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Spawning Stock, Population Fecundity and Year-class Strength of Greenland Halibut (*Reinhardtius hippoglossoides*) in the Northwest Atlantic, 1969–88

V. P. Serebryakov
All-Union Research Institute of Marine Fisheries and Oceanography (VNIRO)
17 V. Krasnoselskaya, Moscow B-140, 107140, Russia

and

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

Abstract

An attempt was made to analyse spawning stock abundance and population fecundity of Greenland halibut (*Reinhardtius hippoglossoides*) against the background of fluctuations in year-class strength. Population fecundity varied from 8×10^{11} to 24×10^{11} eggs in 1969-88. Survival indices of year-classes 1969-88 were calculated during early life history and a five-fold difference between maximum and minimum survival rates was revealed. An inverse correlation was found between survival rate and water temperature at 50-200 m depth on the hydrographic section across the Hamilton Bank. This was used for survival index projections.

Introduction

Greenland halibut (*Reinhardtius hippoglossoides*) are distributed above the continental shelves and slopes off Canada from 42°N to 78°N in the Baffin Sea (Andriyashev, 1954; Boyar, 1964; Hubbs and Willimovsky, 1964; Leim and Scott, 1966; Smidt, 1969; Templeman, 1973). This fish is an important commercial species off eastern Newfoundland, along the Baffin Island slope, off Labrador and in the West Greenland fjords (Bowering, MS 1977, MS 1978, MS 1979, 1980, MS 1987; Chumakov and Savvatimsky, MS 1983, MS 1984, MS 1987; Bowering and Brodie, MS 1981, MS 1986). A single population is recognized to inhabit these areas (Templeman, 1973; Chumakov, 1975; Bowering MS 1977, MS 1982; Chumakov and Serebryakov, MS 1982; Ernst, MS 1987).

The Greenland halibut spawns in areas of the southern part of Davis Strait at depths of 1 000–1 500 m and temperatures of 3.2° to 3.4°C during January–April. Egg development takes place mainly in deep water layers of the continental slope (Jensen, 1935; Smidt, 1969; Templeman, 1970) and the larvae ascend to the upper surface layers in June–July where they are dispersed with the currents to the west to Baffin Island and Labrador shelves and to the north along the West Greenland coast.

The maximal number of larvae are observed in the upper 50 m layer (Smidt, 1969). The young halibut, at ages of 3–4 years, are distributed mainly at depths of 200–350 m over the continental shelves practically everywhere along West Greenland, Baffin Island, Labrador and on the Grand Bank of Newfoundland (Bowering and Chumakov, MS 1987; Chumakov *et al.*, MS 1988).

The fishery for Greenland halibut was initiated by Canada in the inshore areas of eastern Newfoundland in the 1950s and extended later to the high seas. The trawl fishery for Greenland halibut was not actually developed until 1968. The species was incidentally taken as by-catch by USSR and European countries in the cod and redfish fishery. The total catches in 1965–67 were less than 29 000 tons (Fig. 1).

The fishery was not regulated until 1977 and the catches until that time varied from 29 000 to 53 600 tons. The annual catch was influenced mainly by the fishing effort applied. The introduction of 200-mile coastal fishing zones in 1977, and the subsequent termination of fishery for Greenland halibut by USSR, Poland and ex-German Democratic Republic in Subarea 1 as well as a reduction in fishing effort by the same countries in the Canadian 200-mile fishing zone in Subareas 0, 2 and 3, resulted in

