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# Movement Patterns of Greenland Halibut, *Reinhardtius hippoglossoides* (Walbaum), at West Greenland, as Inferred from Trawl Survey Distribution and Size Data

**Ole A. Jørgensen**
Greenland Institute of Natural Resources, Pilestrædet 52
DK-1016 Copenhagen K, Denmark


## Abstract

During 1988–93, several bottom trawl surveys were conducted in West Greenland covering depths from 38 to 1 497 m. The movement of Greenland halibut (*Reinhardtius hippoglossoides*) (Walbaum) from important nursery grounds west and southwest of Disko Island towards greater depths and towards the spawning area further south in the Davis Strait were inferred by statistically significant changes in mean lengths by area and depth. Surveys were conducted at different times of the year during April–December. The spatial distribution of Greenland halibut apparently changes considerably throughout the year based on contour maps of estimated stock density. Migration between areas is likely related to significant changes in stages of maturity during the year. Bottom temperature does not appear to have a significant influence on stock movements and distribution.


*Key words*: distribution, Greenland halibut, maturity, movement pattern, temperature, West Greenland

## Introduction

Greenland halibut (*Reinhardtius hippoglossoides*) (Walbaum) are widely distributed in the Northwest Atlantic, from 78°N in the north to Gulf of Maine in the south. They are found in almost all fjords in West Greenland and on the slopes of the banks and the continental slope itself along the entire coast from Cape Farewell to Thule (78°N). In the Northwest Atlantic Greenland halibut are considered to belong to a single spawning complex and the main spawning area is believed to be located at great depths in the Davis Strait south of 67°N (Jensen, 1935; Smidt, 1969; Templeman, 1973). Based on observations of pelagic eggs and larvae, the spawning time has been inferred as winter and early spring, but no direct observations of spawning individuals have been made. Studies suggest that the eggs and larvae drift with the currents along the West Greenland and the Canadian coasts, and post larvae settle on the slopes of the banks off Greenland (Smidt, 1969; Riget and Boje, 1988) and Canada (Bowering and Chumakov, 1989).

Templeman (1973) showed that Greenland halibut in Canadian waters gradually move to greater depths as they grow. Riget and Boje (1989) suggested that this movement might also take place in West Greenland waters. Templeman (1973) hypothesized that Greenland halibut off Canada migrate northwards to spawn. This theory was supported by results of tagging experiments (Bowering, 1984) and studies of maturation (Bowering, 1983).

Seasonal migration of Greenland halibut between spawning areas and feeding areas has been observed in the Gulf of St. Lawrence (Bowering, 1982) and in Icelandic waters (Sigurdsson, 1979). Results of tagging experiments at the Funk Island Bank, Newfoundland, have indicated that small fish migrate towards inshore areas in summer (Bowering, 1984), which may also be considered as feeding migrations.

The purposes of this paper are (1) to evaluate the movement of Greenland halibut from nursery areas in the north towards deeper waters and towards what is suspected to be the spawning area further south, and (2) to document and describe the existence of seasonal migrations in West Greenland waters. Seasonal migration is viewed in relation to development in maturity and bottom temperatures.

The investigation is based on data obtained during nine bottom trawl surveys conducted in West Greenland during the period 1988 to 1993. The surveys covered offshore areas including important nursery and feeding areas, some suspected spawning areas, and the area where the offshore commercial fishery takes place.

## Material and Methods

From 1988 to 1993 nine stratified random bottom trawl surveys were conducted in West Greenland between April and December (Table 1). The surveys covered areas between the 3-mile limit and the 200 mile limit, or the midline between Greenland and Canada (Fig. 1), and were conducted by the Japanese research vessel *Shinkai Maru*, 3 395 GRT stern trawler with 5 000 HP.

A total of, 727 trawl hauls were carried out in NAFO Div. 1A (south of 70°N) – 1D, of which 538 were taken in Div. 1C–1D (Fig. 1); 635 of the hauls covered depths between 400–1 497 m, while 92 hauls covered depths between 38–386 m in Div. 1A and 1B (Cruise 1 and 2 in 1991 only). The average wing spread was 40 m and tow-duration and towing speed was 30 min and 3.5 knots, respectively. Mesh size was 140 mm, however, the codend was equipped with a 30 mm mesh liner. For further information about vessel and gear see Yamada *et al*. (MS 1988). All catches of Greenland halibut were weighed to 0.1 kg and measured as total length (ttl) to one cm below. In a few cases, subsamples were taken due to large catches, however, a minimum of 200 specimens were measured from each haul.

North-south migrations and migrations into deeper waters as fish grow were inferred by changes in mean lengths by area and depth. Mean lengths were calculated for males and females separately, due to differences between growth rates and distribution patterns. Calculations were done by NAFO Divisions and 200 m depth intervals. A depth interval of 100 m was used from 1401–1500 m. In order to get the best coverage data from four surveys, which were all conducted in August–September in the period 1990 to 1993, were included (Table 1). These surveys were selected to avoid interaction with seasonal migration, e.g. it was assumed that the distribution pattern is the same every year in August–September. Furthermore, it was assumed that growth rates have remained unchanged over the years. The mean lengths at depth strata 1–200 m and 201–400 m were based on one survey (1991:1) and sexes were combined in these two depth strata due to a large number of small unsexed specimens.

As data were aggregated over several years, there was the possibility that a year-class phenomenon may have influenced changes in size by depth and Division. A three-way ANOVA (Anon., 1985) on mean length including the variables year, depth and Division and the first order interaction effects was used to test for year-class effects. The test was conducted on data covering depths between 401 and 1 200 m in Div. 1C and 1D that was surveyed in all four years. The model was reduced stepwise for effects not significant at the 5% level judged by Type III Sum of Squares Test. The final reduced model showed that there were no significant differences (5% level) between mean lengths at different depths and Divisions by year, neither for males nor females.

A likelihood-ratio Chi-square test (Anon., 1985) was performed in order to test whether the differences in mean lengths between Divisions and depth strata, were due to statistically significant differences in size distributions between depth strata, and areas. The test was carried out on 3-cm length groups; the smallest and the largest length group were usually pooled into (plus)-groups in order to prevent that more than 20% of the estimated expected values were less than 5. Adjacent depth strata within a Division were tested to see whether length distributions differed with depth. Length distributions at the same depth stratum in adjacent Divisions were tested for significant differences in a north-south direction. The test was carried out by sex, except in Div. 1A and 1B depth strata 1–200 m and 201–400 m. When comparing depth stratum 201–400 m with depth stratum 401–600 m in Div. 1A the length distributions for the latter stratum were combined for the two sexes to make data comparable to data from depth stratum 201–400 m.

Seasonal changes in the distribution of Greenland halibut were analyzed using the spline approximation method of contouring estimated stock density (Stolyarenko, MS 1986; MS 1987). Catch data from eight surveys (Table 1) standardized to kg caught per $km^2$ swept were included. Analyses were carried out on data from Div. 1C and 1D, because these Divisions were surveyed at almost all times of the year.

In Div. 1D, the length distribution in a spring survey (1989) was tested *versus* the length distribution in a summer/autumn survey (1990:2). Similarly, a summer/autumn survey was tested *versus* a winter survey (1992:1 + 2) (Table 1), by a likelihood-ratio Chi-square to see if length distribution in the stock changed within areas by season. The test was carried out for the three depth intervals between 800 and 1 400 m. (There were too few observations to carry out a reliable test at depth stratum 1 401–1 500 m, and too few observations from 1989 to make a test for females at depth stratum 801–1 000 m.)

