NAFO Sci. Coun. Studies, 14: 51–65

Distribution of Greenland Halibut (*Reinhardtius hippoglossoides*) and Roundnose Grenadier (*Coryphaenoides rupestris*) in the Northwest Atlantic in Relation to Hydrographic Conditions in 1968–86

A. K. Chumakov and P. I. Savvatimsky
Polar Research Institute of Marine Fisheries and Oceanography (PINRO)
6 Knipovich Street, Murmansk 183763, USSR

Abstract

The directed fishery for Greenland halibut (*Reinhardtius hippoglossoides*) and roundnose grenadier (*Coryphaenoides rupestris*) on the continental slope of the Northwest Atlantic began in 1967. However, the fishing activities and the total annual catch have fluctuated significantly and changed over time in response to the changes in accessibility of commercial concentrations. The distribution of these species in NAFO Subareas 0, 1 and 2 and in Div. 3K was investigated in relation to hydrographic conditions in the South Labrador area (Section 8-A) and the factors affecting the formation and stability of commercial concentrations were considered. The vertical and horizontal distribution and the density of Greenland halibut and roundnose grenadier concentrations were found to be directly related to the changes in the thermal regimes of the water. In years when the whole shelf was occupied by below 0°C bottom temperatures, Greenland halibut were found concentrated over the continental slope and when warm waters penetrated part of the shelf, Greenland halibut were scattered over a wide area. Data are presented to suggest that the ice edge location and research surveys conducted 1–2 months in advance of the fishery, can be used to predict the thermal state of the waters and the conditions for the Greenland halibut fishery in the Baffin Island area.

Introduction

The Greenland halibut (*Reinhardtius hippoglossoides*) and roundnose grenadier (*Coryphaenoides rupestris*) have since the late-1960s become important fishes of the deepwater trawl fishery. The peculiarities and conditions of their life cycles on the continental slopes of the Northwest Atlantic, have attracted the attention of many scientists in the development of the research investigations conducted by the USSR and some European countries, especially by the German Democratic Republic (GDR) and Poland.

Mixed concentrations of roundnose grenadier found by the USSR vessels along the continental slope north of 50°N stimulated the development of the deepwater trawl fishery. The directed fishery for these species on the continental slope of the Northwest Atlantic began in 1967, although episodic catches of roundnose grenadier and Greenland halibut were taken as early as 1962–63 (Voss and Draffehn, 1963; Savvatimsky, MS 1969). The commercial ships were initially fishing during the summer period only in a limited area, because of poor knowledge of the grounds and the continental slope relief as well as the biology and life cycles of the species. The fishing activity was extended significantly during investigations of biology and the area of their distribution. The commercial concentrations of roundnose grenadier and Greenland halibut, depending upon seasonal and hydrographic conditions in different areas and the different depths over the continental slope, were then fished periodically in all accessible areas to the trawl fishery from 50°N to 67°N. The largest catches of roundnose grenadier were registered in Div. 3K and in waters of the northern and central Labrador area (Div. 2GH) and those of Greenland halibut were off Baffin Island (Div. 0B) and in the northern and central Labrador area (Div. 2GH).

In the period from the beginning of trawl fishery to the establishment of 200-mile zones (1977) the total annual catch of roundnose grenadier in the Northwest Atlantic fluctuated from 15,500 tons to 83,700 tons (average 36,100 tons) and that of Greenland halibut ranged from 29,000 tons to 53,600 tons (average 39,900 tons) (Table 1). In 1968–76 the mean annual Soviet catches of roundnose grenadier and Greenland halibut were 33,600 tons and 15,400 tons respectively, representing 93.0 and 38.1% of the USSR total catch. From 1978 to 1984 the total catch of roundnose grenadier declined from 26,500 tons to 3,900 tons and similar reductions were noted in all NAFO Divisions. After

TABLE 1. Roundnose grenadier and Greenland halibut catches (tons) in Subareas 0+1 and 2, Div. 3KL from 1968 to 1984. (ICNAF/NAFO Statistical Bulletins 1968-84.)

Year	Canada	Greenland (Denmark)	GDR	Poland	FRG	USSR	Other countries	Total catch
			Roundnose grenadier					
1968	—	—	4,735	—	—	32,719	—	37,454
1969	—	—	446	—	—	15,043	—	15,489
1970	—	—	1,564	—	—	29,389	—	30,953
1971	—	—	1,185	105	—	82,459	—	83,749
1972	—	—	445	270	—	31,765	—	32,480
1973	—	11	2,519	294	—	19,624	—	22,448
1974	—	5	4,580	181	199	35,779	—	40,734
1975	—	6	2,890	1,499	33	27,949	—	32,378
1976	16	1	678	101	148	28,152	—	29,096
1977	15	10	674	—	693	16,922	7	18,321
1978	9	32	1,801	51	6,780	17,760	108	26,541
1979	4	21	480	96	6,794	7,307	—	14,702
1980	—	—	898	36	1,753	1,119	—	3,806
1981	—	39	1,407	18	353	5,747	—	7,564
1982	—	37	1,640	15	11	2,732	—	4,435
1983	—	22	2,586	50	—	979	—	3,637
1984	—	35	3,650	51	23	172	2	3,933
			Greenland halibut					
1968	13,322	1,568	4,259	5,806	137	10,217	—	35,309
1969	11,553	1,477	10,022	5,406	270	10,204	98	39,030
1970	10,706	1,212	9,158	8,266	26	8,047	875	38,286
1971	9,408	1,159	1,021	5,234	16	10,937	1,215	28,990
1972	8,952	2,950	965	7,121	214	19,825	3,692	43,719
1973	6,840	4,567	2,435	9,060	772	12,783	2,045	38,502
1974	5,745	4,058	3,302	7,105	517	19,201	1,492	41,380
1975	7,807	3,724	2,081	8,447	646	29,669	1,255	53,629
1976	9,306	3,546	1,672	5,942	1,020	17,733	1,168	40,387
1977	17,965	6,110	2,428	5,998	1,345	8,664	1,978	44,590
1978	24,692	5,985	1,636	5,215	5,987	5,632	1,038	50,185
1979	29,940	5,273	178	1,813	12,893	2,948	212	53,257
1980	31,774	5,356	316	203	1,229	1,784	252	40,914
1981	24,125	5,755	1,350	1,806	10	6,951	246	40,243
1982	19,248	5,397	2,487	1,111	66	5,009	2,177	35,495
1983	17,113	4,136	2,587	5,258	16	4,709	2,707	36,526
1984	17,181	6,949	2,498	943	24	549	4,037	32,181

establishing 200-mile zones, Canada and Greenland (Denmark) significantly increased Greenland halibut catches in their coastal waters, however, the total catch decreased from 53,200 tons in 1979 to 32,200 tons in 1984 (Table 1) and the catches never exceeded the total allowable catch.

There were many explanations for the roundnose grenadier total catch decrease and the reduction of the catch-per-unit effort (Atkinson, MS 1982, MS 1984; Chumakov and Savvatimsky, MS 1983, MS 1984; Bowering, MS 1984; Bowering and Brodie, MS 1984; Ernst, MS 1984; Kulka, MS 1985). Various oceanographic conditions were identified as reasons for the shift of roundnose grenadier concentrations to deeper layers and their inaccessibility to the fishery. The inaccessibility has been a reason why many authors argued the expedience of the lifting of Greenland halibut by-catch limitation (of a maximum of 10%) during the direct fishery for roundnose grenadier.

In 1986 the allowable by-catch of Greenland halibut in the directed fishery for roundnose grenadier was increased from 10 to 30%. This permitted ships which were fishing on the continental slope to extend to more productive areas and improved the possibility for realization of the roundnose grenadier national quota in Subarea 2 and Div. 3K.

Significant changes in Greenland halibut distribution and decrease in density of concentrations at various depths over the continental slope in Div. 0B have been observed in recent years (Chumakov and Borovkov, MS 1986). These changes had a negative influence on the USSR fishery efficiency in Div. 0B and resulted in very little fishing effort during 1984-86 as a result of the very small catches. The understanding of the reasons for such changes in distribution is important from a biological and fishery point of view.

This paper is devoted to the investigations on distribution of Greenland halibut and roundnose grenadier in relation to hydrographic conditions, and the factors affecting the formation and stability of commercial concentrations of these species in the Northwest Atlantic during autumn/winter.

Materials and Methods

USSR trawl surveys for Greenland halibut stock assessment, the research and exploratory cruises during 1968–86 in Subareas 0, 1 and 2 and in Div. 3K and the NAFO catch statistics constitute the database of this study (Fig. 1).

Subareas 0 and 2 catches were divided into three periods (1969–71, 1972–80, 1981–86) to study the correlation of the roundnose grenadier and Greenland halibut catches. The catches were stratified by 100 m layers and only catches with more than 5 kg of roundnose grenadier-per-hour trawling were considered. Data sampling and processing of icthyological materials were conducted in accordance with the PINRO methods and NAFO standards.

