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Spawning of the Barents Sea/Norwegian Sea Greenland halibut (*Reinhardtius hippoglossoides*)

By O.T. Albert[A1], E.M. Nilssen[B], A.Stene[C], A.C.Gundersen[D], K.H.Nedreaas[E]

A: Norwegian Institute of Fisheries and Aquaculture, 9005 Tromsø, Norway
B: Norwegian College of Fishery Science, University of Tromsø, N-9037, Tromsø, Norway
C: Høyskolen i Ålesund, P.O. Box 5104, N-6021, Ålesund, Norway
D: Møre Research, Section of Fisheries, P.O. Box 5075, N-6021, Ålesund, Norway
E: Institute of Marine Research, P.O. Box 1870, Nordnes, N-5024, Bergen, Norway

Abstract

Based on eight trawl surveys of the spawning area along the continental slope between North-Norway and Svalbard, the paper gives a preliminary description of the spawning time and spawning area of Greenland halibut (*Reinhardtius hippoglossoides* Walbaum). Spawning started in November, peaked in December and ended in late January. Mature fish arrived to the spawning area in early autumn and left during the first months of the year. Spawning occurred between 500 and 800 m in waters of approx. 2°C. All length groups spawned within the same period, though running males were recorded within a wider range, both bathymetrical, latitudinal and temporal. Different maturity classes were identified with frequency analyses of the Gonadosomatic Index. First-time spawners may possibly be identified more than one year before spawning. Eggs were found pelagically in December and January, probably at depth below 400m. This is the first time ever that eggs of this stock were found in the sea. Although the spawning season in this area was well defined, other observations showed that spawning also occurred half a year later in nearby areas, thus underlining the dichotomy in the literature as to the spawning time of this stock.

[1] Email: OLETA@FISKFORSK.NORUT.NO; Fax: +47 77 62 91 00

1. Introduction

The Barents Sea/Norwegian Sea Greenland halibut (*Reinhardtius hippoglossoides* Walbaum) is an arcto-boreal flatfish (Fedorov, 1971) that utilise partly separated spawning, nursery and feeding areas (Godø & Haug, 1989). The spawning and drift phase is not fully understood, but the overall pattern seems to be as follows: Spawning occurs along the continental slope from Bear Island and southwards along the North Norwegian coast (Figure 1); eggs and larvae drift towards nursery grounds which are at least partly found in Svalbard waters; larger juveniles and adults spread out in large parts of the Barents Sea from where the mature fish undertake spawning migrations to the slope (Godø & Haug, 1989; Albert *et al.*, 1997).

The distribution of spawning activity in space and time is uncertain. There are indications that the latitudinal distribution of spawners may vary inter-annually (Kovtsova *et al.*, 1987). It is also possible that the spawning season may vary between years. Milinsky (1944) and Hognestad (1969) reported that spawning occurred in the period April-July, while Fedorov (1971) indicated spawning mainly in October-January, and possibly more or less year round.

There are indications that recruitment of juvenile Greenland halibut to different areas are related to oceanographic features in the spawning and drift phase (Godø & Haug, 1989; Albert et al., 1997). In order to understand and realistically model the spawning-recruitment relationship it is important to know the spatial and temporal dimensions and variability.

This paper is one in a series from a comprehensive study of the spawning and recruitment processes of Greenland halibut in the Barents Sea and the Eastern Norwegian Sea. The objective of this paper is to give a preliminary description of the spawning activity throughout the spawning season, with emphasis on when and where the spawning occurs; when the mature fish arrive and leave the area; and differences between sexes and size groups.

2. Material and methods

Sampling at sea

Greenland halibut was sampled on eight research surveys of the spawning area along the Norwegian continental slope between Vesterålen and Bear Island (Figure 1). Two cruises were made during the autumn/winter 1996/97 and six in 1997/98. Sampling was made by means of bottom trawling using the 64m long stern trawler R/V "Jan Mayen". Three slightly different trawls had to be used in order to get data from all depths and from cruises other than those designed for this project. They were all of the same general type and size and they were used with the same rigging. The characteristics of each trawl are listed in Table 1 together with the equipment and procedures used.

A systematic design was applied and trawls were allocated to each of six depth-transects across the slope. All trawls within a transect were made along the slope (i.e. at constant depth) and generally at approximately the same latitude. In the southernmost transects, trawls were more dispersed latitudinally due to scarcity of suitable trawling bottom. Within each transect, individual trawls were initially allocated to the following depths: 450, 500, 550, 600, 650, 700, 750, 800, 900, 1000 and 1100 m. However on most cruises the sampling plan had to be considerably reduced due to severe whether conditions. Number and depth of successful trawls on the different cruises and transects are listed in Table 2. In order to see the effect of changing trawl type consecutive hauls were made with each trawl type at the same locality.

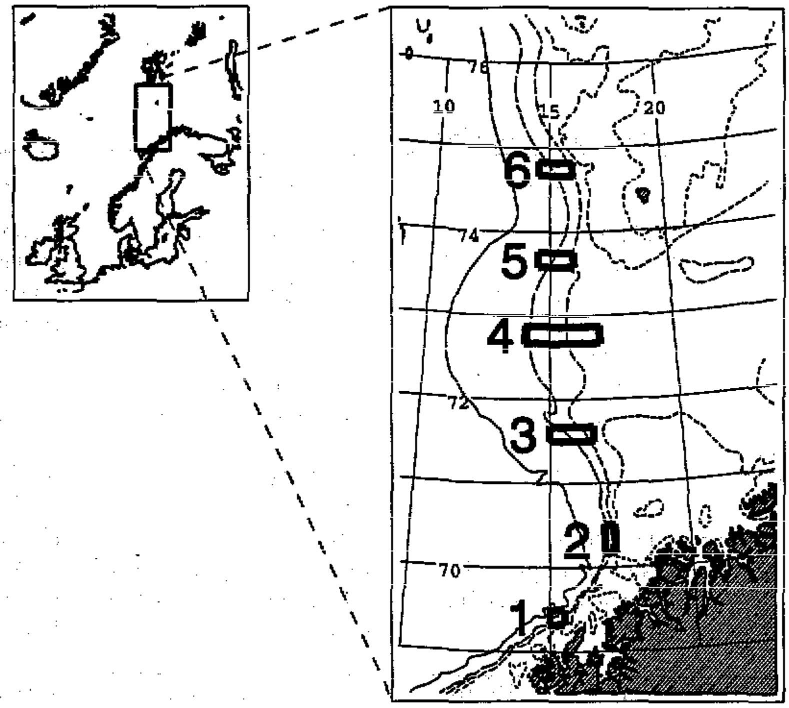

Figure 1. Bathymetric map of the survey area from north of Bear Island (the southernmost island in the Svalbard archipelago) to the coast of North-Norway. Isobaths are indicated for 100, 300, 500, 1000, and 2000 m depth. Trawls were allocated to areas 1-6. (Scale 1:10 000 000)

From each trawl catch the catch of individual species in terms of weight and numbers were recorded. Individual data were recorded from all Greenland halibut in the catch. Total length was measured to nearest 1 cm below, and round weight to nearest 1 g. Maturity status was recorded by three measures: Maturity index (MI), egg size, and gonad weight. The index was a standard four-level macroscopic maturation index for demersal fish (Immatures, maturing, running, and spent) (Table 3). It was usually rather straightforward to use, although there were often doubt for gonads in the transition phase between two stages, and for immatures versus spent. These problems were greatest on the first cruise (Oct. 96) and in December 1997, when less experienced staff members were used. Egg size was recorded as an index with three levels, corresponding to <1mm, 1-2mm, and >2mm respectively. Allocation of fish to each level was based on a rough estimation by eye. Gonad weight was recorded to nearest 1 g. On some cruises (e.g. Nov. 97) the weight was unstable for small samples (1-3 g), and often 1g was recorded to represent those very small gonads. This was probably an underestimation and resulted in a broader range (smaller min. value) of GSI values for immatures.