In order relate seasonal distribution to spawning, and to estimate spawning time and spawning area more precisely, gonads were collected from Div. 1C and 1D from both trawl surveys and the commercial catch by the *Shinkai*

TABLE 1. Number of hauls, period and area covered in bottom trawl surveys for Greenland halibut.

| Year | Cruise | Number of Hauls | Area | NAFO Div. | Date |
|---|---|---|---|---|---|
| 1988 | | 88 | 63°00'N–70°00'N | 1D–1A | 12 Sep – 11 Oct |
| 1989 | | 61 | 63°00'N–66°15'N | 1D–1C | 30 Apr – 17 May |
| 1990 | 1 | 75 | 63°00'N–68°50'N | 1D–1B | 9 Jun – 28 Jun |
| 1990 | 2 | 87 | 63°00'N–70°00'N | 1D–1A | 27 Aug – 12 Sep |
| 1991 | 1 | 139 | 63°00'N–70°00'N | 1D–1A | 4 Aug – 30 Aug |
| 1991 | 2 | 51 | 66°15'N–70°00'N | 1B–1A | 11 Nov – 22 Nov |
| 1992 | 1 | 90 | 63°00'N–70°00'N | 1D–1A | 11 Aug – 28 Aug |
| 1992 | 2 | 49 | 63°00'N–66°15'N | 1D–1C | 24 Nov – 10 Dec |
| 1993 | 1 | 87 | 63°00'N–68°50'N | 1D–1B | 20 Aug – 8 Sep |
| Total | | 727 | | | |

*Maru* at different times of the year. The total period covered was from 24 March to 10 December. Gonads were weighed to 0.1 g and a gonado-somatic index (GSI) was calculated: (gonad weights (g) $\times$ 1 000)/ttl$^3$).

Temperatures were measured to 0.1°C as near as possible to the bottom by CTD or in a few cases XBT, at 584 of the trawl stations, to investigate the relationship between near bottom temperatures and the observed distribution pattern of Greenland halibut.

## Results

### Mean length by depth and area in north-south direction

If the assumed migration towards deeper water and from north to south takes place as Greenland halibut grow, an increase in mean lengths would be expected at increasing depths and distances from the nursery area.

Two surveys in 1991 covered what is, according to Smidt (1969) and Riget and Boje (1988), the most important nursery area in West Greenland – the slopes of the Disko Bank and especially the slopes of the western and northern part of Store Hellefiske Bank (Fig. 1). Both surveys showed a high abundance of small fish, primarily at depths between 200 and 400 m. In August, a very clear mode around 11 cm, corresponding to one year of age, was seen (Jørgensen, 1997) (Fig. 2). When the survey was repeated in November these fish had grown about two cm, and a large number of 0+ post larvae with a mode around 7.5 cm had settled in the area.

An increase in mean length is seen for both sexes with depth and, distance southward from the nursery area, in Fig. 3 and 4, respectively.

The likelihood-ratio Chi-square test showed that there was a statistically significant difference in the length distributions by depth in all Divisions for both unsexed, males and females. In most cases the difference between depth strata were highly significant (P <0.000), however, the levels of significance for males between 1 001–1 200 m and 1 201–1 400 m in Div. 1A and 1 201–1 400 and 1 401–1 500 m in Div. 1D were P = 0.048 and P = 0.017, respectively. Similarly, the level of significance for females between 1 001–1 200 m and 1 201–1 400 in Div. 1D was P = 0.043. In all cases the test overestimated the number of fish in the smaller length groups and underestimated the number in the larger length groups in the deeper depth strata in comparison to the observed value. The increase in mean length by depth shown in Fig. 3 and 4 is therefore a reflection of a gradual increase in size by depth. The only case where the test was insignificant was for females between depth strata 1 001–1 200 m and 1 201–1 400 m in Div. 1A (P = 0.092). The drop in mean length in Div. 1A between depth strata 1 001–1 200 m and 1 201–1 400 m seen for both sexes, did therefore not reflect a significant difference in the length distribution for females, while the difference in length distribution was only barely significant for males (P = 0.048). The length distributions used in the test are shown in Fig. 5.

Generally the observed increase in mean length in a north–south direction was seen for all Divisions at all depths, and the difference in length distribution between the different Divisions were significant (P <0.000) for all depth strata with the exception of males and females between Div. 1C and Div. 1D in depth stratum 801–1 000 m (P = 0.129 and P = 0.759, respectively), and females in depth stratum 1 001–1 200 m (P = 0.078). In almost all depth strata, the statistical differences between Divisions was caused by the fact that the likelihood-

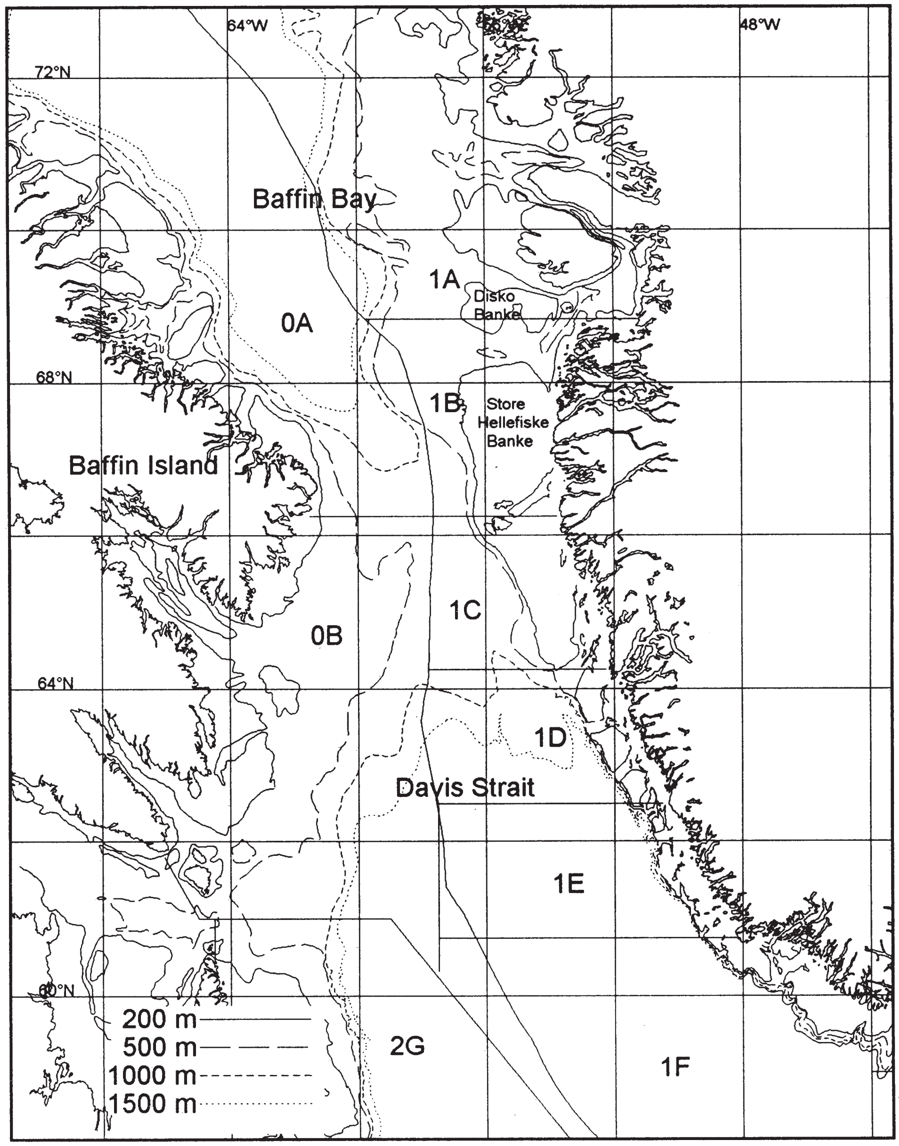


Fig. 1. The investigation area indicating locations mentioned in the text.

ratio test overestimated the number of fish in the smaller length groups and underestimated the number in the larger length group, in the most southerly Division in comparison to the observed, indicating a gradual increase in size in a southward direction. However, the opposite was true for both males and females when comparing depth stratum 401–600 m in Div. 1C and 1D, due to a large number of small fish in Div. 1D (Fig. 5). The significant difference in length distribution between Div. 1A and 1B in depth strata 201–400 m and 401–600 for both sexes was caused both by an underestimation of the number of small fish in the most northern Division, compared with Div. 1B, and because the number of larger fish were underestimated in Div. 1A compared with the observed number (Fig. 5).

