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Changes in Size-at-age of Atlantic Cod (*Gadus morhua*) off West Greenland, 1979-84

Holger H. Hansen
Greenland Fisheries and Environmental Research Institute
Tagensvej 135, Copenhagen N, DK-2200, Denmark

Abstract

Analysis of sampling data for Atlantic cod (*Gadus morhua*) from the offshore catches of trawlers off West Greenland in the first and second quarters of 1979-84 revealed significant reductions in the size of fish comprising the major age-groups from 1979 to 1984. Mean length-at-age of age-groups 5-8 declined by 15-17% and mean weight-at-age declined by 44-47%. Hydrographic conditions as well as the distribution and migration patterns of cod have changed substantially during the 1979-84 period. The change in size-at-age may be attributed in part to the effect of environmental conditions on growth and perhaps in larger part to the effect of changing distributional patterns of the cod population.

Introduction

The Atlantic cod (*Gadus morhua*) population and fishery in West Greenland waters have experienced great changes since the peak years of the fishery (1961-68) when nominal catches varied between 350,000 and 450,000 (metric) tons (ICNAF, 1976). After 1968, catches declined rapidly to a low of 32,000 tons in 1976. Slight improvement to about 60,000 tons in 1983 was followed by near-collapse of the fishery with a nominal catch of only 15,000 tons in 1985 (NAFO, 1985, MS 1986).

Substantial changes in the growth of Atlantic cod (hereinafter called cod) and the structure of the population off West Greenland have been observed during the early 1980's. These changes have been attributed to a combination of low recruitment and substantial migration of cod from West Greenland waters (Cornus *et al.*, MS 1985). Both processes are believed, at least in part, to be influenced by water temperatures, which were unusually low during the same period (Rosenorn *et al.*, MS 1985; Buch, MS 1986). The purpose of this paper is to document the considerable decrease in mean size-at-age of cod in recent years and to discuss briefly the possible causes for this change.

Materials and Methods

Biological sampling of the cod fishery in West Greenland waters (Fig. 1) has been conducted for many years. However, only the data for 1979-84 have been computerized, and analysis of this data set was prompted by recent changes in apparent growth of cod. During 1979-84, there were few problems with sample coverage of the offshore trawl fishery, which is conducted mainly by a fleet of state-owned trawlers. These vessels usually fished on the same grounds, but their catches were landed at various ports in West Greenland, including Nuuk where most of the sampling took place because the fisheries research laboratory is located there. Sampling coverage of the inshore fishery, on the other hand, was very patchy because of the numerous small fishing communities and the large distances between many of them. Because of differences in size composition of inshore and offshore

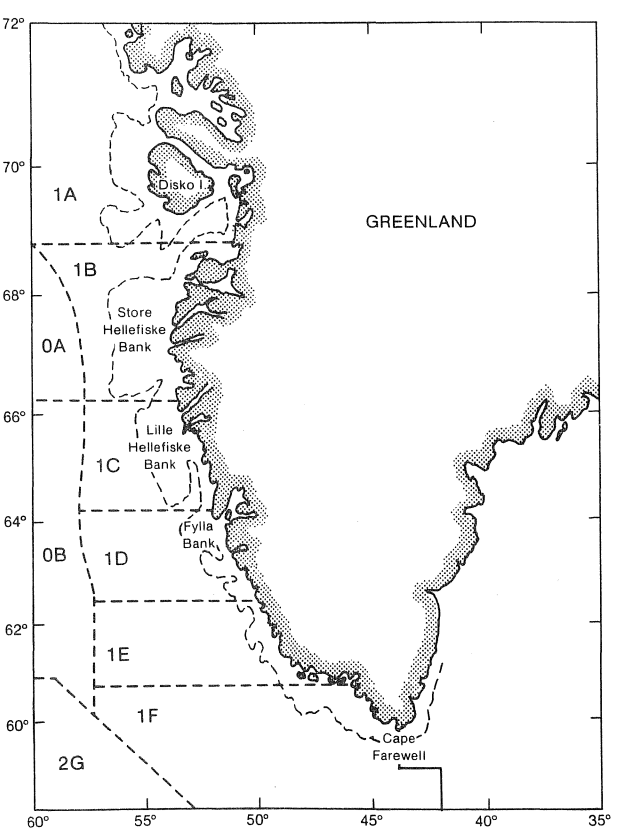

Fig. 1. Map of Greenland showing the NAFO divisions and other areas mentioned in the text.

catches, only the data from the offshore trawl fishery were used to reduce the effect of unbalanced geographical sampling coverage over the years.

