SECTION I

Eggs and larvae

ECOLOGICAL ADAPTATION OF REPRODUCTION IN ARCTIC COD

By

GUNNAR SÆTERSDAL and HARALD LOENG

Institute of Marine Research

ABSTRACT

A recent period (1977–1982) of cold climate in the Barents Sea resulted in a greatly reduced feeding area available for the Arctic cod and in consistent low recruitment. With the start of a warmer period in 1982/83 the area and potential for production of cod biomass expands and recruitment has increased. An hypothesis is presented that through evolutionary processes the reproduction of the Arctic cod is adjusted to the variations in the feeding area caused by climatic fluctuations. Historical data on sea temperature and ice cover are used to describe the climatic fluctuations for the period 1900–1983 and these are compared with data on fluctuations in yearclass strength. It is concluded that conditions favouring high survival rates of cod larvae must be related to the occurrence of high temperatures in the Atlantic component of the Norwegian current. The processes and/or phenomena must have a large time- and space scale. This is also confirmed by the high incidence of temporal similarity in survival success of the stocks of cod, haddock and herring in this area.

INTRODUCTION

Through evolutionary processes fish populations must have been adapted to a varying environment in a way which ensures their survival in unfavourable periods and an optimum use of favourable periods. There may be considerable interests in trying to find the ways in which these adaptions function.

The cod as a species belongs in the northern temperate and boreal regions, but reaches into sub-arctic areas where conditions are suitable, e.g. S.E. and S.W. Greenland and Barents Sea – W. Svalbard. In these populations which live close to the northern limits of distribution of the species, periodical fluctuations in stock size have been described (Rollefsen, 1954; Ottestad 1942). It has been partly assumed and partly demonstrated that these are in some ways related to climatic shifts occurring in the stock environments.

The feeding area of the Arctic cod in which the main production of the stocks biomass occurs is subject to large fluctuations related to changes in the ocean climate especially in the eastern and central Barents Sea. Although cod can survive in temperatures below $0^{\circ}C$, it is seldom found in abundance in waters of less than $2–3^{\circ}C$. The physiological significance of the temperature relationship is probably its direct effect on the capacity for growth of the cod. A more indirect effect relating cod distribution and climate is that also the distribution of one of the principal food organisms of the cod, the capelin demonstrate large scale shifts with climatic changes.

Maslov (1968) describes changes in the distribution of cod and haddock in the Barents Sea which he relates to changing climatic conditions. And the effects on the distributions of these two large fish stocks of the onset of a period of cold climate in the Barents Sea in 1978–1981 have been described by Loeng, Nakken and Raknes (1983) and Midttun, Nakken and Raknes (1981). The last mentioned paper demonstrate a clear westward shift of the distribution of young cod and haddock in this period resulting in an occurrence of these species limited to the western half of the Barents Sea. A simultaneous similar change took place in the distribution of the fisheries. Recruitment to these stocks was at a low level in this period particularly in the eastern Barents Sea. During these cold years with extreme southern ice limits migrating herds of harp seals reached the Finnmark coast where also the white whale was commonly observed. With the change of climate which took place in 1982 and 1983 a marked eastward shift of capelin distribution has been observed and the 0-group recruitment indices for both cod and haddock have increased to relatively high levels.

Thanks to the joint international survey systems operated by USSR and Norway, these large scale and dramatic events in the stocks can now be followed more or less "on line". Simpler observations on stocks and environment are, however, available for a considerable time period and it would be of interest to analyse these in a search for general ecological relationships. The following working hypothesis was formulated:

> In periods of "cold climate" the feeding areas of the cod in the Barents Sea are restricted and there is a similar restricted need for recruitment. Production of rich year-classes in such periods would be a waste. From a survival strategy point of view it would be an advantage in such periods to send a larger part of the recruits to the west Svalbard region where the environmental conditions seem to be less variable. The history of the fishery indicate that periods of high and low recruitment to Svalbard have occurred, but these fluctuations will not be further examined in this paper.
>
> After a shift from a "cold" to a "warm" period the capelin with its short life cycle will repopulate the eastern areas in the cause of 1–2 years and with the increase of temperature, conditions will soon be favourable for production of cod in a greatly expanded area of the eastern and central Barents Sea. In order to utilize this potential both in

space and time, there is a need for high recruitment during the first few years of a new "warm period".

We will in this paper examine to what extent such a strategy can be demonstrated in the data on stock biology and the physical environment. The available time series of data are unusually long and takes us back to the turn of the century. The nature and quality of the data are varying and they must therefore be carefully examined.

VARIATIONS IN RECRUITMENT

THE DATA

The available data which can be used for assessing the variations in yearclass abundance comprise age data on various parts of the stock and, in later years, surveys of the relative abundance of 0-group and juvenile fish. The following series have been used: (Indices listed in Table 3).

<u>Yearclasses 1902–1919 in the skrei stock</u>.

The data are based on early scale-readings by Oscar Sund and on the yield of the skrei fisheries. This aging method has later been shown to be lacking in reliability, especially on higher age groups and the sampling was inadequate. The main findings were, however, corroborated by a large programme of length sampling where the periodical recruitment of abundant yearclasses can be identified. The age distributions of Lofoten skrei 1913–1928 from Sund (1920, 1926 and 1936) were combined with the yield of the total skrei fisheries in numbers and the yield in numbers of each yearclass was expressed as a ratio of the average yield of the corresponding age groups for the whole period.

Some early survey data from the Barents Sea and Bear Island grounds 1905, 1907 and 1913 also support the main findings from the early periode of Sund's skrei-analysis, see Hjort, (1914, p. 111 and p. 130).

Yearclasses 1917–1945 in the skrei stock

G. Rollefsen introduced otolith age readings of skrei and on this basis calculated an index of each yearclass's contribution to the stock. His data cover the yearclasses 1917–1943 (Rollefsen, 1952). Further observations include the yearclasses 1944 and 1945 (Rollefsen, 1954).

