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Relative selectivity in trawl, longline and gillnet fisheries for cod and haddock

Irene Huse, Svein Løkkeborg, and Aud Vold Soldal

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A full-scale fishing experiment on north-east Arctic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*), involving a trawler, a longliner and a gillnetter was conducted in order to determine how the length distributions and life history parameters of the catches were affected by gear type. Relative selectivity was analysed for catches taken when the boats fished simultaneously in the same area, and when the skippers were allowed to fish under conditions as close as possible to commercial operation. Trawl and longline-caught cod had similar length distributions, but cod caught by trawl were on average 2.3 cm smaller than longline-caught cod. Cod caught by longline had a lower condition factor and length at age. The longliner caught smaller haddock than the trawler when the boats fished in the same area. When the skippers were allowed to change fishing ground, the mean length of cod increased in the trawl catches and became larger than the mean length in the longline catches. The mean length of haddock in the longline catches increased by 2.8 cm and became larger than that of the trawl catches. Gillnet catches consisted almost solely of large cod. Mean length of gillnet caught fish in 186 mm nets decreased from 86.2 cm to 82.3 cm even if the boat did not change area. Separate selectivity experiments for trawl and gillnet were conducted, and the parameters for the mesh selection are presented. To find the functional form of the longline selectivity we used relative catch proportion in each 5 cm length-group for longline compared to trawl and gillnet, whose selectivities were assumed to be known. When compared to that of the gillnet, the plots indicate that the longline selectivity curve takes the form of a unimodal distribution. When longline catches was compared to trawl catches none of the suggested models seemed to fit, and to conclude anything about the form of the longline selection curve is not possible.

Key words: selectivity, trawl, longline, gillnet, catch-comparisons.

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Irene Huse, Svein Løkkeborg and Aud Vold Soldal: Institute of Marine Research, PO Box 1870, N-5817 Bergen, Norway; E-mail: irene.huse@imr.no.

Introduction

Exploitation of fish stocks is dependent on effort, catchability and selectivity of gear used, and the fishermen's choice of time and fishing area. Knowledge of fishing gear selectivity is of fundamental importance when recommendations for harvest strategies are being made. As stock abundance estimates are often based partly on catch data obtained from commercial fishing gears, such information is also of importance for the proper assessment of fish stocks.

Most studies of the selectivity of fishing gear have focused on how various gear characteristics affect size selection in trawl and gillnet. Few comparative investigations of the size selectivity of different gears have been carried out, although fixed gears such as longline and gillnet are regarded as more size-selective than towed gears (see McCracken, 1963; Sætersdal, 1963; Klein, 1986; Hovgård and Riget, 1992; Nedreaas *et al*., 1996). With few exceptions (Engås *et al*., 1996), this conclusion is based on comparisons of catches taken from different fishing grounds, at different times, or using a commercial gear in comparison with a survey gear.

The size composition of fish in commercial catches is affected both by gear characteristics (e.g. mesh size, bait size) and fishing strategy (e.g. choice of fishing ground and depth). Choice of fishing ground and depth is based on the skipper's experience of how and where to operate the fishing gear in order to obtain the most profitable catches of the desired species and size composition.

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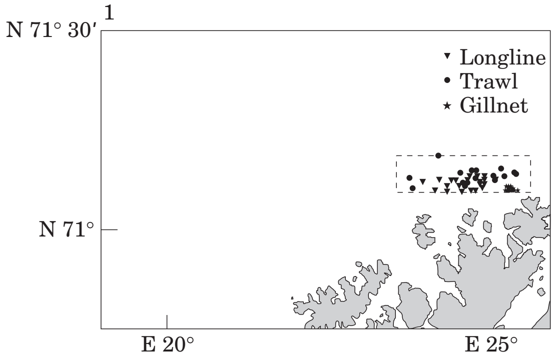

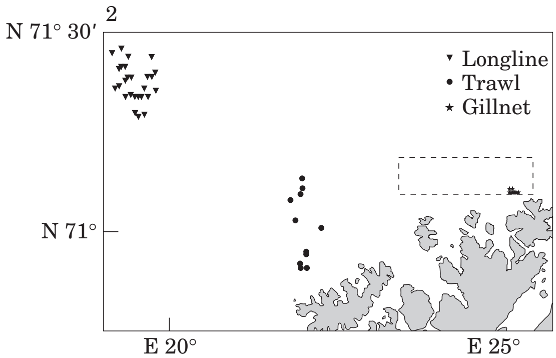

Figure 1. Fleet positions fished in Period 1 of the experiment, when the boats fished as close as possible to each other within a pre-determined area.

Figure 2. Fleet positions fished in Period 2, when the skippers were allowed to decide their own fishing strategies.

We conducted a fishing experiment in the Barents Sea, where cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) were fished simultaneously with trawl, gillnet and longline, the most important types of gear for harvesting these species (Bjordal and Løkkeborg, 1996). In the first period of the experiment (Period 1), the gears were operated on the same fishing ground, whereas in the second period (Period 2), the skippers of the three fishing vessels were allowed to choose their preferred fishing grounds. To find the mesh selection curves for trawl and gillnet, we conducted a trawl codend selectivity experiment, using the trouser trawl method, and several gillnet mesh-sizes for mesh-selectivity analysis.

