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# Climatic Effects on Cod Distribution Deduced From Trawl Surveys

by

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## Introduction

A biomass estimate from random stratified surveys, conducted during the fall months of every year, is one of the key inputs to the stock assessment model for Gadus morhua, the Atlantic cod, in the Northwest Atlantic Fishing Organization (NAFO) Divisions 2J3KL off Newfoundland and Labrador (Fig. 1). The surveys are conducted in the autumn because during the winter and early spring a large portion of the stock area is ice covered, while during summer a high proportion of the stock is out of the survey area having migrated to the bays and headlands along the coast. Based on the hypothesis that the best estimate from a fisheries survey can be achieved when the stock is not overly aggregated, a fall survey of the stock was deemed most appropriate, since some time during the fall, the northern cod is known to migrate from the coastal regions off Newfoundland and Labrador to its winter habitat along the slopes of the continental shelf. An additional survey is conducted during spring as part of the Grand Bank annual survey, however, only the 3L portion of the 2J3KL management unit is covered at that time.

The purpose of this paper is to examine the research survey data set to delineate some of the characteristics of the cod distribution in 2J3KL Divisions and to relate them to changes in the environment. The data set used for the analysis consists of time series of abundance for autumn in 2J3KL and spring in 3L, as well as the two sets of summer and winter estimates from 3L.

## Aggregation index

There are different ways of synthesizing the trawl data to examine the distribution. For the stock assessment, means of the catches from each stratum are used to estimate a stratum abundance, which is then used to compute the total abundance for each year. Another approach is to map the survey data onto a fixed grid; the gridded data can then be used to calculate the mean distribution over any selected period (Lilly, 1993), and then examine the variability. One problem with using the actual catches as an aggregation index, however, is that the year-to-year abundance variability at any one location is not only due to distribution changes, but also is a function of year-class strength. In this analysis, the abundance in each stratum relative to the total abundance is considered to reduce the effect of the stock-size changes.

For each year, the abundance density may be defined for each stratum (for each division and for the total area) as the ratio of the stratum (division, total) abundance to the stratum (division, total) area. To facilitate between-year comparisons of cod distribution, relative densities for each stratum and division can then be defined as the ratio of the stratum (division) density to the total density.

Since the spring surveys and the seasonal surveys were not conducted in 2J or 3K, the stratum densities cannot be normalized with respect to the overall 2J3KL density; the 3L division density is used for this purpose.

## Distribution by season

Before addressing the climatic effects on the cod distribution based on annual surveys, we will examine the variability between seasons. Unfortunately, only the fall data is available for the Div. 2J and 3K. Furthermore, winter and summer surveys were carried out only for two years. In spite of these limitations, this data set does provide some insight into the seasonal variability in the distribution.

### Fall

The average relative densities computed by averaging over the period from 1981 to 1989 is shown in Fig. 2 (actual catches for each year are presented in Bishop et al., 1993). Periods prior to 1981 had to be excluded from the analysis due to lack of survey coverage in Div. 3L. Data from 1990 onwards was not included because of the anomalous conditions that existed during these years.

As indicated by the average catches in Lilly (1993), highest densities were on the southern Labrador Shelf, northeastern Funk Island Bank, along the Bonavista trough located between Grand Bank and Funk Island Bank and on the adjacent slope, and on the plateau of Grand Bank. A semi-circular band of very low density $(<0.5)$ was found to exist around the plateau aggregation year after year, separating this group from the trough/slope aggregation. Similarly, the Funk Island Deep, a deep trench separating the Funk Island Bank from the near-shore region and from Belle Isle Bank, is also found to separate the slope aggregation from the Labrador Shelf aggregation. On the Labrador Shelf, even though the relative densities are high on average, strata on Hamilton Bank and near-shore were comparatively of lower densities than other strata in 2J.

For the low-density strata, the standard deviations are in general quite low. On the other hand, because of the *inter-stratum shift in the centroid of the aggregations*, some of the strata where the highest concentrations within each group are found also had higher standard deviations. The general area of concentration, however, did not significantly differ between years in the 1980s.

