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Population Structure of Greenland Halibut (*Reinhardtius hippoglossoides*) in the Northeast Arctic, 1992–2000

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Abstract

The variation in population structure of Greenland halibut (*Reinhardtius hippoglossoides* Walbaum) in the Northeast Arctic is analysed using data from three different surveys using trawl, longline and gillnet gears, in the slope area of the western Barents Sea in the period 1992–2000. The design of the longline and gillnet survey had limitations in that they were set to simulate the commercial fisheries, but the vessels were forced to cover the most important part of the slope area. Greenland halibut was the dominant species both in numbers and weight and was usually caught in the range of 5–15 years old, but the catch was dominated by ages 6–12. The data showed differences in sex composition and age composition both by area and by depth, and catches from trawl showed the most evident pattern. Greenland halibut caught by gillnet were larger and older than fish caught by trawl and the results from longline were in between. In most of the age groups, males were significantly smaller than females and this general trend was shown for all gears. Males also dominated the younger age groups in all gears and Greenland halibut older than 10 years were virtually all females. Fish from the earliest cohorts in the years investigated were generally smaller than fish from later ones.

Key words: ANOVA, gillnet, Greenland halibut, longline, Northeast Atlantic, trawl

Introduction

Greenland halibut (*Reinhardtius hippoglossoides,* Walbaum) is distributed in the Arctic and boreal waters in the North Atlantic and in the North Pacific (Fedorov, 1971; Godø and Haug, 1989; Bowering and Brodie, 1995; Bowering and Nedreaas, 2000). In the northeastern Atlantic the distribution is more or less continuous along the continental slope from the Faeroe Islands and Shetland to north of Spitsbergen (Whitehead *et al.*, 1986; Godø and Haug, 1989), with the highest concentrations from 500 to 800 m depth between Norway and Bear Island, which is also regarded as the main spawning area (Godø and Haug, 1987; Albert *et al.*, 2001b). Peak spawning occurs in December in the main spawning area, but also in nearby localities during summer (Albert *et al.*, 2001b). Eggs and larvae drift northwards and the juveniles are distributed in the deeper parts of the Barents Sea and to the north and east of Spitsbergen, to the waters around Franz Josef Land (Godø and Haug, 1987; 1989; Albert *et al.*, 2001a).

Before the mid-1960s, the fishery for Greenland halibut in the Northeast Arctic was mainly a coastal longline fishery off the coasts of eastern Finnmark and Vesterålen in Norway. Following the introduction of international trawlers in the fishery in the mid-1960s, the total landings increased from a level of about 3 000 tons to about 80 000 tons in the early-1970s. The total landings decreased steadily to a level of about 20 000 tons during the early-1980s (ICES, MS 2001). The commercial trawl fishery was concentrated in the main distribution area for the adult stock. Based on the regular 0-group survey in the Barents Sea, a drop in the year-class indices were observed during the late-1980s and beginning of the 1990s, and also a historic low spawning stock biomass was detected in the same period (Hylen and Nedreaas, 1995; Smirnov, 1995). There was also a reduction in the commercial catch per unit of effort (CPUE) and this led to strong regulations starting in 1992, including a total fishing ban for Greenland halibut north of 71°30N. South of this limit the regulation rules allowed only a limited longline and gillnet fishery, by vessels smaller than 28 m, to be directed for Greenland halibut. Trawl catches were limited to by-catch only (Bowering and Nedreaas, 2000).

When the catches from the commercial fishery declined after 1992, it became very important to increase the research effort in order to confirm or invalidate the perceived reduction in recruitment and the decrease in spawning stock. To continue the already established time series of commercial trawl CPUE data and to improve biological sampling as a basis for stock assessment, commercial fishing vessels were contracted. The vessels performed commercial-scale fishing, but restricted to certain time periods and areas. The gears used were trawl, longlines and gillnets. In 1994, a scientific bottom trawl survey started in the slope area from 68°N to 80°N.

Based on a stratified trawl survey in the Svalbard area, Godø and Haug (1987) documented that depth distribution of Greenland halibut was size dependent, i.e. higher proportions of large fish were found in deeper strata. The same investigation concluded also that north of 76°N the stock consisted of a relatively higher proportion of small fish. The structure of the catch, i.e. length, age and sex composition changes with different gear. Longline and gillnet catch larger fish than trawl (Nedreaas *et al.*, 1996). The present study therefore used data from all three gear types with the objective to describe how the population structure of the Greenland halibut stock varied between years, areas and gears along the slope area between Norway and Svalbard in the period 1992–2000.

Material and Methods

Surveys and sampling

Data were collected during several surveys between Norway and Svalbard in autumn in the period 1992–2000 (Table 1, Fig. 1). Some of the trawl surveys were designed as a stratified bottom trawl survey with Greenland halibut as target species, but all the longline and gillnet surveys were set up in a way attempting to mimic the commercial Greenland halibut fishery. Commercial fishing vessels were contracted to conduct regular fishing operations, but there were some restrictions in the area where they were able to operate, i.e. between 70°N and 76°N. The scientific bottom trawl survey operated in a wider area, 68°N–80°N, with fixed positions of the hauls in a depth range of 400 to 1 500 m. Due to the expectation of low catches deeper than 1000 m, very few hauls were carried out at these depths. The survey series, with exception of longline and gillnet, have been evaluated and used in the Arctic Fisheries Working Group in ICES as tuning series in the Greenland halibut assessment (ICES, MS 2001). In addition some publications have used parts of the available data from the time series analyzing selectivity, fecundity and distribution of Greenland halibut (i.e. Nedreaas *et al.*, 1996; Huse *et al.*, 1999; Gundersen *et al.*, 1999; Bowering and Nedreaas, 2000).

