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Offshore Distribution Pattern of Greenland Halibut (*Reinhardtius hippoglossoides* (Walb.), at West Greenland

by

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Introduction

The main spawning area for Greenland halibut in the Davis Strait is located at great depths south of 67°N (Jensen, 1935; Smidt, 1969; Templeman, 1973). Greenland halibut are supposed to spawn in winter and early spring, although no direct observations of spawning individuals have been made. The pelagic eggs and larvae drift with the current along the West Greenland and the East Canadian coasts and small fish settle at the banks off Greenland and Canada (Bowering and Chumakov, 1989). Bowering (1984) showed that Greenland halibut in Canadian waters gradually move to greater depth and northward towards the expected spawning area, as the grow.

Seasonal migration of Greenland halibut between spawning areas and feeding areas has been observed in Gulf of St. Lawrence (Bowering, 1982) and in Icelandic waters (Sigurdsson, 1979). Further, results of tagging experiments at the Funk Island Bank indicates a migration of small fish towards inshore areas in summer (Bowering, 1984), which might be considered as feeding migrations.

Ernst (1987) combines the observations from Canada and he describes the two types of migrations as spiral like combination of a gradual northward movement with a seasonal feeding and (for larger fish) spawning migrations between shallow and deep water, Based on limited information from various sources Riget and Boje (1989) indicate that a north south movement towards the assumed spawning area and a gradual movement from shallow to deeper water might take place at West Greenland as well. The present paper documents that these migrations in fact takes place at West Greenland and shows a seasonality in the distribution of Greenland halibut that is related to spawning migration.

Material and methods

From 1988 to 1993 9 random stratified bottom trawl surveys were conducted off West Greenland at different time of the year:

Year	Cruise	Hauls no of	Date
1988		88	12. 9 - 11.10
1989		61	30. 4 - 17. 5
1990	I	75	9. 6 - 28. 6
1990	II	88	27. 8 - 12. 9
1991	I	139	4. 8 - 30. 8
1991	II	51	11.11 - 22.11
1992	I	90	11. 8 - 28. 8
1992	II	49	24.11 - 10.12
1993	I	87	20. 8 - 8. 9
Total		728	

In total 728 trawl hauls were carried out in NAFO Divisions 1A (south of 70°N) - 1D of which 539 were taken in NAFO Division 1C-1D (Fig. 1). The surveys were carried out by the Japanese stern trawler SHINKAI MARU and covered areas between the 3-mile limit and the 200 mile limit or the midline against Canada. 636 of the hauls covered depths between 400 - 1500 m, while 92 hauls covered depths between 38 and 400 m in 1A and 1B (Cruise I and II in 1991 only). Wing spread was 40 m and towduration and towing speed was 30 min and 3.5 kn., respectively. The codend was equipped with a 30 mm mesh liner. For further information about vessel and gear see Yamada et al., 1988. All catches of Greenland halibut were measured as total length (ttl) to cm below and weighted and catches were standardized to kg pr swept km^2. The distribution of Greenland halibut was calculated by the spline approximation method of stock density (Stolyarenko, 1986, 1987). Gonads were weighted to 0.1 g and samples collected in Div. 1C and 1D from both the trawl surveys and commercial fisheries with same vessel are include in the calculation of the gonadindex: (gonad weight*1000)/ttl^3. The total period hence covered was 24.4 - 10.12. Near bottom temperatures were measured at all stations by CTD or in few cases XBT.

Results

Mean length by north-south direction and depth.

In all surveys the mean length for both males and females increased within the same depth stratum (200 m depth intervals) from north to south (Div. 1A to Div. 1D) in the five depth strata covering depths between 400 and 1400 m (Table I). The length distribution by depth strata and Divisions from August 1991 is given in Fig. 2a-b as an example of a typical length distribution in summer.

The mean length at the different depth strata in each cruise has been analyzed by a two way ANOVA:

Model: Mean length = depth + NAFO Div + noise

The increase was highly, significant P > 95%, for both sex in cruise 1990 (II), 1991 (I) and for males in 1992 (I) when there were a good coverage in all three surveys in almost all Divisions and depth strata (Table II). The trend was generally very clear, although not statistically significant, for both sex in all other surveys and for females in 1992 (I).

Within the same Division the mean length was generally increasing by depth in all surveys (Table I). The increase was highly significant (p > 95%) for both males and females in 1989, 1990 (II), 1991 (I) and 1992 (I) and for females in 1990 (I) (Table II). The trend was clear for both sex in all other surveys and for males in 1990 (1), although not statistically significant.

In 1991 survey I also covered depths shallower than 400 m in Div. 1A and 1B, besides depths between 400 and 1500, and later that year a second survey was conducted covering shallow waters (1-1000 m) in Div. 1A and 1B only (Table III). In these two surveys there were found no significant differences between mean length in the two Divisions (Table IV) (the analysis was performed for the two sexes combined due to a large number of small fish not sexed). In both surveys an increase in mean length by depth was seen. The increase was highly significant (P > 99%) in the I. survey. The drop in mean length from the I. survey to the II. was due to settling of small Greenland halibut observed as a distinct mode at 6-9 cm in the length distribution in the II. survey.

A Duncans Multiple Range Test on the mean lengths (results not included) showed for both sex, in all cases where there were sufficient data (except in 1993 when Div. 1A not was surveyed), that there was a clear grouping of the two northern Divisions 1A and 1B and a grouping in the two southern Divisions 1C and 1D. When testing for depth there was a grouping for both sex in shallow strata 400-800 m, while there were no evident groupings in the deeper strata. In the two surveys in 1991 there was a grouping in the two shallow strata 0-400 m and in the three deep strata 400-1000 m in the I survey, while there were no groupings in the II survey.

Seasonal variation in distribution.

The main distribution area in spring is at deep water, > 1200 m, in the southern part of the area (Fig. 3). During early summer (June) Greenland halibut is gradually moving north into shallower water and the densest concentration is found at 900 - 1200 m (Fig. 4). In August/September the main concentration is found between 64°N and 65°N at depth around 700 - 1000 m (Fig. 5). In late September early October the migration towards deeper water seems to have started (Fig.6). Later in the year, November/December, the main distribution area is again at deep water in the southern part of the area (Fig. 7).

Figure 5 shows the mean of four surveys conducted in August/ September from 1990 - 1993. The distribution in each of these surveys is given in Fig. 8 a-d, from which it is seen that there is a good consistency between years.

Gonadindex.

The gonadindex is increasing significantly from spring to summer and again to autumn for both males and females (Fig. 9). The index for males is below 2 in spring, between 1 and 4 for a part of the population in summer and between 1 and 9 in the autumn. The same development is seen for females where the index generally is below 3 in spring and increases during the summer and increasing further in the autumn to be between 2 and 11. Males start to mature at about 38 cm and females about 48 cm. But a number of large individuals of both sexes don't seem to mature.

Near bottom temperature.

The mean near bottom temperatures were not significantly (P>95%) different between years or seasons in any of the 4 Divisions (Table V). The overall mean for all surveys ranged from 1.23 °C in 1A and 3.54 °C in 1C. In Greenland halibuts main distribution areas in 1C and 1D the bottom temperature ranged from 3.0 to 4.0 °C throughout the years and also here no seasonal variation was observed.

Discussion

Mean length by north-south direction and depth.

Small Greenland halibut are very abundant at the bank West of Disko (1A) and on the northern and western slope of Store Hellefiske Bank (1B) (Smidt 1969, Riget and Boje 1988) and the area is considered to be an important nursery ground, which is supported by the clear grouping of these two Divisions in the Duncan Multiple Range Test. Further, the results of this study shows an increase in means size of both males and females when moving from north to south as they grow and start maturing, which can be interpreted as a gradual movement from the nursery grounds towards deeper waters and the spawning area in south.

Bowering and Chumakov (1989) found a similar increase in size off east Canada when moving progressively from Div. 3K in south to Subarea 0 in north and they also found that larger fish predominated in the deeper water. Taking into account results from tagging experiments at East Canada, that supports the theory of a northward migration (Bowering 1984), and the observation of a decreasing size at maturity from south to north (Bowering 1983) Bowering and Chumakow (op. sit) conclude that Greenland halibut migrates to the Davis Strait for spawning as they matures.

Seasonal distribution.

Based on the good consistency in the distribution pattern found in four surveys conducted in August/September (1990 II, 1991 I 1992 I and 1993) (Fig. 8 a-d) the following pattern of seasonal migration of Greenland halibut at West Greenland can be revealed, although data are not collected in the same year.

