RELATIVE SELECTIVITY IN TRAWLS, LONGLINE AND GILLNETS ON GREENLAND HALIBUT

by

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ABSTRACT

Selectivity parameters for Greenland halibut (*Reinhardtius hippoglossoides*, Walbaum) are compared to catches reported from trawl, gillnets and longline in the Norwegian scientific fisheries for Greenland halibut. A trouser trawl selectivity experiment reported here gives an L50 at 43 cm in 135 mm codend. A selectivity analysis of the gillnets using loglinear models is done, and shows maximum retention probability for lengths at 40.6 - 63.8 cm for the five mesh-sizes used. The effect of the fishing strategy is analysed in respect to the selectivity of the gear used and the distribution of length and age in the catches. To avoid possible bias from strong dominating yearclasses and selection in these comparisons, length-at-age data are used. The sex-ratio in gillnet catches is shown to be a linear function of meshsize. Our data show no trend in length distribution with depth. We show that calculated growth of female Greenland halibut is affected by the selectivity of the gears. It is shown that growth parameters calculated from gillnet catches may be biased due to the selection properties in the gillnets. These analyses will provide a better understanding of possible sampling bias when sampling a stock with only one gear.

INTRODUCTION

Since 1992 the fisheries for North-East Arctic Greenland halibut in ICES Subareas I and II have been strictly regulated and all direct fishing by trawl and vessels longer than 28 m long is banned. These restrictions have been invoked after the stock showed several signs of recruitment failure and over-exploitation. Selectivity analyses for all commercial gears usually used in this fisheries is important in a period of rebuilding the stock and hopefully later reopening the fisheries of Greenland halibut. To ensure time-series data on commercial gears, a restricted scientific fishing has been conducted every year by fishing boats under contract with the Institute of Marine Research. Calculations of yield per recruit and maximum sustainable yield is affected by the growth parameters used. Results from cod (Huse *et al.* 1996) shows that the calculations of growth parameters is affected by the selection of the gears used for sampling procedures. To analyse if this effect is significant for Greenland halibut, the data from the scientific fishery is analysed here.

In addition to the catch-comparisons analyses we carried out a selectivity experiment for Greenland halibut for the commercial trawl used. In the scientific survey a 100 mm bag is used in the predestined stations for the trawler, while the minimum legal meshsize in this area is 135 mm. Attempts to estimate the selectivity in the commercial trawls used in this fishery was first done by Nedreaas (1991) by comparing length distributions in the Greenland halibut fisheries and the trawl fishery for shrimp. A cover codend selectivity experiment for 130 mm codend (de Cardenas *et al.*, 1995) shows the L_{50} for 1 hour hauls to be 38.7 cm and a selection range of 7.5 cm. Selectivity experiments with trouser trawl was conducted in ICES Division IIb in

August 1995 (Huse and Nedreaas, 1995) but few small Greenland halibut was found, and the estimates were not statistically satisfying. In this paper a trawl selectivity experiment done in September 1996 is presented.

For estimating the selectivity in gillnets we used the data from the scientific fisheries in 1994.

METHODS

Catch comparisons

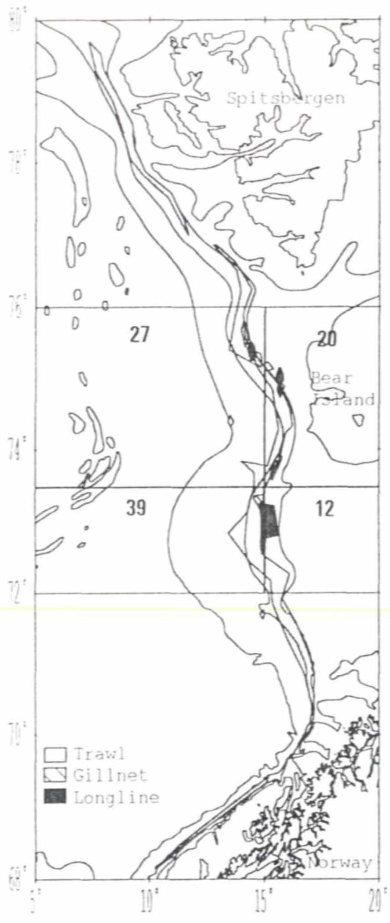

Fig. 1. Area investigated. Depth contours are 200, 500, 1000 and 2000 m. Numbers indicate different Norwegian statistical areas.