Near bottom temperature was recorded during each haul using SCANMAR trawl sensor. This sensor was not used at the October 1996 cruise. On several occasions the trawl sensor was calibrated against a CTD recorder.

Table 1. Trawl equipments and procedures used in the project.

Trawl	A	B	C
Name	Cod trawl	Deep-water shrimp trawl	Shrimp trawl
Type	Campelen 464	Campelen 1800	Campelen 1800
Area/period of application	Standard trawl above 800 m depth	Below 800 m depth	Cruises other than those designed for this project
Mesh size: Wings	155 mm	80 mm	80 mm
Belly and bag	155 mm	60 and 40 mm	60 and 40 mm
Cod-end	140 mm	20 mm (4 m length)	20 mm (4 m length)
Number (and bouyancy) of floats: Headline	75 (2770g)	60 (3875g)	90 (2770g)
Fishing line	none	none	40 (2770g)
Each side of bag	10 (2770g)	none	15 (2770g)
Gear	Rockhopper ground gear [1]	Rockhopper ground gear [1]	Rockhopper ground gear [1]
Doors	Steinshamn doors 2050 kg	Steinshamn doors 2050 kg	Steinshamn doors 2050 kg
Sweep length	40 m	40 m	40 m
Vertical opening[2]	Mean: 6.3 m (SE: 0.08)	Mean: 4.8 m (SE: 0.15)	Mean: 4.7 m (SE: 0.07)
Distance between doors[2]	Mean: 52 m (SE: 0.6)	Mean: 45 m (SE: 0.7)	Mean: 46 m (SE: 0.3)
Duration of trawls	25 min	25 min	20 min
Towing speed	4.1 knots (2.1 m s^{-1})	3.3 knots (1.7 m s^{-1})	3.6 knots (1.9 m s^{-1})

[1] Engås and Godø, 1989.
[2] Measured with SCANMAR wireless gear control system.

Table 2. Time of cruise and distribution of hawls according to cruise, area, depth and trawl type A, B and C (See Table 1). ab (ac): Consecutive hauls with trawl types A and B (A and C) respectively.

	CRUISE																												
	Oct 96			Jan 97				Oct 97				Nov 97					Dec 97		Jan 98					Feb 98				May 98	
From:	17/10			15/1				13/10				4/11					18/12		25/1					25/2				2/5	
To:	19/10			19/4				17/10				10/11					19/12		29/1					27/2				3/5	
Appr.	Area			Area				Area				Area					Area		Area					Area				Area	
depth	2	3	4	1	2	3	4	2	3	4	5	2	3	4	5	6	4	5	2	3	4	5	6	2	3	4	5	5	6
400							ac																						
450			C		A	A	ac	A	A	A	A	A		A	A				A	A	A	A	A			A		C	
500	C	C		A	A	A		A								A													
550	C	C	C	A	A	A	ac		A	A	A	A		A	A							A							
600	C	C	C	A	A	A	ac	A	A	A	A	A		A	A	A	A	A	A	A	A	A	A		A	A		C	C
650	C	C	C		A	A	ac	A	A	A	A	A		A	A		A	A			A	A							
700	C	C	C		A	A	ac	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A		A	A		C	C
750	C	C	C		A	A	ac	A	A	A	A	A	A	A	A			A											
800	C	C	C	A	A	A	ac	ab	ab	ab	A	ab	A	ab	ab	A			A	A	A	A	A		A	A		C	C
900								B	B			B	B	B	B							B		B	B	B	B		
1000								B				B	B	B	B														
1100													B		B														

Eggs of Greenland halibut were searched for by plankton nets. Initially a small standard plankton net (type WP-II, 0.8 m diameter, 0.5 mm meshes) was hauled vertically. Later a MIK plankton trawl was applied (Methot, 1986; Munk, 1993). This trawl consists of a net (1.5 mm mesh-size) attached to a 2 m wide ring and equipped with a wireless SCANMAR depth sensor. The speed of the ship during the haul was 1.5 knots. Two types of hauls were applied: Diagonal and horizontal. For diagonal hauls the wire was paid out fast (one hour down to 800 m depth), then retrieved slowly to the surface (two hours from 800 m depth). For horizontal hauls both descending and ascending were quick, while at the desired depth the MIK was towed at 1.5 knot for 30 min.

Table 3. Definition of the maturity index (MI) used on board.

Maturity index	(MI)	level name	Description
MALES	1	Immatures	very small testes
	2	Maturing	larger testes, not running
	3	Running	sperm released by a light press on the abdomen
	4	Spent	smal, slack gonads
FEMALES	1	Immatures	very small ovaries, eggs not visible by eye
	2	Maturing	larger ovaries, eggs visible
	3	Running	large transparent eggs that are released by a light press on the abdomen
	4	Spent	ovaries are slack and hollow, often redish and with residual eggs

Table 4. Definition of a modified maturity index (MMI) for females

Modified maturity index (MMI)	level name	Maturity index (MI)	Egg-size if measured	Min. logGSI	Max. log GSI
1	Mode 1: Immatures	1			0.5
2	Mode 2: Next years spawners	2-4	1-2	-0.5	0.5
3	Mode 3: Spent	2-4		0.5	1.5
4	Mode 4: This years spawners	2-3	2-3	1.5	

Analyses

Before further analyses, catch rates were standardised to number of fish per one nautical mile towing distance. A gonadosomatic index (GSI) was calculated as: $GSI = 100 \cdot W_G / W_R$, where W_G is weight of the gonads and W_R is the round weight of the fish.

Frequency distributions of log-transformed GSI's for females were analysed by fitting normal components. This was made by using the software MIX 3.0 (Ichthus Data Systems, Ontario, Canada, January 1990) based on the work of MacDonald and Pitcher (1979). Two types of fitting were used: With and without subsampling data. For each log-GSI interval, the subsample data were number of females in each level of a modified maturity index (MMI). Table 4 shows how the four levels were defined on the basis of maturity index (MI), egg size, and modal groups in the log-GSI frequency histograms (Figures 3-5). When subsample data were used, no constrictions were set for the parameters being estimated (i.e. proportion, mean and standard deviation of each component). Without subsample data, means and standard deviations were fixed for three of the four components.

Such estimation of maturity groups by separation of normal components is only feasable in periods when individuals in different stages of the maturation cycle are separated along the GSI axis. Unlike length frequencies, some modes in log-GSI distributions (e.g. the one representing immatures) are expected to pass through other modes (e.g. that representing spent fish) during development. This means that fitting of normal components to such data must be based on prior interpretation of maturity for the whole range of log-GSI values.

3. Results and discussion

Differences between trawl types

During trawling, the configuration of the cod trawl differed from the two shrimp trawls. Both vertical opening and distance between the doors were larger for the cod trawl (Table 1), resulting in a 48% larger trawl opening. Pairwise comparisons of the consecutive hauls (Table 2) showed that differences in catch rates were generally small and not significant. When the test was made for each 10 cm length interval, the difference was significant ($p<0.05$) only for 40-49 cm fish. For fish less than 50 cm, mean catch rates were lower in the cod trawl. For larger fish there were no differences between the trawl types. Thus larger trawl opening did not increase catch rates of adult Greenland halibut. Since this paper focus on mature fish, no corrections were made for differences in trawl type.