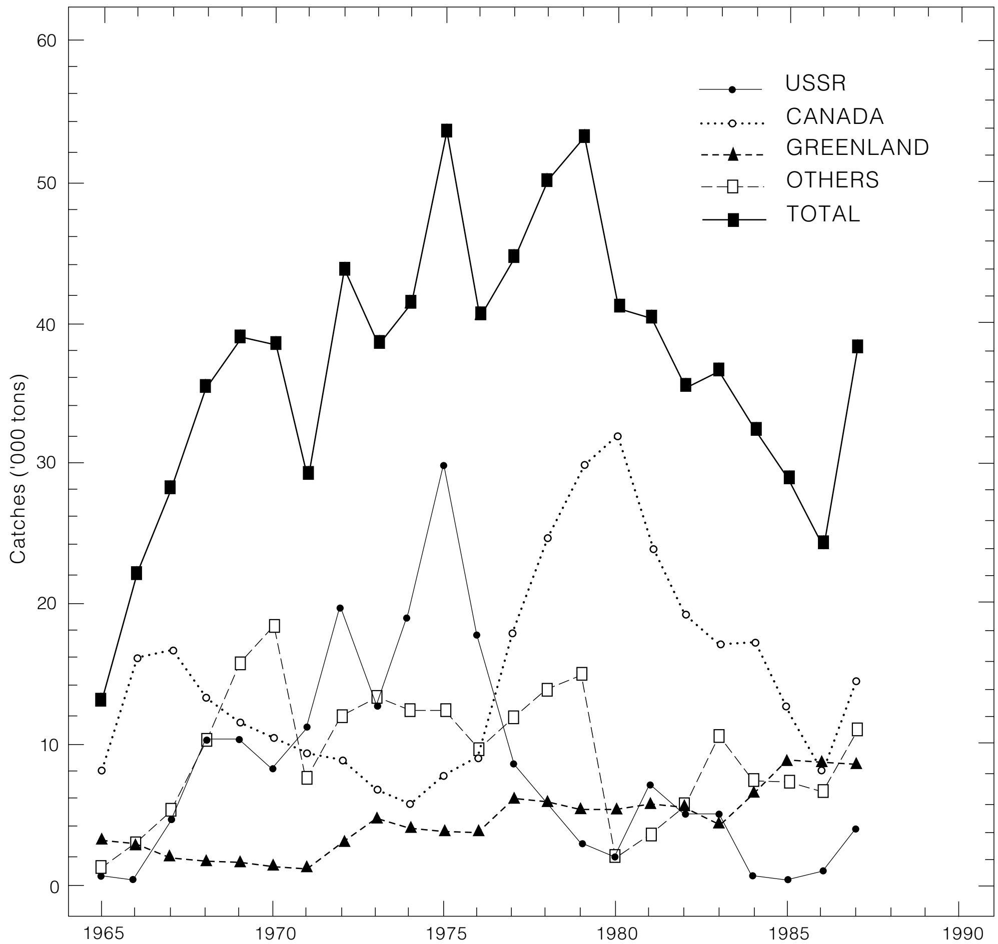

Fig. 1. Greenland halibut catches in the Northwest Atlantic (Subareas 0+1 and Divisions 2+3KL).

a downward trend in the catches. At the same time, the Canadian and Greenland catches in inshore areas showed an increase which resulted in the total catch of 38 000 tons in Subareas 0, 2 and 3 in 1987 (Fig. 1).

Spawning stock biomass estimates are usually used as a starting point in regulating a fishery by establishing a Total Allowable Catch to prevent recruitment overfishing and to protect the reproductive capacity of the population. Population fecundity is a more sensitive indicator of the reproductive capacity than spawning stock biomass and it has been used by Beverton (1962), Beverton and Holt (1957), Oosthuizen and Daan (1974) and Schaaf (1978).

The present study attempts to estimate Greenland halibut reproductive capacity in terms of population fecundity, year-class strength and survival during 1969–88.

Materials and Method

Biostatistical data from the period 1969–88 were used in this analysis, and a total of 13 898 fish were aged. A constant natural mortality coefficient of 0.1 was used for spawning stock biomass estimation of ages 5 to 17 in virtual population analyses (Ernst and Borrmann, MS 1987).

Individual absolute fecundity was determined in 245 females caught in the Davis Strait off Baffin Island, western Greenland, and northern and central Labrador in 1975–80 and 1987–88. The material for fecundity estimation was collected during October through December.