If we would be able to compare the catch proportion of each length group for all three gears, both the shape of the selectivity curve for longline and the efficiency of the trawl in taking the largest specimens could be examined. This can be done if one of the gears can be assumed to be presented by its true selection curve. If we assume that the available part of the stock is the same for all three gears in the same area, this can be a rational experiment. The assumption include that the higher catchability of large fish in passive gears due to higher swimming capacity (Rudstam *et al*., 1984) and/or search area (Engås and Løkkeborg, 1994; Løkkeborg, 1994) will be of the same magnitude as the larger effect of vertical herding of large fish in trawling (Aglen, 1996). It will also be assumed that the underrepresentation of small fish in trawl due to low sweeping effect (Dickson, 1993) is in the same magnitude as underrepresentation in longline catches due to inter-specific competition (Godø *et al*., 1997). We expected that changes in fishing area would lead to larger differences in longline catches, due to the fact that physical selection in gillnet and trawl codend is a more stringent selection criterion than selection based on competition and behavioural differences, which are assumed to be important mechanisms for size and species selection in longline fishing.

We studied whether the fish caught by the different gears had different growth rates, which would have affected the calculated results of yield per recruit (Y/R). This is important for the understanding of various harvest strategies and may cause bias in the results of surveys that use only one gear.

Materials and methods

The experiment was conducted in February 1996 off the coast of northern Norway, in Norwegian statistical areas 03 and 04. The sea-bottom temperature during the experiment was 3.5–4.5°C. The fishing experiment was divided into two periods, each of six days in length. The length of the fishing experiment and amount of data sampled were decided according to an earlier experiment on gear selectivity and comparisons of trawl and longline catches in a nearby area (Engås *et al*., 1996). The experiment was constrained by a maximum quota and a time limit, and the boats were limited to a predetermined area during the first half of the experiment. In the first period, an area of 10 × 40 nautical miles was defined for fishing. Data from this period are used for catch comparisons between the gears. In Period 2, the boats were allowed to leave this area.

During Period 1, the three vessels fished at similar depths (mean values: trawl 293 m, longline 289 m, and gillnet 290 m), and as close as possible to each other within the predetermined area (Fig. 1). The skippers chose shallower depths in Period 2 (Fig. 2), with no significant differences between the gears (mean depths: trawl 245 m, longline 259 m, and gillnet 227 m).

Three fishing vessels were chartered to fish with commercial fishing gears normally used in the Barents Sea. The gillnetter (29 m, 500 HP) used nets with a nominal mesh size of 186 mm stretched mesh and a hanging ratio of 50%. A further ten fleets were set with smesh sizes 140, 200 and 220 mm (Table 1). Each fleet consisted of

Table 1. Mesh sizes, number of fleets and rigging of nets used by the gillnetter.

Mesh (mm)	Period 1	Period 2	Hanging ratio (%)	Twine (mm)	Height × length (m)	Nets in fleet
140	1	0	50	0.60	6.8 × 27.5	40
186	18	9	50	0.60	7.2 × 27.5	40
200	3	2	58	0.70	4.5 × 27.5	40
220	4	0	58	0.70	4.6 × 27.5	40

one mesh size only, to ensure that neighbouring nets did not affect one another's catchability, with small nets acting as guiding nets, thus overrepresenting larger fish sizes in the larger mesh sizes. The fishing with different mesh sizes was spread out in time during Period 1. The 140 mm net was rigged with a floating rope instead of floats, and this net was not used in the mesh selection analysis. Only the 186 mm nets were used in the catch comparisons with other gears in the same area. The other fleets in Period 1 were used for selectivity analysis of gillnets only. The gillnet fleets were bottom-set and anchored at both ends. The nets were soaked for from 8 to 16 hours.

The longliner (38 m, 1100 HP) was equipped with a Mustad Autoline System. The longline used was a 7 mm swivel line rigged with Mustad EZ-baiter hooks no. 12/0, with a hook spacing of 1.4 m. The lines were baited with a combination of squid and mackerel (ratio = 2:1) cut to a bait width of 3 cm. Each longline fleet had 6300 or 8230 hooks and was treated as a single observation in the experiment. A total of 50 longline fleets were set in the course of the experiment: 24 in Period 1, and 26 in Period 2.

The trawler (50.7 m, 2400 HP) was fishing with a standard fishing trawl, Euronete/Alfredo no. 3 with a twin codend and rockhopper gear, using W11 doors of 7.8 m^2 and 2275 kg. The mean mesh size of the twin bags was measured to 140 mm stretched mesh (range: 135–148 mm). The sweep length was 144 m and the door spread 135 to 146 m. The vertical opening of the trawl was 3.6 to 4.6 m. The towing duration was three–four hours at a speed of 2.1 $m\ s^{-1}$ (4 Kt). A total of 30 hauls were made: 19 in Period 1 and 11 in Period 2.

The overall lengths of a sample of 250–350 cod and haddock were measured for each fleet/haul. Individual biological data (length, weight, otoliths, sex and stage of maturity) were collected from three cod in each 5 cm length group at every second station. The individual data were weighted according to the length distribution of the catch for each gear and period. The condition factor ($k = 100 \times \text{weight} \times (\text{length})^{-3}$) of the fish was estimated from the weighted data. For haddock only length data were sampled.

Between Period 1 and Period 2, in an area closer to shore than where the comparable fishing experiment took place, selectivity experiments were conducted by the trawler. This area was chosen to obtain enough small fish in the catches. The trouser trawl method was used, with a vertical separation panel mounted from the middle of the belly to the codend. One of the 140 mm mesh twin bags was blinded by an inner net of 60 mm mesh size. The duration of each selectivity haul was 0.5 h, and a total of 10 hauls were made. All fish were measured. We pooled all 10 hauls in the estimation of codend selection, ignoring the interhaul variance. This probably resulted in an underestimation of the standard deviations of the selection parameters. A GLM analysis of the dependent variable mean length in the control and experiment codends with independents effects depth (25 m intervals) and area was not significant. However, the number of observations at each length was small (<5) for several hauls in each of the two codends, and the data were not adequate for interhaul variance analysis and estimation of individual selectivity parameters as described by Fryer (1991). The SELECT method (Share Each LEngth's Catch Total) described by Millar (1992, 1993; Millar and Walsh, 1992) was used to establish a selection curve and to determine the selection parameters (25%, 50% and 75% retention length (L_{25}, L_{50}, L_{75}), and selection range) for cod and haddock in the 140 mm codend. These parameters were used in theoretical catch proportion plots to examine longline selectivity.