Most of the trawl catches were taken in Div. 1C, 1D and 1E (Fig. 1), and this is reflected in the sampling coverage (Table 1). In order to reduce the possible effects of growth differences between the extreme parts of the West Greenland area, only the data for these divisions (88% of the age readings) were used. Seasonally, most of the offshore fishery, and hence sampling effort, took place in the first, second and fourth quarters of the year. However, only the data for the first and second quarters were used, because this is the period when growth is minimal. The resulting database consisted of length, weight and age data for nearly 12,000 fish. Lengths were recorded as total lengths to the cm below (i.e. 50.0–50.9 = 50 cm), weights were recorded in grams, and ages were determined by microscopic examination of otolith cross-sections showing alternating opaque and translucent zones.

TABLE 1. Numbers of age determinations for cod in samples of trawl catches by division off West Greenland and by quarter in Div. 1CDE, 1979–84.

	1979	1980	1981	1982	1983	1984	Total
Total age determinations by division							
1B	—	483	—	990	501	—	1,974
1C	1,134	387	502	748	—	14	2,785
1D	1,449	604	682	2,368	2,434	218	7,755
1E	—	1,325	152	1,443	2,174	1,708	6,802
1F	314	—	—	—	—	185	499
Total	2,897	2,799	1,336	5,549	5,109	2,125	19,815
Age determinations for Div. 1CDE by quarter							
1	1,416	1,334	297	2,295	1,512	1,170	8,024
2	1,167	415	456	669	1,109	14	3,830
3	—	46	—	811	512	500	1,869
4	—	521	583	784	1,475	256	3,619
Total	2,583	2,316	1,336	4,559	4,608	1,940	17,342

In an assessment context, the most interesting variable is weight-at-age. However, much of the reproductive cycle (maturing, spawning and refattening) occurs in the first and second quarters, with consequent changes in conditions of the fish. For this reason, the analysis was performed on length-at-age data, which were subsequently converted to weight-at-age values by using condition factors for the prespawning period (i.e. January–February), the condition factors (CF) being defined by

$$CF = 100\ W/L^3$$

where W is weight (gm) and L is length (cm). The calculated weight-at-age values were considered to be closely representative of conditions at the beginning of the year, because practically no growth in length occurs during the first and second quarters.

Results

Changes in length-at-age

A substantial reduction in average length of cod was evident for nearly all age-groups during 1979–84 (Table 2). The reduction is clearly illustrated in Fig. 2 for the most numerous age-groups (4 to 8). The trend for age 4 cod is less consistent than those for age-groups 5–8, mainly because the minimum landing size of 40 cm would bias the mean length of age 4 cod upward when the population mean approaches the minimum landing size.

The decrease in mean length-at-age is approximately linear for each of age-groups (Fig. 2), with increasing negative slope for the older fish. Linear

TABLE 2. Number of cod examined and average length by age-group in samples of trawl catches from Div. 1CDE off West Greenland during the first two quarters of 1979–84.

Age	Number of cod						Average length (cm)					
(yr)	1979	1980	1981	1982	1983	1984	1979	1980	1981	1982	1983	1984
2	—	—	—	1	—	1	—	—	—	22.0	—	16.0
3	2	46	—	118	1	93	38.0	34.3	—	32.2	27.0	26.1
4	520	233	234	40	471	92	47.6	47.6	48.0	41.9	45.2	39.3
5	736	533	86	1527	159	486	59.0	57.7	58.9	54.6	50.8	49.3
6	1052	277	207	293	1437	50	70.7	68.1	65.2	64.7	59.8	59.8
7	55	590	50	503	161	368	78.0	76.4	74.4	72.5	70.4	65.6
8	133	19	156	232	229	17	87.2	85.3	81.5	81.2	76.1	72.2
9	28	40	4	166	97	40	89.1	86.6	80.8	86.1	81.0	78.3
10	26	5	13	16	53	11	95.4	91.0	88.8	95.5	79.9	80.6
11	17	1	2	50	2	23	97.8	94.0	95.5	98.7	103.5	82.5
12	3	4	—	1	7	—	115.7	86.5	—	115.0	87.3	—
13	5	1	—	11	2	3	104.6	102.0	—	108.9	111.0	78.0
14	4	—	1	4	2	—	110.0	—	86.0	101.3	81.5	—
15	1	—	—	2	—	—	115.0	—	—	113.0	—	—
16	—	—	—	—	—	—	—	—	—	—	—	—
17	1	—	—	—	—	—	108.0	—	—	—	—	—