The trawl catches used for the comparisons with gillnets and longline were collected at the contracted scientific fishing for Greenland halibut in 1994. These data were chosen because of the overlap in depth between the stations fished with different fishing gears and the wide depth-range covered by the trawl.

In this scientific fisheries in August-September 1994 the trawler fished at predestined locations in a stratified trawl survey in the depth range 510-1420 m. The stations are situated along the continental slope from the northern part of Norway to the northern part of Svalbard (Fig 1). The trawler made a total of 153 hauls. In the analyses presented here we used the stations between 72° and 76° N latitude where the overlap between the gears was best. In this area the trawler made 70 hauls. A gillnetter and a longliner fished in this area at the same time as described by Nedreaas and Sæverud (1994). The gillnetter fished a total of 149 fleets with different meshsizes (5 fleets of 140mm stretched mesh, 1 of 160 mm, 8 of 180 mm, 40 of 200 mm and 76 fleets of 220 mm). In this paper we will denote the meshes of the gillnets as the bar-length, and thus the range of gillnet sizes will be 70-110 mm. The longliner made a total of 71 settings during the 8 days of fishing, wetting more than 335 310 hooks. In the scientific fishery a representative sample of ca. 250 fish is measured at each station. In every second station a length-stratified sub-sample was age, sex and maturity determined.

The statistical analysis is made in SAS, using GLM and NLIN (SAS Institute Inc., 1989). The GLM-procedure uses the method of least squares to fit general linear models. For unbalanced data this is the best way to perform ANOVA with the model stated as: dependent variable = independents effects with or without interaction effects (factorial model). The NLIN procedure is used for the computation of the von Bertalanffy's equation.

Trawl selectivity

A factory trawler (60.5 m, 4000 Bhp) was chartered for the trawl selectivity investigation. The selectivity experiments were conducted during a survey north of Svalbard in September 1996. The trawl used was a Alfredo no.3 with twin codend and rockhopper gear as used in commercial fishing, rigged with Tyboroen doors (3200 kg), and monitored by Scanmar sensors. The codend was in knotless ultracross material, and the meshsize was 136 mm in the experimental codend. The trouser trawl method was used for the selectivity experiments, and a vertical panel was mounted from the middle of the belly to the twin codend, thus separating the two bags. One of the bags was blinded with an inner-net of 60 mm mesh size. Four hauls of 1 hour fishing time were done. The headline height was 4.2 m and speed 2.1 m/s. The depth was 375-430 meters and the water temperature at the bottom was 2.6 °C.

The SELECT-method (Share Each Length's Catch Total) described by Millar (1991; 1992; 1993); Millar and Walsh (1992) was used for calculating the selection parameters (25%, 50% and 75% retention length (L25, L50, L75), and selection range) with standard errors, and the selection curve was adjusted according to the model.

Gillnet selectivity

The selectivity of gillnets has been modelled in several ways. The modal length of maximum retention is very robust for method (e.g. normal, gamma, lognormal and logistic) used to estimate the parameters, but extremely sensitive to different fishing efficiencies (Millar, 1994).The principle of geometrically similarity (Baranov, 1948) establish that the selectivity in gillnets depends on the relationship between the geometry of the fish and the mesh. Thus the modal length and spread of the curve is both proportional to the meshsize. Using a general linear model it is possible to estimate the selectivity for each mesh size with the information of the total catch in each length-group (Kirkwood and Walker, 1986; Millar and Holst, 1996). In this analysis a loglinear model (Millar and Holst, 1996) is used to adjust selectivity-curves based on a lognormal form (GillNet software, ConStat, constat@nscentre.dk) . The gillnet data used are from the scientific fishery in 1994.

RESULTS

The overall length distribution of each gear (Fig.2, Tab.1) shows the length composition differences of the catches.

