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Northeast Arctic Greenland Halibut (*Reinhardtius hippoglossoides*): Population Structure from Nursery to Spawning Areas

by

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Abstract

Based on 12 trawl surveys to spawning, nursery and feeding areas of Greenland halibut (*Reinhardtius hippoglossoides* Wabaum) between October 1996 and January 1999, the paper describes the population structure of the concentrations in relation to distribution area and state of maturity. The paper considers how the migration from nursery to spawning area depend on individual characteristics, such as sex, maturity stage and previous growth history, and how emigration from nursery is linked to immigration to spawning areas. The paper also describes the age and length structure of the different maturity groups in the spawning area. It was found that for both males and females, the fast growing individuals left the nursery first, and there were no obvious sex-difference in emigration rate from the nursery area. Further, the early maturing females that are found along with those close to spawning are not representative of next years spawners, as previously suggested. Before spawning stock biomass can be realistically modelled, similar studies should also be made on the vertical component of migration and all the migration processes should be quantified.

Introduction

Greenland halibut (*Reinhardtius hippoglossoides* Walbaum) in the Northeast Atlantic is categorised to several management units. Those occurring in the Barents Sea and along the coasts of Norway, including Svalbard, have been termed the Northeast Arctic stock. This stock is rather pragmatically defined and its relation with those occurring in other parts of the Northeast Atlantic is not known. There have been much uncertainty relating to its dynamics and, accordingly, the annual assessments have been uncertain, resulting in much controversy between fishermen and management. It's main distribution pattern is as follows: It spawns along the continental slope from Bear Island and southwards to the North Norwegian coast (Albert *et al*., 2001a). Eggs and larvae drift towards nursery grounds which are at least partly found in Svalbard waters (Albert *et al*., 2001b, Bowering & Nedreaas, 2000). 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).

Although this overall migration pattern is known, the dynamics of migration is not understood. It is not known how individual fish migrates throughout its life, or how the distribution of a yearclass changes with age, size and maturation stage. This is necessary to know in order to weight samples from different localities to get accurate age and maturity compositions of the stock. For several years there has been a consistent inconsistency in the age-compositions used in the assessments (ICES, 2001). One consequence is that age 9 has been estimated low in abundance for several consecutive years. The age groups for which it is most important to know the distribution are those where the rate of maturation is highest, i.e. approx. age 6-12.

Albert *et al*. (2001a) showed that two very distinct groups of maturing females were present at the spawning grounds prior to and during spawning. One of these was characterised by ovaries filled with large (2-4 mm) eggs and represented those that were just about to spawn. The other group had ovaries filled with small (<1 mm) even-sized eggs. The status of this last group is uncertain. It may represent a second spawning event several months later in another spawning area, it may be the next year's spawners, or it may be females that are not completing the spawning process.

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 (Albert *et al*., 1997, 1998, 2001a, 2001b; Albert & Høines, *in subm.*; Gundersen *et al*., 2000; Stene *et al*., 1999; Ådlandsvik *et al*., 1999). The purpose of this paper is to further analyse the transition of Greenland halibut from nursery to spawning condition. At what size and age do they migrate from the nursery to the spawning grounds? How does this migration depend on individual characteristics, such as sex, maturity stage and previous growth history? What characterises the fishes that constitute the different maturity stages, especially who are the early maturing females during the spawning season?

Material and Methods

Greenland halibut was sampled from 12 research surveys to the spawning area along the Norwegian continental slope between October 1996 and January 1999. This covers the three spawning seasons 1996-97, 1997-98 and 1998-99. Trawls were allocated to 50 m depth intervals between 450 and 900 m in each of six transects across the slope. In November 1997 trawls were also made in the Hopen Deep of the Barent Sea. In addition, Greenland halibut was also sampled on annual routine surveys in the Barents Sea and Svalbard waters in the period April-August 1997-99. On these surveys a few trawls were also allocated to the slope area. All trawls were made with a modified Campelen shrimp trawl towed by the R/V "Jan Mayen". Details of trawl equipment, procedures and sampling sites were given by Albert *et al*. (1998; 2001a) for the surveys to the spawning areas, and by Aschan and Sunnanå (1997) for the annual routine surveys.

For the purpose of this paper, trawls were grouped in the four main areas Spawning Area (Area 1), Barents Sea (Area 2), Svalbard south (Area 3) and Svalbard north (Area 4) and the two time periods October-February (the spawning period) and April-August. Table 1 gives an overview of the data and Figure 1 shows the areas and distribution of trawls.

From each trawl haul, individual data were recorded for 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 a standard four-level macroscopic maturation index (Immatures, maturing, running, and spent). In addition, for females, egg size and gonad weight was also recorded.

As described by Albert *et al*. (2001a) the different measures of female maturity status were combined and a new modified maturity index, MMI, was defined based on the modal composition of log-transformed classes of the gonadosomatic index. This index identifies four distinct maturity stages of Greenland halibut in the spawning season. They may respectively be termed "Immature", with no visible eggs (by naked eye), "Early maturing", with evenly sized small eggs and apparently many months (perhaps a year) to go before spawning, "Close to spawning", with large eggs, and "Spent", without eggs but still distinctly different from the immature. In this paper the first two groups are sometimes collectively called juveniles, while the last two represent the mature individuals.

