm codend configuration were inversely related to catch rate. For grid separately, only L_{50} was inversely related to catch rate. This catch dependency is likely a consequence of limited sorting capacity of the grid when large numbers of fish arrive at the grid simultaneously. Some fish of sizes that at low densities would pass through the grid are at high densities not exposed to the grid surface and therefore end up in the codend. A similar inverse relationship for L_{50} was also seen for the 2001 experiments (Kvamme and Isaksen, 2004). For mesh selection, neither the 2002 nor the 2003 experiment presented evidence of a catch rate dependency for the selectivity parameters. Other experiments have shown a weak inverse relationship between L_{50} and catch rate also for codend selection at low catch rates (Madsen and Holst, 2002).

Based on the modelled selectivity, no systematic difference in the catch of undersized cod is predicted for a trawl with a 155 mm codend and one with a 55 mm bar spaced grid in combination with a codend of 135 mm. However, a small-scale experiment consisting of 6 comparative hauls taken with a twin trawl fishing two identical trawls, one fitted with grid and a 135 mm codend and the other with a 155 mm codend only, consistently showed a 20 – 40 % higher proportion of undersized cod in the trawl with no grid (unpublished data, B. Isaksen, IMR). A possible explanation is that the high catches of flatfish taken in the area blocked the meshes, causing a reduced selectivity of the

codend, a phenomenon previously addressed by Þorsteinsson (1989). Grids on the other hand are known to effectively exclude flatfish from trawls (Graham et al., 2004). Further studies are needed here.
The successful introduction of selective devices also relies on the enforcement of regulations and the compliance of the fishing industry. For both grids and meshes, several controllable factors have been shown to affect the selectivity. In the Norwegian EEZ of the Barents Sea the use of grids has been mandatory since 1997 and the parameters determining grids selectivity, such as bar spacing and grid angle are strictly controlled by technical regulations and so all attempts to modify the grid installation to change its selectivity will be an infringement. Parameters other than mesh size that affect codend selectivity, such as twine thickness (Lowry and Robertson, 1996), codend extension length and codend diameter (Reeves et al., 1992) are not regulated. Such regulations would have to be considered in case the grid regulations will be abolished.
The implementation of additional selective devices such as grids into legislation should also be viewed from a commercial perspective. As mentioned, grids are known to be effective in excluding flatfish from trawls and therefore renders the use of grids unsuitable in fisheries where flatfish form an economically important portion of the catch. Grids also increase the cost of fishing. The first grid systems (i.e. the Sort-X) were large and cumbersome in use and represented a safety risk to the deck crew during periods of bad weather. The introduction of the smaller Sort-V and Flexi-grid considerably reduced the safety problems and simplified onboard handling. However, in fisheries where vessels use power blocks or have limited space on the stern of the vessel, handling problems still exist.

Concluding remarks

The two selectivity experiments carried out in 2002 and 2003 presented no evidence of a narrower selection range for sorting grids than for conventional diamond mesh codends. Based on the model predictions, similar selectivity can be obtained by using a 135 mm mesh codend in combination with 55 mm Sort-V grid and a codend with a 155 mm mesh size. The introduction of the grid in the Barents Sea in 1997 in reality meant an increase in L_{50} corresponding to an increase in mesh size from 135 to 155 mm. In terms of L_{50}, mesh selectivity is more sensitive to changes in stomach fullness and condition than the grid selectivity. On the other hand, the L_{50} of the grid was found to be sensitive to differences in catch rates, while the mesh selectivity was not. The choice of a selectivity device is thus a trade-off between selectivity properties, industry acceptance and ease of enforcement. Since the fisheries are regulated by proportion of small fish in the catches, the final test of the size selective performance of a device should be the level of retained catch below the minimum catch (landing) size. It is recommended to carry out comparative fishing experiments to verify the model predictions and further explore the effect of large flatfish catches on the selectivity properties of codends.

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