### Winter

The major difference between the average fall distribution and the *winter ones is the absence of the* plateau aggregation in winter (Fig. 3). Since the survey was not conducted south of 3L for this period, there was no way of assessing whether the aggregation normally found on the plateau during the fall migrates southward, or moves offshore to merge with the aggregation from the Bonavista trough to form an aggregation occupying an extensive area as was found in 1985.

The relative densities also indicate significant differences in the distribution between 1985 and 1986 winters. In 1985, moderate concentrations were found along a more extensive area on the slope, and concentrations with relative densities between 0.5 and 1.0 over a large area on the inner shelf. The outer strata in the Bonavista trough also had high concentrations. In 1986, on the other hand, the slope aggregation was significantly more concentrated and covered over fewer survey strata. There were some moderate concentrations at the southern end of the inner shelf, but very little where the plateau aggregation is normally found during the fall.

### Spring

For most years, the spring distribution shows evidence of the onshore migration from the winter habitat to the near-shore region. The stratum densities relative to the 3L values, averaged over the 1981-1989 period (Fig. 4) indicate higher densities along the trough and the adjacent slope, extending all the way to the coast, indicative of the spring migration through the Bonavista corridor. Also evident in the data is an increase in the plateau densities, *suggesting the return of at least a portion of* the aggregation which moved elsewhere in winter. The sparse area around the inshore edge of the Grand Bank is less predominant in the spring, also suggestive of an inshore migration along the Bank. Since the timing of this inshore migration is found to vary significantly from year to year, as indicated by the inshore fishery, larger interannual variability in the relative densities, especially for the strata on the inner shelf, is to be expected.

### Summer

The most noticeable characteristics of the summer distribution (Fig. 5), both in 1984 and 1985, is the absence of the aggregations along the cross-shelf trough north of Grand bank; during the spring, densities over this area extending from the coast to the slope are higher than 1.5. There were also significant differences in the distribution between the two summers. The plateau aggregation in 1984 had relative densities comparable to the average spring distribution, whereas in 1985 the pattern was similar to the fall, with dense aggregation confined to a smaller geographical area.

## Interannual variability in the fall distribution

A comparison of the relative densities between the three divisions for the fall period indicates that the cod distribution was significantly more dense in 2J compared to 3K and 3L (Fig. 6) up to 1988. Even though the 3K and 3L densities were more or less of the same order of magnitude until 1988, they seem to have an inverse relationship. A regression analysis with 3L relative density as the independent variable and 3K relative density as the dependent, confirms that the two are negatively correlated ($r = 0.6$, $p = 0.07$). Fig. 6 also indicates a decline in 2J densities from 1989 to 1991 with a corresponding increase in 3K densities. A possible hypothesis is that the cod distribution has shifted southward since 1989, even though the data set is not sufficiently long to test it. However, the apparent absence of any reasonable size catches during the surveys since 1991 except in a limited area around the 3K/3L boundary with no comparable increase in abundance south of 3L, cannot be explained even if the shift hypothesis is proven; the cause for the recent distribution is currently under investigation.

For the rest of the paper, we focus on the plateau and Bonavista trough/slope aggregations. If we use the mean relative densities as a guide to establishing boundaries of each aggregation, then the plateau aggregation may be considered to spread over the strata 363 and 372 (Fig. 2). Between these two strata, relative density in 372 is found to be larger compared to 363, except in 1985, 1988 and 1989. Relative density computed for the combined area of the two strata had the largest value in 1984 followed by 1990; in terms of the lowest values, 1991 ranked first, followed by 1986 and 1981 (Fig. 7a). A comparison of the plateau relative density to 3L relative density shows significant correlation between the two ($r = 0.81$, $p = 0.002$).

Using the mean fall distribution pattern the trough/slope aggregation may be considered to be occupying the strata 637 and 638 in 3K, and 346, 366, 368 and 369 in 3L (Fig. 2). Even though each of these strata has relative densities greater than one for most years, the location of the peak density shifted from one year to the next; reasons for this inter-strata shift is not obvious. What is interesting is that the relative density of this aggregation, calculated from the combined abundances of these six strata, has been increasing since mid-80's (Fig. 7b), but not correlated with the 3KL relative density. In terms of the actual abundances, during the early 80's, the trough/slope aggregation consisted of about 20% of the 3KL cod, whereas in 1990 and 1991, over 40% was located in this region. The fact that this increase is not related to 3KL density suggests that, processes in addition to those contributing to a north-south shift in the cod distribution, may be affecting the offshore shift along the trough/slope.