The 1-cm length intervals had to be pooled in larger intervals in order to make length distributions for sub-groups of individuals, e.g. age groups, maturity groups, for which total numbers were restricted. The pooled length groups were labelled with their midpoints, i.e. for 2-cm length-groups '6' represents 5-6 cm, and for 5-cm groups '15' represents 13-17cm.

Results

Length and maturity vs. area and season

Females

Female Greenland halibut in the Svalbard North (Area 4) was characterised by a predominance of small juveniles (Figure 2). The two first length-modes were at 15 and 23 cm and a third one may be seen around 30, but not well separated from the second. 80% were below 40 cm. Some of these smaller juveniles were also found in Svalbard South (areas 3) and Barents Sea (areas 2), while in Spawning Area (Area 1) almost no fish were recorded below 40 cm. In the Barents Sea area, 81% of females below 40 cm were found in the Hopen Deep, north of 74°30'N, whereas only 20% of the larger ones were found in this northern region.

In the Svalbard South and Barents Sea areas larger juveniles, in the range 40-70 cm, dominated (Figure 2). Mature individuals were recorded in low numbers, but among those larger than 60 cm 20-40% were classified as mature. These mature individuals were all recorded in the southern part of the areas. No mature females were recorded in Svalbard north.

At the spawning ground in the spawning season the length frequency distribution of females was characterised by one major modal group of larger juveniles, in the range 40-70 cm, and another consisting of mature individuals in the range 60-80 cm (Figure 2). In the spawning period 41% of the females in this area were characterised as mature, while only 11% in the feeding period. In the other five area-period combinations percentage of mature females ranged from 0.3 to 4%.

Males

The male Greenland halibut showed much the same distributional pattern as the females. Small juveniles were mainly found in Svalbard North were they dominated the catches (Figure 3). The small juveniles were also found in Svalbard South and Barents Sea, mainly in the northern part of each area. But, as for females, individuals above 40 cm dominated in all other areas than Svalbard North. In contrast to the females though, the right-hand sides of the length frequency distributions of males were quit similar in all areas and both seasons.

In Svalbard north the three first length-modes were relatively well separated, more so than for the females. Ages 1-3 could be distinguished with modes at 13, 21 and 30 cm respectively. As for the females, a separate mode of larger juvenile males could be distinguished that co-occurred with the mature individuals. The two groups did not comprise separate modes in the total length distribution though. This is partly because the length difference was small and partly because, in all areas, the larger juveniles (>40cm) were outnumbered by the mature individuals.

The mature males were apparently more widely distributed than the mature females and were found in significant numbers in all areas and both seasons (Figure 3).

Comparison of aged fish in Svalbard North and Spawning Area

Females

In Svalbard North, most females were younger than 10 years, and in Spawning Area, age 10-11 represented the most common age-groups of immature females (Figure 4). The mature females were slightly older, with 10-12 years as the most common ages. The age composition of early maturing females resembled the mature females more than the immature.

At the spawning grounds in October-January the mean length of females in maturity stages Immature, Early maturing, Close to spawning, and Spent were 53, 58, 64, and 64 cm respectively. Also within each age-group, Immature and mature ("Close to spawning" and "Spent") constituted two relatively well separated modes with the Early Maturing females in between (Figure 5). The mean length of immature females was 82% of the mature individuals of same age. The early maturing females were in the upper length range of the immature ones. All females that were at least 20% larger than the mean of the age-group were mature, while those that were 20% smaller than the mean were all immature or early maturing.

Figure 6 shows the mean length at age of Greenland halibut in different stages of their ontogeny. It shows that the fastest growing females arrive at the spawning grounds at age 5 and spawn at age 7. The slowest growing individuals in our data remained in the nursery area north of Svalbard at least up to age 9. The highest age estimate of females in Svalbard north was 13 years (Figure 4). Figure 6 also shows that the Early Maturing females constituted a separate group, with mean length consistently between immature and mature females.

Males

In Svalbard north, most males were younger than 10 years, whereas in the spawning area, age 8-11 represented the most common age-groups of both mature and immature males (Figure 4). The irregularities in the numbers at age curves in Svalbard north were mostly similar for males and females, i.e. heights at age 5 and 8-9 and low at age 7. An exception was age 1, for which there were recorded many more males than females. The reason for this difference was that most small fish (<15 cm) were classified as males. Given the difficulties of sex-identification by visual macroscopic inspection of the smallest Greenland halibut, it is reasonable to assume that this difference was mainly caused by miss-classification.

The age composition of mature males in the spawning area was broadly similar to the immature ones. However, the relative proportion of maturity was lower both for those less than seven years and those older than 11 years. In Svalbard north the proportion mature was 50 % for age seven and older.

At the spawning grounds in October-January, mean length of immature males of all age-groups combined was 46 cm, and 50 cm for those classified as Maturing, Running or Spent. Immature males were also on average smaller than the mature males of same age, but the distributions overlapped much more than for females (Figure 5). The mean length of immature males in the spawning area was 90% of the mean length of individuals of the same age classified to a higher maturity stage.

The fastest growing males arrived at the spawning grounds at age 4 and spawned at age 5, whereas the slowest growing remained in the nursery area north of Svalbard at least up to age 10. The highest age estimate of males in Svalbard north was 12 years (Figure 4). Figure 6 also shows that the minimum length at age and the mean length of immatures in Svalbard north were similar for males and females. The main sex-difference in length at age was that for ages above 6 years, some females had a much higher growth than any males.