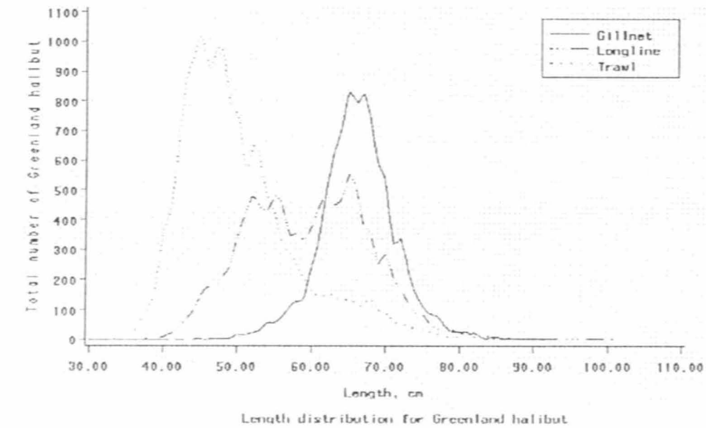

Fig. 2. Length frequencies of the catches from the different gears used in the fishing. For gillnet only the two largest meshsizes are included. Both sexes are included.

Table 1. Mean length and quantiles for the samples from the catches.

	Mean length (cm)	Quantiles (95%-5%)
Trawl	50.1	67 - 40
Longline	59.6	73 - 46
Gillnet	65.9	74 - 58

The amount of females in the catches differs among gears (Tab. 2), and is in accordance with the size distribution in the catches, as it is assumed that males have higher natural mortality (Kovtsova and Nizovtsev, 1985; de Cardenas, 1996) and therefor a small part of the Greenland halibut over 65 cm will be males. As expected, there is an inverse correlation between the amount of immature individuals and the mean length in the catches (Tab. 2).

Table 2. The numbers and percentages of each sex and maturity status in the catches.

	Trawl		Longline		Gillnet	
	Female	Male	Female	Male	Female	Male
Sex proportion	42.4	57.6	72.5	27.5	88.4	11.6
Proportion mature	28.3	63.1	76.6	89.5	90.0	100
N	1975	2682	7819	2973	12973	1697

Both maturity and sex-proportion is correlated with the length of the fish, and it is possible that the selectivity of the gears used here is not only dependent on length but also on behaviour that differs among the sexes and the maturity status. In fact, a GLM model for the effect on length from gear, maturity, sex, and all cross effects gives a significant result both for the total model ($p=0.001$, $R^2=0.69$), and for each of the effects. However, because of the known correlation between length, sex and maturity, we can not conclude which variable is the most important.

Variation of length distribution by depth and area

To analyse this material statistically can be rather complicated. We do know that there are main effects of the length distributions in the catches from each gear used. But since length is dependent on both age, sex and the proportions of each sex in the catches, we will have to simplify to make testable hypotheses. Starting with the effect of depth and area, we have a hypothesis that larger fish tend to aggregate in deeper water. We separate the data with one group for each gear and sex before testing the model.

In the survey in 1994 the trawler covered a number of predestined stations over a wide depth-range (Tab. 3) . We investigated the effect of depth and area (Norwegian statistical areas 12, 20, 27 and 39) on length distribution in the trawl catches. Even if the model shows significant results in almost all combinations, the R^2 (ratio of the sum of squares for the model divided by the sum of squares for the corrected total) is very low, still, there is a small, but significant, correlation between the depth, area and the size of Greenland halibut in the catches (Tab. 4) for several combinations of gear and sex.

Table 3. Number of fleets/hauls in different depth-strata during the survey in the area between 72 and 76 degrees latitude.

	400-499	500-599	600-699	700-1400
Trawl	0	12	11	47
Longline	23	48	0	0
Gillnet	4	123	2	0

Table 4. General linear model (GLM, SAS Institute) for the effect of fishing area and depth on the mean length of Greenland halibut in the catches.