**Seasonal variation in distribution**

The coverage of the main distribution area of Greenland halibut in West Greenland by bottom trawl surveys conducted at five different points in time, covering most of the year, has presented the possibility of investigating the dynamics of the distribution pattern throughout the year (Table 1) (Stolyarenko, MS 1986; MS 1987).

During spring, the main distribution occurred in deep water, >1 100 m, in the southern part of the area investigated (Div. 1D) (Fig. 6). The surveys covered depths down to 1 500 m, however, the area with high density seemed to extend well beyond 1 500 m. During early summer (June), Greenland

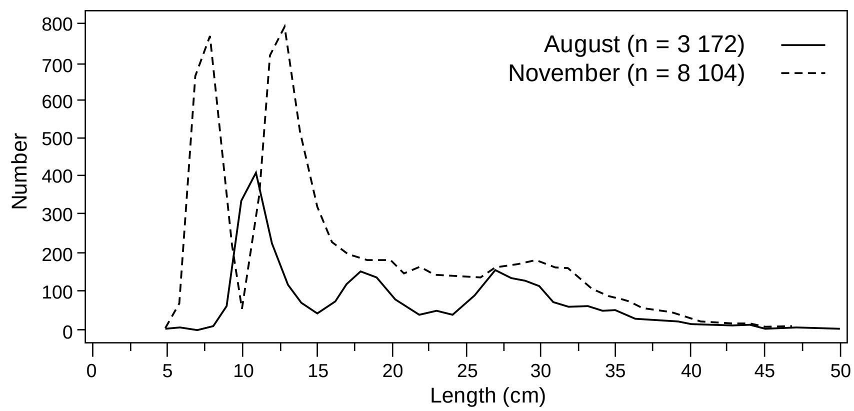


Fig. 2. Length distribution of Greenland halibut in Div. 1A and 1B at depths <400 m in August (cruise 1) and November 1991 (cruise 2).

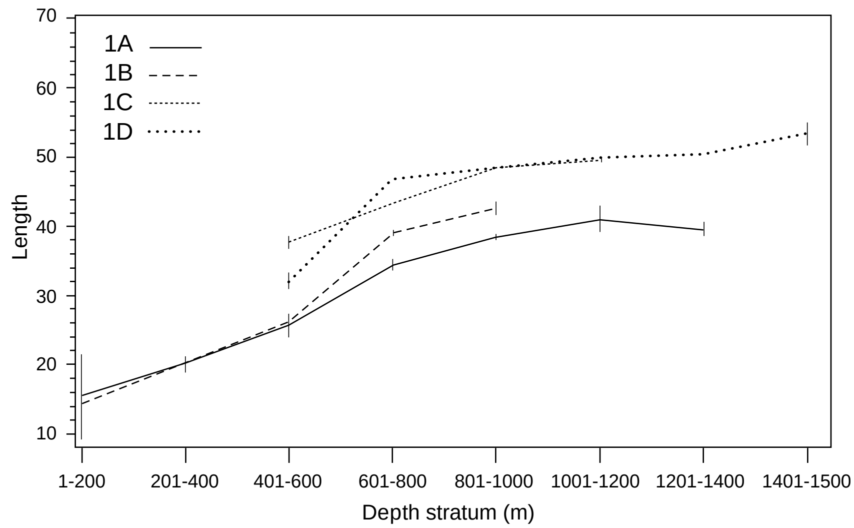


Fig. 3. Mean length of unsexed and male Greenland halibut by Division and depth stratum with ±2 SE. Depth <400 m: unsexed; depth >400 m: males.

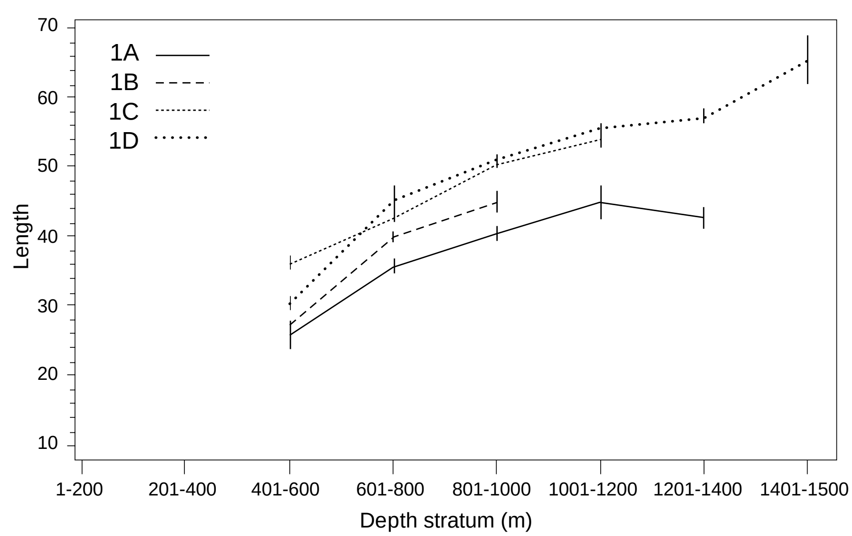


Fig. 4. Mean length of female Greenland halibut by Division and depth stratum with ± 2 SE.