To study the hydrographic conditions in the South Labrador area, the standard Section 8-A (Burmakin, 1972) which is carried out annually in early November was chosen (Fig. 2). Water temperatures were measured at standard layers. Water temperatures obtained in 1964–86 were averaged by 10 stations in the sector ABC (0–200 m layer) and by three stations in the sector C, these stations being located close to the continental slope (in 0–200 m, 200–500 m, 500–1,000 m layers). Average water temperatures were obtained for each year.

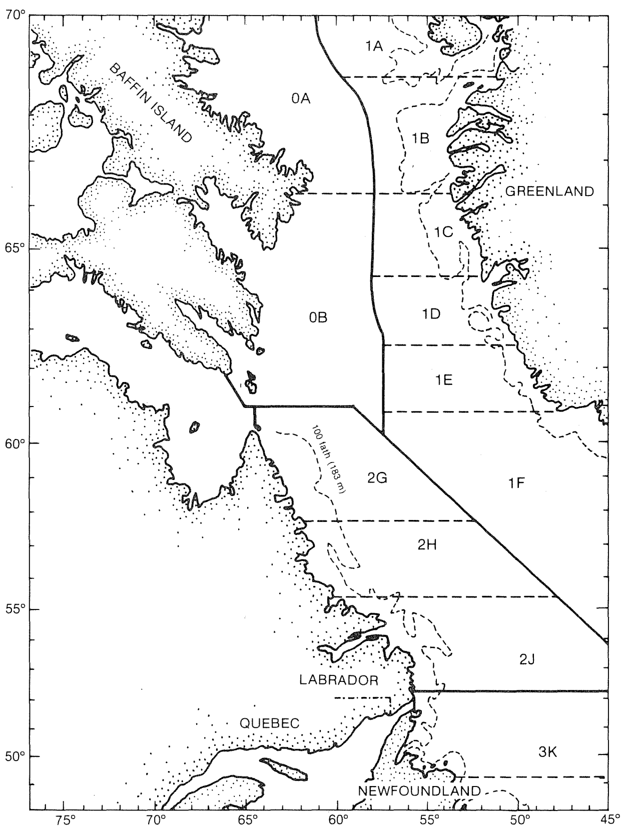

Fig. 1. Map showing the NAFO subareas and divisions mentioned in text.

To calculate the frequencies of temperature fluctuations, the method of Shickendan and Bowen (1977) was used. The water temperature (Y_i) in the defined layer and year, was calculated by the equation[1]:

$$Y_i = A_o + \sum_{k=1}^{r} A_k \cdot \sin(W_k \cdot i) + B_k \cdot \cos(W_k \cdot i)$$

where r = quantity of frequencies obtained

W_k = frequencies

A_o = absolute term

A_k, B_k = coefficients of sin and cos (A_o, A_k, B_k are calculated on the basis of known frequencies by the least square method)

i = year

and k = frequency

The following parameters of the water temperature fluctuations in the chosen sectors and layers of the hydrographic section were obtained.

W = frequency of fluctuations

T = period, in years

R^2 = spectral density

S^2 = mean root-square error (for all obtained frequencies)

and R = coefficient of correlation between the input series of water temperature and series restored for all obtained frequencies.

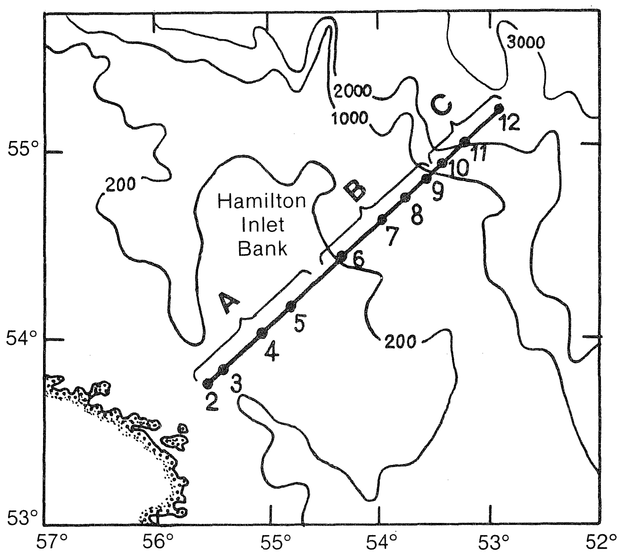

Fig. 2. The position of oceanographic stations on USSR standard section 8A.

[1] The method of calculation was worked out by V. G. Korytov in the Laboratory of the short-term prediction, PINRO, Murmansk, USSR.

The near-bottom temperatures taken after each trawl were used to compare near-bottom isotherms with isobath locations and Greenland halibut catches. The ice edge location during the trawl survey and the mean monthly location of the ice in the area of Baffin Island in September, October and November of 1982-85, calculated from the Murmansk Meteorological Centre data, are also represented.

Results and Discussion

After establishment of 200-mile zones, the USSR fished for Greenland halibut mainly in the area of Baffin Island (Div. 0B) and to a lesser degree in Subarea 2 and Div. 3K, where Greenland halibut by-catch was permitted in the direct fishery for roundnose grenadier. The USSR trawl fishery in the Baffin Island area began in 1968 after the detection of the mixed concentrations of roundnose grenadier and Greenland halibut. Roundnose grenadier catches then consisted of 20–30% Greenland halibut by-catch. In subsequent years the composition and size of catches changed because of a shift of roundnose grenadier and Greenland halibut concentrations to greater depths.

In the early period (1969–71), trawls in Subarea 0 were conducted to 1,000 m and the mean catches of roundnose grenadier at 600–1,000 m were more than 1,000 kg-per-hour trawling (Table 2). The largest catches in 1972–80 were taken at 800–1,200 m. In recent years catches were significantly less and increased with depth.

In the early period (1969–71), in Subarea 2 the largest catches (above 2,000 kg) were at 800–1,000 m and during 1972–80 they were at 900–1,100 m. In recent years catches were low but increased at 1,200–1,300 m (Table 3). General patterns of reduced catches and the concentrations moving to greater depths are shown in Fig. 3.

The analysis of research catches shows that in the 1968–71 period Greenland halibut were distributed in the Davis Strait (Subareas 0 and 1) without forming dense concentrations. The largest catches were then registered at 450–600 m. Catches more than 1.5 tons-per-hour trawling were taken occasionally at those depths in 1969 where the near-bottom temperature was about 3° C (Fig. 4A). In subsequent years the Greenland halibut catches from that area increased greatly and those of roundnose grenadier were on a gradual decline (Fig. 3, 4B, 4C and 4D).

The correlation of these species in the catches change in relation to the thermal conditions of the sea, since Greenland halibut are more resistant to low temperatures than roundnose grenadier (Burmakin *et al.*, 1977). Proceeding from this relationship, Burmakin (1978) suggested an equation to predict the percentage by-catch of Greenland halibut in the month of September as follows:

$$Q = 34.02\ t + 153.9$$

where Q was Greenland halibut percentage in trawl catches in September (percent of the total catch) and t was water temperature on the hydrographic Section

TABLE 2. Mean catch (kg) of roundnose grenadier per trawling hour (numerator) and number of catches (denominator) at different depth strata in the Baffin Island area from 1969 to 1986.

Depth (m)	1969–71 Aug	1969–71 Sep	1969–71 Aug/Sep	1972–80 Aug	1972–80 Sep	1972–80 Oct	1972–80 Nov	1972–80 Aug/Nov	1981–86 Sep	1981–86 Oct	1981–86 Nov	1981–86 Dec	1981–86 Sep/Dec
501–600	600/1	240/2	353/3	93/4	157/5	544/5	—	277/14	—	—	—	—	—
601–700	1,471/66	1,296/46	1,399/112	464/131	217/55	842/4	1,625/2	413/192	—	—	40/6	—	40/6
701–800	1,181/74	1,249/53	1,209/127	351/194	452/26	323/10	289/3	360/233	—	—	33/8	35/1	34/9
801–900	1,121/4	1,597/26	1,534/30	684/110	737/32	783/15	294/9	682/166	111/4	5/1	32/12	—	51/17
901–1,000		1,000/1	1,000/1	573/10	568/9	641/5	—	585/24	189/4	50/2	57/14	810/2	149/22
1,001–1,100	—	—	—	283/2	—	327/2	—	305/4	219/5	7/1	83/16	—	111/22
1,101–1,200				771/4	—	1,687/2	—	1,077/6	124/2	—	207/14	—	196/16
1,201–1,300	—	—	—	—	—	—	—	—	—	—	259/11	—	259/11

TABLE 3. Mean catch (kg) of roundnose grenadier per trawling hour (numerator) and number of catches (denominator) at different depth strata in Subarea 2 from 1969 to 1971, 1972 to 1980 and 1981 to 1986.

