Flødevigen rapportser., 1, 1984. ISSN 0333-2594
The Propagation of Cod *Gadus morhua* L.

VARIATION OF PEAK SPAWNING OF ARCTO-NORWEGIAN COD (*Gadus morhua* L.) DURING THE TIME PERIOD 1929-1982 BASED ON INDICES ESTIMATED FROM FISHERY STATISTICS

T. Pedersen

Department of Fisheries Biology, University of Bergen,
P.O.Box 1839, N-5011 NORDNES Norway

ABSTRACT

Pedersen, T., 1984. Variation in peak spawning of Arcto-Norwegian cod (*Gadus morhua* L.) during the time period 1929-1982 based on indices estimated from fishery statistics. In: E. Dahl, D.S. Danielssen, E. Moksness and P. Solemdal (Editors), The Propagation of Cod *Gadus morhua* L. Flødevigen rapportser., 1, 1984: 301-316.

The weekly amounts of roe and cod landed in the main spawning area at Vestfjorden are known since 1929. An index of the median of the spawning intensity curve was constructed on the basis of an analogy to the gonosomatic index using the weight ratio roe/cod.

The index of median reveals a delay of about one week during the time period from 1929 to 1982. This method is compared to the median of spawning curves based on net hauls of newly spawned eggs from the traditional spawning grounds for the time period 1976 to 1982.

Sources of errors in the fishery statistics are discussed.

INTRODUCTION

The Lofoten and Vesterålen area is the main spawning area of the Arcto-Norwegian tribe of cod. The spawning period lasts from February to May with the main spawning in March and April (Sars, 1879; Rollefsen, 1932; Wiborg, 1957; Ellertsen et al., 1981a). The cod appear at the spawning grounds in February and March after the spawning migration from the Barents Sea (Rollefsen, 1955). The most concentrated spawning is on the shelf on the western side of Vestfjorden close to the shore (Wiborg, 1952; Ellertsen et al., 1981a, 1981b). There is also spawning on the coastal banks outside Lofoten and Vesterålen and north to Sørøya (Hjort, 1902).

The cod spawn in the thermocline between the cold coastal water and the warmer and more saline bottom water of Atlantic origin. Spawning occurs at 3.5-6.5°C (Rollefsen, 1955; Ellertsen et al., 1981b).

The older and bigger fish generally appear earlier in the catches than younger and smaller fish (Rollefsen, 1937, 1939, 1940; Sund, 1937, 1938). The older fish also leave the Lofoten area before the younger fish (Hylen, 1962).

The age and size frequency distribution of the spawning stock have changed during the period 1929 to 1982 because of the increasing exploitation, and most of the spawning stock now consists of young fish (Hylen, 1962; Sætersdal and Hylen, 1964; Hylen and Dragesund, 1973; Ponomarenko, 1982).

A delay in peak of spawning would be expected because of the combined effects of later spawning time of younger fish and the change in age structure of the spawning stock towards more young fish during the time period (Wiborg, 1957; Hylen, 1962; Solemdal, 1982).

The fishery statistics from the Lofoten fishery have earlier been used to indicate the length of the spawning period and peak of spawning (Wiborg, 1957; Cushing, 1969). Besides the fishery statistics, egg data from net hauls in 1976-1982 in the eastern part of Lofoten were available (Solemdal, 1982).

The aim of this investigation was to decide whether fishery statistics can be used to establish a time series of indices of peak spawning which could be used to test the hypothesis of a delay in peak spawning during the time period 1929-1982. The results from the fishery statistics will be evaluated by comparing them to results from spawning intensity curves based on vertical net hauls for the period 1976-1982.

MATERIALS AND METHODS

Estimation of spawning intensity curves 1976-1982

From 1976-1982 eggs were sampled with vertical Juday net hauls from the three subareas: Henningsværstraumen, Høllа and Austnesfjorden (Solemdal, 1982). These stations are located in the eastern part of Lofoten on the traditional spawning grounds. Samples were usually taken each second or third day from the middle of March until spawning was finished in the beginning of May.

