NAFO Sci. Coun. Studies, 10: 7–11

Prediction of Year-class Strength of Atlantic Cod (*Gadus morhua*) off West Greenland

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

Abstract

Variables which have been used for prediction of year-class strength of Atlantic cod off West Greenland include temperature, density stratification, larval abundance and spawning stock biomass. The use of these factors as predictors are evaluated and discussed. Only temperature and larval abundance provide some useful information, but greater knowledge is required about the relative proportions of recruitment from the West Greenland and the East Greenland-Iceland cod stocks before realistic predictions of year-class strength can be made.

Introduction

During the 1950's and 1960's, the cod stock off West Greenland (NAFO Subarea 1) (Fig. 1) frequently yielded catches in excess of 300,000 (metric) tons, with peak yields of 451,000 and 430,000 tons in 1962 and 1967 respectively (ICNAF, 1972). Catches declined rapidly in the early 1970's and were in the range of 32,000–63,000 tons during 1973–83 (NAFO, 1985). The trends in catch generally reflected the changes in stock size, except that the biomass declined at a faster rate than the catches, due mainly to extended periods of poor recruitment in recent years.

From information on the present age composition and stock size of cod off West Greenland, forecasts of abundance and biomass are very dependent on the presumed strengths of recruiting year-clases. In the most recent assessment of the cod stock (Cornus *et al*., MS 1985), forecasts could be provided only for 1986, because the number of recruits in 1987 was estimated to constitute more than 50% of the fishable stock in numbers.

The Greenland Fisheries and Environmental Research Institute has, for many years, collected data on the abundance of cod in plankton samples and on hydrographic conditions off West Greenland. These data have been used to predict year-class strengths by various correlation and regression procedures (Hermann, 1953, MS 1961; Hermann *et al*., 1965) and by less formal methods in recent stock assessments (Horsted, MS 1980, MS 1981, MS 1982; Horsted *et al*., MS 1983, MS 1984; Cornus *et al*., MS 1985). However, the significant down-grading of expectations about the strength of the 1982 year-class, which in 1983 was expected to be fairly large (200 million recruits at age 3), to the low level of 20 million recruits in 1985 demonstrated that hydrological and larval-abundance data should be used with great care. The purpose of this paper is to present data which could be used in predicting year-class strength and to make a first evaluation of their quality for predictions.

Materials and Methods

Year-class strength

Virtual population analysis (VPA) was used to derive estimates of the strength of the 1953–79 year-classes of cod at age 3 (Table 1). The catch-at-age

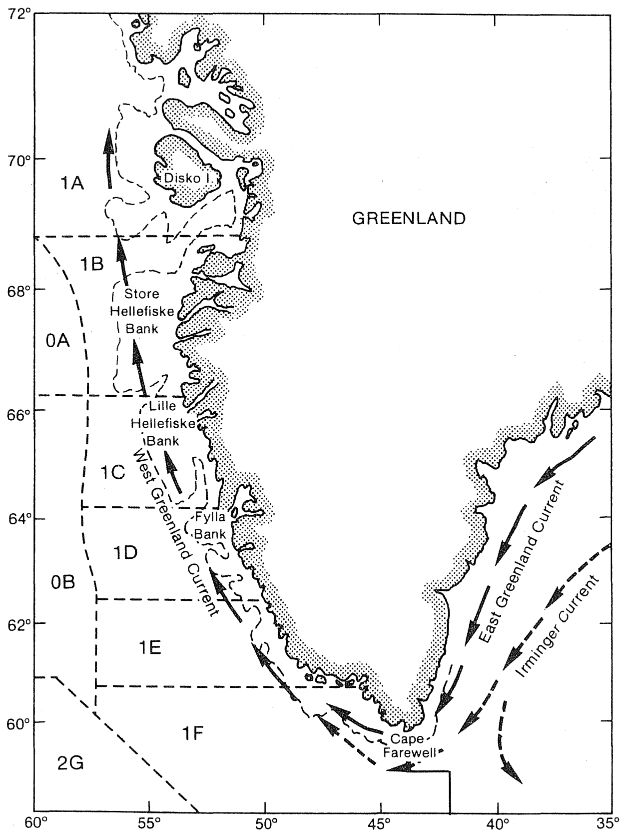

Fig. 1. Map of Greenland showing the Fylla Bank hydrographic section and other areas mentioned in the text.