To estimate the selectivity of gillnets, we tried to fit four different selection curves to the catches of the mesh sizes used. The models were fitted in principle in the same way as in the SELECT method (Millar, 1992) given in the GillNet software (commercial product available at http://www.constat.dk), with three of the models accepting Baranov's principle of geometrical similarity (in Hamley, 1975), and fitting relative catch per length-group in all nets simultaneously. Normal scale (with constant spread, and therefore not according to Baranov's principle), normal, lognormal, and gamma models were tested, and the model that gave the best fit was chosen. The parameters estimated were used in the theoretical curves of expected catch ratio for the estimation of longline selectivity.

For the longline selectivity analysis we used the observed catch proportion in each length group

Table 2. Mean catch (kg) per station (trawl haul, longline fleet and gillnet fleet) during the experiment. Standard deviations of catch weights are shown in parentheses. Bycatches are shown in numbers per tonne of target species.

Period	Species	Trawl		Longline		Gillnet	
1	Cod	3238	(2092)	1773	(723)	1657	(593)
	Haddock	1973	(1181)	665	(279)	4	(4)
	Bycatch	41		54		9	
2	Cod	4096	(6390)	1754	(593)	3391	(1392)
	Haddock	1153	(1508)	1055	(573)	7	(3)
	Bycatch	38		206		5	

Table 3. GLM analysis of the effect of spatial and temporal variation in the catches by gear and period.

Period	Independents	Longline d.f.	Longline Pr>F	Trawl d.f.	Trawl Pr>F	Gillnet d.f.	Gillnet Pr>F
1	Day	4	0.348	5	0.560	4	0.128
	Depth	2	0.405	3	0.476	1	0.172
	Day × Depth	0	—	0	—	2	0.678
2	Day	5	0.003	3	0.0456	1	0.106
	Depth	2	0.644	4	0.0497	2	0.276
	Day × Depth	4	0.799	1	0.1607	0	—

compared with those of trawl and gillnet. Experiments on hook or bait sizes have shown only minor effects on mean length of cod (Løkkeborg and Bjordal, 1992), and we expected the comparison between different gears to provide more valuable information. To examine the selectivity of longline we used a form of Millar plot (Millar, 1995), which shows the proportion of catch in each 5 cm length group for each gear. These proportions are always defined, under weak assumptions (Millar, 1992), they have a binomial sampling distribution, and the theoretical catch proportion is the expected value of the observed proportion (Millar, 1995). A conservative 90% confidence interval is calculated for the observed proportions by

$$\hat{p} \pm \frac{z_{\alpha/2}}{2\sqrt{n}},$$

where $\hat{p}$ is the observed proportion, $z_{\alpha/2}$ is the quantile of the standard normal distribution, and n is the total number of fish in the length group from the gears that are compared.

Assuming the gillnet and trawl codend selectivity to be known, the relative catch per length-group in longline was compared to the relative catch in each length-group in trawl and gillnet rather than to other sizes of hooks or baits. These plots were compared with plots of the expected frequency in the theoretical curves. Our aim was to use the more established and "known" selectivity parameters of the codend and gillnet to find the selection curve of the longline. Millar (1995) has shown that several different selection curves may give precisely the same fit for a set of data, thereby making it impossible to determine the precise shape of the selection curve when comparing pairs of gears with unimodal selection curves. We wished to use the life history parameters of length at age as an additional decision parameter in the choice of selection curves for the longline and the trawl. In the terminology of Millar and Fryer (1999) we will use the contact-selection curve for codend and gillnet comparatively to draw conclusions regarding the available-selection curve for trawl and longline.

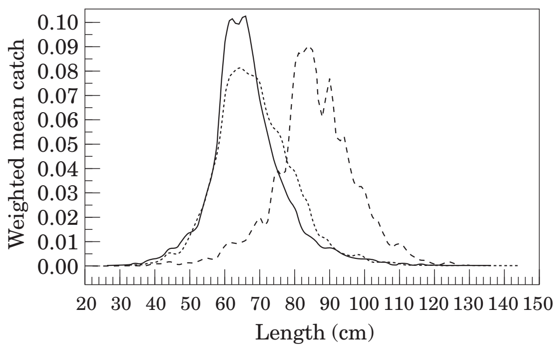

Figure 3. Length distribution for cod caught in Period 1. Mean catch in each cm length group weighted by the catch in each haul. Gillnet, stippled line; trawl, whole line; longline, dotted line.

Table 4. Mean total length (cm) in catches of cod by gear and time period. p-Levels from Kruskal–Wallis test for differences between gears (columns) and between time periods (last row) are given. Quantiles of 5% and 95% of the length distribution are shown in parentheses.