Sex composition

Disregarding the probable mis-sexed one-year-olds (see above), the sex-composition in Svalbard north remained 50-50 up to age 9 (Figure 7). At the spawning ground, percentage of females increased gradually with age. For age-groups older than10 years there were more females than males, and for those older than 12 years 90% were females.

Discussion

Maturation, growth and migration

It appears that migration and spawning of Greenland halibut is largely determined by the previous growth history. The females left the northern nursery grounds when they approach 40 cm and appeared in spawning condition at about 60 cm. The transition occurred within a broad age-span. While the youngest female spawner recorded was age 7, the oldest immature was 14 years old. Males also spread out from the nursery areas when they approached 40 cm. They were largely mature at this size and had a much broader distribution than mature females.

The growth indicated by the present analyses of length at age is broadly in accordance with previous accounts. The growth curves estimated for the same stock in the same years in Bowering & Nedreaas (2001) pass approximately in the middle of the minimum and maximum observed length at age. Also those from Milinskii (1944) and Kovtsova & Nizovtsev (1985) lie within the range observed in this work. However, given the broad range in length at age observed here, that may not be surprising. None of the other accounts reported about the distribution of lengths around the means at age.

Since the fast growing individuals left the nursery and entered the spawning area first, in both areas, with increasing age, the length at age curves gradually consisted of less fast-growing individuals. This is important to consider when establishing growth curves for this stock. Not only may the growth curve be biased due to non-proportional sampling of slow and fast growing individuals. In addition, between-year variation in growth estimates may result from changes in distribution of different parts of the population. Such changes may not be recognised in the surveys and may result in erroneous inferences about the growth in the stock. Albert *et al*. (2001b) and Albert & Høines (*in subm.*) have shown that such variation in distribution relative to the surveys have occurred for younger age-groups of Greenland halibut. These distributional changes were related to variations in the physical environment and resulted in completely erroneous conclusions in the stock assessment. It may well be that corresponding effects also apply for mature specimen. Adult Greenland halibut seems more stenothermal than juveniles (Godø & Haug, 1989), and may thus be more susceptible to environmental changes.

In the Northwest Atlantic, Bowering (1983) found differences in growth between nearby geographical areas and Morgan & Bowering (1997) found that also age at maturation varied inexplicably. The reason for variation in growth and maturation within a sex may be related to environmental variability, but may also be attributable to different individual strategies. Geographical differences in length and maturity at age may thus occur if distribution at age varies according to individual growth strategies. This paper shows that migration is closely related to individual growth.

The sex-difference in growth was mainly that the variation in length at age, and therefor in growth rate, was much higher for females than for males. This was apparent both with the modal groups of 1-3 year old fish, where the internal variability within each modal group was less for males, and from the length at age distributions of older fish based on otoliths. At all ages, a large part of the females, the slow growing ones, had the same length at age as the males. In most previous studies in both Northeast and Northwest Atlantic, females have larger length at age than males from age 5-6 onwards (Bowering & Nedreaas, 2001). However, the actual estimates are dependent on the sampling areas relative to the distribution of all size classes within each sex and age-group. This paper has shown that distribution of mature males and females are very different, and adequate sampling is therefore also sex-specific. Thus most reported differences in mean length at age between sexes are probably of low realism.

However, also this paper showed a distinct sex-difference in growth. While females showed a continuos increase with age in both the lower and upper limits of length at age, males appeared to grow towards an asymptotic length of about 60 cm. As in previous studies the central tendency therefore levelled off after age 6. Krzykawski (1976) suggested that this be due to earlier maturation in males combined with a slowing of growth after maturity. This view was also held by Godø & Haug (1989), while Bowering & Nedreaas (2001) suggest that maturation may not be so influential on male growth as previous believed. It is possible that the levelling off in mean length at age is related to mortality more than to changes in growth rate of individual fish. Based on back-calculation of individual growth of long rough dab (*Hippoglossoides platessoides*), another long-lived flatfish, Fossen *et al.* (1999) suggested that the levelling off in the length at age curve was related to size-selective mortality. As for long rough dab, this paper shows that also for Greenland halibut there appears to be a correlation between slow growth, delayed maturation and high expected maximum age. In the future back-calculation from otoliths together with mark recapture experiments may prove useful to establish reliable estimates of growth and mortality of Greenland halibut.

The early maturing females

Combining information from a visual maturity index, an index of oocyte size and the gonadosomatic index (GSI), Albert *et al.* (2001a) showed that a separate group of early maturing females might be distinguished at the spawning ground during the spawning season. These early maturing females were characterised by having small (<1mm) oocytes when other females had large (approx. 4mm) even-sized (Stene et al., 1999) transparent oocytes and were close to spawning. These two groups of oocytes were also described by Sorokin (1967) and Fedorov (1968, 1971) who stated that the small oocytes were released during spawning in the following year. However, this paper showed that the size at age distribution of these early maturing females coincided with the larger immature ones, and consisted of individuals with a history of slow or moderate growth rates. Most mature females have had high growth rates, so this early maturing group could not be representative of all next year’s spawners. Based on the distribution of logarithmic GSI of the early maturing females, which were between the immatures and the spent ones, Albert *et al*. (2001a) suggested that the early maturing ones represented next year’s first-time spawners. Rønneberg *et al*.

