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Recent Trends in Bottom Temperatures and Distribution and Abundance of Atlantic Cod (*Gadus morhua*) in NAFO Divisions 3LNO during the Spring and Autumn

by

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ABSTRACT

Near-bottom temperatures and their anomalies in NAFO Divisions 3LNO during recent spring and autumn surveys are presented together with the spatial distributions of cod catches. Interannual variations in the near-bottom thermal habitat were examined by calculating the areal extent of the bottom covered with water in different temperature ranges. The analysis revealed a significant shift in the thermal habitat in the region, from the cold sub-zero ^{o}C conditions of the early 1990s to a relatively warmer environment of the late 1990s, with approximately 60% of the bottom covered with water above 2^{o}C by the autumn of 1999. During this time there has been a significant increase in the number of cod per tow in survey sets in Divisions 3NO and larger catches have become more widespread in shallower water on top of the Grand Bank. There has been no significant increase in cod catches in Division 3L, however, the 1999 spring and autumn surveys showed marginally fewer zero catches on the plateau of Grand Bank and a few larger catches at the shelf break. These observations are discussed in terms of an improved thermal environment and other possible factors.

Introduction

Canada has been conducting stratified random groundfish trawl surveys in NAFO Divisions 3LNO since 1971. Each area was stratified based on the depth contours from available standard navigation charts. Areas within each division, within a selected depth range, were divided into strata and the number of fishing stations in each stratum was allocated based on an area weighted proportional allocation (Doubleday 1981). The stratification scheme is constantly being revised as more accurate navigation charts become available and efforts are being made to extend the stratification scheme shoreward and into deeper water along the shelf edge (Bishop 1994 and Murphy 1996).

Surveys have been conducted in both the spring and autumn in 3L, 3N and 3O with inshore strata in 3L being fished only in the spring of 1999 and the autumn of 1996-1999. In spring the surveys were conducted in 3L from 1971-1999, except 1983 and 1984, in 3NO from 1971-1999, except 1983 in 3N and 1972, 1974 and 1983 in 3O, in water depths to 366 m in most years and more recently to 548 m. Surveys were conducted in the autumn in 3L from 1981-1999, in 3N from 1990-1999 and in 3O from 1990-1999. Since the autumn of 1995 the research vessel surveys have used the Campelen 1800 shrimp trawl. During all of these surveys oceanographic data were collected as described below at each station and archived in oceanographic databases as well as included in the trawl set details.

In this report the near-bottom temperature fields and the spatial distributions of Atlantic cod for NAFO Divisions 3LNO on the Newfoundland Shelf are presented for recent annual spring and autumn research vessel surveys. Interannual variations in the thermal habitat are then considered by examining the areal extent of the bottom covered

with water in various temperature bins (Narayanan *et al*. 1993, Drinkwater *et al*. 1997). The purpose of this analysis is to review recent spatial distributions of Atlantic cod in relation to their thermal habitat.

Data and Methods

The historical oceanographic data are available from archives at the Marine Environmental Data Service (MEDS) in Ottawa and from databases maintained at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia and at the Northwest Atlantic Fisheries Center (NAFC) in St. John's Newfoundland. From 1971 to 1988 temperature data on fisheries assessment surveys were collected using bottles at standard depths and/or MBT/XBTs, which were deployed usually at the end of each fishing set. Since 1989 net-mounted conductivity-temperature-depth (Seabird model SBE-19 CTD systems) recorders have replaced XBTs. This system records temperature and salinity data during trawl deployment and recovery and for the duration of the tow. Data from the net-mounted SBE-19 CTDs are not field calibrated, but are checked periodically and factory calibrated annually maintaining an accuracy of 0.005^{o}C in temperature and 0.005 in salinity. The XBTs are accurate to within 0.1^{o}C.

Near-bottom temperature grids for NAFO Divisions 3LNO were produced from all available data for spring and autumn separately for the period 1961 to 1990 to establish the long-term mean and for the spring and autumn time periods for the years 1990 to 1999. All bottom-of-the-cast temperature values for each time period (except those for which the cast depths were not within 10% of the total water depth) were interpolated onto a regular grid and contoured using a geostatistical (2-diminsional Kriging) procedure. Bottom temperature anomalies were computed by taking the difference between the yearly and the average grids. Bottom temperatures for each grid element were computed as described above and the grid area integrated to produce a yearly estimate of the percentage of the total area covered by water above 2^{o}C and a yearly estimate of the mean near-bottom temperature for the region.

Potential sources of error in this analysis include temporal biasing, arising from the wide time interval during which a typical survey is conducted. This source of error is probably small however given the low magnitude of the annual cycle over most of the near-bottom depths encountered. An additional source of error that can potentially affect the results, particularly along the shelf edge, occurs when the spatial scales of temperature variations are shorter than the grid size. This error will be small over the banks where the landscape is relatively flat and larger along the shelf slope.

The number of cod per set is also displayed with the temperature contours from 1996 to 1999 for the spring surveys and from 1995 to 1999 for the autumn surveys. The cod distributions were restricted to the surveys that used the Campelen 1800 shrimp trawl. The annual survey stratified mean number of cod was also computed for each survey and compared to the average bottom temperature. At present these values are only reported for 3NO. Finally, stratified cumulative frequency distributions of temperature weighted both by cod catch numbers and by weight were produced for all survey data from 1972-1999 based on the methods of Perry and Smith (1993).

Results

The spring and autumn bottom temperatures and their anomalies for Divisions 3LNO are shown in Fig.. 1 and 2 for the years 1990 to 1999. During this time period in the northern areas spring bottom temperatures ranged from sub-zero ^{o}C in the inshore regions of the Avalon Channel to over 3^{o}C at the shelf edge. Over the central and southern areas bottom temperatures ranged from 1^{o}C to above 3.5^{o}C on the Southeast Shoal and above 3^{o}C along the edge of the Grand Bank. During the cold years of the early 1990s (Fig. 1a-1f) virtually the entire 3L area (except the deeper slope regions) and a significant portion of 3NO was covered by sub-zero ^{o}C water. During these years temperatures for the most part were below normal (indicated by the shaded areas in the figures) over the entire region (except for 3O in 1995), with anomalies reaching at least 0.5^{o}C below normal, but also as low as 2^{o}C below normal in some regions. Beginning in 1996 (Fig. 1g) the area of sub-zero ^{o}C water began to retract and by 1998 and 1999 it was restricted to a small area in the Avalon Channel (Fig. 1i and 1j). As a result above normal conditions persisted over the entire northern Grand Bank with temperatures up to 1^{o}C above average. Over the central and southern Grand Bank bottom temperatures ranged from 1-2^{o}C above the long-term average.

During the autumn near-bottom temperatures in 3L were very similar to those in the spring with sub-zero ^{o}C water covering most of the area during the cold years of 1990 to 1994 (Fig. 2a to 2e) and mainly restricted to the deeper portions of the Avalon Channel during the warm years of 1998 and 1999 (Fig. 2i and 2j). In the shallower regions of 3NO however, autumn bottom temperatures are generally warmer than spring values (by 2-3^{o}C) as a result of summer

surface heating. Similar to the spring, temperatures for the most part were below normal with anomalies reaching at least 0.5°C below normal, but also as low as 2°C below normal in some areas. Beginning in 1995 (Fig. 2f) temperatures began to moderate, but remained below normal over some areas into the autumn of 1998. By the autumn of 1999 above normal conditions persisted over the entire 3LNO area with temperatures up to 1°C above average in the north and up to 4°C above normal on the Southeast Shoal (Fig. 2j).

The numbers of cod caught per set during each survey are also displayed with the temperature fields in Fig. 1g to 1j for the spring surveys and in Fig. 2f to 2j for the autumn surveys. In Division 3L the number of cod per tow has been extremely low with most sets on the plateau of the Grand Bank having less than 10 cod and the majority having none. Sets in the inshore and those at the shelf break have slightly higher catches. There is no distinguishable difference in the cod distribution from spring to fall. The 1999 spring and autumn surveys showed marginally fewer zero catches on the plateau of Grand Bank and a few larger catches at the shelf break.

In Division 3N catches have been extremely low, with a few larger catches on the slopes of the Grand Bank. Most of the catches had less than 10 cod and there were many zero catches on top of the bank. In the spring of 1998 catches increased slightly on top of the bank and this increase persisted through the autumn 1999 survey. The observed increase in catch numbers has been almost entirely ages 3 and less.

In Division 3O in all years with the exception of 1997 catches were higher than those observed in Divisions 3L or 3N and there have been fewer zero catches. Also there have been larger catches along the southwestern slopes of Grand Bank. The larger catches in this area in recent surveys comprise not only recruits but also older fish as well. Since the spring of 1998, the number per tow in 3O survey catches has increased significantly and larger catches have become more widespread in shallower water on top of the bank.

The time series of mean bottom temperature and the areal extent of the bottom covered by water above 2°C during spring in Divisions 3LNO in all fishing strata is shown in Fig. 3a and 3b. The mean bottom temperature increased gradually from the low (less than 0.5°C) in 1990 to about 1°C by 1997 and to 2°C by 1999. The increase in 3NO catches during 1999 is also shown (Fig. 3a). The percentage area of the bottom covered with water above 2°C was about 10% from 1990 to 1992. This area increased to about 20% during 1993 to 1995 after which it increased to 45% during 1999 (Fig. 3b). During the spring of 1998 and 1999 water with temperatures above 1°C covered 50-60% of the bottom area on the Grand Bank, compared to about 10% in 1990. The 1998 and 1999 values represents the largest area of relatively warm water on the Grand Bank since 1983 (Colbourne 2000). The shift in the thermal habitat from the early 1990s to that observed during the late 1990s is clearly evident in Fig. 4, which displays the percentage area covered by water in various temperature bins during the spring for the cold years of 1990-1994 and for 1999.

The time series of mean bottom temperature and the areal extent of the bottom covered by water above 2°C during the autumn in Divisions 3LNO in all fishing strata is shown in Fig. 5. Mean bottom temperatures increased from a low of 1°C in 1993 to about 1.7°C by 1995 and to 2.6°C by 1999. The increase in the mean number of cod in Division 3NO during the autumn coincides with the large increase in mean bottom temperature (Fig. 5a). The percentage area of the bottom covered with water above 2°C was about 20% from 1990 to 1994, 30-40% from 1995 to 1998 and increased to near 60% during 1999 (Fig. 5b). During the autumn of 1999 sub-zero °C water covering the region had decreased to about 15% of the total area. Similar to spring conditions, the shift in the thermal habitat from the early 1990s to that observed during 1999 is clearly evident (Fig. 6).

In an effort to investigate temperature preference by cod, a cumulative distribution of temperature and a catch weighted (in terms of numbers and weight) cumulative distribution of temperature from the spring 3LNO survey time series (1972-1999) are displayed in Fig. 7. The temperature distributions have been weighted annually by sampling intensity within each stratum and by strata area. The cumulative frequency distribution of temperature shows the temperature available to cod historically during the spring period in Divisions 3LNO. The cod number and catch weighted temperature distributions show the distribution of cod catches in relation to the average temperature. An initial interpretation of this result indicates that cod are associated with the warmer portion of the available temperature range with a slightly warmer preference based on numbers than weights. Approximately 25% of the cod by number are associated with sub-zero °C water, while approximately 50% are associated with water above 1°C. This distribution may be explained by factors other than temperature, for example, by factors that may co-vary with temperature such as prey distribution or other environmental variables.

Discussion and Summary

The thermal habitat in the 3LNO region has shifted from mainly cold sub-zero ^{o}C conditions of the early 1990s to a relatively warm environment from 1998 onwards with approximately 60% of the bottom covered with water above 2^{o}C by the autumn of 1999. The 1998 and 1999 values represents the largest area of relatively warm water on the Grand Bank since 1983 (Colbourne 2000). During this time above normal conditions (relative to the 1961-1990 time period) persisted over the entire 3LNO area with temperatures up to 1^{o}C above average in the north and up to 4^{o}C above normal on the Southeast Shoal of the Grand Bank. By contrast, during the cold years of the early 1990s virtually the entire 3L area and a significant portion of 3NO was covered by sub-zero ^{o}C water, with anomalies reaching at least 0.5 ^{o}C below normal, but also as low as 2^{o}C below normal in some regions.

Since the spring of 1998 there has been a significant increase in the number of cod caught per tow in survey sets in Divisions 3NO and larger catches have become more widespread in shallower water on top of the bank, mainly in water with temperatures above 2^{o}C. There has been no significant increase in cod catches in Division 3L, however, the 1999 spring and autumn surveys showed marginally fewer zero catches on the plateau of Grand Bank and a few larger catches at the shelf break. There are several possible reasons for these observations. There are obvious signs of improved recruitment in Divisions 3NO as a significant portion of the increase in catch numbers during the surveys is comprised of fish age 3 years and less. Also, during 1998 a significant increase in the abundance of O-group Atlantic cod was sampled in the region (Anderson *et al*. 1999) and a further increase in both abundance and distribution during 1999 (Anderson per. commun.).

It appears that the recent increase in water temperature in the area may have made the southern Grand Bank a more suitable environment for cod spawning and possibly improved survival rates. The increase in catch per tow in Division 3O was most obvious in the spring of 1998 close to the 3Ps boundary. These increases have become more easterly distributed in subsequent surveys. It is possible that this is a result of range expansion from the adjacent 3Ps stock as a result of a more favorable environment on the Grand Bank, either for cod or their prey, or both. Also the apparent increases may be the result of a temperature dependent increase in catchability or related to other biological or environmental factors such as increase in prey species or a shift to a more suitable environment for prey species. More research however is required to investigate this. Finally, we emphasize that even though there was a significant increase in the number of fish caught in some areas of 3LNO during the research surveys of 1998 and 1999, the catch rates by weight are still very low compared to historical levels, being more than an order-of-magnitude smaller than pre-1990s values.