Yearclasses 1946–1952 in the stock of young cod

This series from Sætersdal and Hylen (1959) gives indices of relative abundance based on observations of age and yield in the fisheries for young cod 1950–1959. These observations are important because of the great increase in fishing mortality in the total stock in this period.

Virtual population analysis

This gives estimates of abundance at age 3 of the yearclasses 1946–1977 (Anon. 1979 and 1982).

USSR young fish surveys

This provides a trawl survey index of abundance at age 3 for the yearclasses 1957–1979 (Anon. 1982).

0-group surveys

The data derive from the international 0-group surveys in the Barents Sea which cover the period 1965–1983. Use is made of the logarithmic index estimated by Randa (1983).

2.2 Analysis of the data on yearclass abundance

The frequency distributions of the 6 series of observations on yearclass abundance are shown in Table 1. In order to obtain a rough comparison of the range and distribution of the series, the total range of variance was grouped into three subranges and the

Table 1. Frequency distributions of series on yearclass abundance of Arctic cod, 1902—1983. For explanations see text.

Yearclasses 1902-1920 "Skrei" stock O. Sund

.1		
.2		
.3		
0.4	2	
.5	3	
.6	2	
.7		11
.8	2	m_1=0.63
.9	1	
1.0	1	
.1	3	
.2		
.3	1	
.4		
1.5		6
.6		m_2=1.33
.7	2	
.8		
.9		
2.0		
.1		
.2		
.3		
.4		
2.5	1	2
.6		m_3=2.75
.7		
.8		
.8		
3.0	1	
	19	

Yearclasses 1917-43 "Skrei" stock Rollefsen

.2	4	
.4	3	
.6	2	19
.8	2	m_1=0.7
1.0	5	
.2	2	
.4	1	
.6	2	
.8	1	
2.0		5
.2	2	m_2=1.9
.4		
.6		
.8		
3.0	2	
.2		
.4		3
.6		m_3=3.4
.8		
4.0		
.2	1	
	27	

Yearclasses 1946-52 Young cod Sætersdal & Hylen

.2	1	4
.4	1	m_1=0.55
.6	2	
.8		
1.0	1	2
.2	1	m_2=1.2
.4		
.6		
.8		
2.0		1
.2	1	m_3=2.3
	7	

Yearclasses 1946-77 VPA-estimate total stock

0.1	1	
.2	6	
.3	2	19
.4	3	m_1=0.36
0.5	4	
.6	3	
.7	3	
.8	4	11
.9	1	m_2=0.84
1.0	1	
.1	1	
.2	1	
.3		
.4		-
1.5	1	3
.6	1	m_3=1.63
.7		
.8	1	
	33	

Yearclasses 1957-79 III-group Barents Sea USSR-trawl survey

0	8	
5	4	
10	2	17
15	2	m_1=7
20	1	
25		
30		
35	1	
40		
45	1	3
50	1	m_2=45
55		
60		
65		
70	2	3
75		m_3=79
80		
85		
90	1	
	23	

Yearclasses 1965-83 0-group Barents Sea

1-20	7	
21-40	4	15
41-60	2	m_1=29
61-80	2	
81-100	1	
101-120		
121-140		. 2
141-160	1	m_2=120
161-180	1	
181-200		
201-220		
221-240		2
241-260	1	m_3=210
	19	

frequencies and mean values within each sub-range calculated. Table 2 lists these frequencies and the ratios of the mean of the highest sub-range over that of the lowest, and similarly for the middle sub-range. This represents an estimate of the average abundance of rich and medium yearclasses measured in units of the abundance of poor broods.

Table 2. Frequency distribution of yearclasses of low, medium and high abundance in the various data-series and the ratios of mean yearclass strength.

Abundance	O. Sund Yearcl. 1902-20	%	G. Rollefsen 1917-43	%	Sætersdal & Hylen 1946-52	%	VPA 3 year 1946-77	%	USSR Trawl estimate 1957-79	%	0-group survey 1965-83	%
Low	11	58	19	70	4	57	19	58	17	74	15	79.0
Medium	6	31	5	19	2	29	11	33	3	13	2	10.5
High	2	11	3	11	1	14	3	9	3	13	2	10.5
	19		27		7		33		23		19	
$\frac{m_3}{m_1}$ =	4.4		4.9		4.2		4.5		11.3		7.2	
$\frac{m_2}{m_1}$ =	2.1		2.7		2.2		2.3		6.4		4.1	

A comparison of the frequencies and ratios of abundance for the six data sets shows the following: the four series based on age determination of commercial fish are characterized by a ratio of highest to lowest sub-range of 4.2 to 4.9 with a mean of 4.5. The ratio middle to lowest is 2.1–2.7 with a mean of 2.3. The corresponding ratios for the two survey data sets are considerably higher, 11.3 and 7.2 for the highest and 6.4 and 4.1 for the middle range. Also the frequencies of occurrence of the various ranges show a consistent difference with higher frequencies of middle-range yearclasses for the data series based on older fish. It seems reasonable to assume that these differences between the two sets of data are real: the variation in yearclass abundance is considerably higher when observed directly as juveniles than the apparent variation in the adult stock. There may be a number of factors contributing to this phenomenon: differential natural and fishing mortalities, incorrect age readings and landing statistics. Comparisons of VPA and survey data covering the same series of yearclasses show the same discrepancy. Whatever the causes, we will for the purposes of this analysis assume that the survey data provides the best estimates of the true variations in recruitment, and for the whole period the yearclasses in the highest sub-range will be presented as being 10 times as abundant as those in the lowest range, the middle range 5 times. If yearclasses of low, medium and high abundance occur with frequencies of about 75%, 12% and 12% as is indicated by the survey data this means that about 70 per cent of all recruitment derive from the broods of high and medium abundance. Their occurrence is therefore of a similarly high significance for the survival of the stock.