Hydrography

The hydrography of the slope area is characterised by warm Atlantic water overlaying cold Norwegian Sea deep water. Between these is a transition zone where the two main watermasses mixes. The depth and bathymetric range of this transition zone may vary both with latitude and time (Helland-Hansen and Nansen, 1909). Within the time period and area studied, the overall pattern was that relatively high near-bottom temperatures (2-4°C) were found down to 700m, whereas below-zero temperatures were found mainly deeper than 850m (Figure 2a). This main bathymetric trend was also seen within each survey and area (Figure 2b). Within each depth range in Figure 2b, the temperature decreased with increasing latitude. This latitudinal effect increased during the time period studied due to a marked fall in temperature in area 4 at latitude 73°30'. In the southern areas temperature was higher without any clear temporal trend.

Female maturity groups

In this work the reproductive status of each fish was assessed by use of both a subjective maturity index and by calculating the gonadosomatic index (GSI). Figures 3-5 show frequency distributions of logarithmic GSI-classes (0.2 units intervals), subdivided by the maturity index. For fish with low GSI, the distribution of maturity indices in October 96, December 97 and May 98 was clearly different from the other cruises. The two former cruises were made with other and less qualified personnel and the results may not be comparable with other cruises. The last one was clearly from a different period in the maturation cycle and the GSI of maturing gonads were therefor also not comparable with the other cruises. These tree surveys were thus excluded from Figure 3, where maturity data from the remaining five cruises were combined.

When all females from these cruises, were pooled, three well-defined modes appeared in the frequency distribution of log GSI classes (Figure 3, top panel). Taking account of the maturity index and egg-size (Figure 3, middle panel) as well, the lower modal group may be divided in

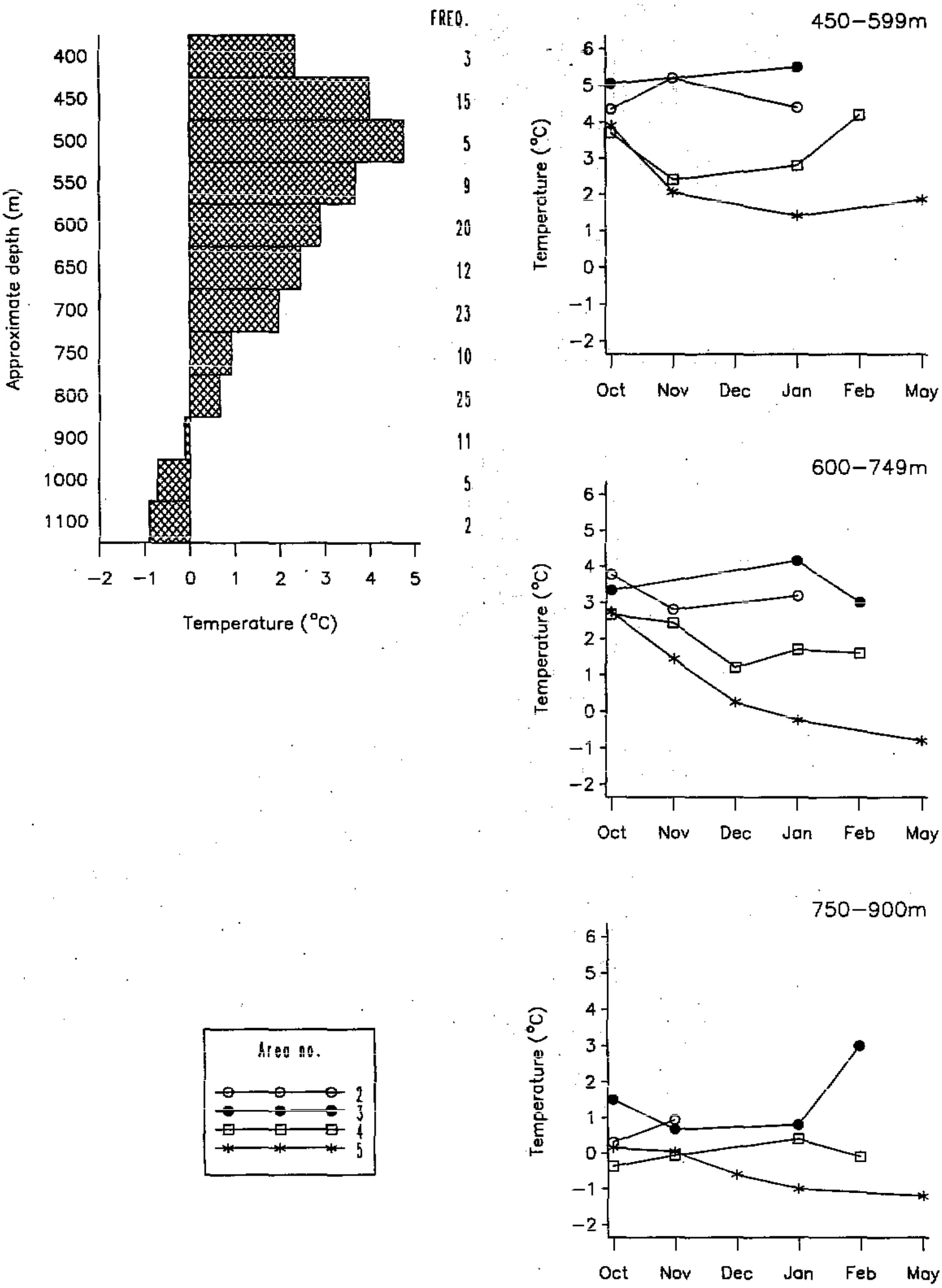

Figure 2. Bathymetric, latitudinal and temporal trends in bottom temperatures. Temperature was recorded on most trawl hauls during the surveys from October 1997 to May 1998.

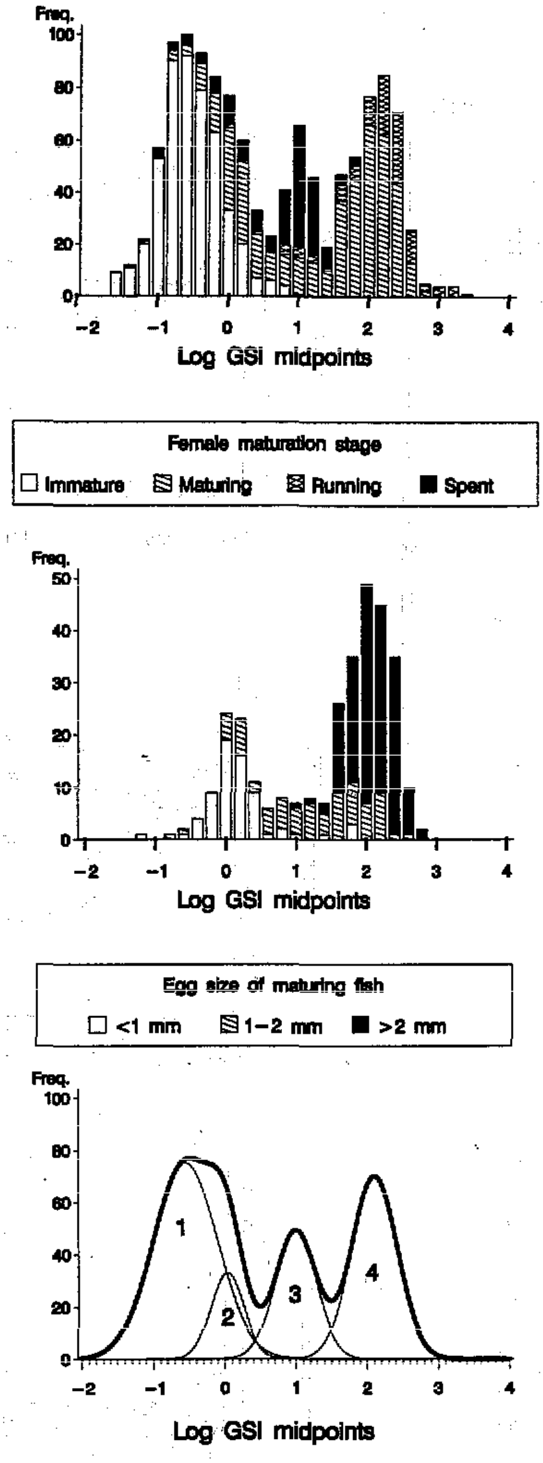

Figure 3. Top and middle: Frequency distributions of log GSI classes of females from several surveys combined. Each bar subdivided acording to maturity stage recorded on board (MI), or by egg size-group. Bottom: Normal components fittet to the frequencies above.