## Environmental conditions

A relevant question to address is: how much of this interannual variability is caused by the environment. The meteorological and oceanographic conditions on the Newfoundland and Labrador Shelves have been quite variable since 1980 effecting higher than normal ice cover, and below normal air and water temperatures (Narayanan et al., 1993). Furthermore, it has been shown that the climatic conditions that prevailed in 1980's had a significant effect on the timing of inshore migration of certain pelagic species (Narayanan et al., 1993). Even though the near-bottom oceanographic variability on the banks is expected to have comparatively smaller amplitudes, it is still possible that the shift in the aggregation locations is effected by the physical environment.

If environmental influences are important, then indices representative of the environmental variability, such as the volume of the sub-zero temperature water on the shelf (commonly referred to as the cold intermediate layer, or CIL), ice cover and bottom temperatures, etc., may be correlated with the shifts in the location and density of the aggregations. Figure 7 also shows a comparison of the Plateau and Bonavista trough/slope densities in the fall with the normalized area of sub-zero temperature water averaged over the four NAFO transects, Seal Island, White Bay, Bonavista and Flemish Cap (Fig. 1). Though the cod abundance has been decreasing during the recent years, the relative densities associated with the plateau and trough/slope aggregations appear to be positively correlated with the CIL area, ($r = 0.5$, $p = 0.16$ and $r = 0.6$, $p = 0.7$), indicating a southward and offshore shift in the distribution during the cold years.

Cod distribution may also be influenced by the near-bottom water temperatures. As part of the assessment survey temperature profiles have been collected routinely, either using expendable bathythermographs, or recently using net-mounted CTDs. However, the bottom temperature data for the two strata 363 and 372 (Fig. 8), while being consistent with the anomalously cold and warm years, is surprisingly noisy. Even for the more recent years, when the temperature data were collected using the net-mounted CTD, the scatter is very high.

## Discussion

An examination of the abundance data from the research surveys indicates that, year after year, northern cod distributed during autumn into distinct aggregations separated by large geographical regions with very low concentrations. Two of these aggregations are found in 3KL, one on Grand Bank and the other on the adjacent northeastern slope, both of which had a high degree of variability in the size of the aggregation relative to the overall stock size. Furthermore, the cod densities in these two aggregations appear to fluctuate partly in response to changes in the environment; an overall increasing trend in the relative density associated with the trough/slope aggregation is also noticeable.

The limited seasonal data lend themselves to a partial description in a qualitative sense, of the seasonal variability in the 3L distribution. It appears that the slope and the plateau aggregations behave differently with season. During winter, the slope aggregation is concentrated towards the nose of the bank, even though its areal extent and densities may vary between years. In spring, this aggregation is less concentrated around its winter habitat and extends towards the coast, on average. The areal extent, especially on the inner part of the trough and the relative densities have significant interannual variability. This aggregation may be leaving the trough area and become more dispersed during the summer months, as indicated in 1984. The shift in the sampling window relative to the biological cycle may be the cause for the 1985 summer distribution resembling the fall conditions along the trough.

The plateau aggregation also appears to become more dispersed during the spring and summer months. However, what happens during the winter is not clear. Unfortunately, there is not enough information to examine whether this aggregation merges with the slope aggregation during winter or moves out of the region (there were no strata on the plateau with relative densities greater than 0.5 in 1987). Because of this seasonal variability in the distribution, the timing of the survey relative to the phase of the seasonal cycle may be important. For example, using the 1984 summer survey results as a data point in the fall time series, as was done in the past, may not be appropriate.