	Trawl			Longline			Gillnet	
	Mean length	Hauls	p	Mean length	Fleets	p	Mean length	Fleets
Period 1	67.1 (52–87)	25	0.05	69.4 (54–88)	24	0.0001	86.2 (67–105)	19
Period 2	68.7 (52–90)	11	n.s.	68.3 (54–85)	26	0.0001	82.3 (65–98)	10
p	n.s.			n.s.			0.0001	

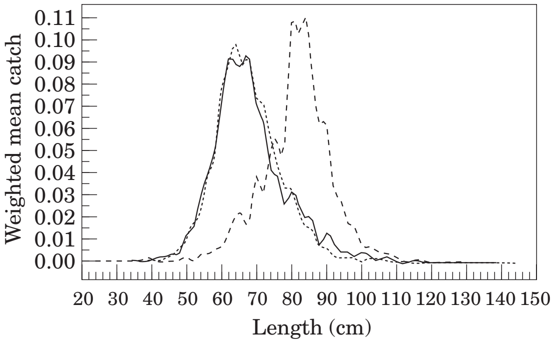

Figure 4. Length distribution for cod caught in Period 2. Mean catch in each cm length group weighted by the catch in each haul. Gillnet, stippled line; trawl, whole line; longline, dotted line.

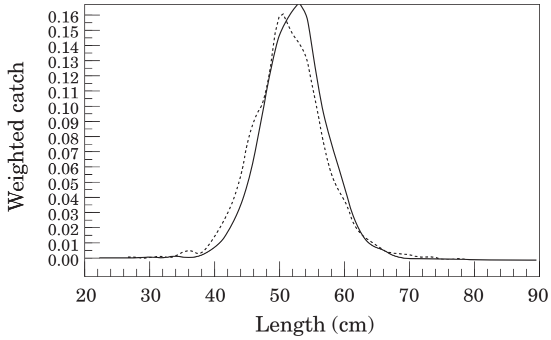

Figure 5. Length distribution of haddock from Period 1. Percentage of each 1 cm length group weighted by catch size at each haul/fleet. Trawl, whole line; longline, dotted line.

Results

A total of 320 tonnes (t) of cod and 113 t of haddock (Table 2) were caught during the experiment. The mean bycatch in numbers of non-target species per tonne of target species (cod and haddock) was 8 for gillnets, 41 for trawl and 133 for longline. The dominant bycatch species in the trawl catches was saithe (*Pollachius virens*, 26 individuals per t), while in the longline catches skates (*Raja* sp.) dominated the bycatch (90 individuals per t).

In order to test for spatial and temporal variation in catches within each gear and period, a GLM analysis was performed (Table 3). The analysis demonstrated no significant effects of day or depth within gear in Period 1, but there seems to have been an effect of day in longline catches, and of both day and depth in the trawl catches in Period 2. No combined effects were shown for any gear in any period.

During Period 1, the length distribution of cod caught by longline was slightly wider and more skewed to the right (Fig. 3) than that of cod taken by trawl. The mean length of cod was 2.7 cm larger in longline than in trawl catches (Table 4). During Period 2, the length distributions of trawl and longline catches nearly overlapped, and there was no difference in mean lengths (Fig. 4).

The mean length of cod caught by gillnets was significantly greater and was shifted approximately 17 cm to the right compared to that of the trawl and longline catches (Table 4).

The gillnetter stayed in the same area during both periods. This was chosen to the interactions between active and passive gears in the frontal zone of the cod migration where most of the fishing fleet, as well as the two other boats in this experiment, followed. There was a decrease in the mean length of cod taken by gillnets from Period 1 to Period 2, but the mean catch increased from 1654 to 3391 kg per fleet. The mean length and length range of cod decreased in the longline catches from Period 1 to Period 2, whereas both mean length and length range increased in the trawl catches (Table 4).

During Period 1, the longliner caught smaller haddock than the trawler (Fig. 5). In Period 2, however, the longliner caught larger haddock than the trawler (Table 5, Fig. 6). The mean length of haddock caught by longline increased by 3 cm from Period 1 to Period 2, and their size range rose by 3 cm. Mean lengths from each haul/fleet were weighted according to total catch. In the trawl catches, neither the mean length nor the size range of haddock changed between the two periods (Table 5).

The selectivity curve for cod of the trawl codend of 140 mm nominal mesh is shown in Figure 7. The L_{50} for cod was estimated to be 55 cm, and the selection range was 14.4 cm.

The selectivity curve for haddock based on the 10 trawl selectivity hauls is shown in Figure 8. The selection

Table 5. Mean total length (cm) of haddock by gear and time period. Probability-levels from t-test for mean lengths between gears (columns) and between time periods (last row). n.s., not significant. Quantiles of 5% and 95% of the length distribution are shown in parentheses.

	Trawl Mean length	Hauls	Probability	Longline Mean length	Fleets
Period 1	53.0 (45–61)	25	<0.05	51.4 (43–61)	12
Period 2	53.1 (45–60)	9	<0.05	54.5 (45–66)	15
Probability	n.s.			0.0001	

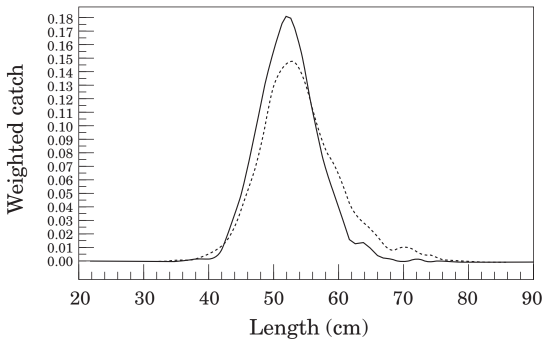

Figure 6. Length distribution of haddock from Period 2. Percentage of each 1 cm length group weighted by catch size at each haul / fleet. Trawl, whole line; longline, dotted line.