Fig. 1 and Table 3 presents the assessment of yearclass abundance in three categories: low, medium and high abundance corresponding to the subranges into which each series were grouped. Our general view is that the 0-group surveys provide the most reliable and least biased estimate of zero group recruitment. There is a fair degree of correspondence between the three different estimates for the yearclasses 1965–1979, but with one important exception. The yearclass 1969 appears in the VPA-series with an abundance in

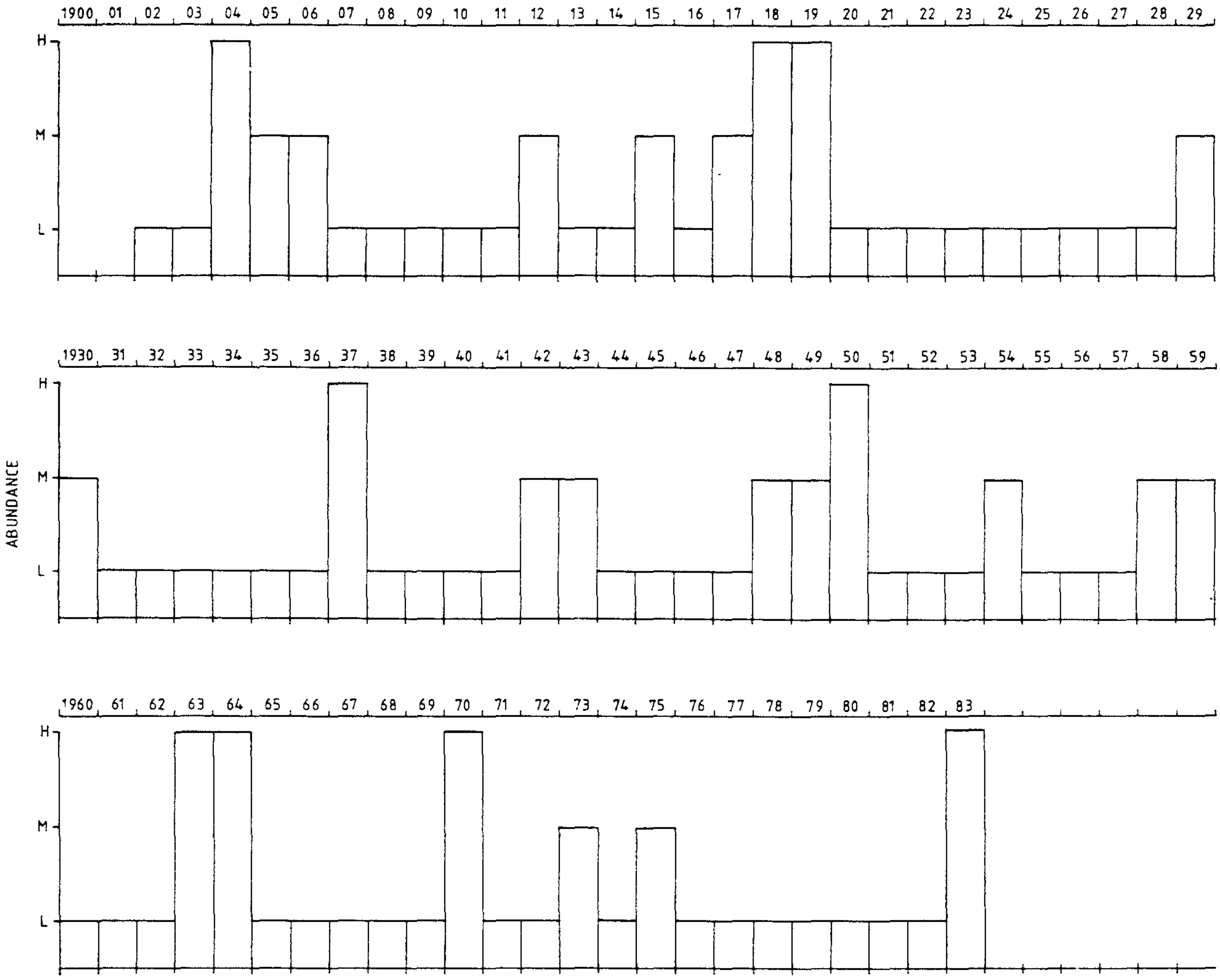

Fig. 1. Assessment of yearclass abundance in three categories: low (L), medium (M) and high (H) abundance for the period 1902—1983.

the upper "medium" range, while both of the survey data sets present this yearclass in the lower "low" range. It seems likely that this discrepancy is caused by an "overspill" in the VPA data from the rich 1970-yearclass caused by aging problems. If this is so, the same effect may have caused biased estimates of yearclasses adjacent to those of high abundance also in the earlier VPA data, e.g. yearclasses 1962, 1957, 1947—49.

Table 3. Indices and assessment of yearclass abundance 1902—1983.