Gear	Sex	Source of variation	Degrees of freedom	Model total R^2	Significance level
Trawl	Female	Depth	1	0.0249	<0.001
		Area	3		0.003
	Male	Depth	1	0.0326	<0.001
		Area	3		0.005
Longline	Female	Depth	1	0.0051	<0.001
		Area	3		0.3262
	Male	Depth	1	0.2084	<0.001
		Area	3		<0.001
Gillnets	Female	Depth	1	0.0062	<0.001
		Area	3		0.0774
	Male	Depth	1	0.2785	<0.001
		Area	3		<0.001

Does sex influence the depth distribution of the Greenland halibut? If the proportion of female/male does changes with depth, this can partly influence the length-distribution of the gears, since the stations covered by the trawler lies deeper than the stations fished by longliner and the gillnetter. Even only very weak correlation between length and depth is found when length distribution is analysed per gear and sex (Tab. 4), a possible bias could be that the proportion of males is higher at the greater depths in this time of the year. If the proportion of males are higher, the mean length in each gear can be biased by the proportion of males, even if the mean length of each sex is constant with depth. A general linear model shows that the relationship between depth and sex in the trawl-catches is almost significant, but hardly a important trend ($p=0.0567$, $R^2=0.0008$, depth male:787 m, depth female:794 m), and the males are more shallow than the females. The same distribution with males most shallow is found for longline catches, but depth explain only a very small part of the variation of the sex distribution ($p=0.0001$, $R^2=0.0148$, depth male:508 m, depth female: 520 m). This means that there is an effect on the proportion of the sexes by depth, but this will actually give a higher proportion of small fish in the most shallow stations, which is not seen in the catches of the different gears: the trawl, catching the biggest proportion of males, is the gear covering the deepest stations (tab. 3, Fig.2). In the gillnet catches there was no effect of depth on the sex distribution.

Selectivity in trawl.

From the experiment conducted on the selectivity of the codend, a selectivity curve (Fig. 3) and parameters (Tab. 5) was estimated.

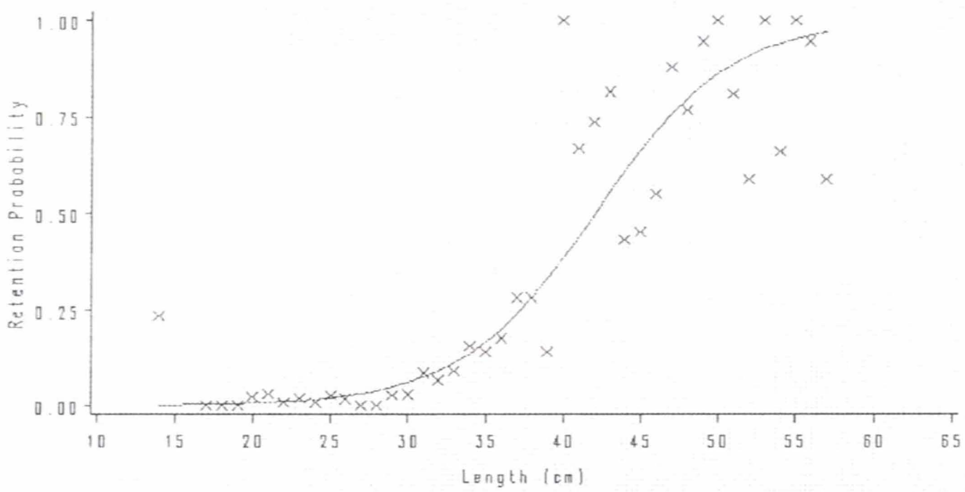

Fig. 3. Selection curve for the 135 mm codend with knotless (ultra-cross) meshes.

Table 5. Parameter estimates (cm) with asymptotic standard errors for the Alfredo no.3 trawl for Greenland halibut.

Parameter	Estimated value	Asymptotic standard error
25% retention length	37.2	1.7
50% retention length	42.0	2.2
75% retention length	46.8	2.7
Selection range	9.6	

Gillnet selectivity

Gillnets are known to be very size-selective. By choosing the meshsize, the fishermen may determine both the mean length (Fig. 4) and the sex ratio (Tab. 6) of the catch. In commercial fishing for Greenland halibut, the bar-lengths 100 and 110 mm is most often used. For the contracted fishing also settings with 70, 80 and 90 mm bar-lengths were done.

Table 6. Sex ratio in catches from gillnets with different bar-lengths.