The ovaries of the stages of maturity III and IV of freshly-caught fish were weighed, labelled and preserved in 5% formaldehyde, and later dried in the laboratory and weighed. Subsamples (3 g each) were taken from different parts of the ovaries. Eggs were separated from the ovarian tissue, weighed to the nearest 0.0001 g and the number of eggs in each subsample counted. Individual fecundity was estimated by expanding the number of eggs per g to the total ovary weight.

The following regression equations were derived to describe individual fecundity (F_{ind}) as a function of age (A), length (L) and weight (W) of fish:

$$F_{ind} = 0.22 \; A^{2.11} \qquad (r = 0.992) \qquad \ldots (1)$$

$$F_{ind} = 6.3 \; 10^{-6} \; L^{3.62} \qquad (r = 0.975) \qquad \ldots (2)$$

$$F_{ind} = 7.62 \; W^{1.07} \qquad (r = 0.978) \qquad \ldots (3)$$

The individual fecundity of the Greenland halibut caught in the Davis Strait off northern and central Labrador was found to be similar to that of individuals of the same age and size from the southern Labrador area, as reported by Lear (1970) and Bowering (1980).

Population fecundity (E_p) was defined as the total sum of the contribution of all age groups:

$$E_p = \sum_{i=5}^{n} C_E \qquad \ldots (4)$$

where $i = 5$ is age at recruitment to the spawning population,

n oldest age group in the data set

C_E is the contribution to population fecundity by each age group.

Then:

$$C_E = E \; N \; m \; R \qquad \ldots (5)$$

where E is the mean individual absolute fecundity of the given age group,

N is the virtual population analysis derived abundance of a given age group,

m is the mature fish proportion of females in a given age group, and

R is the sex ratio (i.e. proportion of females).

Year-class survival rate was estimated as the percentage of 5-year olds which have survived from the total number of eggs laid:

$$S_j = N_j \; 10^2 / E_{pj} \qquad \ldots (6)$$

where S_j is the survival of a given generation j up to the age of 5 years,

N_j is the number of 5-year olds in a given generation j, and

E_{pj} is population fecundity in a given year j.

Water temperature was taken along the standard hydrographic Section 8A across the southern Labrador shelf and slope (Fig. 2). The hydrographic observations were taken by the Polar Fishery Research Institute (PINRO) regularly in November only. The temperature observations were compared with the strength of the year-classes and the survival rates.

Simple and multiple regression analyses were made to examine relationships between spawning stock biomass, population fecundity, strength of the year-classes, survival rate and water temperature.

Results and Discussion

Males in the study areas first became mature at

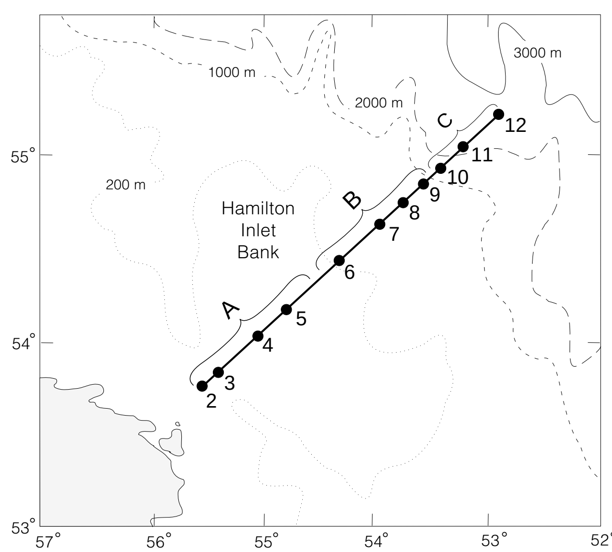

Fig. 2. The positions of hydrographic stations occupied by the USSR on the standard Section 8A.

Part A positions: 53°40′N 55°44′W – 54°11′N 54°47′W

Part B positions: 54°26′N 54°19′W – 54°49′8″N 53°32′W

Part C positions: 54°55′N 53°22′5″W – 55°13′N 52°52′W

TABLE 1. Relative number (%) of mature Greenland halibut on the continental slopes in Subareas 0 and 1, and Divisions 2GH and Division 2J (using aged samples for 1970–88).