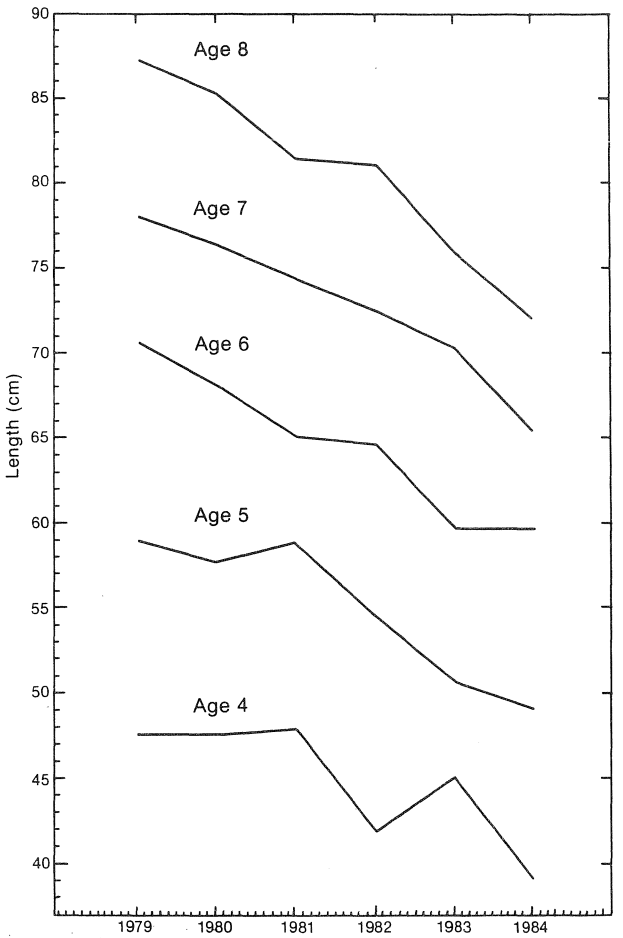

Fig. 2. Trends in mean length of cod of age-groups 4 to 8, from samples of offshore catches in Div. 1CDE during 1979-84.

regressions were fitted for each age-group, and predicted lengths were calculated for 1979 and 1984 (Table 3). For age-groups 5-8, the reductions in predicted length were between 14.9 and 17.4%.

Condition factors

Condition factors for cod in January and February of each year were calculated and regressed against length to check for any relationship between these parameters (Table 4). No significant effect was found in the data for 1979, 1981 and 1984 ($P>0.05$), but significant deviations of the slopes of the regression lines from zero were found for 1980, 1982 and 1984. The pattern was not consistent, because condition factor increased with length (positive slope) in 1982 and decreased with length (negative slope) in 1980 and 1983. The simplest interpretation of these somewhat ambiguous results was to assume that fish condition is independent of length, in which case the significant effects in some years may be attributed to unbalanced sampling or to errors in the initial recording of fish lengths and weights. The largest absolute deviation of the slope from zero occurred in the 1980 data (Table 4).

TABLE 3. Parameters of the relationship between mean fish length and year of sampling for ages 5-8 cod off West Greenland over the 1979-84 period, and predicted lengths for 1979 and 1984.

Age (yr)	Regression parameters[a]		Predicted length (cm)		Percent length decrease
	Intercept (a)	Slope (b)	1979	1984	
5	226.2	-2.10	60.3	49.8	17.4
6	250.8	-2.28	70.4	59.0	16.2
7	263.6	-2.34	78.7	67.0	14.9
8	330.2	-2.94	87.9	73.2	16.7

[a] Linear model is $L = a + bY$, where L is mean length (cm) and Y is year.

TABLE 4. Parameters and test statistics of the relationship between condition factor and fish length for cod off West Greenland, 1979-84.

Year	Regression parameters[a]		Sign. test P(b=0)
	Intercept(a)	Slope(b)	
1979	0.99	-0.0003	0.31
1980	1.15	-0.0021	<0.001
1981	0.92	0.0003	0.64
1982	0.98	0.0010	<0.001
1983	1.00	-0.0020	<0.001
1984	0.94	-0.0005	0.18

[a] Linear model is $CF = a + bL$, where CF is condition factor and L is length (cm).