Frequency / %	70 mm	90 mm	100 mm	110 mm
Female	139 22.7	940 81.7	4532 87.5	8667 96.5
Male	473 77.3	210 18.3	650 12.5	929 3.5

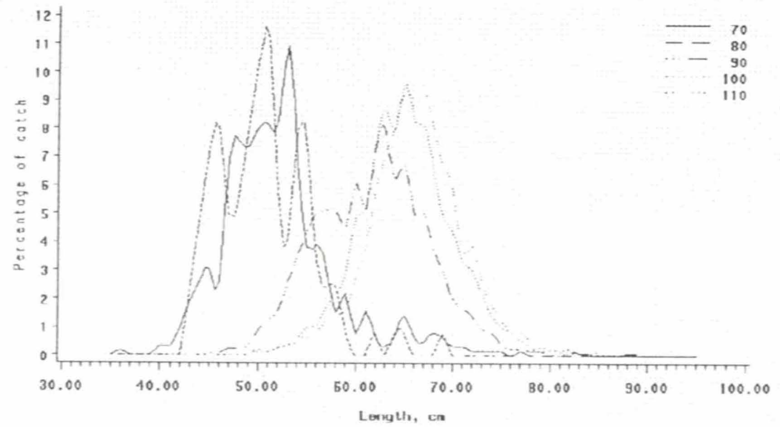

Fig. 4. Length distribution in the used gillnets. Note that the material only include 1 fleet of 80 mm bar-length.

The selectivity properties of the gillnets (Tab. 7) reflects the assumptions of the model with spread correlated to meshsize. The selectivity curve (Fig. 5) has equal height of nodes, this is because the fishing power of each mesh size can be estimated and adjusted for in the log-linear model (Millar and Walsh, 1992; Millar and Holst, 1996). The selectivity factor (Modal length/bar length) is 5.8 from these results.

Table 7. Fit for lognormal model and selectivity estimates for the gillnet with 70, 80, 90, 100 and 110 mm bar-lengths.

Deviation 2876.15	df 348	p <0.005
Bar-length in meshes	Modal length in catch (cm)	Spread (cm)
70	40.6	24.6
80	46.4	28.1
90	52.2	31.7
100	58.0	35.2
110	63.8	38.7

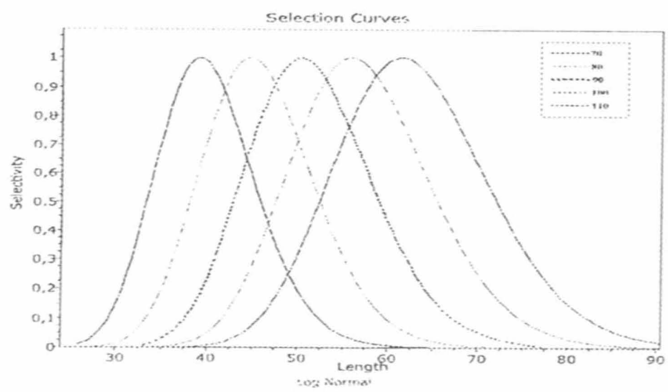

Fig. 5. The selection curves obtained with lognormal model in GillNet software.

Growth

To investigate if selection in the gears will give different calculated growth, the size-range 45-85 cm from all gears in the limited area was fit to a von Bertalanffy growth equation $L_{(t)} = L(1 - e^{-k(t-t_0)})$ (Beverton and Holt, 1957). When data were also split by sex it was found that females caught in gillnets had slower growth and higher $L\infty$ than the females caught by longline or trawl (Tab. 8) (Appendix A).

Table 8. Growth parameters based on length-group 45-85 cm in catches from the three gears.

	Female		Male	
	K	$L\infty$	K	$L\infty$
Trawl	0.100	102.9	0.153	79.1
Longline	0.099	102.5	0.145	81.5
Gillnets	0.067	131.4	0.152	81.6

DISCUSSION AND CONCLUSIONS

The gears used in the scientific fishery utilise fish behaviour in different ways in the catching process, and thus sample the population differently. In the active fishing operation of the trawl, the sound of the vessel is the first stimuli to induce a reaction in the encountered fish while the doors and sandclouds are the visual stimuli supposed to guide the fish in front of the trawl. The sight of the headline with it's floats can keep large fish swimming in front of the trawl without entering the net (Hemmings 1973; Engås 1994).