The cod eggs were staged by a key given by Westernhagen (1970), modified by Strømme (1977). The number of eggs less than 48 hours of development were sorted out of the samples and counted. Yearly spawning curves were calculated by pooling the data from the three subareas. The curves were smoothed by a three point moving mean.

Cumulative spawning curves were calculated by trapezoidal integration. The median (M), which is the point of 50 per cent of the total amount of eggs spawned, was estimated from these cumulative curves. Because eggs less than 48 hours of development were counted, one day was subtracted from the median, assuming that the mean age of the eggs was one day.

A mean curve was calculated from the spawning curves for 1976-1982. This curve represents the mean numbers of eggs less than 48 hours of development per square meter for the years 1976-1982. Day of year, which is the number of days from 1 January, has been used as the time unit.

Fishery statistics

From 1929 onwards the fishery statistics include tables of the quantity of cod roe and cleaned gutted cod landed every week of the fishery in the Lofoten area. The values used are from the pooled statistics from all fishing stations in the area. The gonosomatic index (GSI) is the ratio (gonad weight/body weight) · 100%, and is defined for individual fish. GSI have been used to describe the maturity cycle and spawning period of a fish population (Eliassen and Vahl, 1982; de Vlaming et al., 1982). The roe index (RI) is defined as the ratio (weight of roe/weight of females)$\cdot$ 100%, and is defined for the landed catch. RI is an analogy to GSI and is deduced below.

$$RI = (R/W_{♀}) \cdot 100\%$$

R - roe weight in the landed catch in tonnes

$W_{♀}$ - weight of females in the landed catch in tonnes

$$W_{♀} = k \cdot P_{♀} \cdot w$$
$$k = 1.6$$

k - conversion factor between total body weight and the weight of cleaned gutted cod, assuming that cleaned gutted weight is 62.5 per cent of total body weight

$P_{♀}$ - fraction of female body weight in the landed catch

w - weight of cleaned gutted cod in the landed catch in tonnes

$$RI = \frac{R}{k \cdot P_{♀} \cdot w} \cdot 100\% \qquad (1)$$

In the present paper it is assumed that $P_{♀}=0.5$ and was constant through the period studied.

From the fishery statistics the ratio (R/w) is known and equation (1) is used to transform the weekly points (R/w) so that the scale of RI can be compared to that of GSI. RI have then been used instead of GSI.

The weekly points of RI for 1978 are shown in Fig. 1 as an example. A cubic spline function has been fitted to the weekly points of RI. This fitting procedure has the advantage over linear interpolation in this case that it is not so sensitive to single deviating data points (Wold, 1974).

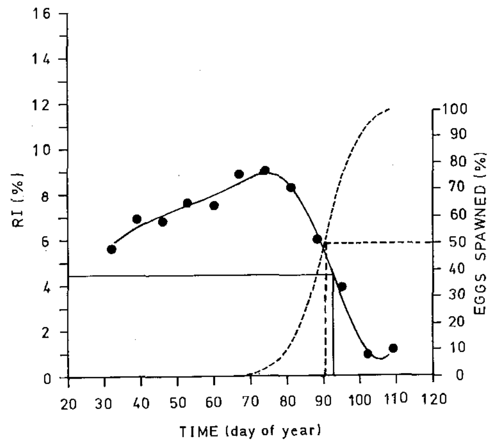

Fig. 1. Comparison of the data from fishery statistics and the eggdata for 1978. Weekly points of RI are indicated by dots and the fitted cubic spline function is shown by solid line. Vertical solid line indicate index of median (MRI). Cumulative spawning curve from egg net hauls is shown by broken line and the median (M) indicated by vertical broken line.

The upward trend of RI (Fig. 1) in the first part of the season is due to ovary growth which is rapid during this period (Sorokin, 1967). The sudden fall in RI from the middle of March is caused by the beginning of spawning. Official criteria and control of the quality of roe that is acceptable at the fishing stations has existed since 1934 (Anon., 1981). Roes with many ovulated transparent eggs, being in the stage of spawning, are not suitable as human food and therefore in general not accepted at the fishing stations. These rejected roes are not included in the roe quantity (R) in the fishery statistics. The roe quantity (R) is an underestimate of the true quantity of roe in the catch before delivery to the fishing stations (Anon., 1929-1982).