The trawlers used standard cod bottom trawls (Alfredo 5) with 135 mm mesh width (inside stretched mesh), and a 60 mm inner lining in the codend. The vertical opening of the trawl was about 4 m and the distance between the doors averaged to 170–175 m. The trawls were equipped with rock-hopper gear. The length of the ground gear was approx. 110 m and the lengths of the sweeps were 130–140 m. The warp length under towing was 2.5–2.8 times the bottom depth depending on current and bottom conditions. Towing speed was 4 knots and the towing duration in the "commercial" experiments were normally 4–5 hours. Towing duration in the bottom trawl survey was usually one hour.

The longliners used in most cases Mustad EZ-baiter hooks no. 12 with hook spacing of 1.4 m. During the time period each setting varied between 3 000 and 6 000 hooks. The hooks were baited mechanically (Mustad Autoline System) mostly with sequences of squid and mackerel, but also other bait types were used occasionally. The soak time varied between 6 and 24 hours. Each setting was treated as one separate station.

The gillnets were made of monofilament with a varying mesh size from 70 to 110 mm (bar-length, i.e. 140–220 mm stretched mesh), but most of the settings were made with 110 mm bar-length, which is most often used in the commercial fishery. The proportion of different mesh sizes was constant between years. Each setting consisted of 30 nets each 30 m long, tied end to end in a fleet. The height of the nets was 20 meshes, and the hanging ratio 60%. The fleets were bottom-set, anchored to the bottom at one end only, letting the other end drift freely with the current. The soak time varied from 50 to 140 hours and each fleet was treated as one separate station.

The procedure for collecting individual samples was unfortunately not consistent throughout the time-series, but individual samples, when collected, were stratified both geographically and by depth. The inconsistency in sampling caused problems getting enough samples from different gears in some of the years, but for most of the years weight and numbers of Greenland halibut for each separate station were recorded. Total length-frequency distributions (to the nearest cm below) were obtained, either by measur-

TABLE 1. List of surveys from which data for this paper were collected. Number of samples by gear, N denotes number of stations, N_L is number of stations with length samples and N_A is number of stations with age sampling.

Year	Gear type	Time period	N	N_L	N_A
1992	Trawl	6.10–21.10	108	107	41
	Longline	5.10–21.10	85	84	28
	Gillnet	9.10–21.10	120	120	30
1993	Trawl	10.10–23.10	56	53	19
	Longline	7.10–16.10	41	40	15
	Gillnet	7.10–20.10	235	234	52
1994	Trawl	13.9–30.9	34	34	16
	Longline	27.9–8.10	71	49	8
	Gillnet	27.9–11.10	130	126	13
1995	Trawl	16.8–7.9	38	38	11
	Longline	22.9–3.10	58	41	4
	Gillnet	22.9–5.10	88	69	8
1996	Trawl	2.8–23.8	38	38	7
	Longline	17.9–27.9	43	26	3
	Gillnet	19.9–26.9	46	43	9
1997	Trawl	2.8–21.8	47	47	7
	Longline	17.9–29.9	67	34	0
	Gillnet	21.9–30.9	42	29	0
1998	Trawl	2.8–25.8	55	55	6
	Longline	21.9–1.10	58	27	3
	Gillnet	19.9–29.9	26	25	2
1999	Trawl	2.8–21.8	46	46	4
	Longline	21.9–5.10	64	27	8
	Gillnet	23.9–1.10	32	28	11
2000	Trawl	31.7–20.8	53	53	5
	Longline	21.9–3.10	42	19	6
	Gillnet	19.9–28.9	33	31	16[1]

[1] Data not available for analysis.

ing the entire catch or from a random subsample. In some stations individual length and weight were recorded, stratified to 5 individuals of each sex in 5 cm length groups. From these fish the otoliths were collected for age determination at a later stage in laboratory. The procedure used for age determination is described in Bowering and Nedreaas (2001). In addition, the individually sampled fish were classified to maturity stage using a general description for macroscopic determination of maturity stage (Table 2). Only stages 2–4 were used in the analyses as mature fish.

Analyses

Different population characteristics and structures were studied using three different models. The first model used age as the dependent variable and related age in catch to year, sex, area and depth using a traditional analysis of variance (ANOVA).

$$AGE = YEAR + SEX + AREA + DEPTH \quad (1)$$

This model is predicting the mean age in a catch by sex given year area and depth interval. In addition