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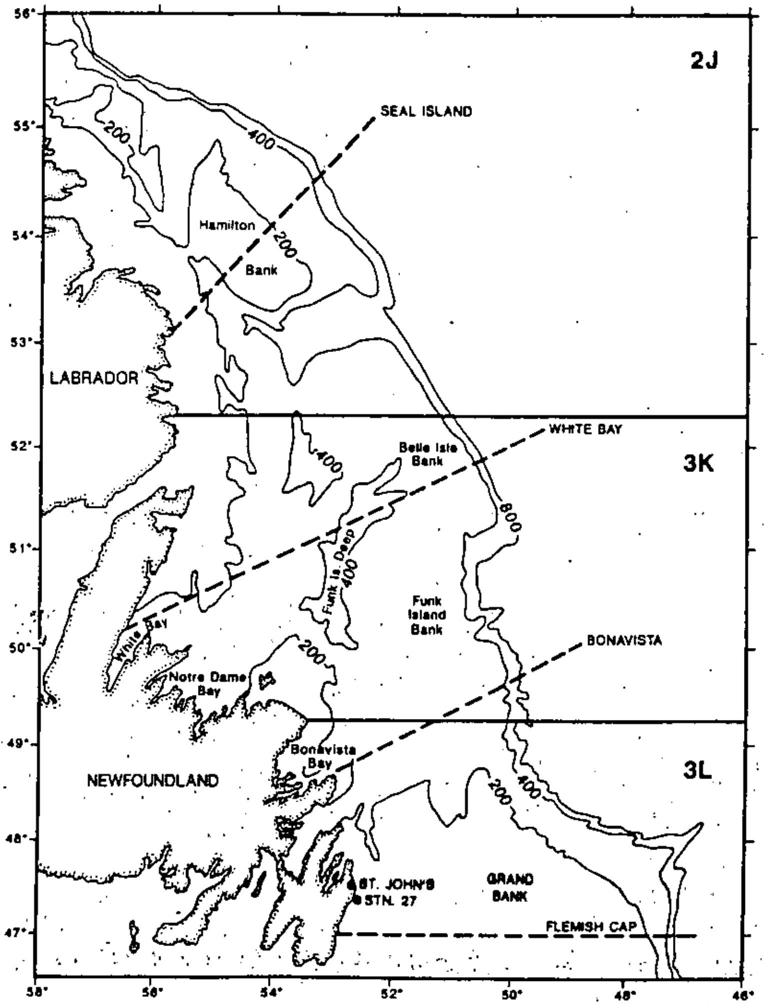

