Northwest Atlantic Fisheries Organization

Serial No. N1851 NAFO SCR Doc. 90/115

SCIENTIFIC COUNCIL MEETING - SEPTEMBER 1990

Prediction of Year-class Strength Under Uncertainties Related to Survival in Early History of Some North Atlantic Commercial Fish

by

V. P. Serebryakov

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

SPECIAL SESSION ON MANAGEMENT UNDER UNCERTAINTIES
RELATED TO BIOLOGY AND ASSESSMENTS

Survival of a year-class during early life history is the most important factor affecting the recruitment abundance. The rate of survival could be expressed as a ratio of a quantity of animals survived to any particular age (e.g. age of recruitment) to the total number of animals born in a population during the particular time.

Year-class survival rate can be regarded as an integrated index of survival conditions during early life. This index reflects biotic as well as abiotic factors of natural mortality during early life, either which may be density dependent or density independent.

Year-class survival index or something like it, of course, been used before (Beverton, 1962; Beverton and Holt, 1957; Dragesund and Nakken, 1973; Nelson *et al.*, 1977; Schaaf, 1978; and others).

An attempt was made in this paper to present long-time series of year-class survival rate fluctuations in comparison with reproduction capacity changes in herring, capelin, cod, blue whiting and Greenland halibut.

Materials and Method

Year-class survival rate is found as permimillion of fish reaching maturity from the total amount of eggs laid during the spawning in the year of birth of this generation:

$$S_i = R_m \, 10^6 / E_{pi} \qquad \text{..............(1)}$$

where S_i - is the survival rate up to three-year-olds of the given generation (per million of eggs),

R_m - is the number of fish reaching maturity, and

E_{pi} - is the population fecundity in the given year.

The population fecundity is defined as the total sum of contributions of each age group to the overall amount of eggs which was shed by the population:

$$E_p = \sum_{1}^{n} C_E \qquad \text{.........(2)}$$

where E_p - is the population fecundity, i - is the age at recruitment into the spawning population,

n - is the oldest age group in the data set, and

C_r - is the contribution to population fecundity made by fish of the same age groups determined as follows:

$$C_r = E.N.m.r \qquad (3)$$

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

N - is the abundance of fish in the given age group obtained through VPA, or by other methods of determination of overall abundance,

m - is the proportion of mature fish of the given age group according to the maturity ogive, and

r - is the proportion of females, i.e. sex ratio, in the given age group.

Data on the age composition, abundance and biomass of the spawning population, maturity ogive, and sex ratio of the Norwegian spring-spawning herring and the Barents Sea capelin were obtained from reports of working groups of the International Council for the Exploration of the Sea (Anon., 1970, 1975, 1983, 1984, 1986, 1987b), as well as from Dragesund *et al.*, 1980. Also for Northeast Arctic cod ICES working groups reports and other data sources were used (Anon., 1959, 1980, 1981, 1987a; Rollefsen, 1953; Glebov, 1963, 1982; Serebryakov *et al.*, 1984).

Abundance of fish aged 3 years (R_{III}) was used as criterion for herring, capelin, cod and blue whiting year-class strength and age 5 for Greenland halibut as indicated in the table below:

Year-class category	Herring $R_{III}x10^9$	Capelin $R_{III}x10^{11}$	Cod $R_{III}x10^9$	G. halibut R_Vx10^7	Blue whiting $R_{III}x10^9$
Strong	More than 7.0	More than 3.5	More than 1.0	More than 6.5	More than 1.0
Medium	2.0-7.0	2.5-3.5	0.5-1.0	5.1-6.5	0.5-1.0
Poor	Less than 2.0	Less than 2.5	Less than 0.5	Less than 0.0	Less than 0.5

There are three different levels of population fecundity, which could be identified as follows:

SAFE Population FECUNDITY (SPF) is the level of population fecundity when the emergence of a strong year-class is guaranteed under average survival conditions of the year-class at its early life history.

$$E_{spf} = R_{ab}/S_{med} \qquad (4)$$

MINIMUM REQUIRED POPULATION FECUNDITY (MRPF) secures the appearance of strong year-classes under propitious survival conditions, medium year-classes in average, and poor year-classes in unfavourable survival conditions.