	Skrei O.Sund		Skrei G.Rollefsen		Estimate used
1902	0.9	L			
3	1.0	L			
4	2.5	H			
1905	1.3	M			
6	1.1	M			
7	0.8	L			
8	0.6	L			
9	0.4	L			
1910	0.5	L			
11	0.6	L			
12	1.7	M			
13	0.5	L			
14	0.5	L			
1915	1.1	M			
16	0.4	L			
17	1.7	M	2.2	M	M
18	0.8	L	4.2	H	H
19	3.0	H	3.1	H	H
1920			1.0	L	
21			1.1	L	
22			1.1	L	
23			0.3	L	
24			0.3	L	
1925			0.4	L	
26			0.7	L	
27			1.0	L	
28			1.4	L	
29			1.9	M	

	Skrei cont.		Young cod Sætersdal, Hylen		VPA		III-gr. survey		Estimate used
1930	2.2	M							
31	0.9	L							
32	0.4	L							
33	1.3	L							
34	1.3	L							
1935	0.9	L							
36	1.1	L							
37	3.0	H							
38	0.5	L							
39	0.2	L							
1940	0.3	L							
41	0.7	L							
42	1.6	M							
43	1.7	M							
44	<1	L							
1945	<1	L							
46			0.51	L	50	L			L
47			0.74	L	71	M			L
48			1.33	M	110	M			M
49			1.17	M	120	M			M
1950			2.20	H	160	H			H
51			0.76	L	65	L			L
52			0.29	L	27	L			L
53					44	L			L
54					81	M			M
1955					50	L			L
56					69	L			L
57					79	M	13	L	L
58					92	M	19	L	M
59					73	M	16	L	M

	VPA		III-gr.		0-gr.		Estimate used
1960	47	L					
			13	L			
61	34	L	2	L			
62	80	M	6	L			L
63	158	H	76	H			H
64	129	H	46	M			H
1965	18	L	1	L	-	L	
66	12	L	1	L	0.02	L	
67	20	L	1	L	0.04	L	
68	41	L	5	L	0.02	L	
69	102	M	9	L	0.25	L	
1970	182	H	76	H	2.51	H	
71	52	L	32	M	0.77	L	
72	62	L	40	M	0.52	L	
73	62	L	46	M	1.48	M	
74	37	L	4	L	0.29	L	
1975	79	M	62	H	0.90	M	
76	24	L	3	L	0.13	L	
77	18	L	1	L	0.49	L	
78	26	L	2	L	0.32	L	
79	19	L	3	L	0.40	L	
1980					0.13	L	
81					0.10	L	
82					0.59	L	
83					1.74	H	

In the cases where estimates differ for the same yearclasses the choise is based on the following arguments: For the yearclass 1918 Rollefsens assessment of "high" abundance was chosen rather than Sund's "low" on the assumption that the otolith readings were more reliable. For the 1947-yearclass also the VPA estimate is close to "low". The 1957—59 yearclasses all appear as "low" in the USSR trawl survey data. In the "USSR assessment" (Anon. 1982 and Anon. 1967) which is based on the appearance of the year-classes in the USSR trawl fishery mainly on young cod, these yearclasses are estimated as —Average,+Average and +Average respectively. The trawl fisheries in Division I, Barents Sea which are based mainly on 3—5 year old cod showed a marked increase both of c.p.u.e. and total yield in 1962 and 1963 which is also consistent with relatively high abundance of the yearclasses 1958 and 1959 (Anon, 1967). Finally Mankevich (1965) describes the 1958-yearclass as "above average" and the 1959-yearclass as "rich". The USSR trawl survey during these first years were thus probably not representative. The 1962-yearclass has a low index in the III-group trawl survey. It is estimated as "poor" in the USSR assessment and the VPA "medium" value is probably a result of an "overspill" from the rich 1963 and 1964 yearclasses.

The "USSR Assessment" gives both the 1963 and the 1964 year-classes as "rich". In the few cases where the estimates differ in the years after 1965 the 0-group estimate has been relied on.

One must note that this analysis of a number of independent series of estimates cannot reveal any possible long-term trends in yearclass abundance.

CLIMATIC VARIATIONS

THE HYDROGRAPHIC DATA

With exception of two periods, 1906–20 and 1941–1944, regular observations of temperature in the Kola section (along 33°30'E) have been carried out since 1900. Monthly mean temperature for the depth layer 0–200 m (between 70°30'N–72°30'N) have been made available to the Institute of Marine Research by the Knipowich Polar Research Institute of Marine Fisheries and Oceanography, Murmansk. Midttun, Nakken and Raknes (1981) have calculated monthly mean temperatures for the period 1921–80. Anomalies from these mean values have been calculated for the whole observation period.

During the period 1900–1925 we have used sea surface temperature data from the meteorological station Gjesvær. This station, located at 71°06'N, 25°22'E, was operated in the period 1881–1925. Based on monthly temperature means presented by FROGNER (1948), anomalies for the quarter April–June have been prepared. During this quarter the water masses are relatively well vertically mixed, and the surface data should therefore reflect temperature changes in most of the water column. It is also shown by Blindheim, Loeng and Sætre (1981) that there is a fair interrelationship between the trends from the meteorological stations and those in the upper 200 m of the Kola section. However, the anomalies can not be directly compared with each other.

THE ICE DATA

Data on the ice conditions in the Barents Sea since 1900 have been taken from several sources. Table 4 lists the different periods, for which there exist data on the ice conditions.

Table 4. The different sources used in order to make an ice index for the Barents Sea.

Period	Data source (References)	Classification made by	Period of the year	Area
1900–31	The Danish Meteorological Institute, Copenhagen	Kissler (1934)	April–August	Spitsbergen–Novaya Zemlya
1932–38	The Danish Meteorological Institute, Copenhagen	The authors	April–August	Spitsbergen–Novaya Zemlya
1946–63	Institute of Polar Research, Oslo	Lunde (1965)	February–September	West of about 40°E
1964–70	Meteorological Office, Bracknell	The authors	February–September	Spitsbergen–Novaya Zemlya
1971–	The Norwegian Meteorological Institute, Oslo	Loeng (1979)	January–October	Spitsbergen–Novaya Zemlya

The classification of the ice conditions made for some of these periods could not directly be compared with each other. Therefore we found it convenient to use a common scale for the whole period. We have chosen a scale ranging from –2 to 2 where –2 characterize a year with extremely large ice covered areas and 2 is a year with extremely little ice. A normal ice year is indicated by 0 while –1 and 1 indicate a year with ice conditions between normal and extreme.