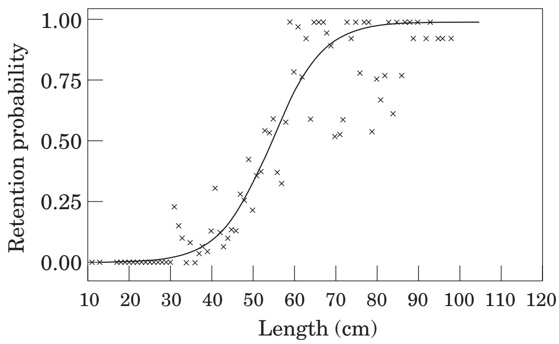

Figure 7. Combined selectivity curve for cod in the 140 mm mesh trawl. Based on 10 0.5 hour hauls between Period 1 and Period 2. In these hauls the trawl was divided by a small mesh liner from the middle of the belly of the trawl, and one of the two codends was blinded by small mesh liner.

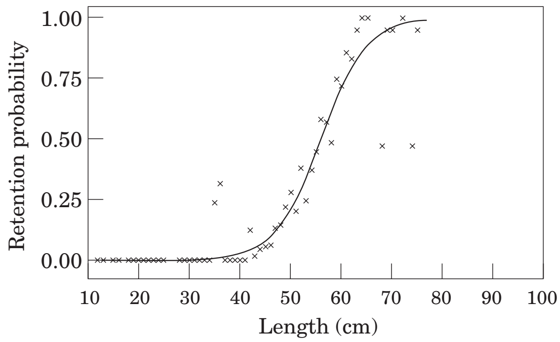

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Table 6. Trawl selectivity experiments with parameter estimates (cm) for cod and haddock with asymptotic standard errors (s.e.) for the 140 mm codend in the Alfredo no. 3 trawl.

	Haddock		Cod	
	Estimate	s.e.	Estimate	s.e.
25% retention length	51.5	2.84	47.8	1.21
50% retention length	56.6	4.46	55.0	1.8
75% retention length	61.6	7.37	62.2	2.6
Selection range	10.1		14.4	

parameters showed a L_{50} at 56.6 cm and a selection range of 10.1 cm (Table 6). The data did not support an analysis of between-haul variance, as several hauls gave very few fish (<5) in each length group. However, a GLM analysis of mean length in the control or experiment codend gave no effect of depth or position of the hauls.

The selectivity of the gillnet was estimated from catch data for three different mesh sizes. The selectivity model gave the best fit for gamma function, described by:

$$P = \left(\frac{l}{(\alpha - 1) \times k \times m_j}\right)^{\alpha - 1} \exp\left(\alpha - 1 - \frac{l}{k \times m_j}\right),$$

where l is fish length, m_j is j'th mesh size, k and α are estimated in the fitting process) and based on the Baranov principle of geometrical similarity (Table 7; Figs 9 and 10). The modal length for the selection curve of the commonly used mesh size of 186 mm was found to be 94.7 cm (spread: 13.7 cm). Because of the large mesh size used (186 mm), the gillnetter caught a total of only 153 haddock, too few for size selection analysis.

Longline selectivity was found by comparing the relative catch in each length group with those of trawl and gillnet, analogous to the Millar method (Millar,

Table 7. Gillnet selectivity for cod. Length and standard deviation in cm and parameters for the estimated gamma selectivity curves.

Mesh size	Modal length	Spread	Deviance	d.f.
186	94.7	13.67	240.8	180
200	101.8	14.70	α	48.9558
220	112.0	16.17	k	0.0106

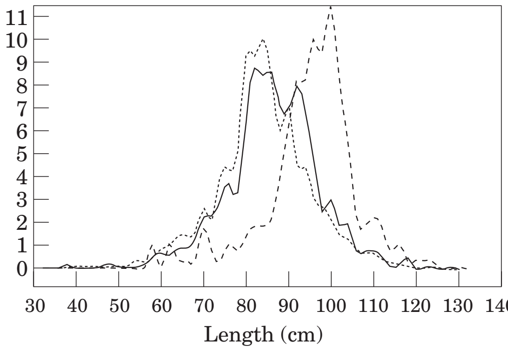

Figure 9. Length distribution in gillnet catches with 2 cm length groups. 186 mm, dotted line; 200 mm, broken line; 220 mm: stippled line.

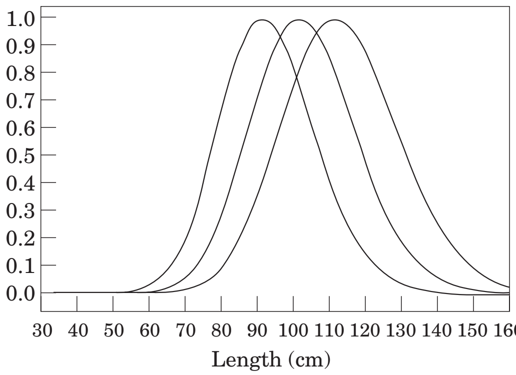

Figure 10. Gillnet selection curves for cod for the mesh sizes 186, 200 and 220 mm with gamma function.