RI_{max} is defined as the maximum of the RI function. Since in the present computation it is assumed that $P_♀=0.5$, then both variations in sex ratio and relative ovary weight between years will affect the computed RI_{max}. The index of median (MRI) is defined as the point of time when half the RI_{max} is passed. This definition would make MRI independent of variations in sex ratio and relative ovary weight between years. MRI have been estimated from the functions fitted to the weekly points of RI from 1929 to 1982.

The RI curve would be delayed if much roe of spawning fish is accepted relative to the official criteria for acceptance because of very great demand for roe. This would lead MRI to be delayed. The opposite situation would occur if roes at prespawning maturity stages were rejected at the fishing stations because of great supply and low demand for roe. In this case the result would be very early MRI.

In the middle of March the supply of roe exceeded the capacity of the fishing stations in 1944, 1946 and 1972, causing much roe to be discarded. In 1947, 1952 and 1953 salting of roe was prohibited and much roe was dumped. These years show extreme RI's with a sharp drop in the middle of March and have been omitted from the analysis.

The mean date of capture (MD) was used by Cushing (1969) as an index of peak spawning for the time period 1893-1967. MD has been calculated by equation (2) for those years where estimates of the median from egg data (M) exist.

$$MD = \left(\frac{1}{\sum_{i=1}^{n} C_i} \cdot \sum_{i=1}^{n} C_i \cdot D_i\right) -3 \qquad (2)$$

i - number of weeks in the fishery

n - total number of weeks in the fishery

C_i - catch in tonnes landed week i

D_i - day of year when C_i is reported

Three days is subtracted from the terms within brackets in equation (2) because the catch is reported on the last day in the week.

RESULTS AND DISCUSSION

The spawning curves for 1976-1982 show that both the start and end of the spawning period is very stable (Fig. 2). The spawning intensity increases in the middle of March and decreases from the middle of April. This material has been published by Ellertsen et al. (1981a), Solemdal (1982). The median estimates from egg data 1976-1982 indicate a very stable spawning period in this period (Table 1).

The medians (M) have been read from the cumulative spawning curves given by Smedstad and Øiestad (1974) for the years 1968-1972 (Table 1) (Fig. 3). These spawning curves are based on a combination of results from egg net samples and samples of cod where the maturity stages were determined. However, the method is difficult to repeat from the description given. The median is stable with the mean on day 90 (31 March).

When pooling the results from 1968-1972 given by Smedstad and Øiestad (1974) and the results from the egg data (1976-1982), the mean date of the median (M) is day 90 (31 March) with a standard deviation of 2.2 days. This indicates a very stable peak spawning during the time period 1968-1982.

The curves of RI from different years have a very similar shape. The agreement between the median from the egg data (M) and the index of median (MRI) seems acceptable except for 1971, 1979 and 1980 (Table 1). There is a positive correlation between the index of median (MRI) from fishery statistics and the median (M) from the egg data, although this is not a very high correlation (Table 2). 1971, 1979 and 1980 are years with an extreme MRI (Table 1) (Fig. 3). The correlation coefficient improves slightly when these years are excluded (Table 2). This suggests that MRI are biased by nonbiological factors in 1971, 1979 and 1980.

The time series of MRI reveal a trend towards higher values from 1929 to 1982 (Fig. 3). This trend is indicated