In spring individuals with undeveloped gonads, probably after spawning, gradually moves from deep water > 1200 m towards shallow water in early summer and further towards what probably can be considered as summer/autumn feeding grounds at depths between 700 and 1000 m, while the gonads develop. In late autumn and early winter Greenland halibut starts to move back towards deeper water again, while the gonads develops further.

The Greenland halibut seems to stay in the area in this relative warm water after they have become mature, and there are no

evidence of migration back into colder waters for feeding. Chumakov and Serebryakov (1982) reached the same conclusion conserning the mature part of the stock on the continental slope in Div. 0B west of Div. 1D.

From the development of the gonads it seems that spawning takes place somewhere between mid December and mid April, probably some time from the two periods because no individuals with ripe eggs or running milk were observed in neither the spring nor the winter cruise, and spawning seems to take place south of 64°N at depths beyond 1200 m at temperatures between 3.5 and 3.0 °C (temperature at 2000 m) (Pers. com., E. Buch, Royal Danish Administration of Navigation and Hydrography, Ovengaden O. Vandet 63B, DK-1023 Copenhagen K, Denmark).

Not all fish seem to spawn every year but juvenile and immature fish take part in the migration and what can be considered as an annual displacement of the population from shallower water in the summer to deeper water in the winter seems to take place.

This type of seasonal movements of Greenland halibut have been seen elsewhere. In Subarea 0, near what is assumed to be the spawning area, Bowreing and Chumakov (1989) found the main abundance at depths between 750 and 1000 m in summer and beyond 1000 m in autumn/winter surveys, respectively, indicating a migration pattern very similar to what is found off West Greenland. And based on the distribution maps it can be concluded that Greenland halibut in the eastern and western side of the Davis Strait is part of the same population.

At Iceland tagging experiments have shown that Greenland halibut in early summer moves eastward towards the feeding grounds north of Iceland, and data based on fisheries statistics together with tagging experiments shows that the fish leaves the feeding grounds at the end of August to migrate towards the spawning grounds west of Iceland were they spawn in late winter and early spring at about 1000 m depth south of 65°N. In April they leave the spawning grounds to migrate back to the feeding grounds (Sigurdsson, 1979).

Temperatures.

Small Greenland halibut settle at the nursery grounds were near bottom temperatures normally are about 1-2 °C, although temperatures down to about 0 °C frequently are observed. From here they gradually moves southward into areas with bottom temperatures between 3 and 4 °C. With no significant differences in the temperature between different times of the year at the feeding grounds it does not seem to be the temperature that trick the seasonal migrations.

Bowering and Chumakov (1984) found peak temperatures at 3.1-4.0 in 2GH in summer and < 0 °C in autumn in 2J an 3K far from the supposed spawning area, and Sigurdson (1979) reports temperature at the feeding grounds < 0 °C and at the spawning grounds 4-5 °C, all of which is in good agreement with what is found at West Greenland.

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Table I. Mean length by year, cruise, depth stratum and division for males and females, respectively.

Year / Depth	Crs. Div.		1988	1989	1990		1991	1992		1993
			1	1	1	2	1	1	2	1
401-600 m	1A	M	33.5			29.4	37.4	32.5		
		F	36.5			31.0	37.5	34.0		
	1B	M	27.8		37.6	35.2	29.9	31.3		36.3
		F	22.8		38.1	36.3	31.0	32.2		38.1
	1C	M	40.1	40.7	47.9	37.3	40.8	35.7	40.0	38.7
		F	37.5	43.2	49.4	33.8	41.3	33.5	40.2	39.3
	1D	M		43.8	44.0	47.1	41.5	33.3		28.6
		F		45.8	43.9	43.2	38.0	29.8		31.3
601-800 m	1A	M					37.7	30.0		
		F					38.2	33.6		
	1B	M	42.8			40.0	39.9	38.4		37.7
		F	43.5			41.4	40.8	39.5		40.1
	1C	M	42.2	42.1	48.7	44.3	44.4	44.3	38.6	40.6
		F	41.0	44.2	51.9	45.4	44.2	43.6	37.0	40.6
	1D	M			49.6	49.1	47.3	45.5	44.0	
		F			52.1	51.8	44.1	44.7		
801-1000 m	1A	M	40.0			39.4	38.3	37.6		
		F	40.6			40.9	40.7	41.5		
	1B	M	44.2			45.5	40.7			
		F	48.8			50.1	43.1			
	1C	M	48.5	45.3	49.7	48.4	49.2	48.7	42.5	45.4
		F	52.0	48.5	55.0	49.0	52.2	51.0	43.4	48.5
	1D	M	50.6	45.8	49.2	49.6	49.1	48.0	43.8	47.5
		F	53.7	47.9	54.6	53.0	53.3	49.7	44.7	50.2
1001-1200 m	1A	M				41.3				
		F				45.6				
	1C	M	52.3	48.4	51.0	50.8	50.9	49.1	44.8	48.1
		F	62.0	50.1	54.9	56.1	58.3	54.5	45.0	49.3
	1D	M	52.2	49.5	51.7	51.1	50.4	50.0	47.6	49.1
		F	59.6	53.1	58.1	57.3	54.6	57.8	48.8	55.6
1201-1400 m	1A	M	39.5			36.9	37.0	42.0		
		F	43.9			40.0	38.4	48.2		
	1D	M	51.9	52.6	51.4	52.0	50.3	51.3	48.1	50.3
		F	60.0	59.7	63.2	57.2	58.8	57.4	49.8	58.0
1401-1500 m	1A	M						39.5		
		F						42.6		
	1D	M	49.3	52.1	52.6	53.5	53.8			
		F	55.5	67.4	68.4	67.9	65.5			

Table II. Results of a two-way ANOVA by year, cruise and sex. (F^{*}, F^{**} and F^{***}: significant at 90%, 95% and 99% level, respectively).

Year	Cruise	Sex	Division F-value	Depth F-value	r^2
1988		M	4.18^{*}	3.67^{*}	0.91
		F	1.35	2.92	0.87
1989		M	3.97	20.17^{**}	0.99
		F	2.14	35.29^{**}	0.99
1990	I	M	9.62^{*}	3.73	0.96
		F	3.80	11.43^{**}	0.97
1990	II	M	28.57^{***}	9.41^{***}	0.95
		F	30.69^{***}	32.46^{***}	0.98
1991	I	M	14.62^{***}	5.98^{**}	0.93
		F	5.41^{**}	7.25^{***}	0.90
1992	I	M	8.21^{**}	8.68^{***}	0.92
		F	2.81	14.89^{***}	0.93
1992	II	M	6.99	3.95	0.94
		F	4.16	8.13	0.99
1993		M	0.35	4.74	0.88
		F	0.06	6.21^{*}	0.91

Table III. Mean length by cruise, division and depth in 1991. Sex unknown.

Depth	Div.	1991 I	1991 II
1-200 m	1A	15.3	10.8
	1B	14.5	8.7
201-400	1A	20.2	13.9
	1B	20.2	18.8
401-600 m	1A	37.1	
	1B	27.2	18.2
601-800 m	1A	37.8	
	1B	40.3	32.8
801-1000 m	1A	39.3	
	1B	41.6	

Table IV. Results of a two-way ANOVA in 1991 by cruise. (F^{*}, F^{**} and F^{***}: significant at 90%, 95% and 99% level, respectively).

Year	Cruise	Division F-value	Depth F-value	r^2
1991	I	0.27	20.06^{***}	0.95
	II	0.16	7.42	0.97

Table V. Mean temperatures, °C, and Standard Error by Division year and cruise.