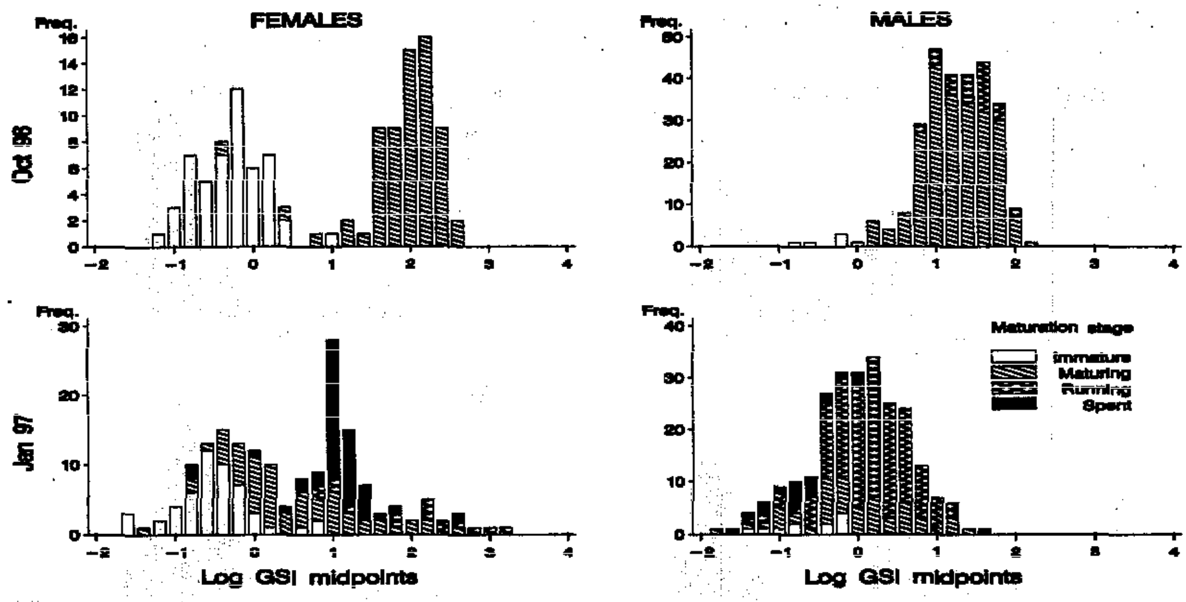

Figure 4. Frequency distributions of log GSI classes subdivided acording to maturity stage recorded on board (MI). Data from spawning season 1996-97.

two. These four approximately normal-distributed maturity groups (Figure 3, lower panel) with means close to -0.7, 0, 1, and 2 respectively were seen throughout the whole series of cruises (Figure 4-5). On several cruises (e.g. Oct. and Nov. 97), the bimodality in the lower end of the distributions (i.e. the lower modal group in the top panel of Figure 3) was very clear.

The four maturity groups (GSI-modal groups), numbered from low to high GSI, may be characterised as follows:

1. Mostly classified as "immatures". A few individuals probably misclassified as maturing or spent.
2. Mostly classified as "maturing" (e.g. Oct. 97). When egg-size was determined it was classified as "small" (<1mm). On some cruises they were classified as "immatures" (e.g. Oct. 96) or "spent" (e.g. Jan. 98). They were however in another modal group than the major part of those classified as "spent". With respect to the known problem of deciding between "immatures", "spent", and "maturing" in early stages of rebuilding, it is believed that the two former were the result of misclassifications. The second modal group in the GSI distributions is thus assumed to represent females in a very early stage of building up gonads.
3. Mostly classified as "spent" (e.g. Jan. 97, 98). In January 97 some were classified as "maturing", but they were clearly separated from the main part of that group (compare Oct. 96 and Jan. 97). Also in May 98 gonads from this modal group were classified as "maturing" and egg-size was "medium" (1-2mm). Mean log GSI was slightly increased since the immediate post-spawned situation in January. It is assumed that the third modal group represents fish that had spawned in the previous spawning season, and in May they were preparing for the next.
4. Classified as "running" or "maturing". When egg-size was determined it was classified as "large" (>2mm). This modal group presumably represents females that were very close to spawning.

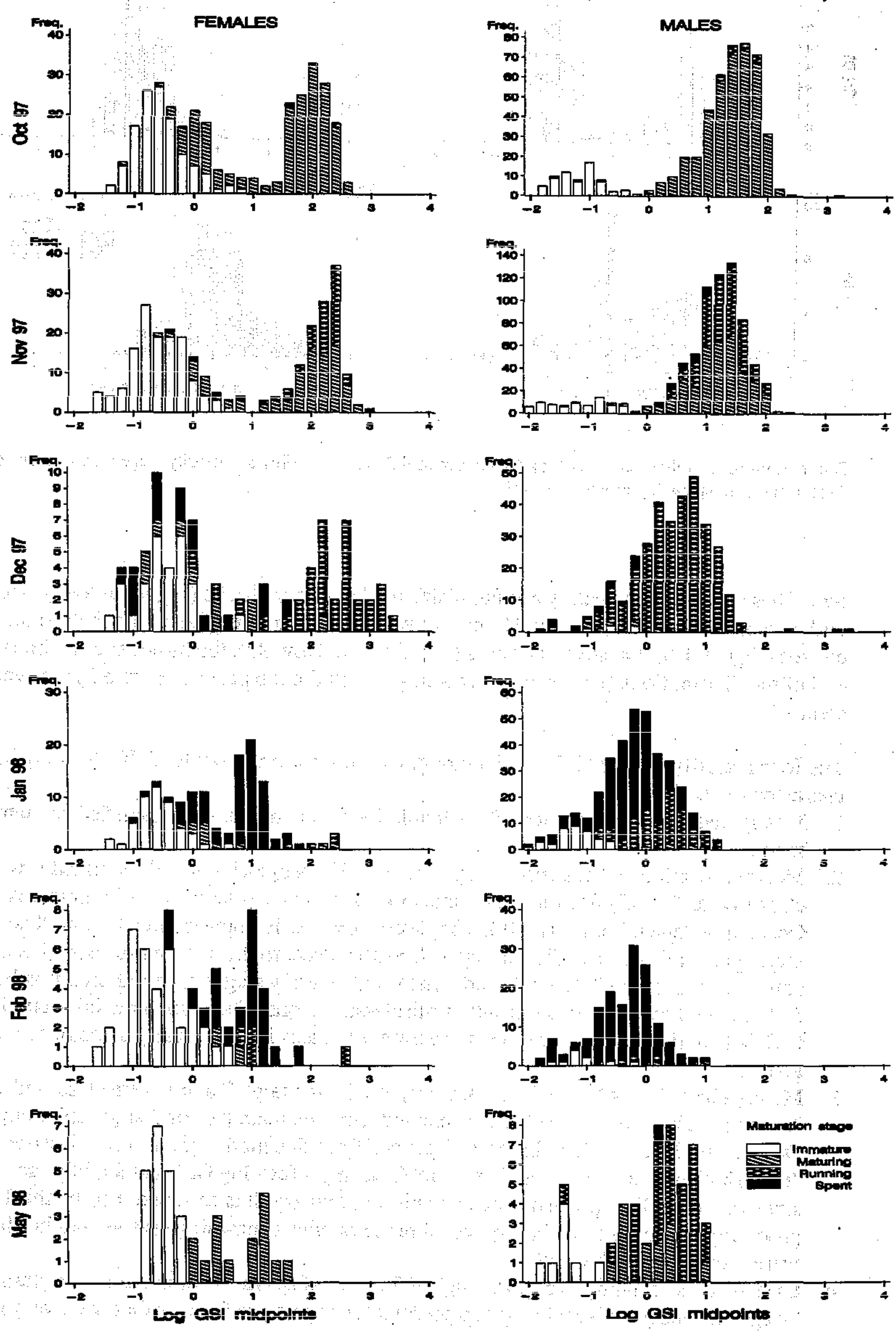

Figure 5. Frequency distributions of log GSI classes subdivided according to maturity stage recorded on board (MI). Data from spawning season 1997-98.