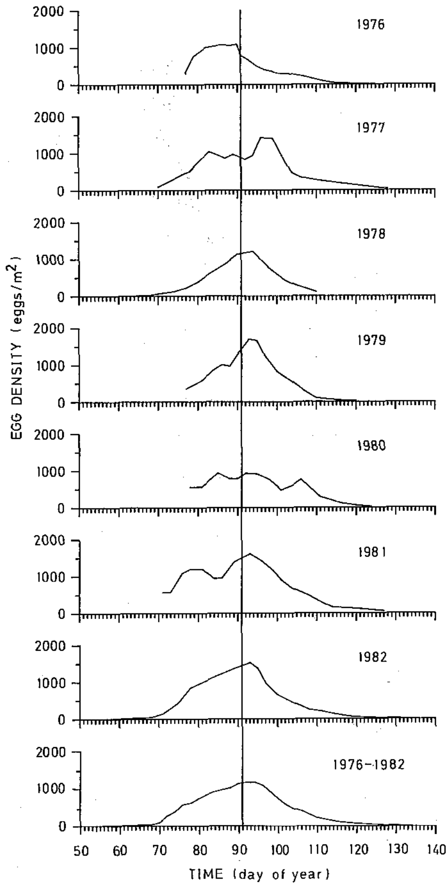

Fig. 2. The spawning curves for 1976-1982. The last curve is the mean curve for 1976-1982. Vertical line indicate day 91 (1 April).

by a five years moving mean. A nonparametric test against the trend was applied (Lehman, 1975), and the trend is statistically significant, $p<0.001$.

TABLE 1

Comparison of the median from egg data (M), the index of median from the fishery statistics (MRI) and the mean date of capture (MD). M from 1968-1972 are read from the graphs given by Smedstad and Øiestad (1974). The differences between MRI and M and between MD and M are given. Time unit is day of year.

Year	M	MRI	MRI-M	MD	MD-M
1968	89	87	-2	69	-20
1969	93	95	2	72	-21
1970	86	90	4	72	-14
1971	90	79	-11	72	-18
1972	92	-	-	71	-21
1976	88	93	5	77	-11
1977	93	95	2	78	-15
1978	90	93	3	77	-13
1979	92	109	17	67	-25
1980	93	102	9	78	-15
1981	90	94	4	71	-19
1982	89	89	0	71	-18

Since about 1955 the variance in MRI seems to have increased (Fig. 3), and is large compared to the more stable median (M) from egg data (Fig. 3) (Table 1). The late MRI in 1955 and 1957 is probably caused by the great demand for roe in these years, causing much partly spent roe to be accepted late in the season. In 1971, 1972 and 1973 the catches were great compared to those in the sixties. Some roe was discarded in 1971 and 1973 and much in 1972 (Anon., 1929-1982). These years have an early MRI. 1979 and 1980 show an extreme late MRI, this may be caused by the great demand for roe in these years. The main source of error in the index of median

(MRI) from fishery statistics seems to be variations in demand for roe between years at the fishing stations. Variations in demand for roe explain much of the variations in MRI since the fifties.

TABLE 2.

Correlation coefficients between the median from eggdata (M) and the index of median from fishery statistics (MRI), and between M and mean date of capture (MD). The median (M) from 1968-1972 are taken from Smedstad and Øiestad (1974).

Time period	M vs MRI	M vs MD
1968-1972		0.07
1968-1971	0.23	
1976-1982	0.65	0.12
1968-1972 and 1976-1982		0.15
1968-1971 and 1976-1982	0.52	
1968-1970 and 1976-1982 except 1979 and 1980	0.65	

The trend towards a delayed MRI occurs before 1955 (Fig. 3), and there seems to be less variance in MRI before 1955 than afterwards. This relatively small variance can be explained by a more stable demand for roe in the time period before 1955. A long term trend in the demand for roe before 1955, so that the roe was rejected at the fishing stations at prespawning maturity stages, could severely bias MRI and be the cause of the trend observed in MRI. There is sparse information about the demand for roe before 1955, but there is no sign of a long term trend in the demand for roe in the available literature.