(1998) found the small oocytes in spent ovaries together with residual eggs. These females may thus represent next year's repeat-spawners. However, still we miss the fast growing next year's first-time spawners. They were apparently not present at the spawning ground a year before spawning.

Sampling

In our study, females in Spawning Area in October-January showed a bi-modal length distribution. The lower mode consisted of immature females (including the Early Maturing ones), the upper of mature females. The lower mode coincided with the total length composition of males. Huse *et al*. (1999) sampled Greenland halibut along the slope in September 1996, using trawl, longline and gill-nets of different mesh-sizes. In their data the lower mode was totally dominating in the trawl catches and the upper one in the gill-net catches, whereas catches from longline showed both modes. Sex and maturity compositions from each gear were in accordance with this.

The reason for this huge difference in trawl composition is probably that few of the mature females were present in the spawning area in September compared to October-January. The length composition in trawl catches in September (Huse *et al*., *op cit.*) resembled the one from April-August in our study. Thus, availability of mature females near the bottom in the spawning area seems to increase sharply just prior to the spawning peak in late autumn. This is after the annual routine surveys that make the basis for stock assessments. It is obviously of crucial importance to know the migration dynamics of Greenland halibut in order to realistically model the maturation process and thus calculate the spawning stock biomass.

It is very probable that our sampling underrepresented part of the population. Huse *et al*. (*op cit.*) found a bell-shaped selectivity of the sampling trawl. However, the length distribution in our samples from Spawning Area in October-January was similar to the combined un-weighted length-composition from all three gear types in Huse *et al*. (*op cit.*). Thus, it seems that all length-groups present in the area were sampled in our study. Accounting for a bell-shaped selectivity would have increased the relative abundance of the upper length-mode, and thus significantly increased the proportion of mature females.

Huse *et al*. (1999) gives a thorough discussion of several relevant mechanisms that may cause under-representative sampling of some parts of the Greenland halibut population. A related problem is the possible individual differences in residence time in the area sampled. It is particularly noteworthy that almost no actually running females were caught at the spawning grounds, only those just prior to or after spawning (Albert *et al*., 2001a). This calls for behaviour models at the individual level, but also more descriptive knowledge on distribution and composition. In this respect it seems particularly important in the future to investigate the vertical dimension of distribution in relation to stock composition in terms of length, sex, age and maturity. Although Jørgensen (1997) only found the youngest Greenland halibut (<3 years) pelagically, feeding studies clearly indicate that also larger fish have a pelagic distribution (Hovde *et al*., *in subm.,* Michalsen & Nedreaas, 1998).

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Table 1. Number of individual Greenland halibut for which individual data were recorded.

				Oct-Feb		Apr-Aug		Whole year
Area number	Name	Year	Total	Aged	Total	Aged	Total	Aged
1	Spawning area	96	681	255	249	68	930	323
		97	4820	995	0	0	4820	995
		98	1371	430	70	66	1441	496
		99	848	236	3	0	851	236
2	Barents Sea	96	0	0	451	2	451	2
		97	87	0	392	0	479	0
		98	0	0	558	12	558	12
		99	9	0	494	0	503	0
3	Svalbard South	96	0	0	156	0	156	0
		97	0	0	7	6	7	6
		98	0	0	646	28	646	28
		99	0	0	367	0	367	0
4	Svalbard North	96	0	0	383	263	383	263
		97	0	0	554	132	554	132
		98	0	0	645	45	645	45
		99	0	0	436	0	436	0
Total			7816	1916	5411	622	13227	2538