To illustrate the possible involvement of errors (outlying values) when applying a constant conversion factor, the frequency distribution of observations on condition factor and fish length for 1980 are shown in Fig. 3. The high outlying points pertain predominantly to small cod, and these contributed to making the slope of the CF-length relationship negative in that year. It is clear that a great majority of the observations fall within a narrow range of CF values (0.8-1.2) and that the points seem to be randomly distributed around the mean CF, which was 1.01 in that year (Table 5).

Changes in weight-at-age

Mean weight-at-age values, which are considered to be representative of cod at the beginning of each year, were calculated from the mean condition factors (Table 5). The decreases in weight from 1979 to 1984 for the most important groups (ages 4-8) were in the range of 44-47%.

Discussion

The change in size-at-age of cod off West Greenland can be interpreted as a change in growth but it can also result from a selective migration of older fish. In the following discussion, emphasis has been placed on these two aspects of the changes.

Changes in growth of cod

The most important factors which regulate the

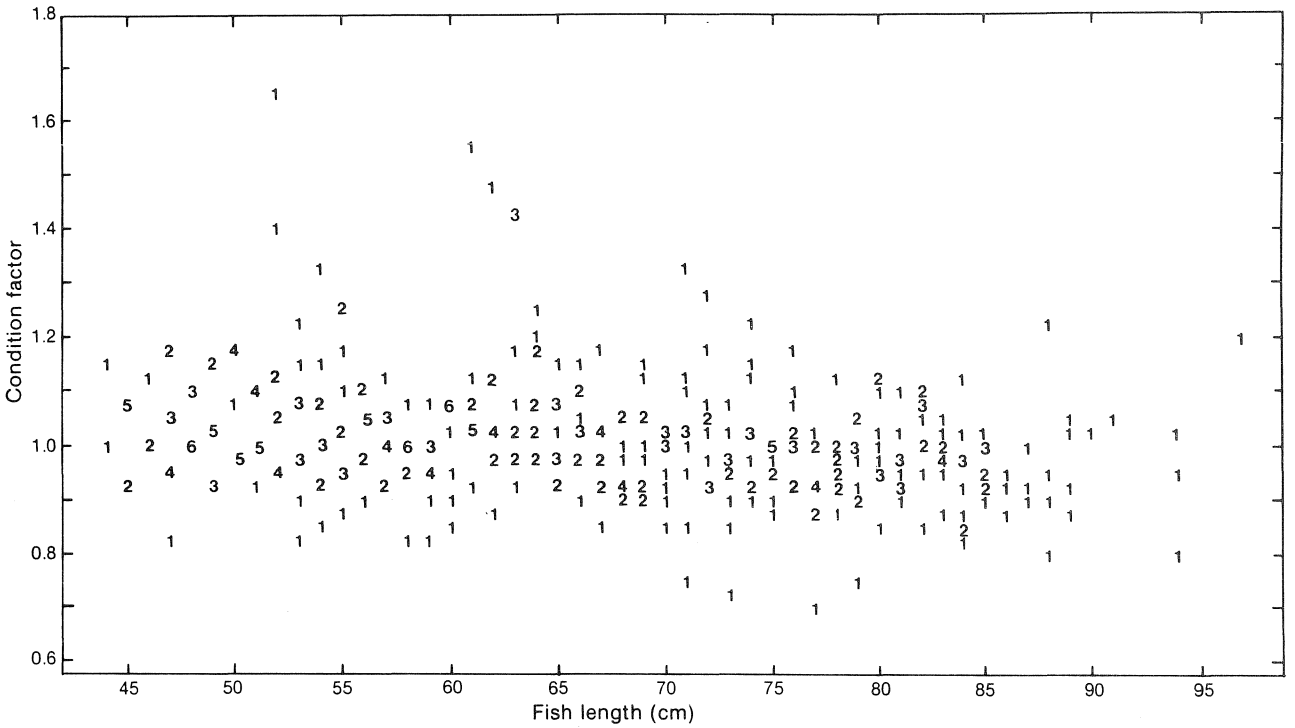

Fig. 3. Frequency distribution of observations on condition factor and length of cod from offshore catches in January-February 1980.