Cushing (1969) used mean date of capture (MD) as an index of peak spawning for the period 1893-1967. There is a trend of about five days from the thirties to the sixties towards

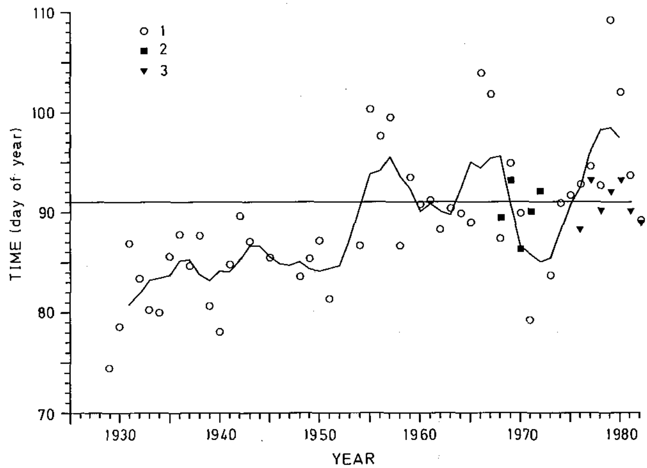

Fig. 3. The time series of the index of median (MRI) for 1929-1982 and the median from eggdata (M) 1968-1972 and 1976-1982. A five year moving mean is fitted to MRI. Horizontal line indicate day 91 (1 April). 1) Index of median (MRI) from fishery statistics, 2) median (M) read from spawning curves given by Smedstad and Øiestad (1974) and 3) median (M) from eggdata 1976-1982.

earlier MD (Cushing, 1969). This is the opposite of the trend in MRI found in this investigation. The MD for the years 1968-1972 and 1976-1982 occur 11 to 25 days earlier than the median from egg data (M) (Table 1). There is a very small correlation between MD and M (Table 2). The catches usually peak in the last part of March after an increase from the start of the fishery. After the peak the catches drop and the migration from the spawning area is rapid. Fig. 4 shows that the mean distribution of weekly catches in the period 1970-1979 is skewed.

The spawning period of Arcto-Norwegian cod was first described by G.O. Sars (1879). According to him the peak of

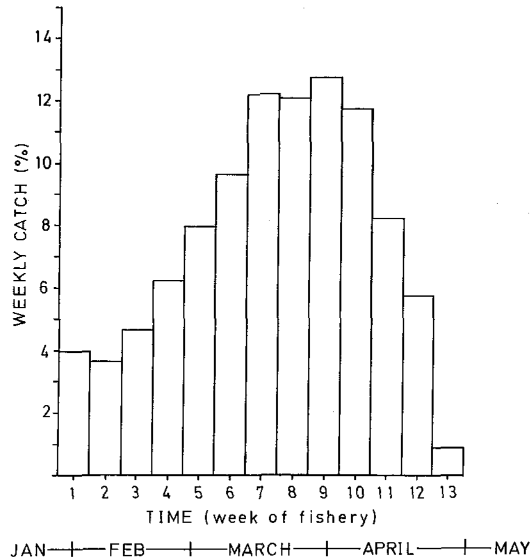

Fig. 4. Mean distribution of weekly catch in percent of total yearly catch for the period 1970-1979.

spawning occurred at the end of March. According to Rollefsen (1932) the main spawning took place in the last part of March. Wiborg (1957) states that the main spawning period is from middle of March to the beginning of April.

Since 1949, cod eggs have been sampled by vertical net hauls on a single station located outside the shelf near to Hølla (Ellertsen et al., 1981a). The date of peak number of eggs for the years in the period 1949-1977 indicates that the mean date of peak spawning is around the first week of April (Ellertsen et al., 1981a).

Because of the trend in the index of median (MRI) from the fishery statistics, and also the earlier records of the spawning period, it seems that the possible change in peak spawning is a maximum of 10 days towards later spawning. The delay seems to have occurred before 1955.