TABLE 1. Trends in spawning stock biomass, mean temperature density stability and larval abundance relevant to prediction of year-class strength of cod off West Greenland, 1953–79.

Year	Year-class size age 3 (millions)	Spawning stock (000 t)	Mean temp. (°C)	Stability factor (E)	Larval cod index[a]
1953	451		2.1		8.44
1954	86		2.3		2.34
1955	91		1.2		2.21
1956	247	1,496	0.9		1.22
1957	516	1,335	2.3		45.67
1958	164	1,210	2.2		3.46
1959	95	1,031	1.6		2.15
1960	391	985	2.7		5.00
1961	530	883	3.2		4.36
1962	225	711	2.2		
1963	244	605	1.6		1.54
1964	77	478	2.3	2.2	1.12
1965	86	403	2.1	5.5	
1966	69	339	1.6	6.0	2.89
1967	40	324	1.5	7.5	
1968	88	286	2.1	7.0	6.94
1969	15	256	0.3	5.2	2.09
1970	12	200	0.3	9.1	0.75
1971	18	171	0.8	2.3	1.00
1972	22	118	0.7	4.7	1.05
1973	228	78	1.7		0.93
1974	46	66	1.0	9.0	0.72
1975	52	54	1.9	3.0	3.00
1976	60	31	1.4	6.6	0.67
1977	139	27	2.1	3.0	0.77
1978	20	41	0.9	2.2	0.29
1979	74	78	2.2	0.8	1.22

[a] Number per 30-min tow.

matrix was constructed from the age compositions which were used in stock assessments by Schumacher (1971) for 1956–66 and by Horsted *et al.* (MS 1983, MS 1984) and Cornus *et al.* (MS 1985) for subsequent years to 1984. Natural mortality (0.20) was assumed to be constant for all age-groups. Because some cod were known to migrate to East Greenland and possibly Iceland waters (ICES, MS 1984), the emigration coefficient (E) was assumed to be 0.05 for age-group 6 and older cod during 1956–82. In 1983 and 1984, the emigration coefficient was increased to 0.30 on the basis of the results of recent bottom-trawl surveys in the autumn (Horsted *et al.*, MS 1984; Cornus *et al.*, MS 1985). Other parameters, such as fishing mortality (F) in 1984 and F-values for the oldest age-groups, were those that were used in recent stock assessments. The resulting year-class strengths at age 3 were extracted from the population matrix and expressed in millions of fish.

Spawning stock biomass

Maturity ogives and mean weight-at-age data, which had been used in recent assessments of the cod stock (authors cited in preceding paragraph), were applied to the population matrix to obtain an estimate of the spawning stock biomass at the beginning of each year of the time series. In the absence of maturity data before 1960 and weight-at-age data before 1965, the relevant vectors for these years were applied to the population vectors for all preceding years. The resulting estimates of spawning stock biomass (SSB) are expressed in thousands of metric tons.

Temperature

Observations of temperature on the top of Fylla Bank off West Greenland (approximately 64° N) have been made in mid-June of each year since 1950, and the mean temperature of the near-surface layer was calculated by averaging the observations at 0, 10, 20, 30 and 40 m. In discussing the spatial and temporal temperature variations off West Greenland, Buch (1984) showed that temperature trends in neighboring areas and periods were similar to those on Fylla Bank due to the processes of advection and solar heating. Therefore, the mid-June temperature regime on Fylla Bank is considered to be a representative index of conditions off West Greenland.