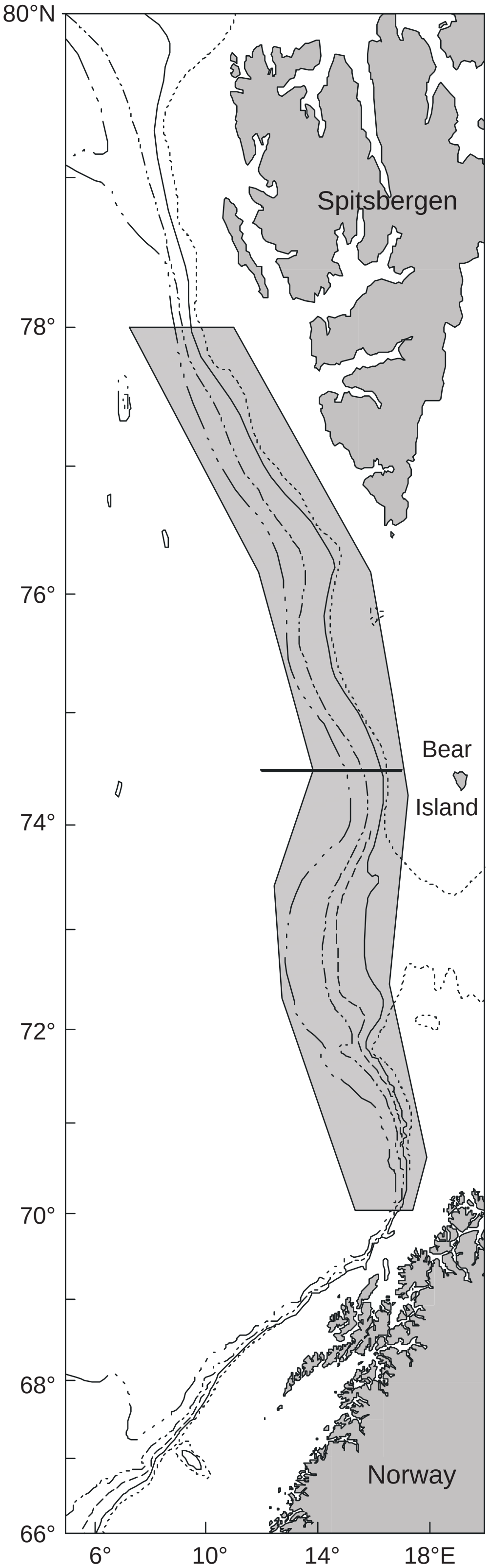

Fig. 1. Experimental area (shaded), with depth contours 400, 500, 700, 1 000 and 1 500 m drawn. The horizontal line is the geographic division used in the paper.

to the intercept, up to nine-year effect parameters were estimated (1992–2000). Due to the lack of unique solutions, the last year parameter was not really estimated, but set to zero. The sex and area effect had two levels each, while the depth effect had two or three levels. This was because age was sampled in three different depth intervals (400–500, 500–600 and 600–700 m) in the longline survey, but only in two intervals (400–500 and 500–600 m) in the gill-net survey and (500–600 and 600–700 m) in the trawl survey.

The second model had length as the dependent variable explained by age, cohort, sex and maturity (both interacting with age) and depth.

$$LENGTH = AGE + COHORT + AGE * SEX + AGE * MATURITY + DEPTH \quad (2)$$

The importance of sex in the two first models led us to look at a third model which used age, depth and area as explanatory variables for the proportion females. The proportion females $P_{females}$ was modelled using a logistic regression:

$$LOGIT(P_{females}) = AGE + AREA + DEPTH \quad (3)$$

One age parameter for each age group (ages 5–12), two areas and two or three depth intervals. The model was checked for over-dispersion and if the model showed a significant lack of fit the covariance matrix was rescaled. Note that the parameter estimates are not changed by this method. However, their standard errors are adjusted affecting their significance tests.

Results

Comparison of mean age in the catches revealed a relatively clear pattern, i.e. the mean age of Greenland halibut caught in different gears were not the same. Gillnet caught the oldest fish and trawl the youngest. Fish caught with longline had a mean age between gillnet and trawl (Fig. 2). The model predicting fish age exposed some differences between gears, but only catches from trawl revealed significant differences by all effects investigated (i.e. year, sex, area and depth; Table 3). Longline and gillnet showed a significant difference in mean age only by sex, year and area, and sex and year, respectively.

The length distributions of Greenland halibut in the catches from the different gear types showed some variability throughout the period, but they were relatively stable within gillnet and longline surveys. In

TABLE 2. Definition of the macroscopic determination of maturity stages of Greenland halibut used at sea.

Stage	Description
Blank	**Undecided/not checked**
1	**Immature** Gonads are small. No visible eggs or milt.
2	**Maturing** Gonads are larger in volume. Eggs or milt are visible but not running.
3	**Spawning** Running gonads. Light pressure on the abdomen will release eggs or milt.
4	**Spent/Resting** Gonads small, loose and/or bloody. Regeneration starting, gonads somewhat larger and fuller than stage 1. No visible eggs or milt.
5	**Uncertain** Use only when difficult to distinguish stages 1 and 4.

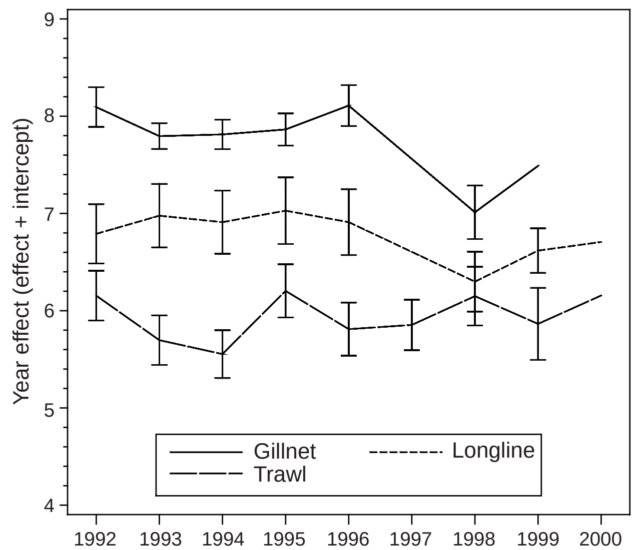

Fig. 2. Trends in mean age in catches of Greenland halibut in the period 1992–2000.

TABLE 3. Type III analyses of effects for the models predicting fish age.

