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Stability Of Water Masses – Impact On Cod Recruitment Off West Greenland?

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Abstract

Based upon the hypothesis of Meyer (1968) that periods of low stability of the water column in autumn should parallel good cod year-classes in the following year, this paper analyses available time series of cod recruitment, subsurface oceanographic stability data and wind stress data off West Greenland. Correlation analysis yielded no significant results between stability, wind stress and recruitment when considering the entire length of available time series. Instead, splitting of the autumn based oceanographic data set into a pre-1970s part (when warm climatic conditions and high recruitment prevailed), and a recent part (for the past twenty years of cooling climate) yielded significant coherence of recruitment and environmental conditions of the cold climate period. For the warm climate period only occasional consistency was seen. The possible influence of the Great Salinity Anomaly on recruitment of cod is discussed. It is suggested that during the past twenty years a new correlation mechanism, an advective coupling instead of a low stability coupling, explains the variability of recruitment from the environmental point of view.

Key words: Cod, oceanography, recruitment, West Greenland, wind

Introduction

The fluctuations of several cod stock fisheries, e.g. Baltic, Arcto-Norwegian, Icelandic, West and East Greenland, and Canadian Atlantic cod stocks, are among the best documented in the world (Hermann and Horsted, 1976; Bjorke and Sundby, 1984; Kosior and Netzel 1989; Rose and Legett, 1989; Hovgård and Buch, 1990; Sundby and Fossum, 1990; Jakobsson, 1992). The intensity of the fluctuation has been different from one stock to another but they all have suffered great fluctuations over the decades. Considering the economical and social importance of cod fisheries, many investigation have been conducted into this problem, specially on the recruitment variability. As pointed out by Kosior and Netzel (1989), "the abundance of a cod year-class is only slightly affected by the abundance of its spawning stock and the quality of reproducers. What is important is the survival rate of eggs, larvae and juveniles". Among various physical processes affecting cod recruitment, larval and egg transport from the spawning grounds to their nurseries, temperature, salinity and turbulence are the most important. From the biological processes, predation and food availability are the dominant controlling mechanisms for recruitment success. Climate appears as a key to link those biological and physical processes. At West Greenland cod occurs at one of its northern limits (Hansen and Hermann, 1965). This stock is sustained not only by his own reproduction in the waters off West Greenland and in local inshore fjords, but also by the eggs and larvae advected from cod spawning sites at Iceland (Icelandic cod stock). The main feature of that West Greenland cod stock related to the fisheries is that both abundance and spatial distribution have shown considerable changes in historical time. The large variations are reflected in the annual yield which have varied by a factor of 10^2 within the present century (Buch and Hansen, 1988). The climate at West Greenland has also undergone very marked changes (Stein and Messtorff, 1990). These changes in the West Greenland climate are in part due to variations of the main current components of the West Greenland Current system, and due to air temperature variations. Periods of warm water temperatures correlate with air temperature as demonstrated by Stein and Buch (1991). These periods coincide with periods of high cod abundance. The general warming of the northern hemisphere around 1920 evidently led to the establishment of a self sustaining and very abundant West Greenland cod stock which through the 1930s–1960s produced good year-classes at relatively short intervals. But since the late-1960s the West

Greenland cod stock has produced only few good year-classes and fisheries have dwindled recently by nearly 100%. At present, cod abundance is at a very low level, with the 1992 catches being the lowest experienced since 1925. The effect of the climate changes in West Greenland on cod stocks appears to be evident but the way those climate changes have affected, and affect, the size of the year-classes is poorly understood.