TABLE 5. Calculated average weights (using mean condition factors) of West Greenland cod by age-group and year, 1979-84. (See Table 2 for numbers of cod sampled.)

Age	Calculated average weight (kg)						% decrease
(yr)	1979	1980	1981	1982	1983	1984	1979-1984
4	1.07	1.11	1.06	0.81	0.83	0.57	46.7
5	2.04	2.00	1.94	1.77	1.17	1.13	44.6
6	3.51	3.31	2.65	2.87	1.94	1.98	43.6
7	4.77	4.64	3.96	4.09	3.10	2.62	45.1
8	6.53	6.43	5.22	5.78	3.95	3.46	47.1
9	7.00	6.68	5.09	7.02	4.79	4.47	36.1
10	8.49	7.66	6.86	9.42	4.69	4.94	41.8
11	9.24	8.40	8.20	10.25	9.84	5.43	41.1
CF[a]	0.97	1.01	0.94	1.05	0.88	0.91	

[a] Mean condition factor.

growth of fish are temperature and food availability, with the latter factor also being largely dependent on the former one. Knowledge of food availability for cod off West Greenland is scarce. No studies on food and feeding of cod have been carried out in recent years, and none of the organisms (fish and invertebrates) which are believed to be the major prey of cod are presently being studied with regard to their abundance and biomass.

The overall temperature regime in West Greenland waters has undergone substantial changes during the past decade, with pronounced cooling of the water masses from 1982 to 1984 (Rosenorn *et al.*, MS 1985). This decline in temperature may be responsible for the observed reduction in size-at-age of cod, but it might be misleading to use overall temperature indices as major contributing factors, because cod are quite capable of seeking water strata with suitable temperatures.

The cod populaton off West Greenland undertakes fairly regular annual migrations from the deep offshore areas where they stay from autumn to early summer to the shallow coastal waters where they are fished during late summer and early autumn. To obtain some indication of the changes in temperature conditions during these migrations, data for three hydrographic regimes in the Fylla Bank area were summarized, two for the offshore area (Station 4 at 63°53'N, 53°22'W) in February and November, and one for the coastal area (64°01'N, 52°10'W) in July, enabling the comparison of average temperatures over the 1973-84 period (Fig. 4). In general, the temperature conditions did not vary much and there was no evidence of a marked decline in temperature during 1979-84.

A significant question in relation to the effect of temperature on the growth of fish is: how much temperature change will be necessary to account for the reduction in size-at-age as large as that which has been observed for cod off West Greenland? As a starting point, one can assume that growth rate is proportional to temperature, i.e. the degree-day model

$$\text{Time} \times \text{Temperature} = \text{Constant}$$

where "Time" refers to the time necessary for the

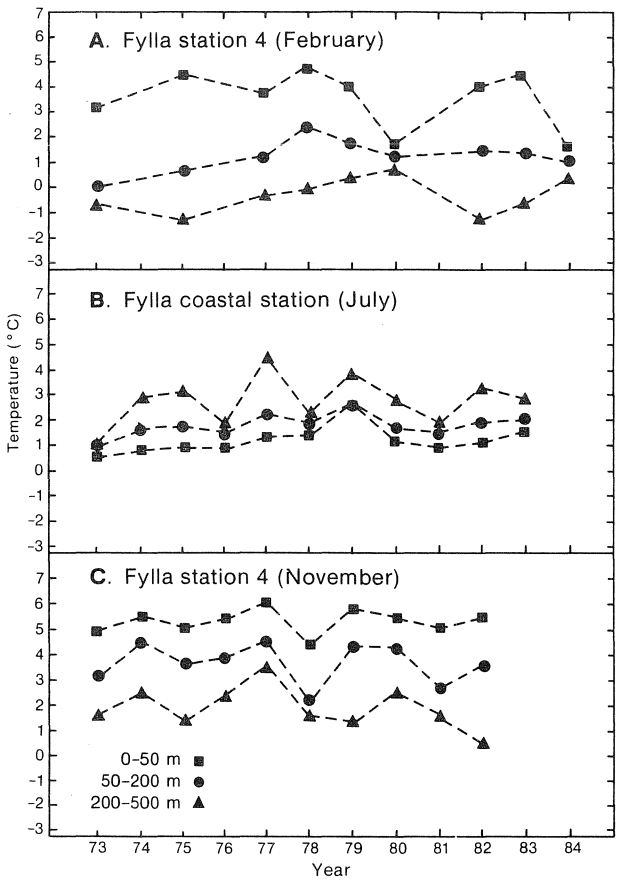

Fig. 4. Trends in mean water temperature of three depth zones in the vicinity of Fylla Bank, 1973-84: **A**, Fylla station 4 in February; **B**, Fylla coastal station in July; and **C**, Fylla station 4 in November.