Model	R^2	Effect	*df*	Type III SS	MS	F Value	*P*
Longline	0.5143	Year	7	6.4098	0.916	3.39	0.0013
		Sex	1	608.90	608.9	2256.6	<0.0001
		Area	1	9.0322	9.032	33.47	<0.0001
		Depth	2	0.7078	0.354	1.31	0.2695
Gillnet	0.3953	Year	6	59.831	9.972	17.07	<0.0001
		Sex	1	660.08	660.1	1130.1	<0.0001
		Area	1	0.0345	0.035	0.06	0.8081
		Depth	1	0.6120	0.612	1.05	0.3062
Trawl	0.2076	Year	8	1668.8	208.6	11.63	<0.0001
		Sex	1	8467.0	8467	471.85	<0.0001
		Area	1	718.25	718.2	40.03	<0.0001
		Depth	1	2506.8	2506	139.70	<0.0001

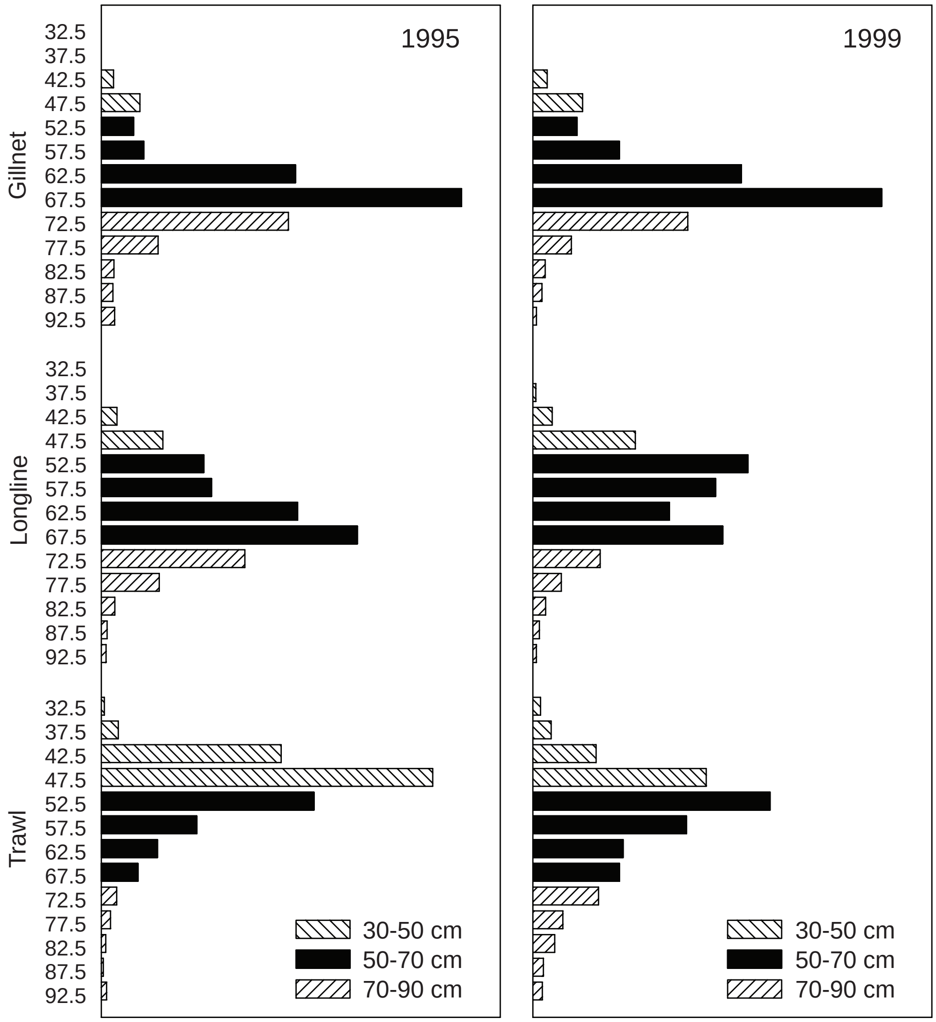

Fig. 3. Length distributions from catches of Greenland halibut in gillnet, longline and trawl in 1995 and 1999. All distributions are scaled to a fixed catch to enable comparison of size composition.

the trawl catches the length increased during the period, with relatively small changes from year to year. The length distributions from the years 1995 and 1999 are shown since these years are the most extreme years (Fig. 3). The modal lengths of fish caught in gillnet and longline was generally 15–20 cm larger than fish caught in trawl. The estimated age parameters in the length model (length at age) showed that the different gears caught fish of the same size at age (Fig. 4). Fish caught in gillnet showed slightly lower R^2, with no clear reason. No difference in the mean length by depth was found in catches from gillnet and longline, but in trawl catches the depth effect was significant (Table 4).

The length of Greenland halibut showed an increasing trend from the 1980 year-class to the year-classes in the beginning of 1990s, i.e. fish from the earliest cohorts in the years investigated were generally smaller than fish from later ones (Fig. 5). Even if there were few observations for the first and the latest years, the cohort effect was significant in all gears (Table 4).

In most age groups males were significantly smaller than females (Fig. 6, Table 4). The trend increased with age (i.e. the difference between the sexes became larger with older ages), but in the oldest age groups the numbers of observations were few and this