Fig. 1 Area map showing NAFO divisions and oceanographic transect lines

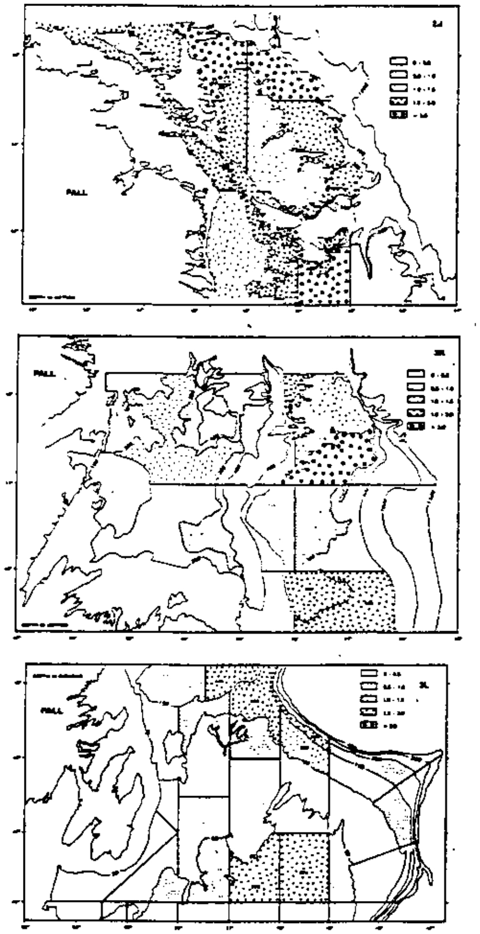

Fig. 2 Average relative densities for the fall survey period

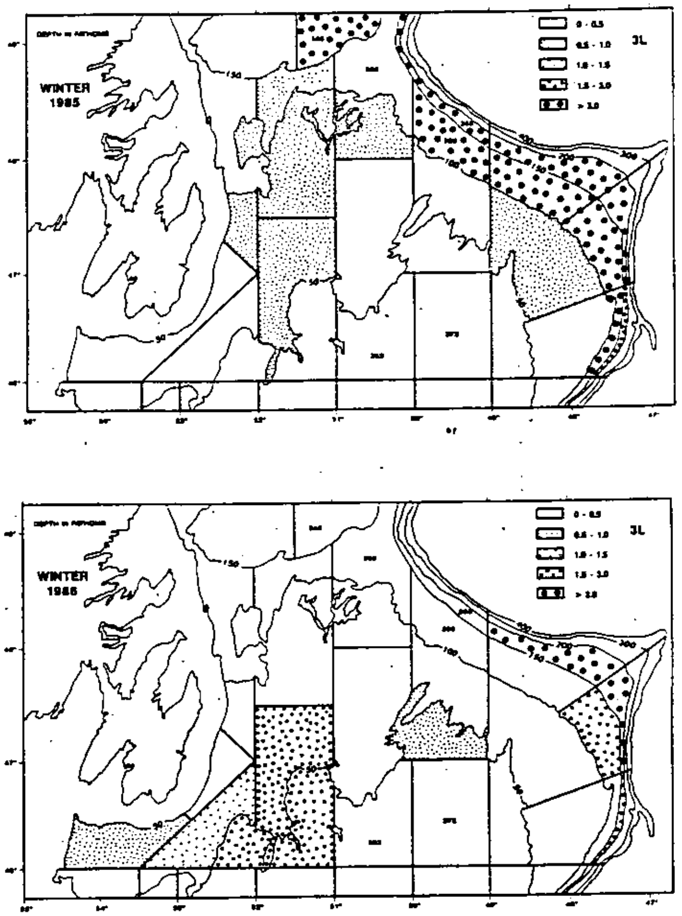

Fig. 3 Winter relative densities in 3L

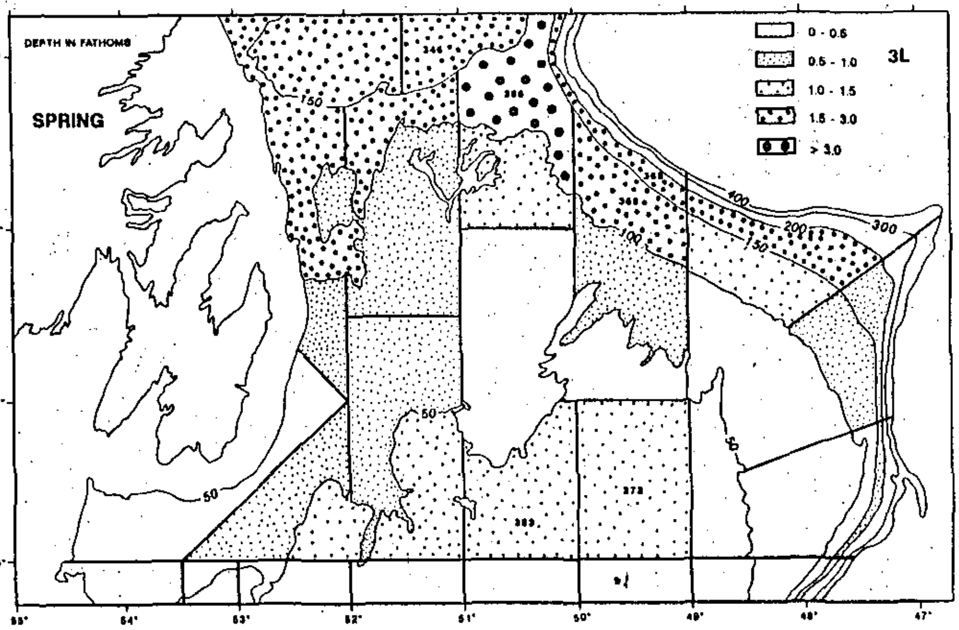

