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The Distribution and Abundance of Yellowtail Flounder (*Limanda ferruginea*) in Relation to Bottom Temperatures in NAFO Divisions 3LNO Based on Multi-Species Surveys from 1990-2005

by

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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 years 1990 to 2005. The thermal habitat in the 3LNO region has shifted from mainly cold sub-zero °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°C by the fall of 1999 in water depths ≤100 m. Since the record-warm year of 1999 temperatures began to decrease reaching the lowest value since 1994 in the spring of 2003. During 2004 and 2005 however bottom temperatures recovered to warmer than normal values, similar to the late 1990s. The shift in the thermal habitat from the cold sub-zero °C conditions of the first half of the 1990s to a relatively warm environment during the latter half of the 1990s and early 2000s resulted in an increase in bottom temperatures to >0°C values over almost 100% of the traditional bottom habitat of yellowtail flounder on the Grand Bank. Coincident with these changes there has been a significant increase in the number of yellowtail flounder per tow in survey sets in Div. 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. A strong association was found between bottom temperatures and mean catches rates in water depth <100 m on the southern Grand Bank with catch rates increasing with temperature. The results are discussed in terms of an improved thermal environment and other factors, possibly resulting in an associated increase in catchability and distribution.

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 Div. 3L, 3N and 3O with inshore strata in Div. 3L being fished only in the spring of 1999 and the fall of 1996-1999. In spring the surveys were conducted in Div. 3L from 1971-2005, except 1983 and 1984, in Div. 3NO from 1971-2005, except 1983 in 3N and 1972, 1974 and 1983 in Div. 3O, in water depths to 730 m in most years and more recently to 1500 m. Surveys were conducted in the fall in Div. 3L from 1981-2005, in Div. 3N from 1990-2005 and in Div. 3O from 1990-2005 covering depths to 730 m in most years and to 1 500 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 of yellowtail flounder have indicated a significant increase in the biomass and abundance 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 2001. In addition, the population has also expanded its range onto the northern Grand Bank in Div. 3L (Simpson and Walsh, 2003). The purpose of this analysis is to review the recent trends in the distribution and abundance of yellowtail flounder in relation to their thermal habitat by updating the analysis presented in Colbourne and Bowering (2001). Inter-annual variations in the bottom temperature are compared to the mean catch rates for each survey and the spatial distribution of yellowtail in relation to the near-bottom temperature fields is presented.

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°C in temperature and 0.005 in salinity. The XBTs are accurate to within 0.1°C.

Near-bottom temperature grids for NAFO Div. 3LNO were produced from all available data for spring and fall surveys separately for the years 1990 to 2005. 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 mean near-bottom temperature based on this interpolated grid was constructed for each year for both spring and fall surveys. 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 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. The cumulative frequency distributions of catch numbers for each temperature bin are compared to the available temperature distribution within the Div. 3LNO region for all surveys from 1990-2005. For the purpose of this preliminary analysis, these distributions are not weighted by sampling intensity or stratum area. Finally the number of yellowtail flounder per set is displayed with the temperature contours from 1990 to 2005 for the spring and fall surveys in NAFO Div. 3LNO.

Results

The temperature maps displayed in Fig. 1 show examples of the extremes in bottom thermal habitat experience on the Grand Banks in recent years. Within the decade of the 1990s bottom temperatures ranged from record cold conditions the near-record highs 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°C below normal, but also as low as 2°C below normal in some regions of Div. 3NO. By the middle of the decade however, temperatures moderated and were above normal over most areas by 1999 with anomalies on the entire northern Grand Bank up to 1°C above average. Over the central and southern Grand Bank bottom temperatures were even higher ranging from 1-4°C above the long-term average. After 1999 bottom temperatures started to decrease reaching a minimum by 2003 before increasing again in 2004 and 2005 (Fig. 1).

To quantify the temperature habitat of yellowtail flounder on the Grand Bank, cumulative distributions of available temperature and catch numbers were computed based on all data from the spring and fall Div. 3LNO stratified surveys for the time period 1990-2005, these are displayed in Fig. 2. 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 about 10% of the catches on average are associated with <0°C water, while between 40 to 50% of the surveyed region is covered with <0°C water. Also, during the fall a greater proportion (40%) of the fish are associated with temperatures >3°C as a result of summer heating of the shallower bottom areas of the southeast shoal. While these results clearly show a limited thermal habitat, the distributions may be explained by other factors such a bottom substrate and therefore do not necessarily indicate a temperature preference by yellowtail flounder.