	Subareas 0+1		Divisions 2GH		Division 2J	
Age	Male	Female	Male	Female	Male	Female
4	0.0	0.0	0.0	0.0	0.0	0.0
5	13.8	0.0	0.0	0.0	0.0	0.0
6	44.5	6.1	2.5	0.0	0.0	0.0
7	64.2	7.7	23.2	1.7	4.3	0.0
8	80.5	11.7	34.1	2.1	8.1	2.2
9	88.6	18.2	72.8	7.6	10.1	5.5
10	94.6	35.1	82.1	14.5	36.4	12.5
11	99.1	52.0	90.2	25.0	40.0	18.0
12	100.0	66.2	94.2	41.8	50.0	30.0
13	100.0	78.4	98.4	59.8	80.2	40.1
14	100.0	88.3	100.0	69.8	100.0	55.0
15	100.0	95.0	100.0	81.5	100.0	70.1
16	100.0	100.0	100.0	90.6	100.0	83.2
17	–	–	–	95.0	–	90.5
18	–	–	–	100.0	–	98.0
19	–	–	–	100.0	–	100.0
Total	2 448	1 185	2 948	2 135	2 680	2 502

ages of 5–7 years (Table 1) and lengths of 46–47 cm, whereas the respective figures for females were 6–8 years and 52–53 cm. Age at 100% maturity can vary in males depending on the area of observations. In Subareas 0 and 1, 100% maturity was recorded at the ages of 12–13 years and 70–73 cm and 16–17 years and 92–95 cm in males and females, respectively. In Div. 2J and 3K immature females were only occasionally found. Mature individuals were not abundant along the continental shelf and slope of southern Labrador. Scarcity of mature fish along the continental shelf and slope off Baffin Island and western Greenland was probably the result of the northward migration (Chumakov, 1975; Chumakov and Serebryakov, MS 1982).

Noticeable variations were found in the total spawning stock biomass, fecundity and abundance of 5-year olds in the Greenland-Canadian population throughout the entire period of observation (Table 2). The highest and lowest abundance of spawning stock was recorded during 1974–79 and 1969–70, respectively. The population fecundity varied from 844.2 $\times 10^9$ eggs in 1969 to 2 446.6 $\times 10^9$ in 1977.

Year-class survival rate can be regarded as an index of ambient conditions during early life. Of course population fecundity is not the exact number of total abundance of eggs spawned because not all ripe oocytes are spawned. Therefore the estimated survival rate should be regarded as a relative index. The survival rate of poor year-classes in 1969 and 1970 was found to be higher than that in the strong year-class of 1976. Survival rate coefficients as estimated for the 1969–83 year-classes showed higher variability than the population fecundity. There was a 5-fold difference between the maximum (1982) and minimum (1977) survival rates (Fig. 3).

There was an inverse correlation between the population fecundity and the strength of the year-class ($r = -0.425$, $N = 15$, $P = 0.05$). Mechanisms of density dependent survival are not yet understood for this species. The role of ambient environmental conditions could be examined by correlating between the survival index and an indicator of environmental conditions.

The water temperature of various horizons is often used as an abiotic environmental indicator. The comparison of the survival coefficient to the water temperature at three different horizons of Section 8A across the Hamilton Bank (Fig. 2) revealed inverse correlations (Table 3).

Regression analysis indicated a significant ($r = 0.754$; $N = 15$; $P \leq 0.05$) relationship between survival rate and water temperature at 50–200 m of Part C of Section 8A in November. A simple model to forecast the survival index (S) based on population fecundity (E_p) and temperature is:

$$S = (-0.02107\ E_p - 12.98633\ T + 115.48901)\ 10^{-4} \quad \ldots(7)$$

and the recruitment (R) is given by:

$$R = S\ E_p\ 10^{-2} \quad \ldots (8)$$

This regression equation could be used to predict recruitment 5 years in advance. Thus the 1984 year-class can be estimated as strong and the 1985–88 year-classes as medium strength (Fig. 3 and 4).