Density stability

According to Meyer (1968), the amount of food for cod larvae may be closely related to the quantity of nutrients in the surface layer at the time of the plankton bloom, which in turn may be dependent on the effectiveness of the vertical convection process during the previous winter. Stein and Buch (MS 1984) suggested that low stability of the surface layer during autumn of the preceding year could be an indicator of favorable environmental conditions during the egg and larval stages of cod. To examine this hypothesis, mean stability (E) of the upper 200 m of the water column at Station 4 on Fylla Bank in November was calculated by the formula

$$E = \frac{1}{\rho}\frac{d\rho}{dz}$$

where ρ is the mean density of individual layers and $d\rho/dz$ is the rate of change in density with depth.

Abundance of cod larvae

Plankton surveys for determining the abundance of gadoid larvae have been carried out in early July since 1953 on NAFO standard oceanographic sections from Fylla Bank (64° N) and Store Hellefiske Bank (67° N). Oblique tows of 30 min duration at a speed of 2 knots (62 m/min) were made from a maximum depth of 50 m to the surface with a stramin net (2 m diameter and 1 m mesh size). Larval abundance is expressed as mean number per 30 min tow. It is not possible to distinguish between Atlantic cod and Greenland cod (*Gadus ogac*) larvae, but it is generally believed that most of the larvae are Atlantic cod because Greenland cod are restricted mainly to coastal waters.

Results and Discussion

Year-class strength and temperature

Year-class strength of cod is positively correlated with temperature (Fig. 2), the Spearman rank correlation coefficient being 0.67 (P <0.001). However, precise prediction is impeded by great variation in year-class strength (50-500 million recruits at age 3) at temperatures around 2° C.

The main cod spawning areas off West Greenland are on the banks in Div. 1D and 1E (see Fig. 1), but, in some years, there is evidence of larval drift from spawning in Iceland and East Greenland waters (Harden-Jones, 1968). E. Smidt of the Greenland Fisheries and Environment Research Institute (pers. comm.) has collected data on this subject and has classified some of the year-classes as being mainly eastern origin, on the basis of the observed catch distributions of the year-classes. Year-classes with distributions mainly off Southwest and Southeast Greenland were assumed to have originated from spawning in the east, whereas year-classes with more northerly distributions off West Greenland were assumed to have originated from spawning off West Greenland. Use of these criteria resulted in classification of the 1956, 1961, 1963 and 1973 year-classes as "easterners" (Fig. 2). If these four year-classes and four other outlying points (1953, 1957, 1960 and 1962 year-classes) are excluded, the remaining 19 points for year-classes (YC) with less than 200 million recruits show a linear increase in year-class strength with increasing temperature (T):

$$YC = 47.46\ T - 5.20 \qquad (r^2 = 0.60)$$

If high temperatures in some years can be taken as a sign of great inflow of Irminger Current water, it is tempting to classify these other four outlying year-classes also as being of eastern origin despite the fact that they were observed mainly as young fish in the northern area (Div. 1A to 1C). Therefore, some consideration should be given to the possibility of larval drift from East Greenland and Iceland to this northern area.

Direct current measurements off West Greenland are scarce. Drift-bottle experiments by Hermann and Thomsen (1946) indicate a mean velocity of about 0.2 m/sec, and measurements with Aanderaa current meters in 1975–79 during the summer gave velocities of about the same magnitude with maximum about 0.3 m/sec (Anon, 1979; Buch, 1982). Indirect estimation of current velocities from geostrophic calculations confirms that they are, on the average, about 0.2 m/sec, but they vary greatly from year to year (Alekseev *et al.*, 1972). For example, the hydrographic data for Fylla Bank in July give geostrophic velocities of 0.26 m/sec in 1981 but only 0.06 m/sec in 1982.

Seasonal variations in current velocity also occur. As noted by Soule *et al.* (1963) and Buch (1984), the intensity of the West Greenland Current is high during the spring and autumn and minimum during the summer. The current velocities in the preceding paragraph were all from observations during the summer. Geostrophic calculations from hydrographic data in November yield velocities around 0.4 m/sec. Therefore, it is likely that velocities at the beginning and during the period of egg and larval drift in the spring is higher than 0.2 m/sec.