Depth (m)	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jun-Dec	Jul-Dec
1969-71									
401-500	—	608/3	—	1,112/19	916/9	804/33	471/6	865/70	—
501-600	—	598/7	—	996/24	1,444/21	893/42	528/37	881/131	—
601-700	1,745/3	2,261/5	—	—	2,516/5	1,111/21	342/11	1,249/45	—
701-800	2,551/26	2,660/28	—	3,983/4	900/1	970/5	511/14	2,175/78	—
801-900	2,126/24	2,945/10	—	2,960/4	—	1,164/4	500/1	2,267/43	—
901-1,000	3,388/2	2,051/10	—	998/4	—	—	—	1,955/16	—
1,001-1,100	—/13	1,998/13	—	2,823/1	—	—	—	2,057/14	—
1,101-1,200	—	526/4	—	800/1	—	—	—	581/5	—
1972-80									
301-400	—	—	—	—	552/3	—	7/5	211/8	—
401-500	—	—	356/4	1,042/5	877/32	10/1	40/1	808/43	—
501-600	—	68/4	818/8	2,672/8	1,082/29	71/10	202/4	970/63	—
601-700	480/1	434/10	627/6	1,892/14	730/17	829/16	234/6	888/70	—
701-800	—	273/7	271/5	1,897/18	1,489/10	925/4	511/15	1,079/59	—
801-900	2,002/21	1,676/34	199/4	1,470/10	1,384/13	486/7	382/19	1,326/108	—
901-1,000	4,470/4	3,661/37	2,235/5	1,623/6	1,400/19	632/4	790/8	2,526/83	—
1,001-1,100	3,568/16	2,956/45	3,500/1	2,147/17	2,122/12	1,736/5	2,700/2	2,751/98	—
1,101-1,200	—	1,647/8	68/1	—	1,000/1	—	5/1	1,295/11	—
1981-86									
501-600	—	—	—	—	171/1	300/1	17/1	—	163/3
601-700	—	—	—	200/1	25/1	1,100/1	12/4	—	196/7
701-800	—	300/1	—	164/1	—	15/1	168/12	—	166/15
801-900	—	100/1	—	175/3	5/1	1,140/1	216/20	—	235/26
901-1,000	—	200/1	—	314/1	67/4	775/4	508/31	—	498/41
1,001-1,100	—	—	—	182/1	136/3	600/1	319/19	—	296/24
1,101-1,200	—	—	—	—	—	940/1	255/17	—	294/18
1,201-1,300	—	—	—	—	—	—	698/3	—	698/3

7-A in May in the 200-500 m layer. During the period 1968-74, the correlation coefficient between the compared values was -0.962 ± 0.018. Unfortunately however, there are no further oceanographic observations on this section available to test this equation on a larger number of examples.

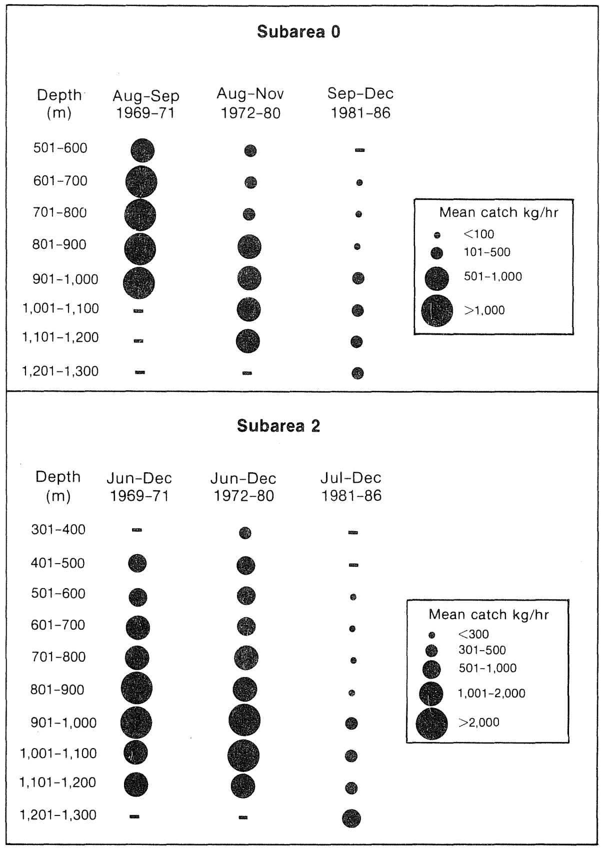

Fig. 3. Mean catches of roundnose grenadier taken by bottom trawl at different depths in Subarea 0 and 2 from 1969 to 1986.

According to the data of annual trawl surveys conducted in that area since 1979, the correlation between roundnose grenadier and Greenland halibut in the catches changed greatly in comparison with the initial period of the fishery. During 1981-83 Greenland halibut were the main species in the trawl catches from all surveyed areas and low roundnose grenadier catches were reported only from the southern part of the area at depths below 800 m. At the same time the by-catch of northern wolffish (*Anarchichas latifrons*) and roughhead grenadier (*Macrourus berglax*) increased significantly. During 1984-86, however, roundnose grenadier catches increased (up to 500 kg-per-hour trawling) and were usually taken at the 800-1,300 m depths.

Year-to-year changes in roundnose grenadier Greenland halibut ratio in Subarea 0 and 1 during 1968-84 can be detected by summing up the statistical data on the total catches taken by the USSR, GDR and Federal Republic of Germany (FRG) vessels. The analysis of the curves of roundnose grenadier/Greenland halibut ratio shown in Fig. 5 allows us to mark the three periods (1968-71, 1972-80, 1981-86) with different types of the spatial distribution of Greenland halibut and roundnose grenadier in Subareas 0 and 1. Until

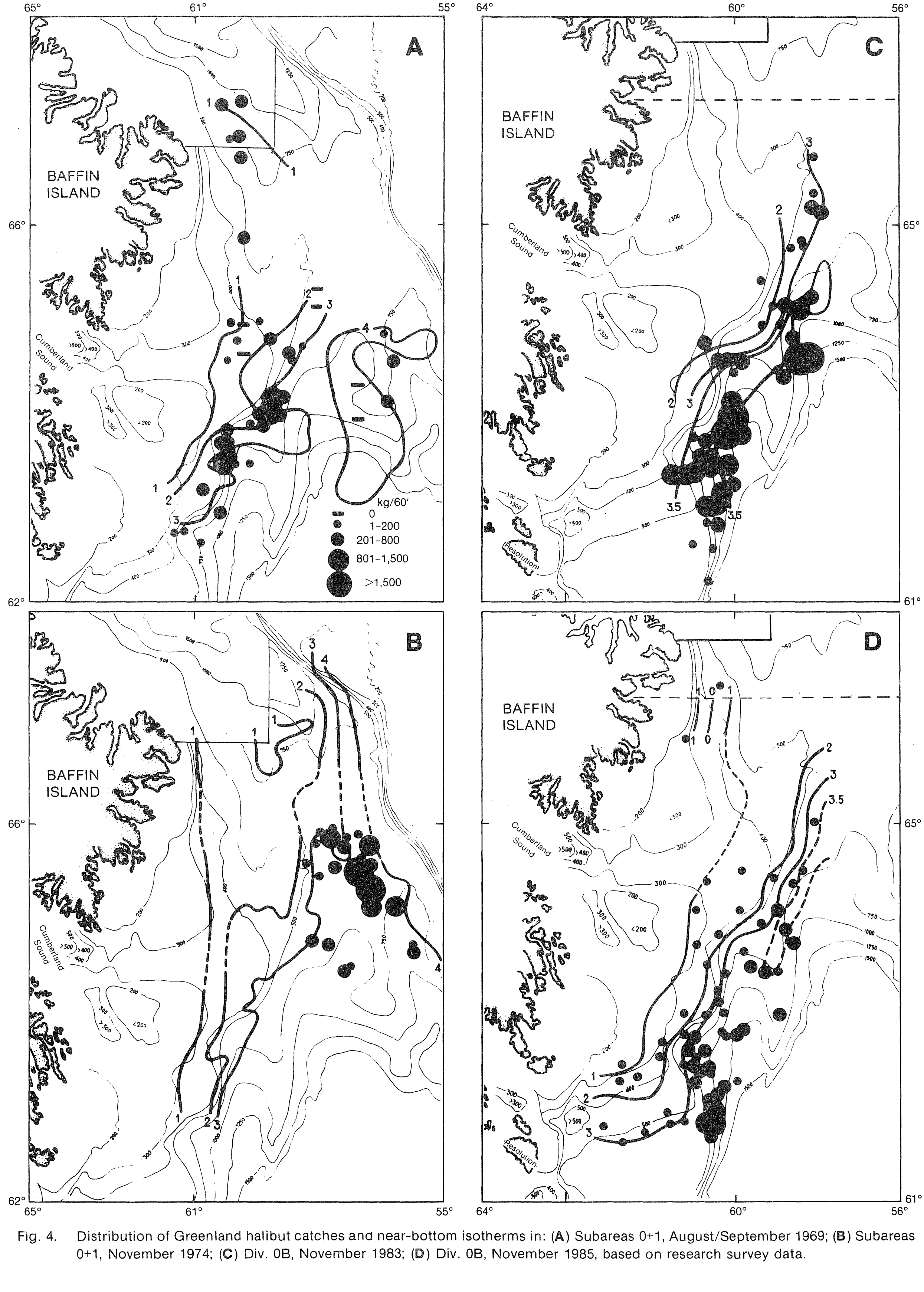

Fig. 4. Distribution of Greenland halibut catches and near-bottom isotherms in: (**A**) Subareas 0+1, August/September 1969; (**B**) Subareas 0+1, November 1974; (**C**) Div. 0B, November 1983; (**D**) Div. 0B, November 1985, based on research survey data.