1995). This means, in detail, that the catch proportion for each 5 cm length group in longline is divided by the sum of the catch proportion of the longline and the catch proportion of one of the two other gears. For these comparisons we assumed that the trawl selectivity was sigmoid, with L50 at 55.0 cm and a selection range of 10.1 cm, and that the gillnet selection had the form of a gamma distribution with a modal length of 94.7 cm and standard deviation of 13.7 cm. We also present the expected catch proportion between gears if the trawl is modelled to have a selection curve of a normal distribution, with mean length 66.7 and a standard deviation of 8.75 cm. We looked at whether the selectivity of the

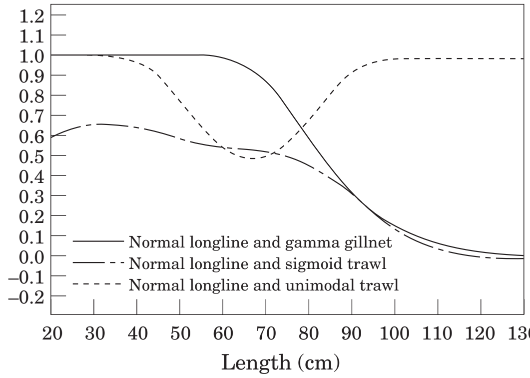

Figure 11. Expected catch proportion for cod when selectivity of longline is assumed to be normally distributed, with mean length 70 cm and standard deviation 16 cm. The parameters for trawl and gillnet selectivity are as estimated from the respective selection experiments.

Table 8. Mean condition factor ($K = 100 \times \text{weight} \times \text{length}^{-3}$) for cod by age and gear. All pairs are significant when tested by Kruskal–Wallis.

Age	Gillnet	Longline	Trawl
4	*	0.82	0.84
5	*	0.82	0.86
6	1.06	0.89	0.87
7	1.13	0.87	0.88
8	1.14	0.87	0.96

Table 9. Mean total length of cod by age and gear. p-Levels from Kruskal–Wallis test for differences between gears. Significant differences were found for all ages. Each pair is then tested with Wilcoxon, and all differences are significant.

Age	Gillnet	Longline	Trawl
4	*	45	47
5	*	52	54
6	69	63	64
7	82	76†	76†
8	91	85	89

*Too few data in gillnet catches for analysis.
†Differences less than 1 cm.

longline could best be described by a bell-shaped selection curve (normal distribution), or the selectivity curve was sigmoid. Assuming the selectivity in longline to follow a normal distribution, with a mean length and variance as indicated in these catches (median length 70 cm, standard deviation 16 cm), the expected catch proportion in each length group taken by longline and the other two gears is shown in Figure 11.

If we assume a sigmoid pattern of selectivity also in longline, the expected catch proportion between longline

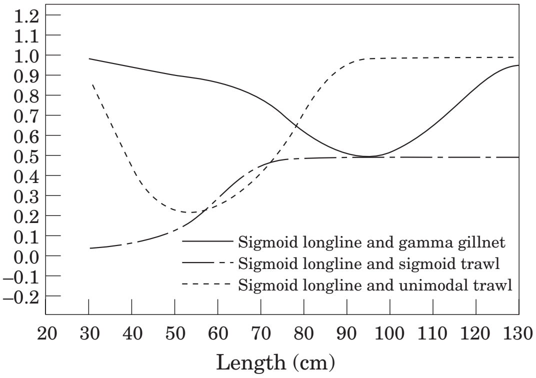

Figure 12. Expected catch proportion for cod for the proportions longline/trawl and longline/gillnet when assuming longline selectivity as sigmoid with L_{50}=65 cm.

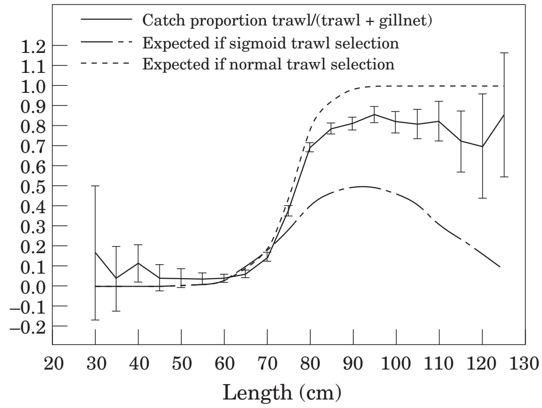

Figure 14. Expected and observed catch-proportion between trawl and gillnet.

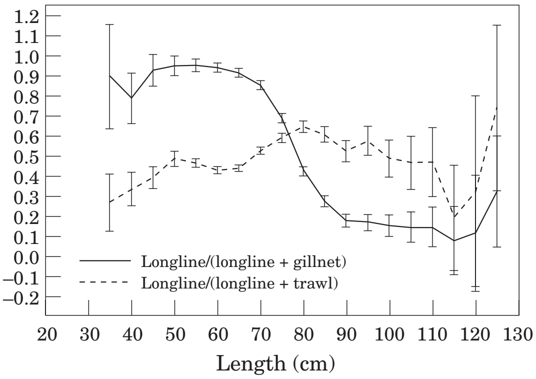

Figure 13. Actual catch rates for longline/(longline+trawl) and longline/(longline+gillnet) in Period 1.

and each of the two other gears is illustrated in Figure 12. The actual catch proportion of this experiment is shown in Figure 13. The plot of the actual catch does not fit either of the two scenarios for the expected longline selectivity catch proportion. As an illustration of the trustworthiness of these plots the expected and observed catch-proportion for trawl (with "known selectivity") to gillnet ("known selectivity") is shown in Figure 14.

The condition factor calculated from weight and length at age was lowest for the longline-caught fish (Table 8). The mean length at age was lower for longline- and trawl-caught fish than for those caught by gillnet, and mean length at age for longline caught fish was lower than for those caught by trawl (Table 9).

Discussion

Comparisons of gears

This study demonstrated significant differences in the species and size compositions of catches taken by trawl, longline and gillnet when the vessels were fishing in the same area. The longliner caught slightly larger cod than the trawler. This finding agrees with earlier investigations (Engås *et al.*, 1996), and may be explained by the catching principles of the longline, where bigger cod might enjoy the advantages of a higher swimming capacity, a larger searching area and the ability to frighten off smaller fish, thus leading to a larger proportion of large cod in the longline catches (Løkkeborg and Bjordal, 1992). The longliner also caught cod of a wider range of sizes. This may be explained by the escape of smaller fish from the trawl.