The lowest population fecundity which still allows the appearance of a strong year-class under favourable environmental conditions during early life but fails to ensure average recruitment under average environmental conditions is the "critical population fecundity". This critical population fecundity (E_{cri}) can be calculated as:

$$E_{cri} = \frac{N_{ab}}{S_{max}} \quad \text{... (9)}$$

where N_{ab} is strong year-class abundance at age 5, and S_{max} is the maximal survival rate.

A lower than critical population fecundity would deprive the population of the opportunity to produce a strong year-class even under the best survival conditions.

Population fecundity of the critical level was observed in 1969 and 1970, when poor year-classes emerged with moderate survival indices. In all the other cases the Greenland halibut population fecundity was either close to or well above the critical level.

TABLE 2. Greenland halibut spawning stock biomass (SSB), population fecundity (E_P), year-class strength at age 5 years (R) and survival rate coefficient to 5 years (S) for the period 1969–88.

Year	SSB ('000 tons)	$E_P \times 10^9$ eggs	Abundance of 5-year-olds $\times 10^6$ (after 5 years)	R[a]	S (%)
1969	90.3	844.2	39.2	P	0.0046
1970	94.5	883.4	48.6	P	0.0055
1971	129.6	1211.6	55.3	m	0.0046
1972	170.1	1590.0	62.3	m	0.0039
1973	184.4	1724.0	63.7	m	0.0037
1974	230.2	2057.9	44.1	P	0.0021
1975	232.6	2147.7	48.5	P	0.0022
1976	221.3	2426.1	44.8	P	0.0018
1977	225.6	2446.6	36.0	P	0.0015
1978	221.4	2339.1	44.5	P	0.0019
1979	209.5	2178.1	50.4	m	0.0023
1980	153.6	1676.1	54.3	m	0.0032
1981	143.8	1480.3	65.6	St	0.0044
1982	124.7	1231.8	88.3	St	0.0072
1983	133.9	1157.9	68.1	St	0.0059
1984	134.6	1205.1	75.9[b]	St	0.0063[b]
1985	148.9	1302.2	54.7[b]	m	0.0042[b]
1986	142.1	1666.4	60.1[b]	m	0.0044[b]
1987	167.0	1492.6	62.7[b]	m	0.0042[b]
1988	185.1	1686.4	59.0[b]	m	0.0035[b]

[a] P = poor: <50 x 10^6 number of fish,
m = medium: (50–65) x 10^6 number of fish,
St = strong: >65 x 10^6 number of fish.
[b] Forecast.

TABLE 3. Correlation factors between the Greenland halibut year-class strength at age 5 years, survival rate and water temperature in the layers of 0–50, 50–200 and 0–200 m in Parts A and C of the hydrographic Section 8A, in November 1969–88.

	Part A			Part C		
	0–50 (m)	50–200 (m)	0–200 (m)	0–50 (m)	50–200 (m)	0–200 (m)
Survival to 5 years	–0.258	–0.522	–0.543	–0.464	–0.754	–0.676
Number of fish aged 5 years	–0.175	–0.533	–0.465	–0.457	–0.717	–0.655