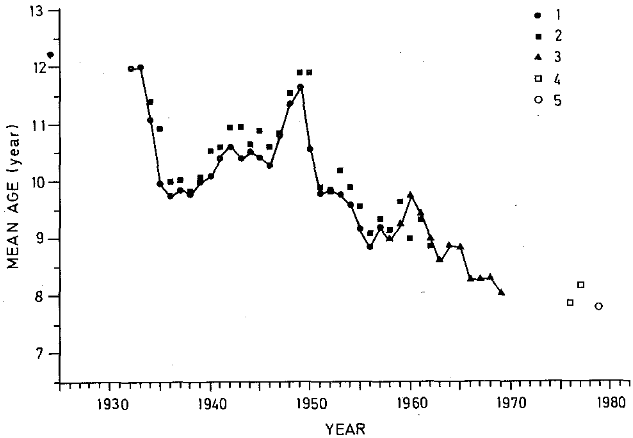

Fig. 5. The mean age of the spawning population of Arcto-Norwegian cod. 1) Taken from Sætersdal and Hylen (1964), 2) taken from Ponomarenko (1967), 3) calculated from the age frequency distributions given by Hylen (1962) for the period 1958-1962 and Hylen and Dragesund (1973) for the period 1963-1969, 4) calculated from the age frequency distributions given by Jakobsen (1978a, 1978b), 5) from Ponomarenko and Yaragina (1981).

The change in the age frequency distribution of the spawning population has been quite drastic during the time period from 1929 to 1982 (Fig. 5). The Norwegian data from 1929-1969 are from long line catches from Lofoten (Sætersdal and Hylen, 1964; Hylen and Dragesund, 1973). The data given by Jakobsen (1978a, 1978b) are from purse seine catches from the same area. According to Ponomarenko (1982) the mean age in the period 1971-1981 was 8.1 years with 8.6 years in the period 1971-75 and 7.6 years in the period 1976-1981.

Comparison of Fig. 3 and 5 shows that the delay in peak spawning estimated by the index of median (MRI) from the fishery statistics occurred at a time of a change in the age structure of the spawning stock towards more young fish. This delay can be explained with younger fish spawning later than older fish, and this is in accordance with the hypothesis mentioned in the introduction.

ACKNOWLEDGEMENTS

I would like to thank Per Solemdal for his supply of the egg data and his advice concerning the investigation and the manuscript, Svein Sundby for helpful critisism of both methods and manuscript, Elsa Strand and Per Bratland for their work with the egg material, and Pauline Dayrathne for help with the English language in the manuscript.

REFERENCES

Anon., 1929-1982. Årsberetn. Norg. Fisk. (Lofotfisket). Fiskeridirektøren, Bergen.

Anon., 1981. Norsk Fiskerilovgivning. Aasm. Engens Forlag A.S., Oslo, 531 pp.

Cushing, D.H., 1969. The regularity of the spawning season of some fishes. J. Cons. int. Explor. Mer, 33: 81-92.

Eliassen, J.-E. and Vahl, O., 1982. Seasonal variations in the gonad size and the protein and water content of cod, (*Gadus morhua* L.), muscle from Northern Norway. J. Fish Biol., 20: 527-533.

Ellertsen, B., Solemdal, P., Strømme, T., Sundby, S., Tilseth, S. and Westgård, T., 1981a. Spawning period, transport and dispersal of eggs from the spawning area of Arcto-Norwegian cod (*Gadus morhua* L.). Rapp. P.-v. Réun. Cons. int. Explor. Mer, 178: 260-267.

Ellertsen, B., Furnes, G.K., Solemdal, P. and Sundby, S., 1981b. Influence of wind induced currents on the distribution of cod eggs and zooplankton in Vestfjorden. In: R. Sætre and M. Mork (Editors). The Norwegian coastal current, University of Bergen, Bergen, pp. 604-628.

Hjort, J., 1902. Fiskeri og Hvalfangst i det Nordlige Norge. Årsberetn. Norg. Fisk., 1902(1): 39-59.

Hylen, A., 1962. Notfisket i Lofoten. Fisken Hav., 1962(3): 10-16.

Hylen, A. and Dragesund, O., 1973. Recruitment of young Arcto-Norwegian cod and haddock in relation to parent stock size. Rapp. P.-v. Réun. Cons. Perm. int. Explor. Mer, 164: 57-68.

Jakobsen, T., 1978a. Skreiinnsiget i 1976. Fisken Hav., 1978(1): 1-8.

Jakobsen, T., 1978b. Skreiinnsiget i 1977. Fisken Hav., 1978(1): 9-19.