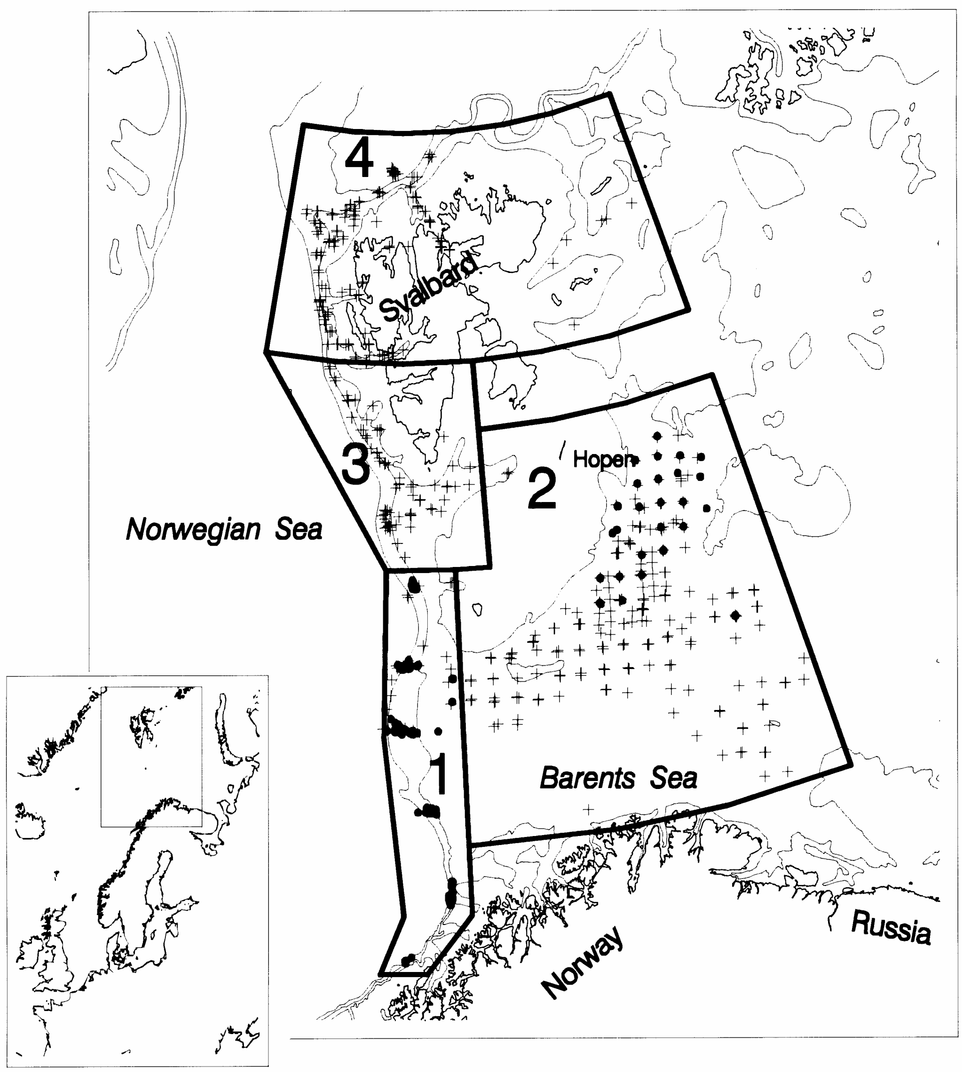

Fig. 1. Bathymetric map of the survey area with the 200, 500 and 1000m isobaths indicated. Areas referred to in the text are 1: Spawning Area, 2: Barents Sea, 3: Svalbard South, and 4: Svalbard Norh. Each trawl haul sampled in April-August is marked with a cross, and those from October-January with a dot.

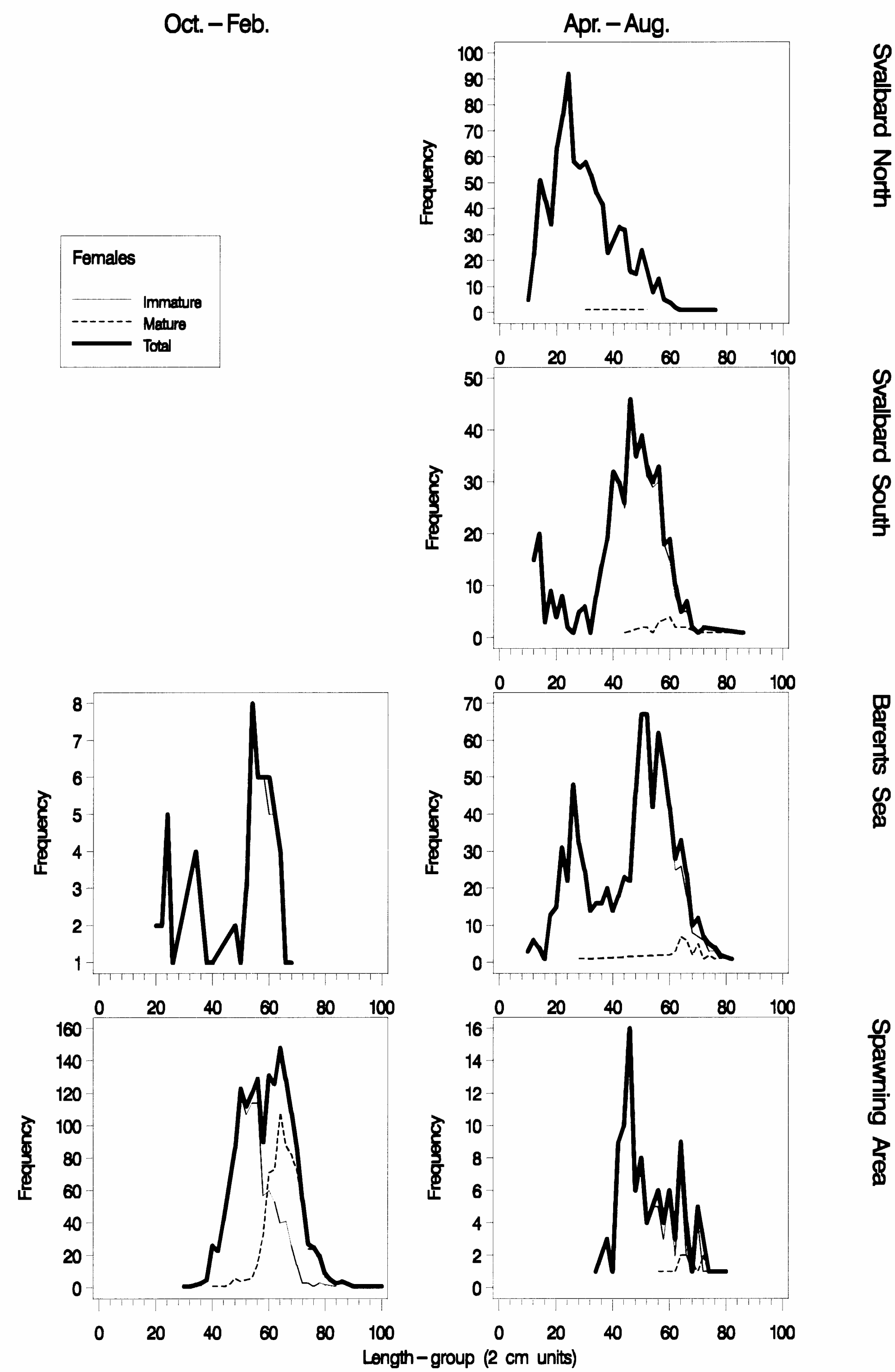

Fig. 2. Length compositions of female Greenland halibut from each area and sampling season. All years combined.