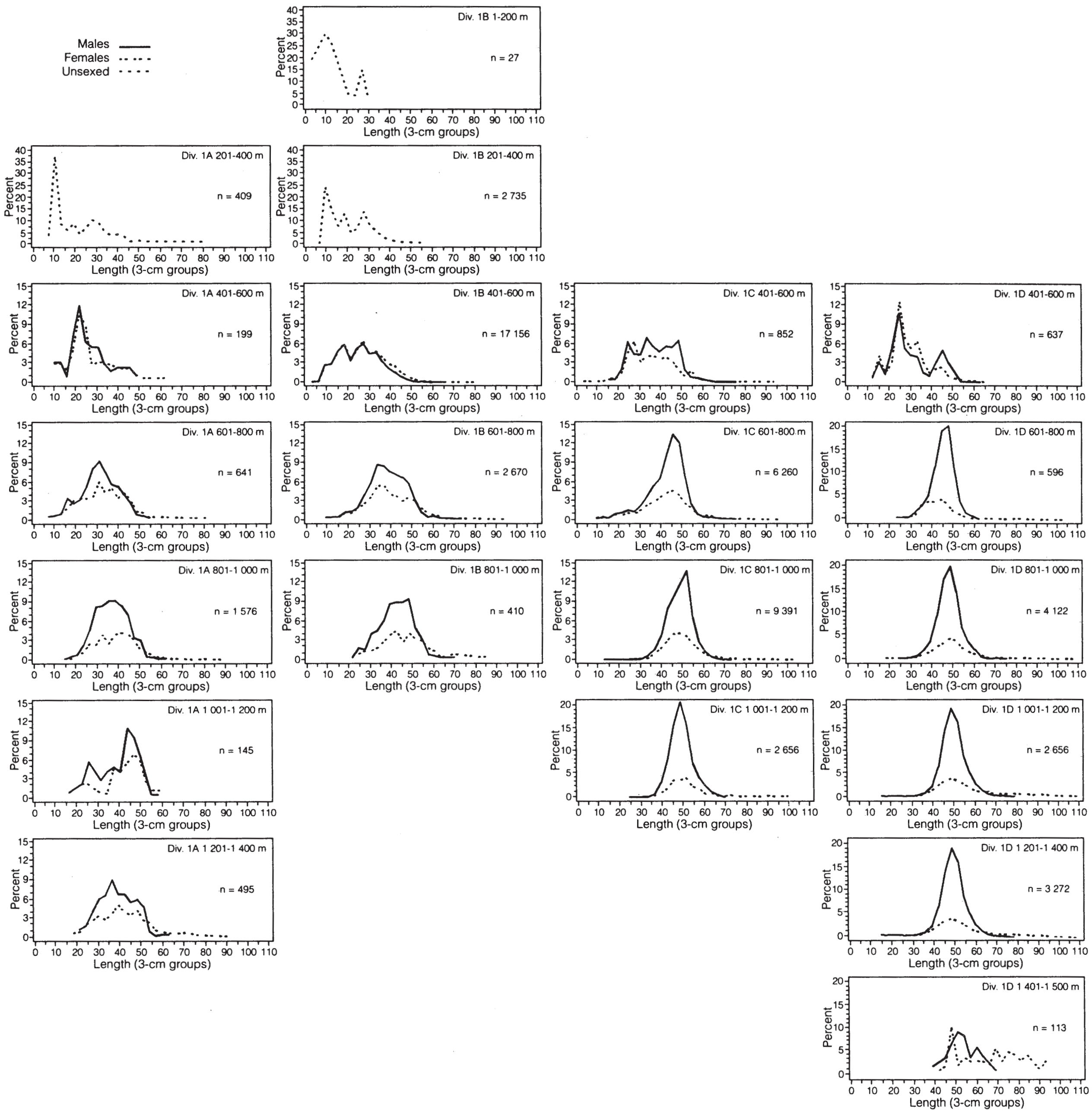


Fig. 5. Mean length distributions of Greenland halibut from four surveys conducted in August–September in the period 1990–93 by Division and depth stratum.

halibut were found more northward in shallower water, with the main concentration occurring at 900–1 100 m (Fig. 7). In August/September, the area with highest density was located further north and the stock concentrated in a rather limited area between 64°N and 64°45'N at depths around 700–1 000 m (Fig. 8). In late-September early-October, the stock dispersed over a large area and in deeper water (Fig. 9). Later in the year, November/December, the main distribution occurred once again in deep water in the southern part of the area investigated (Fig. 10). The main concentration was found at greater depths than in early-May. The distribution shown in Fig. 10 is based on a limited number of observations, and there were no observations from the important central part of the distribution area. On the other hand, the catches were high at all the deep stations, while the catches around the main

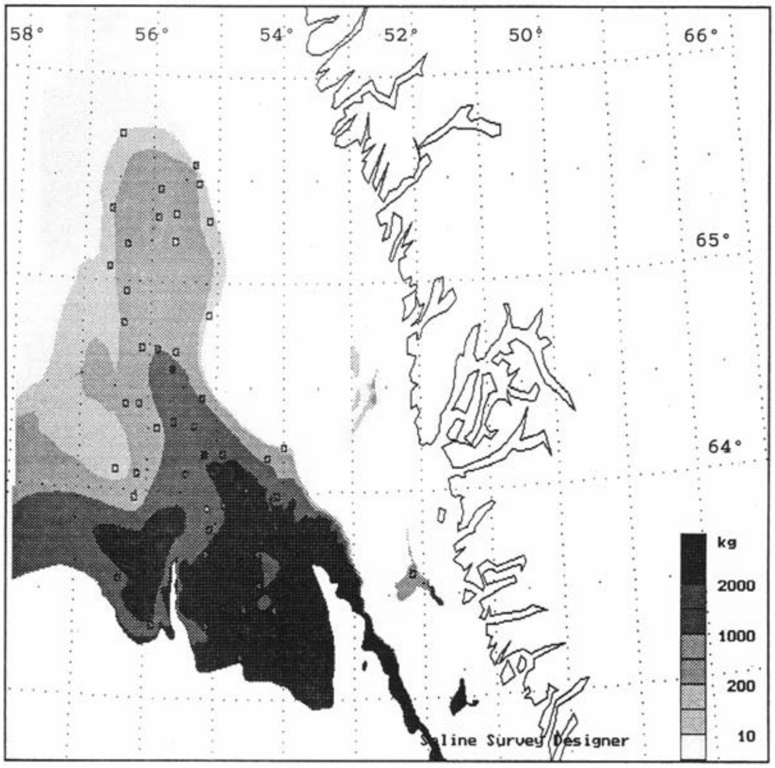


Fig. 6. Distribution (kg km$^{-2}$) of Greenland halibut in spring (30 April–17 May 1989).

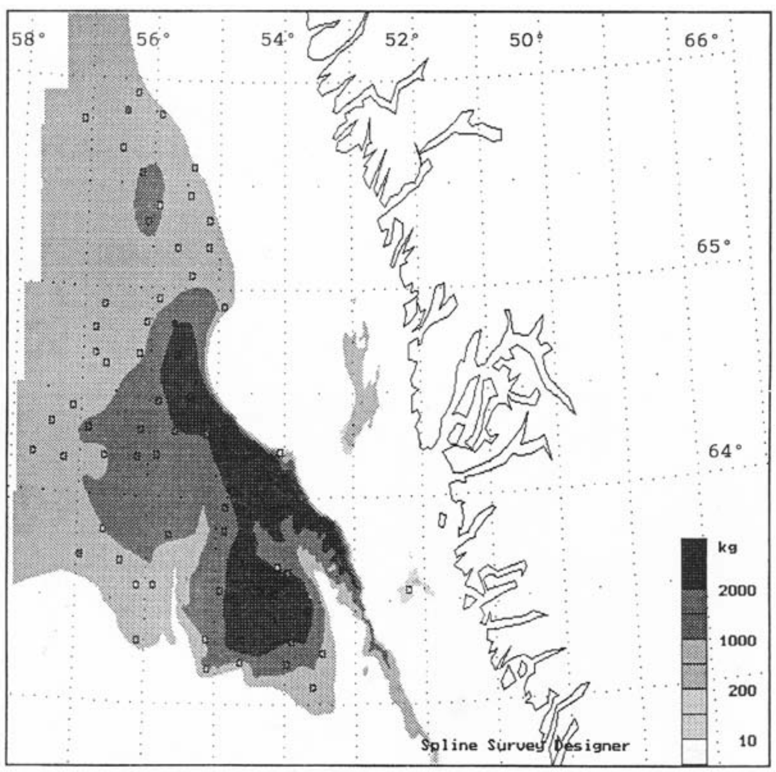


Fig. 7. Distribution (kg km$^{-2}$) of Greenland halibut in early summer (9 June–27 June 1990).