Lehman, E.L., 1975. Nonparametrics based on ranks. McGraw-Hill International Book Company, San Francisco, 457 pp.

Ponomarenko, I.Ya., 1982. Portion of mature cod specimens and sex ratio in different age and length groups within the sixties and seventies. Coun. Meet. int. Coun. Explor. Sea, 1982(G:18): 1-20 (Mimeo.)

Ponomarenko, I.Ya. and Yaragina, N.A., 1981. Relation between mature and immature specimens among cod of different ages and sizes in 1978-1980. Coun. Meet. int. Coun. Explor. Sea, 1981(G:22): 1-11, 6 tabs., 1 fig. (Mimeo.)

Ponomarenko, V.P., 1967. Reasons of changes in the rate of growth and maturation of the Barents Sea cod. Coun. Meet. int. Coun. Explor. Sea, 1967(F:16): 1-13 (Mimeo.)

Rollefsen, G., 1932. Litt om skreiens gyting. Årsberetn. Norg. Fisk., 1932(2): 95-97.

Rollefsen, G., 1937. Aldersundersøkelser. Årsberetn. Norg. Fisk., 1937(2): 113-122.

Rollefsen, G., 1939. Skreibestanden i 1939. Årsberetn. Norg. Fisk., 1939(2): 98-107.

Rollefsen, G., 1940. Skreibestanden i 1940. Årsberetn. Norg. Fisk., 1940(2): 100-112.

Rollefsen, G., 1955. The Arctic cod. Proc. UNSci. Conf. Conserv. Utiliz. Resources, Rome, pp. 115-117.

Sars, G.O., 1879. Indberetninger til Departementet for det indre. Departementet for det indre, Christiania, 221 pp.

Smedstad, O.M. and Øiestad, V., 1974. Preliminary report of investigations of cod-eggs and larvae in the Lofoten area in the years 1968-1972. Coun. Meet. int. Coun. Explor. Sea, 1974(F:37):1-19. (Mimeo.)

Solemdal, P., 1982. Report of the working group on larval fish ecology. Coun. Meet. int. Coun. Explor. Sea, 1982 (L:3): 71-78. (Mimeo.)

Sorokin, V.P., 1967. The oogenesis and reproduction cycle of the cod. U.K. Min. Agr., Fish. Food. Lowestoft Fish. Lab. Transl. No. 119, 26 pp.

Strømme, T., 1977. Torskelarvens lengde ved klekking og virkningen av utsulting på larvens egenvekt og kondisjon. En eksperimentell undersøkelse på Norsk-Arktisk torsk (*Gadus morhua* L.). Thesis. University of Bergen, Bergen, 95 pp.

Sund, O., 1937. Torskebestanden i 1937. Årsberetn. Norg. Fisk., 1937(2): 101-112.

Sund, O., 1938. Torskebestanden i 1938. Årsberetn. Norg. Fisk., 1938(2): 87-102.

Sætersdal, G.S. and Hylen, A., 1964. The decline in the skrei fisheries. FiskDir. Skr. Ser. HavUnders., 13: 56-69.

de Vlaming, V., Grossman, G. and Chapman, F., 1982. On the use of the gonosomatic index. Comp. Biochem. Physiol., 73A: 31-39.

Westernhagen, H. von., 1970. Erbrutung der Eier von Dorsch (*Gadus morhua*), Flunder (*Pleuronectes flesus*) und Scholle (*Pleuronectes platessa*) unter kombinierten Temperatur und Salzgehaltsbedingungen. Helgoland. wiss. Meeresunters., 21: 21-102.

Wiborg, K.F., 1952. Forekomst av egg og yngel i nordnorske kyst og bankfarvann våren 1950 og 1951. FiskDir. Småskr., 1952(1): 1-22.

Wiborg, K.F., 1957. Factors influencing the size of the year classes in the Arcto-Norwegian tribe of cod. FiskDir. Skr. Ser. HavUnders., 11: 1-24.

Wold, S., 1974. Spline functions in data analysis. Technometrics, 16: 1-11.