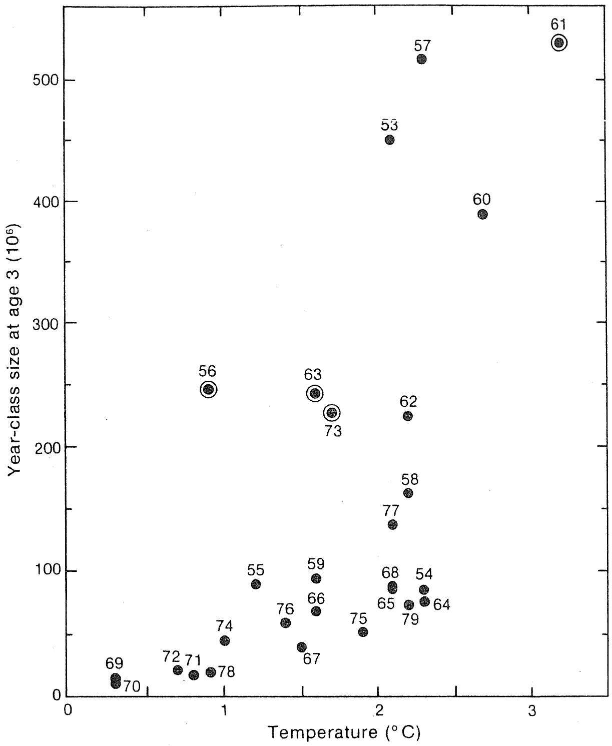

Fig. 2. Relation between year-class strength of age 3 cod and temperature off West Greenland. (Four year-classes (circled) were classified as being mainly of eastern origin.)

A mean current velocity of 0.2 m/sec implies that cod larvae which are found in the region from Fylla Bank to Store Hellefiske Bank in July were spawned off Southeast Greenland. If current velocities in some years were as high as 0.4 m/sec, the larvae could have originated from spawning southeast of Iceland. Therefore, the use of temperature on Fylla Bank as the only factor in prediction of year-class strength is complicated by not knowing whether recruitment from East Greenland and Iceland has taken place.

Year-class strength and density stability

There is no correlation between year-class strength and density stability (Fig. 3), the Spearman rank correlation coefficient being only 0.16 (P>0.50). For years when it was possible to compute stability factors (1964–72, 1974–79, Table 1), the linear relationship between year-class strength (YC) and temperature (T) is

$$YC = 42.94\ T - 6.17 \qquad (r^2 = 0.72)$$

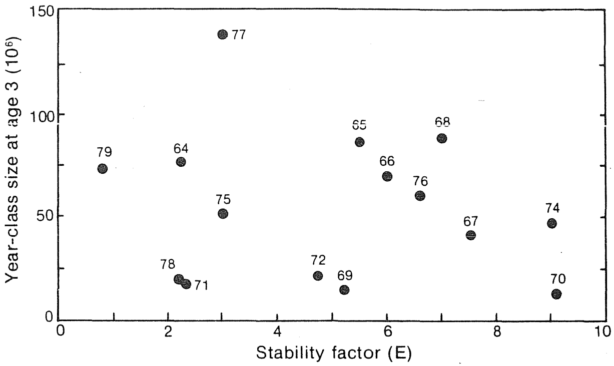

Fig. 3. Relation between year-class strength of age 3 cod and density stability in the autumn off West Greenland.

The inclusion of stability (E) in the linear model (YC = a + bt + cE) did not give a better explanation of total variation (r^2 increased only to 0.74).

Year-class strength and spawning stock biomass

Year-class strength is positively correlated with spawning stock biomass (Fig. 4), the Spearman rank correlation coefficient being 0.62 ($P<0.01$). However, spawning stock has gradually declined with time from high values in the late 1950's to very low values in the 1970's (Table 1). It is possible that both year-class strength and spawning stock biomass are correlated with some unknown factor which has changed during the period. Year-class strength is not correlated with spawning stock biomass for values of the latter less than 500,000 tons (1964–1979). There is no evidence of any reduction in recruitment at high biomass levels and, therefore, no justification for computing Ricker-type stock-recruitment curves.