While the trawl selection curve given (Fig. 3) shows the proportion of fish retained in the codend, there is also a selection of fish in front of the trawl. Small fish might be lost under the sweeps if they are unable to keep up with the speed of the narrowing wires, and large halibut can avoid swimming into the trawl opening. If fish are swimming in front of the trawl the condition of each individual fish can determine whether it is to be caught in the trawl or not. There is a relationship between the length distribution in the catches combined (Fig. 2) and the length at age giving the growth parameters (Tab.8). The results illustrate the selectivity process in this way:

The $L\infty$ is smallest for the trawl and longline-caught fish. This can be explained by the fact that the trawl is an active gear and it is most efficient for the small fish with low swimming speed and capacity. However, the mesh selection in the codend of the trawl will exclude the smallest fish (if present) and also exclude the smallest of a given yearclass in the selection range with greater probability than a larger fish, giving overestimation of length per age for the lengths under the L_{100} for the mesh selection (Korsbrekke, this volume). Thus the trawl will over-represent the fast-growing fish in the youngest yearclasses (in the selection range of the codend) simultaneously as it over-represent the slow-growing individuals in the older year-classes.

For fish larger than the selection range in the codend the results here (same estimated growth for trawl and longline-caught fish) suggest that the trawl-catches are not over-represented by slow growing / slow swimming fish compared to the longline-catches. This is because if there were large fish is swimming in front of and avoiding the trawl, they would be individuals with larger length at age and better growth than fish winning the competition to be first to the longline and choosing the baits (Godø *et al.,* 1997). This seems unlikely, since it would be expected that fish large and fit enough to out-swim the trawl would also have an advantage in the longline fishing situation, and the fact that we do not have differences between trawl and longline-catches in calculated growth suggest that there are very few (if any) fast growing and large Greenland halibut actually avoiding the trawl. Clark and Parma (1995) found that calculated growth for Pacific halibut from trawl catches was lower than growth in setline catches. They assume that the fish's vulnerability to trawl is decreasing down to 80 % for fish at 100 cm. As Greenland halibut seldom reaches sizes like that, and our growth calculations are based on the lengths 45-85 cm, this could explain why our data does not support the trend in Clark and Parma's report.

Based on measurements of 45-85 cm fish, the overall growth-rate seems to be larger for male than female irrespective of gear used to sample the Greenland halibut. This is in accordance with Nizovtsev (1991). Bowering (1983) found faster growth of female Greenland halibut over 5 years old.

The longline is a gear that utilises the food searching behaviour of the target fish. The selectivity process in longline is often explained in a two-step behaviour procedure. First we assume that larger fish has wider feeding-grounds due to their high swimming capacity. The probability of a large fish to encounter a gillnet or a longline due to greater searching area should give the same overrepresentation of large fish in both gears compared to trawl. Since we assume there is a directive response towards the bait after the attractants have been detected (Løkkeborg, submitted; Pawson, 1977) and a competitive situation for the food after it is found (Godø *et al.*, 1997), this will induce larger fish in longline compared to trawl catches. In this comparison we found that gillnet caught larger fish than the longline and trawl, and fish caught in gillnets seems to have had slower growth. In comparison with the longline catches we assume the encounter rate due to swimming capacity to be equal for large fish in the same size group. There is no rigid mechanical selection in longlining as in mesh selection, and the length distribution of catches in longlining will be more variable than catches in gillnets and trawl.

The fact that the female Greenland halibut caught in the gillnets had slower growth and higher $L\infty$ (Tab. 8), can be explained by the selectivity in the gillnets in the following way:

Accepting Baranov's (1948) principle of geometrical similarity, the gillnet will over-sample the most wedge-shaped fish in a given yearclass, thereby over-representing the individuals with large gonads or high degree of stomach-fullness. These variables will be dependent on feeding success and time of the year. Maturity is found to be more dependent on length than age, and it is shown (Alm 1959; Bowering 1976) that with good initial growth-rate the maturity is reached at an earlier age than at slower growth rates. Linear growth will decrease after the first spawning (Nizovtsev 1991), and this will result in lower estimates of growth-rate. It is clear that when gillnets catch a bigger proportion of wedge-shaped fish with big gonads, these fishes are old (Nedreaas et al. 1996), large and probably not first time spawners.