Fig. 4 Average 3L relative densities for the spring period

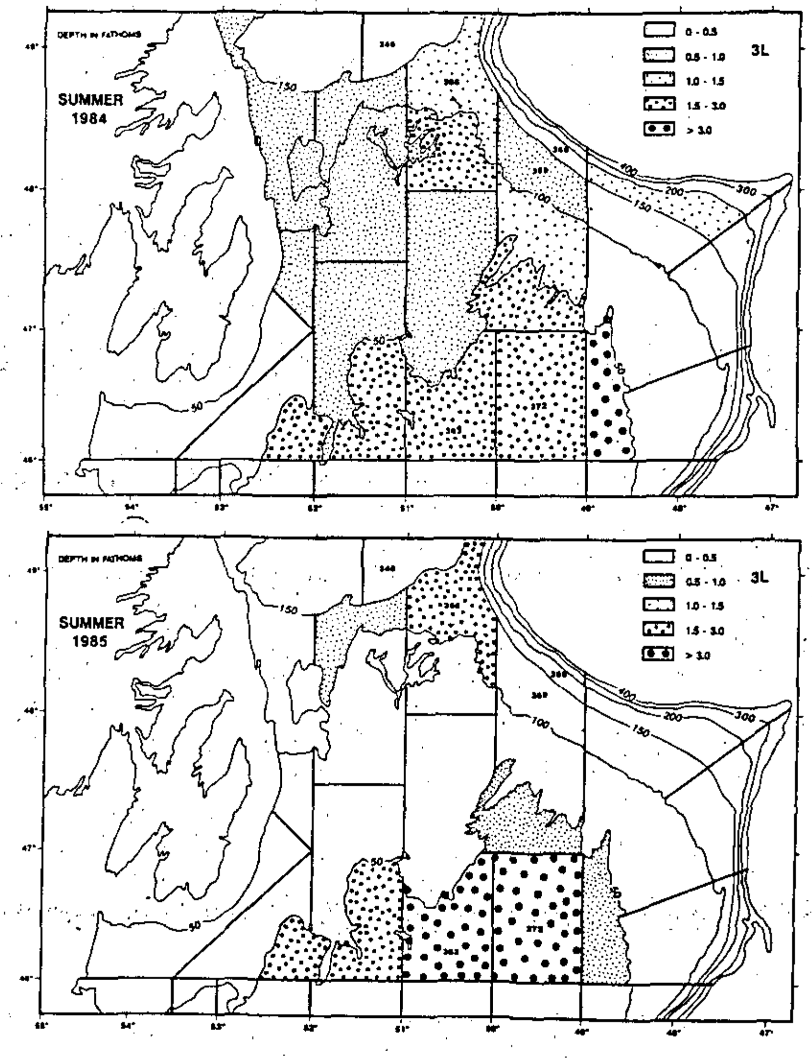

Fig. 5 Summer relative densities in 3L

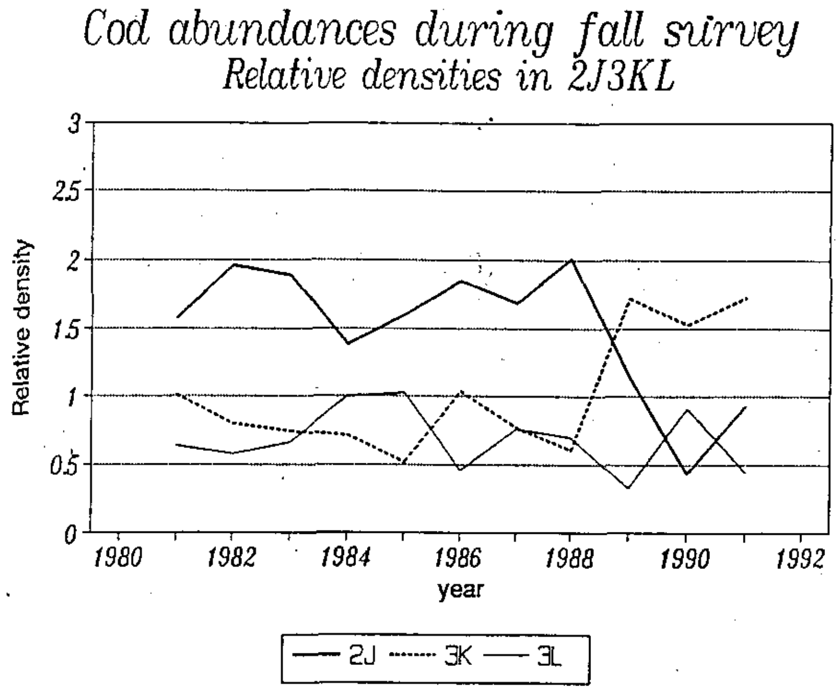

Fig. 6

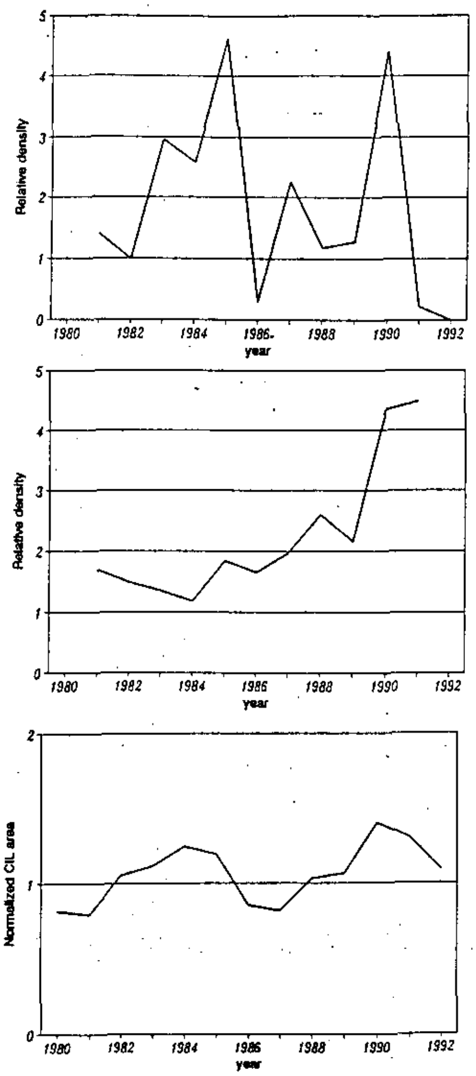