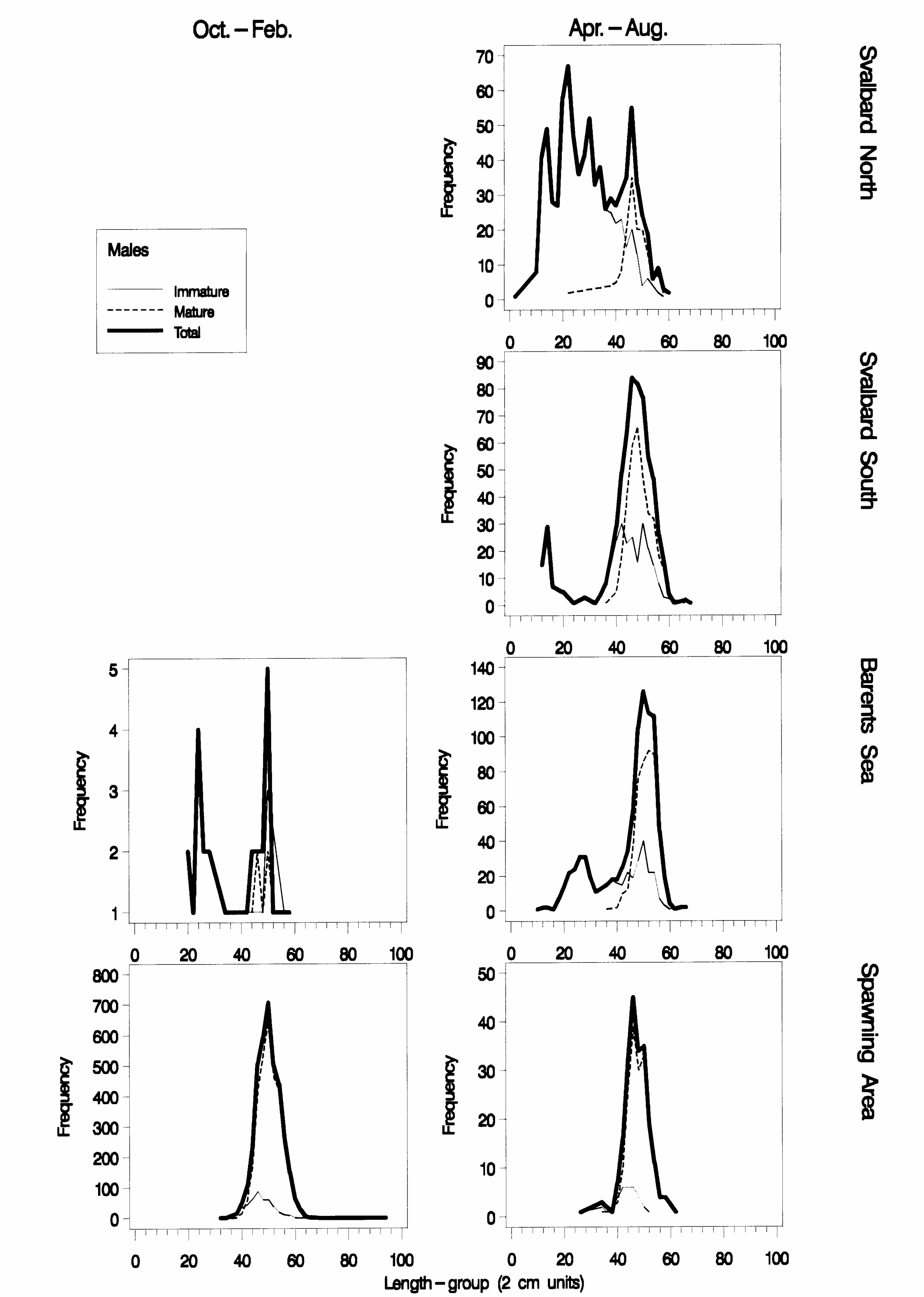

Fig. 3. Length compositions of male Greenland halibut from each area and sampling season. All years combined.