The estimates of selectivity factor in gillnets (5.8) are lower than found by Boje and Hovgård (1995) (6.85) and Olsen and Tjemsland (1963) (6.4 for Atlantic Halibut). This might be because of differences in rigging (hanging ratio) of the nets. Still, there are results of selection factors of 3.3 to 3.7 (calculated from figure) in a report from gillnetting Greenland halibut in the Northwest Atlantic Ocean (Duthie and Marsden, 1995). The selectivity curves and estimated fishing power of the nets will make comparisons between gears possible for the catchability of large Greenland halibut.

The selectivity parameters found for the 135 mm codend (L_{50} = 42.0 cm) corresponds to a selectivity factor of 3.2, which is a bit higher than reported by de Cardenas *et al.* (1995) (2.99

for 1 hour hauls). The selectivity in codend meshes can be influenced by duration of hauls, material in net, light and contrast of netting to background light, amount of fish in bag and rigging of gear besides the actual meshsize of the codend (Isaksen *et al.* 1990; Isaksen and Valdemarsen 1994). Also the physical perimeter of the flatfishes will give wider selection range and less selection than for fish like cod. A metal grid as in the SORT-X (Norwegian) or SORT-V (Russian) system can often give less varying results and sharper selection. Lisovsky *et al.* (1996) has estimated selection in the SORT-V system and found a L_{50} at 33 cm and the selection range 3.6 cm. The selection range in a grid will also increase with increasing bar-distance in accordance with Baranov's (1948) principle of geometrical similarity, and a approximate extrapolation of the results from the 35 mm SORT-V to 55 mm (minimum bar distance in SORT-X in Norwegian trawl-fisheries in the Barents sea) will result in a selection range of ca. 7 cm and a L50 at ca. 55 cm.

We did find only weak depth-dependence of the length-distribution in our data. This is in accordance with Nedreaas *et al.* (1996) who analysed similar data from 1992, even if the gear effect could not be excluded in that analysis due to the different fishing depth of the gears. Other workers have shown an increase of mean length with depth (Godø and Haug, 1989; Gundersen *et al.*, 1994 (longline), Junquera and Zamarro 1994; de Cardenas *et al.*, 1996 (longline)). We have also found a tendency for females to distribute at deeper waters than males, but could not find any significant effect between maturity index and the distribution of fish.

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APPENDIX A.

Table of medium length per age sorted by sex and gear. The number of observations in parentheses shows the number of the length-distributions represented. In this way the data are compensated for the length-stratification.

Age, years		4	5	6	7	8	9	10
	Trawl	36.35 (223)	42.9 (358)	47.3 (250)	51.0 (405)	57.1 (208)	59.5 (44)	63.4 (208)
Female	Longline		43.4 (217)	47.7 (276)	51.8 (626)	57.4 (1360)	60.0 (513)	63.2 (2525)
	Gillnet		43.5 (32)		51.8 (132)	57.5 (407)	58.8 (370)	63.6 (6534)
	Trawl	37.8 (207)	43.5 (939)	47.7 (566)	51.1 (735)	56.4 (208)		61.0 (20)
Male	Longline		44.1 (146)	47.7 (322)	52.1 (1736)	54.8 (514)		61.5 (214)
	Gillnet		44.0 (16)	48.0 (208)	53.3 (599)	56.8 (333)	61.3 (163)	63.7 (378)

Age, years		11	12	13	14	15	16
	Trawl	69.4 (170)	73.9 (66)	77.9 (15)	88.1 (25)	86.3 (3)	
Female	Longline	68.6 (1391)	73.0 (581)	76.3 (192)	82.0 (110)	86.9 (28)	
	Gillnet	68.9 (3825)	72.6 (1339)	77.5 (198)	80.4 (102)	87.5 (34)	
	Trawl	69.7 (7)					
Male	Longline		73.0 (41)				
	Gillnet						