Fig. 7 Comparison cod density and CIL area: a) fall plateau relative density, b) fall Bonavista trough/slope density, c) normalized summer CIL area averaged over the four NAFO transects.

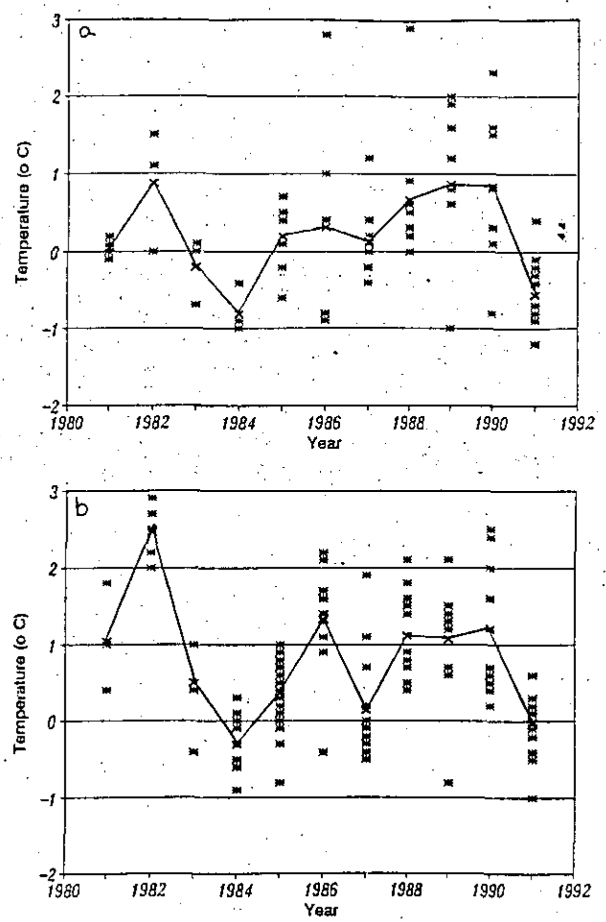

Fig. 8 Bottom temperatures associated with plateau distribution: a) stratum 363 and b) stratum 372.