Thus, maturing females were recorded within both maturity groups (GSI modal groups) 2 and 4, which were widely separated along the GSI-axis. These maturity groups probably represent separate spawning periods. No progression in mean GSI was seen for the lower of these modes until May. At that time it was still below those that were rebuilding after spawning (GSI modal group 3), and both groups were well below the pre-spawning situation in October (Figure 4-5). Thus, it seems reasonable to assume that the two groups of maturing females in May represented first-time spawners and second (or more) time spawners respectively. The two groups will then presumably constitute GSI-modal group three in the following October.

The lower panel of Figure 3 shows the results from fitting normal components to the distribution of total frequencies in the upper panel. Using the means and variances from these components, the proportion of each component was estimated for each survey separately. In the fitting, the one most well defined group (i.e. group 4 in Oct.-Dec. and group 3 in Jan.-Feb.) was allowed to be estimated from the frequencies.

The frequency histograms from each cruise were all well described by the components ($p>0.1$). Table 5 shows the estimated proportions of the normal components on each cruise, together with the proportions of females in each level of the modified maturity index. The last one was more variable between cruises, probably because of differences between staff members in application of the maturity index (MI).

Male maturity groups

For males, separation of the log-GSI distribution into modal groups was not as clear as for females. In addition, the visual maturity index (MI) may be less informative for males. This is partly because the "maturing" stage could not be subdivided since there is no correlate to the female egg-size. Moreover, misclassifications were probably also more common for males.

However, by inspection of Figures 4 and 5, four groups may be identified that seems very similar to the female groups:

1. On several cruises immature males were seen as a separate modal group with a mean log GSI of approx. –1.5.
2. In December 1997 and February 1998 a separate modal group appeared with mean –0.6. This group may very well be part of the broader group seen in several other periods (e.g. November and January), and in May the mean had increased to –0.3.
3. Spent males were mainly recorded in January and February with a modal value of approx. –0.2.
4. Maturing and running males were found in a separate modal group. The mean value decreased continuously from 1.5 in October to 0.5 in January.

Due to the lack of precise maturation data, the set of GSI groups identified here may only be one of several possible. Since the groups therefor are rather arbitrary, normal components were not fitted for males.

Spawning period

In October, most Greenland halibut with high GSI's were classified as "maturing" (MI=2), whereas "running" (MI=3) fish were found in November and December (Figure 4-5). In November, the distribution of fish between these two MI levels was significantly different between staff members of the two watches. This only demonstrates the arbitrarity of such indices, and both MI and MMI (Table 5) indicated that few fish were spent until January. In January most of the spawning was over, at least for the females. Many running males were recorded both in January, February and May, but the GSI was clearly much lower than in the prespawning and main spawning periods (i.e. October to December). From February to May the GSI increased for those classified as "running" (Figure 4-5). It is possible that the males had residual milt that was not spawned.

The distribution of log GSI classes was very similar in the two spawning periods 1996-97 and 1997-98. The main difference was for running and spent males and females in January. The proportion of running to spent was slightly higher in January 1997 than in January 1998 (Table 5, Figures 4-5). This compares with the timing of the cruises, which were 10 days earlier in 1997 (Table 2). The results indicate a rather well defined spawning season from November to mid January, with peak spawning in December.

Within this spawning season there were sexual differences in the development of gonads. The mature males constituted a single mode with gradually decreasing GSI from October through February. This probably means that individual males were spawning over a protracted period of time. This was not seen for mature females, which were found in either of two well-defined modal groups, either pre or postspawning. If they were also spawning in portions they must have some mechanisms that counteract the fall in gonad weight. However, swelling of eggs was not observed with the coarse measure of egg-size used in this study.

For females the proportion of "this years spawners" (MMI 3-4) to those not spawning this year (MMI 1-2) was rather stable from October to January, i.e. from prior to spawning to end spawning (Table 5). Within this period the estimate varied from 0.8 to 1.2. After this the proportion of this years spawners decreased and in May it was only 0.3.

Table 5. Percentage composition of female maturity groups on each cruise, and the rate of those spawning this year (MMI 3-4) to those not spawning this year (MMI 1-2). Percentages estimated by fitting normal components (NC) or by frequencies of the modified maturity index (MMI).

Cruise	Normal Components				Modified Maturity Index				Group 3-4 / Group 1-2	
	Maturity group				Maturity group					
	1	2	3	4	1	2	3	4	NC	MMI
Oct. 96	27	17	3	52	44	3	0	54	1.2	1.2
Jan. 97	36	14	38	12	31	26	24	19	1.0	0.8
Oct.97	43	10	4	42	40	16	0	44	0.9	0.8
Nov. 97	48	5	4	43	49	6	+	45	0.9	0.9
Dec. 97	46	8	9	37	39	8	4	49	0.9	1.1
Jan. 98	38	16	40	6	41	8	47	5	0.9	1.1
Feb. 98	58	2	37	3	65	4	24	7		
									0.7	0.4
May 98	65	12	0	0	57	20	0	23	0.3	0.3

Distribution

All surveys combined, Greenland halibut was found from 450 to 1100 m depth (Figure 6a). Highest catch rates were between 500 and 850 m and males had a slightly wider bathymetric distribution than females. Overall, they were more or less equally abundant in all areas. However, seasonal variations in distribution or changes during the maturation cycle were not possible to detect in this study because of the highly variable spatial coverage (Table 2) due to frequent gales.