Dickson and Brander (1993) suggested that the intensification of the Irminger current during warm periods increased the drift of cod larvae from the spawning grounds off south-west Iceland, thus leading to strong year-classes off West Greenland. They also pointed at the possibility that cod year-classes which survive the drift to Greenland as larvae may later return as adults to Iceland. Cushing (1988, 1990a,b) concludes that there is an impact of the Great Salinity Anomaly (GSA, Dickson *et al.*, 1988) on Northwest Atlantic cod stocks. Accordingly, poor recruitment was observed due to low zooplankton abundance or due to mismatch of cod larvae and zooplankton abundance peak. Mertz and Myers (1994) indicated that cod recruitment off West Greenland showed a reduction in the peak GSA years. Meyer (1968) speculated that the amount of food for cod larvae (which hatch in April) in the waters off West Greenland, might 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. This vertical convection depends on two factors:

i) The stability (E) of the water column during autumn, and

ii) the wind intensity during winter.

To examine the hypothesis of Meyer (1968) mean stability (E) at standard oceanographic depths down to 200 m at five NAFO Standard Oceanographic Stations off West Greenland in autumn was calculated and correlated with recruitment data series, as well as with wind stress data.

Materials and Methods

The Standard Oceanographic Stations (Stein, MS 1988) chosen to calculate the stability are given in Fig. 1: Cape Farewell 4 (CF4: 59°00'N 45°20'W), Cape Desolation 3 (CD3: 60°28'N 50°00'W), Frederikshab 3 (FR3: 61°47'N 51°09'W), Frederikshab 4 (FR4: 61°41'N 51°45'W), and Fylla Bank 4 (FY4: 63°53'N 53°22'W). The formula used to calculate the stability was:

$$E = 1 / r * dr / dz$$

where r is the mean density of individual layers and dr / dz is the rate of change in density with depth.

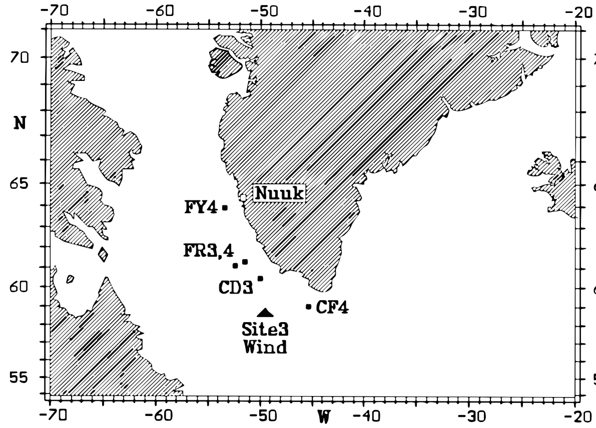

Fig. 1. Location of sites used for correlation analysis of available time series.

Temperature and salinity series at standard depths to calculate the stability were available from our own measurements at the Institut für Seefischerei, Hamburg and the Greenland Fisheries Institute, Copenhagen. Those series have been collected nearly every year in July and November or December since 1950 (July-data, FY4), 1963 (Autumn-data, FY4) and since 1982 (for the other stations). It has to be considered that the understanding of the dynamics of a fish population in relation to climate and fisheries requires long time series, such as those presented from Fylla Bank which cover low and high exploitation under different environmental conditions.

Year-class size at age 3 data were taken from literature and cover all the West Greenland area. The year-class size at age 3 data from 1953 to 1979 had been estimated by Virtual Population Analysis (VPA, Hansen and Buch, 1986), and the year-class size at age 3 data from 1982 to 1992 had been calculated proportionally using age compositions from East Greenland surveys (Anon., MS 1984; MS 1988). With the autumn oceanographic data, a correlation between the year-class strength and the water mass stability of the year preceding the year-class, was calculated for standard oceanographic depths. To check the accuracy of the derived stability data, correlation analysis was done between the initial parameters, temperature anomaly, salinity anomaly, and year-class strength, and between temperature anomaly, salinity anomaly and stability.