1971 roundnose grenadier was the dominating species in catches (75-80%). During the 1972-80 period roundnose grenadier averaged 50% and since 1981 the percentage decreased to about 20%. These changes again demonstrate the year-to-year vertical displacements of fish concentrations.

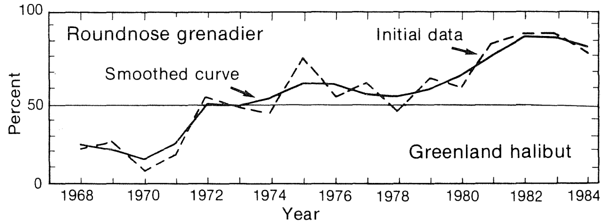

Fig. 5. Roundnose grenadier to Greenland halibut ratio in the total catches taken by the USSR, GDR and FRG during 1968-84 in Subareas 0+1.

It is known that the mature Greenland halibut migration route to spawning grounds in the southern part of the Greenland-Canadian Threshold (Subarea 1) lies within the study area. It is therefore of interest to analyze year-to-year fluctuations of Greenland halibut length composition based on trawl survey data. Figure 6 shows Greenland halibut length composition in Div. 0B in 1979-86 was not stable. In the period 1979-83,

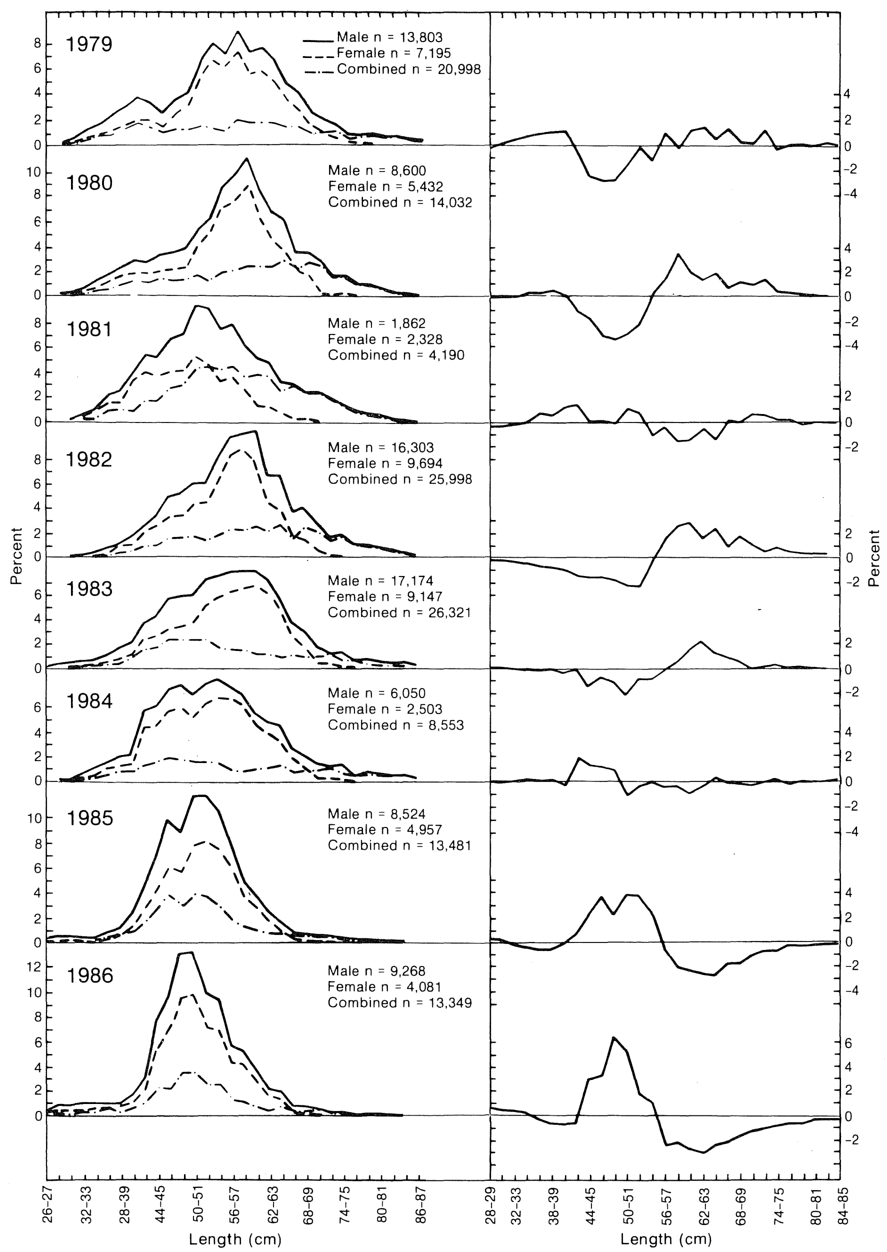

Fig. 6. Length composition of Greenland halibut and mean long-term errors in Div. 0B in 1979-86 based on trawl survey data.

males and females at lengths above 56-65 cm dominated the trawl catches, while in 1984-86 their relative quantity was sharply reduced and the number of fish at 44-45 cm lengths increased.

Such sharp and significant changes in the length composition, and the productivity in the trawl fishery as reflected in the reduction of Greenland halibut biomass from 355,300 ± 102,400 tons in 1982 to 158,600 ± 33,800 tons in 1986 (Table 4) cannot be explained by the fishery influence because NAFO statistical data show that the fishery in the area then was minimal and in 1984 it was stopped. We believe, the changes were caused by the redistribution of the older age groups in Subareas 0 and 1.

The largest catches (more than 2,000 kg-per-hour trawling) were registered at 800-1,100 m depths in Subarea 2 during the 1969-71 period, and at 900-1,100 m in 1972-80. In the last years of this the latter period, however, catches were relatively small but increased at depths greater than 1,200 m. The reasons for these changes in the vertical and horizontal distribution and also in the density of Greenland halibut and roundnose grenadier concentration can be explained, firstly by observed changes of water thermal regime.

The sharp fall of water temperature in the Northwest Atlantic registered in early-1970s led to the descent of grenadier stocks to greater depths. Reduced accessibility of concentrations to the bottom trawl may be one of the reasons for the total roundnose grenadier catch decline in those years. The same conclusion was drawn by Ernst (MS 1984) for the reduction of roundnose grenadier catches on the continental slope in Subarea 2. The trawl fishery for roundnose grenadier at great depths along the continental slope is hampered by the bottom relief which results in a higher number of unsuccessful hauls. In addition, the gear requires special rigging for deepwater fishing.

The changes in the hydrographic regime promoted the increase in density of Greenland halibut concentrations in Div. 0B and Subarea 2 (Tables 5 and 6, Fig. 4B and 4C). This was a result of migration of Greenland halibut to deeper waters which can be shown by a comparison of the mean catch data for 1983-84 with those in 1969 (Table 5, Fig. 4A and 4C). In 1969 the largest Greenland halibut catches were taken in the 450-600 m layer and in 1983 they were in the layers below 1,000 m (Fig. 7).

Immature specimens of Greenland halibut were distributed mainly in the southern part of the area on the continental shelf and slope within a relatively wide temperature range (-0.9° C to +4.5° C). The relative quantity and the mean fish length were noted to increase towards the north (Chumakov, 1975). In the northern areas (Subarea 0), Greenland halibut were distributed within a narrower temperature range (Fig. 7).

It has been reported (Savvatimsky, MS 1986; Ernst, MS 1984; Kulka, MS 1985) that, the gradual shift of concentrations of Greenland halibut, roundnose grenadier and also redfish into deep waters was caused by

TABLE 4. Trawl survey results for Greenland halibut in Div. 0B from 1979 to 1986.

Index	Sep/Nov 1979	Nov/Dec 1980	Dec 1981	Nov 1982	Nov 1983	Sep 1984	Nov/Dec 1985	Oct/Nov 1986
Depth (m)	401-1,250	301-1,250	501-1,250	401-1,500	401-1,500	501-1,250	201-1,500	200-1,250
Abundance, individuals (x 10^6)	109.1	161.3	64.5	191.0	179.0	72.6	122.7	138.5
± error (x 10^6)	±14.7	±26.5	±19.6	±49.5	±43.0	±16.9	±37.8	±32.9
Biomass (x 10^3) tons	200.9	240.0	105.1	355.3	304.1	119.1	110.2	158.6
± error (x 10^3) tons	±27.9	±48.9	±38.7	±102.4	±80.5	±23.0	±27.0	±33.8
Number of hauls	98	39	13	53	71	33	77	66
Percentage of area surveyed	44.1	56.7	23.8	40.7	48.2	35.4	77.5	95.5

Table 5. Greenland halibut average catches from different depths of the continental slope in Div. 0B from 1979 to 1986 (kg-per-hour trawling). (The number of hauls is indicated in parentheses).