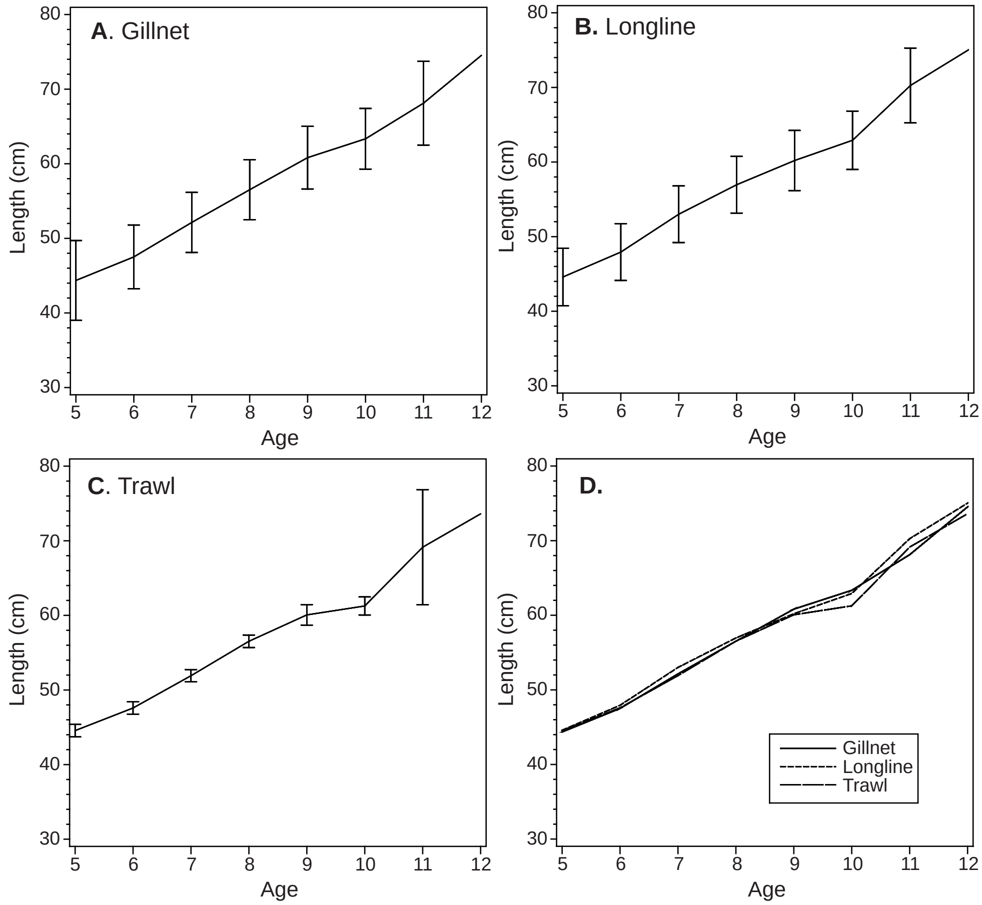

Fig. 4. Estimated age parameters (age effect) with error bars (±2SD) in catches of Greenland halibut from gillnet, longline and trawl. Parameter estimates for all models shown in D).

could be the cause for an unexpected change in this pattern. For these age groups the size of males and females were not different or the males were larger, but in these observations females were highly dominant. The general trend was shown for all gears.

Immature Greenland halibut were smaller than the mature with exception of the youngest age group (Fig. 7), and the difference was significant in catches from all gears (Table 4).

Generally males dominated the younger age groups in all gears and Greenland halibut older than 10 years were virtually all females (Fig. 8, Table 5). The youngest age group from gillnet (5 year old) was different from the others, showing higher proportion of females in the different strata. In catches from longline, the area and depth difference was not significant, i.e. corresponding proportions of females were found both north and south of 74°30'N and in all depth strata. The trawl caught a larger proportion of females in the north, and catches from the depth stratum between 500 and 600 m also had higher a proportion of females both in the north and south.

Discussion

The analyses of the three survey series from the slope area between Norway and Spitsbergen expressed a more homogenous pattern in the investigated population parameters than expected, but still there were some differences. Earlier work in the same area has demonstrated that there are patterns in size, and thus age, distribution along the slope. Polish investigations stated in 1973 that Greenland halibut west of Spitsbergen were smaller than individuals further south (Kosior, 1975). This was also observed on Norwegian groundfish surveys in early 1980s (Randa and Smestad, MS 1982; MS 1983; Godø *et al.*, MS 1984), but all these surveys compared fish from a wider