Other climatic data used in this paper were air temperatures from Nuuk (64°11'N, 51°44.5'W), and estimates of seasonal surface averages of the wind stress for the area (Fig. 1). From the air temperature data, the annual mean from 1950 to 1993 relative to the climatological mean (1961–90) was calculated (Fig. 2). Wind data were available from literature and as ASCII-File (Drinkwater and Pettipas,

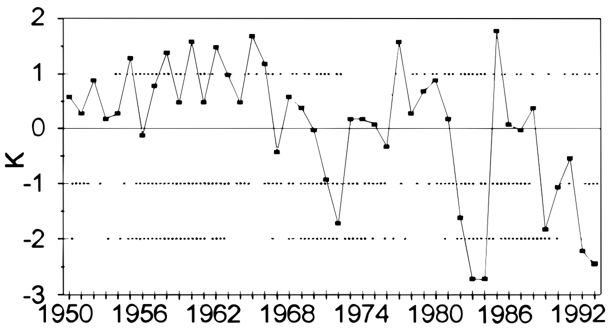

Fig. 2. Annual mean air temperature anomaly (k) at Nuuk given relative to 1961–90 climatic mean.

1993). These data, U- and V-components of the wind stress vector, cover the period from 1946 to 1991. The stress direction was the wind direction after adjustment for frictional effects, plus 180° to convert it into oceanographic convention, i.e. the direction towards which the wind blows. Further details are given in (Drinkwater and Pettipas, 1993). Seasonal averages were calculated taking December–February as winter, March–May as spring, June–August as summer, and September–November as autumn. These seasonal means were correlated with the stability data at Stations FY4, FR3, FR4, CD3 and CF4, and with the year-class strength data. For the July-data (ICES data), the 1953–79 stability of FY4 was computed at standard oceanographic depths and correlated with the year-class of the same year, as well as with U,V wind stress components.

All correlations were calculated with the programme QUATTRO PRO for Windows, Version 5.0.

Results

The climatic conditions of the West Greenland area are given in Fig. 2, based upon the air temperature anomalies during the past 43 years. Accordingly, the climate of the region was characterized during the 1950s and 1960s by warmer-than-normal air temperatures, which exceeded the climatic mean (1961–90: -1.4°C) by 1–2K. The downward trend in mean air temperatures, as experienced from the late-1960s onwards, was dominated by anomalous cold events during the beginning of the 1970s, 1980s and 1990s. During the mid-1970s and 1980s warmer-than-normal events were recorded. Since 1989, mean annual air temperature anomalies were well below normal.

Wind stress components, derived from the geostrophic wind field at selected sites in the Labrador Sea (Drinkwater and Pettipas, 1993) revealed characteristic differences for the winter and spring season, and for the summer and autumn season (Fig. 3). The wind stress differed by about one order of magnitude from winter to summer, and was about constant during spring and autumn. The anomalous event during 1983 (upper panels of Fig. 3) did only emerge during the first two seasons. This event, which was unique throughout the 45 years of record, deviated by a factor of about five to six from the normal level, indicating stronger than normal winds into a southeasterly direction.

Stability of the water masses at Station 4 of the Fylla Bank during the past thirty years is displayed for the surface layer 0–50 m (Fig. 4), and for the sub-surface layer 50–200 m (Fig. 5). It would appear that there is an increase in surface layer stability from the mid-1980s onwards, reflecting the presence of diluted water masses (see below).

Temperature and salinity anomalies were found to be positively correlated, indicating that cold, diluted water as of East Greenland Current origin alternates with more saline, warmer oceanic water. Stability correlated negatively with the salinity anomaly at all stations. Comparing stability and temperature anomaly, only two stations (CF4 and FR3) indicated negative correlations; the rest of the stations (FY4, CD3 and FR4) did not give any correlation. Thus, salinity as advected by the oceanic Irminger component of the West Greenland Current system, has the dominating influence on the stability.

Discussion

Is there an impact of water mass stability on the recruitment of cod? Does wind stress influence recruitment? Correlation analysis performed for the available sub-surface ocean time series (CF4, CD3, FR3, F4, FY4), wind stress data and recruitment data off West Greenland reveal no significant dependence between stability and recruitment, as well as between wind stress components and recruitment. Only trends were detectable.