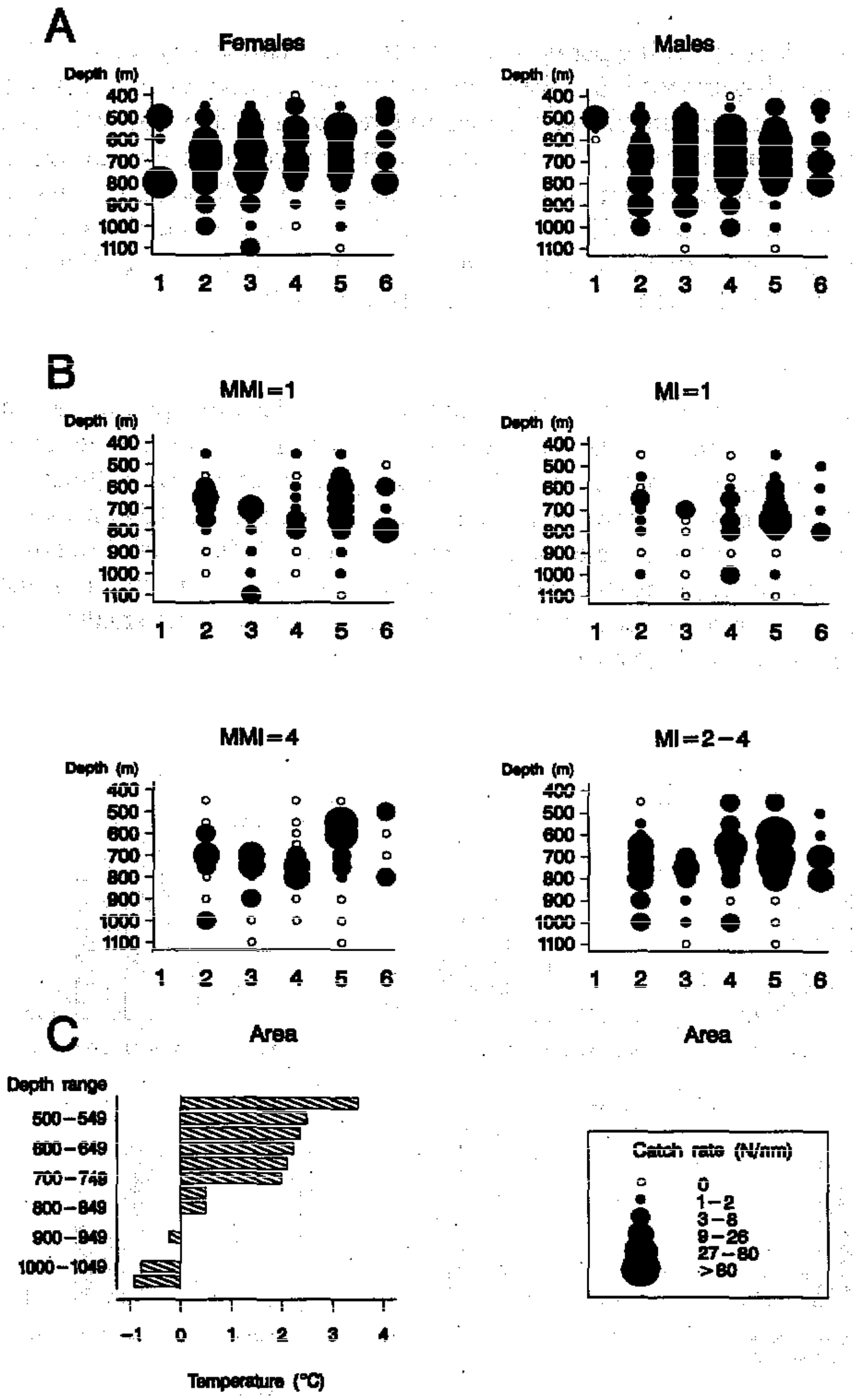

Figure 6. A: Mean catch rates of male and female Greenland halibut in different areas and depth-zones. Data from all surveys combined. B: Catch rates of immatures and matures in November 1997. C: Mean bottom temperature in selected depth-intervals from the survey in November 1997.

The cruise during the peak spawning period in December, was particularly reduced. However, in the preceding cruise (November 1997) the coverage was quite good. On that cruise the bathymetric distribution of both immature and mature Greenland halibut was well defined and coincided roughly with temperatures of 2-3 °C (Figure 6b). Prespawning females (MMI=4) had a much more restricted depth distribution than the immatures (MMI=1). In areas 2-4 they were mostly found between 700 and 800 m, and in area 5 between 550 and 600 m. This compares to the shallower distribution of isotherms in the area 5 (Figure 2). In December, running females were recorded at temperatures between 1.6 and 2.1 °C.

Spawning vs. length

For both sexes the mature part of the population contributed to the upper part of the length distributions (Figure 7a,b). For females, there were no significant difference in mean length between the spent ones (MMI 3) and those that were going to spawn (MMI 4) (66.3 and 65.8 cm respectively). The immatures were much smaller (mean 50.8 cm, SE 0.27 cm) and the presumed next years spawners were in between (mean 60.8 cm, SE 0.47 cm). Length differences between maturity groups were much smaller for males. Mean length for maturing, running and spent males varied from 49.6 to 50.1 cm. The immatures were smaller though, with mean length 45.8 cm (SE 0.25 cm).

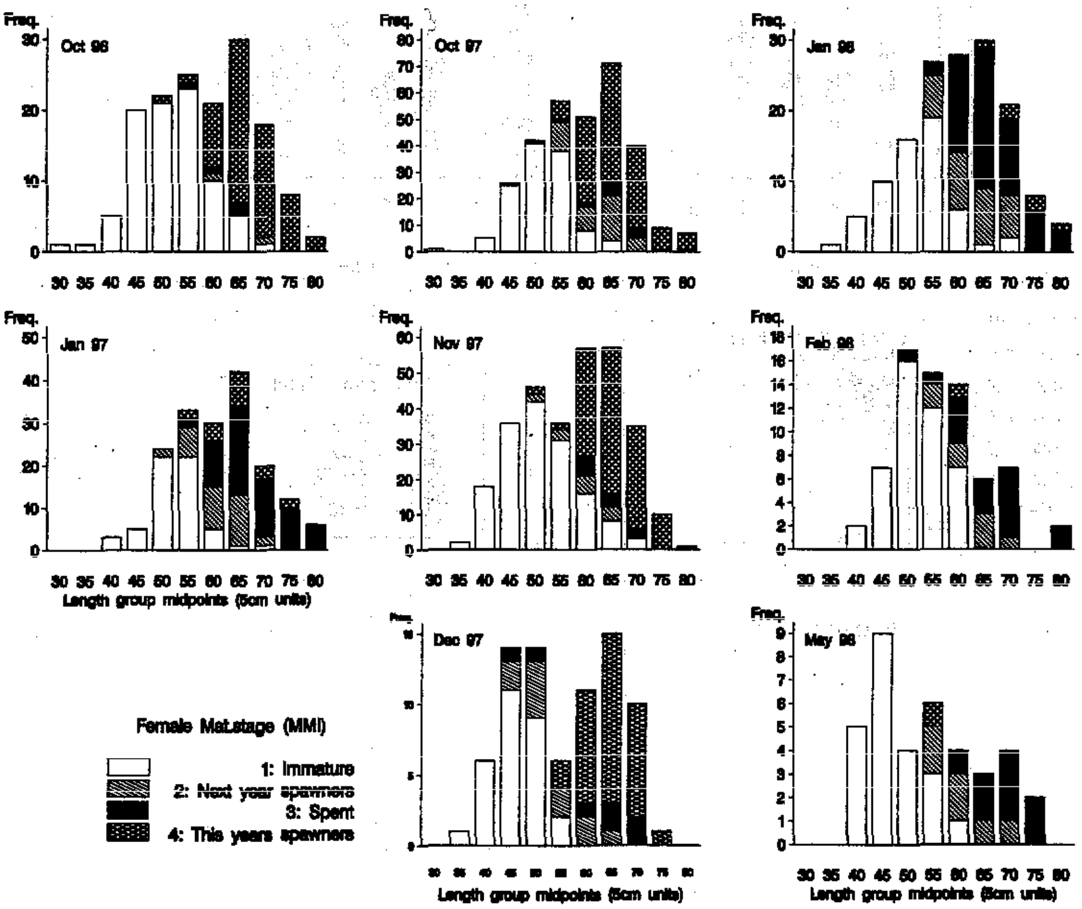

Figure 7a. Length frequency distributions of female Greenland halibut from each survey. Each bar subdivided according to the modified maturity stage. The 80 cm length-group is a pluss-group.

The spawning occurred at the same time for all length groups, and the mature part was present in the survey area in approximately the same degree from October through January (Figure 7a,b). In February most of the large mature females disappeared from the catches, and in May also the larger mature males were gone.