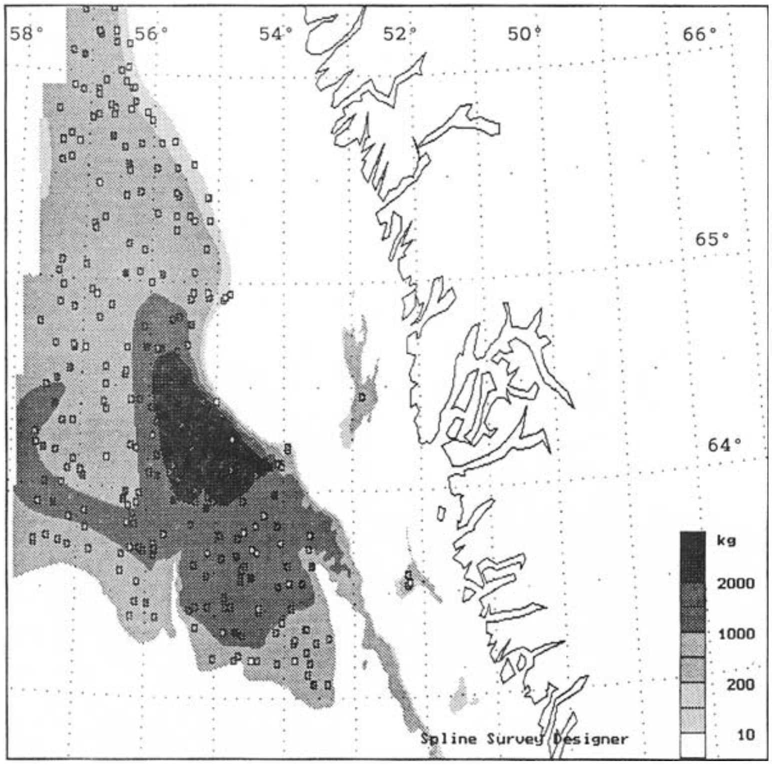


Fig. 8. Distribution (kg km$^{-2}$) of Greenland halibut in late summer. Mean distribution of four surveys conducted in August–September 1990–93.

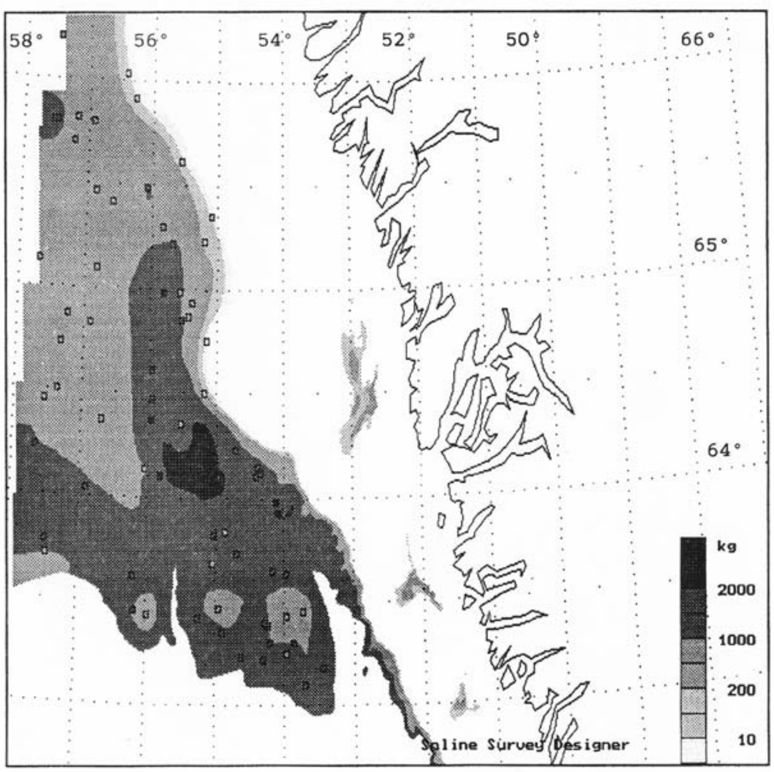


Fig. 9. Distribution (kg km$^{-2}$) of Greenland halibut autumn (12 September–11 October 1988).

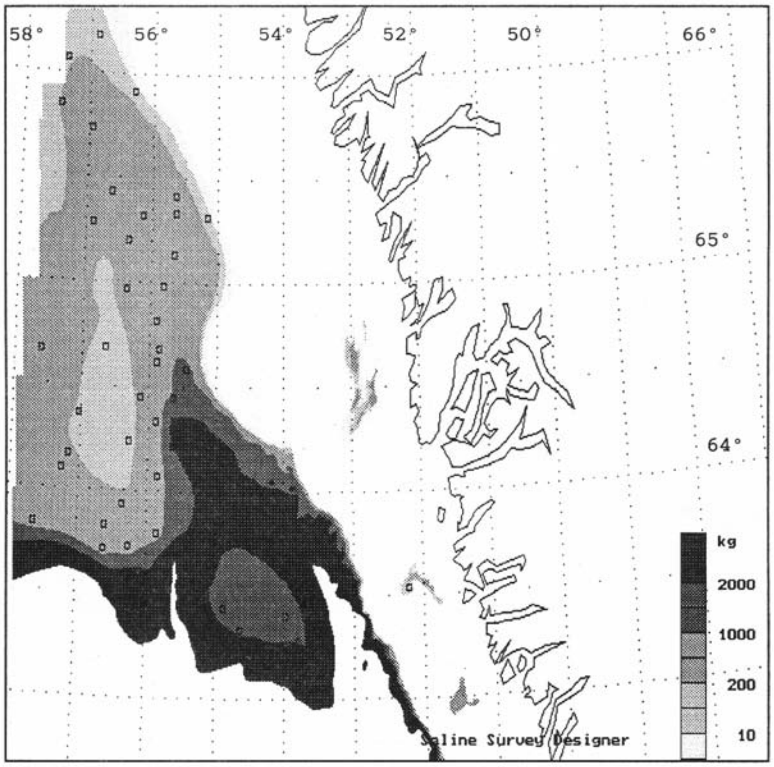


Fig. 10. Distribution (kg km$^{-2}$) of Greenland halibut in early winter (24 November–10 December 1992).

summer distribution area were low at all stations except one.

The surveys were conducted in different years and the observed distribution pattern may be caused by an inter-year variation in the distribution. However, the distribution patterns found in four surveys conducted in August/September from 1990 to 1993 were similar (Fig. 11a–d) suggesting that the distribution is reasonably constant between years. Data from these surveys are thus combined in Fig. 8.

A comparison of the length distributions in Div. 1D in spring (1989) with those in summer/autumn (1990:2) (Table 1) with a likelihood-ratio Chi-square test, showed that length distributions were significantly different (P <0.01) between the two periods for both sexes at all three depth strata between 801 and 1 400 m. There were more males smaller than 48 cm and less greater than 48 cm in spring than expected by the test in depth stratum 801–1000 m. The same pattern was seen for males at depth stratum 1 001–1 200 m – more males below 51 cm and less greater than 51 than expected. No test could be performed for females in depth stratum 801–1 000 m. In depth stratum 1 001–1 200 m the tendency for females was not quite unambiguous – there were less females than expected below 45 cm, more between 45 and 65 cm and less females greater than 65 cm in spring. At depth stratum 1 201–1 400 m the picture was somewhat reversed in comparison to the two shallower depth strata i.e. there were less males below 42 cm and generally more greater than 42 cm, and less females below 51 cm and more greater than 51 cm in spring than expected.