Fylla Bank Station 4 July stability data compared to recruitment data derived from VPA (Hansen and Buch, 1986) for the years 1953–79, yielded positive but not significant correlation ($r = 0.45$, $p > 0.01$). The results (Fig. 6) corroborate in part the theory that low stability favours good recruitment, and vice-versa (Meyer, 1968). However, despite low stability levels from 1974 onwards, no significant recruitment had been encountered thereafter.

A composite of two recruitment time series (from Hansen and Buch, 1986 and Anon., MS 1984) was used to compare recruitment and stability until the end of the 1980s (Fig. 7). Low recruitment during the 1980s, except for the strong 1984 year-class and the good 1985 year-class, characterizes the last decade.

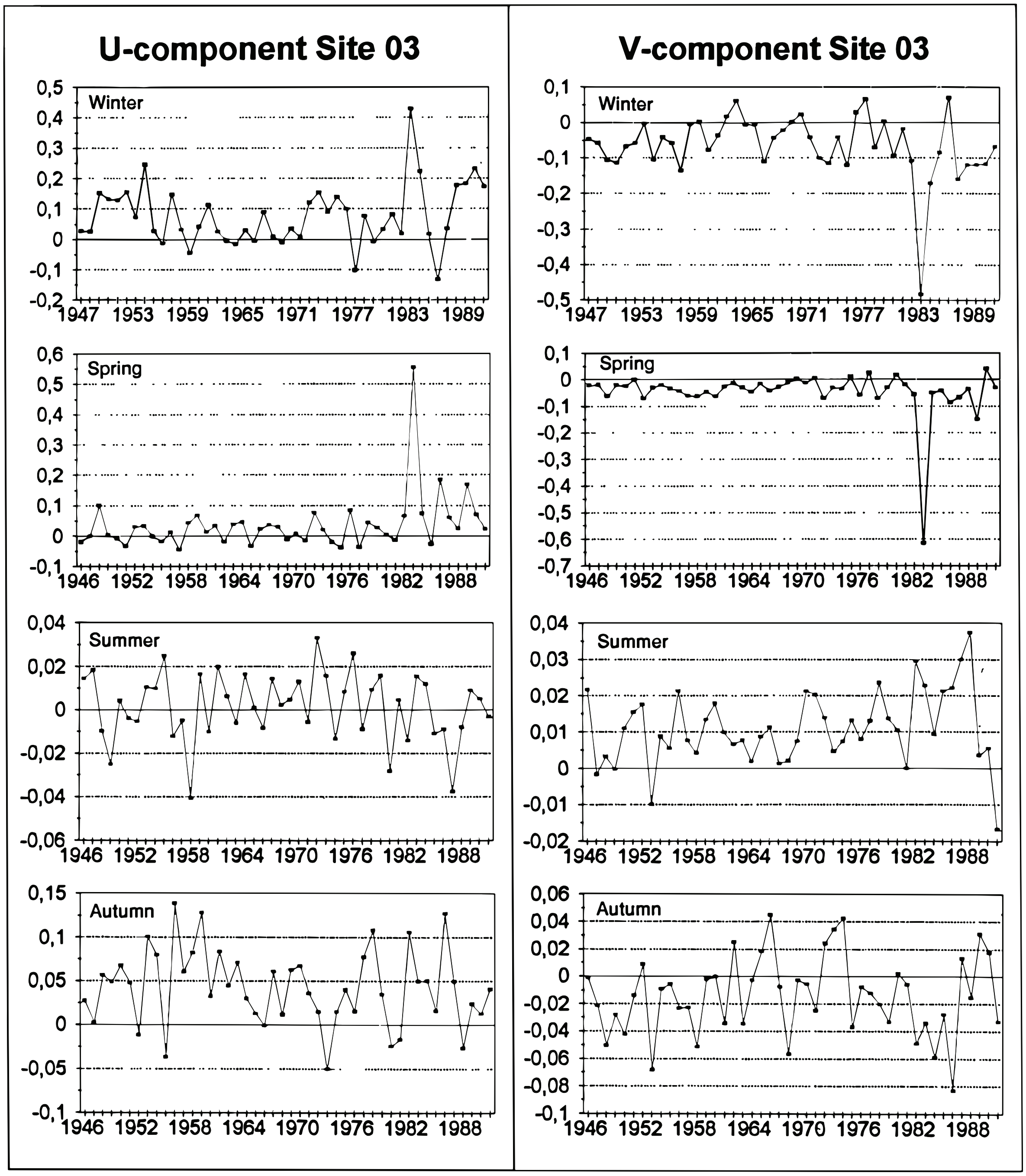

Fig. 3. Wind stress components at site 03 in winter, spring, summer and autumn for the period 1947–91.

From the late-1960s onwards, the climatic conditions of West Greenland were dominated by negative air temperature anomalies (Fig. 2). Stability of the surface layers increased during