The longline caught more small haddock than the trawl. A similar difference was demonstrated by Engås *et al.* (1996), who explained the differences by the fact that a large proportion of the haddock in the area fished were smaller than L_{50} for the Alfredo trawl (L_{50} for haddock: 51.5 cm (Isaksen *et al.*, 1990), with the result that they might have escaped through the meshes. The L_{50} for haddock was larger in our selectivity experiment (56.6 cm), and this may be due to differences in the codend material or differences in fish condition. Ozbilgin *et al.* (1996) found seasonal differences in L_{50} of more than 5 cm for haddock. The fact that the mean length of haddock in the trawl catches was less than L_{50} indicates that there were a lot of small haddock available to the trawl.

Fishing gears based on different catching principles are likely to harvest differently on fishing grounds with mixed species and size compositions. The trawl is an active gear which sweeps along the bottom, and in principle, harvests all fish in the trawl path if they are large enough to be retained by the meshes in the codend. There has therefore been a tradition of representing trawl selectivity as a sigmoid curve. However, avoidance reactions to the approaching ship and gear, and fish escaping below the ground gear and above the headline, both of which behaviours may differ among species and age groups, are known to bias the length and species composition of trawl catches (Engås and Godø, 1989; Ona and Godø, 1990; Michalsen *et al*., 1996). In experiments conducted with only one gear, it is not possible to estimate the proportion of fish that do not come into contact with the gear due to early avoidance reactions, for example to vessel noise. Experiments on the effects of different towing duration showed that the quantity of large fish lost was negligible in short tows compared to long tows, indicating that larger fish do not swim to exhaustion ahead of the trawl (Godø *et al*., 1990).

Longline and gillnets are stationary gears; the former attracts fish by scent released from the bait, while the latter takes advantage only of the swimming activity of the fish. The selective properties of longline gear depend on several factors such as feeding motivation, the hooking probability of different groups of fish, and competition between species and size groups for the available baits (Fernö *et al*., 1986; Bertrand, 1988; Løkkeborg and Bjordal, 1992). Gear modification experiments to improve longline selectivity have resulted in only minor changes in mean length of cod taken (Johannessen, 1983) and showed no effect for haddock (Soldal and Huse, 1997). The discussion on whether longline selectivity is sigmoid or bell-shaped, (Kenchington, 1993) illustrates how little is actually known about the selectivity properties of longline. The underlying assumption of bell-shaped selectivity curve in longline includes the competitive aspect of larger fish having a greater swimming capacity, and an assumption that the bait size is optimal for a limited range of fish sizes. Before synthetic snoods, swivels and new stronger hooks were introduced, a large proportion of the largest fish was lost during hauling, but this is no longer regarded as a serious problem.

The Millar plot does not explain which processes are most important; it merely indirectly shows the form of the selectivity curve, suggesting that a normal selectivity curve for the longline would be the best for our data (Figs 11 and 13). It is clear that the competitive selectivity in longline fishing will exclude small fish from the catches only when larger specimens are present in the area, and thus, if the longline is set in areas populated more or less homogeneously by small fish, there will be no exclusion of small fish as long as bait and hook are suitable for these fish. The expected and observed proportions between longline and trawl are inconclusive with regard to the "available-selection" curve of these gears. Approximately 90% of the cod taken by trawl and longline were between 55 and 85 cm in Period 1 (Table 4), and this part of the plots (Fig. 11) is the most reliable.

The mean length of cod caught by gillnets was approximately 17 cm greater than those taken by longline and trawl. Almost no haddock were caught by gillnets, which may be explained by the mesh size being too large. The selectivity of gillnets has been well documented (e.g. Olsen, 1959; Hamley, 1975; Hylen and Jacobsen, 1979; Kirkwood and Walker, 1986; Aldebert *et al*., 1993), and is believed to remain fairly constant regardless of the size composition of the fish in the area. In this study we found a small decrease in the mean length of cod from Period 1 to Period 2, although the gillnet vessel stayed on the same fishing ground during both periods. This may be explained by a change in the size distribution of cod in the area. Spawning cod migrate westwards through the experimental area in February, and it has been shown that the largest fish are the first to migrate to the spawning grounds (Sund, 1938). The proportion of large cod may therefore have fallen from Period 1 to Period 2.

Estimates of gillnet selectivity have been made using various assumptions about the bell-shaped distribution of selectivity curves (Kirkwood and Walker, 1986; Millar, 1995; Holst and Moth-Paulsen, 1995), while trawl selectivity is considered to be monotone increasing up to 100% retention length (Pope *et al*., 1975; Wileman *et al*., 1996). However, our findings showed that the trawl caught fish within a narrower range of lengths than either gillnet or longline, suggesting that total trawl selectivity should also be fitted to a bell-shaped curve. This is supported by Figure 9, which indicates that the "available-selection" curve for trawl is unimodal compared to that of gillnet. It has been shown that fish avoid the path of the vessel (Ona and Godø, 1990), and that large fish are able to leave the trawl mouth even after entering it (Wardle, 1983, 1986). Our comparisons of catch proportions per length-group indicate that the trawl is less efficient for large cod than expected (Fig. 14), but the result is based on less than 5% of the catches in the trawl, and the total deviance from the expected catch has not been taken into account here. Studies of swimming speed and endurance (Videler and Wardle, 1991; He, 1993) showed that at 4°C a 85 cm cod has a burst swimming speed of $2.3\ \mathrm{m\,s^{-1}}$ and a small cod (34×36 cm) has a maximum sustainable swimming speed of $0.6\ \mathrm{m\ s^{-1}}$ (He, 1993). This means that for the lengths represented in the catches, the possibility fish avoiding the trawl or vessel-path or even of using the moving trawl as a feeding area, swimming in and out of the trawl opening while foraging on smaller individuals (video observations, unpublished) is highly variable. Thus the selection curve of the trawl is most likely to be bell shaped and skewed to the right. We have continued to use the sigmoid selection curve for the trawl codend as a selection curve for the whole gear and will do so until another model is shown to give a better fit. However, the assumption that trawl selection is unimodal may be fatal, and may partly explain the collapse of cod stocks in Canadian waters. When employing this assumption, that catchability of large cod in trawl was decreasing with length, it doubled the estimates of the spawning stock, and opened for larger total quotas (Myers and Cadigan, 1995).