The length distributions in the summer/autumn survey and winter survey in 1992 (Table 1) were significantly different (P<0.00). The test showed that there were observed more small fish and less large fish than expected during the winter at each of the depth strata for both sexes. In the case of the males, there were more fish less than, and fewer greater than expected for 39, 48 and 51 cm, respectively, for successive depths. Similarly, for females there were more smaller than, and fewer less than 45, 48 and 60 cm, respectively.

These observed differences in the pattern of the length distributions, with a dominance of small fish in spring and especially in winter compared to summer/autumn, strongly supported the hypothesis

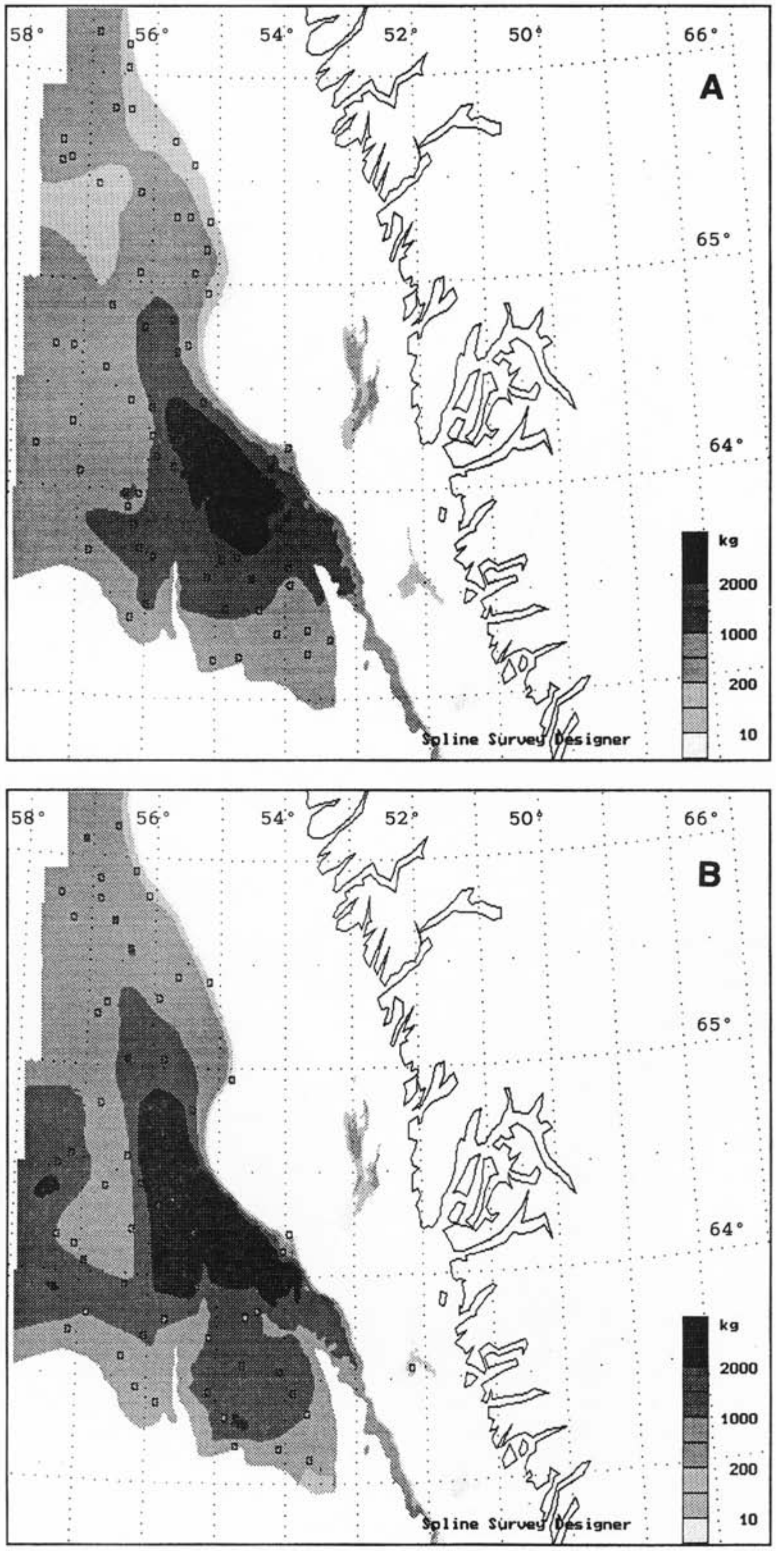


Fig. 11. Distribution (kg km$^{-2}$) of Greenland halibut in (**A**) August–September (8 August–12 September 1990), (**B**) August (4 August–30 August 1991), (**C**) August (8 August–28 August 1992), (**D**) August–September (20 August–8 September 1993).