animal to grow to a certain size. For comparison of two different growth situations

$$\text{Time(1)/Time(2)} = \text{Temp.(2)/Temp.(1)}$$

Weight-at-age data for 1979 and 1984 were used to calculate the Time(1)/Time(2) ratios relevant to unit increase in fish weight (Table 6). In a general sense, this implies that a temperature reduction of about 20% is sufficient to account for a reduction in mean weight-at-age values as large as those observed from 1979 to 1984. For the prevailing temperature regime, the change in size-at-age could result from a 1°C decline in temperature from about 5° to 4°C. There is, however, no *a priori* reason to expect a simple proportionality, and it has been suggested (Ricker, 1979) that the degree-day model should be modified to

$$\text{Time} \times (\text{Temperature} - T_o) = \text{Constant}$$

where T_o is a positive temperature below which no growth takes place. If, in the case of cod, T_o is assumed to be 2° C, a 0.5° C reduction in temperature from 4.5° to 4.0° C would be sufficient to account for the observed reduction in size-at-age.

TABLE 6. Calculated time (years) for cod to grow to various weight levels in 1979 and 1984, based on the weight-at-age data in Table 5.

Weight (kg)	Time(1) 1979	Time(2) 1984	Ratio
1.0	3.90	4.75	0.82
1.5	4.45	5.48	0.81
2.0	4.95	6.05	0.82
2.5	5.32	6.75	0.79
3.0	5.65	7.45	0.76
3.5	5.99	8.05	0.74
4.0	6.40	8.55	0.75

If these very rough considerations reflect situations close to reality, i.e. that temperature reductions as small as 0.5° to 1.0°C may cause reductions in size-at-age as large as those which have been observed for cod, it will be quite difficult in practice to construct a realistic growth model due to the magnitude of the spatial and temporal temperature variations in nature.

Changes in size due to migration

Recent analyses of data relevant to determining the state of the cod stocks off West Greenland for management purposes have been carried out under the assumption that large numbers of cod migrate from West Greenland to East Greenland and possibly Iceland (Horsted *et al.*, MS 1984; Cornus *et al.*, MS 1985; ICES, MS 1985). These mass movements have been interpreted as spawning migrations. Recent maturity data for cod off West Greenland indicate that the mean size-at-age of mature fish is only slightly larger than that for immature fish. Thus, the idea cannot be excluded that the reduction in mean size was caused, at least in part, by increased migration of large mature cod away from the West Greenland area. Nevertheless, the reduction in size-at-age seemed to affect all age-groups uniformly, irrespective of the proportion of mature fish in each age-group.

Concurrently with the large migrations in recent years, there has been a gradual southern displacement of the cod fishery off West Greenland. This trend is clearly reflected in the catches of Greenland trawlers during 1979-84 (Table 7). The southern movement of the stock complex may have affected the mean size-at-age of cod in the region under investigation (Div. 1CDE). Length frequencies from recent autumn bottom-trawl surveys by research vessels of the Federal Republic of Germany indicated that the smallest cod were found in the northern areas (Div. 1BC) and that there was a gradual increase in size from Div. 1C to 1F, with the largest fish off East Greenland (Messtorff and Cornus, MS 1984; Cornus *et al.*, MS 1985). Thus, a general southern displacement of the stock complex would result in the movement of relatively small cod to

TABLE 7. Total catch of state-owned Greenland trawlers and percentage distribution by area off West Greenland, 1979–84.

Year	Catch (tons)	Catch distribution by area (%)				
		1B	1C	1D	1E	1F
1979	10,750	—	59.8	33.4	6.6	0.2
1980	6,654	26.9	24.8	27.0	21.0	0.3
1981	13,336	—	31.9	35.3	32.9	—
1982	20,938	0.6	19.2	35.0	45.1	0.1
1983	16,322	1.8	3.4	24.4	69.7	0.7
1984	4,491	—	—	43.3	52.6	4.1

Div. 1CDE from the north and the southward migration of relatively larger fish out of the area.

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