Depth (m)	Sep/Nov 1979	Nov/Dec 1980	Dec 1981	Nov 1982	Nov 1983	Sep 1984	Nov/Dec 1985	Nov 1986
501-600	455 (12)	45 (4)	130 (1)	170 (4)	907 (2)	—	101 (2)	116 (5)
601-700	521 (13)	71 (4)	—	336 (7)	242 (7)	317 (5)	292 (3)	—
701-800	482 (15)	130 (2)	—	783 (6)	247 (9)	635 (9)	277 (7)	346 (8)
801-900	488 (8)	918 (4)	220 (3)	986 (11)	400 (9)	490 (7)	466 (15)	534 (19)
901-1,000	398 (5)	1,379 (11)	618 (6)	934 (9)	615 (12)	369 (3)	497 (11)	341 (8)
1,001-1,100	455 (2)	1,316 (6)	761 (3)	2,130 (13)	865 (8)	280 (5)	224 (4)	242 (4)
1,101-1,200	—	—	—	1,681 (1)	1,482 (11)	109 (3)	215 (3)	—
1,201-1,300	—	—	—	—	1,024 (5)	—	212 (4)	—
501-1,300	478 (55)	886 (31)	522 (13)	1,101 (51)	715 (63)	425 (32)	360 (49)	391 (44)

TABLE 6. Greenland halibut average catches from different depths of the continental slope of the Northern and Central Labrador from 1979 to 1986 (kg-per-hour trawling). (The number of hauls is indicated in parentheses.)

Depth (m)	Oct/Nov 1979	Nov/Dec 1980	Dec 1981 and Jan 1982	Nov/Dec 1982 and Jan 1983	Nov/Dec 1983 and Jan 1984	Dec 1984 and Jan 1985	Dec 1985	Oct/Nov 1986
301-400	426 (16)	34 (4)	33 (13)	—	—	—	7 (2)	—
401-500	295 (16)	16 (2)	113 (3)	197 (4)	22 (3)	44 (5)	4 (3)	244 (1)
501-600	288 (20)	218 (2)	264 (5)	439 (4)	291 (4)	49 (5)	25 (6)	122 (2)
601-700	344 (11)	427 (4)	427 (4)	1,379 (3)	473 (3)	115 (5)	25 (3)	39 (2)
701-800	384 (15)	1,737 (3)	506 (6)	1,862 (6)	1,446 (5)	319 (6)	18 (2)	45 (1)
801-900	697 (6)	2,783 (6)	2,865 (6)	1,732 (7)	2,914 (8)	763 (6)	110 (8)	281 (1)
901-1,000	440 (3)	2,762 (10)	1,753 (9)	3,520 (5)	2,686 (16)	1,088 (7)	210 (5)	537 (4)
1,001-1,100	938 (4)	1,831 (6)	1,504 (1)	1,139 (7)	1,492 (10)	1,220 (4)	374 (6)	534 (2)
1,101-1,200	—	1,146 (1)	—	623 (1)	2,749 (5)	439 (4)	136 (5)	866 (2)
1,201-1,300	—	—	—	—	454 (1)	265 (3)	—	—
1,301-1,500	—	—	—	—	—	101 (7)	—	—
301-1,500	397 (91)	1,699 (34)	879 (47)	1,518 (37)	1,914 (55)	448 (52)	147 (34)	390 (15)

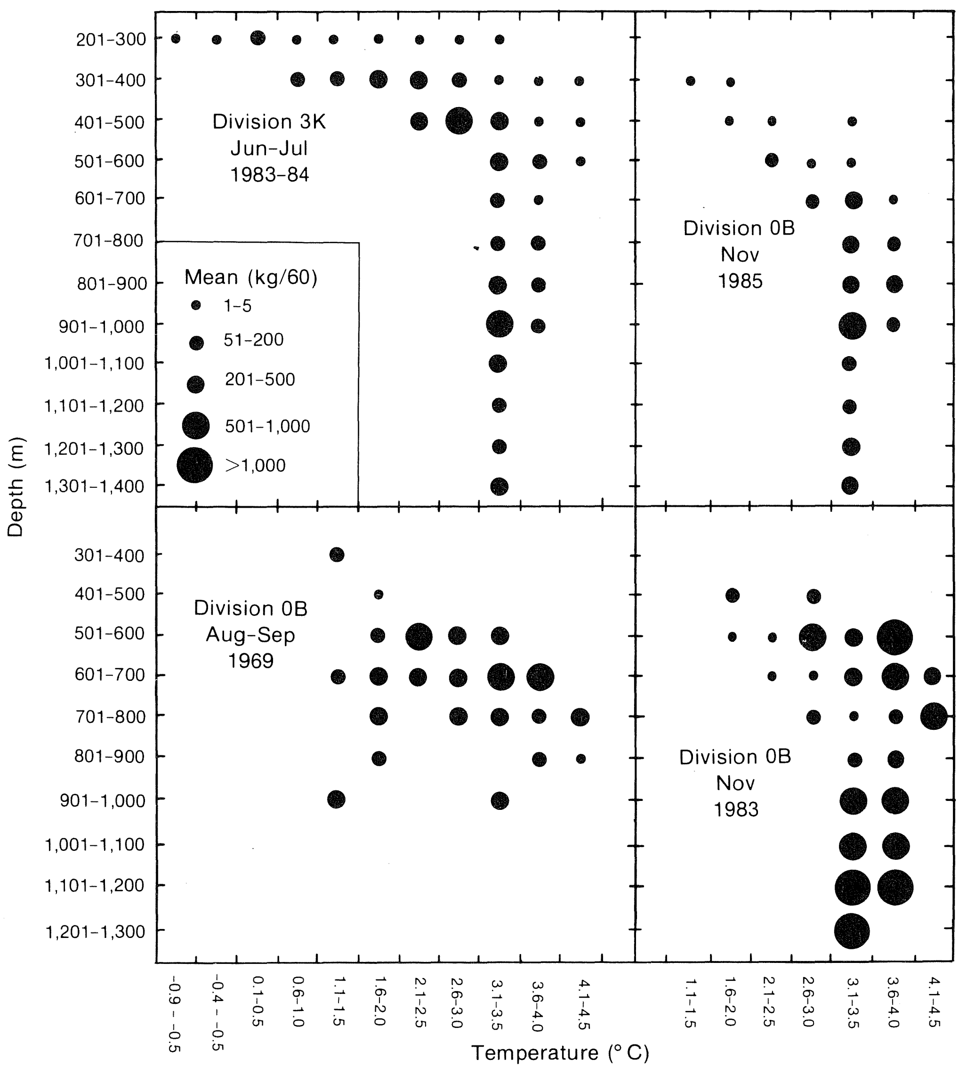

Fig. 7. Distribution of Greenland halibut mean catches within 100 m depth ranges in relation to near-bottom temperatures.

changes of the hydrographic conditions. The ratio of these species in the research and commercial catches has changed in recent years. According to our data, the Greenland halibut distribution is strongly related to the hydrographic regime in the area, thus affecting the trawl survey and fishery results.

It is known that in years with low water temperatures in the main branch of the Labrador Current, conditions become ideal for Greenland halibut to form dense concentrations necessary for an effective fishery. With rise in temperature the roundnose grenadier catches increased and mixed concentrations of roundnose grenadier and Greenland halibut were then observed near the continental slope (Konstantinov and Noskov, MS 1977; Burmakin, 1978). The water temperatures in the main branch of the Labrador Current have fallen notably since 1973 and the temperature in the 200–500 m and in the 500–1,000 m layers of the continental slope of Labrador (Section 8-A, sector C) have been lower than the long-term mean level (Savvatimsky, MS 1986, 1987). In 1986 the water temperature in the 200-500 m layer was 3.64° C (mean temperature was 3.91° C during 1964–86) and in the 500–1,000 m layer it was 3.45° C (mean was 3.76° C) (Table 7).

In order to study year-to-year fluctuations in the hydrographic conditions in the area of these fish distributions, the results of the long-term observations on Section 8-A were analyzed to determine the periodicity of water temperature fluctuations in the upper layers of the shelf and slope as well as in deep layers along the slope. Three periods of fluctuations with rather high (and important) correlation coefficients (11.4, 2.1 and 3.8 years) were determined in the 0–200 m layer of Sector ABC (Table 8). Two periods (11.5 and 2.1 years) were revealed in the 0–200 m layer of Sector C. In Sector C two further periods were determined in the 200–500 m layer (30.2 and 6.3 years) as well as in the 500–1,000 m layer (35.3 and 4.4 years). The long-term fluctuations in the 200–500 and 500–1,000 m layers were also characterized by high correlation coefficients ($R>0.7$).

TABLE 7. Mean water temperatures in the 200–500 m and 500–1,000 m layers of the main branch of the Labrador Current from 1964 to 1986 (Section 8-A, sector C).