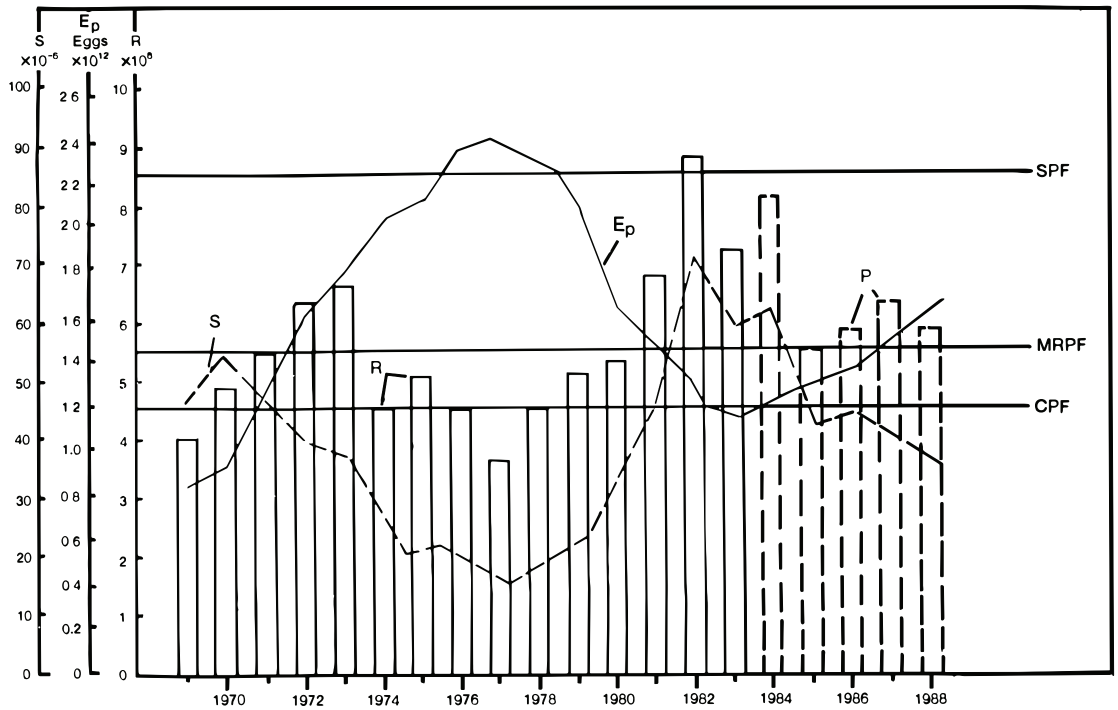

Fig. 3. Greenland halibut population fecundity (EP) , year-class strength at age 5 (R), survival index observed (S) and survival index predicted (Sp.). P – provisional year-class strength.

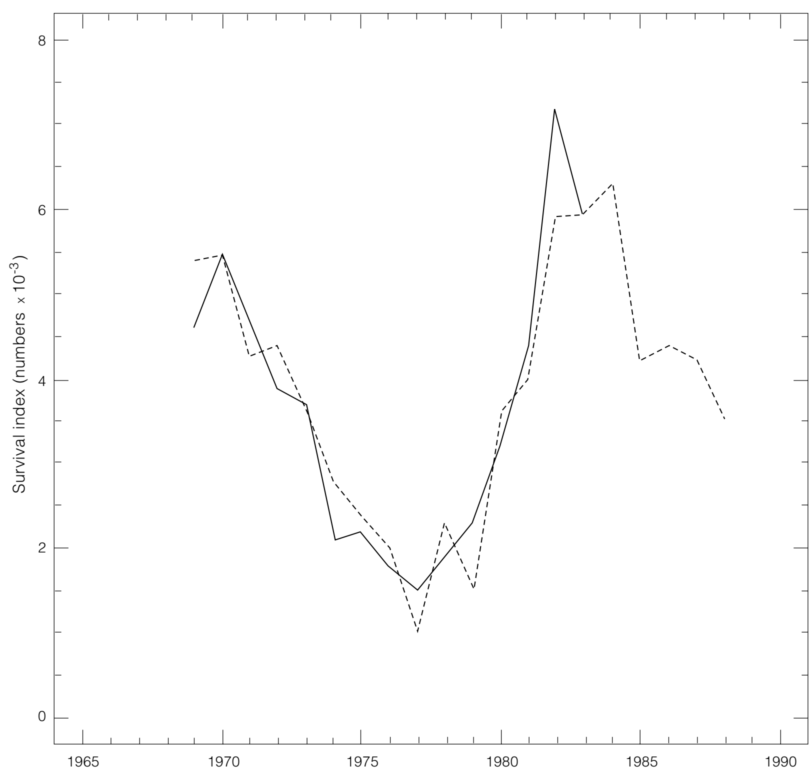

Fig. 4. Greenland halibut survival index fluctuations observed (solid line) and predicted by using equations 8 and 9 in the text (broken line).

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