Figure 8 shows the percentage of males and females that were mature at each length interval. Length at 50% maturation (L_{50}) was estimated to 40 cm for males and 62 cm for females. This compares to estimates of 65 to 85 cm for females from the Canadian northwest Atlantic (Morgan and Bowering, 1997). The present cruises only sampled the larger individuals from the immature part of the Greenland halibut population. Very few less than 40 cm was recorded. This compares to the young fish areas where few fish were found above 50 cm (Albert et al., 1997). Failure to include the fish in the young fish areas tends to overestimate the percentage maturity in this study. Since this bias applies mainly to fish less than 50 cm the L_{50}'s were probably only slightly underestimated.

Spawning products

A total of 12 eggs were recorded in the plankton hauls. They ranged from 3.8 to 4.7 mm in diameter, with 4.2 mm as a mean. Both colour (unpigmented) and size was equal to unfertilised eggs from running female Greenland halibut. The embryos resembled those from artificially fertilised eggs from the same cruise (Stene *et al.*, 1998).

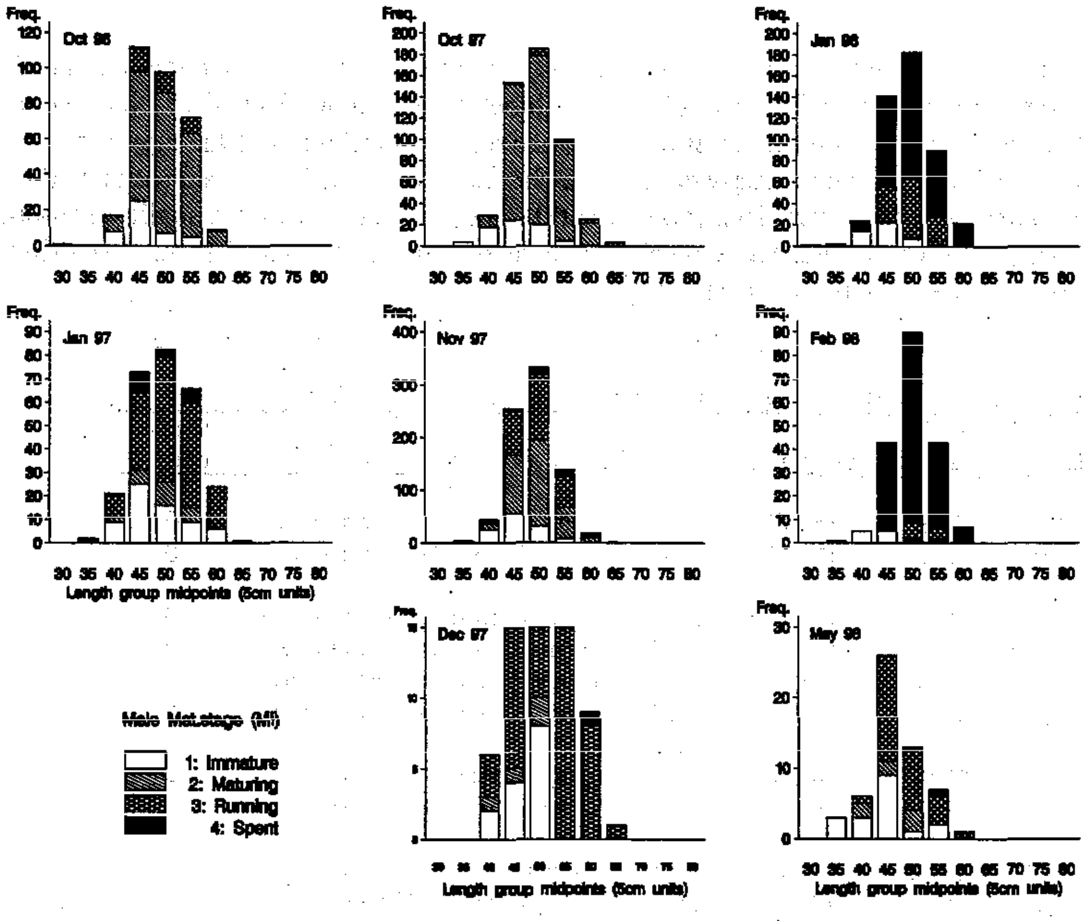

Figure 7b. Length frequency distributions of male Greenland halibut from each survey. Each bar subdivided according to the maturity stage.

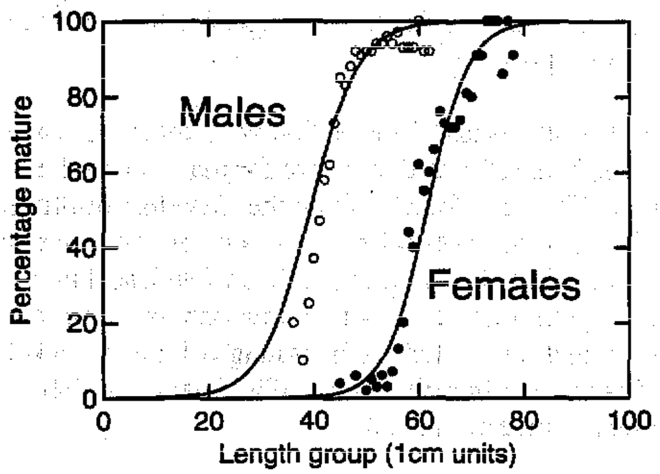

Figure 8. Percentage maturation of each length-group of male and female Greenland halibut. Each data point represents at least five observations. A logistic growth curve was fitted to each sex.

All the eggs were recorded in December and January, no one in October or November (Table 6). They were caught pelagically over 1000 m depth between latitudes 73 and 75°N. Since the net could not be closed within the water column, the vertical distribution of the eggs are uncertain. However, they were mostly caught in rather deep hauls. Of the seven hauls made in December or January, four were deep (down to 600 or 800 m) and three were shallower (400, 200 and 50 m). 92% of the eggs were caught in the deep hauls. This is the first time ever that eggs of this stock were found in the sea.

Table 6. List of plankton hauls and catch of Greenland halibut eggs.

Cruise/Date		Latitude	Longitude	Net	Type and depth of haul	Number of eggs
Oct. 97						
	15/10	71°33'	15°10'	WP-II	Vertical from 800 m to surface	0
	16/10	70°18'	17°06'	WP-II	Vertical from 800 m to surface	0
Nov. 97						
	5/11	70°23'	17°08'	MIK	Diogonal from 650 m to surface	0
	8/11	73°24'	14°21'	MIK	Diogonal from 800 m to surface	0
	10/11	73°52'	15°11'	MIK	Diogonal from 800 m to surface	0
	10/11	74°38'	15°28'	MIK	Diogonal from 800 m to surface	0
Dec. 97						
	18/12	73°40'	14°50'	MIK	Diogonal from 800 m to surface	3
	18/12	73°27'	14°29'	MIK	Diogonal from 800 m to surface	3
Jan. 98						
	28/1	74°38'	15°38'	MIK	Diogonal from 800 m to surface	2
	28/1	73°32'	14°40'	MIK	Horisontal at 10-50m in 30 min.	0
	28/1	73°20'	14°20'	MIK	Diogonal from 600 m to surface	3
	28/1	73°15'	14°28'	MIK	Horisontal at 400 m in 30 min.	0
	28/1	73°14'	14°22'	MIK	Horisontal at 200 m in 30 min.	1

4. General discussion

Maturity indices based on a (quick) visual macroscopic inspection of the gonads are inherently uncertain. This is partly because the definition of each level is often based on criterias that are difficult to see by eye, and partly because the criterias may be arbitrary. The result is often a high degree of subjectivity and a significant effect of training, which in turn may give differences between staff members. In this work we showed that the log-transformed GSI may be used to partly correct and partly redefine the maturity index for Greenland halibut. The modified index (MMI) seems to be more accurate and to represent more biological information than the raw field-recorded index. This holds especially for females, and particularly when data are available from different periods of the maturation cycle. Thus it was shown that two groups of maturing females may be identified, one that was close to spawning, the other presumably with one year to go before spawning for the first time. The two groups were separated on the basis of both GSI and egg-size.