	Year			
Depth (m)	1964–86	1984	1985	1986
200–500	3.91	3.70	3.84	3.64
500–1,000	3.76	3.62	3.50	3.45

Prognostic values of water temperature for 1987–91 in the chosen layers were obtained taking into account all the determined periods of fluctuations with correlation coefficients exceeding 0.8. The sharp water cooling in the upper layers (0–200 m) on the shelf and near the continental slope of Southern Labrador started in 1982 (Fig. 8). Cooling was maximum in 1984, and by 1985–86 water temperature was about the long-term mean (1964–86). The rise in temperature in the upper layers was expected in the subsequent years with the maximum in 1989–90.

The cooling in the 200–500 m and 500–1,000 m layers near the continental slope started much earlier than in the upper layers and lasted for a long time from 1974 to 1986. The temperatures in these layers were expected to reach the long-term mean by 1988 and exceed it by 1991 (Fig. 8).

Though water cooling during 1984–86 seemed to have favoured the Greenland halibut fishery, no dense Greenland halibut concentrations in the Baffin Island area in those years were observed (Table 5, Fig. 4D) and consequently, the fishery was not successful. The hydrographic conditions in 1984 were similar to those in 1985. The water temperature on 1 November 1984 was lower than the 1964–86 mean level (Table 7).

During trawl surveys in the area of Baffin Island and Labrador during the cold years, 1984 and 1985, mean Greenland halibut catches-per-hour trawling were significantly less than when the temperature of the main branch of the Labrador Current waters was

TABLE 8. Calculated frequencies of water temperature fluctuations in the 0–200 m, 201–500 m, 501–1,000 m layers of the ABC and C sectors on standard hydrographic Section 8A from 1964 to 1986.

Sector	Depth (m)	Frequency of fluctuations (W)	Period in years (T)	Spectral density (R^2)	Mean-root-square error (S^2)	Coefficient of correlation (R)
ABC	0–200	0.549	11.437	0.448	0.439	0.669
		2.996	2.097	0.199	0.351	0.804
		1.629	3.856	0.185	0.242	0.912
C	0–200	0.547	11.494	0.420	0.598	0.648
		2.969	2.116	0.245	0.455	0.815
C	201–500	0.208	30.223	0.628	0.191	0.792
		0.997	6.305	0.107	0.171	0.837
C	501–1,000	0.178	35.276	0.562	0.210	0.750
		1.426	4.407	0.135	0.183	0.818

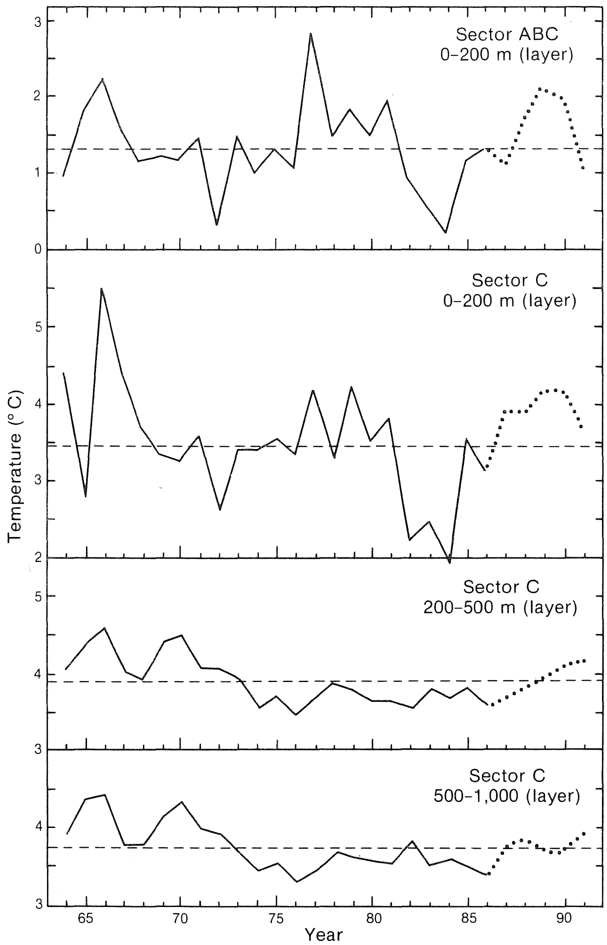

Fig. 8. Mean water temperature at various layers of the hydrographic Section 8-A in November 1964–86 (solid line), the average for 1987–91 (dotted line) and mean temperature for 1964–86 (dashed line).

previously low. The trawl fishery conditions and the accessibility of the fish concentrations were more difficult than in previous years because of wider fish distribution over the shelf and slope, which was probably related to the hydrographic conditions on the shelf.

There are insufficient data to analyze completely the year-to-year anomalies of the oceanographic conditions, nevertheless, we know that the area of Arctic waters on the shelf was reduced slightly from the autumn of 1984 to the end of 1985, i.e. the area of waters with below 0° C temperatures decreased. The near-bottom 0° C isotherm in Div. 2G was very far from the continental slope in December 1985 whereas it was close to the slope, in December 1982 (Fig. 9). Thus, in 1982, practically the whole shelf was occupied by waters with below 0° C temperatures in the bottom layers. The water cooling in the shelf area of Baffin Island in 1982 was probably greater than in the area of Labrador. This was demonstrated by the location of the ice edge along the 1,000 m isobath in November 1982 (Fig. 10), which was very far from the slope. It was farther to the west in November 1983 than in 1982 and the mean monthly location of the ice edge in November 1984 was similar to that in 1985 (Fig. 11), that is a year-to-year gradual movement of the ice edge from the slope towards the shelf was observed. This also indicated the rise in temperature in the upper layers over the shelf and the continental slope. This rise in temperature depends not only on solar radiation heat but also on the interaction of the cold Baffin Island Current and the warm branch of the West Greenland Current, and if the latter becomes stronger, warm waters penetrate farther to the west than usual to occupy part of the shelf. In such years Greenland halibut are scattered over a wide area not forming dense concentrations and the fishery productivity is not usually high. Conversely, when cold waters force the fish out of the shelf, they form dense concentrations in the narrow areas of the slope under the so-called "core" of the branch of the West Greenland Current.

It is evident that the trawl survey in the area of Baffin Island conducted in September 1984 was in relatively warm waters (according to the location of the ice edge and near-bottom isotherm on the shelf), when the autumn/winter migration of Greenland halibut into great depths has not yet started. A significant part of the shelf was occupied by relatively warm water and on 29 November 1984 the ice edge was located 20–25 miles west of the 500 m isobath. The near-bottom 0° C isotherm was located between 200 and 500 m isobaths. In September 1984 during the trawl survey the fish were scattered over a wide area (Fig. 12), and catches were low (up to 700 kg-per-hour trawling). In fact the Greenland halibut fishery was not conducted in that area. The greatest catches were taken from shallow depths (Table 5). There was also no increase of the mean length of fish with depth which is usually noted when the Greenland halibut migration from coastal to offshore waters comes to an end (Chumakov, 1982).

A similar hydrographic situation was noted in the Baffin Island area in November 1985. The near-bottom 1° C isotherm was located between 200 and 500 m isobaths, the 2° C isotherm corresponded approximately to the 500 m isobath and the 3° C isotherm was between the 500 m and 1,000 m isobaths (Fig. 4D). In November the ice edge was far from the slope and was located over the shallow waters (Fig. 10). Greenland halibut were scattered in a wide area without forming dense concentrations and consequently catches were small.

November 1983 was anomalously cold (Chumakov *et al.*, MS 1984; Borovkov and Burmakin, MS 1985) and the hydrographic situation was different. On 15 November the ice edge was located between 500 m and 1,000 m isobaths. The Greenland halibut catches were

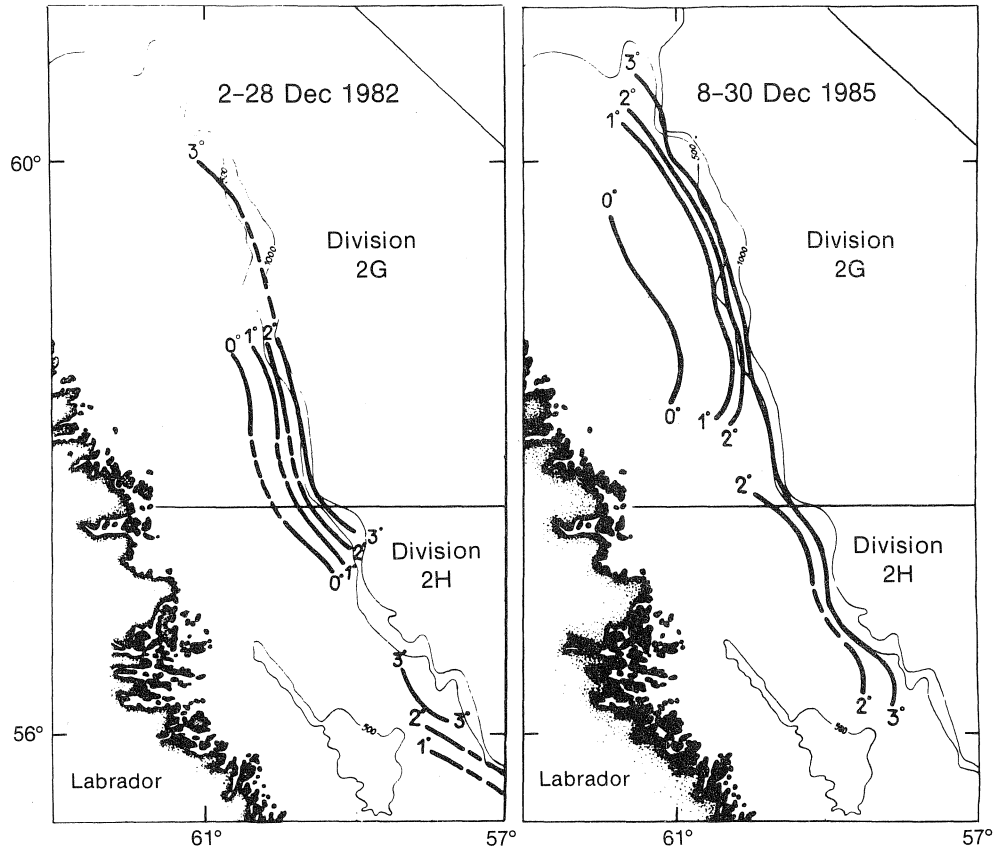

Fig. 9. Near-bottom isotherms in the area of the continental shelf and slope of Northern and Central Labrador in December 1982 and 1985.