Year-class strength and larval abundance

Year-class strength is positively correlated with larval abundance (Fig. 5), the Spearman rank correlation coefficient being 0.60 ($P<0.01$). High larval abundance (≥5 larvae per haul) has historically given rise to large year-classes (1953, 1957, 1960), which had a predominantly northern distribution off West Greenland. Other large year-classes (>200 million recruits), for which larval abundance was low (1956, 1961, 1963, 1973), had a predominantly southern distribution and may have originated from the eastern spawning grounds. For example, the 1973 year-class was found in great numbers in 0-group surveys off East Greenland in the autumn of 1973. More recently, the 1982 year-class, for which the larval index is the second largest on record for West Greenland, has not appeared in significant numbers during later surveys (Cornus *et al.*, MS 1985), indicating that it will likely be classified as a poor one. Thus, much variability is associated with using larval data as a means of predicting year-class strength of cod off West Greenland.

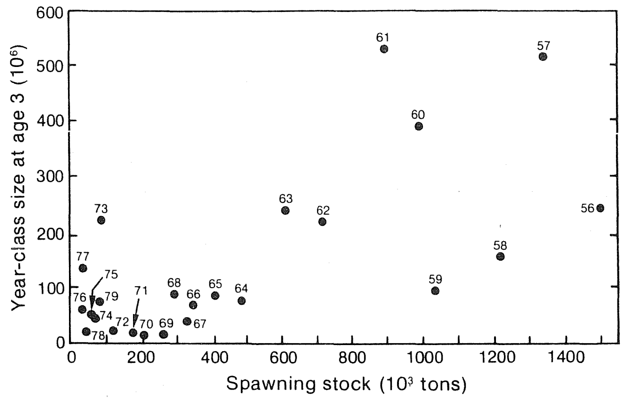

Fig. 4. Relation between year-class strength of age 3 cod and spawning stock biomass off West Greenland.

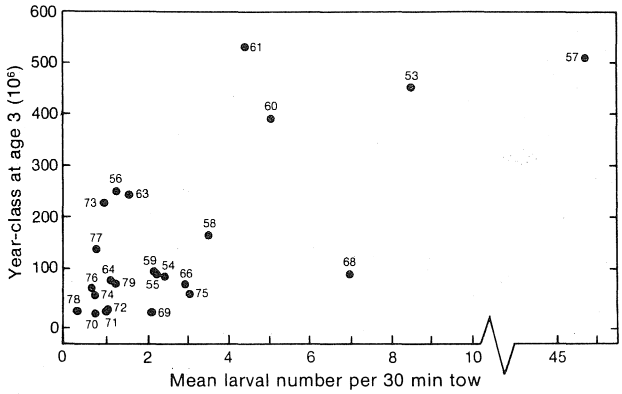

Fig. 5. Relation between year-class strength of age 3 cod and larval abundance off West Greenland.

Conclusions

Temperature and larval abundance off West Greenland provide some information on the size of cod year-classes, but predictions on the basis of these will be quite speculative unless more information becomes available on the relative proportions of recruitment from the West Greenland and the East Greenland-Iceland stocks.

Old plankton data, which might show the relationship of different species compositions to different water masses, and tagging results, which might show variable year-class migrations, should be reanalyzed. Such studies, of course, will not help in predicting future recruitment but might give better insight into the processes which generate year-class variability.

Better estimates of recruitment might be obtained from the results of young fish surveys instead of hydrographical and larval data, and a pilot study is planned by the Greenland Fisheries and Environmental Research Institute.

References

ALEKSEEV, A. P., B. P. KUDLO, V. N. YAKOVLEV, A. F. FEDOSEYEV, and A. A. BARINOV. 1972. Some aspects of water circulation in the Northwest Atlantic. *ICNAF Spec. Publ.*, **8**: 149–164.

ANON. 1979. Environmental conditions offshore West Greenland. *Greenl. Tech. Organ. Dan. Hydrol. Inst.*, III: 76 p.

BUCH, E. 1982. Review of oceanographic conditions in Subareas 0 and 1 during the 1970–79 decade. *NAFO Sci. Coun. Studies*, **5**: 43–50.

1984. Variations in temperature and salinity of West Greenland waters, 1970–82. *NAFO Sci. Coun. Studies*, **7**: 39–44.

CORNUS, H. P., H. H. HANSEN, Sv. Aa. HORSTED, J. M. JENSEN, K. M. LEHMANN, J. MESSTORFF, and A. SCHUMACHER. MS 1985. Status of West Greenland cod stock and management considerations. *NAFO SCR Doc.*, No. 63, Serial No. N1013, 26 p.

HARDEN-JONES, F. R. 1968. Fish migrations. Edward Arnold Ltd., London, 325 p.

HERMANN, F. 1953. Influence of temperature on strength of cod year-classes. *ICES Ann. Biol.*, **9**: 39.

MS 1961. Some considerations about correlations between the West Greenland stock of cod and environmental factors. *ICNAF Res. Doc.*, No. 34, Serial No. 896, 8 p.

HERMANN, F., and H. THOMSEN. 1946. Drift bottle experiments in the northern North Atlantic. *Medd. Komm. Dan. Fisk. Havunders.*, *Ser. Hydrogr*, **3**(4): 87 p.

HERMANN, F., P. M. HANSEN, and Sv. Aa. HORSTED. 1965. The effects of temperature and currents on the distribution and survival of cod larvae at West Greenland. *ICNAF Spec. Publ.*, **6**: 389–395.

HORSTED, Sv. Aa. MS 1980. Subarea 1 cod: data for 1979 and early 1980, and estimates of stock and yield for 1980–82. *NAFO SCR Doc.*, No. 72, Serial No. N124, 38 p.

MS 1981. Subarea 1 cod: data for 1980 and estimates of stock and yield for 1980–84. *NAFO SCR Doc.*, No. 48, Serial No. N330, 31 p.

MS 1982. Status of Subarea 1 cod and estimates of stock and yield for 1982–85. *NAFO SCR Doc.*, No. 50, Serial No. N540, 27 p.

MS 1984. Subarea 1 cod: fisheries and stock composition, 1983. *NAFO SCR Doc.*, No. 78, Serial No. N867, 14 p.

HORSTED, Sv. Aa., J. MESSTORFF, and A. SCHUMACHER. MS 1983. Status of Subarea 1 cod and estimates of stock and yield for 1983–85. *NAFO SCR Doc.*, No. 60, Serial No. N719, 43 p.

HORSTED, Sv. Aa., J. M. JENSEN, J. MESSTORFF, and A. SCHUMACHER. MS 1984. Stock size of cod at West Greenland by the beginning of 1984 and projection of yield and stock size, 1984–87. *NAFO SCR Doc.*, No. 92, Serial No. N883, 10 p.

ICES. MS 1984. Report of the working group on cod stocks off East Greenland. *ICES C.M. Doc.*, No. Assess:5, 25 p.

ICNAF. 1972. Tabular summary of fish and seal catches, 1958–72. *ICNAF Stat. Bull.*, **22**: 11–18.

MEYER, A. 1968. 1967 ein erfolgreiches Jahr fuer die deutsche Groenlandfischerei. *Hansa.*, **16**: 2–4.

NAFO. 1985. Tabular summaries of nominal catches, 1968–82. *NAFO Stat. Bull.*, **32**: 17–22.

SCHUMACHER, A. 1971. Fishing mortality and stock size in the West Greenland cod. *ICNAF Res. Bull.*, **8**: 15–19.

SOULE, F. M., A. P. FRANCESCHETTI, R. M. O'HAGAN, and Y. W. DRIGGERS. 1963. Physical oceanography of the Grand Banks region, the Labrador Sea and the Davis Strait in 1962. *Bull. U.S. Coast Guard*, **48**: 153 p.

STEIN, M., and E. BUCH. MS 1984. An unusual year off West Greenland? *NAFO SCR Doc.*, No. 59, Serial No. N847, 18 p.