The first author who gave an index for ice covered areas for a longer period in the Barents Sea was Kissler (1934). He used ice charts from The Danish Meteorological Institute for the months April–August and classified each year according to a scale from 1 to 5. His results therefore could easily be transferred to our scale.

Det Danske Meteorologiske Institut (1926) published mean ice borders for the period 1898–1922. On the basis of this mean we have characterized the years 1932—1938 in the same way as described above. We also classified some years before 1932 in order to get our classification consistent with Kissler (1934). It should be mentioned here that the ice charts from The Danish Meteorological Institute cannot be relied upon in detail as there exist very few observations from the areas considered. Nevertheless, since there are no better data available, these ice data are used.

For the years 1939—1945 no ice data have been available. From 1946 to 1963 Lunde (1965) has given an ice index for the western Barents Sea, i.e. the area west of about 40°E. He gave each month from February to September a value, characterizing the ice coverage. The sum for all months then characterized the period February—September. His scale has been divided in 5 parts in order to get the same classification as for the earlier years.

From February 1960 the Meteorological office, Bracknell (1960—) started to present regular monthly ice charts. These have been used in order to characterize the years 1964—70. The years 1960—1963 were used to compare our index with the one given by Lunde (1965) in order to get the indices fairly consistent.

An ice index for the Barents Sea based on ice-charts from The Norwegian Meteorological Institute up to 1978 is published by Loeng (1979). The years 1979—83 have been treated in the same way. We have also transformed this index to the one used here.

It is obvious that our ice index is not any absolute measure of the ice condition during the period 1900—1981. However, the main intention is to show the relative changes in the ice condition. That purpose is, in our opinion, satisfied by the index.

ANALYSIS OF THE CLIMATIC DATA

Temperature anomalies from the Kola-section and Gjesvær are shown in Fig. 2 together with the ice index for the Barents Sea. There is a fairly good accordance between the temperature anomalies and variations in the ice coverage for most of the period.

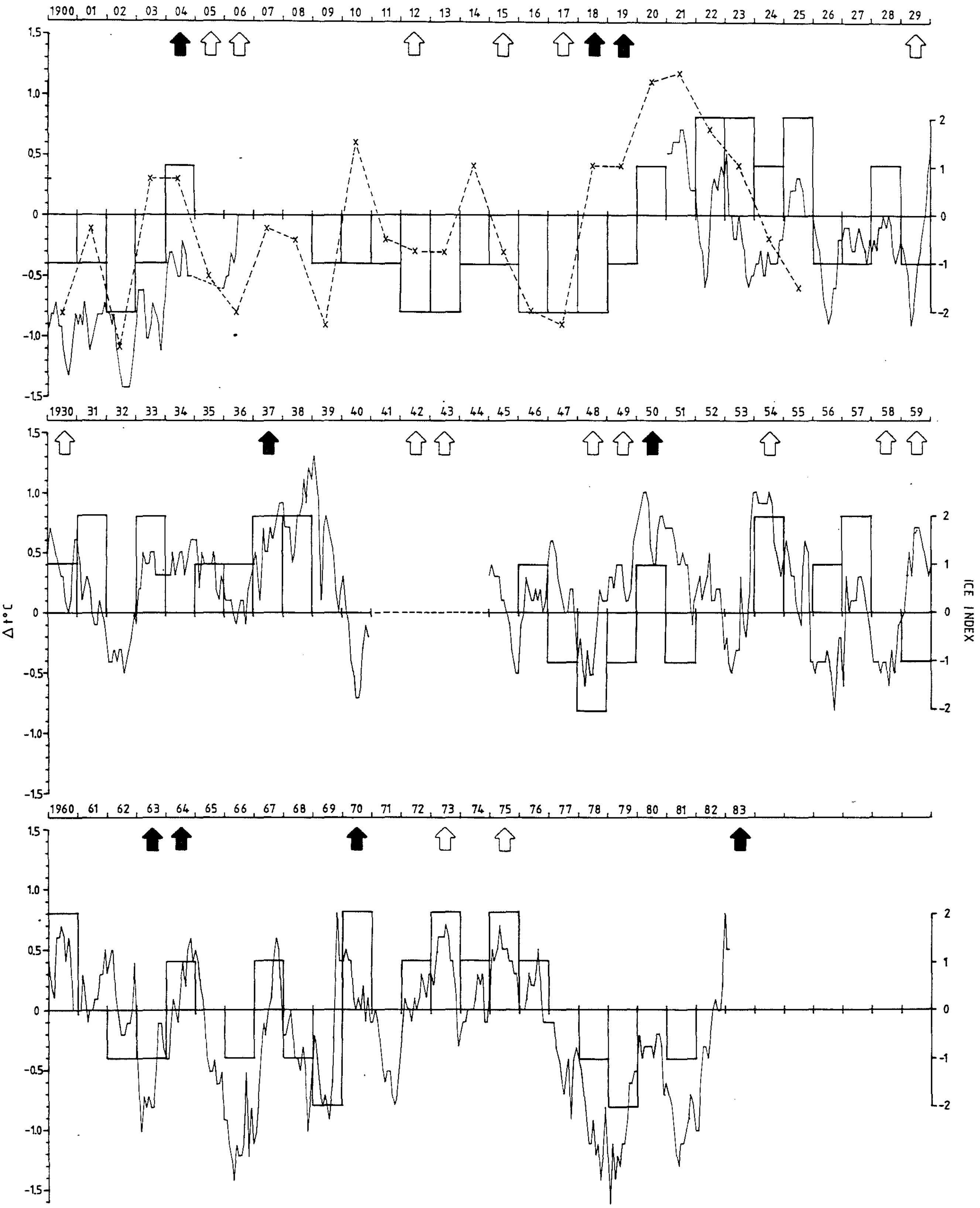

Fig. 2. Temperature anomalies in the Kola section in the period 1900–1983 (continuous line) and at Gjesvær in the period 1900–1925 (broken line). The histograms show the ice indices in the period 1900–1983. Black arrows show yearclass with high abundance, and open arrows show yearclass with medium abundance of cod.