Acknowledgements

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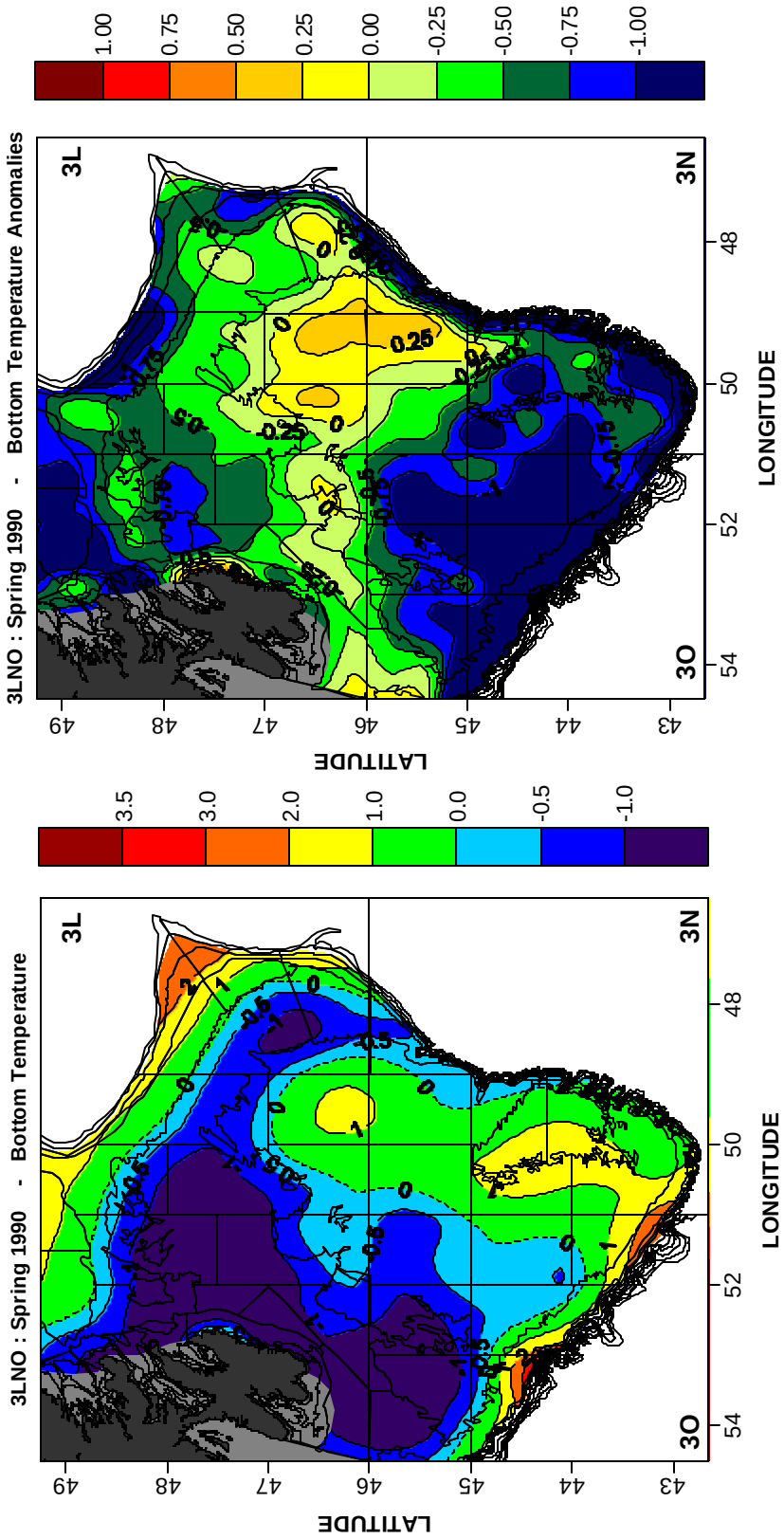

Fig. 1a. Horizontal bottom temperature and anomaly contours (in °C) for the spring of 1990 from the annual groundfish 3LNO survey.

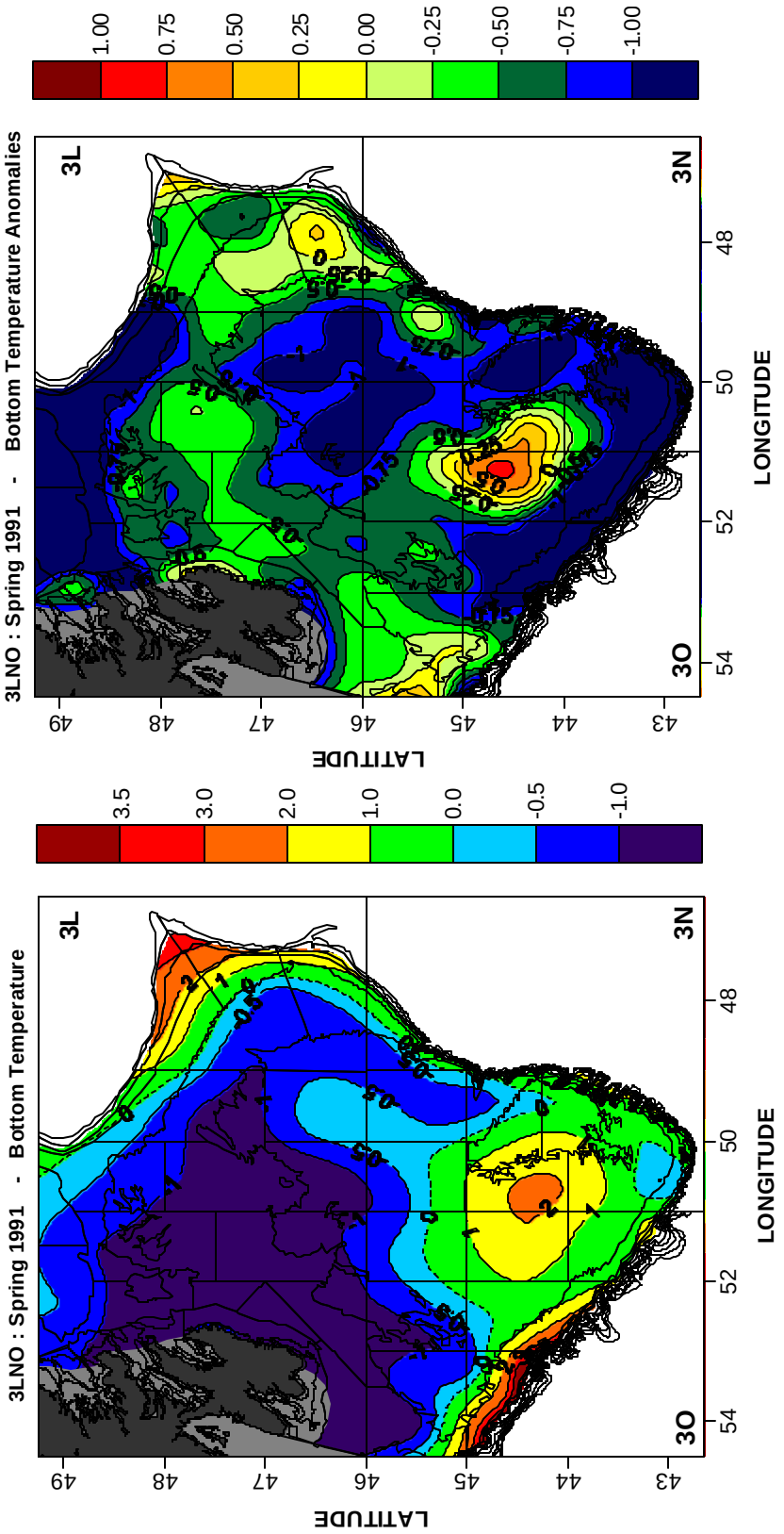

Fig. 1b. Horizontal bottom temperature and anomaly contours (in °C) for the spring of 1991 from the annual groundfish 3LNO survey.

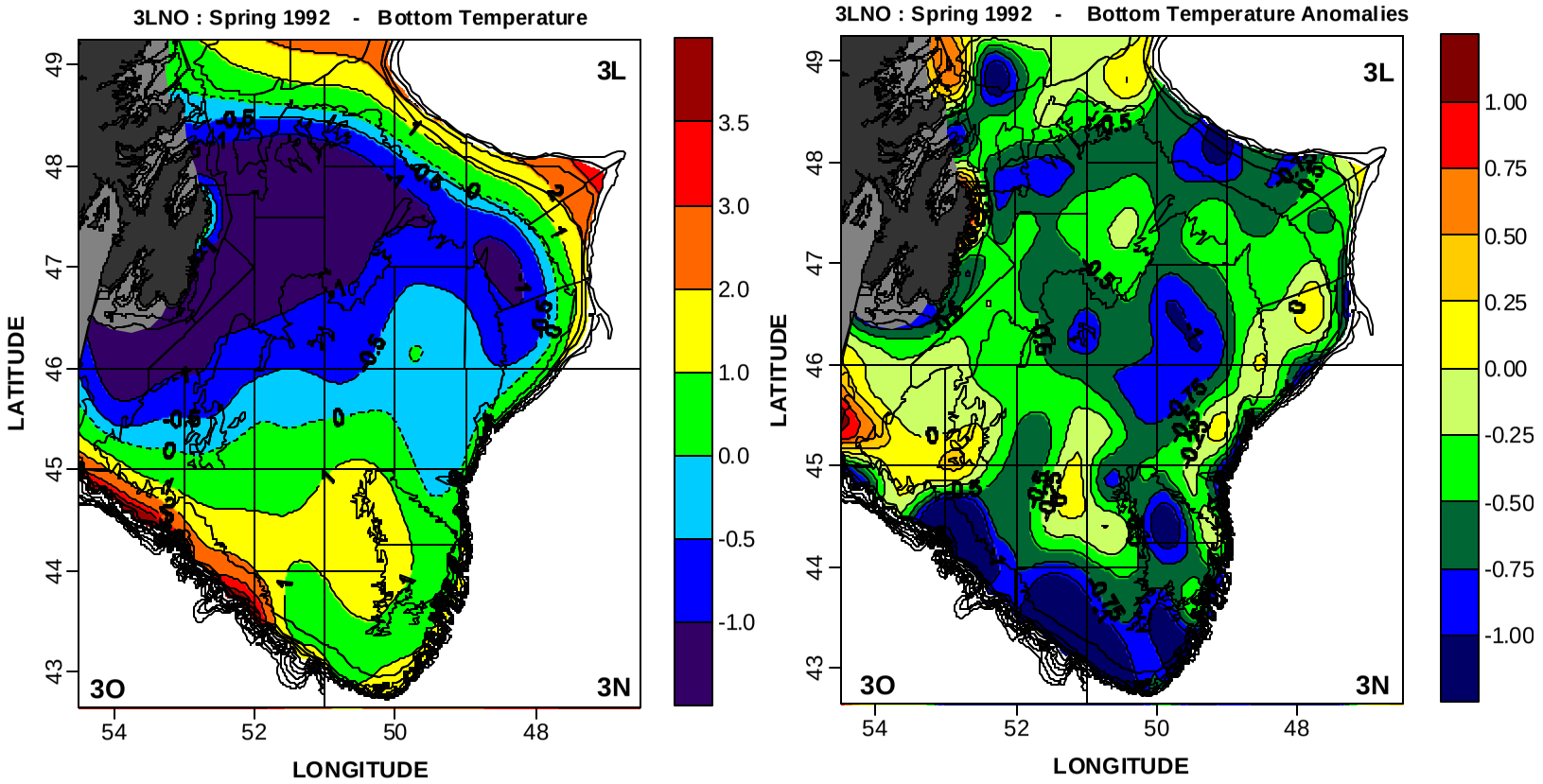

Fig. 1c. Horizontal bottom temperature and anomaly contours (in °C) for the spring of 1992 from the annual groundfish 3LNO survey.