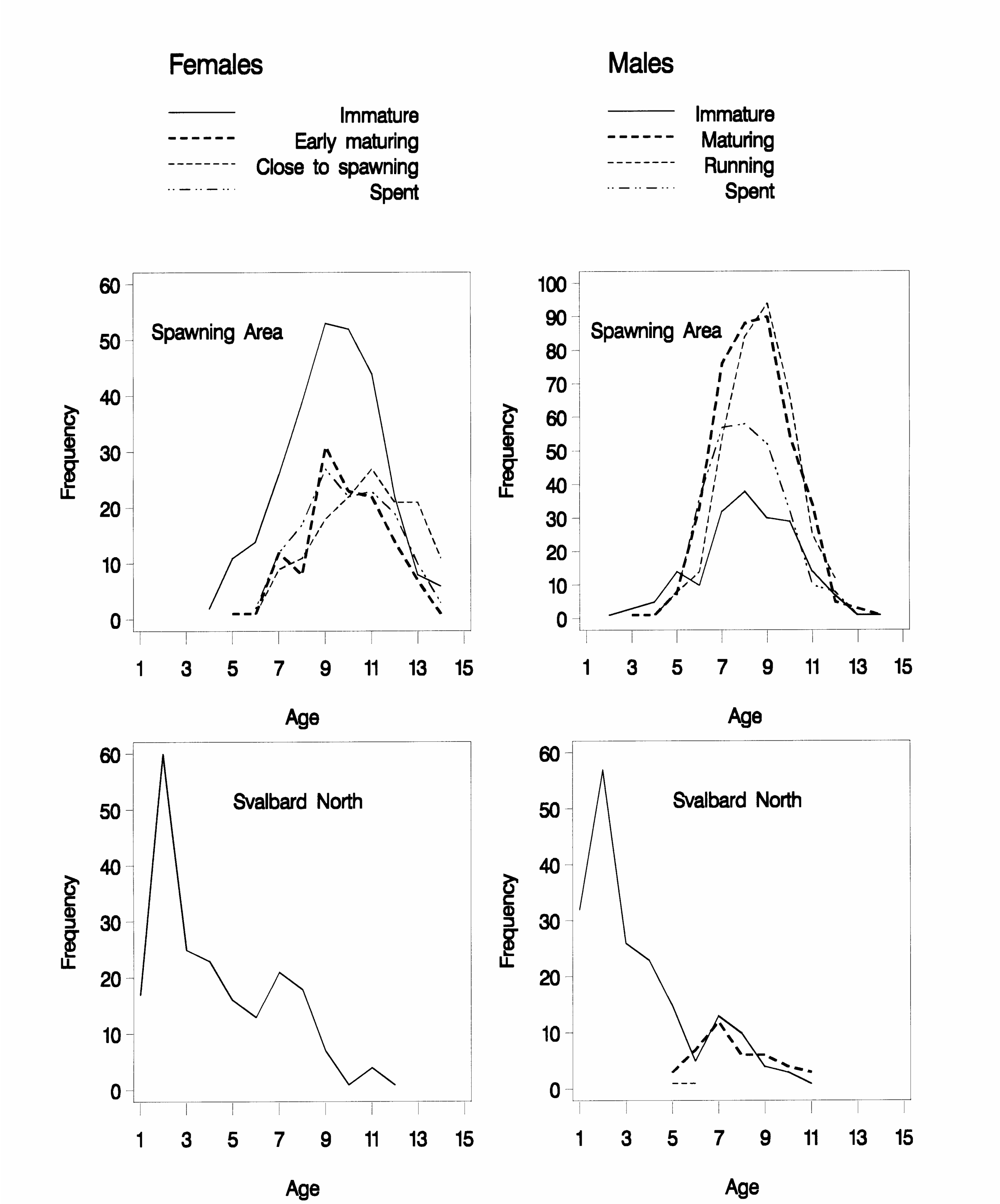

Fig. 4. Age composition of Greenland halibut from Svalbard North (Area 4) and Spawning Area (Area 1) in each sampling season. All years combined.