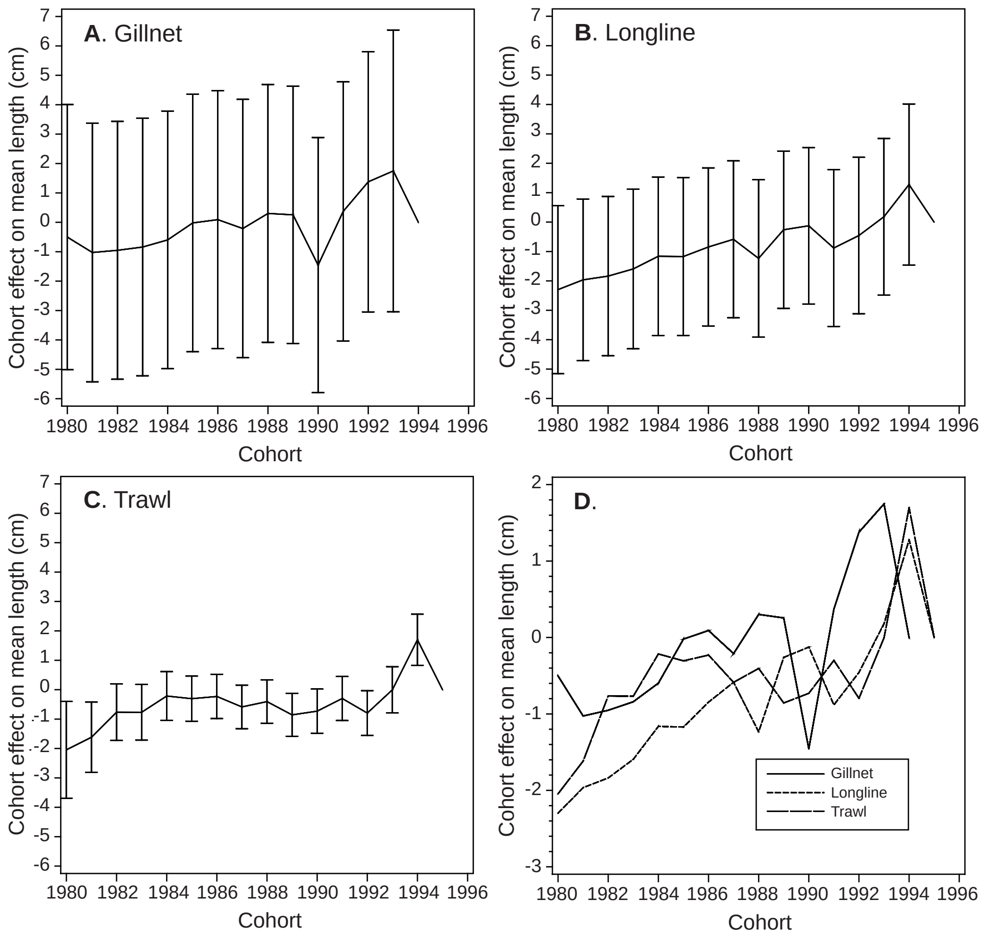

Fig. 5. Estimated cohort parameters (cohort effect) with error bars (±2SD) in the length models. Parameter estimates for all models shown in D).

survey area than our investigation. In the beginning of the 1990s, the limited fishery for Greenland halibut was only allowed south of 71°30'N and the commercial fisheries organizations expressed concern about the stock status in the whole distributional area. The only information on the Greenland halibut stock further north was from the scientific surveys conducted in that area. From 1992, i.e. after implementation of the strong regulations of the Greenland halibut fishery, it was decided to prolong the trawl CPUE-series with an experimental trawl series, and in addition, to meet the request from the fisheries organizations it was decided to start an experimental fishery with longline and gillnet in the area from 71°N to 76°N. These experimental surveys were highly motivated by the fishermen themselves and they were carried out like a "fisherman's choice" on where to put their effort. Hence, there have been changes in area and depth coverage throughout the time series causing problems with the consistency and the sampling regime of these data series. Most effort was carried out in clusters north and south of a natural boundary around 74°30'N, covering an area which is known as the main area for the adult (mature) stock (Godø and Haug, 1987; 1989; Albert *et al.*, 2001b). The Greenland halibut trawl survey has been a scientific fixed-station survey covering a wider area and also a wider depth gradient, i.e. a more homogenous coverage along the whole slope area during the whole time period investigated. The result of this has probably been a better coverage of the adult Greenland halibut stock in the area. The results also reflect this since the analyses showed the highest variability in the population parameters investigated in the catches from this data series.

The selection properties of the different gear types were quite different from each other, especially for

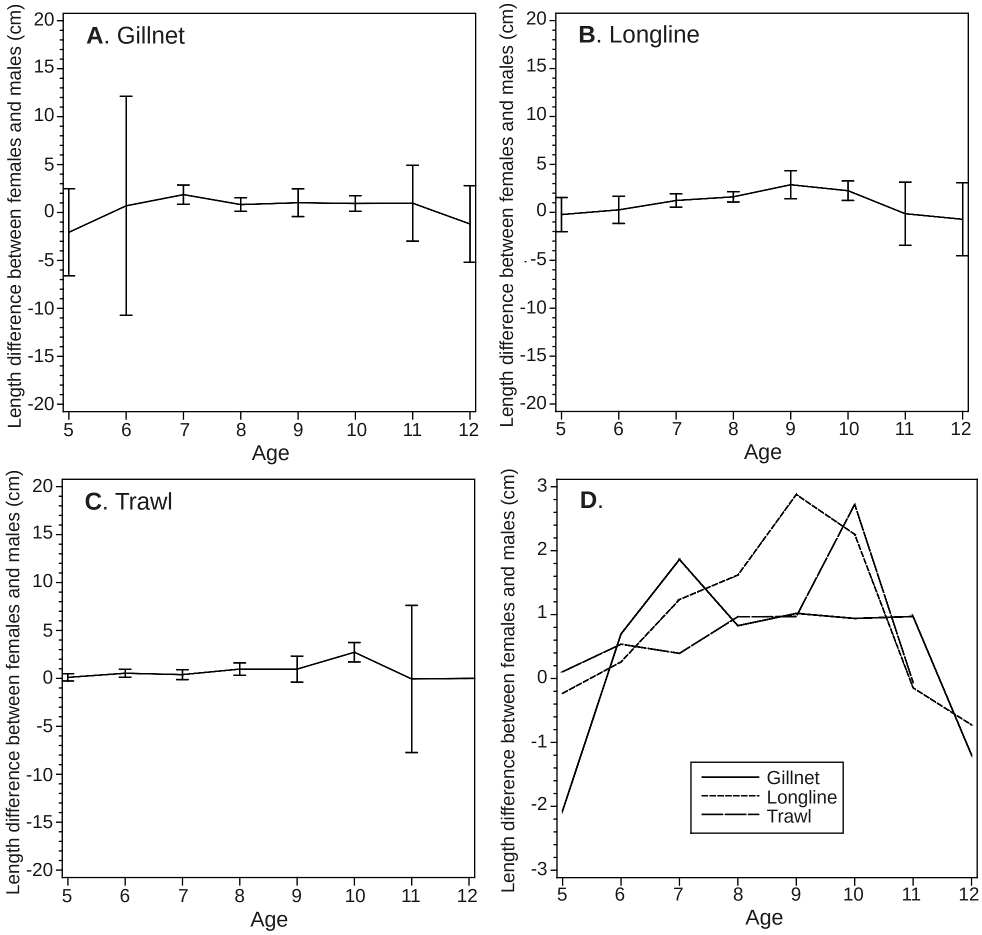

Fig. 6. Estimated interaction between sex and age, with error bars (±2SD). The lines represent the difference in length between females and males at different age groups. Parameter estimates for all models shown in D).

TABLE 4. Type III analyses of effects for the models predicting fish length.