higher than in the corresponding periods of 1984 and 1985 (Fig. 4C), especially in the layers deeper than 1,000 m (Table 5). The maximum catches exceeded 3,000 kg-per-hour trawling. In November 1982 the ice edge was located slightly more easterly than in 1983 and Greenland halibut catches there were also higher. The mean catch-per-hour trawling was 1,101 kg in 1982 and 715 kg in 1983 (Table 5). The USSR Greenland halibut catches taken from the Baffin Island area were 3,500 tons in 1982 and 3,700 tons in 1983 (*NAFO Statistical Bulletin*, 1984; 1985), representing 91.1 and 83.2% respectively, of the total catch. In 1984 the USSR catch in that area was only 109 tons and in 1985 it was 179 tons (Chumakov and Borovkov, MS 1986).

According to the data of Murmansk Meteorological Centre, in October 1986 in the Baffin Island area south of 65° N no ice was detected (ice was found only in the bays), while the ice edge 40 miles wide was observed to the north. According to the data from the *MG-1330 Klintsy* which conducted the Greenland halibut trawl survey in that area, there were positive anomalies of water temperatures in the 50–200 m layer of the shelf. That indicated the intensified influence of the warm branch of the West Greenland Current on the heat content of shelf waters. Greenland halibut were scattered in a wide area resulting in small catches taken by *MG-1330 Klintsy*.

It is therefore apparent that the Greenland halibut distribution is related to the oceanographic conditions on the continental shelf and slope in the areas of Baffin Island and Labrador and allows us to determine the fishery conditions in advance. It is possible to predict ice conditions for November/December (the most favourable period for the Greenland halibut fishery) analyzing the changes in the location of the ice edge in the area of the Baffin Island from September to October. For example in September/October 1984 and 1985, when the shelf was occupied by relatively warm waters, the ice off Baffin Island was not present, while in September/October 1982 and 1983 coastal ice fields were present (Fig. 13) and at the end of October it was 40–50 miles wide.

It is known that the hydrographic conditions of a particular year or season are the main factors influencing the distribution of commercial species and the outcome of trawl surveys conducted for abundance assessment. Baird and Bishop (MS 1986) noted that the

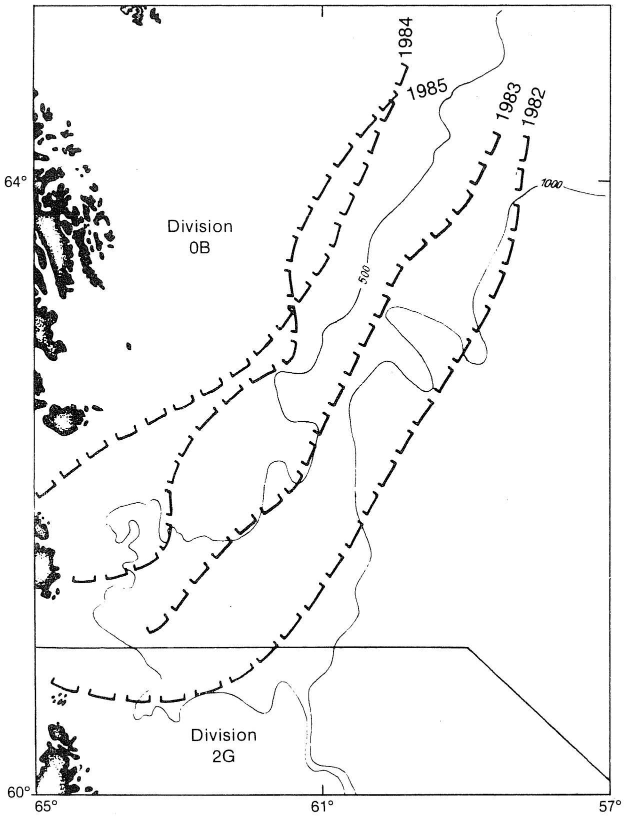

Fig. 10. Ice edge location during trawl surveys off Baffin Island in November 1982-85.

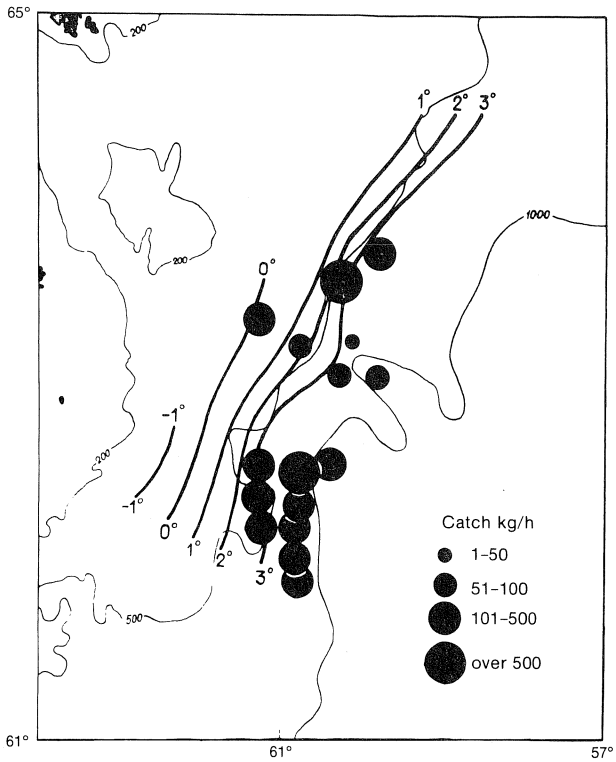

Fig. 12. Mean Greenland halibut catches per trawling hour taken during the trawl survey, and near-bottom isotherms off Baffin Island, during 18-29 September 1984.

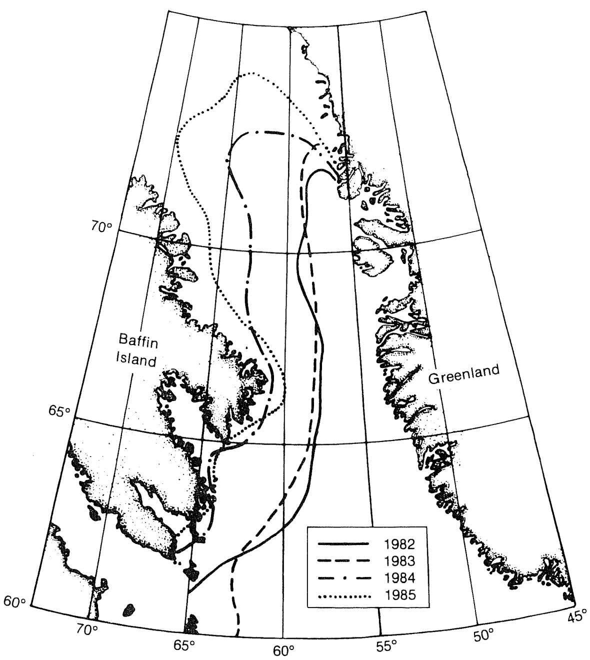

Fig. 11. Mean monthly location of ice edge off Baffin Island in November 1982-85 according to Murmansk Meteorological Centre data.