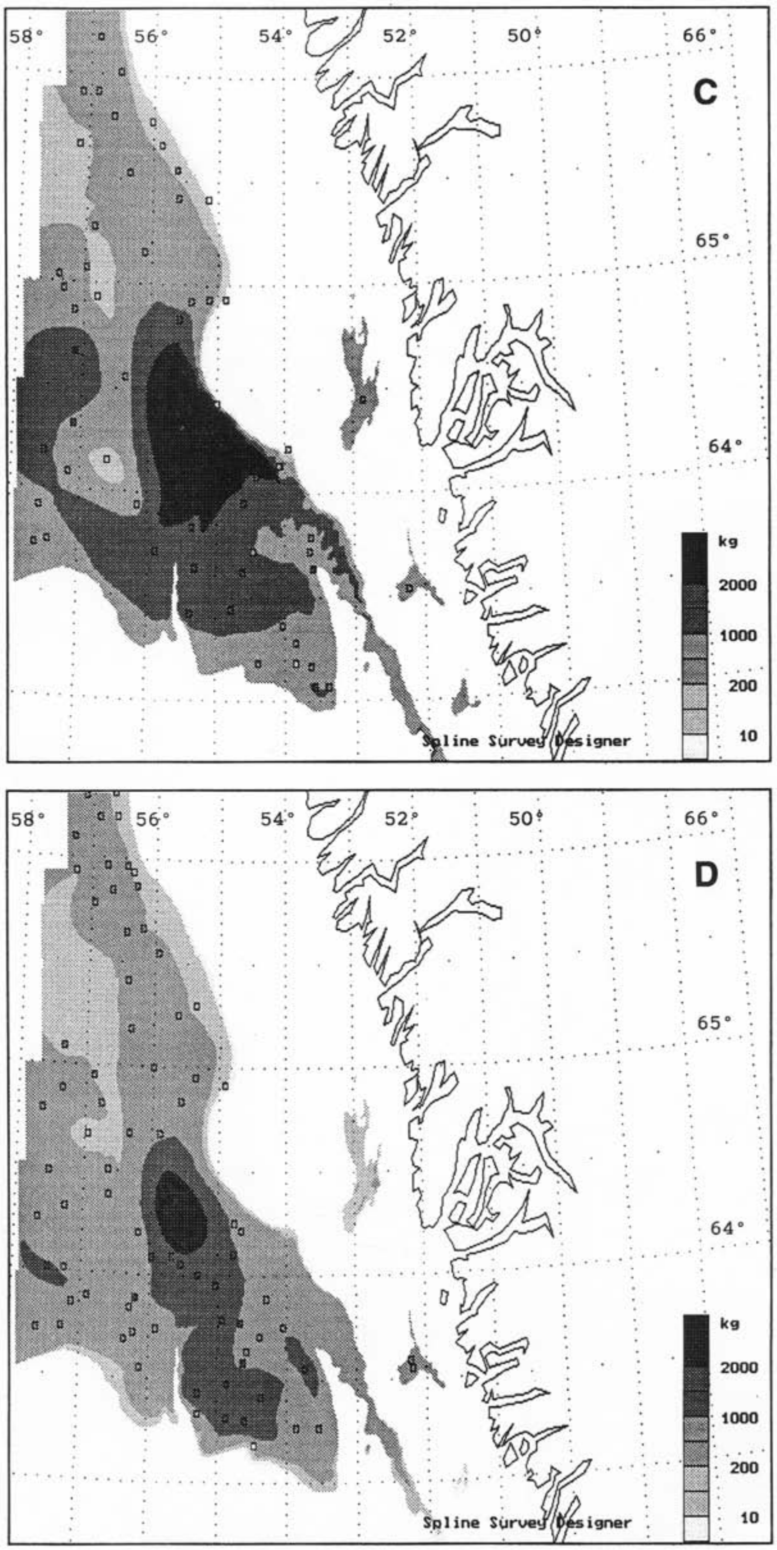


Fig. 11. (Continued). Distribution (kg km$^{-2}$) of Greenland halibut in (**A**) August–September (8 August–12 September 1990), (**B**) August (4 August–30 August 1991), (**C**) August (8 August–28 August 1992), (**D**) August–September (20 August–8 September 1993).

that the whole stock moves to greater depths during winter. The observation of a relatively large number of large fish at depth stratum 1 201–1 400 m in spring suggested that the stock was making its way back towards shallower waters, as the distribution pattern revealed from the comparison between the summer/autumn and the winter distributions indicated that the general winter distribution is deeper, than the spring and summer/autumn distributions.

**Gonadosomatic index**

The GSI for Div. 1C and 1D combined, increased markedly from spring to summer and through to autumn for a large proportion of males and females (Fig. 12). The index was generally below 1 for males in spring, and there was generally very little indication of a beginning maturation. In summer, the development of the gonads started and GSI increased to a maximum of about 4. Gonad development continued through the autumn where the GSI reached a maximum of about 9, however the bulk of the maturing males had a GSI between 2 and 5. The maturation of males seemed to start at a length of about 38–40 cm, however, it should be noted that some of the larger fish did not seem to mature every year, having GSIs below one in the year observed.

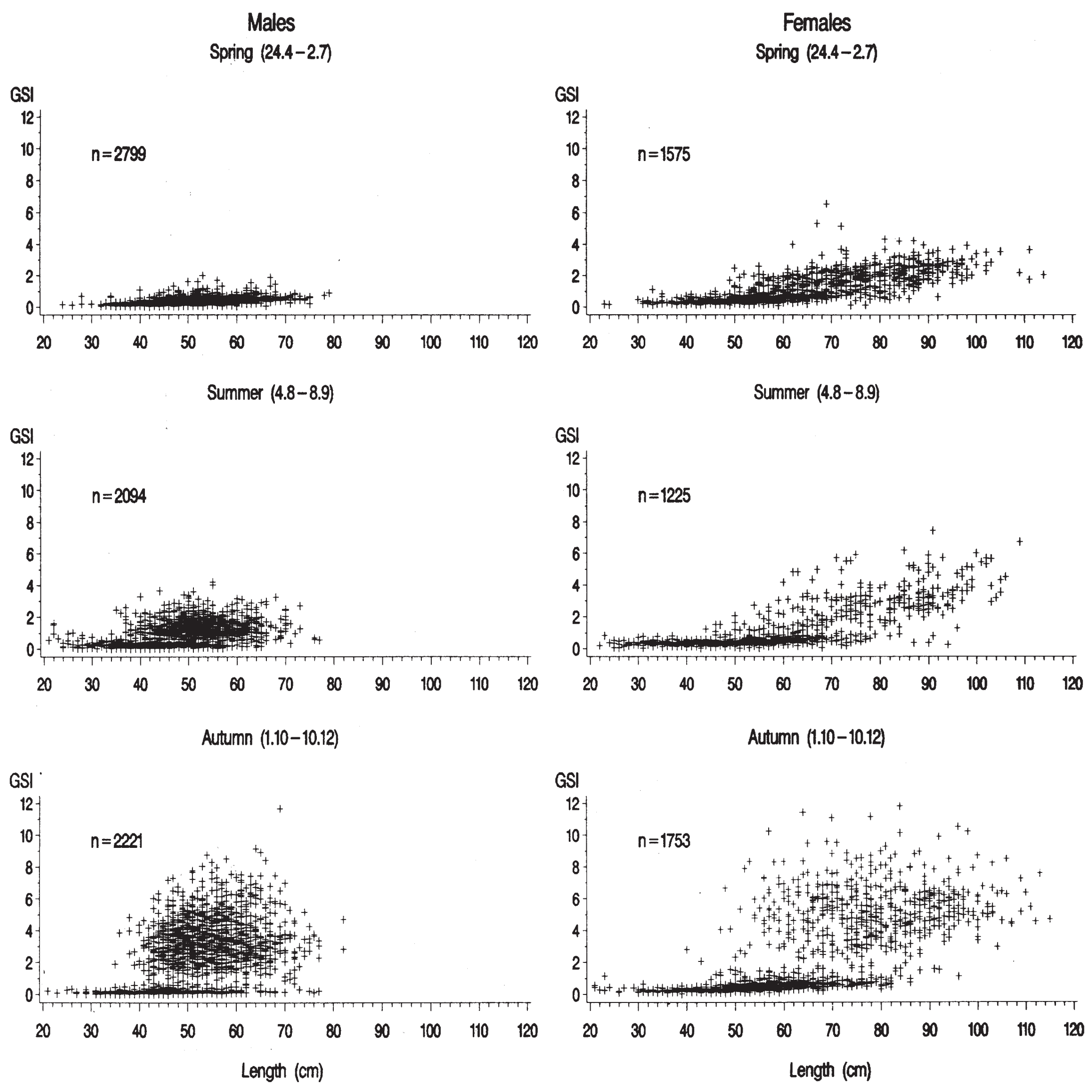


Fig. 12. Gonadosomatic index (GSI) in spring summer and autumn for males and females.

Similar development in GSI was seen for females. GSIs were generally below 3 in spring, increasing during summer and continuing to increase further in autumn to values between 2 and 11. Maturation seemed to begin at a length of 48–50 cm for some females, but, as for males, a number of the larger females did not seem to mature every year.

If one arbitrarily considers fish with a GSI above 1.5 as maturing, there is no increase in maturity with depth. No maturing females were found at depths <800 m in autumn in Div. 1C and 1D. The percentage of maturing females in Div. 1D dropped from summer to autumn, which also may indicate that maturing females leave the area in the autumn for spawning (Jørgensen and Boje, MS 1994, for further documentation).

### Near bottom temperature

The mean near-bottom temperatures for all surveys ranged from 1.2°C in Div. 1A to 3.5°C in 1C. There was no significant difference (5% level) between years or seasons in any of the four Divisions (Table 2). Bottom temperatures ranged from 3.0 to 4.0°C in the main distribution area in Div. 1C and 1D throughout the years with a maximum difference between years of less than 0.6°C.

## Discussion

### Mean length by depth and in north-south direction

The settling of post larvae in late autumn and the large number of one year old fish (Fig. 2) at the slopes of the banks west of Disko (Div. 1A), and especially on the northern and western slopes of Store Hellefiske Bank (Div. 1B), suggest that this area is a nursery ground for Greenland halibut. Inferences about stock density of post larvae based upon bottom trawl data are likely biased because a large proportion of the small fish is found in the water column (Jørgensen, 1997). This investigation has shown that Greenland halibut are progressively distributed from the nursery grounds towards greater depths, either towards the Baffin Bay or the Davis Strait (Fig. 3 and 4) or towards the coast to the fjords of West Greenland (Riget and Boje, 1988). At a size of about 26 cm, the fraction of the population that is not found close to the Baffin Bay or the fjords, likely starts to migrate southward and progressively to deeper waters as they grow (Fig. 5) and begin to mature.