There may be different reasons for this accordance. Novitskiy (1961) was of opinion that the ice conditions are determined by the heat content of the Atlantic influx to the Barents Sea, while Bochkov (1976) claim that both temperature and ice conditions depend on the 11 years solar activity cycle. However, we will not discuss this further in this paper.

Almost the whole period before 1920 was cold with more ice than normal. However, for the two years 1918–19 there is some discrepancies with the ice condition characteristics given by Kissler (1934). Our analysis of the data from the Danish Meteorological Institute indicates that these years should be given the index 0, i.e. normal ice conditions. At the same time there was a marked rise in the temperature at Gjesvær, confirming a change in climate already in 1918.

According to the classical works of Zubov (1943, 1948) the amount of ice in the Barents Sea for the years 1920–33 was in average 15 per cent less than for the period 1900–19. Even if there was little ice during the first half of the 1920's, the temperature was normal or slightly below normal. During the second half of the 1920's the temperature climate is characterized as cold.

The longest period of a warm regime was between 1930–40. Here we also found the year with least ice, 1937. In order to do justice to the year, 3 should have been used in the index.

The years after 1945 are characterized by fluctuations of duration of 3–5 years. During the period 1946–63 there is some discrepancy between the ice index given by Lunde (1965) and the temperature anomalies in the Kola section. One possible explanation of this discrepancy is that Lunde (1965) did not take the ice conditions in the eastern Barents Sea under consideration. The ice conditions in the western and eastern Barents Sea some years vary differently (Loeng 1979).

Table 5. Periods of different climatic regime and yearclass of high and medium abundance.

Period	Climatic regime	Yearclass abundance High	Yearclass abundance Medium
1900–1903	Cold		
1904–1908	Medium	1904	1905, 1906
1909–1917	Cold		1912, 1915, 1917
1918–1922	Medium	1918, 1919	
1923–1929	Cold		1929
1930–1936	Warm		1930
1937–1939	Extra warm	1937	
1940–1944	Unknown		1942, 1943
1945–1949	Medium		1948, 1949
1950–1955	Warm	1950	1954
1956–1958	Cold		1958
1959–1962	Warm		1959
1963	Cold	1963	
1964	Medium	1964	
1965–1969	Cold		
1970–1976	Warm	1970	1973, 1975
1977–1982	Cold		
1983–	Warm	1983	

When the ice conditions for the whole Barents Sea are taken into consideration, as after 1964, the variations in the ice conditions is in fairly good accordance with temperature anomalies in the Kola section. The different periods of climatic regimes are summarized in Table 5.

THE PERIOD 1970–1983

In Table 5 the years 1970–1976 are characterized as "warm" while the years 1977–1982 are "cold". The latter period was very cold and in addition the longest cold period on record, in any case since 1920. For the whole period 1970–1983 we have plotted the ice index made by Loeng (1979) together with the temperature anomalies from the Kola section (Fig. 3). The accordance between the two parameters is very good, and it gives reason to believe that the distribution of ice to a great extent depends on the oceanic climate.

From the beginning of 1982 the temperature started to rise, and at the end of the year the temperature was above normal. Data