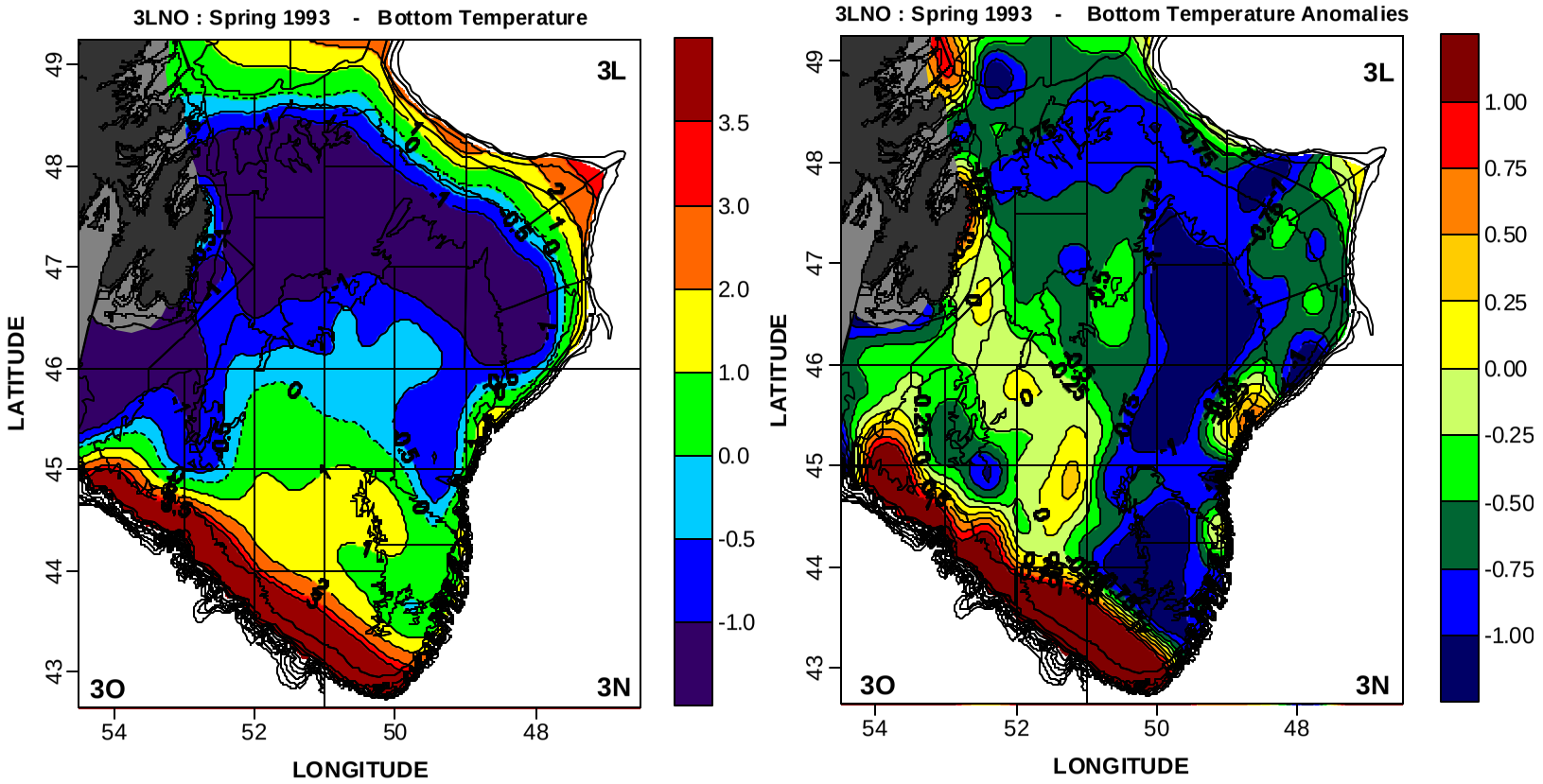

Fig. 1d. Horizontal bottom temperature and anomaly contours (in °C) for the spring of 1993 from the annual groundfish 3LNO survey.

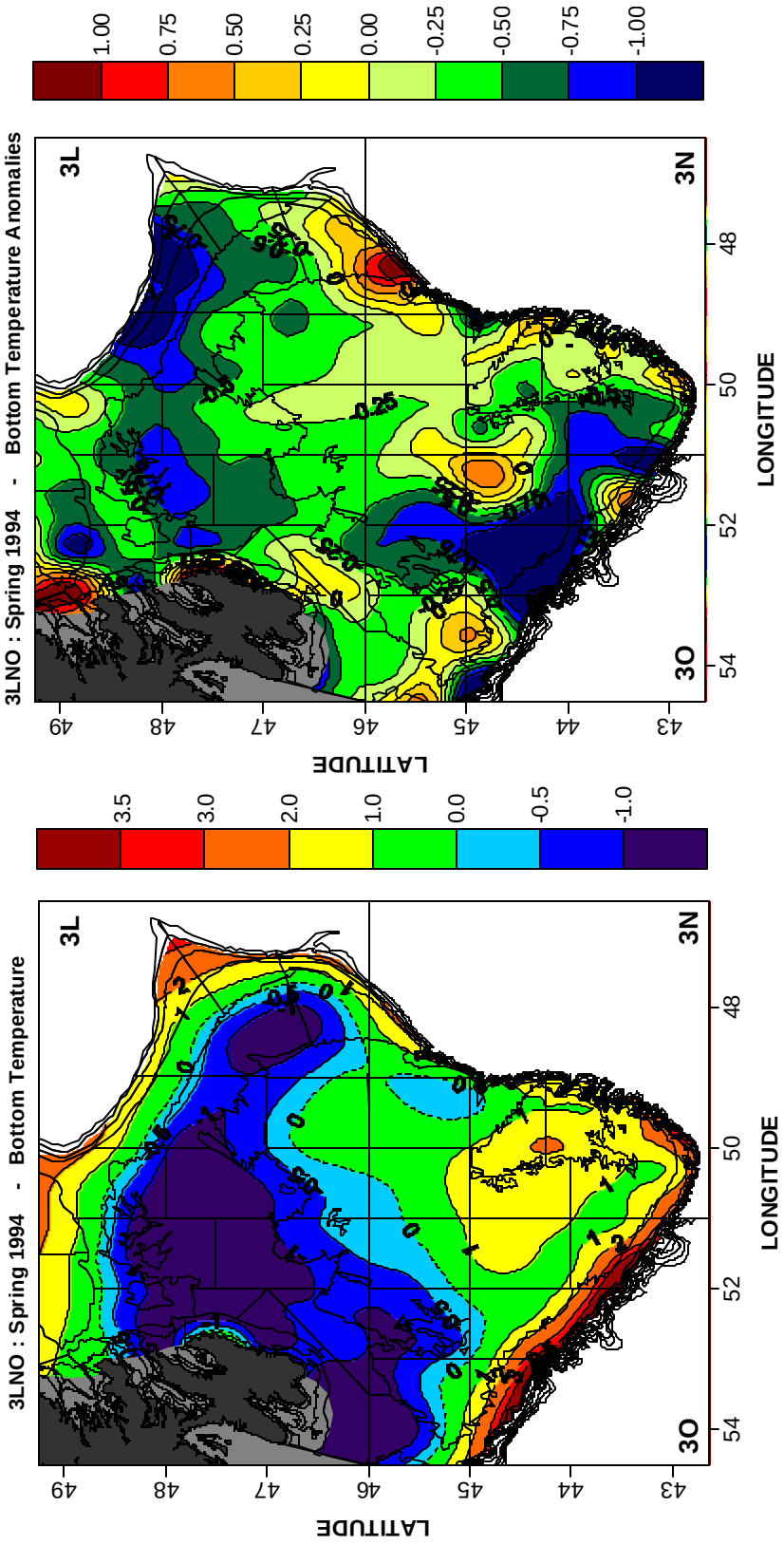

Fig. 1e. Horizontal bottom temperature and anomaly contours (in °C) for the spring of 1994 from the annual groundfish 3LNO survey.

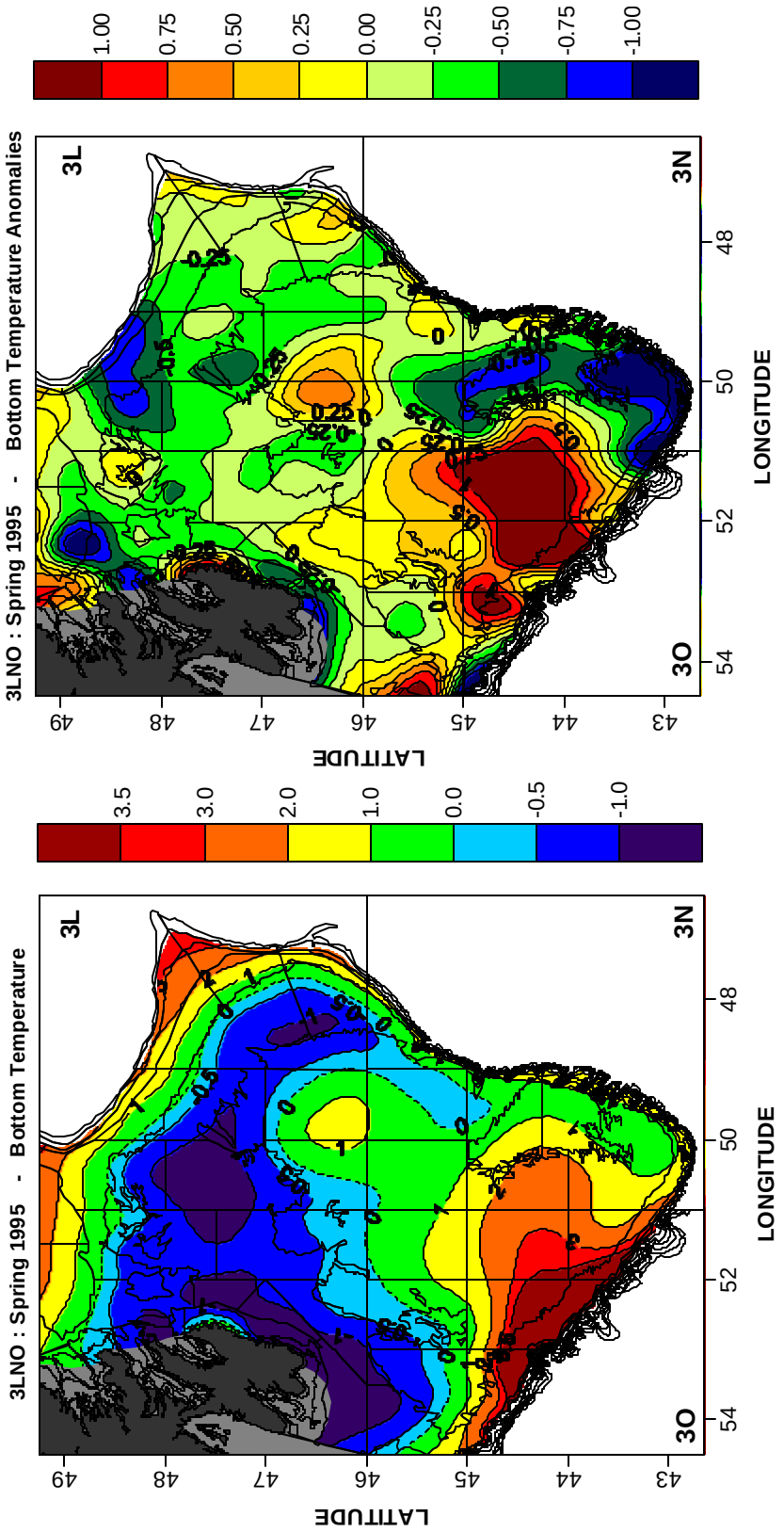

Fig. 1f. Horizontal bottom temperature and anomaly contours (in °C) for the spring of 1995 from the annual groundfish 3LNO survey.

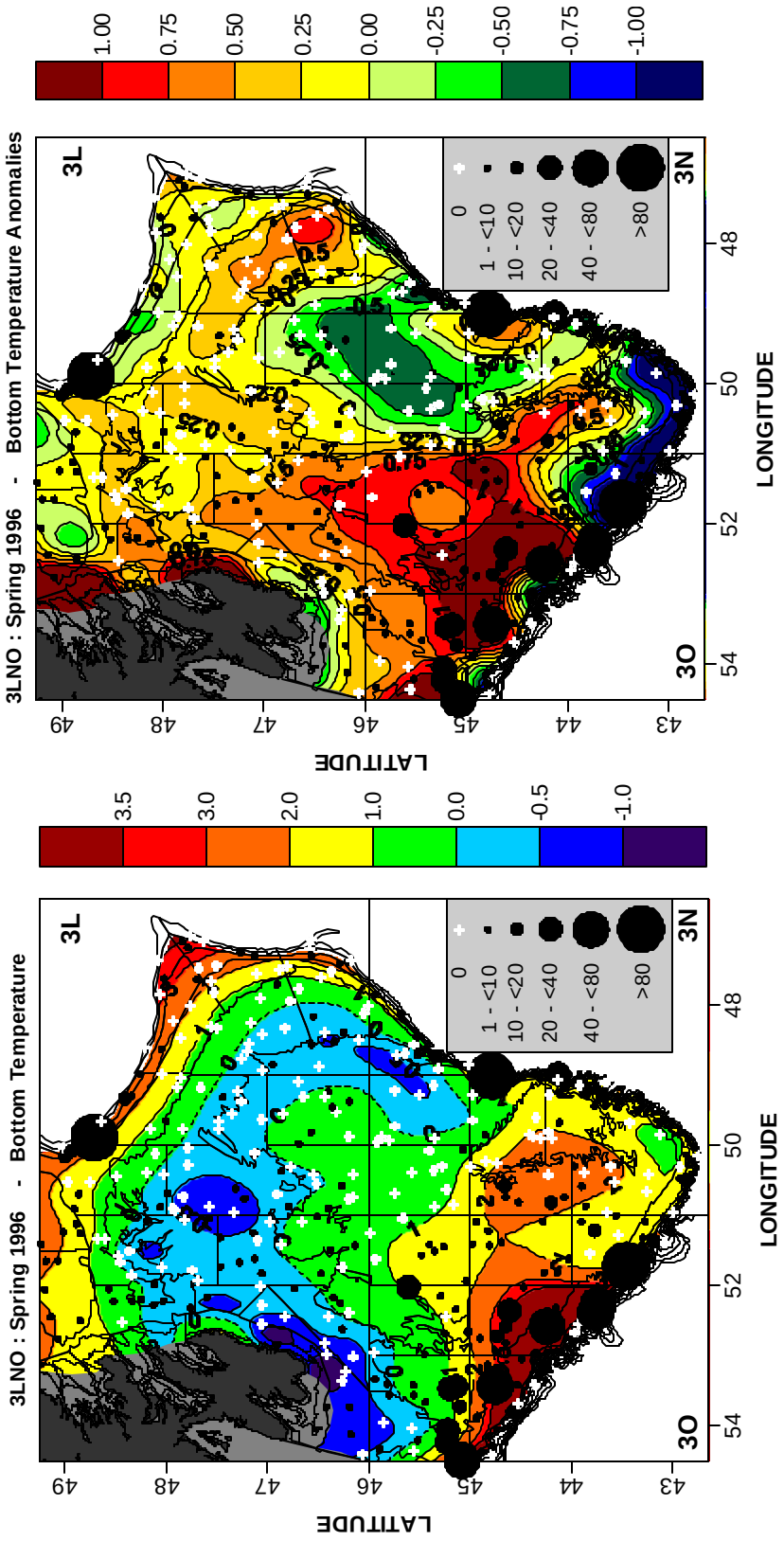

Fig. 1g. Horizontal bottom temperature and anomaly contours (in °C) for the spring of 1996 from the annual groundfish 3LNO survey. The numbers of cod caught in each fishing set are shown as the solid circles.

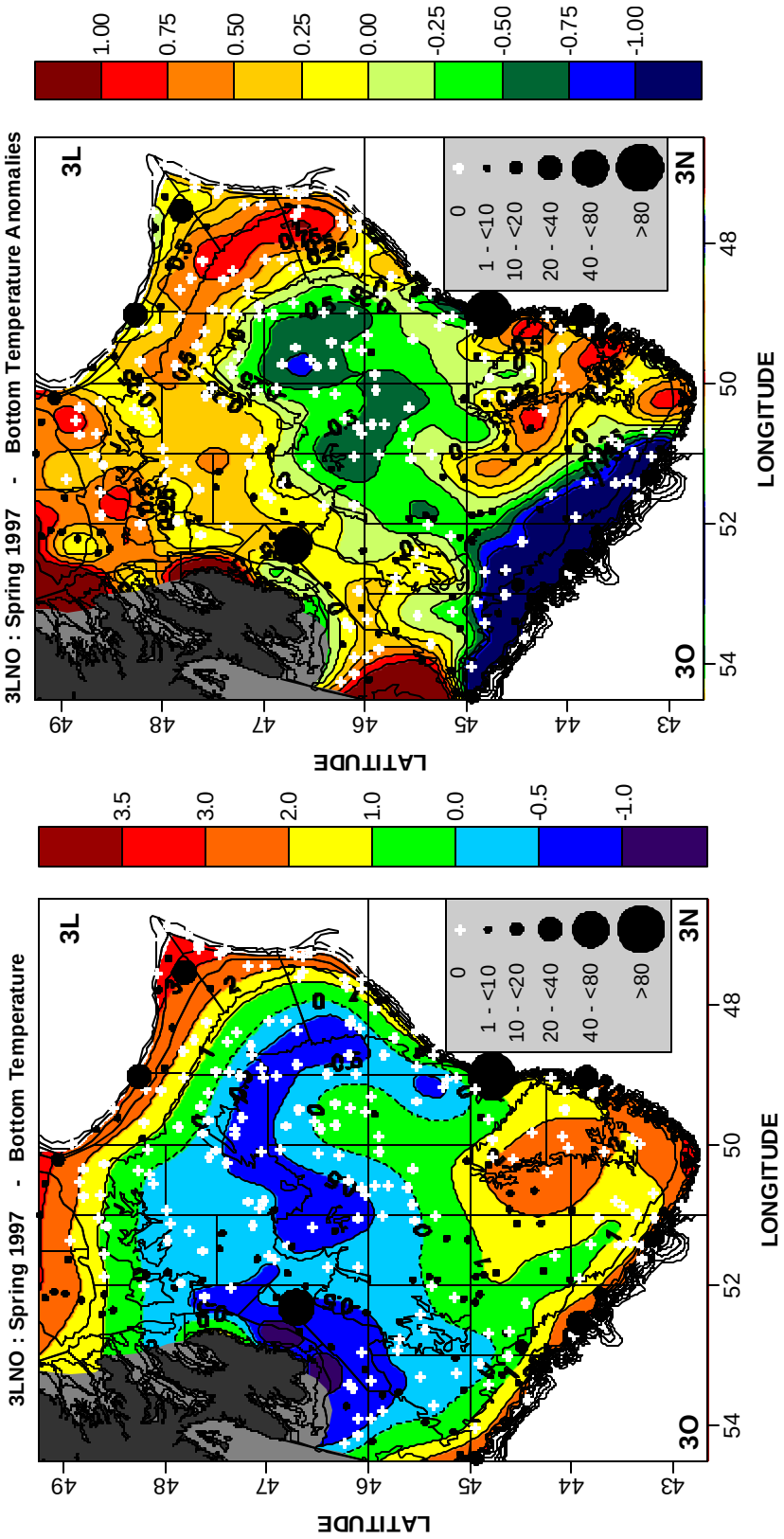

Fig. 1h. Horizontal bottom temperature and anomaly contours (in °C) for the spring of 1997 from the annual groundfish 3LNO survey. The numbers of cod caught in each fishing set are shown as the solid circles.

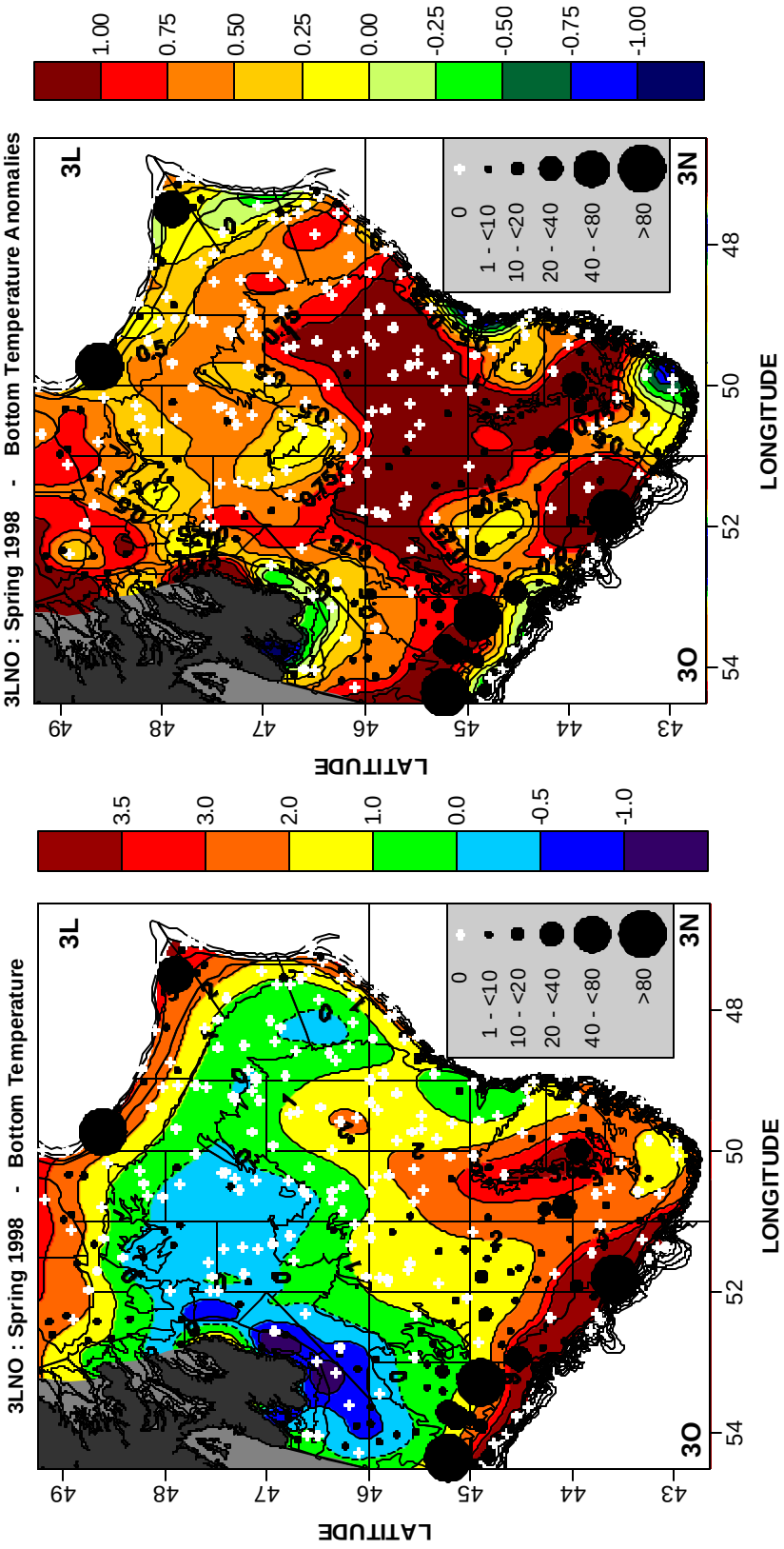

Fig. 1i. Horizontal bottom temperature and anomaly contours (in °C) for the spring of 1998 from the annual groundfish 3LNO survey. The numbers of cod caught in each fishing set are shown as the solid circles.

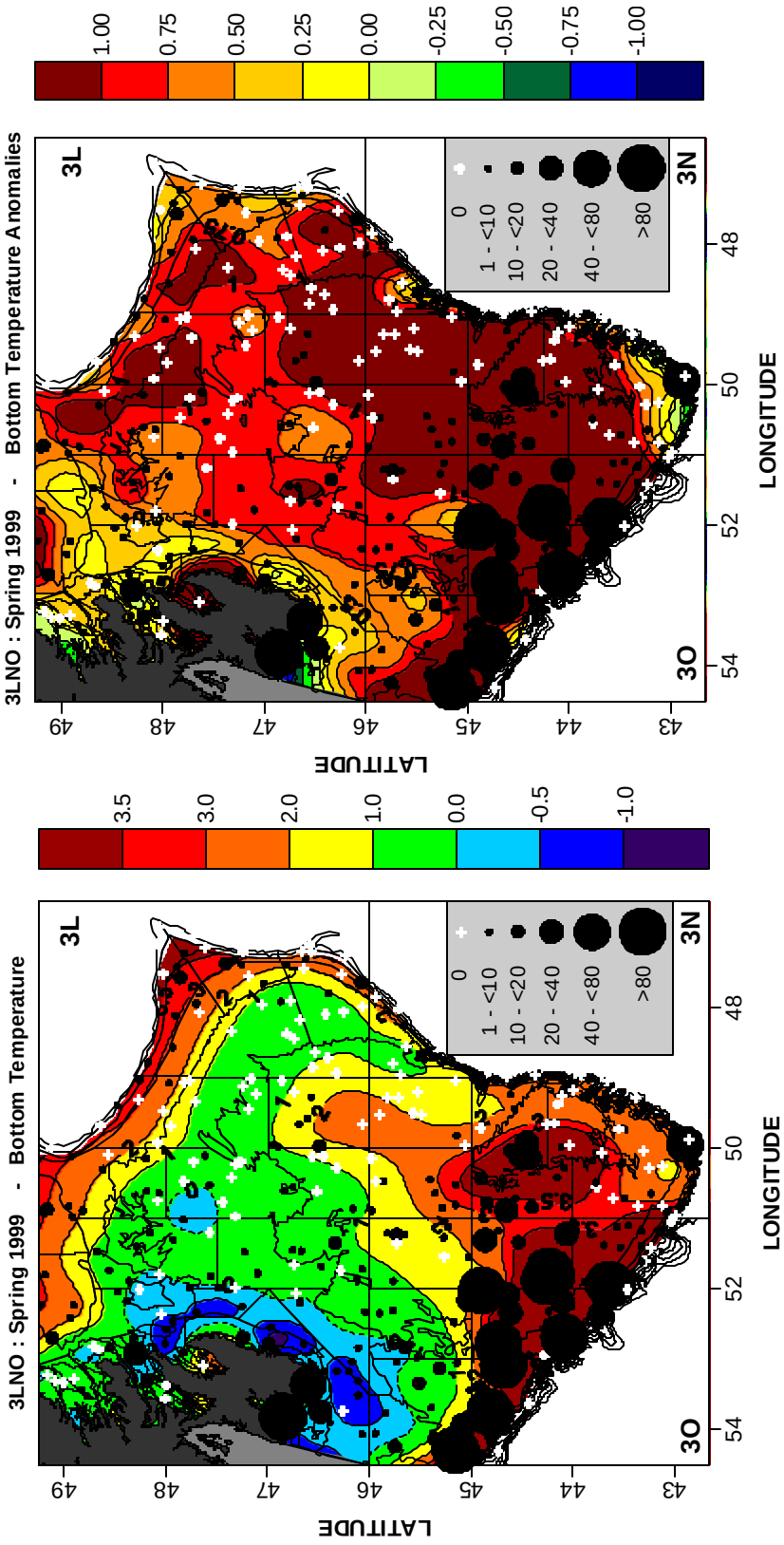

Fig. 1j. Horizontal bottom temperature and anomaly contours (in °C) for the spring of 1999 from the annual groundfish 3LNO survey. The numbers of cod caught in each fishing set are shown as the solid circles.

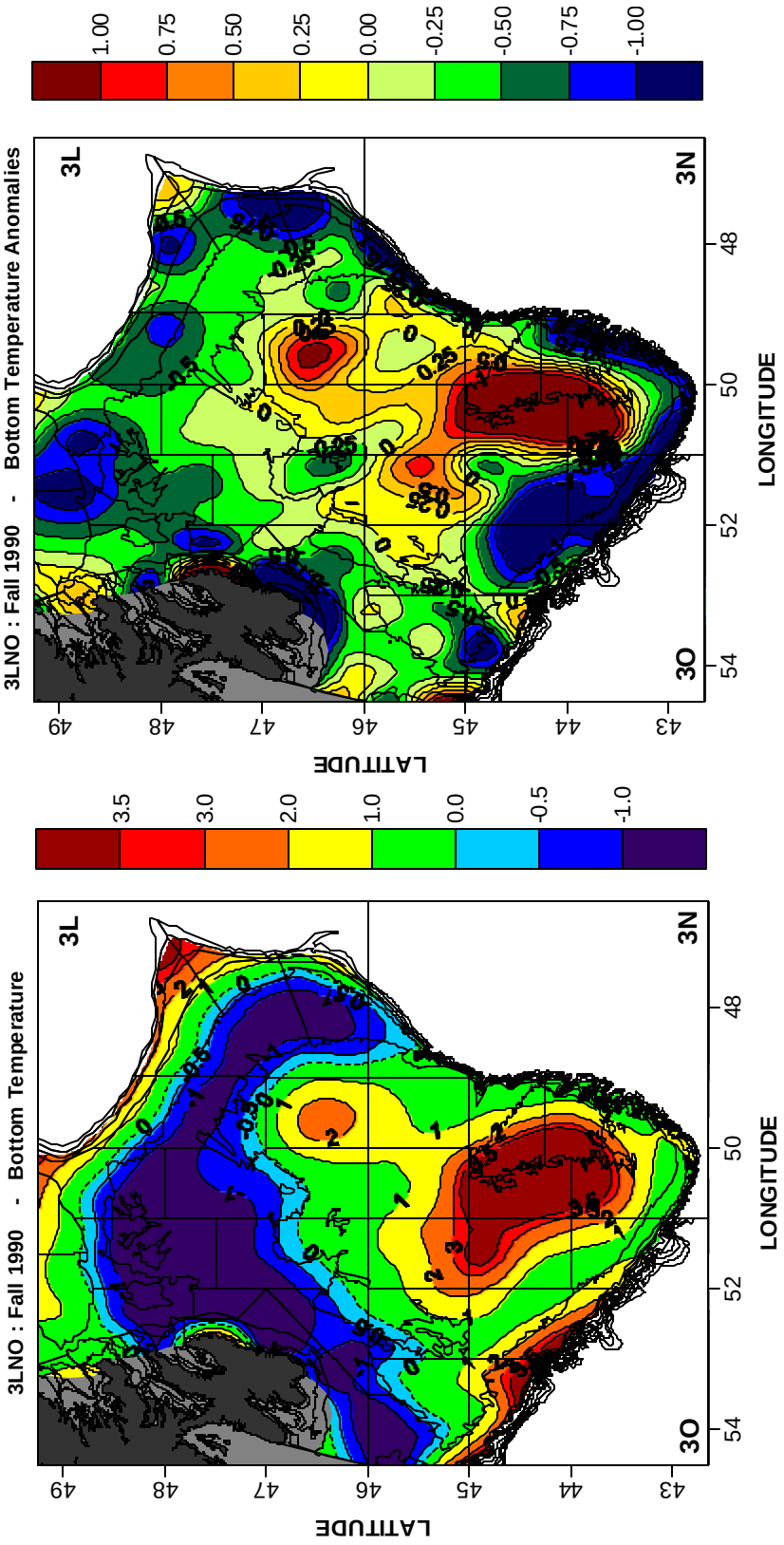

Fig. 2a. Horizontal bottom temperature and anomaly contours (in °C) for the fall of 1990 from the annual groundfish 3LNO survey.

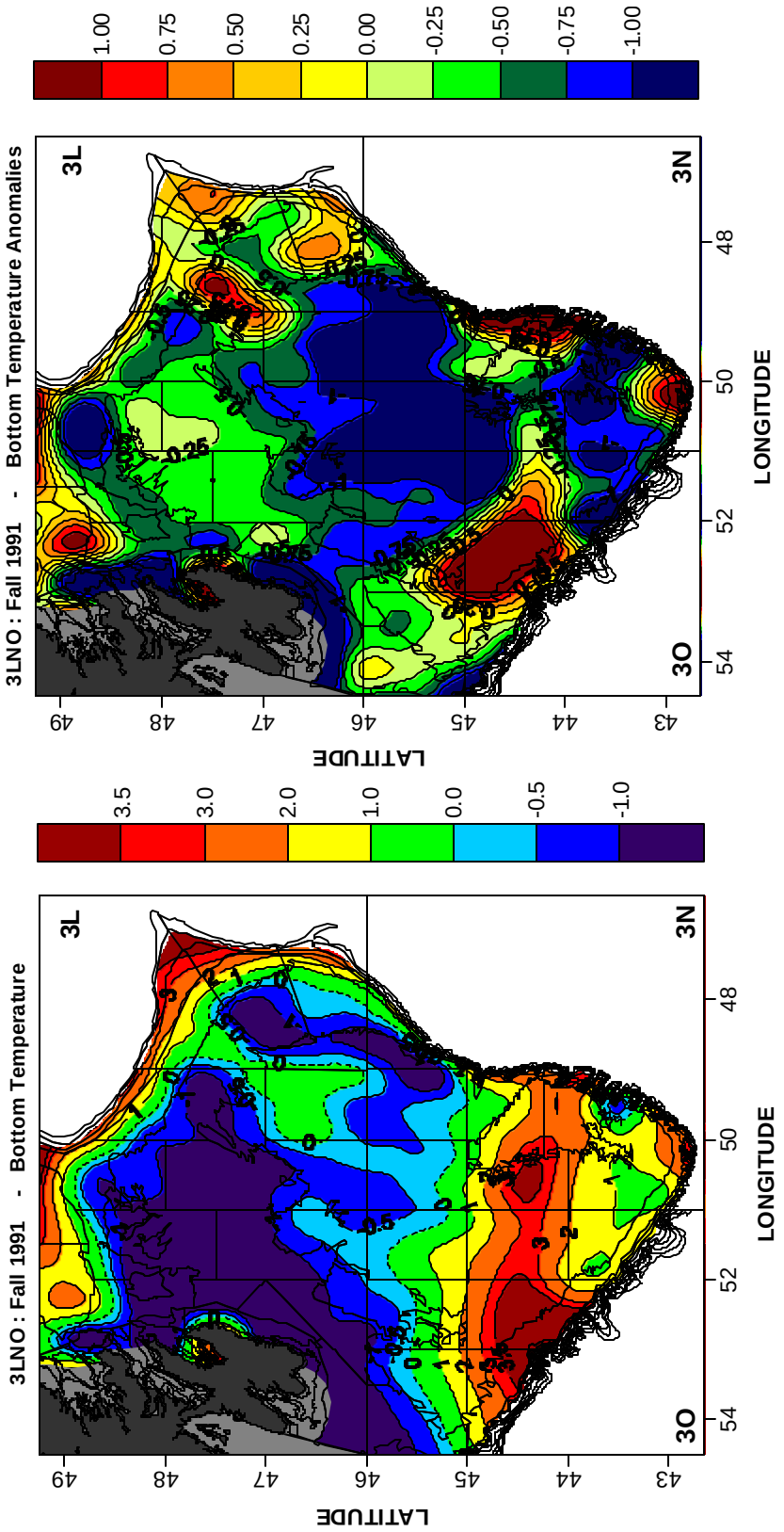

Fig. 2b. Horizontal bottom temperature and anomaly contours (in °C) for the fall of 1991 from the annual groundfish 3LNO survey.

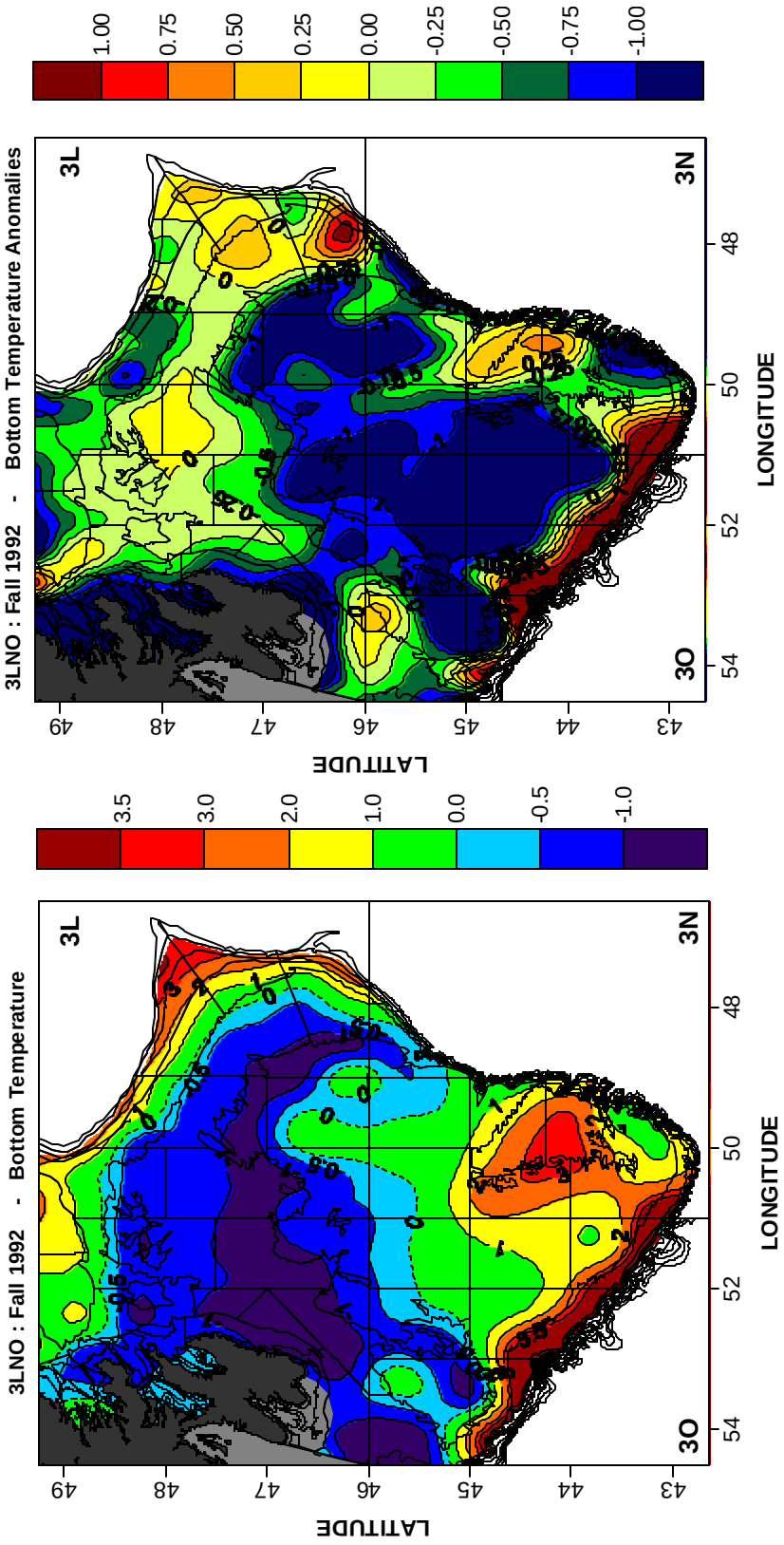

Fig. 2c. Horizontal bottom temperature and anomaly contours (in °C) for the fall of 1992 from the annual groundfish 3LNO survey.

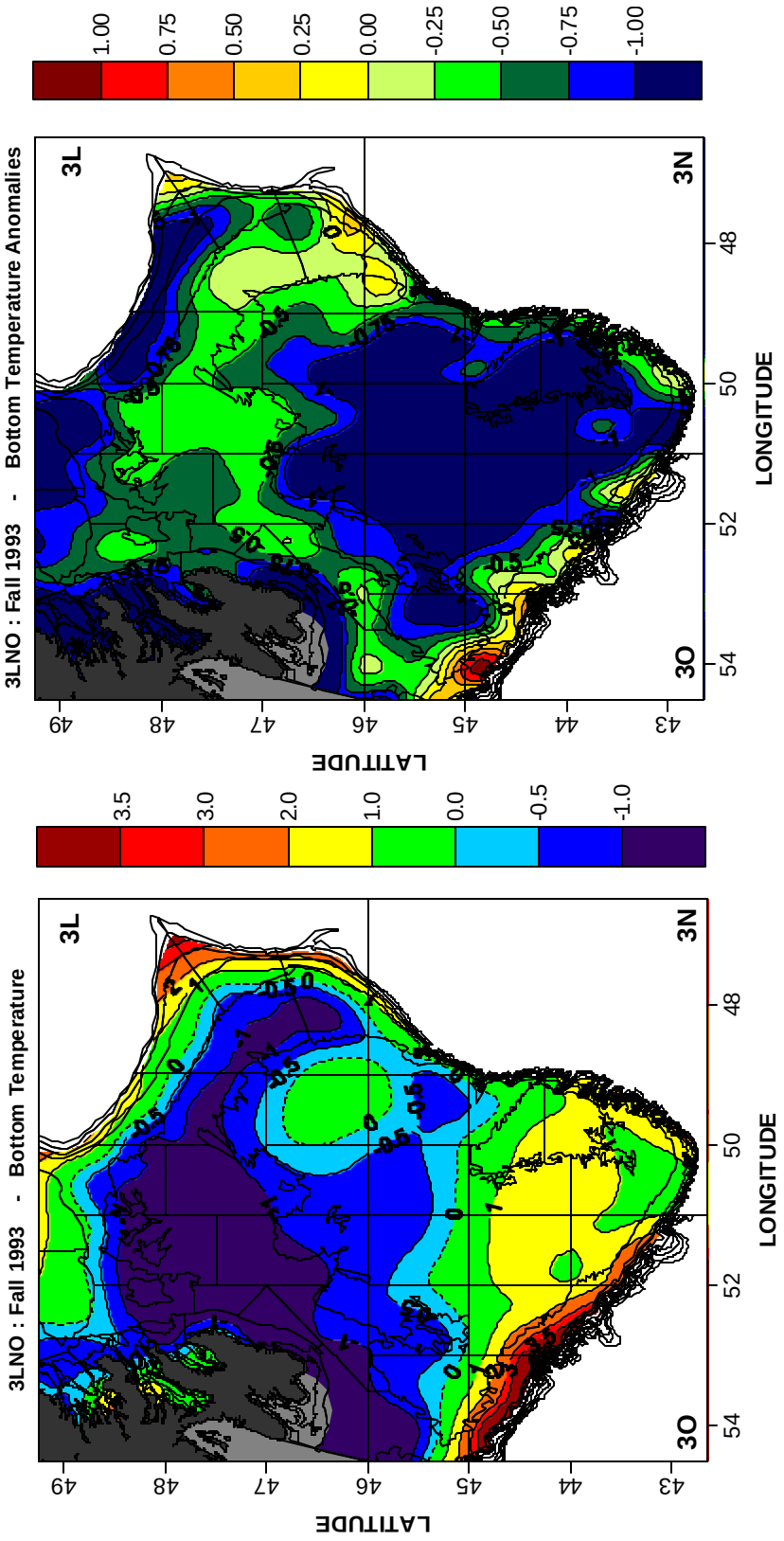

Fig. 2d. Horizontal bottom temperature and anomaly contours (in °C) for the fall of 1993 from the annual groundfish 3LNO survey.

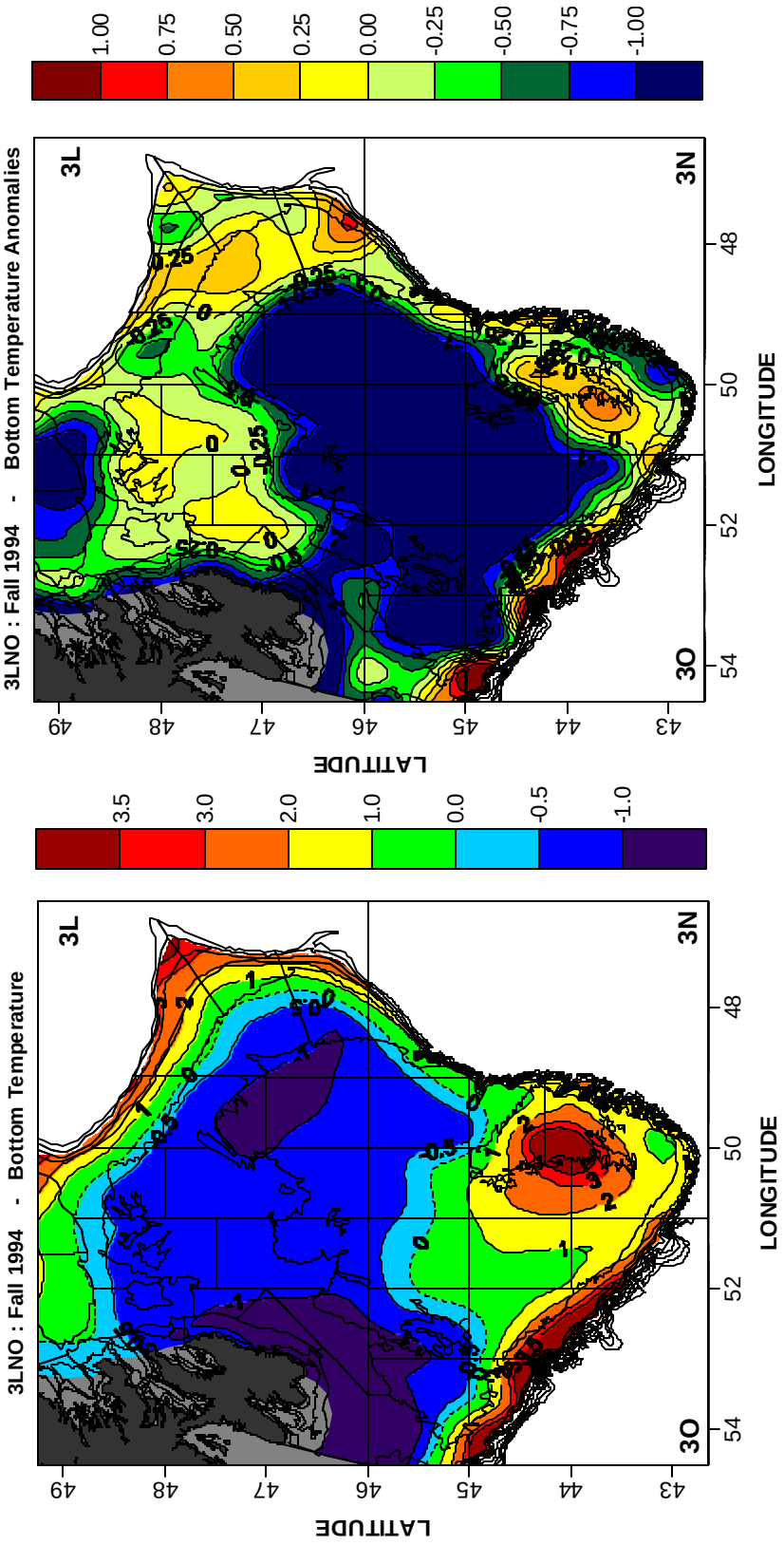

Fig. 2e. Horizontal bottom temperature and anomaly contours (in °C) for the fall of 1994 from the annual groundfish 3LNO survey.

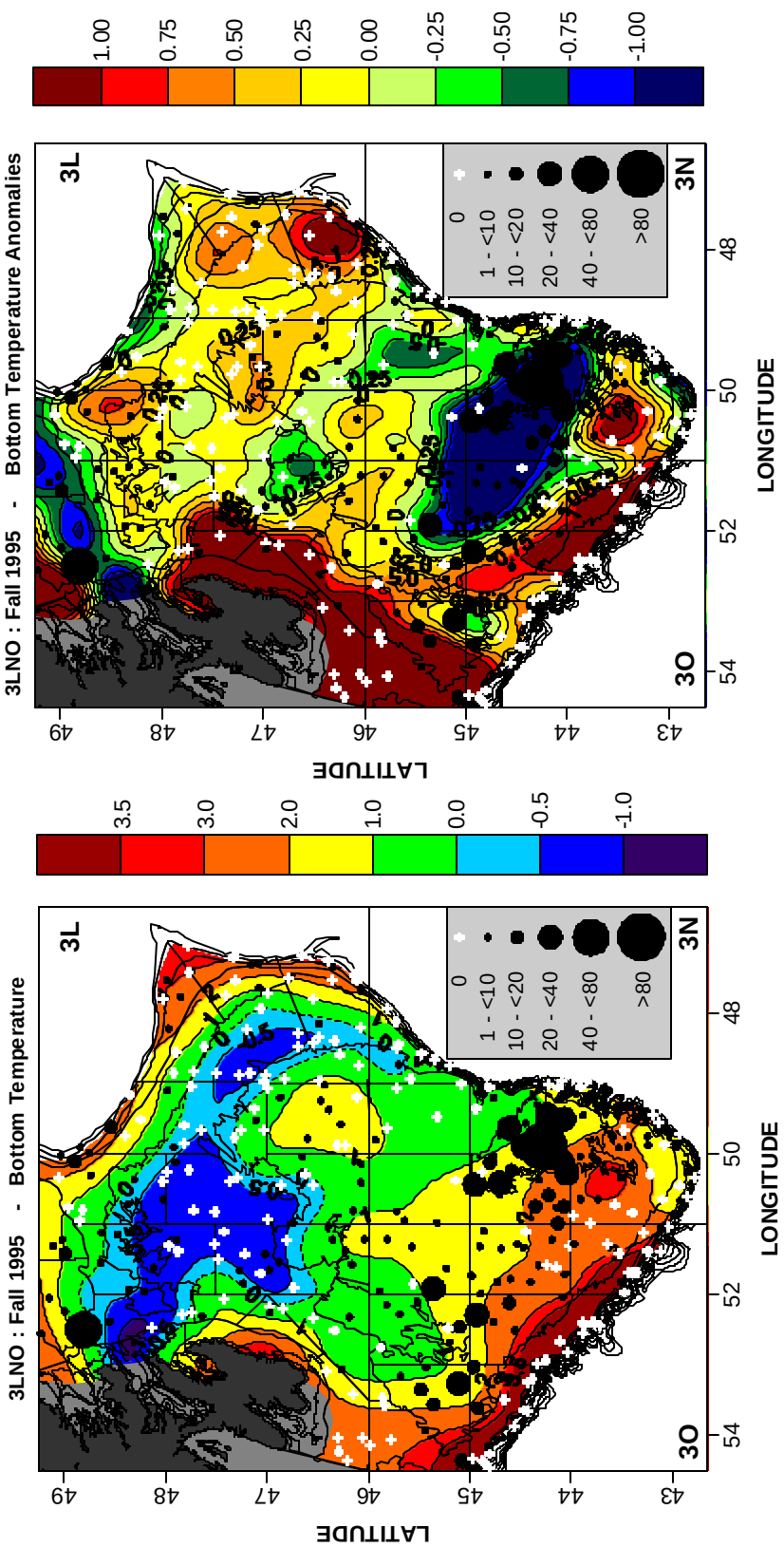

Fig. 2f. Horizontal bottom temperature and anomaly contours (in °C) for the fall of 1995 from the annual groundfish 3LNO survey. The numbers of cod caught in each fishing set are shown as the solid circles.

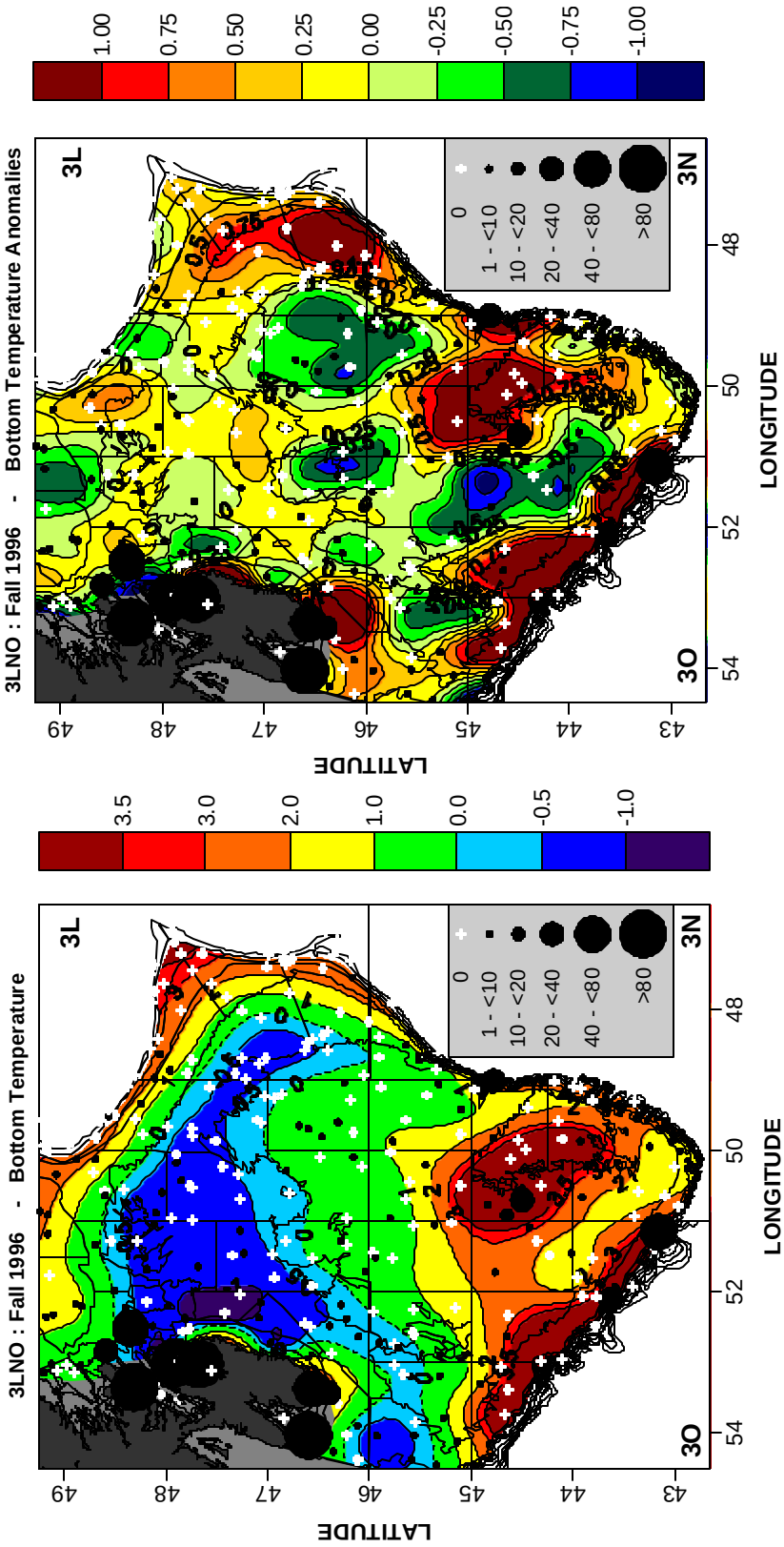

Fig. 2g. Horizontal bottom temperature and anomaly contours (in °C) for the fall of 1996 from the annual groundfish 3LNO survey. The numbers of cod caught in each fishing set are shown as the solid circles.

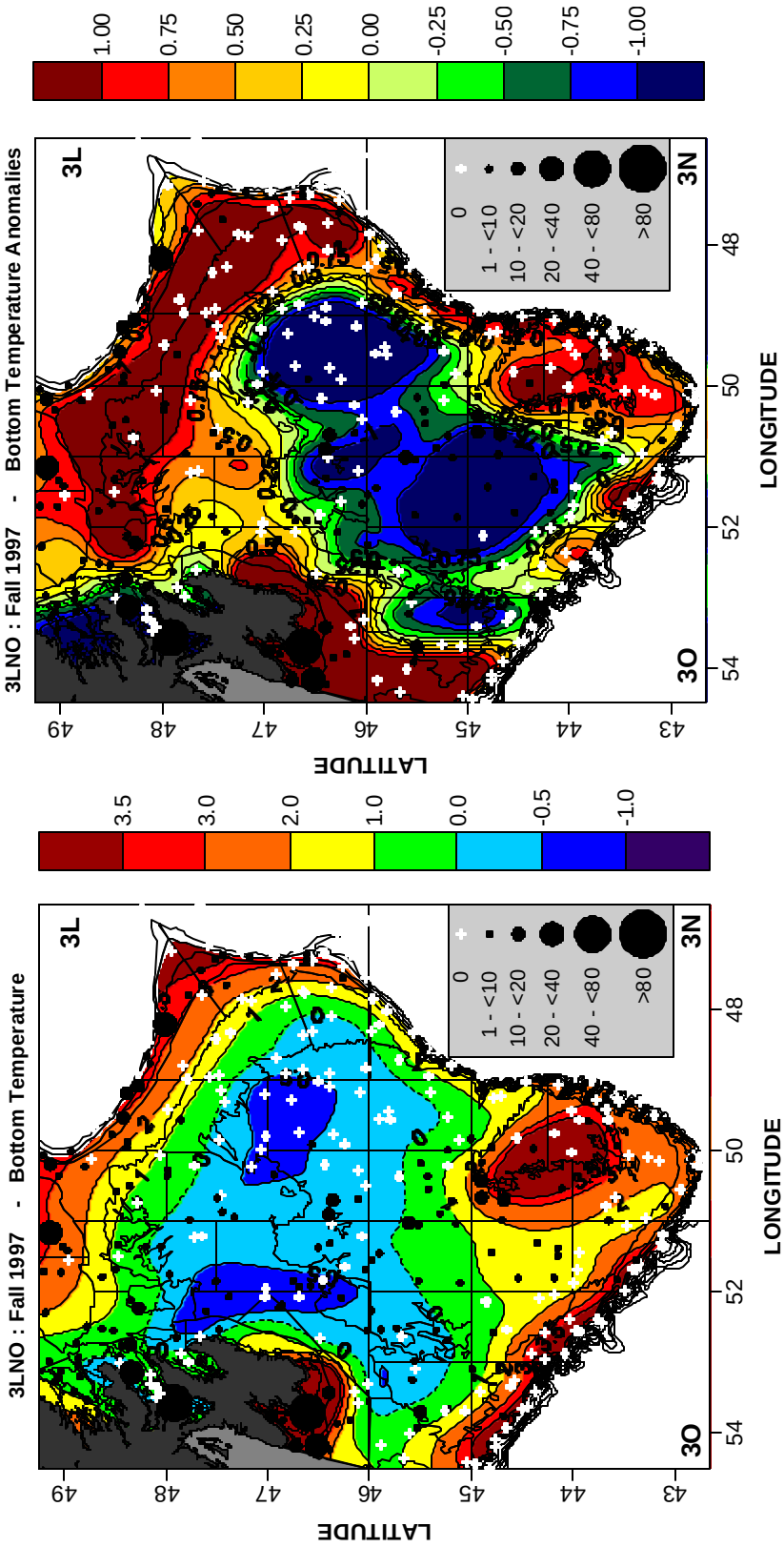

Fig. 2h. Horizontal bottom temperature and anomaly contours (in °C) for the fall of 1997 from the annual groundfish 3LNO survey. The numbers of cod caught in each fishing set are shown as the solid circles.

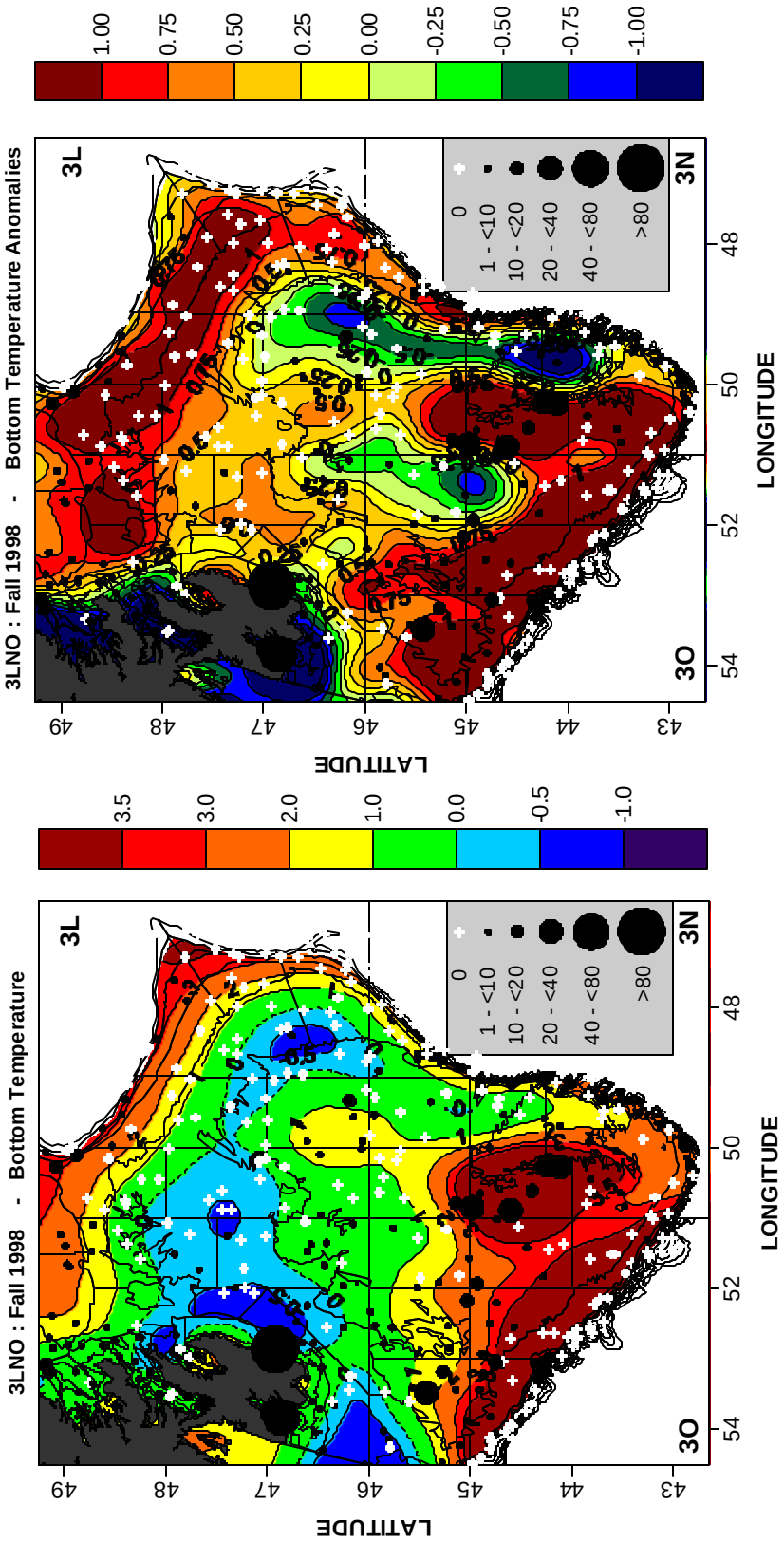

Fig. 2i. Horizontal bottom temperature and anomaly contours (in °C) for the fall of 1998 from the annual groundfish 3LNO survey. The numbers of cod caught in each fishing set are shown as the solid circles.

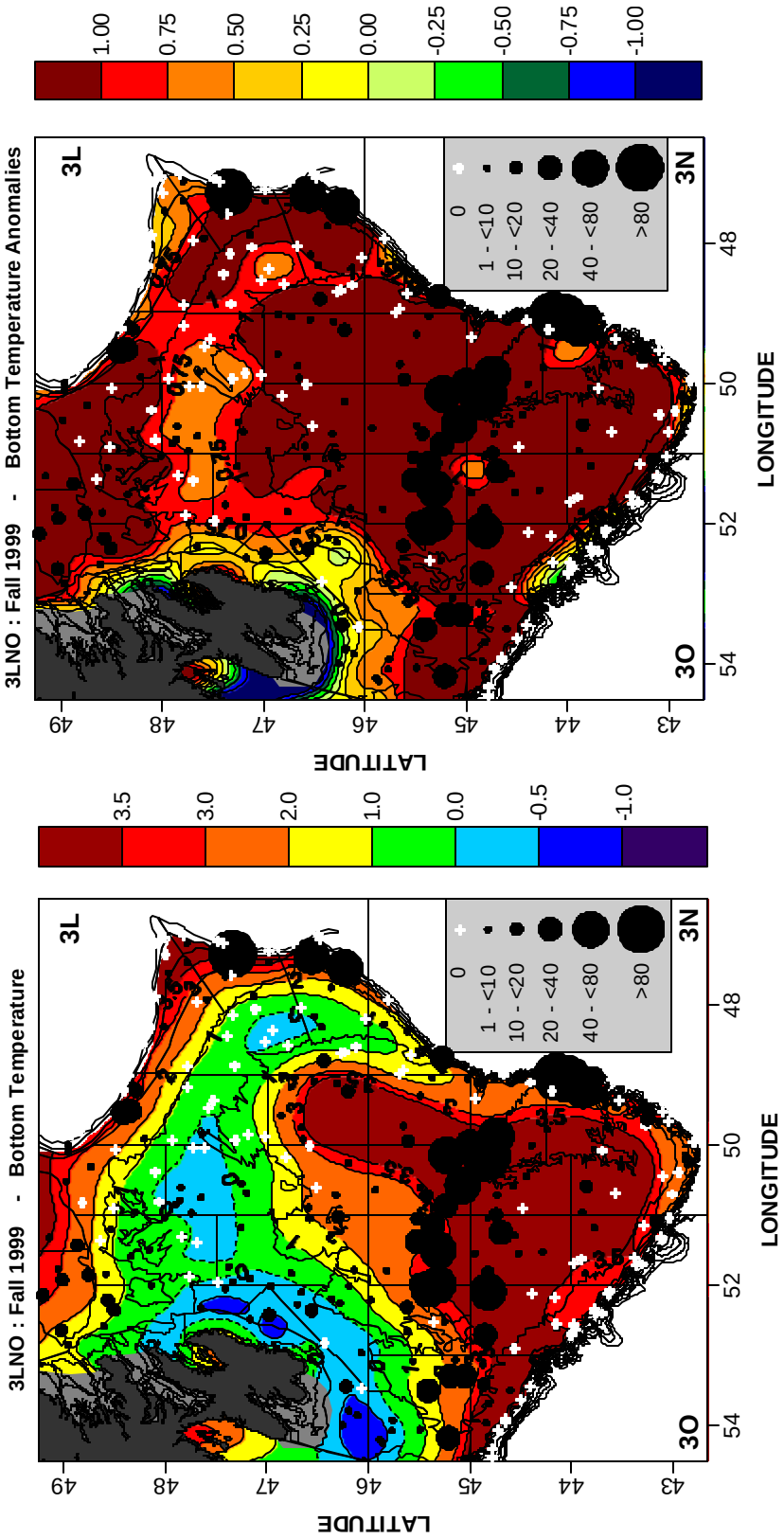

Fig. 2j. Horizontal bottom temperature and anomaly contours (in °C) for the fall of 1999 from the annual groundfish 3LNO survey. The numbers of cod caught in each fishing set are shown as the solid circles.

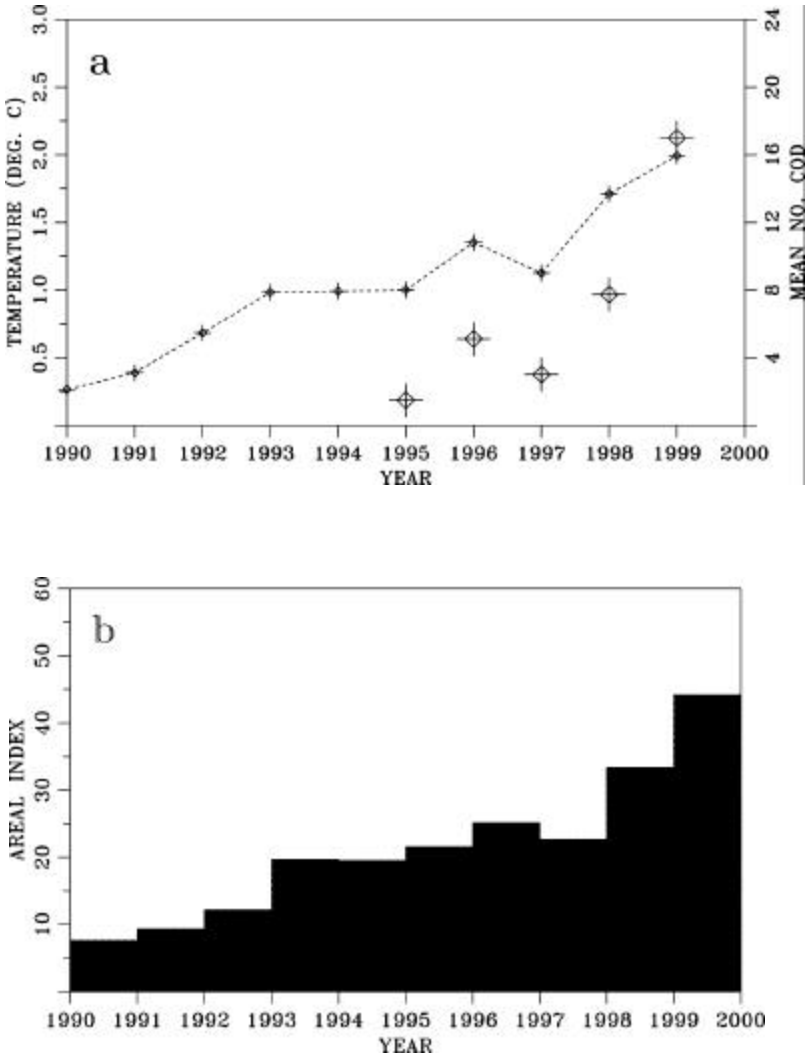

Fig. 3. (a) Time series of the mean bottom temperature (dashed line) and the stratified mean number of cod in NAFO Div. 3NO and (b) the percentage area of NAFO Div. 3LNO covered by water with bottom temperatures ≥2°C, during the spring.

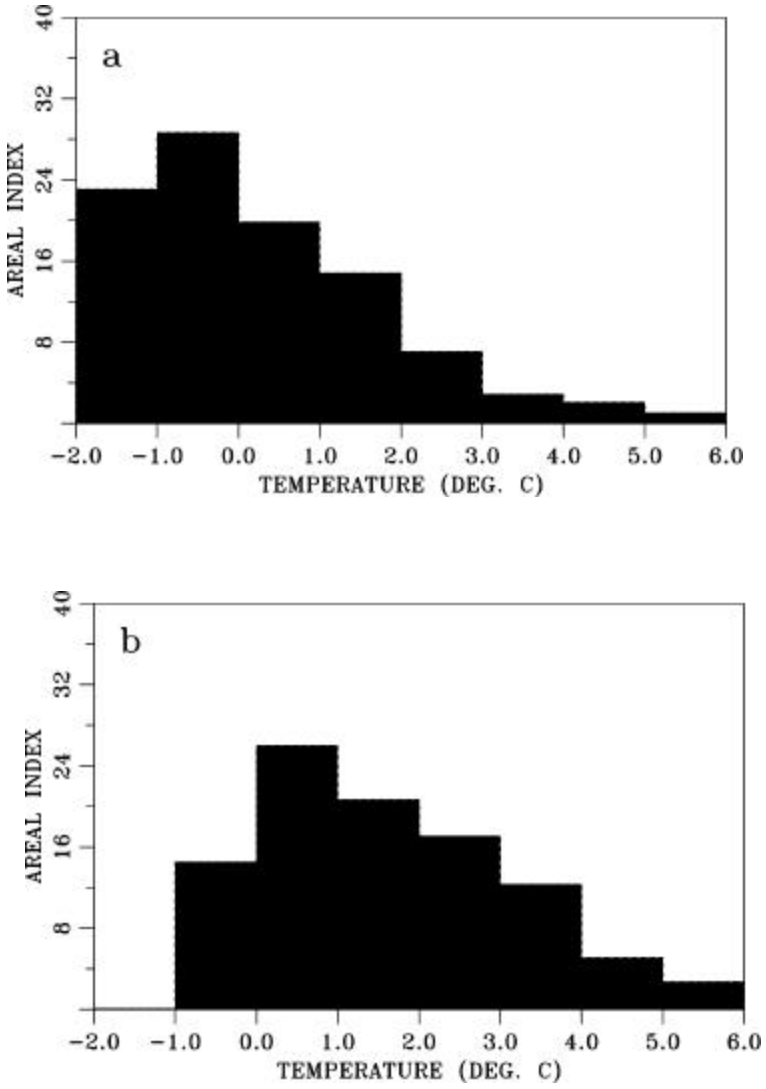

Fig. 4. The percentage area of NAFO Div. 3LNO covered by water in 1°C temperature bins, during the spring for (a) 1990-1994 and (b) for 1999.

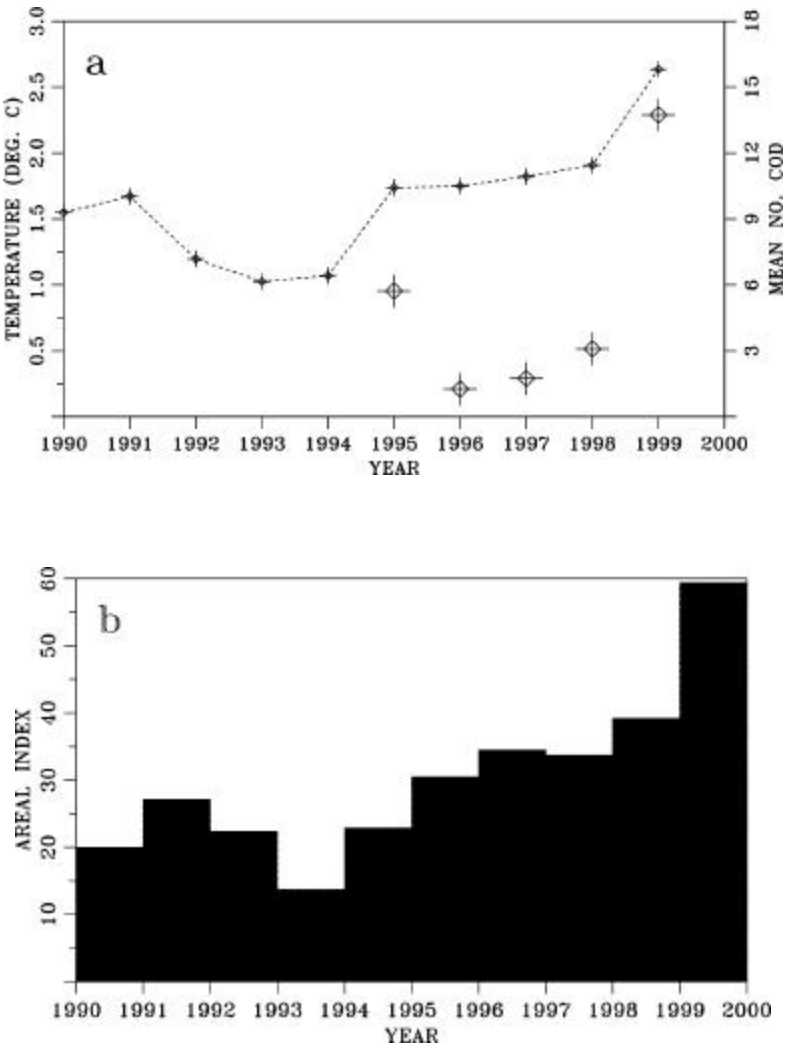

Fig. 5. (a)Time series of the mean bottom temperature (dashed line) and the stratified mean number of cod in 3NO and (b) the percentage area of NAFO Div. 3LNO covered by water with bottom temperatures ≥2°C, during the autumn.

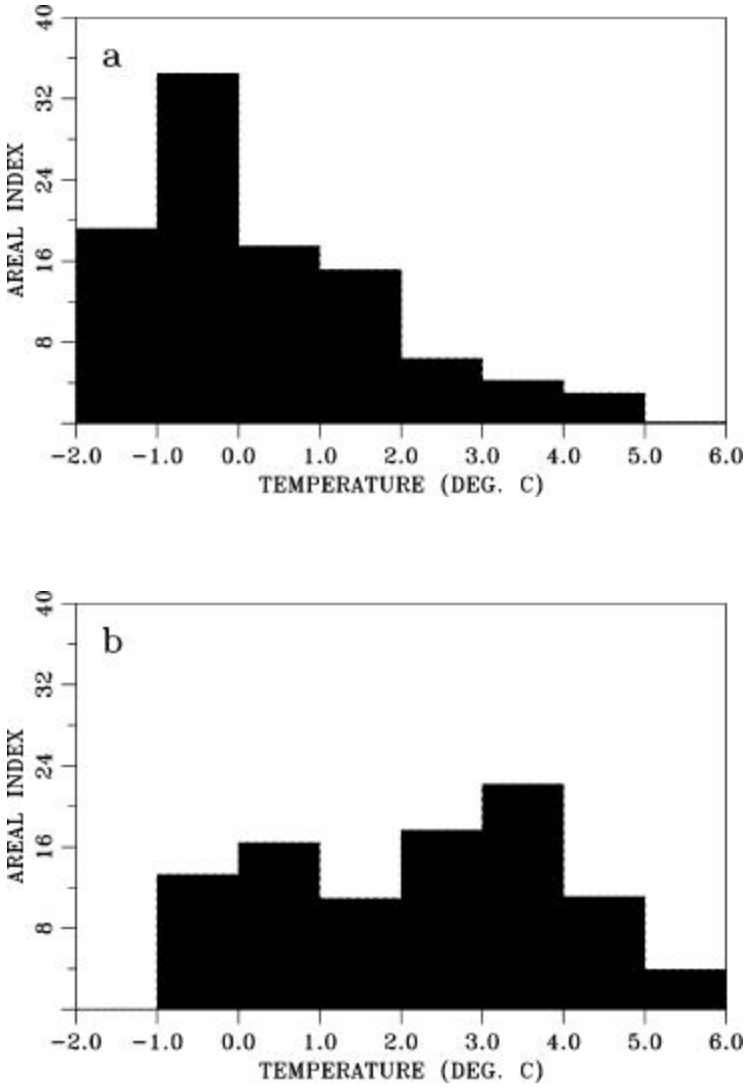

Fig. 6. The percentage area of NAFO Div. 3LNO covered by water in 1ºC temperature bins, during the autumn for (a) 1993 and (b) 1999.

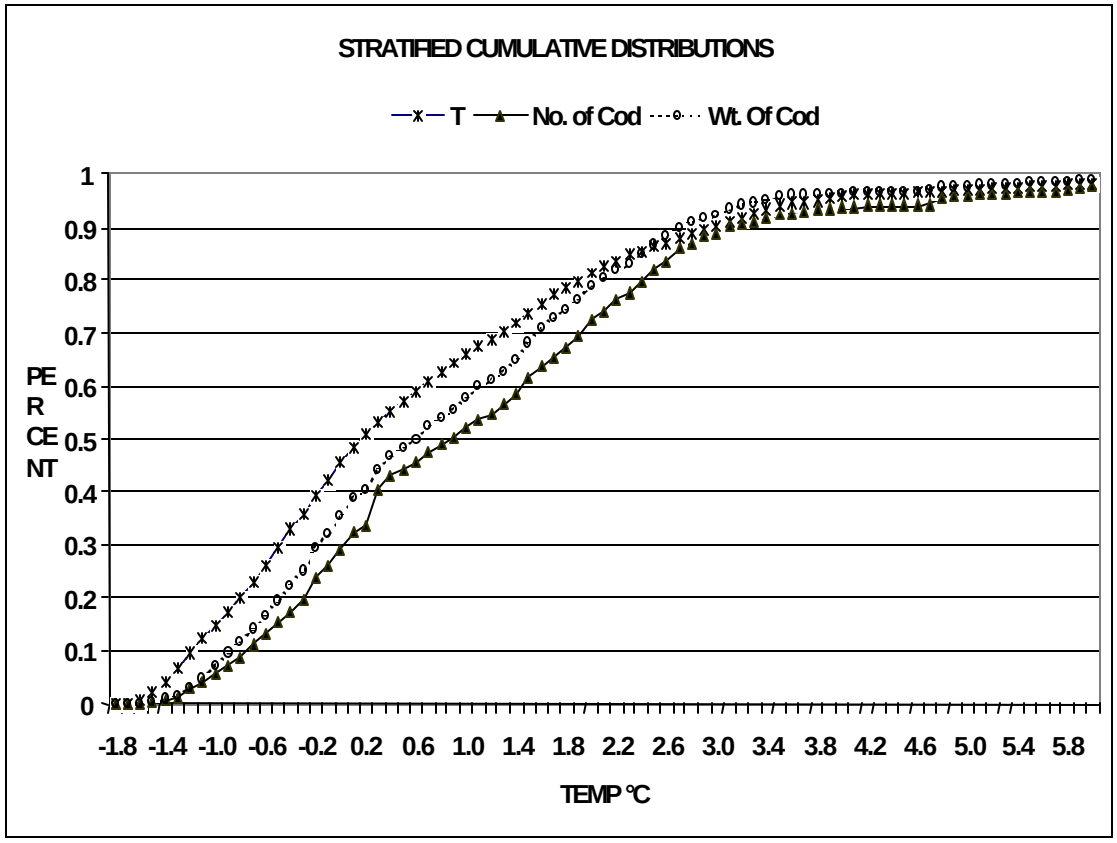

Fig 7. The stratified cumulative frequency distribution of temperature available to cod and the cod number and catch weighted temperature distributions in NAFO Div. 3LNO during the spring from 1972 to 1999.