	1988 1	1989 1	1990 1	1990 2	1991 1	1991 2	1992 1	1992 2	1993 1	Mean
1A										
Temp	0.88			1.18	1.44	1.28	1.38			1.23
SE	0.32			0.28	0.28	0.19	0.40			
1B										
Temp	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			
1C										
Temp	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	
1D										
Temp	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	

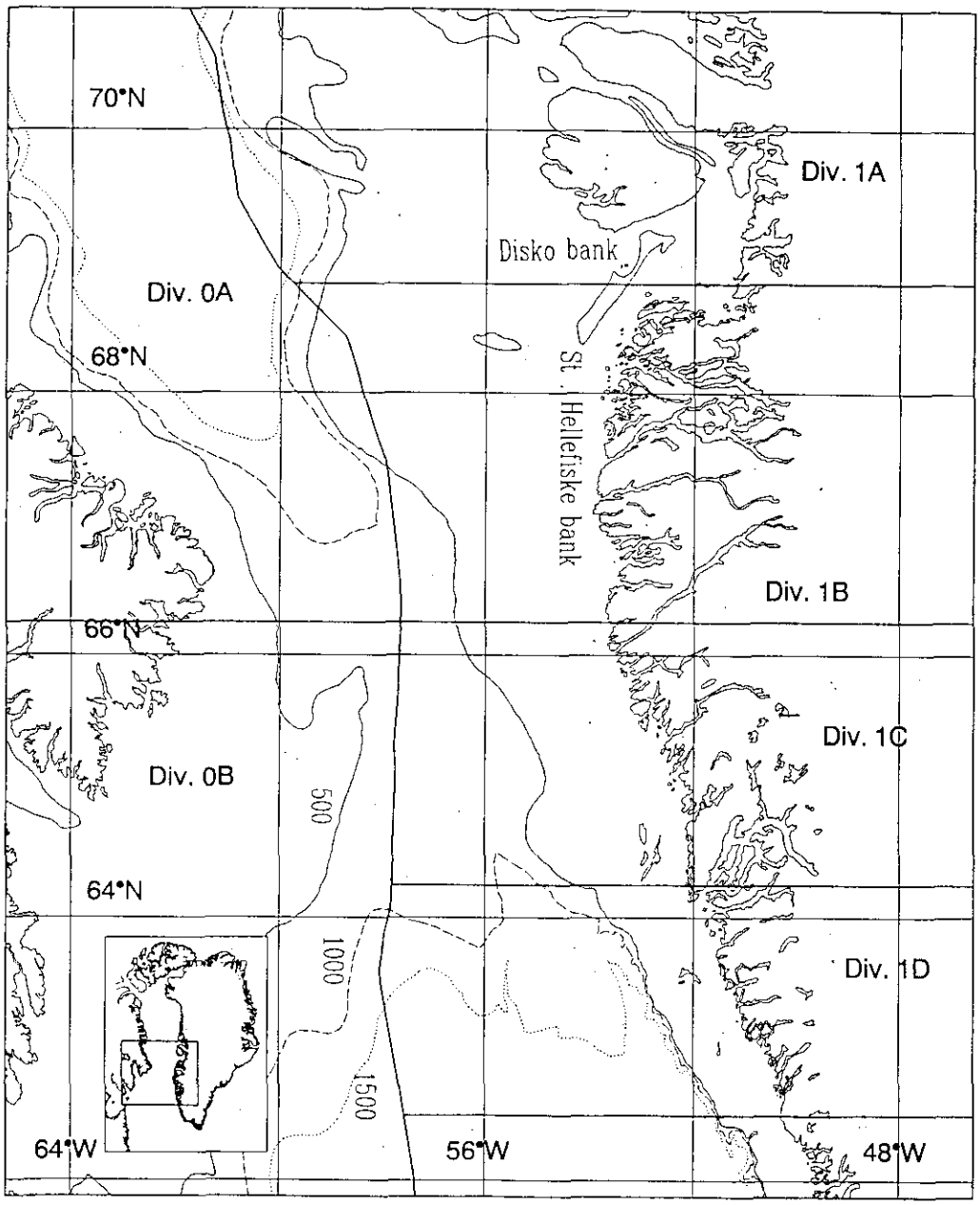

Fig. 1. The investigation area with NAFO Subarea 0 (Divisions A + B) and Subarea 1 (Divisions A-D), the midline between Greenland and Canada, the 500, 1000 and 1500 m depth contour lines and locations mentioned in the text.

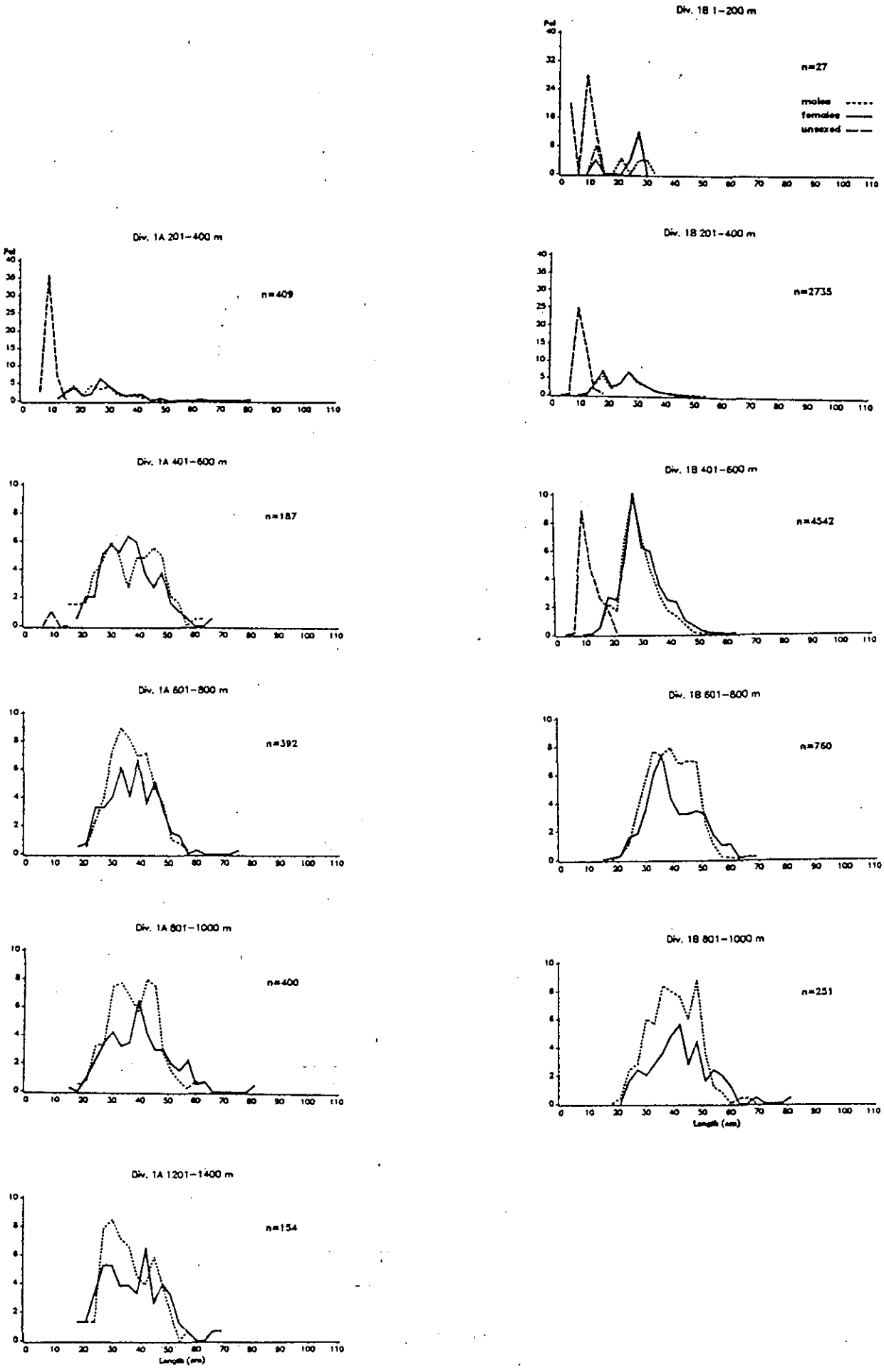

Fig. 2a. Length distribution August 1991 in Div. 1A and 1B distributed on 200 m depth intervals. Notice different scales on y-axis.

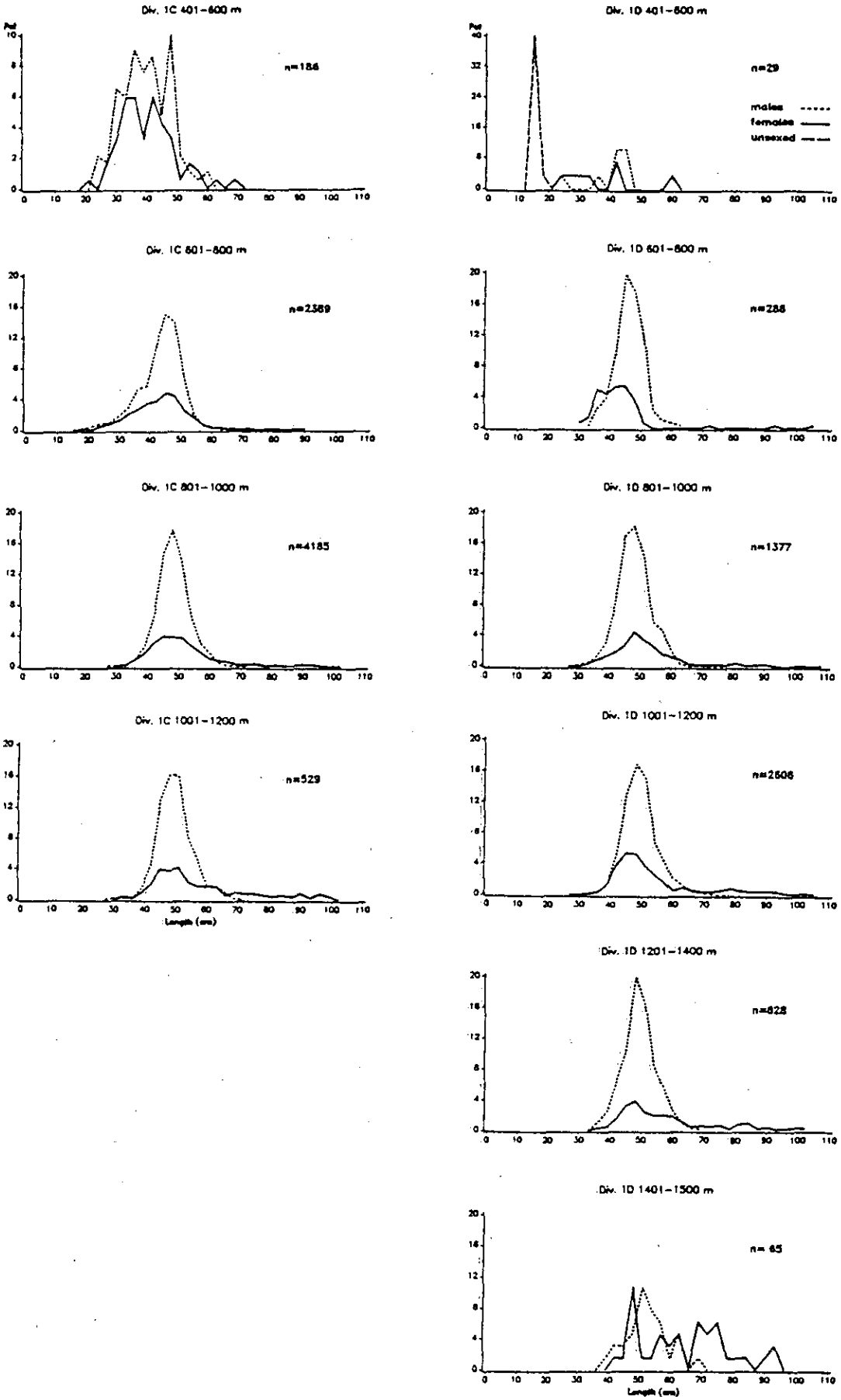

Fig. 2b. Length distribution August 1991 in Div. 1C and 1D distributed on 200 m depth intervals. Notice different scales on y-axis.

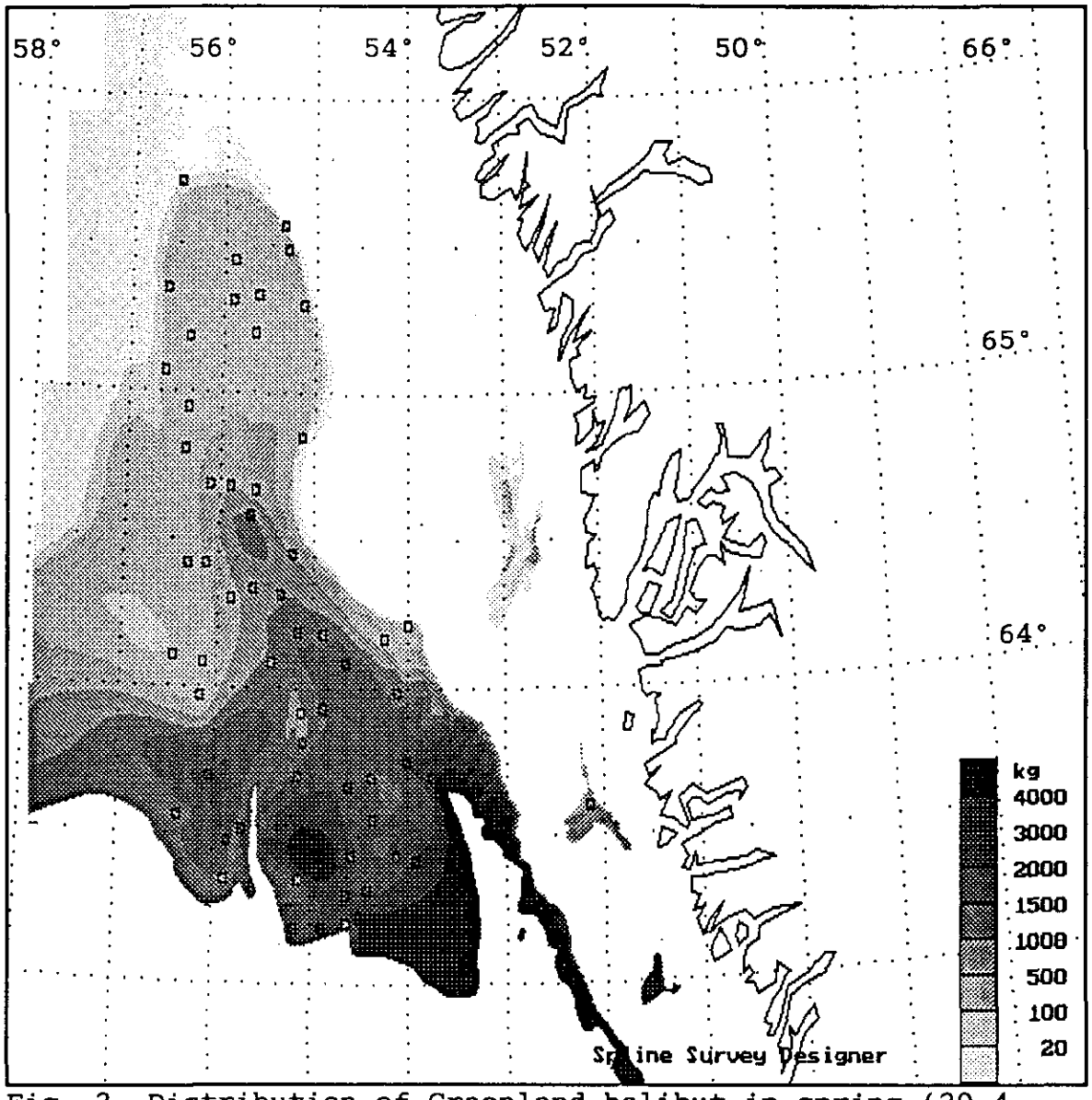

Fig. 3. Distribution of Greenland halibut in spring (30.4 - 17.5 1989)

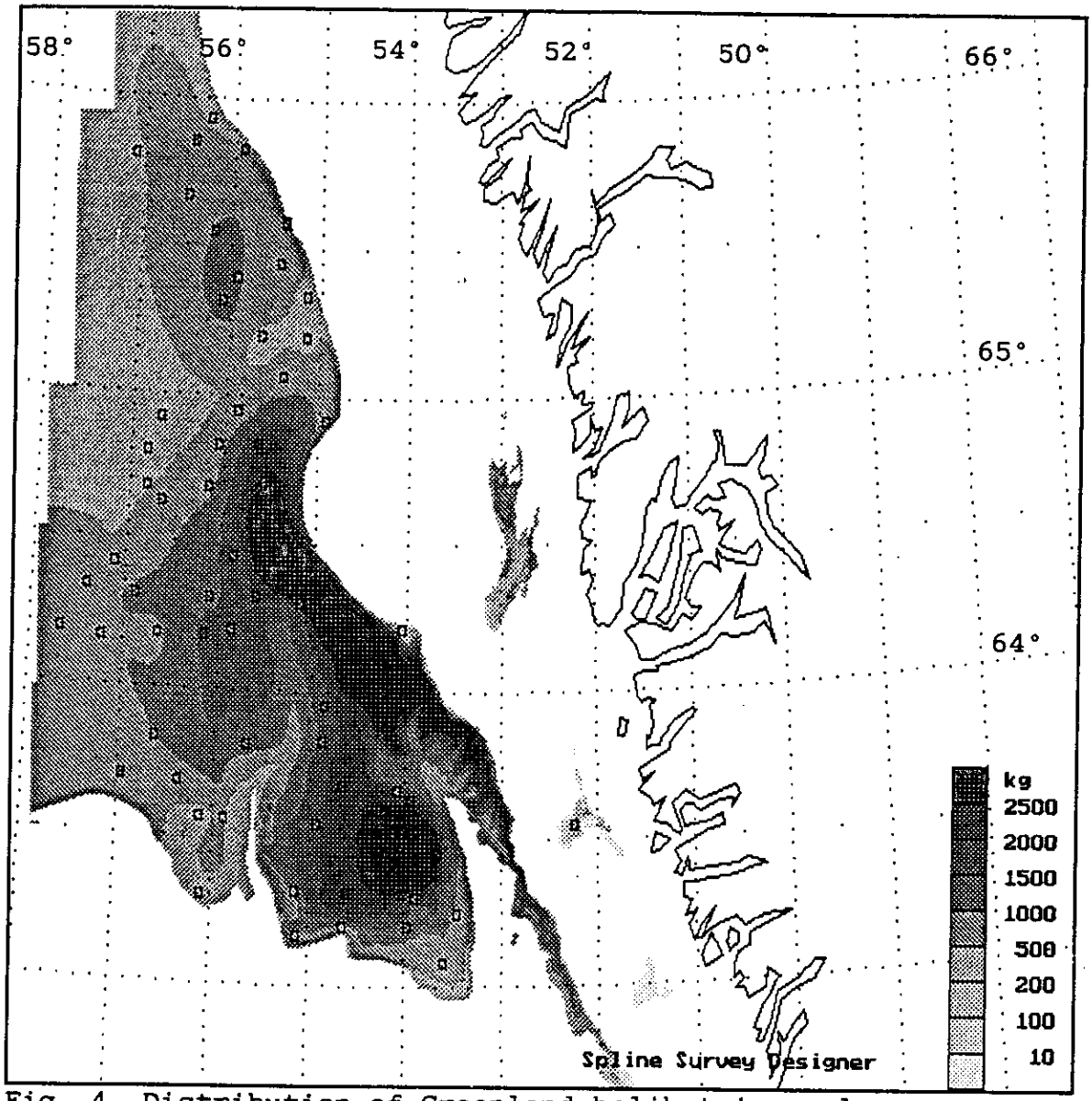

Fig. 4. Distribution of Greenland halibut in early summer (9.6 - 28.6 1990 (1)).

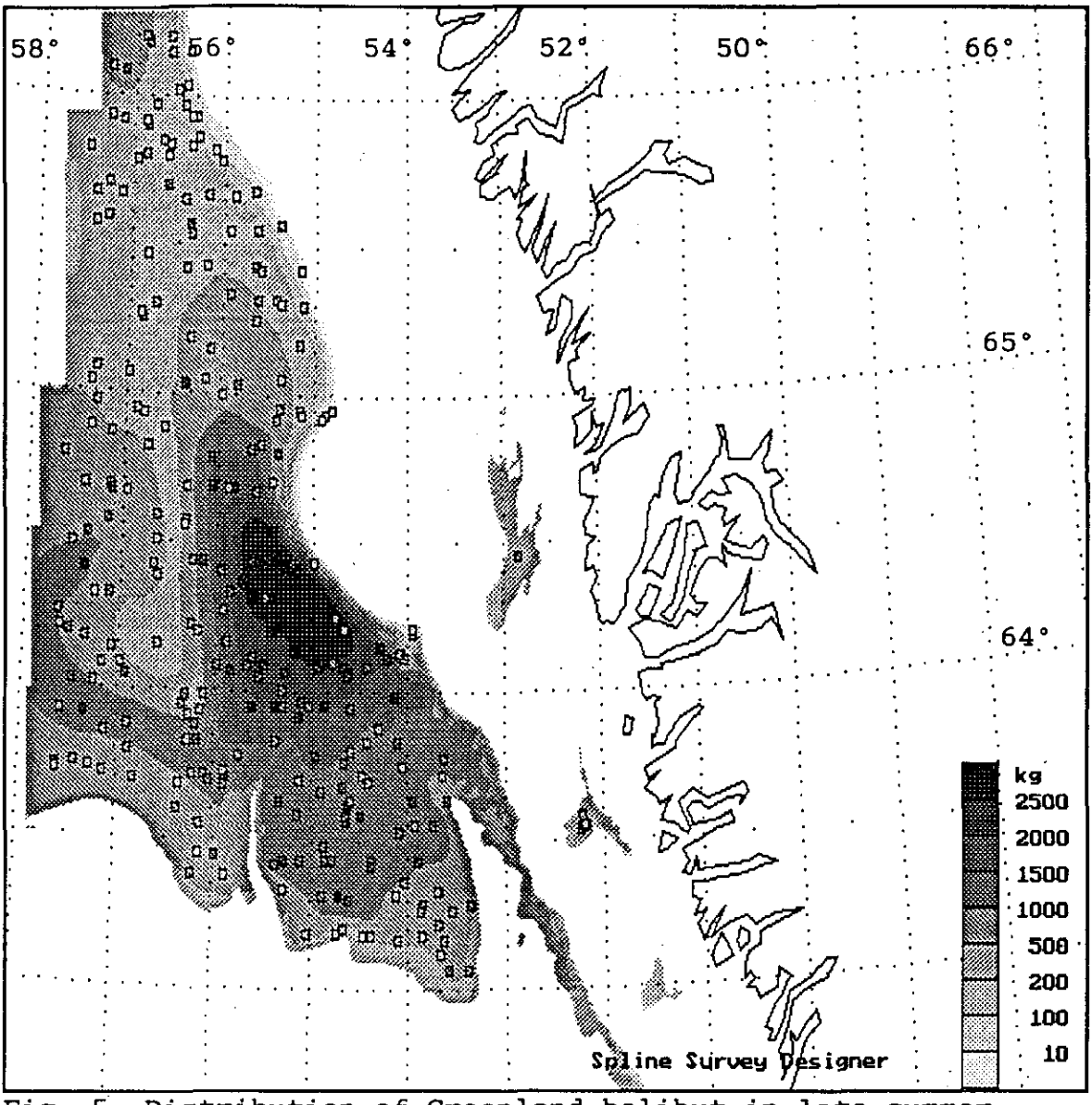

Fig. 5. Distribution of Greenland halibut in late summer. Mean of the distribution in four surveys conducted in August/September 1990-1993.

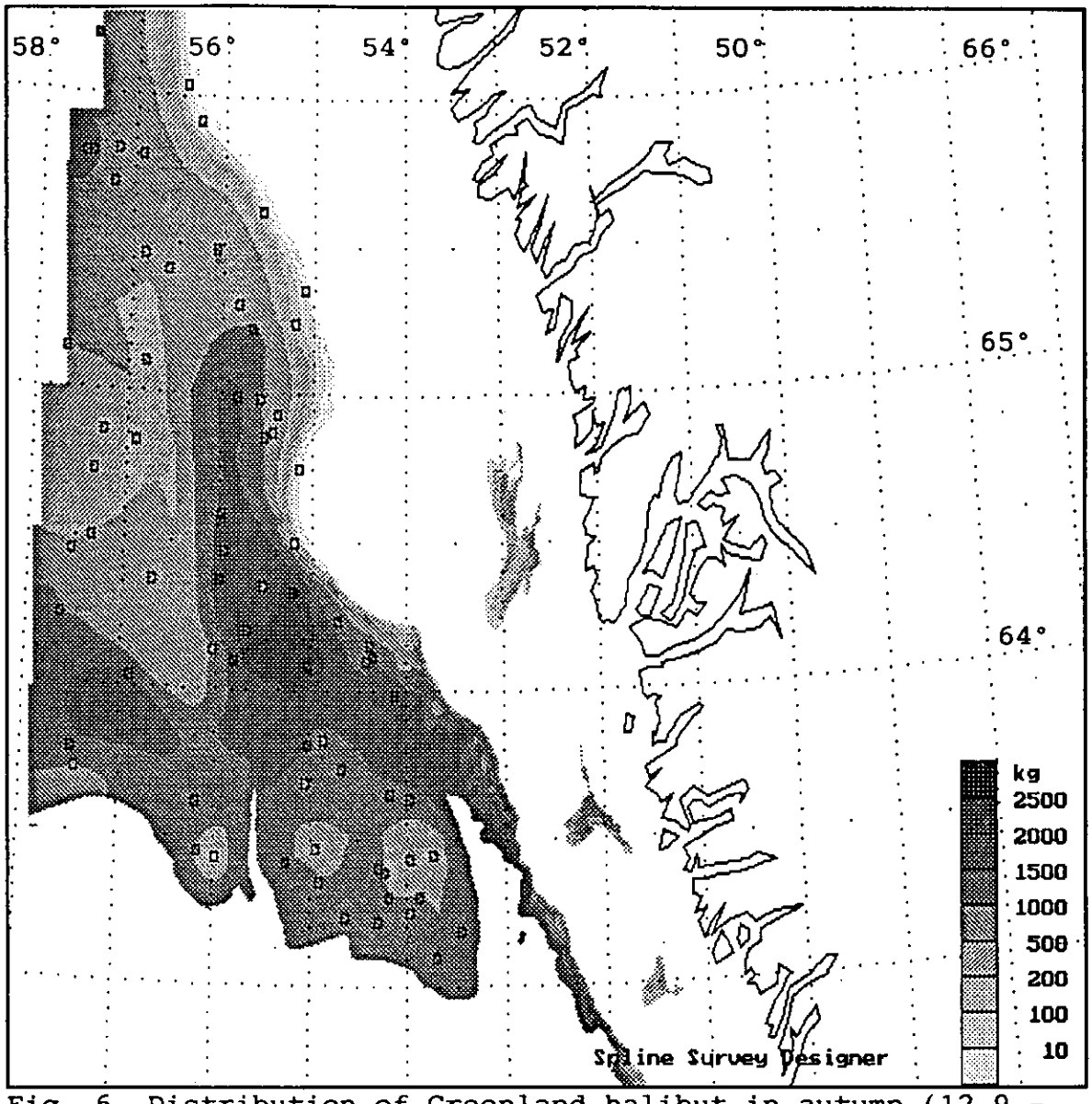

Fig. 6. Distribution of Greenland halibut in autumn (12.9 - 11.10 1988).

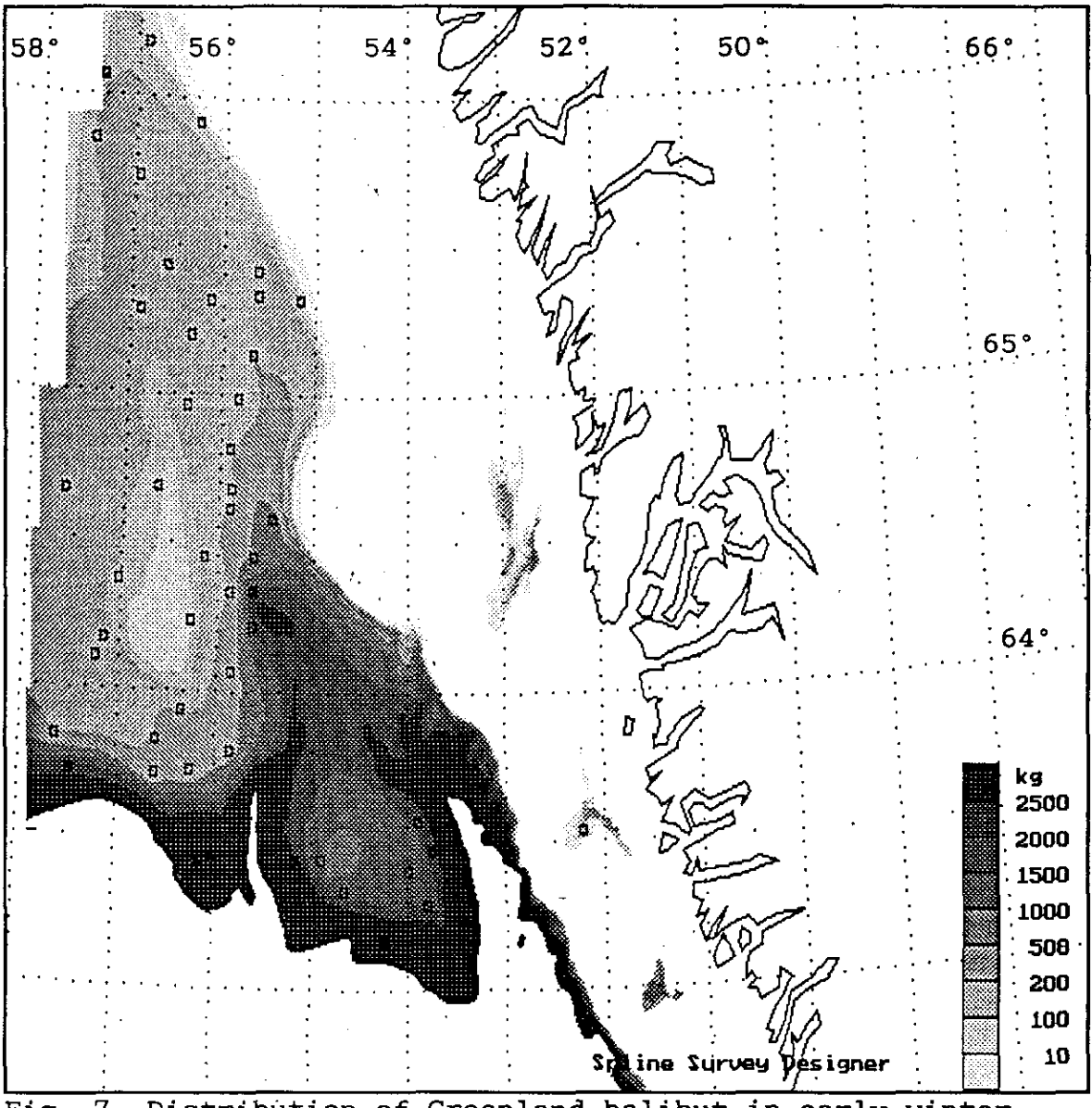

Fig. 7. Distribution of Greenland halibut in early winter (24.11 - 10.12 1992 (II)).

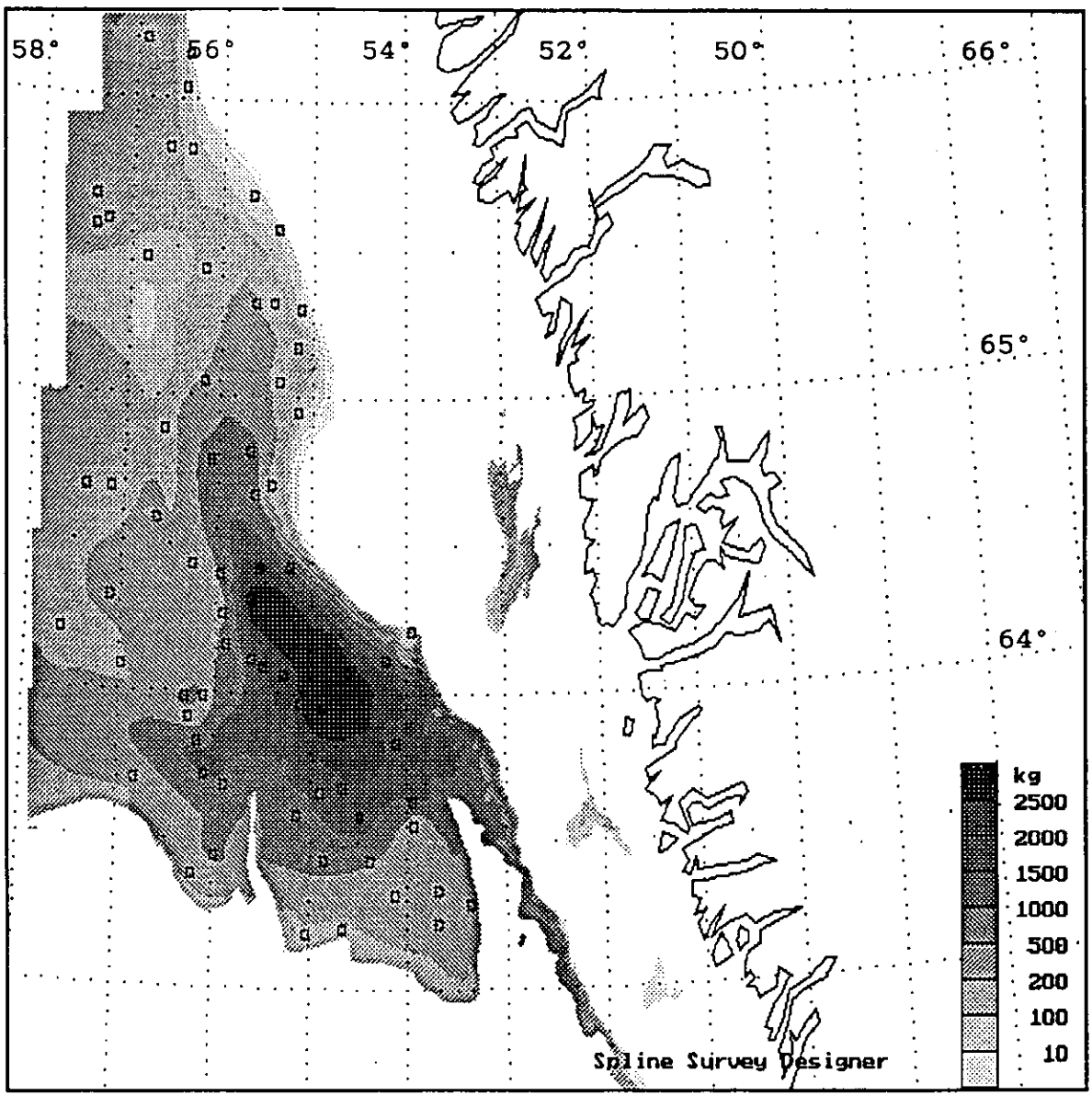

Fig. 8a. Distribution of Greenland halibut in August/September (27.8 - 12.9 1990 (II)).

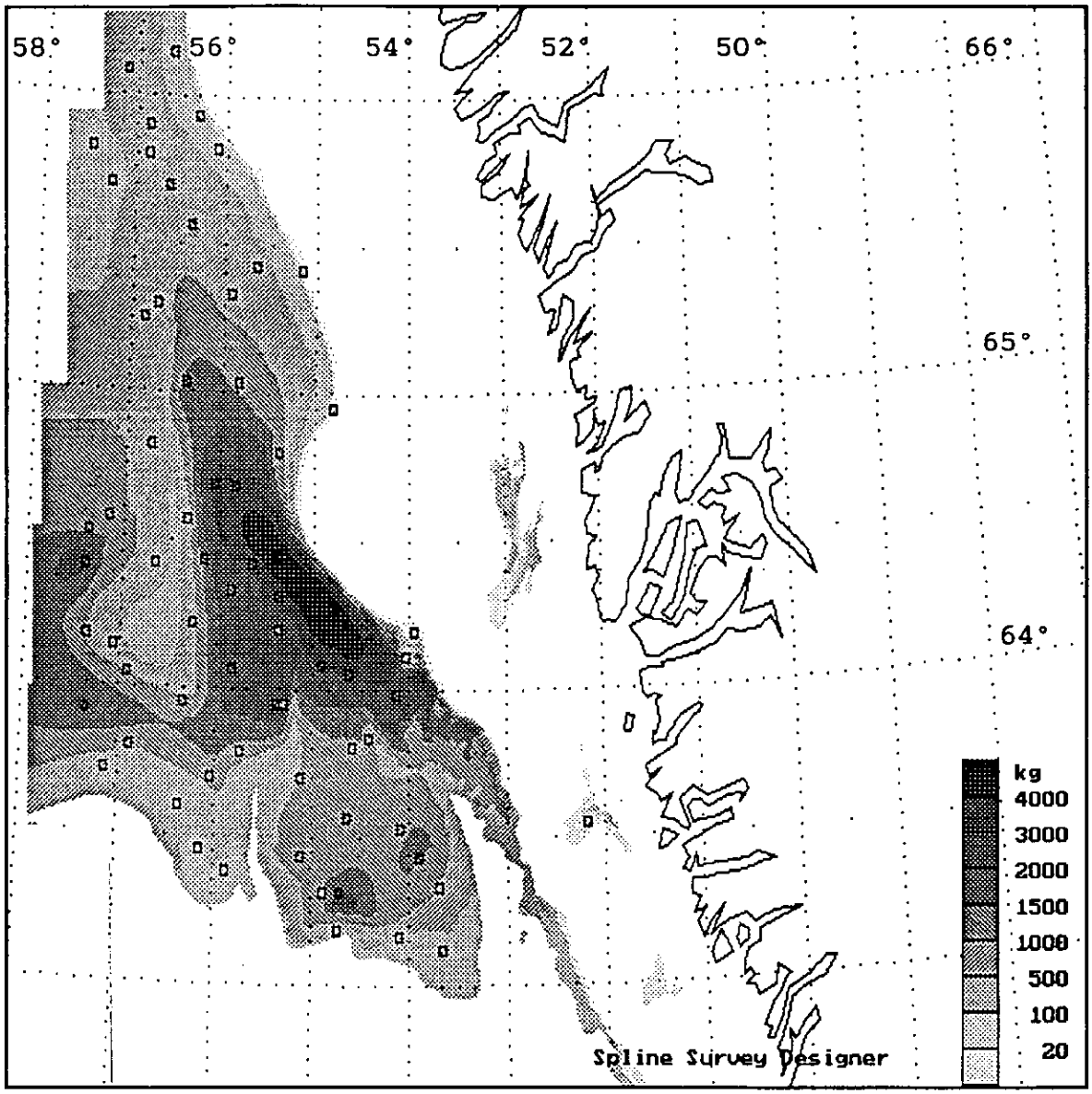

Fig. 8b. Distribution of Greenland halibut in August (4.8 - 28.8 1991 (I)).

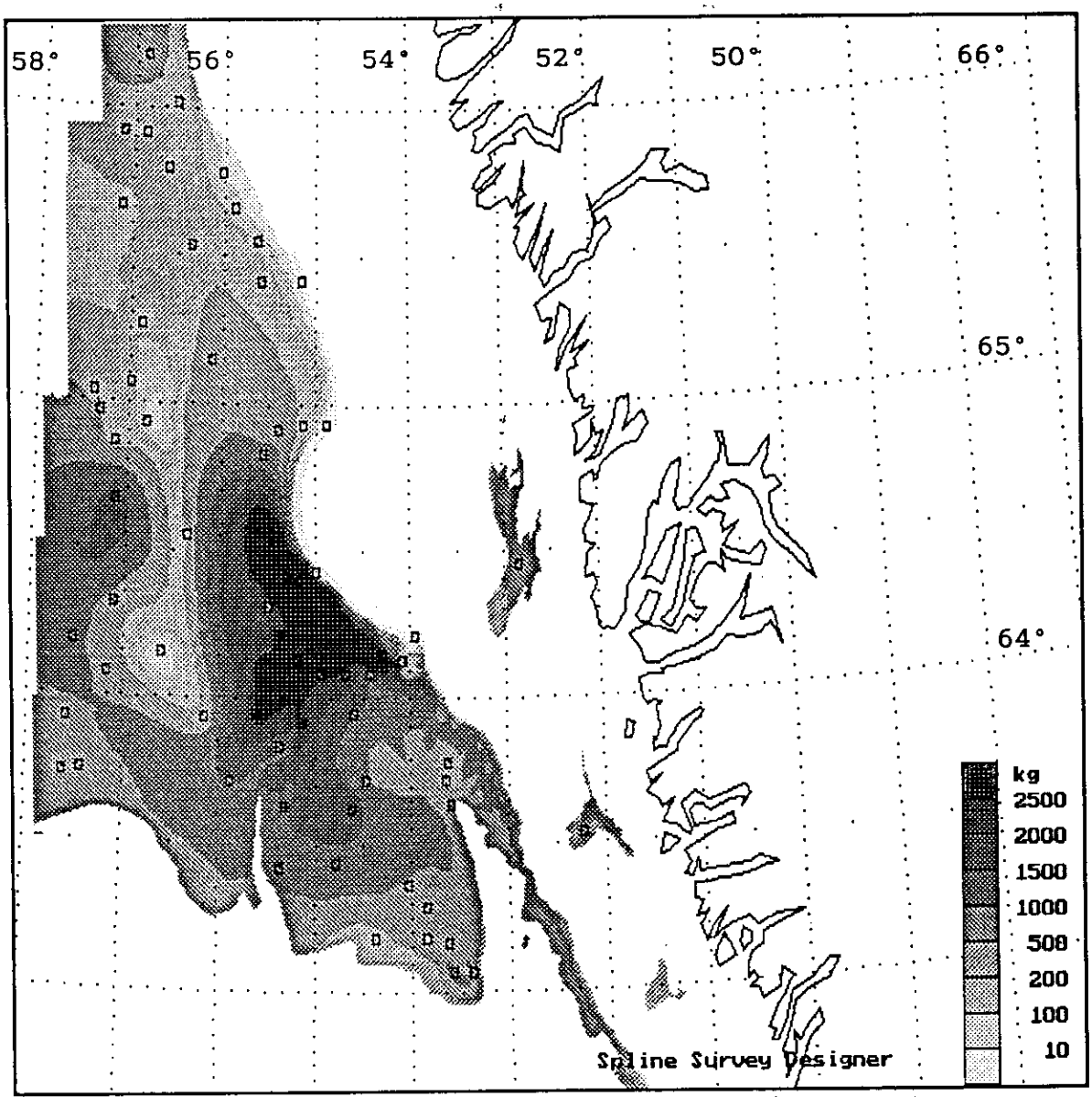

Fig. 8c. Distribution of Greenland halibut in August (11.8 - 28.8 1992 (I)).

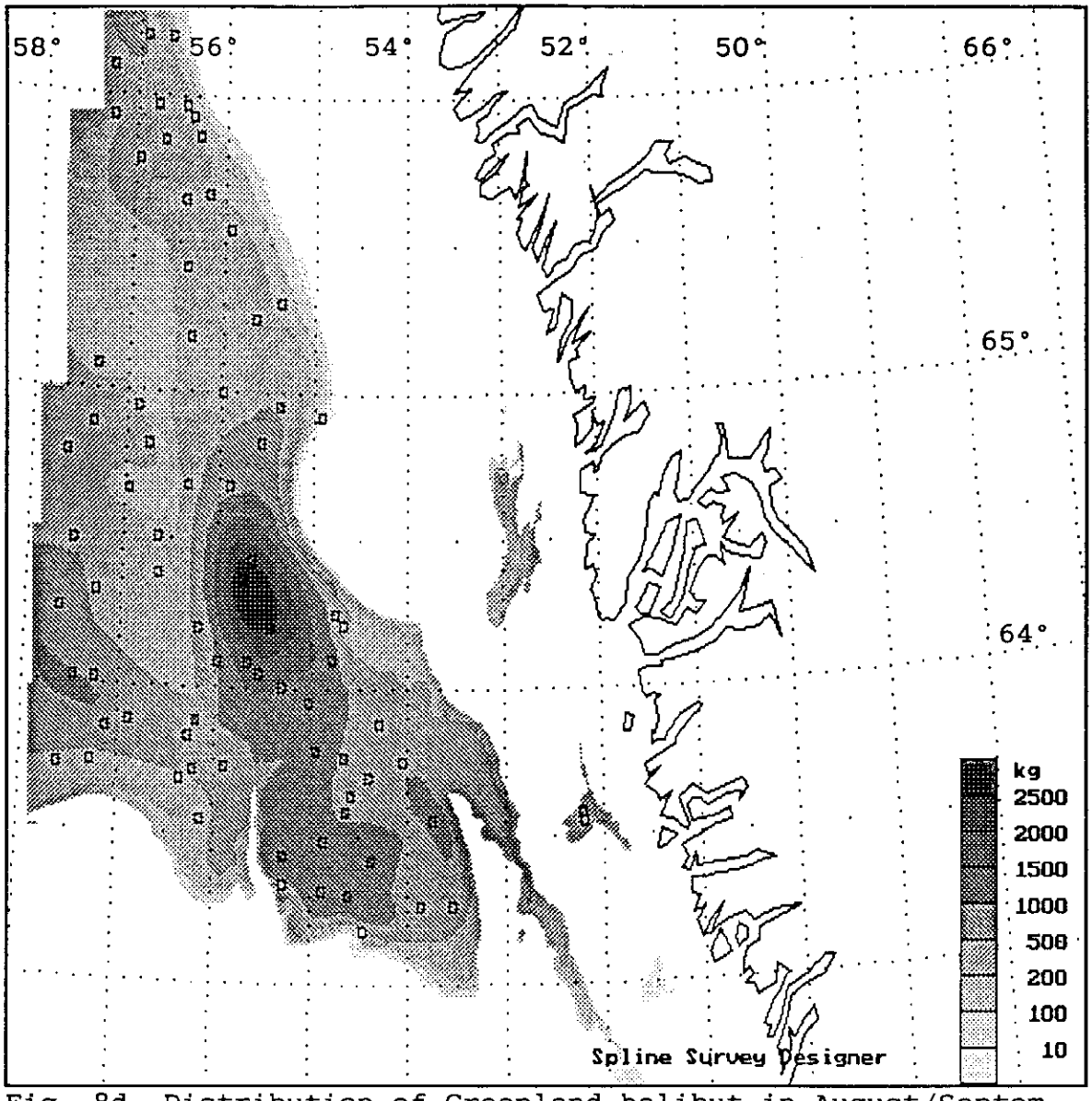

Fig. 8d. Distribution of Greenland halibut in August/September (20.8 - 8.9 1993).

Males

Females

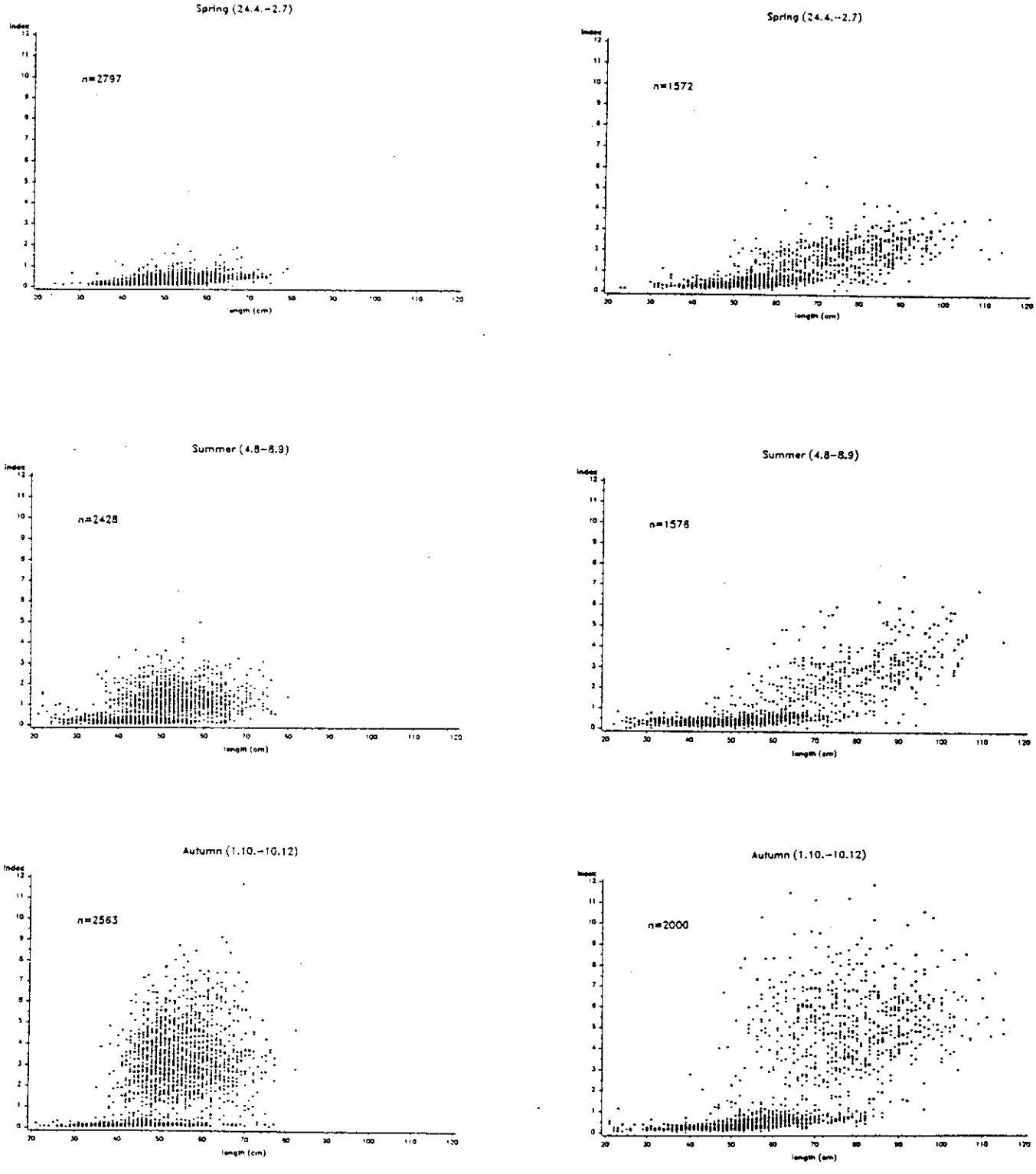

Fig. 9. Gonadindex in spring, summer and autumn for males and females, respectively.