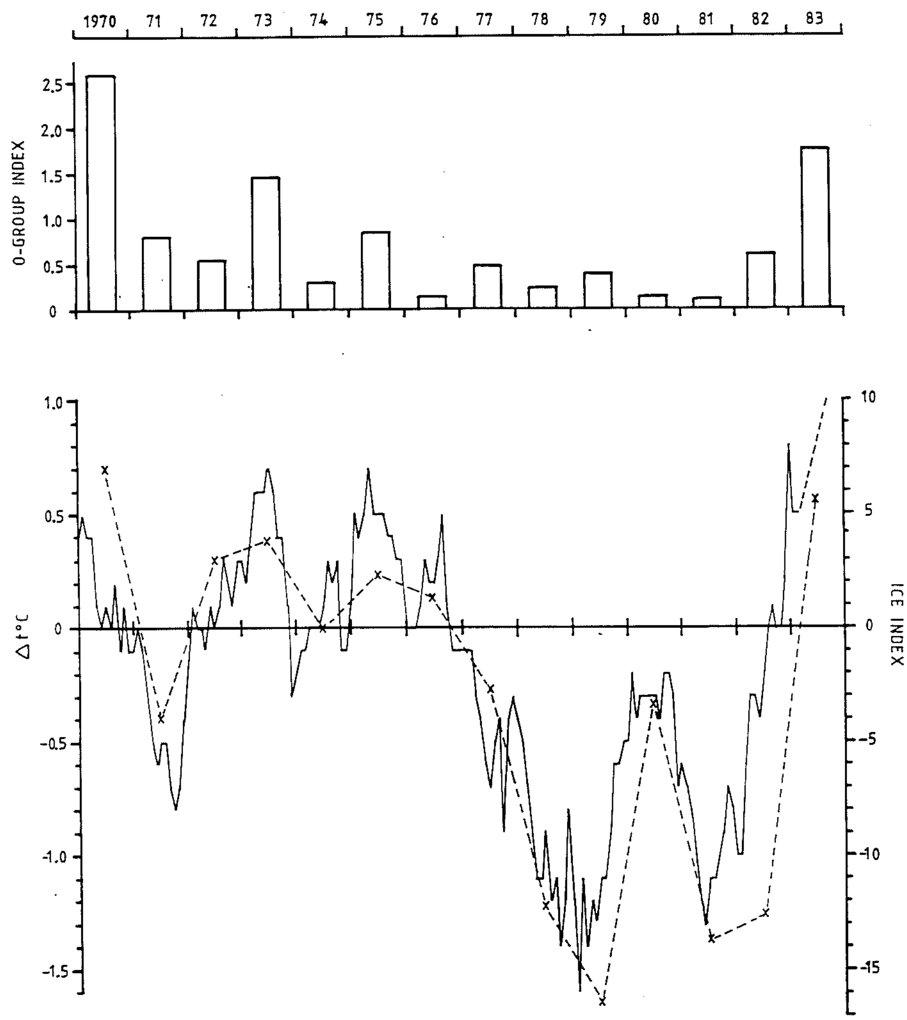

Fig. 3. The period 1970—1983: Logarithmic index estimated by Randa (1983) (upper) and temperature anomalies in the Kola section (continuous line) together with the ice index (broken line) calculated by the method described by Loeng (1979) (lower).

from the month January—March 1983 showed a positive anomaly of 0.5—0.8°C, while the results obtained during the international 0-group survey in August-September 1983 gave a positive anomaly of about 1°C Anon (1983). The ice conditions started also to improve during 1982, and during the winter 1983 ice was rarely observed south of 76°N in the western and central Barents Sea. Also in the eastern Barents Sea ice conditions have been less severe than during the previous years.

Already Helland-Hansen and Nansen (1909) suggested that temperature variations of some duration in the Barents Sea probably are of advective nature. The temperature is determined mainly by the conditions in the Atlantic inflow to the Barents Sea. Therefore, changes in the climate will first be observed in the western Barents Sea. Temperature changes in the eastern part will most often occur about one year later (Loeng, Nakken and Raknes, 1983). The same delay was indicated between Lofoten and the Kola section by Helland-Hansen and Nansen (1909).

RELATIONSHIP BETWEEN CLIMATIC PERIODS AND RECRUITMENT

Various methods of smoothing the temperature and ice-cover data shown in Fig. 2 were attempted. These brought out more clearly the periodicity of the system, but tended to dislocate the times of the shifts of the regimes which we think are of special interest. From Table 5 six cold periods can be identified ranging from 3 to 9 years duration with an average of abt. 6 years, and 7 warm/medium periods ranging from 4 to 7 years with an average of 5.5 years. In addition an extra warm period of 3 years occurred during 1937–39 (the years 1963 and 1964 are not included in this grouping).

As can be seen from the listing of yearclasses of high and medium abundance in Table 5 the shift from a "cold" to a "warm" or "medium" period was related in time to the occurrence of yearclasses of high abundance in 1904, 1918/19, 1970 and 1983 and to yearclasses of medium high abundance in 1929/30 and 1958/59. Yearclasses of high abundance also occurred when the regime changed from "warm" to "extra warm" in 1937 and from "medium" to "warm" in 1950.

The yearclasses 1963 and 1964 both of high abundance do not fit into this picture of high recruitment with a regime of increasing temperature. They occurred after the end of a warm period when a relatively "cold" year was followed by a "medium" year.

It seems, however, fair to conclude from this comparison that the major part of the yearclasses of high and medium abundance are either associated directly with positive temperature anomalies in the early part of a warm period or they occur immediately prior to a shift to a warmer regime (1918, 1929, 1948, 1958). It would thus seem that the hypothesis of an adjustment of the recruitment to a fluctuating potential for stock biomass production is confirmed by this analysis of historic data.

The actual interrelationship has of course not been revealed by this study. Since the maturity age of the Arctic cod of 7–9 years is well within the range of variation of a total climatic period ("warm" + "cold"), fluctuations of the stock size started and influenced by the changing climate could result in variations in recruitment if a close relationship existed between the spawning stock size and recruitment. Such a relationship does, however, not seem to exist. At the levels of intermediate size of the spawning stock, it is thought that the survival rate of the larvae and the resulting abundance of the 0-group stage is determined by conditions of the environment to which the eggs and larva are exposed in an early period. The nature of the conditions favouring survival are the subject of intensive research.

Another possible linkage between the extent of the feeding areas available to the cod in the Barents Sea and the level of recruitment exists in the system of ocean currents in the region. As is shown by the close relationship between the extent of ice cover of the Barents Sea and the temperature of the Kola Section for the period 1970–82 (Fig. 3), the width of the cods production area seems largely to be determined by, the heat transport of the Atlantic water flowing into the southern and central Barents Sea. The variations of temperature observed here can in a general way be predicted from observations up-stream along the Norwegian coast including the parts which form the main spawning areas of the cod. Some special conditions of the Atlantic water of the Norwegian current related to high temperature and/or increased velocity could result in favourable conditions for larval survival. At the far end in the Barents Sea the increase of temperature tends to extend feeding areas. As mentioned under

2.3 above there will be a time lag of about one year between the increase of temperature at Lofoten and that of the central/-eastern Barents Sea. The existence of such a time lag could explain the cases where increased recruitment occurs just before the shift from a colder to a warmer period in the Barents Sea.

If the special conditions of the environment which favour high larval survival are related to major changes in the dynamics or temperature regime of the Norwegian current the phenomen or processes must have a large scale both in time and space. One would then expect that also other stocks which reproduce in this ecosystem would be similarly affected. Dragesund 1971) compared yearclass strength of some stocks spawning at the Norwegian coast for the period 1950-65 and found that there was "a clear tendency towards rich yearclasses of several species". Without going into a detailed comparative analysis the following list of years of common high recruitment in cod, haddock and herring is a convincing demonstration of close temporal relationship in conditions for larval survival:

Cod	1950	1958/59	1963/64	1970	1975	1983
Haddock	1950			1969/70	1975	1982/83
Herring	1950	1959	1963/64	Stock depleted		1983

Systematic comparisons of prior data are not known, except for the outstanding yearclasses of cod and herring from the year 1904 which through Hjort's work belong in the history of fishery science!