Bowering and Chumakov (1989) found that larger fish were predominant in the deeper water and also found that size increased off Canada from Div. 3K in the south towards the spawning area in Subarea 0 in the north. Taking into account results from tagging experiments which support the theory of a northward migration (Bowering, 1984), and the observation of decreasing size at maturity from south to north (Bowering, 1983), Bowering and Chumakov (1989) concluded that Greenland halibut migrate to the Davis Strait for spawning as they mature. The same conclusion was also reached by Atkinson *et al*. (1982).

Although the differences in length distributions between depth strata were statistically significant, and the significance was caused by an increase in the number of large fish with depth, the differences

TABLE 2. Mean bottom temperature (°C) and standard error (SE) by Division, year and cruise.

| | Year and Cruise Number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1988<br>1 | 1989<br>1 | 1990<br>1 | 1990<br>2 | 1991<br>1 | 1991<br>2 | 1992<br>1 | 1992<br>2 | 1993<br>1 | Mean |
| Div. 1A | | | | | | | | | | |
| Temperature | 0.88 | | | 1.18 | 1.44 | 1.28 | 1.38 | | | 1.23 |
| SE | 0.32 | | | 0.28 | 0.28 | 0.19 | 0.40 | | | |
| Div. 1B | | | | | | | | | | |
| Temperature | 3.05 | | 3.17 | 1.99 | 2.46 | 2.21 | 2.29 | | | 2.53 |
| SE | 0.32 | | 0.14 | 0.22 | 0.25 | 0.18 | 0.32 | | | |
| Div. 1C | | | | | | | | | | |
| Temperature | 3.42 | 3.74 | 3.60 | 3.40 | 3.48 | | 3.65 | 3.54 | 3.49 | 3.54 |
| SE | 0.11 | 0.13 | 0.03 | 0.96 | 0.05 | | 0.05 | 0.05 | 0.14 | |
| Div. 1D | | | | | | | | | | |
| Temperture | 3.39 | 3.35 | 3.36 | 3.40 | 3.31 | | 3.33 | 3.28 | 3.18 | 3.33 |
| SE | 0.03 | 0.04 | 0.04 | 0.49 | 0.05 | | 0.46 | 0.03 | 0.07 | |

in the length distributions between the depth strata in Fig. 5, especially in Div. 1D at depths >800 m, are hard to see. The number of large fish was, however, underestimated by the trawl used, since the catchability of Greenland halibut above 50 cm apparently decreases markedly with the size (Jørgensen, 1995). The length distribution seen in trawl catches (Fig. 5) therefore may not represent the true length distribution in the population. The mean lengths in deep waters shown in Fig. 3 and 4 may be underestimated, and the increase in size by depth may be more pronounced than observed.

The comparison between length distributions by depth and area at West Greenland was made on data from August/September. The uniform length distribution observed when comparing Div. 1C and 1D in depth stratum 801–1 000 m and 1 001–1 200 m (Fig. 5) therefore reflects that the majority of the stock is located around the border between Div. 1C and 1D at 64°15'N (Fig. 8) during this period.

**Seasonal variation in distribution**

The pattern of seasonal migration that can be deduced from Fig. 6–10 is based on information collected over a period of six years, assuming that the distribution patterns were the same every year. Variations in the distributions observed could be accidental or caused by environmental factors. However, the distribution patterns found in the four surveys conducted in August/September (Table 1, Fig. 11 a–d) were reasonably consistent, indicating that between-year variation in the distribution is limited. Furthermore, the stability in the bottom temperature with variations of less than 1°C between year, indicates that the seasonal variation in the distribution, described from surveys conducted in different years, are unlikely to be caused by a between-year differences in bottom temperature (Table 2).

The area between 64°N and 64°45'N, where Greenland halibut are found in high densities during summer and autumn, is an area with high primary and secondary production (Smidt, 1971). The seasonal migration observed is thus a migration between feeding areas and spawning areas, although not all large fish appear to participate in spawning every year (Fig. 12). As seen from differences in length distributions at different times of the year, juvenile and immature fish also take part in the migration. The entire population makes what can be considered an annual displacement between shallower feeding areas in summer/autumn to deeper waters in winter.

In Subarea 0, near what is assumed to be the spawning area, Bowering and Chumakov (1989) found that the main distribution occurred at depths between 750 and 1 000 m in summer and beyond 1 000 m in autumn/winter surveys, respectively, indicating a seasonal migration pattern very similar to that observed in West Greenland. In Iceland, tagging experiments have shown that Greenland halibut move eastward towards feeding grounds north of Iceland in early summer (Sigurdsson, 1979). Data based on fisheries statistics, together with tagging experiments, show that the fish leave the feeding grounds at the end of August to migrate towards spawning grounds west of Iceland, where they spawn south of 65°N in late winter and early spring at a depth of about 1 000 m and temperatures between 4 and 5°C. In April they leave the spawning grounds to migrate back to the feeding grounds. Smidt (1969) suggested that mature fish migrate from the fjords in West Greenland to the Davis Strait to spawn and that they return to the fjords after spawning.

From the investigations presented here it seems likely that Greenland halibut stay in the area in the relative warm offshore waters in Div. 1C and 1D after they have matured. There is no evidence of migration back north into colder waters or back into the fjords for feeding. Chumakov and Serebryakov (MS 1982) reached the same conclusion concerning the mature proportion of the offshore stock on the continental slope in Div. 0B, west of Div. 1D. Results of tagging experiments carried out in West Greenland fjords do not support the hypothesis of a migration between the fjords and the Davis Strait, as no fish tagged in the fjords have so far been recaptured offshore in the Davis Strait (Boje, MS 1994).

Spawning seems to take place south of 64°N at depths beyond 1 200 m and temperatures between 3.0 and 3.5°C (temperature at 2 000 m; E. Buch, pers. comm., Royal Danish Administration of Navigation and Hydrography). From the development of the gonads, it seems that spawning takes place somewhere between mid-December and mid-April, probably some time between the two periods because no ripe individuals were observed during the winter cruise and no newly spent individuals were observed during the spring cruise.

Future research should concentrate on locating the spawning area and spawning time of Greenland halibut even more precisely, taking into account that spawning may take place all along the continental shelf in Davis Strait and Labrador Sea, as spawning has been reported from as far south as Flemish Pass east of Grand Bank (Junquera and Zamarro, 1994). Furthermore, the status of the stock in Baffin Bay and its relationship to the stocks in the Davis Strait and Northwest Greenland fjords should be investigated. Baffin Bay is separated from Davis Strait by a submarine ridge between West

Greenland and Baffin Island around 66°30'N. The ridge has a maximum depth of about 700 m and specimens of Greenland halibut which have started to migrate down into Baffin Bay probably stay here and continue to migrate towards greater depths in the central part of the bay and never cross the ridge to get back to the area where they were spawned. Recruitment to the Northwest Greenland fjords is hypothetical to derive from Davis Strait, however, it is difficult to explain how larvae from Davis Strait are able to reach this area, when one considers the slow speed of the northern branch of the West Greenland current into account (Kiilerich, 1943). Are the Greenland halibut in Northwest Greenland, and as far north as Thule, actually recruited from Baffin Bay area?

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