Model	R^2	Effect	*df*	Type III SS	MS	*F* Value	*P*
Longline	0.9246	Cohort	15	66.836	4.456	6.05	<0.0001
		Age	7	2339.8	334.2	453.85	<0.0001
		Age × Sex	8	61.735	7.717	10.48	<0.0001
		Age × Maturity	8	57.644	7.206	9.78	<0.0001
		Depth	2	2.8472	1.424	1.93	0.1449
Gillnet	0.8767	Cohort	14	261.78	18.70	8.77	<0.0001
		Age	7	2187.2	312.5	146.55	<0.0001
		Age × Sex	8	59.993	7.499	3.52	0.0005
		Age × Maturity	8	135.21	16.90	7.93	<0.0001
		Depth	1	0.5074	0.507	0.24	0.6257
Trawl	0.9299	Cohort	15	4135.6	275.7	9.44	<0.0001
		Age	7	288092	41156	1409.68	<0.0001
		Age × Sex	7	1433.2	204.7	7.01	<0.0001
		Age × Maturity	8	3205.9	400.7	13.73	<0.0001
		Depth	1	977.84	977.8	33.49	<0.0001

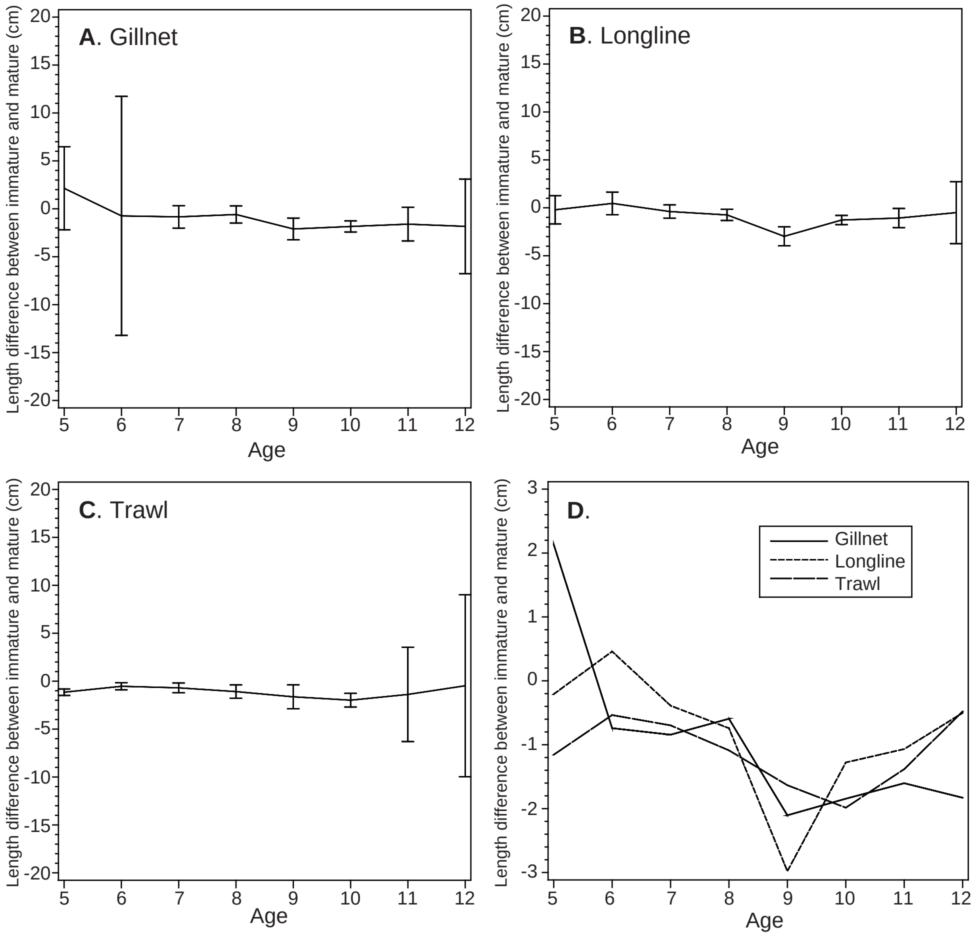

Fig. 7. Estimated interaction between maturity and age, with error bars (±2SD). The lines represent the difference in length between immature and mature fish at different age groups. Parameter estimates for all models shown in D).

the trawl. Trawl catches had a wider size spectrum than catches from gillnets and longlines and also caught more fish of smaller sizes. The differences between gillnet and trawl catches may be explained by the mesh selection properties of the gillnet (Nedreaas *et al.*, 1996) and that the trawl is an active gear catching more or less all in its path. The trawls may better reflect the true size composition in the stock, but the catch is also affected by avoidance reactions to the approaching gear, which may bias the length frequency composition in these catches (Ona and Godø, 1990). This factor is probably most important for the largest individuals causing the trawl catches to be dominated by relatively smaller fish. The selection properties of longlines are dependent on several factors including feeding behavior or feeding motivation, and the hook's ability to catch different groups of fish. Another important factor in longline catches is the competition between species and size groups of species and their different swimming range and speed. It is probable that the largest and fastest fish are approaching the baited hooks first, i.e. hooking the larger ones in the area, which again increases the mean size of fish caught on longlines.

Some differences were found in all gears used, and, as mentioned previously, trawl data showed that there were significant area, depth, length, age and sex effects. Greenland halibut caught in trawls showed that there were significant difference in length and age by depth, i.e. suggesting size segregation of the individuals by depth. The largest fish was found in intermediate depths below 550 m depth, but smaller fish appeared at greater depths. This pattern was not confirmed by gillnets and the reason for this is that gillnets were set in a more narrow depth interval, which did not reveal the difference in size by depth. Even if the difference was not significant for longlines,

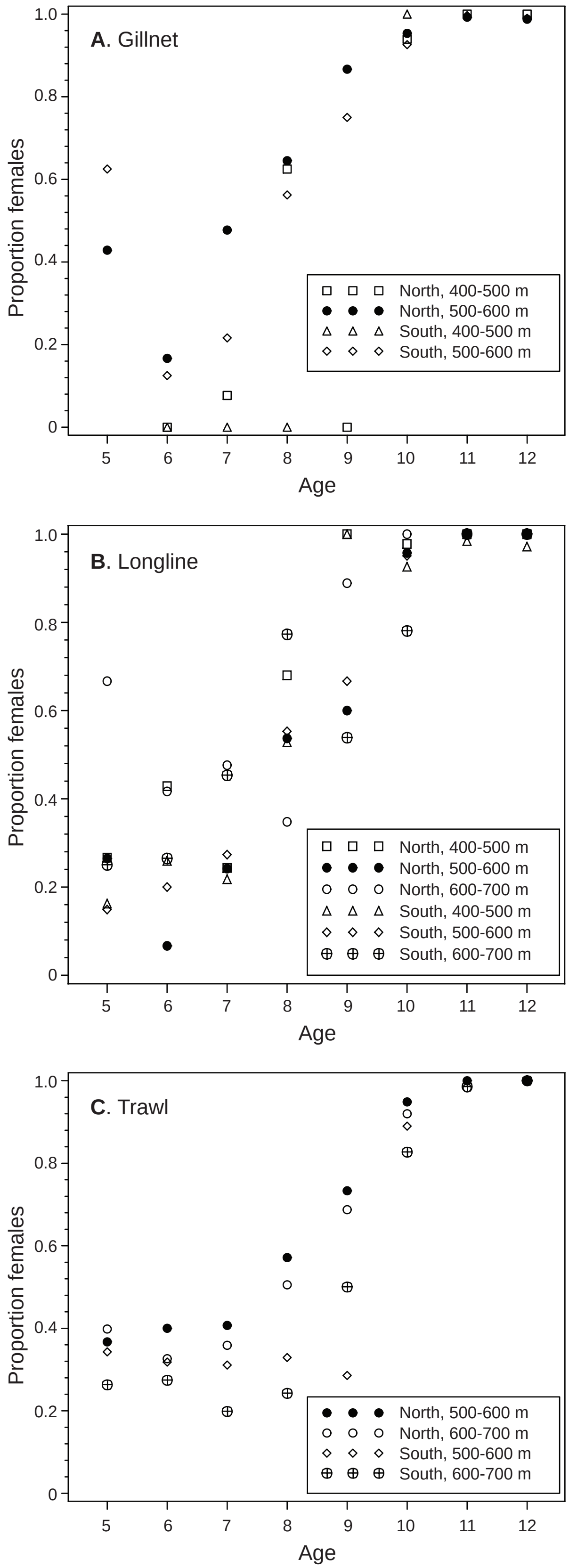

Fig. 8. Proportions of females-at-age in catches of Greenland halibut from **A**) gillnet, **B**) longline and **C**) trawl.

the data showed that the mean length changed during the time period, and these changes could be due to changes in mean depth of the settings (Høines and Korsbrekke, MS 2001). Bowering and Nedreaas (2000) stated that mean individual size in trawl catches increased below 500 m, peaked and then declined, which our findings confirms. The largest fish were found in the southern part of the area and, in the corresponding age groups, the proportion of females was high. This is in accordance with earlier work in this area, because the most important area for mature fish is found between Norway and Bear Island (Albert *et al.*, 2001b), i.e. the southern part of our survey area. Therefore, we would expect the largest fish to congregate in this area. In the younger age groups males dominated, but in these age groups the highest proportion of females was found in the northern area. Catches from gillnets showed the same pattern, but this pattern was not so evident in the trawls. Dominance of females in the largest and oldest part of the stock is due to higher natural mortality for males (Kovtsova and Nizovtsev, MS 1985; de Cardenas, MS 1996).

The analyses also showed that immature fish were smaller than mature fish in all gears and age groups. One probable explanation for the fact that immature Greenland halibut are smaller than mature individuals is that only those that grow fast and reach a given size are maturing. Mature individuals may generally have a higher growth rate than fish that do not ripen, thus the mature fish in each age group are always the larger ones. The survey area only covers the larger individuals from the immature portion of the Greenland halibut population, since the juveniles are distributed further north and east (Smirnov, 1995; Albert and Høines, 2003; Albert *et al.*, 2001a). When growing to the adulthood, the larger individuals migrate to the slope area between Norway and Spitsbergen (Godø and Haug, 1987; Albert *et al.*, 2001a), and this migration to the spawning area may be a continual process starting long before the fish is actually mature. Consequently individuals that are immature reach the spawning area and are mixed together with the mature part of the stock. Another probable cause is that Greenland halibut are not necessarily ripe and spawn every year (Fedorov, 1971), which is causing problems in the determination of maturity stage, i.e. misclassifying mature fish as immature. Generally the largest number of misclassification of smaller fish using macroscopic determination of maturity is between early maturing and resting stages (Morgan *et al.*, MS 2001). Our data were too sparse to go further into these questions.

TABLE 5. Type III analysis of effects for the models predicting female proportion.

Model	R^2	Effect	*df*	Wald c^2	*P*
Longline[1]	0.2335	Age	7	234.89	<0.0001
		Depth	2	2.88	0.2375
		Area	1	0.34	0.5581
Gillnet	0.3617	Age	7	389.48	<0.0001
		Depth	1	5.65	0.0175
		Area	1	10.17	0.0014
Trawl	0.3502	Age	7	439.86	<0.0001
		Depth	1	10.05	0.0015
		Area	1	46.62	<0.0001

[1] Due to significant over-dispersion the covariance matrix was rescaled (multiplied with 2.02616).

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