the 1970s with the trend still persisting (Fig. 4). The general coincidence of the pre-1970s recruitment curves with water mass stability (see also Mertz and Myers, 1994 for the West Greenland cod stock) suggests a splitting of the time series. Before 1970, West Greenland cod stocks were self sustaining and with high spawning stock biomass based on several good recruitment events (1953, 1957, 1960, 1961 to indicate the strong year-classes). These recruitment events happened during warm climatic conditions at

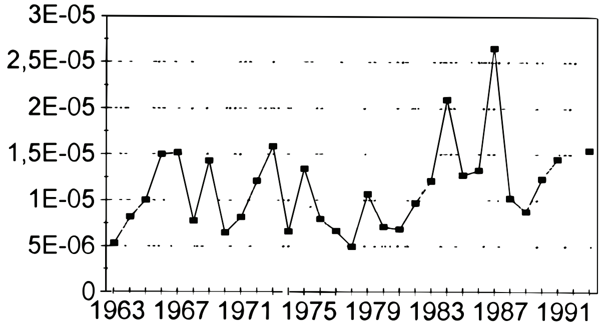

Fig. 4. Stability of surface water layer at 0–50 m, Fylla Bank station 4 in autumn.

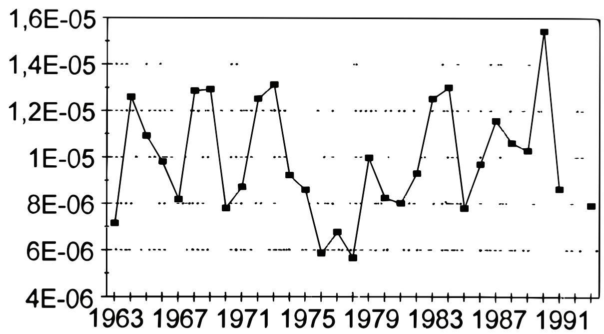

Fig. 5. Stability of sub-surface water layer at 50–200 m, Fylla Bank station 4 in autumn.

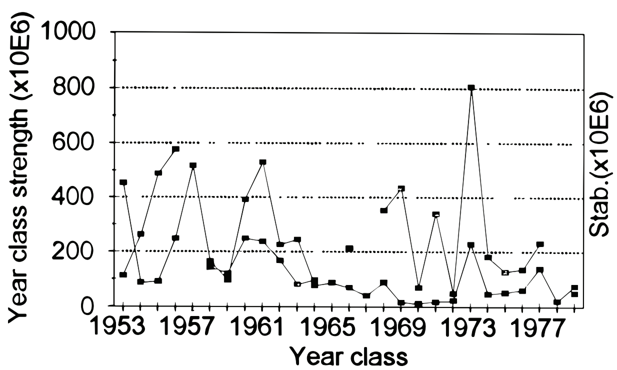

Fig. 6. Recruitment of cod (1953–79) and stability of the near-surface layer 10–20 m at station 4 of the Fylla Bank section during July.

lower than average water mass stability. During this period, the model assumption as anticipated by (MEYER, 1968) holds quite well.