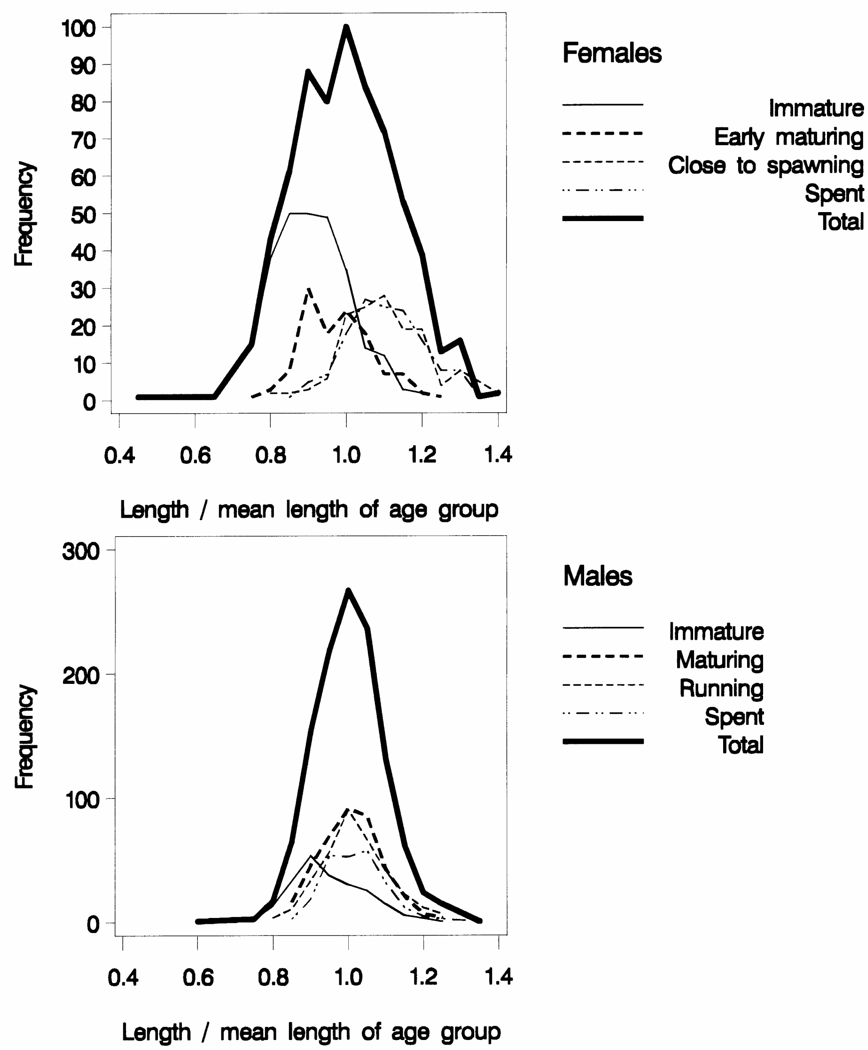

Fig. 5. Frequency distribution of relative length groups of male and female Greenland halibut of different maturity stage. Data from Spawning Area (Area 1) in October-January, all years combined. Units of 0.05 were used for the relative length groups.

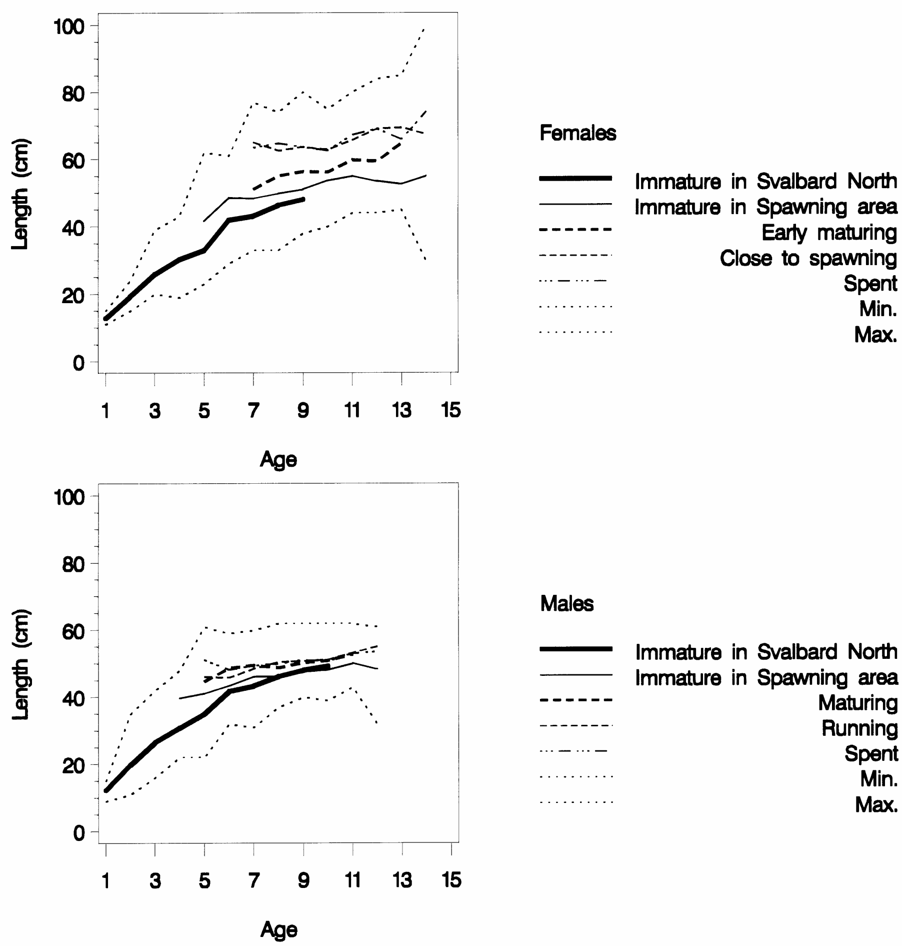

Fig. 6. Mean length at age of male and female Greenland halibut relative to maturity stage and sampling locality.

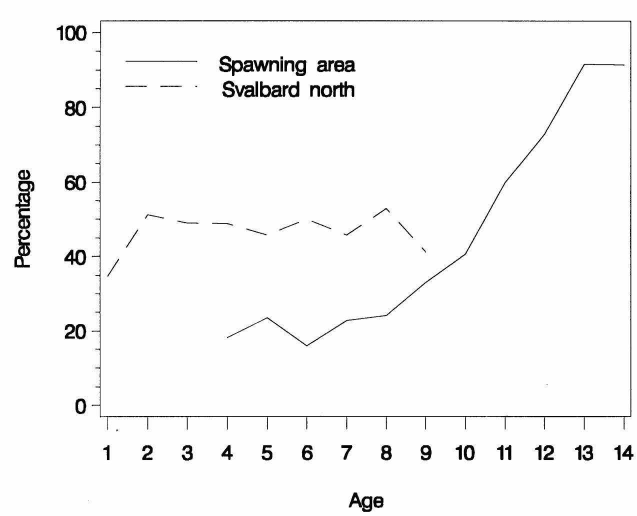

Fig. 7. Percentage females *vs*. age in Svalbard North (Area 4) and Spawning Area (Area 1).