Our analysis for cod as well as the degree of co-variance of several stocks thus indicate that the environmental conditions resulting in yearclasses of high abundance are related to processes or phenomena of the oceanographical environment which must be of a large scale both in space and in time. It is also indicated that they are directly or indirectly related to increased heat transport in the Atlantic component of the Norwegian current.

It is hoped that these indications may point towards a fruitful approach for further studies.

REFERENCES

Anon. 1967. North East Arctic Fisheries Working Group. Report of the Meeting at Copenhagen, December 4–14th 1967.

Anon. 1979. Report of the Arctic Fisheries Working Group. C.M. 1979.

Anon. 1982. Report of the Arctic Fisheries Working Group. C.M. 1982/Assess: 2.

Anon. 1983. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September 1983. Coun. Meet. int. Coun. Explor. Sea, 1983 (G:35): 1–28. (Mimeo.)

Blindheim, J., Loeng, H. and Sætre, R. 1981. Long-term temperature trends in Norwegian Coastal Waters. Coun. Meet. Int. Coun. Explor. Sea, 1981 (C:19): 1–13.

Bochkov, Yu.A. 1976. On the effect of solar activity of various periodicity on the thermal regime of the Barents Sea. Coun. Meet. int. Coun. Explor. Sea, 1976 (C:2): 1–19.

Det Danske Meteorologiske Institut (1901–1940). Isforholdene i de Arktiske Have 1900–1938. Tillæg til Naut.-met. Aarb. 1900–1938, 1901–1940.

Dragesund, O. 1971. Comparative analysis of yearclass strength among fish stocks in the North Atlantic. FiskDir. Skr. Ser. HavUnders., 16: 49–64.

Helland-Hansen, B. and Nansen, F. 1909. The Norwegian Sea. FiskDir. Skr. Ser. HavUnders., 2(2): 1–360.

Hjort, J. 1914. Fluctuations in the great fisheries of northern Europe. Viewed in light of biological research. Rapp. Proc. Verbs. Cons. Int. Expl. Mer. 20: 1–228.

Kissler, F. 1934. Eisgrenzen und Eisverschibungen in der Arktis swischen 50° West und 105° Ost im 34-jährigen Zeitraum 1898–1931. Beitr. Geophys., 42(1): 12–55.

Loeng, H. 1979. A review of the sea ice conditions of the Barents Sea and the area west of Spitsbergen. Fisken Hav., 1979 (2): 29–75. (In Norwegian, abstract in English.)

Loeng, H., Nakken, O. and Raknes, A. 1983. The distribution of capelin in the Barents Sea in relation to the water temperature in the period 1974–1982. Fisken Hav., 1983(1): 1–17. (In Norwegian with English abstract.)

Lunde, T. 1965. Ice conditions at Svalbard 1946–1963. Norsk Polarinst. Årb. 1963: 61–80.

Mankevich, E.M. 1965. Some investigations on Age and Length Compositions of Cod in the Barents Sea in 1963. Ann. Biol. vol. XX: 126–127.

Meteorological Office. Monthly ice charts 1960–. Brachnell, England.

Midttun, L., Nakken, O. and Raknes, A. 1981. Variations in the geographical distribution of cod in the Barents Sea in the period 1977–1981. Fisken Hav., 1981(4): 1–16. (In Norwegian, abstract in English).

Maslov, N.A. 1968. The influence of natural factors and fishing upon the age composition, abundance and distribution of the Barents Sea bottom fishes. Proceedings of the Polar Research Institute of Marine Fisheries and Oceanography, Murmansk, 23: 86–103. (Canadian translation, 1975).

Novitskiy, V.P. 1961. Permanent currents of the Northern Barents Sea. Trudy gos. okeanogr. Inst. 64: 1–32. (U.S. Naval Oceanographic Office, Transl. 349 1967): 1–39.

Ottestad, P. 1942. On periodical variations in the yield of the Great Sea Fisheries and the possibility of establishing yield prognoses. FiskDir. Skr. Ser. HavUnders., 7(5): 1–11.

Randa, K. 1983. Abundance and distribution of 0-group Arcto-Norwegian cod and haddock 1965–1982. Contribution to the PINRO/HI-symposium in Leningrad, September 1983.

Rollefsen, G. 1952. Beretning 1950–52 fra Fiskeridirektoratets Havforskningsinstitutt. Årsberetn. Norg. Fisk. 1952 (6): 1–108.

Rollefsen, G. 1954. Observations on the Cod and Cod Fisheries of Lofoten. Rapp. et Proc. Verb. Cons. Int. Expl. Mer. Vol. 136: 40–47.

Sund, O. 1920. Undersøkelser over torskefiskene. Årsberetn. Norg. Fisk. 1920(1): 46–50.

Sund, O. 1926. Torskebestanden i 1926. Årsberetn. Norg. Fisk. 1926(1): 113–121.

Sund, O. 1936. The fluctuations in the European stocks of cod. Rapp. et Proc. Verb. Cons. Int. Expl. Mer. Vol. CI (3): 1–21.

Sætersdal, G. and Hylen, A. 1959. Skreiundersøkelsene og skreifisket i 1959. Fisken Hav. 1959(1): 1–20.

Zubov, N.N. 1943. Arctic Ice. Moscow 1943. (Translated by U.S. Naval Oceanographic Office and Meteorological Society, 1963: 1–491.)

Zubov, N.N. 1948. In the center of the Arctic. Moscow-Leningrad 1948. (Ch. VI: Arctic ice, ch. VII: The warming of the Arctic. Translation T 14R. Defence Scientific Information Service. Defence Research Board, Ottawa, Canada 1950, 54 p.).