$$E_{mpf} = R_{m\,ab}/S_{max} \qquad (5)$$

CRITICAL POPULATION FECUNDITY (CPF) provides for the appearance of strong year-classes only in the best survival conditions, but fails to ensure the delivery of generations of the average abundance under the average ecological conditions; a lower population fecundity would deprive the population of the opportunity to produce a strong year-class even in the best survival conditions.

$$E_{cpf} = R_{m\,ab}/S_{max} \qquad \text{............(6)}$$

where E_{spf} - is the safe population fecundity,

E_{mpf} - is the minimum population fecundity,

E_{cpf} - is critical population fecundity,

R_{ab} - is the lowest defined abundance of a strong year-class at age of recruitment,

R_{av} - is the lowest defined abundance of a medium year-class at age of recruitment,

S_{med} - is the observed average survival rate of a medium year-class during early life, and

S_{max} - is the maximum survival rate during early life for the period of observations.

Material on the individual fecundity of the Norwegian spring-spawning herring was collected at the Polar Fisheries Research Institute (PINRO) between 1951-1975. Data on the fecundity of fish of each age-group was collected annually throughout this period. Individual fecundity in 4,474 individuals of herring was determined by E. I.Seliverstova (personal comm.).

Capelin population fecundity estimates are based on data taken from the paper by Galkin and Kovalev (1975) which provides individual fecundity values for various age groups of the Barents Sea capelin. Individual fecundity was determined for 5,000 individual capelin from the Barents Sea.

Individual fecundity of Northeast Arctic cod was calculated for 110 females in 1971-1972 (Borisov, 1976; Serebryakov *et al.*, 1984).

The same of blue whiting was estimated in 500 fish (Belikov *et al.*, 1989). For Greenland halibut it was determined in 245 females.

Results

Norwegian spring-spawning herring. Year-class abundance fluctuations in this herring are exceptionally great. For example, the strong year-class of 1959 at age 3 exceeded the poor year-class of 1956 by 125 to one (Table 1 and 2) even though the population fecundities in the years of birth of these year-classes where nearly equal. The poor year-class of 1968 was over a thousand times less abundant than the good 1959 generation. Strong year-classes would appear both in years of exceptionally high and relatively low population fecundity, e.g. in 1951 and 1963, respectively.

Year-class survival till age 3 varied quite significantly through the period of studies, in fact by nearly three orders of magnitude (Fig. 1).

Possessing a quantitative expression of survival conditions in the form of survival factor during the early life history (embryonic, larval and fingerling periods of development) one can retrospectively evaluate the conditions of survival in the period of studies. Hence, there were four strong year-classes recorded in 1951-1981 while conditions favourable for survival of a strong year-class occurred eight times.

The overexploitation of strong year-classes in the 1960s coupled with the unfavourable survival conditions observed in 1965-1968 made the spawning population of herring in the early 1970s consist of individuals from poor year-classes. The population fecundity was very low: two to three orders of magnitude less than the level observed in the 1950s and early 1960s.

Barents Sea capelin. The population fecundity of capelin between 1972 and 1984 varied from 31.8 x 10^{14} to 4.6 x 10^{14} eggs. Strong year-classes were recorded both in years of exceptionally high population fecundity in 1976, and when it was close to the average in 1972. Survival rates for these year-classes turned out to be 116.2 and 287.0 per million of eggs respectively. The strong 1972 year-class had about three times better survival than the 1978 year-class whereas their population fecundity was nearly equal. Conversely, in the case of nearly equal survival observed in 1976, 1977, 1978, 1979 and 1982 there appeared generations of various strength: strong in 1975, average in 1977, poor in 1978, 1979 and 1981 (Fig. 2).

Northeast Arctic cod. This fish had a maximum population fecundity in 1947 (3.8 x 10^{14} eggs), minimum in 1981 - 0.3 x 10^{14} eggs; variations in population fecundity exceeds one order of magnitude (Table 3). The number of three-year-olds throughout the period studied varied between 0.09 x 10^9 and 1.8 x 10^9. Survival variations are over one order of magnitude: from 23.5 for the strong year-class of 1964 to 1.2 per million of eggs for the poor year-class of 1946.

Strong year-classes appear both in years of exceptionally high population fecundity of cod (e.g. 1948) and in years when this value was low (e.g. 1964). Similarly poor year-classes appear both in years of exceptionally high (e.g. 1946), and very low (e.g. 1979), population fecundity (Fig. 3).

The average survival factor to age 3 of strong, medium and poor year-classes in 14.4, 9.08 and 4.2 per million respectively. Given a nearly equal population fecundity, the survival factor in a strong year-class (e.g. 1964) is greater than that of a poor year-class (e.g. 1966) by more than an order of magnitude.

Survival factor (over 10) facilitating the appearance of a strong year-class occurred eight times throughout the period of study. It was only for four cases that they were taken advantage of: 1963, 1964, 1969 and 1970; the remaining cases gave generations of medium strength.

The conditions (survival factor less than 5.0) when only poor year-classes could be expected were observed for twelve times during the period of study but only ten year-classes of that period were poor; one year-class was strong (1948), another medium (1947). The population fecundity in the two latter instances was exceptionally high.

Throughout the period of 35 years there should have been four more strong year-classes (1954, 1957, 1958, and 1975) in addition to the seven which were actually observed. The population fecundity in those years, however, was not high enough to secure juvenile abundance that would fit into the category of "strong year-class".

Blue whitings. The blue whiting strength of the year-class fluctuations were not so significant within the period of 1970-1985 as there were with the herring. The richest blue whiting 1982 year-class exceeded the poorest one of 1980 by factor of 4.7 (Table 3 and 4). The changes of population fecundity have either been not great. The maximal population fecundity of 1982 were higher than minimal one of 1980 by 2.5 times (Fig. 4). Survival index fluctuations were significantly greater - from 1.1 in 1980 to 11.0 in 1982 per million eggs.

Greenland halibut. The survival rate in the poor year-classes of 1969 and 1970 was found to be higher than that in the rich year-class of 1976. Survival rate coefficients as estimated in the year-classes of 1969-1983 showed more significant fluctuations than the population fecundity. There was a 5-fold difference between the maximum (1982) and minimum (1977) survival rates (Fig. 5).

Discussion

Year-class abundance fluctuations were greatest in Norwegian spring-spawning herring. They exceeded two orders of magnitude even before the drastic drop in population fecundity, i.e. prior to 1967. The strong 1970 year-class of Northeast Arctic cod exceeded the abundance of the poor 1980 year-class by 60 times. The smallest fluctuations of year-class abundance were seen in capelin - only about one order of magnitude (Fig. 1-5).

Strong year-classes of all the species investigated appeared both in years of exceptionally high population fecundity, and years when this characteristic was relatively low. The same is true of the emergence of generations of poor and medium abundance. A mere collation of the strength of a year-class with population fecundity does not reveal a close relationship between the recruitment and population fecundity. This due to the well known fact that the formation of year-class abundance depends heavily on the survival conditions at the early life history, i.e. throughout the embryonic, larval and fingerling periods of life.

The most insignificant survival factor was in the case of Norwegian spring-spawning herring of the 1967 year-class 0.17 x 10^{-6}. The greatest fluctuations of this parameter by nearly 2.5 orders of magnitude make up another feature of this population. In comparison the survival rate in Barents Sea capelin was within the range of only 287 to 65 per million eggs.

During the period of 1967-1982 the cause for low abundance (i.e. poor level) of all generations of the herring can be found in the low amount of eggs spawned rather than in unfavourable surrounding ecological conditions for survival at the early stages of life history. Judging by the survival factor during this period, there even could have appeared strong year classes, specifically in 1973, 1974, 1976 and 1979 had the population fecundity been sufficiently high (Fig. 1).

Survival rate assessment is one of the possible ways to analyze the dynamics of fish abundance. This parameter can be used to narrow the possible field of search for the factors which lead to the appearance of poor year-classes. Thus we have to seek the causes for low abundance caused by low survival at the early stages only in the years when there were low survival rates rather than in each year when generations were scarce.

Determination of levels of spawning stock which represent different levels of reproduction capacity is another aspect of the application of retrospective analysis of population fecundity, year-class strength and survival rates.

Population fecundity of Norwegian spring-spawning herring reached CPF in 1966-67), Northeast Arctic cod in 1976 and in 1979-1981 (Fig. 1 and 3). The high intensity of fishing for herring continued after reaching CPF which resulted in decreasing the population fecundity to such a low level that it entailed a series of poor year-classes even under propitious survival conditions at the early stages of development, and a consequent deep long-term depression in stock abundance. It was only in 1983 that the population fecundity had reached the level of approximately one half of CPF which made a potential for the emergence of abundance year-class in the event of the very best survival conditions.

The blue whiting reproduction capacity is influenced by the same features as the Atlanto-Scandian herring one. These are a) low individual fecundity, which give the age composition as important role, b) long life cycle of mature fish (Marty, Fedorov, 1963).

For the sake of preventing a catastrophe with blue whiting population reproduction capacity must be kept and preserved at the level of minimal required population fecundity. Allowable catch should be established considering estimation the spawning stock biomass which could safely ensure MRPF.

In 1983, Northeast Arctic cod population fecundity rose above the level of CPF which provided for the appearance of a year-class of a strong abundance under good survival conditions at the early stages of life.

It is desirable that the spawning stock of this population is to provide a population fecundity at least equal to MRPF. Further commercial exploitation should be organized in such a manner that this is not hindered by fishing.

Greenland halibut population fecundity of the critical level was observed in 1969 and 1970, when the poor year-classes emerged under moderate survival index. In all the other cases the Greenland halibut population fecundity was either close or well above the critical level. That equilibrium state of a reproduction capacity induced the natural fluctuations of the year-classes abundance.

Depending on the strategy of utilization of some fishing population, and on the fisheries management objectives, the basic parameter for the determination of the protected spawning stock size in each specific case may be chosen from one of the three levels of population fecundity: SPF, MRPF or CPF (Table 5). The most cautious treatment here must be given to the exploitation of the population on the CPF level.

References

Anon. 1959. Report the Arctic fisheries working group. ICES, C. M. 1959: 32 p.

1970. Report of the Atlantic-scandian herring. Coop. Res. Rep. Ser., Int. Counds. Explor. Mer. 1970, 17, p. 1-43.

1975. Report of the working group on Atlantic-scandian herrings. ICES, C.M. 1975/H:4, p 1-16.

1980. Report of the Arctic fisheries working group. ICES, C.M. 1980/G: 12, 50 p.

1981. Report of the Arctic fisheries working group. ICES, C.M. 1981/G: 2, 37 p.

1983. Report on the Atlantic-scandian herring and capelin working group. ICES, 1983/Assess.: 4, 37 p.

1984. Atlantic-scandian herring and capelin working group report. ICES, C.M. 1984/Assess.: 4, 31 p.

1986. Report of the Atlantic-scandian herring and capelin working group. ICES, C.M. 1986/Assess.: 7, 47 p.

1987a. Report of the Arctic fisheries working group. ICES, C.M. 1987/Assess.: 5, 59 p.

1987b. Report of the working group on Atlantic-scandian herring and capelin. ICES, C.M. 1987/Assess.: 8.

Belikov, S. V., E. S. Tereshenko, and N. A. Isaev. 1989. Blue whiting population fecundity. *In* Proceedings of the Soviet-Norwegian Symposium on biology and fishery of blue whiting in the Northeastern Atlantic and Norwegian spring-spawning herring. Bergen, June 9-13, 1989.

Beverton, R. I. H. 1962. Long-term dynamics of certain North Sea fish population. *In* "Exploitation of animal populations. Ed. E. D. LeCren and A. M. W. Holdgate. pp. 242-64, Blackwell, *Oxford*.

Beverton, R. I.H., and S. I. Holt. 1957. On the dynamics of exploited fish populations. Fish. Invest. Lond. Ser. 2, 19, 533 pp.

Borisov, V. M. 1976. Resultaty primenenia metoda Tyurina dlya opredelenia yestestvennoy amertnosti arcto-norvezskoy treski, *Gadus morhua morhua* L. Vopr. ichtiologii, V. 16, Iss. 5(100), pp. 889-896.

Dragesund, O., J. Hamre, and O. Ultang. 1980. Biology and population dynamics of the Norwegian spring-spawning herring. Rapp. P.-V. Reun. Cons. Intern. Explor. Mer., V. 177: p. 3-71.

Dragesund, O., and O. Nakken. 1973. Relationship of stock size and year-class strength in Norwegian spring-spawning herring. Rapp. P.-V. Reun. Cons. *Perm. Inter. Explor. Mer.,* V. 164: p. 15-29.

Galkin, A. S., and S. M. Kovalev. 1975. Plodovitist mayvy (*Mallotus villosus villosus,* Mul.) Barentseva morya. Vopr. Ichtiologii, V. 16, No. 4(93), p 646-650.

Glebov, T. I. 1963. Treska murmanskogo poberezya. Trudy PINRO, No. 15, p. 69-130.

Nelson, W. W. R., M. C. Ingham, and W. E. Schaaf. 1977. Larval transport and year-class strength of Atlantic menhaden Brevoortia tyrranus. Fish. Bull., U.S., V. 75: p. 23-42.

Rollefsen, g. 1953. Observations in the cod and cod fisheries of Lofoten. Rapp. P-V. Reun. Cons. Perm. Inter. Explor. Mer., V. 136, p. 40-47.

Schaaf, W. E. 1978. An analysis of the dynamic population response of Atlantic menhaden, *Revoortia tyrranus,* to an intensive fishery. Rap. Proc.-V. Reun. Cons. Perm. Inter. Explor. Mer., V. 177: p 243-257.

Serebryakov, V. P., V. M. Borisov, and V. K. Aldonov. 1984. Population fecundity and abundance of year-classes of Arcto-Norwegian cod. *In:* Reproduction and recruitment of Arctic cod. Bergen, Norway, 1984, p. 139-156.

Table 1. Population fecundity (PF), year-class strength (R) and survival index (S) of the Norwegian spring-spawning herring.

Year	PF eggs x 10^{12}	R x 10^6 stage 3 number of fish	Year-class strength	S in 1 x $1/10^6$
1951	1167.4	7,380	strong	6.3
1952	1075.9	3.448	medium	3.2
1953	899.5	3,820	medium	3.58
1954	946.2	600	poor	0.63
1955	1446.1	494	poor	0.34
1956	880.2	169	poor	0.19
1957	1256.2	252	poor	0.2
1958	1303.1	241	poor	0.18
1959	879.2	21,175	strong	24.08
1960	658.0	7,337	poor	11.5
1961	573.3	2,175	medium	3.79
1962	464.1	203	poor	0.44
1963	208.7	8,281	strong	39.68
1964	375.2	3,832	medium	10.21
1965	500.6	107	poor	0.21
1966	343.3	230	poor	0.67
1967	192.1	33	poor	0.17
1968	43.3	16	poor	0.17
1969	12.3	375	poor	8.66
1970	7.03	13	poor	1.8
1971	-	6		?
1972	4.7	30	poor	6.4
1973	12.4	748	poor	60.3
1974	9.9	421	poor	42.5
1975	11.4	58	poor	5.3
1976	7.8	410	poor	52.6
1977	22.3	180	poor	8.1
1978	32.5	257	poor	7.9
1979	40.4	1,217	poor	31.0
1980	47.1	122	poor	2.6
1981	48.0	89	poor	1.8
1982	56.8	602	poor	10.6
1983	81.4	11,000	strong?	120.0
1984	105.0			

Table 2. Norwegian spring-spawning herring year-class graded by strength.

number at age 3 x 10^6	PF eggs x 10^{12}	Survival 1 x $1/10^6$	Year
21,175	879.2	24.08	1959
8,281	208.7	39.68	1963
7,380	1167.4	6.3	1951
7,337	658.0	11.15	1960
11,000	81.4	120.0	1983
3,832	375.2	10.21	1964
3,448	1075.9	3.2	1952
3,220	899.5	3.58	1953
2,175	573.3	3.79	1961
		5.2	
1,217	40.4	30.1	1979
748	12.4	60.3	1973
600	946.2	0.63	1954
494	1446.1	0.34	1955
421	9.9	42.5	1974
410	7.8	52.6	1976
375	12.3	8.66	1969
257	32.5	7.9	1978
252	1266.2	0.2	1957
241	1303.1	0.18	1958
230	343.3	0.67	1966
203	464.1	0.44	1962
180	22.3	8.1	1977
169	880.2	0.12	1956
122	47.1	2.6	1980
107	500.6	0.21	1965
102	56.8	10.6	1982
89	48.0	1.8	1981
58	11.4	5.3	1975
33	192.1	0.17	1967
30	4.7	6.4	1972
16	43.3	0.18	1968
13	7.0	1.8	1970
6	?	?	1971

Table 3. Population fecundity (PF), year-class strength (R) and survival index (S) of the blue whiting.

Year	PF eggs x 10^{12}	R x 102 at age 3 number of fish x 10^6	Year-class strength	Survival x $1/10^6$
1970	2318	13057	strong	5.6
1971	1983	11897	strong	6.0
1972	2334	11602	strong	5.0
1973	2030	9797	medium	4.8
1974	3147	7331	medium	2.3
1975	3384	6568	medium	1.9
1976	2598	5796	medium	2.2
1977	2351	5259	medium	2.2
1978	2047	7502	medium	3.7
1979	3042	4199	poor	1.4
1980	2803	3121	poor	1.1
1981	1794	4392	poor	2.4
1982	1340	14741	strong	11.0
1983	1616	10762	strong	6.6
1984	1364	6599	medium	4.8
1985	1956	6860	medium	3.5
1986	2479			
1987	1796			
1988	1838			

Table 4. Blue whiting year-class graded by strength.

Number at age 3 x 10^6	PF eggs x 10^{12}	Survival x $1/10^6$	Year
14741	1340	11.0	1982
13057	2318	5.6	1970
11897	1983	6.0	1971
11602	2334	5.0	1972
10762	1616	6.6	1983
9797	2031	4.8	1973
7502	2047	3.7	1978
7331	3147	2.3	1974
6860	1956	3.5	1985
6599	1364	4.8	1984
6568	3387	1.9	1975
5796	2598	2.2	1976
5259	2351	2.2	1977
4392	1794	2.4	1981
4199	3042	1.4	1979
3121	2803	1.1	1980

Table 5. *Three levels of herring, capelin and cod population fecundity* (eggs x 10^{12}).

Species	Safe population fecundity	Minimum required population fecundity	Critical population fecundity
Norwegian spring-spawning herring	1346	570	175
Barents sea capelin	2500	1750	1145
Arctic cod	128	64	42.5
Greenland halibut	2.3	1.5	1.2

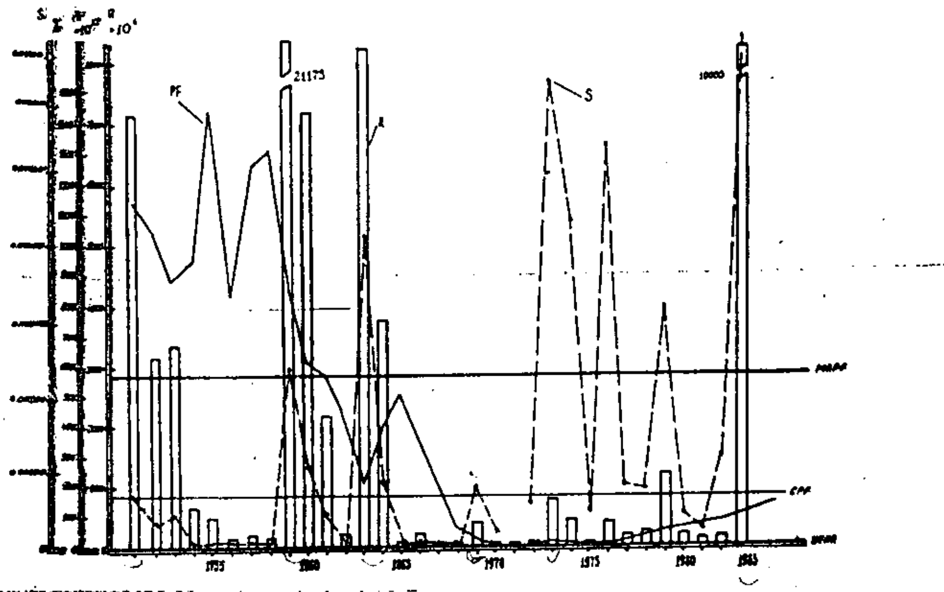

Fig. 1. Norwegian spring-spawning herring population fecundity (PF) year-class strength (R) and survival index (S).

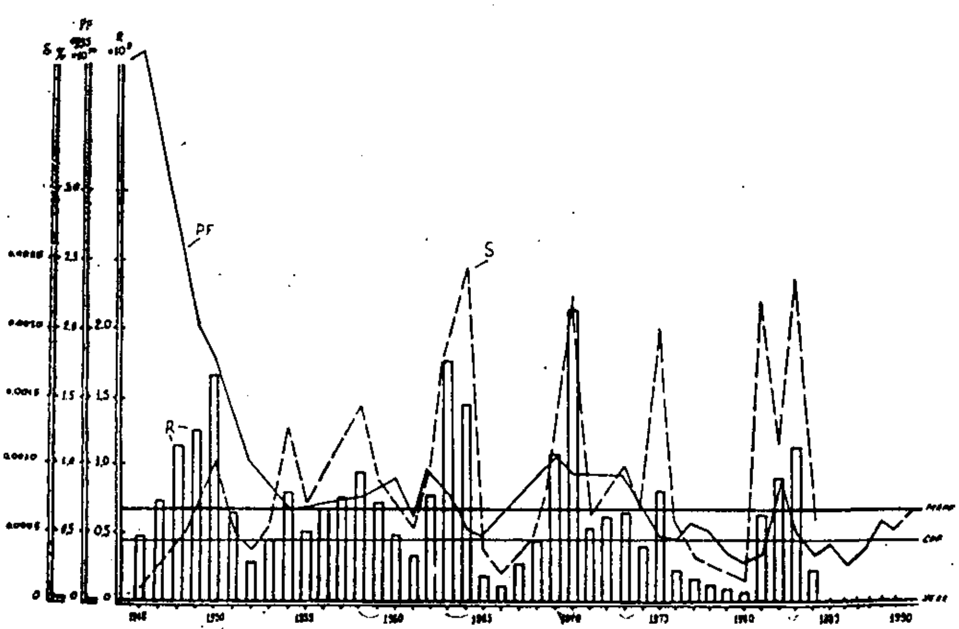

Fig. 2. Arctic cod population fecundity (PF) year-class strength (R) and survival index (S).

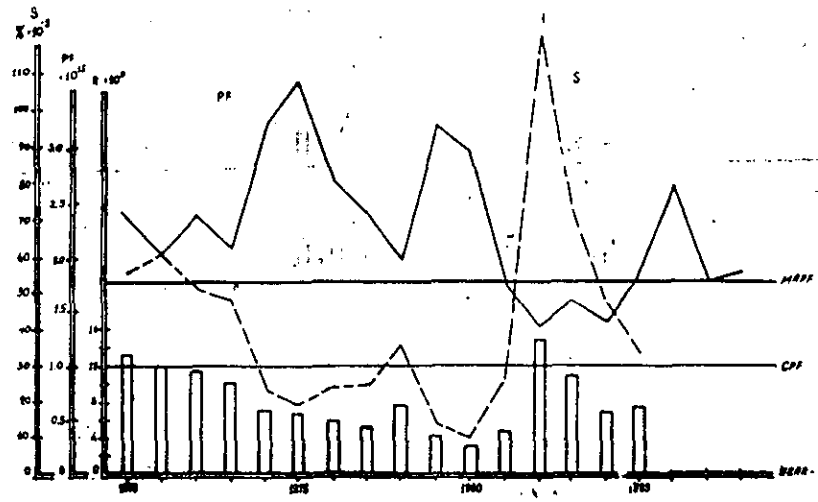

Fig. 3. Blue whiting population fecundity (PF) year-class strength (R) and survival index (S).

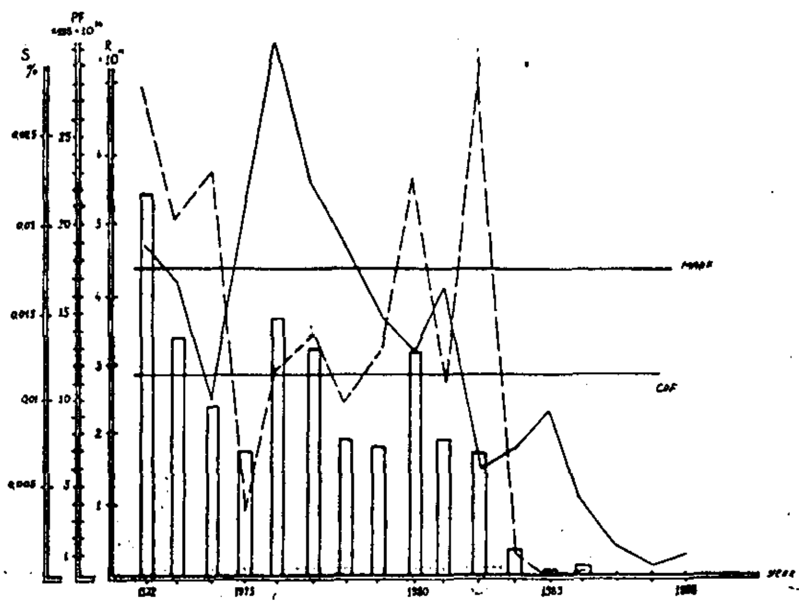

Fig. 4. Barents Sea capelin population fecundty (PF) year-class strength (R) and survival index (S).

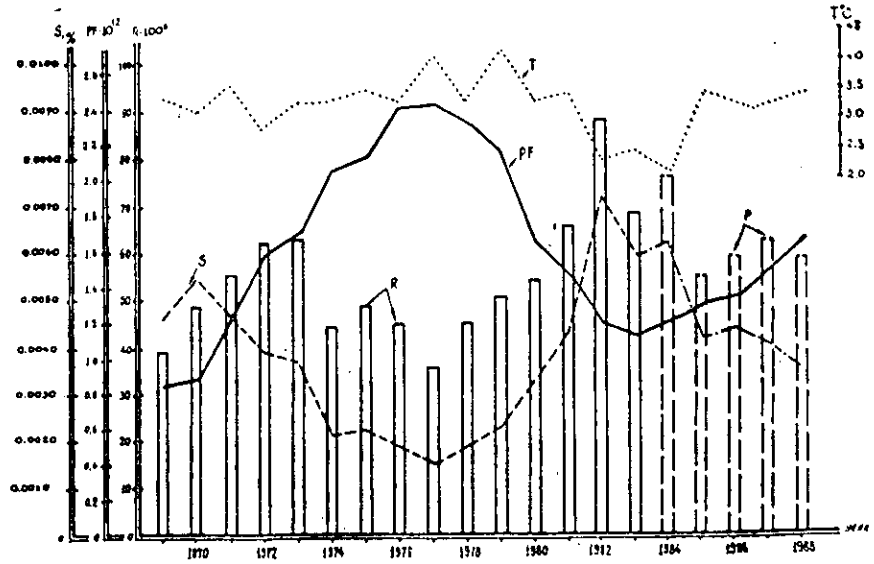

Fig. 5. Greenland halibut population fecundity (PF) year-class strength (R) and survival index (S).