However, when climate started to be colder than normal, and the West Greenland cod stocks had undergone heavy exploitation, the recruitment/stability relation was not valid any longer. There has been a period of low recruitment from 1969 to 1972 (Fig. 6) which Mertz and Myers (1994) attribute to

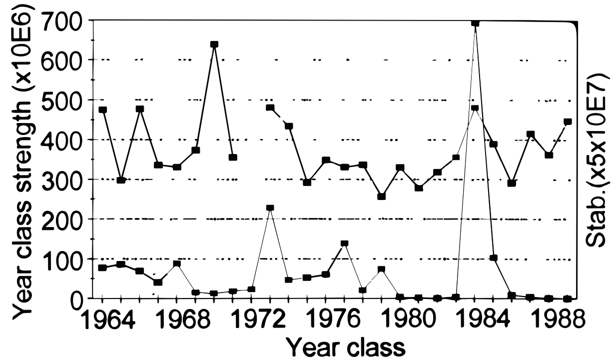

Fig. 7. Recruitment of cod (1964–89) and stability of the deep layer 100–150 m at station 4 of the Fylla Bank section during autumn of the year before hatching.

the passing of the Great Salinity Anomaly (GSA). Our analysis reveals, however, that there is only one high stability event (1969 in Fig. 4) in the surface layer 0–50 m which they referred to. In the deeper layer, 50–200 m (Fig. 5), the years 1968 and 1969 emerge as high stability events. Since our data are the autumn data previous to the considered year-classes, recruitment of 1969 and 1970 cod thus could have been influenced by the GSA. Figure 8 displays year-class strength and water mass stability of the previous autumn at Fylla Bank Station 4. Visual inspection reveals high consistency of both curves. Correlation analysis yields significant results ($r = 0.69$, $p = 0.0018$).

West Greenland cod recruitment was very variable during the past two decades. Considerable recruitment injections from Iceland/East Greenland were observed during 1973 and 1984. These recruitment peaks parallel high stability events (Fig. 8). The recruitment time series of the Icelandic cod stock (redrawn from Jakobsson, 1992) indicates the "injected" year-classes 1973 and 1984, which emerge from a remarkable steady level around 150 to 200 millions recruits at age 3.

As discussed above, salinity has the dominating influence on the stability of water masses. Thus, high stability should coincide with the advection of low saline water. The thermohaline properties of the 150–200 m layer at Station 4 of Fylla Bank are influenced by the Irminger component of the West Greenland Current system. The significant positive correlation of recruitment and stability of this layer – with no significant correlations observed in the upper layers – suggests a coupling of recruitment and changes in the inflow of Irminger (Atlantic) water to the West Greenland area. It would appear that during the past twenty years a new correlation mechanism, an advective coupling instead of a low

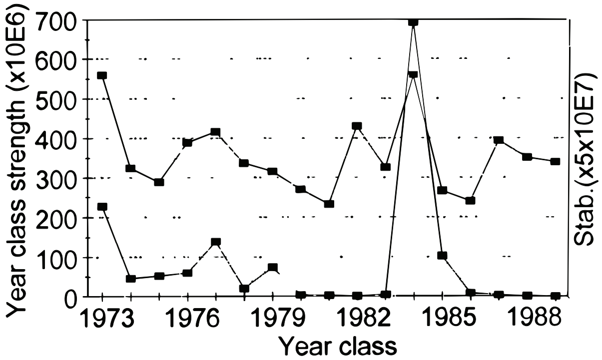

Fig. 8. Recruitment of cod at West Greenland and Iceland, 1973–89, and stability of the deep layer 150–200 m at station 4 of the Fylla Bank section during autumn of the year before hatching.

stability coupling explains the variability of recruitment from the environmental point of view.

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