Different egg-sizes may also be found within separate portions of individual gonads close to spawning (Fedorov, 1968; Gundersen *et al*, 1988). Fedorov (1968) showed that only the larger of these eggs were spawned, and that other eggs may be resorbed. It is not known to what extent the small eggs in the early maturation stage of the assumed first-time spawners may be resorbed, but data from May suggested that the gonads of this group were further developed.

The spawning period seemed rather well defined in this study. It started in November, peaked in December and ended in late January. It occurred mainly between 500 and 800 m in waters of approx. 2°C. Mature fish arrived to the spawning area in early autumn and left during the first months of the year. In May all the fish seemed to be far from spawning. This is in contrast with the finding of running females in a sample from late June 1998 (Own unpublished observation). These fish were caught by long-line at 300-400 m depth off the coast of North-Norway. Ovaries were recorded with small, medium or large (and running) eggs, and several gonads were very large (The fish size was not recorded).

Although the extent of this summer spawning is not known, these findings underline the dichotomy in the literature as to the spawning time of this stock (Godø and Haug, 1989). The main spawning season shown by the trawl surveys is in accordance with Nizovtsev (1969) and Fedorov (1971), while the data from the long-line sample resemble those of Milinsky (1944), Hognestad (1969) and Breiby and Eliassen (1984). Our results indicated a restricted spawning season, which apparently was followed by another separat spawning event. This is in contrast to Fedorov (1971) who found running fish year round along the slope. While Kovtsova *et al.* (1987) showed that distribution and timing of spawning varied between years, our results indicate that such variations may also apply *within* years. The reason for these differences is not known, but our data strongly suggest that the summer-spawners were other individuals than the winter-spawners. The question then becomes who those others were.

One possibility is that they were the really big females, which may have been underrepresented in the trawl catches (However, the largest females were 4-5 kg in the landings from where the June-98 sample was taken. This corresponds to 70-75cm, which was reasonably represented in the trawl catches.). Another possibility is that separate stock components experience different environmental conditions (temperature and food) during the development of sexual products. Greenland halibut is distributed continuously on the continental slope from Norway to Shetland, and further to Iceland and Greenland (Nielsen, 1986). Within this large area no population boundaries are known, and management units are only pragmatically defined. Sigurðsson (1981) showed that significant migrations occur from the Icelandic to the Norwegian management unit, and Albert *et al.* (1997) indicated that pelagic postlarvae can be transported across the northern Norwegian Sea towards Greenland. Thus there are several possibilities for both long and short distance migrations to the spawning grounds, and therefor for a mixture of individuals with different environmental history.

It seems that we still have a long way to go before we understand the population dynamics of Greenland halibut. Properly designed mark-recapture experiments may be a key factor for this understanding. Both the spawning process and the subsequent drift migration should also be further evaluated, both in the field and by modelling.

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References

Albert, O.T., E.M. Nilssen, K.H. Nedreaas and A.C. Gundersen, 1997. Recent variations in recruitment of Northeast Atlantic Greenland Halibut (*Reinhardtius hippoglossoides*) in relation to physical factors. ICES CM 1997/EE:06, 22pp.

Breiby, A. and J.-E. Eliassen, 1984. Forsøksfiske etter isgalt og blåkveite i 1984. Institutt for Fiskerifag, University of Tromsø, Ser.B: Ressursbiologi, 1984(2):1-25.

Fedorov, K.Y., 1968. Oogenesis and the sexual cycle of the Greenland halibut. Trudy Polyarnogo Nauchno-Issledovatel'skogo i Proekttnogo Instituta Morskogo Rybnogo Khozyaistva i Okeanografii im. N.M. Knipovicha (PINRO), 23:425-451.

Fedorov, K.Y., 1971. Zoogeographic Characteristics of the Greenland Halibut (*Reinhardtius hippoglossoides* (Walbaum)). Journal of Ichtyology, 11: 971-976.

Godø, O.R. and T. Haug, 1989. A review of the natural history, fisheries, and management of Greenland halibut (*Reinhardtius hippoglossoides*) in the eastern Norwegian and Barents Seas. Journal du Conseille International pour l'Exploration de la Mer, 46: 62-75.

Gundersen, A.C., O.S. Kjesbu, A. Stene, and K.H. Nedreaas, 1988. Fecundity of Northeast Arctic Greenland halibut (Reinhardtius hippoglossoides). ICES CM 1998/O:29.

Helland-Hansen, B. and F. Nansen, 1909. The Norwegian Sea. It's physical oceanography based upon the Norwegian researches 1900-1904. Fiskeridirektoratets skrifter, serie Havundersøkelser, 2(1): 1-360.

Hognestad, P.T., 1969. Notes on Greenland halibut, Reinhardtius hippoglossoides (Walbaum), in the eastern Norwegian Sea. Fiskeridirektoratets skrifter, serie Havundersøkelser, 15: 139-144.

Kovtsova, M.V., G.P. Nizovtsev and V.V. Tereshchenko, 1987. Conditions for the formation of prespawning and spawning Greenland halibut concentrations of the Norwegian-Barents Sea Stock. *In* The effect of oceanographic conditions on distribution and population dynamics of commercial fish stocks in the Barents Sea, pp. 199-211. Ed. by H. Loeng. Proceedings of the thirdSoviet-Norwegian Symposium, Murmansk, 26—28 May 1986, Institute of Marine Research, Bergen.

MacDonald, P.D.M. and T.J. Pitcher, 1979. Age-Groups from Size-Frequency Data: A Versatile and Efficient Method of Analyzing Distribution Mixtures. Journal of Fishery Research Board of Canada, 36: 987-1001.

Method, R.D., 1986. Frame trawl for sampling pelagic juvenile fish. Calif. Coop. Oceanic Fish. Invest. Rep. 27: 267-278.

Milinsky, G.I., 1944. The biology and fisheries of Greenland halibut of the Barents Sea. Trudy Polyarnogo Nauchno-Issledovatel'skogo i Proekttnogo Instituta Morskogo Rybnogo Khozyaistva i Okeanografii im. N.M. Knipovicha (PINRO), 8:375-386, 1994, Translated by the Translation Bureau (ND), Foreign Languages Division, Departement of the Secretary of State of Canada, Fisheries Research Board of Canada, Biological Station, St.John's, Nfld, 1968, 24pp.

Morgan, M.J. and W.R. Bowering, 1997. Temporal and geographic variation in maturity at length and age of Greenland halibut (*Reinhardtius hippoglossoides*) from the Canadian north-west Atlantic with implications for fisheries management. ICES Journal of Marine Science, 54:875-885.

Munk, P., 1993. Describing the distribution and abundance of small 0-group cod using ring-net sampling and echo-integration. ICES CM 1993/G:40, 13pp.

Nielsen, J.G., 1986. Pleuronectidae. *In*: Fishes of the North-eastern Atlantic and the Mediterranean, p.1299-1307. Ed. by Whitehead, P.J.P., M.-L. Bauchot, J.-C. Hureau, J. Nielsen, and E. Tortonese. UNESCO, Paris, 1473 pp.

Nizovtsev, G., 1969. Soviet investigations on Greenland halibut in the Barents Sea, 1964-1967. Annls. biol., Copenhagen, 25:239-242.

Sigurðsson, A., 1981. Migrations of Greenland halibut *Reinhardtius hippoglossoides* (Walb.) from Iceland to Norway. Rit Fiskideildar, 6(1):3-6.

Stene,A., A. Gundersen, P. Solemdal, K.H. Nedreaas, and O.T. Albert, 1998. Early development of Northeast Arctic Greenland halibut (Reinhardtius hippoglossoides), ICES CM 1998/O: