Northwest Atlantic Fisheries Organization

Serial No. N4409 **NAFO SCR Doc. 01/32**

SCIENTIFIC COUNCIL MEETING – JUNE 2001

Recent Trends in Bottom Temperatures and Distribution and Abundance of Yellowtail Flounder (*Limanda ferruginea*) in NAFO Divisions 3LNO During the Spring and Fall

by

E. B. Colbourne and W. Ray Bowering

Science Branch, Department of Fisheries and Oceans
P. O. Box 5667, St. John's, Newfoundland A1C 5X1

ABSTRACT

An analysis of near-bottom temperatures in NAFO Divisions 3LNO during spring and fall surveys are presented in relation to the spatial distributions and abundance of yellowtail flounder for the decade of the 1990s. Interannual variations in the near-bottom thermal habitat were examined by calculating the areal extent of the bottom covered with water in 1°C temperature bins. The analysis revealed a significant shift in the thermal habitat in the region, from the cold sub-zero °C conditions of the first half of the 1990s to a relatively warmer environment during the latter half. During this time period approximately 60% of the bottom was covered with <0°C water by 1994 but by the fall of 1999 almost 100% of the traditional bottom habitat of yellowtail flounder on the Grand Bank was covered by water with temperatures >0°C. Coincident with these changes there has been a significant increase in the number of yellowtail flounder per tow in survey sets in Divisions 3NO and larger catches have become more widespread in the southern areas of Div. 3L. It appears that the most significant distributions of yellowtail are found south of the 0°C isotherm in warmer water and within the 100-m isobath on the Grand Banks. The recently observed expansion in the spatial distribution and increase in abundance of yellowtail flounder are discussed in terms of an improved thermal environment, possibly resulting in an associated increase in catchability.

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, Murphy 1996).

Surveys have been conducted in both the spring and fall in 3L, 3N and 3O with inshore strata in 3L being fished only in the spring of 1999 and the fall of 1996-1999. In spring the surveys were conducted in 3L from 1971-2000, except 1983 and 1984, in 3NO from 1971-2000, except 1983 in 3N and 1972, 1974 and 1983 in 3O, in water depths to 730 m in most years and more recently to 1500 m. Surveys were conducted in the fall in 3L from 1981-2000, in 3N from 1990-2000 and in 3O from 1990-2000 covering depths to 730 m in most years and to 1500 m more recently. Since the fall 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.

Recent assessments have indicated a significant increase in the biomass and abundance of yellowtail flounder on the Grand Bank beginning in 1995 from the relatively low and declining estimates of the early 1990s. These increases have continued during the latter half of the 1990s reaching record levels in 1999. In addition, the population has also expanded it's range onto the northern Grand Bank in Div. 3L (Walsh et al. 2000). The purpose of this analysis is to review these recent trends in the distribution and abundance of yellowtail flounder in relation to their thermal habitat. We begin by examining the spatial distribution of yellowtail in relation to the near-bottom temperature fields for the annual spring and autumn research vessel surveys during the decade of the 1990s. Interannual variations in the thermal habitat are then considered by examining the mean temperature fields for each survey and the areal extent of the bottom covered with water in various temperature bins. These are then compared to the mean catch rates for time period.

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 bathythermographs (mechanical or expendable MBT/XBT), 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 CTDs are not field calibrated, but are checked and factory calibrated periodically 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 fall surveys separately for the years 1990 to 2000. All bottom-of-the-cast temperature values for each time period were interpolated onto a regular grid and contoured using a geostatistical (2-diminsional Kriging) procedure. The area of each grid element within selected temperature ranges was integrated to produce a yearly estimate of the percentage of the total bottom area within each temperature bin. The selected temperature ranges were $\leq$0^{o}C, 0-1^{o}C, 1-2^{o}C, 2-3^{o}C and $\geq$3^{o}C. The mean near-bottom temperature time series was also constructed for each year for both spring and fall. This analysis was restricted to water depths $\leq$100 m, which corresponds to the main habitat for yellowtail flounder on the Grand Bank. 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 yellowtail flounder per set is also displayed with the temperature contours from 1990 to 2000 for the spring and fall surveys in NAFO Divs. 3LNO. The survey catch data from 1990 to the spring of 1995, which were collected using an Engel 145 bottom trawl, were converted to equivalent Campelen trawl units based on the results of comparative fishing studies. The mean number and weight of yellowtail flounder for all sets for each survey were also computed and compared to the average bottom temperature. Finally, the cumulative frequency distributions of catch numbers for each temperature bin are compared to the available temperature distribution within the 3LNO region for all surveys from 1990-2000. For the purpose of this preliminary analysis, these distributions are not weighted by sampling intensity or stratum area.

Results

The temperature anomaly plots displayed in Fig. 1 show two extremes in ocean climate experience during the decade of the 1990s, with bottom temperatures on the Grand Banks reaching a minimum during the early 1990s and a maximum by the end of the 1990s. During 1993 for example, bottom temperatures for the most part were below normal over the entire region, with anomalies reaching at least 0.5^{o}C below normal, but also as low as 2^{o}C below normal in some regions of 3NO. By the middle of the decade however, temperatures moderated and were above normal over most areas by 1998 and by 1999 temperature anomalies on the entire northern Grand Bank were up to 1^{o}C above average.

Over the central and southern Grand Bank bottom temperatures were even higher ranging from 1-4^{o}C above the long-term average (Fig. 1).

The spring and fall bottom temperature maps together with the number of fish caught per set for Divisions 3LNO are shown in Figs. 2 and 3 for the years 1990 to 2000. In general spring bottom temperatures in the northern areas ranged from <0^{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 from 1990-1995 virtually the entire 3L area (except the deeper slope regions) and a significant portion of 3NO was covered by <0^{o}C water. Beginning around 1996 (Fig. 2b) 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. 2c). During the fall temperatures in 3L were very similar to spring values with <0^{o}C water covering most of the area during the cold years of 1990 to 1994 (Fig. 3a and 3b). During the warm years of 1998 and 1999 again most of the coldest water was restricted to the deeper portions of the Avalon Channel. In the shallower regions of 3NO however, fall bottom temperatures are generally warmer than spring values (by 2-3^{o}C) as a result of summer surface heating.

The numbers of yellowtail flounder caught per set during each survey are also displayed with the temperature fields in Fig. 2 for the spring surveys and in Fig. 3 for the fall surveys as expanding symbols. The majority of fishing sets in Div. 3L shows zero catches in water deeper than 100 m. In the southern part of 3L within the 100-m isobath the number of yellowtail flounder caught per tow has been relatively low (<50 fish) with most sets with non-zero catches restricted to bottom areas with temperatures above 0^{o}C in most years. There were exceptions however, for example, the spring of 1991 showed many non-zero catches in sub-zero ^{o}C water, while the spring of 1996 showed many zero catches in >0^{o}C water. During the warm years of 1998 and 2000 however, much larger catches were found in Div. 3L and more non-zero catches were found further north in the central part of 3L as warmer bottom water (>0^{o}C) spread further northward (Fig. 2c). Sets in the inshore and those along the shelf break continued to show zero catches for all years.

In recent years the centroid of the biomass of yellowtail flounder has been located within Divs. 3NO centred over the southeast shoal of the Grand Bank. This area corresponds to the warmest bottom temperatures found anywhere on the Newfoundland Shelf. Spring bottom temperatures in this region range from a minimum of 1-2^{o}C during cold years (1990) to 3-4^{o}C during warm years (1998 and 1999). Fall bottom temperatures are in general warmer than spring values ranging from 2-3^{o}C in most years to maximum values of between 7-8^{o}C during extreme years (1999). While the abundance of yellowtail flounder in this region was significant from 1990-1995, there was a sudden increase in catch rates during the fall of 1995 and these rates continued to increase from 1997 to 2000. During this time period the spatial extent of larger catch rates also expanded as the area of >0^{o}C water covered the entire 3NO region.

The percentage area of the habitat for this species on the Grand Bank covered with bottom temperatures in 1^{o}C temperature bins are shown in Figs. 4 and 5 (top panels) for the spring and fall periods, respectively. The average number of fish caught per fishing set in 1^{o}C-temperature bins are also shown in Figs. 4 and 5 (bottom panels) for the spring and fall surveys periods. Except for the high spring catches in the 1-2^{o}C temperature range during 1990 and 1991 catch rates have increased substantially from the early 1990s and have shifted into the higher temperature ranges. During the same time period the thermal conditions of the habitat has shifted from mostly covered by sub-zero ^{o}C water during the first half of the decade, to the much warmer environment of the latter years of the 1990s.

Time series of the areal extent of the bottom covered by water in 1^{o}C temperature bins together with the mean bottom temperature and the mean relative number and weight of yellowtail for the survey are shown in Figs. 6 and 7, for the spring and fall surveys, respectively. During the spring the mean bottom temperature increased gradually from the low (<0^{o}C) in 1990 to >1.5^{o}C by 1999. Correspondingly, the percentage area of the bottom covered with water <0^{o}C decreased from over 60% in 1991 to less than 10% in 1999. The increase in both the mean number and weight of yellowtail during spring and fall coincides with the change in the thermal habitat around the mid-1990s. In addition, the total catch continued to increase from the mid-1990s up to 1999 as bottom temperatures in the region continued to increase.

In an initial effort to investigate temperature preferences of yellowtail flounder, cumulative distributions of available temperature and catch numbers were computed based on all data from the spring and fall 3LNO stratified surveys for the time period 1990-2000, these are displayed in Fig. 8. The distributions have not been weighted by sampling intensity within each stratum or by stratum area. The cumulative frequency distribution of the number of sets for each temperature bin shows the temperature available to the survey and the cumulative distributions of catch numbers show the distribution of catches in relation to the available temperature. An initial interpretation of this result indicates that less than 10% of the catches on average are associated with sub-zero ^{o}C water, while 50% of the surveyed region is covered with <0^{o}C water. Also, during the fall a greater proportion (30%) of the fish are associated with temperatures greater than 4^{o}C as a result of summer heating of the shallower bottom areas of the southeast shoal. While these preliminary results clearly indicate a temperature preference, the distributions may be explained by other factors, therefore, a more detailed analysis is required.

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 to 2000 with approximately 60% of the bottom covered by water >2^{o}C by the fall of 1999 in water depths 100 m. The 1998 and 1999 values represent 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 during 1993.

From 1990 to 1994 the abundance of yellowtail flounder remained at a near constant level, however beginning in 1995 both the abundance and average weight of the catches per set increased significantly. This sudden increase coincided with both a significant increase in bottom temperature and with the implementation of the new Campelen 1800 shrimp trawl, which is more efficient at catching smaller fish. From 1997 to 1999 the mean number and weight per set continued to increase as the mean bottom temperature increased further to a maximum in 1999. The spatial extent of larger catches and smaller non-zero catches in both 3L and 3NO also increased as the area of warmer water covered an increasingly larger area of the region. For example, catches in 3L during the spring of 1999 reached its most northern extent in recent years with non-zero catches above 47^{o} N, coinciding with the warmest water on the Grand Banks since the early 1980s.

There may be several possible reasons for these observations. The striking similarity between the trends in the mean bottom temperature and both the average numbers and weight per set may indicate a temperature dependent increase in catchability. Although the numbers of fish from the 1990-1994 surveys have been converted to equivalent Campelen trawl units there may be some residual effects remaining in the series, which may have contributed to the sudden increase in 1995. However, there was a steady increase in the abundance from 1997 up to 1999 that coincided with a further increase in bottom temperatures. Therefore it is possible that the recent increase in water temperature in the area may have made the Grand Bank a more suitable environment for yellowtail spawning success and possibly improved survival and growth rates. These results, albeit preliminary, indicate a temperature preference towards the warm water habitat of the Grand Banks although the distributions may be explained by factors other than temperature, for example, water depth, bottom substrate, prey distribution or other unknown environmental variables. Finally, we note that since the spring of 1998 there has also been a significant increase in the number of cod caught per tow of fish at age 3-years and less in survey sets on the Grand Bank. These observations indicated an improvement in the recruitment of cod in Divisions 3NO probably as a result of an improved thermal environment (Colbourne and Murphy, 2000). A more detailed analysis of the current data sets may provide a more definite assessment of environmental effects on this species that may help to explain some of the year effects observed in the assessment surveys.

Acknowledgements

We thank S. Walsh for helpful comments and suggestions. We also thank the many scientists and technicians at the NAFC for collecting and providing much of the data contained in this analysis and to the Marine Environmental Data Service in Ottawa for providing most of the historical oceanographic data.

References

Bishop, C. A. 1994. Revisions and additions to the stratification scheme used during research vessel surveys in NAFO Subareas 2 and 3. NAFO SCR. Doc 94/43 Serial No. N2413. 23p.

Colbourne E. B. and E. F. Murphy. 2000. Recent trends in bottom temperatures and distribution and abundance of Atlantic cod (*Gadus morhua*) in NAFO Divisions 3LNO during spring and fall. NAFO SCR. Doc 00/20 Serial No. N4249. 30p.

Colbourne, E. B. 2000 Oceanographic conditions in NAFO Divisions 2J 3KLMNO during 1999 with comparisons to the long-term (1961-1990) average. DFO RES DOC. 2000/48. 52p.

Doubleday, W. G., Editor. 1981. Manual on groundfish surveys in the Northwest Atlantic. NAFO Sci. Coun. Studies, 2: 56p.

Drinkwater, K. F., R. Pettipas, L. Petrie and D. P. Swain. Temperature conditions in the Gulf of St. Lawrence and on the Scotian Shelf during 1997 relevant to Snow Crab. DFO RES DOC. 98/56. 30p

Murphy E. F. 1996. Corrections to the stratification scheme in 3Ps. NAFO SCR Doc. 96/55 Serial No. N2731. 11p.

Narayanan, S., S. Prinsenberg and E. B. Colbourne. 1992. Overview of environmental conditions in 2J3KL NAFO subareas in 1991. NAFO SCR Doc. 92/6, Serial No., N2029.

Walsh S. J., M. J. Veitch, M. J. Morgan, W. R. Bowering and W. B. Brodie. 2000. Distribution and abundance of yellowtail flounder *(Limanda ferruginea*) on the Grand Bank, NAFO Divisions 3LNO, as derived from annual Canadian bottom trawl surveys. NAFO SCR. Doc 00/35 Serial No. N4264. 54p.

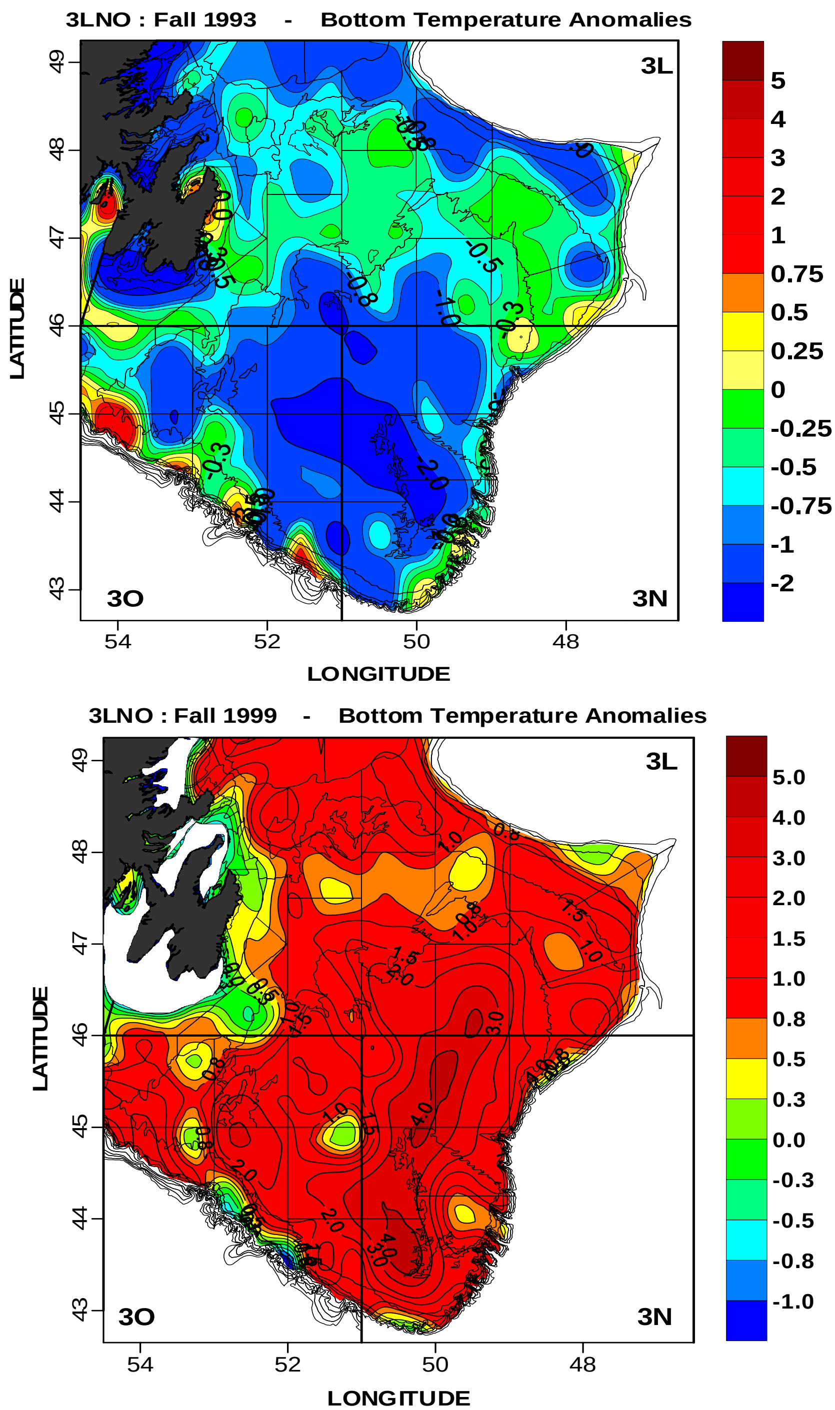


Fig. 1. Contour maps of bottom temperature anomalies (in °C) for the **fall** of 1993 and 1999 for NAFO Divisions 3LNO. The anomalies are referenced to all available data collected in the area from 1961-1990.

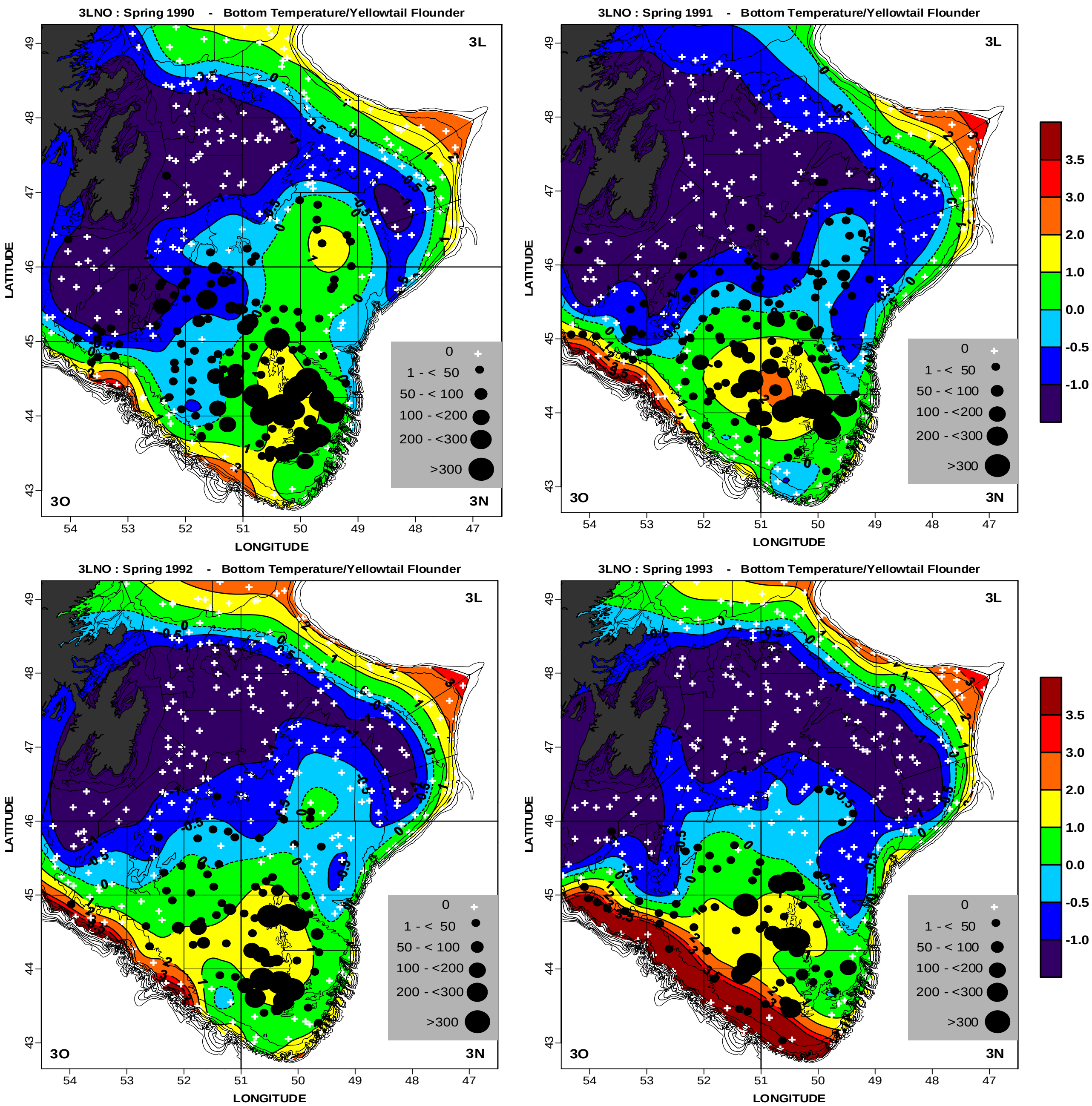


Fig. 2a. Bottom temperature contour maps (in °C) for the **spring** of 1990-1993 from the annual 3LNO survey. The numbers of yellowtail flounder in each fishing set are shown as solid circles. The crosses represent zero catches.

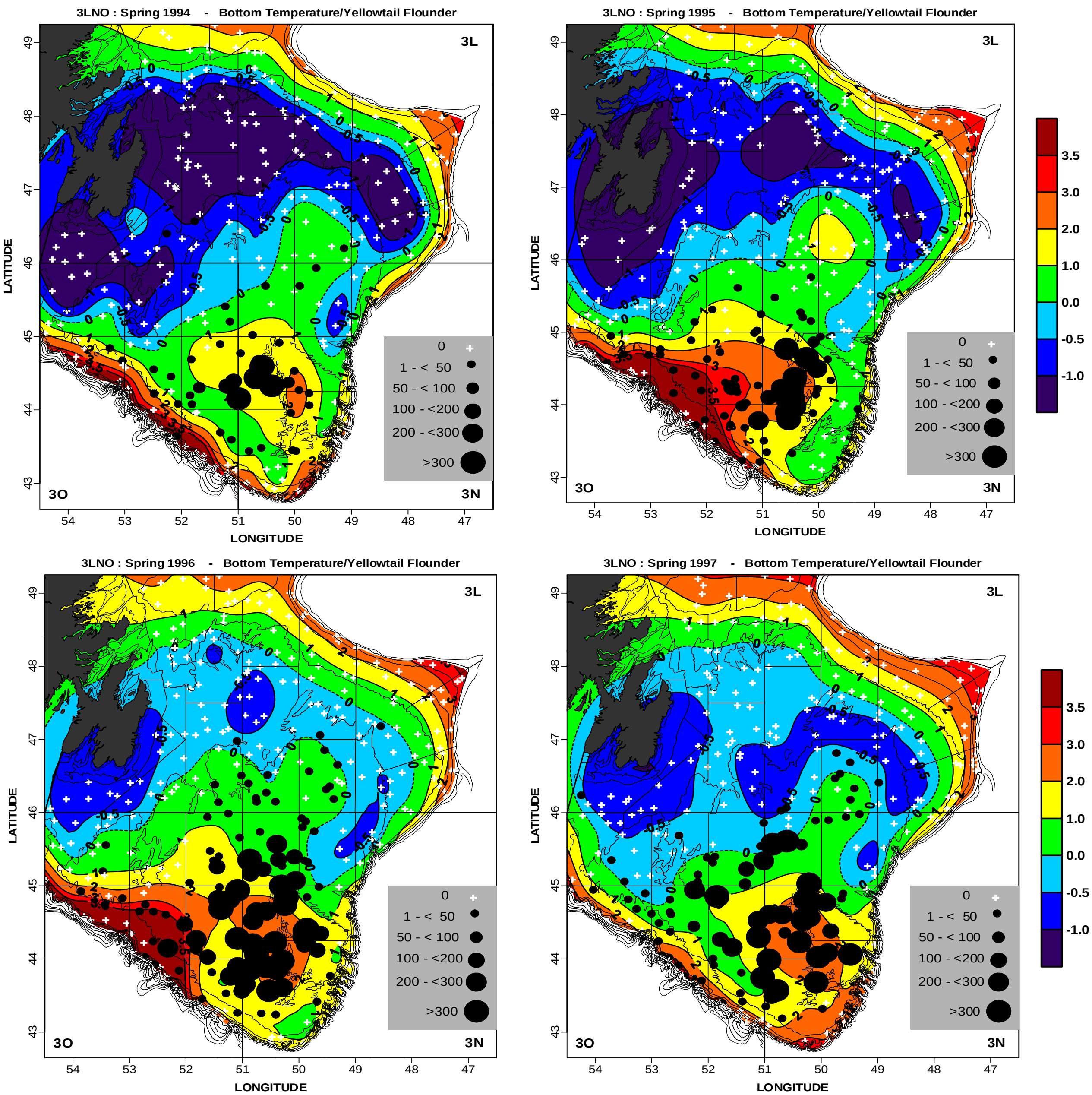


Fig. 2b. Bottom temperature contour maps (in °C) for the spring of 1994-1997 from the annual 3LNO survey. The numbers of yellowtail flounder in each fishing set are shown as solid circles. The crosses represent zero catches.

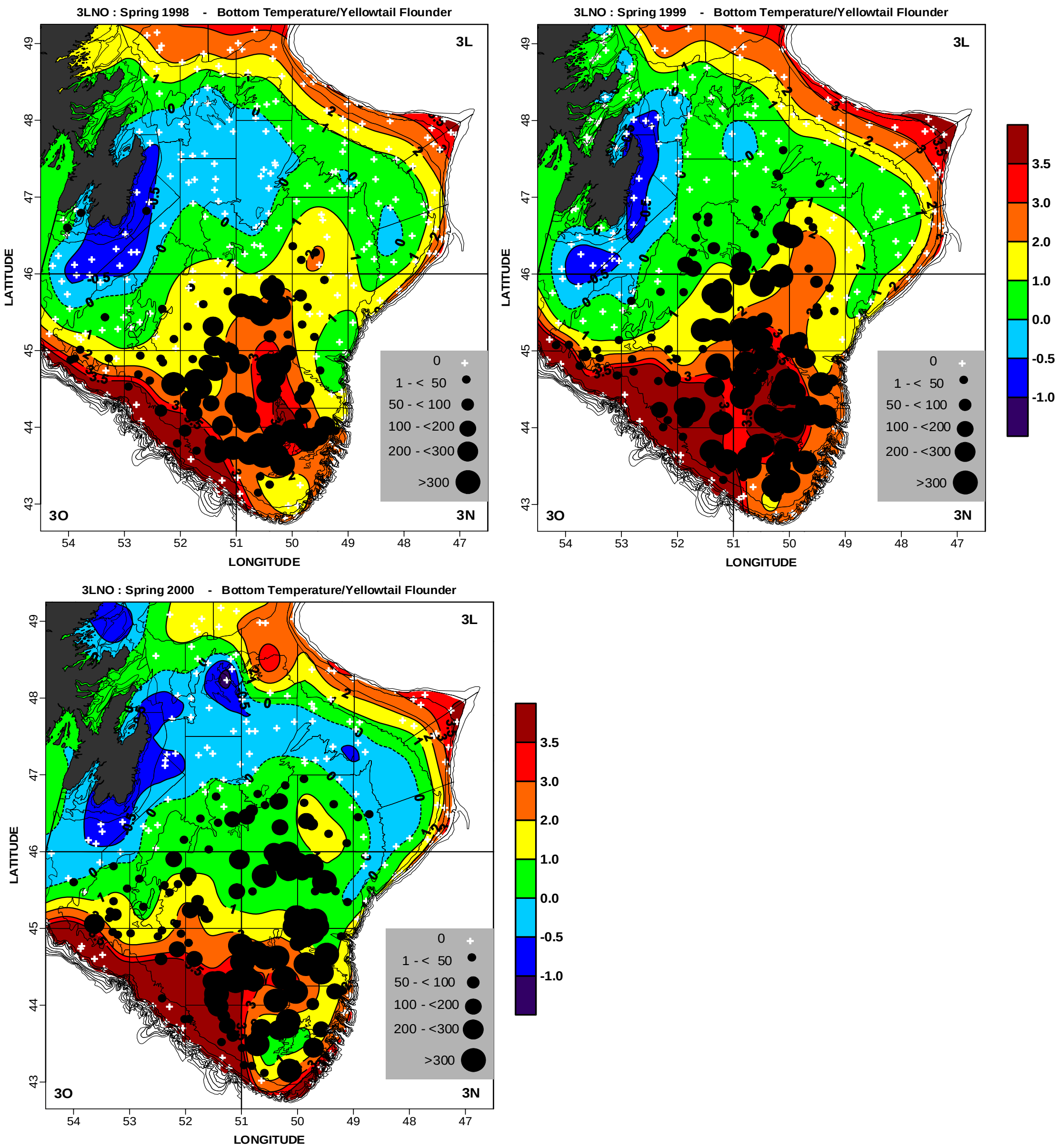


Fig. 2c. Bottom temperature contour maps (in °C) for the **spring** of 1998-2000 from the annual 3LNO survey. The numbers of yellowtail flounder in each fishing set are shown as solid circles. The crosses represent zero catches.

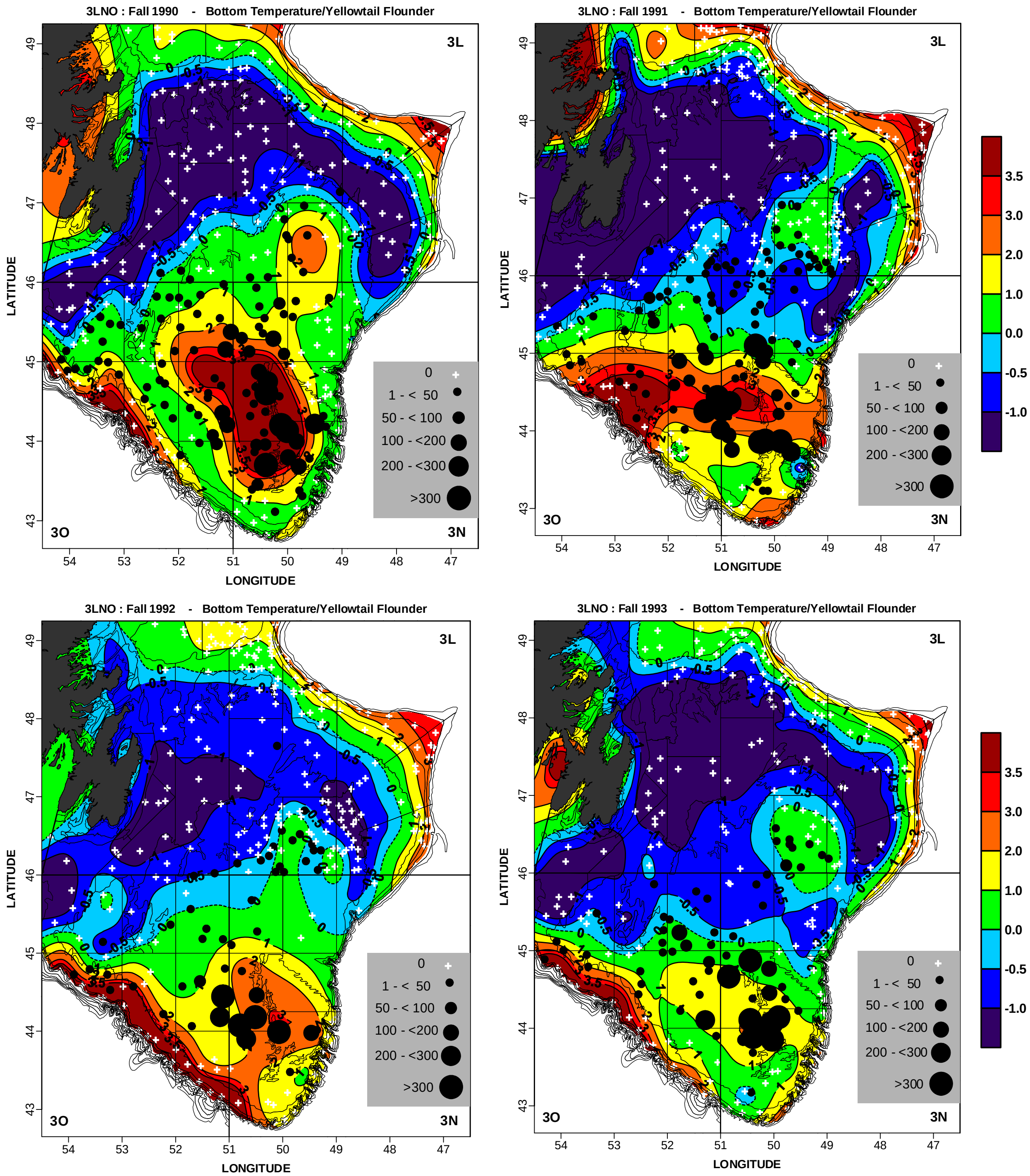


Fig. 3a. Bottom temperature contour maps (in °C) for the **fall** of 1990-1993 from the annual 3LNO survey. The numbers of yellowtail flounder in each fishing set are shown as solid circles. The crosses represent zero catches.

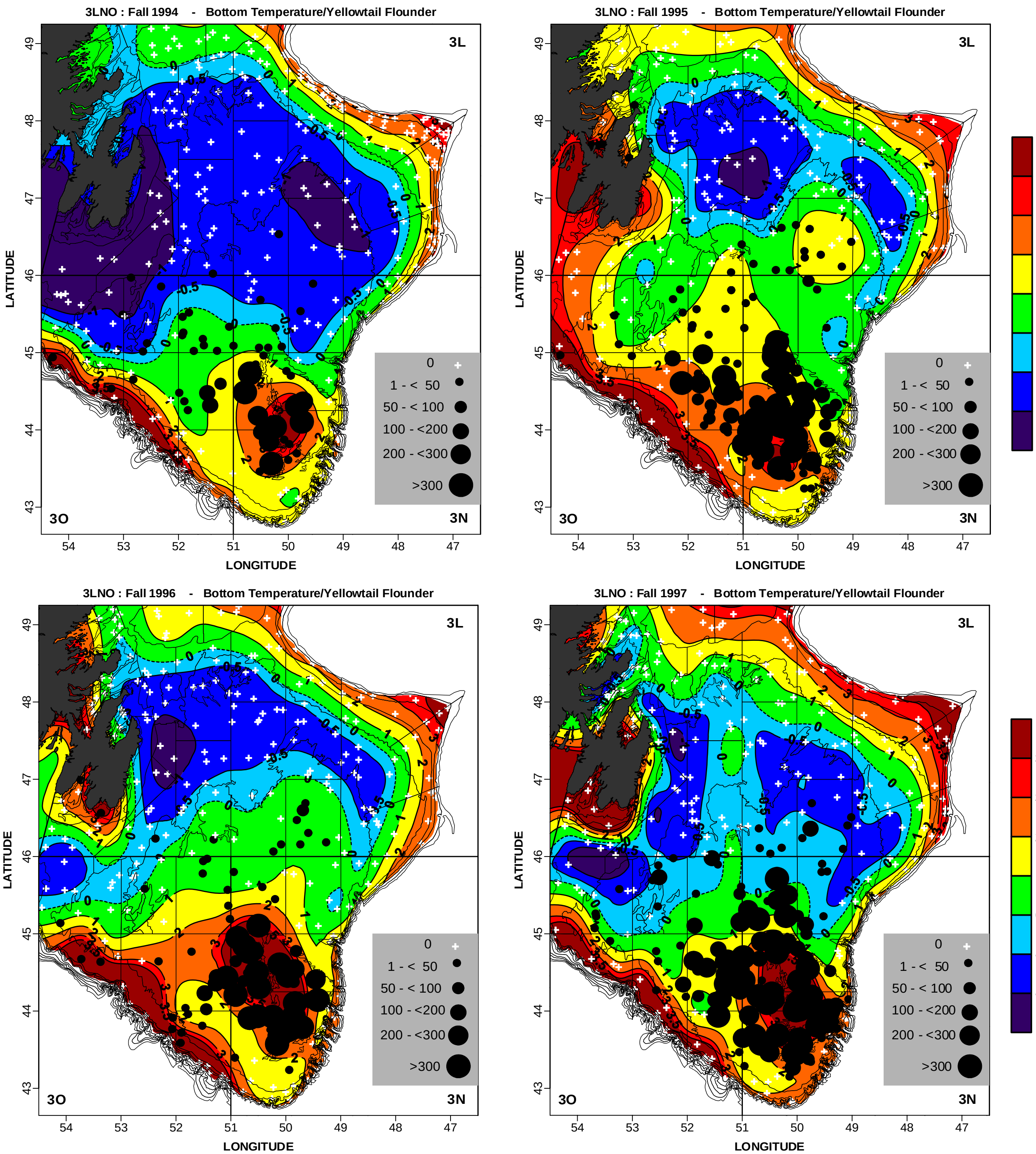


Fig. 3b. Bottom temperature contour maps (in °C) for the fall of 1994-1997 from the annual 3LNO survey. The numbers of yellowtail flounder in each fishing set are shown as solid circles. The crosses represent zero catches.

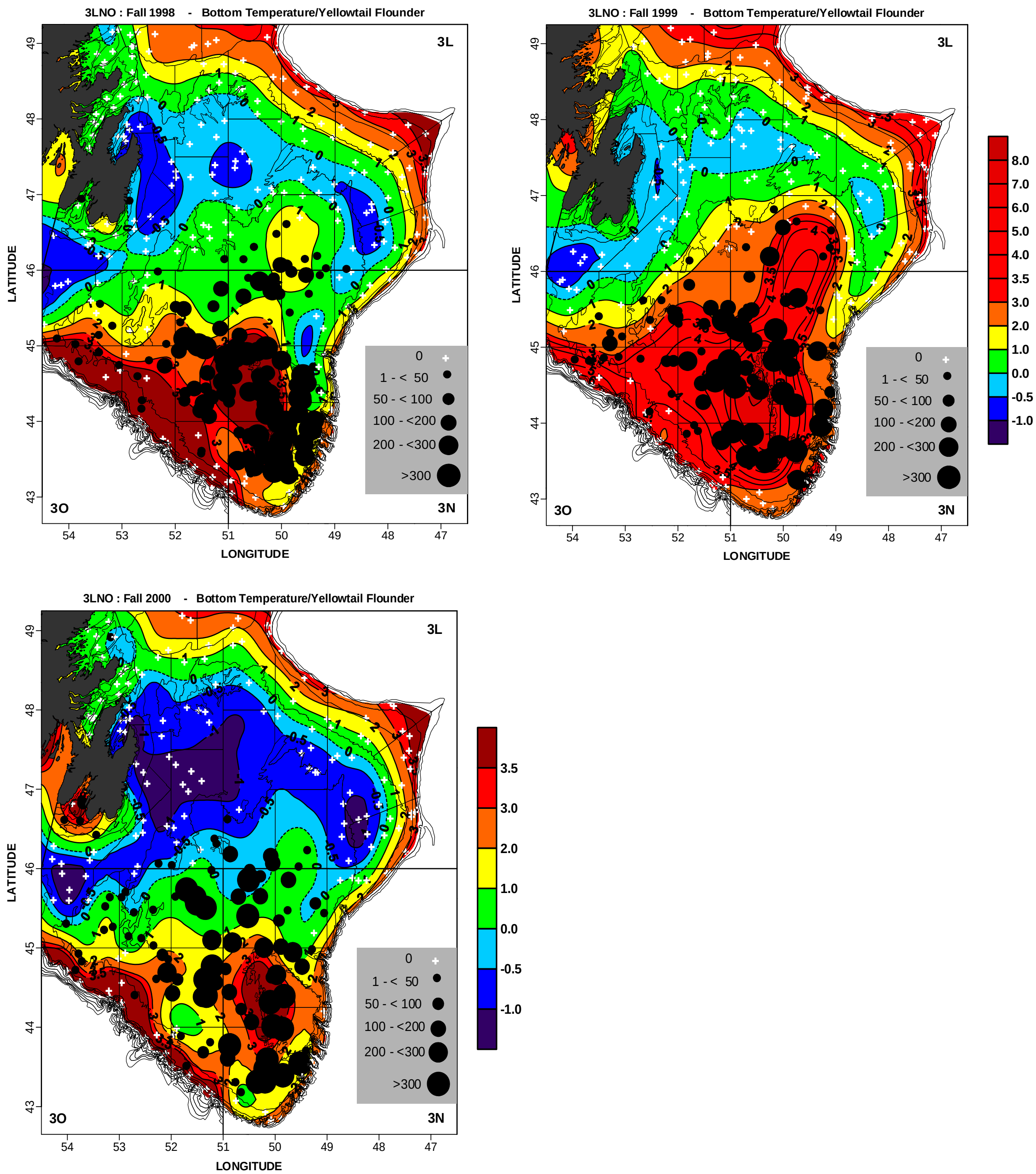
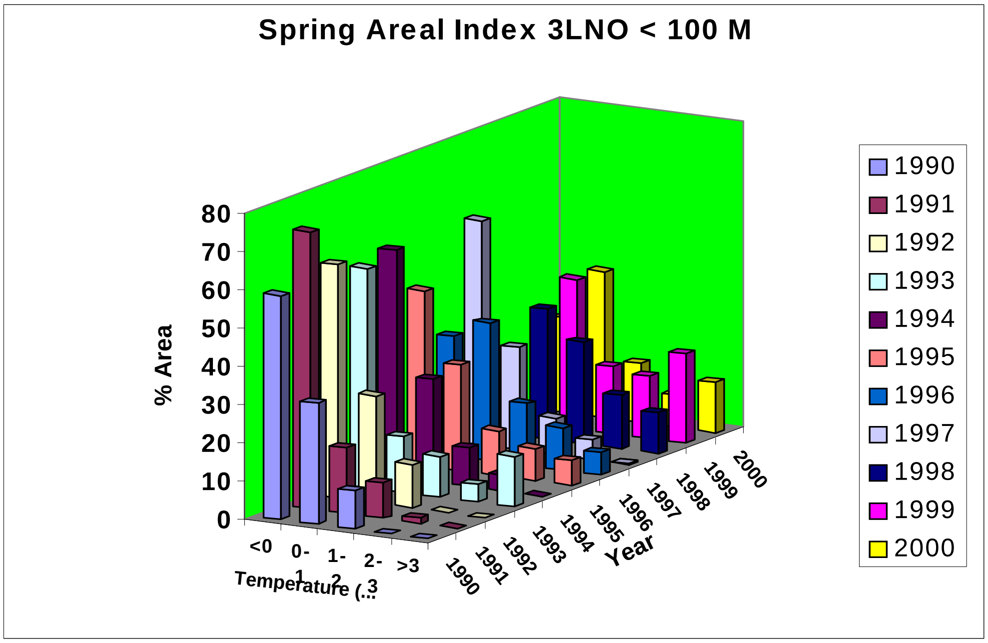


Fig. 3c. Bottom temperature contour maps (in °C) for the **fall** of 1998-2000 from the annual 3LNO survey. The numbers of yellowtail flounder in each fishing set are shown as solid circles. The crosses represent zero catches.



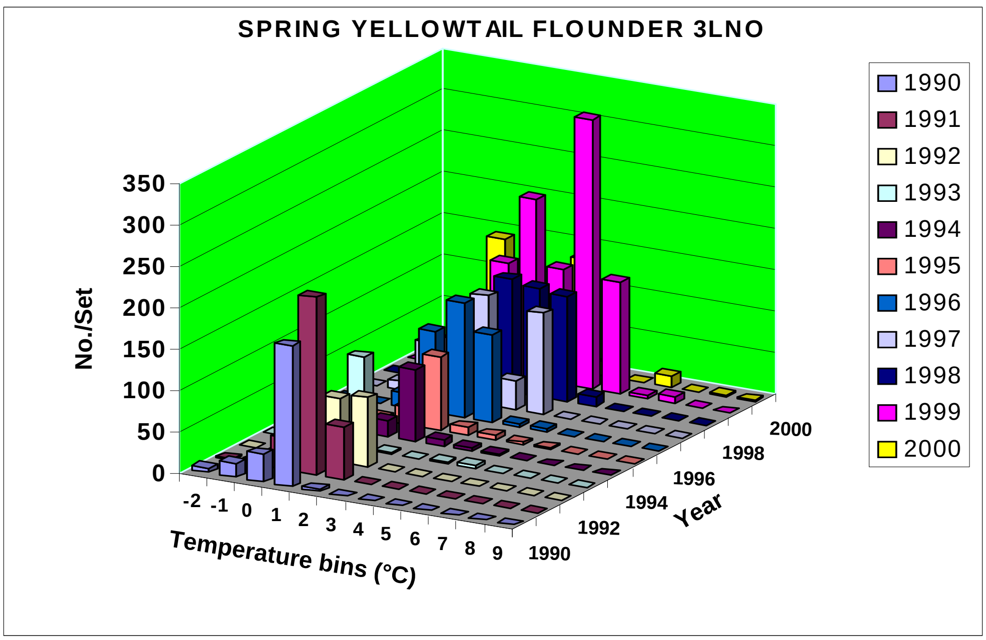
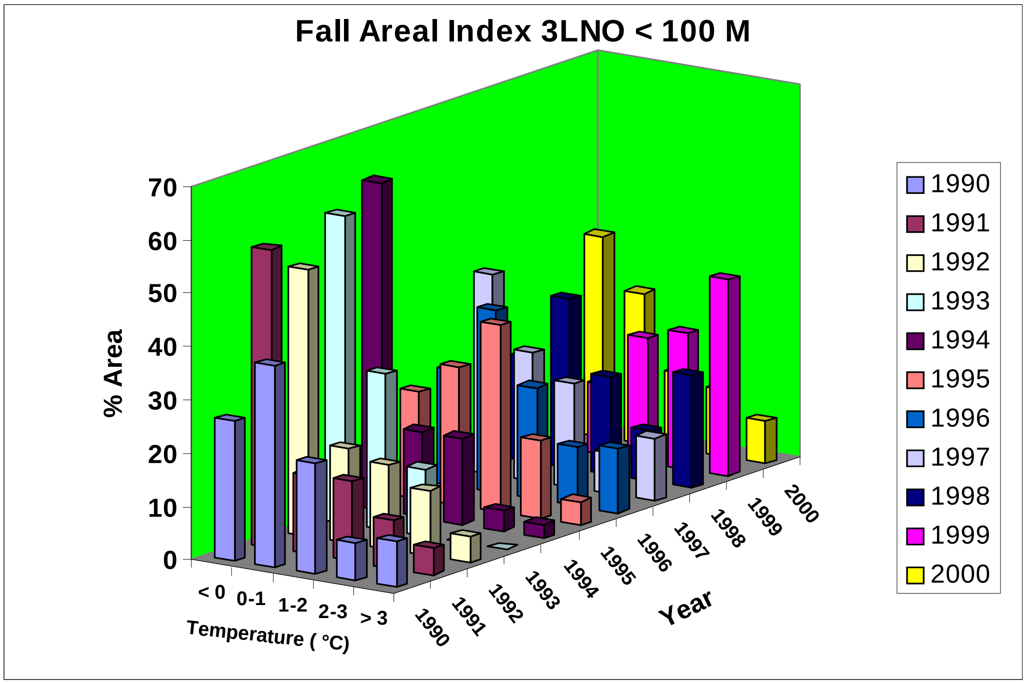


Fig. 4. The percentage area of the bottom covered by water in temperature bins of <0°C, 0-1°C, 1-2°C, 2-3°C and >3°C for the **spring** in NAFO Divs. 3LNO for water depths ≤100-m (top panel) and the average number of yellowtail flounder per fishing set in 1°C temperature bins (bottom panel).



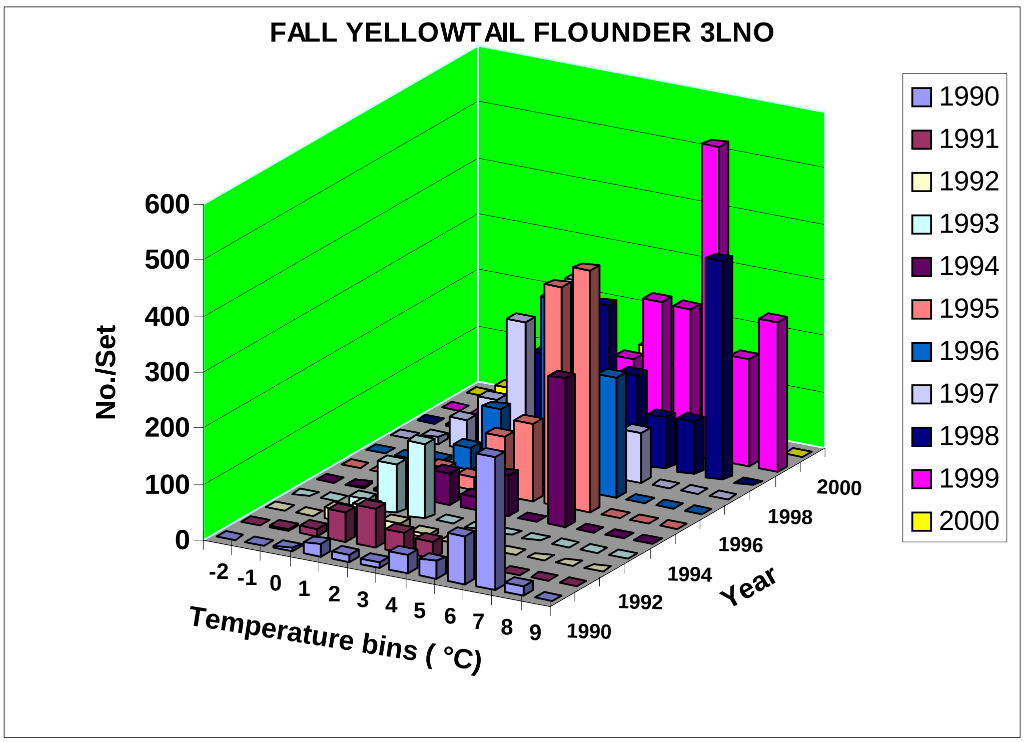


Fig. 5. The percentage area of the bottom covered by water in temperature bins of <0°C, 0-1°C, 1-2°C, 2-3°C and >3°C for the **fall** in NAFO Divs. 3LNO for water depths ≤100-m (top panel) and the average number of yellowtail flounder per fishing set in 1°C temperature bins (bottom panel).

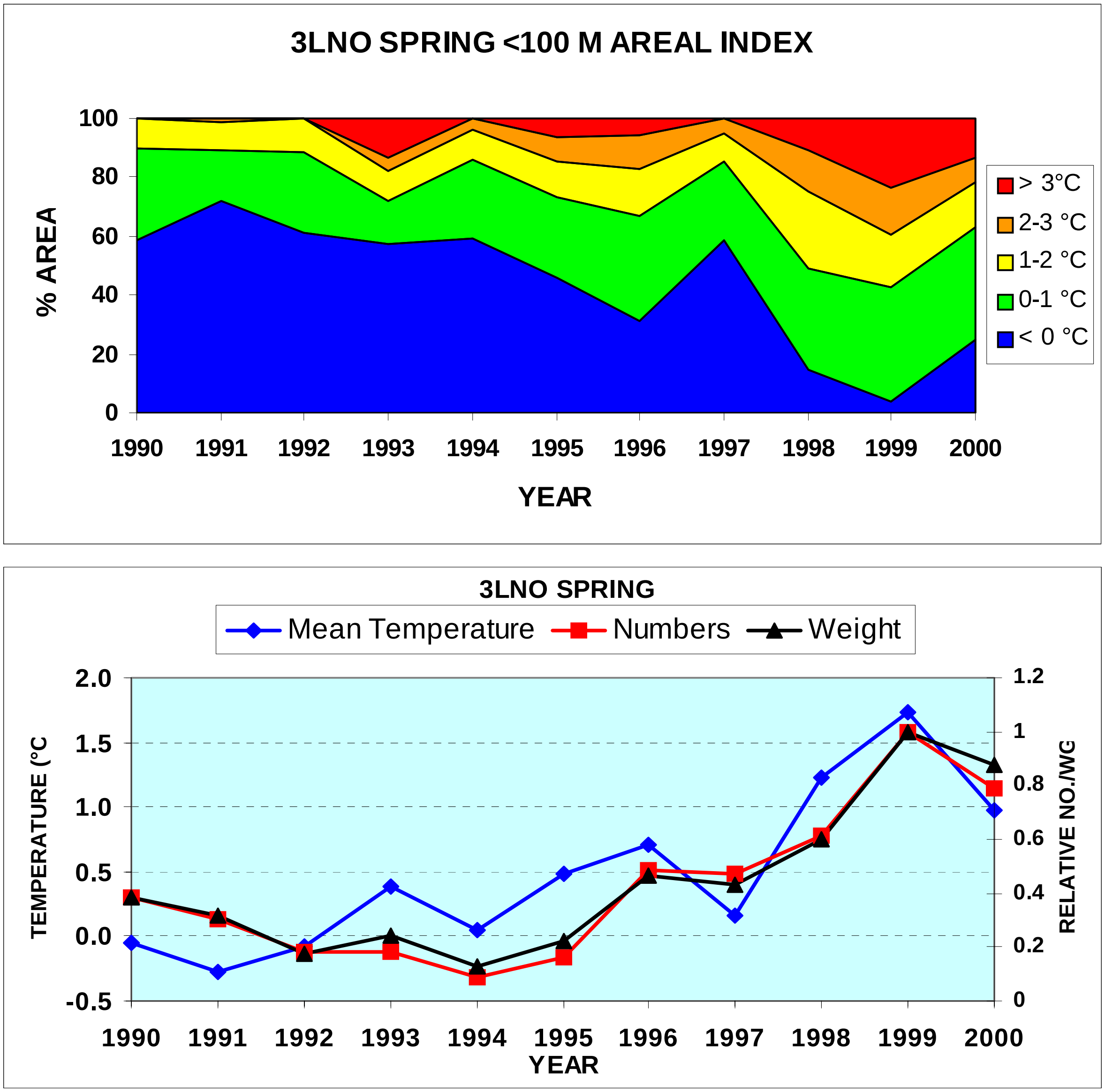


Fig. 6. Time series of the percentage area of the bottom covered by water in temperature bins of <0°C, 0-1°C, 1-2°C, 2-3°C and >3°C for the **spring** in NAFO Divs. 3LNO for water depths ≤100-m (top panel) and the mean bottom temperature together with the mean relative numbers and weight of fish per set for the survey (bottom panel).

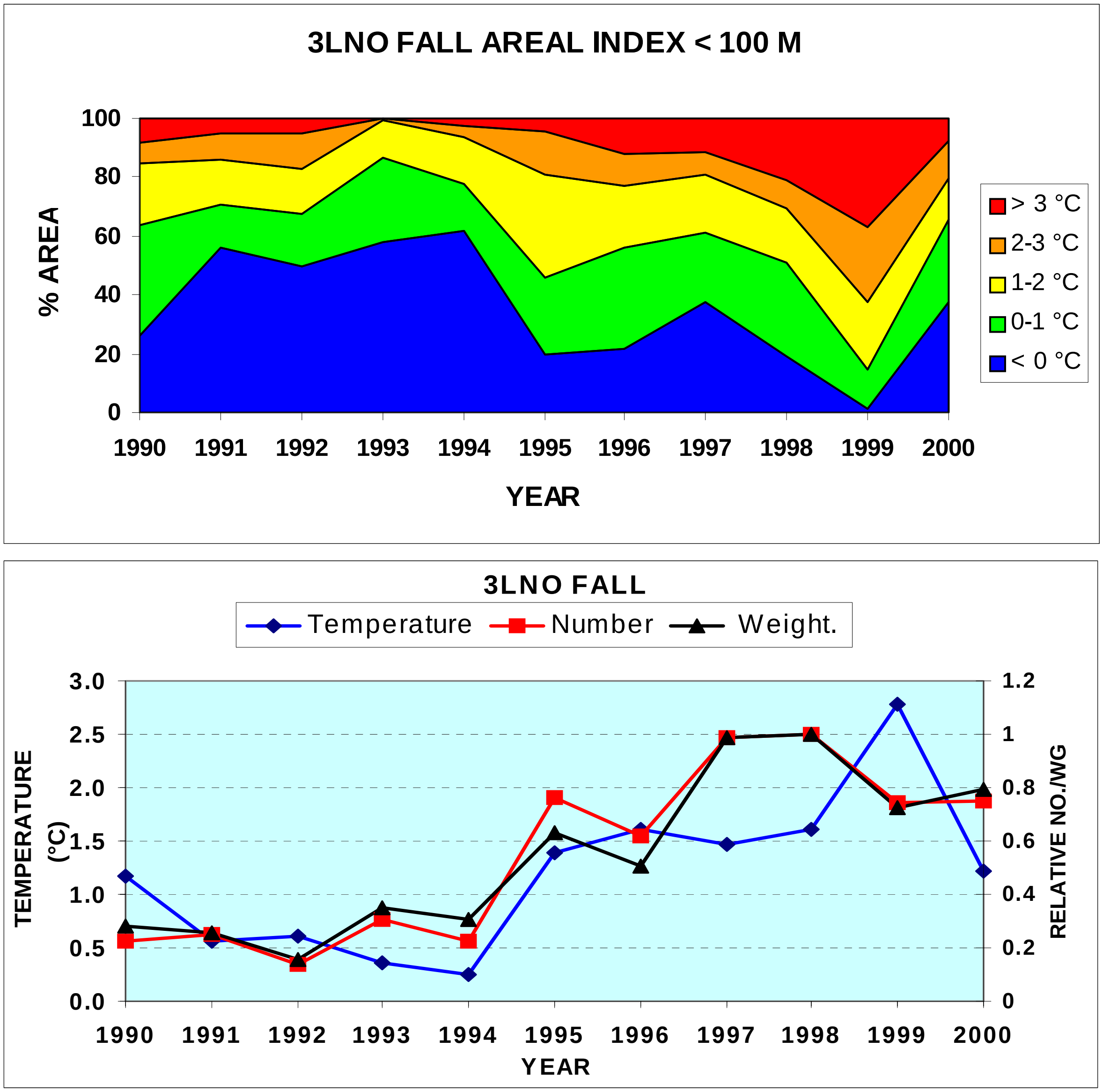


Fig. 7. Time series of the percentage area of the bottom covered by water in temperature bins of <0°C, 0-1°C, 1-2°C, 2-3°C and >3°C for the **fall** in NAFO Divs. 3LNO for water depths ≤100-m (top panel) and the mean bottom temperature together with the mean relative numbers and weight of fish per set for the survey (bottom panel).

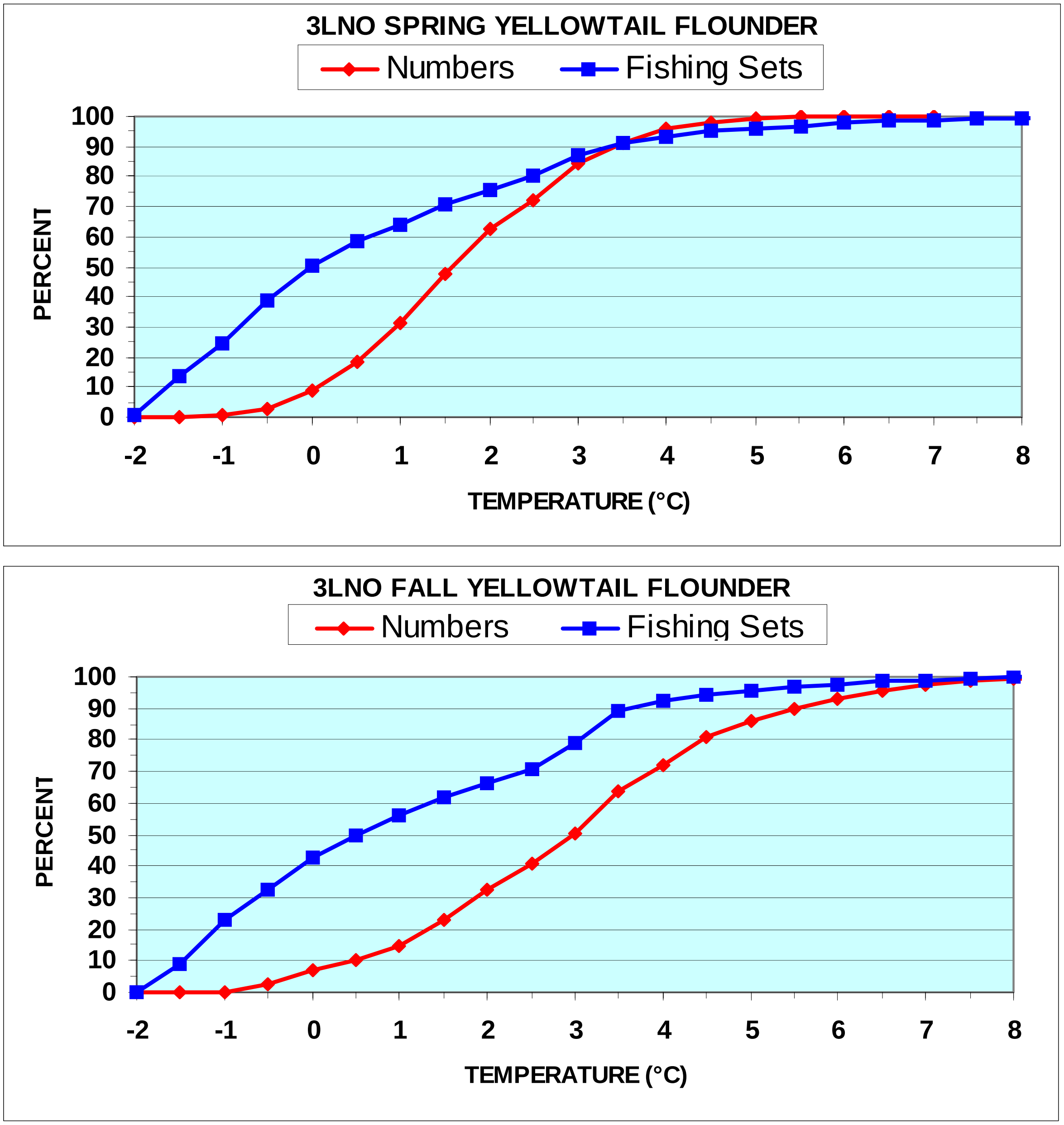


Fig. 8 Cumulative frequency distributions of the number of sets in the 3LNO survey in 1°C temperature bins and the cumulative frequency distribution of the number of fish caught in 1°C temperature bins for the **spring** (top panel) and **fall** (bottom panel) surveys.