The effect of swimming capacity is not taken into consideration in the Millar plot, but should be included in a model of total trawl selectivity. We also assume that fish length and swimming capacity have an effect on encounter probability for gillnet (Rudstam *et al.*, 1984), and both these factors may explain the relatively few large fish taken by trawl compared to gillnet.

The observed differences in condition factor of the fish taken by trawl, longline and gillnet may be explained by fish behaviour in relation to the catching process of these gears. Fish caught by gillnet are mainly gilled by the meshes, and this gear therefore catches fish within a narrow range of sizes. However, a wider size range of more wedge-shaped cod may be caught by gillnet, over-representing smaller mature individuals or individuals with a high condition factor. Fish with a higher condition factor are more wedge shaped than slimmer fish of the same species, and this may explain the high condition factor of the gillnet-caught fish. Fish with low condition factor, i.e. thin fish, probably have higher nutritional requirements and thus higher feeding motivation (Løkkeborg *et al.*, 1995). It is likely that these fish are caught in higher proportions by longline, which exploits the feeding behaviour of the target fish. Trawls, which caught fish of intermediate condition factor, catch fish that are present in their path, and trawl catches are therefore likely to provide a more representative sample of condition factors. Data from trawl surveys showed that interannual variation in length-specific weight can be larger than the differences in the catches reported here (the ratio of minimum/maximum weight for 55.5 cm females was 0.65 in the period 1986–1996 (Marshall *et al.*, 1998). The short-term and long-term effects of these differences in the condition of catches should be investigated.

Stomach weight was not included in the individual measures. If there was a higher proportion of empty stomachs in longline catches due to vomiting, this could bias our results on condition factor. However, Engås *et al.* (1993) found no differences in the proportions of empty stomachs or in the degree of stomach fullness between trawl and longline-caught cod. The observation of a lower condition factor in longline-caught cod is supported by the observed differences in mean length at age, suggesting that fish that were attracted to the longline bait have had also grown more slowly earlier in their lives. A time-lag of one year was shown in weight at length for cod at some length-groups in Marshall *et al.* (1998).

Effects of fishing area

As well as revealing significant differences in gear selectivity *per se* when the vessels fished in overlapping areas, our study also demonstrated differences in total selection of the three fishing methods, i.e. gear selection combined with the fishing strategy of the skipper. This strategy is determined by the way in which the skipper operates the gear in order to achieve maximum catch rates, larger fish and the best bottom ground. The strategy chosen may also include maximising the amount of unregulated bycatch in order to save quotas for the regulated species. In such situations the change of strategy may include fishing area and gear modifications. In our experiment only area was changed. The effects of area change was not dramatic, and we observed that fish migration was important in the current situation. This was most probably affected by the time limit of the contracted fishing, and the fact that there were no other preferable fisheries going on elsewhere. For these reasons, none of the boats chose a fishing area very far from the original experimental area due to the time limits of the contract.

We assumed that catches from a gear with rigid selectivity like gillnet would be less affected by fishing area than a theoretically non-selective gear which reflects the true distribution in the fishing area. The mean length of haddock caught by longline, which was smaller than that taken by trawl in Period 1, increased by 3 cm in Period 2 and became larger than that of trawl-caught haddock. The mean length of cod did not change from Period 1 to Period 2 for the longline or trawl catches. Both skippers chose to follow the front of the migrating cod, but basing their strategies on information from other fishing boats they chose different areas. The longliner chose an area with larger and more abundant haddock whereas the trawler chose a limited area where the catches were very large. The longline is a gear that gets saturated, thus limiting the effects of choosing areas with dense aggregations of fish. This will often make it more profitable for a longliner to choose fishing grounds where the fish are bigger (better prices) and more sparse. The number of hooks occupied by non-target species increased in Period 2 (Table 2), but the mean catch (in terms of weight) was larger than in Period 1. The fact that a larger percentage of the hooks were occupied in Period 2 may have influenced the selectivity of the longline. The species composition in the area may affect the hooking success of cod and haddock (Godø *et al.*, 1997). The magnitude of changed selectivity or different species composition in the area is impossible to distinguish on the basis of the longline data only.

The gillnetter chose to stay in the same area, partly due to gear conflicts in the migration-front area. This resulted in smaller mean catch lengths as the front of large migrating cod passed by.

The size and species selection of fishing gear is influenced by the type of fishing gear, gear performance and characteristics and the fishing area. The overall selectivity of the gears was modified by the skippers' choices of fishing area. A similar effect has been demonstrated in the Norwegian Greenland halibut (*Reinhardtius hippoglossoides*) fishery (Nedreaas *et al*., 1996). The physical state and condition of the fish available for the gear are also of importance for stock assessment based on catch data, the fishery management and the fisherman and his/hers profit.

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