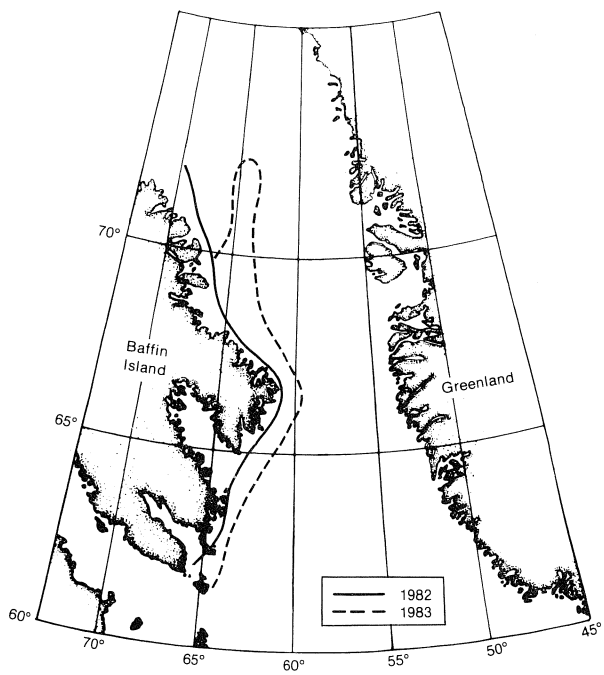

Fig. 13. Mean monthly location of ice edge off Baffin Island in October 1982 and 1983 according to Murmansk Meteorological Centre data.

reduction in abundance and biomass of cod, American plaice, witch flounder and Greenland halibut based on Canadian trawl survey data for 1985 in Div. 2J and 3KL, was related to the fish distribution in near-bottom waters where temperatures were lower than in previous years. Catches taken in USSR trawl surveys for Greenland halibut stock assessment in the Northwest Atlantic have varied by area and from year to year. This has led to significant fluctuations in the calculated values of fish abundance and biomass, and difficulties estimating the stock and predicting the total yield.

In the present study it was shown that variable hydrographic conditions can influence the migrations of mature Greenland halibut to the spawning grounds in the Greenland-Canadian Threshold area and partly in the 200-mile zone of Greenland (Denmark). The migrations which take place annually consequently occur at different periods and intensity and these can influence the results of the trawl surveys. The hydrographic regimes also influence behaviour and distribution of demersal fish and to a great extent the fishery conditions. The cooling of water masses in the Northwest Atlantic in the early-1970s led to displacement of roundnose grenadier and Greenland halibut into deep waters and reduced their accessibility to the bottom trawl fishery. In 1985-86 the water temperature was similar to the long-term mean and the rise in temperature in the upper layers (to reach a maximum in 1989-90) and in the deeper layers near the continental slope (to exceed the long-term mean by 1991) can influence the vertical fish distribution and the fishery conditions.

In the area of Baffin Island and Labrador, the most favourable period for trawl surveys is in November/January when the Greenland halibut migration from the coastal zone to the offshore waters comes to an end and fish form dense wintering concentrations on the continental slope (Chumakov, 1982). Time of concentration, their density and stability are connected with the hydrographic conditions arising on the shelf from the interaction of the cold Baffin Island Current and the warm branch of the West Greenland Current. In those years when the whole shelf is occupied by below 0° C bottom temperatures, Greenland halibut are found concentrated over the continental slope. If relatively warm waters of the West Greenland Current branch penetrate farther to the west than usual and occupy the part of the shelf, then Greenland halibut are scattered in a wide area. The hydrographic front arising from the interaction of these two currents near the 1,000 m isobath is the main factor affecting the formation of Greenland halibut concentrations. The largest Greenland halibut catches are taken in the area of the continental slope where the 1° to 3° C isotherms are located close to each other.

Greenland halibut concentrations in the area of the continental slope of Baffin Island probably occur near the ice edge. The stable Greenland halibut concentrations favouring an effective fishery are formed when the ice edge is between the shelf and the slope. However, it is not clear if the ice cover and the ice edge location affect the formation of Greenland halibut concentrations, though the connection between the commercial fish distribution and the ice edge location is generally known. Commercial experience proves that successful fisheries occur near the ice edge, for example in the upper layers for capelin and in deep waters for redfish and cod. This supports the fact that the ice edge is one of the features affecting the formation and density of commercial concentrations. Data presented here suggest that the ice edge location during the period when Greenland halibut form concentrations near the continental slope can be considered an index of the thermal state of shelf waters. The conditions can be predicted from the research trawl survey 1-2 months in advance and this in turn can possibly be used to predict the conditions for the Greenland halibut fishery in the area of Baffin Island in November/December.

References

ATKINSON, D. B. MS 1982. Status of roundnose grenadier stocks in Subareas 0+1 and 2+3. *NAFO SCR Doc.*, No. 55, Serial No. N548, 9 p.

MS 1984. An update on the status of roundnose grenadier in Subareas 0+1 and 2+3. *NAFO SCR Doc.*, No. 20, Serial No. N793, 6 p.

BAIRD, J. W., and C. A. BISHOP. MS 1986. Assessment of the cod stock in NAFO Divisions 2J+3KL. *NAFO SCR Doc.*, No. 47, Serial No. N1163, 65 p.

BOROVKOV, V. A., and V. V. BURMAKIN. MS 1985. Hydrographic conditions off Labrador and Newfoundland in 1983–1984. *NAFO SCR Doc.*, No. 59, Serial No. N1009, 17 p.

BOWERING, W. R. MS 1984. Distribution and relative abundance of the Labrador-Eastern Newfoundland stock complex of Greenland halibut (*Reinhardtius hippoglossoides*). *NAFO SCR Doc.*, No. 61, Serial No. N850, 14 p.

BOWERING, W. R., and W. B. BRODIE. MS 1984. An assessment of the Greenland halibut (*Reinhardtius hippoglossoides*) stock complex in NAFO Subarea 2 and Divisions 3KL. *NAFO SCR Doc.*, No. 61, Serial No. N851, 19 p.

BURMAKIN, V. V. 1972. Seasonal and year-to-year variations in water temperature in the Labrador and Newfoundland areas. *ICNAF Spec. Publ.*, **8**: 63–70.

1978. Influence of water temperature on the catches of roundnose grenadier and Greenland halibut off Baffin Island. *Trudy PINRO, Murmansk*, **40**: 148–152 (in Russian).

BURMAKIN, V. V., I. I. SVETLOV, and A. K. CHUMAKOV. 1977. Prediction of grenadier and halibut catches off Baffin Island by the temperature factor. *In*: Tezisy dokladov IV Vsesojuznoy konferentsii po promyslovoy okeanologii, Murmansk, 109 p. (in Russian).

CHUMAKOV, A. K. 1975. To the problem on locality of stocks of Greenland halibut in Northwest Atlantic. *Trudy PINRO*, Murmansk, **35**: 203–209 (in Russian).

1982. On trawl survey of Greenland halibut stocks in the Canadian zone of the North Atlantic. *In*: Abundance and mode of life of the Northwest Atlantic commercial fishes (p. 21–31), PINRO, Murmansk, 134 p. (in Russian).

CHUMAKOV, A. K., and V. A. BOROVKOV. MS 1986. USSR research report for 1985. *NAFO SCS Doc.*, No. 17, Serial No. N1179, 32 p.

CHUMAKOV, A. K., and P. I. SAVVATIMSKY. MS 1983. On the Greenland halibut by-catch in the directed fishery for roundnose grenadier on the Labrador continental slope and in Davis Strait (NAFO Subareas 0, 1, 2 and Division 3K). *NAFO SCR Doc.*, No. 91, Serial No. N757, 14 p.

MS 1984. Roundnose grenadier-Greenland halibut ratio in bottom trawl catches taken in NAFO area in 1970–83. *NAFO SCR Doc.*, No. 37, Serial No. N822, 15 p.

CHUMAKOV, A. K., V. A. BOROVKOV, and A. S. NOSKOV. MS 1984. USSR research report for 1983. *NAFO SCS Doc.*, No. 17, Serial No. N837, 41 p.

ERNST, P. MS 1984. A contribution to by-catch of Greenland halibut (*Reinhardtius hippoglossoides* Walb.) in the roundnose grenadier (*Coryphaenoides rupestris* Gunn.) directed fishery in NAFO Subarea 2. *NAFO SCR Doc.*, No. 96, Serial No. N891, 8 p.

KONSTANTINOV, K. G., and A. S. NOSKOV. MS 1977. USSR research report, 1976. *ICNAF Sum. Doc.*, No. 15, Serial No. 5071, 39 p.

KULKA, D. W. MS 1985. The effect of changing effort patterns of catch composition in the roundnose grenadier fishery, 1978–83. *NAFO SCR Doc.*, No. 16, Serial No. N956, 19 p.

SAVVATIMSKY, P. I. MS 1969. The grenadier of the North Atlantic. *Trudy PINRO*, p. 3–72. (Fish. Res. Board Can. Transl. Ser. No. 2879.)

MS 1986. Changes in composition of the bottom fish catches at different depths along the continental slope in NAFO Subareas 0, 2 and 3 in 1970–85. *NAFO SCR Doc.*, No. 87, Serial No. N1184, 26 p.

1987. Changes in species composition of trawl catches by depth on the continental slope from Baffin Island to northeastern Newfoundland, 1970–85. *NAFO Sci. Coun. Studies*, **11**: 43–52.

SCHICKEDAN, P., and E. BOWEN. 1977. The computation of climatological power spectra. *J. Appl. Meteorology*, **16**(4): 359–367.

VOSS, J., and P. DRAFFEHN. 1963. Vorlaufiger Bericht Uber die Durchfuhrung einer Kommerzieller Fischerei in 600 bis 800 m Wassertiefe vor Neufundland-Labrador. *Fischerei-Forschung*, 1 Jahrgang, Heft 1.