The average number of fish caught per fishing set in 1°C-temperature bins are displayed in Fig. 3 for both the spring and fall surveys. Except for the high spring catches in the 1°-2°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 <0°C water during the first half of the 1990s to the much warmer environment of recent years. In addition, catch rates are significantly higher on the southeast Grand Bank during the fall when temperature conditions are warmer compared to spring values.

Time series of the mean bottom temperature and the mean relative number and weight of yellowtail flounder are displayed in Fig. 4 for the spring and fall surveys, respectively. During the spring mean bottom temperature increased gradually from the low (<0°C) in 1990 to >1.5°C by 1999 and then declined to near 0°C in 2003. During 2004 and 2005 temperatures have again increased to >1°C on the Grand Banks in water depths <100 m. During the fall temperatures were generally warmer than spring values by about 0.5-1.0°C however the trends followed a similar pattern. The increase in both the mean number and weight of yellowtail during spring coincided with the warming 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. After 1999 the catches declined with temperature until 2002. Catch rates increased again in 2003 however spring temperatures decreased to the lowest since 1994.

The spring and fall bottom temperature maps together with the number of fish caught per set for Div. 3LNO are shown in Fig. 5 and 6 for the years 1990 to 2005. In general, spring bottom temperatures in the northern areas ranged from <0°C in the inshore regions of the Avalon Channel to over 3°C at the shelf edge. Over the central and southern areas bottom temperatures ranged from 1°C to above 3.5°C on the Southeast Shoal and above 3°C along the edge of the Grand Bank. During the cold years from 1990-1995 virtually the entire Div. 3L area (except the deeper slope regions) and a significant portion of Div. 3NO was covered by <0°C water. Beginning around 1996 (Fig. 5b) the area of sub-zero °C water began to retract and by 1998 and 1999 it was restricted to a small area in the Avalon Channel (Fig. 5c). During the fall temperatures in 3L were very similar to spring values with <0°C water covering most of the area during the cold years of 1990 to 1994 (Fig. 6a and 6b). 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°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 as expanding symbols proportional to the catch rates. The majority of fishing sets in Div. 3L shows zero catches in water deeper than 100 m. In the southern part of Div. 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°C in most years. There were exceptions however, for example, the spring of 1991 showed many non-zero catches in sub-zero °C water, while the spring of 1996 showed many zero catches in >0°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 Div. 3L as warmer bottom water (>0°C) spread further northward (Fig. 5c and d). 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 Div. 3NO centred over the southeast shoal of the Grand Bank. This area corresponds to some of the warmest bottom temperatures found anywhere on the Grand Banks. Spring bottom temperatures in this region range from a minimum of 1-2°C during cold years (1990) to 3-4°C during warm years (1998 and 1999). Fall bottom temperatures are in general warmer than spring values ranging from 2-3°C in most years to maximum values of between 7-8°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 1999. During this period the spatial extent of larger catch rates also expanded as the area of >0°C water covered the entire Div. 3NO region.

Discussion and Summary

The thermal habitat in the Div. 3LNO region has shifted from mainly cold sub-zero °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°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 with temperatures above normal over the entire Div. 3LNO area by 1°C above average in the north and up to 4°C above normal on the Southeast Shoal of the Grand Bank. By contrast, during the cold years of the early 1990s virtually the entire Div. 3L area and a significant portion of 3NO was covered by sub-zero °C water, with anomalies reaching at least 0.5°C below normal, but also as low as 2°C below normal in some regions during 1993. Since the record-warm year of 1999 temperatures began to decrease reaching the lowest value since 1994 in the spring of 2003. During 2004 and 2005 however bottom temperatures recovered to warmer than normal values.

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 in the fall of 1995, 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 Div. 3L and 3NO also increased as the area of warmer water covered an increasingly larger area of the region. For example, catches in Div. 3L during the spring of 1999 reached its most northern extent in recent years with non-zero catches above 47°N, coinciding with the warmest water on the Grand Banks since the early 1980s. Since 1999, with the exception of 2002, catch rates have remained significantly higher that those before 1995. With the exception of 2003 spring bottom temperatures have also been higher than they were in the early 1990s. The cold values observed in the spring of 2003 were anomalous and lasted from April to June and were above average during the remainder of the year (Colbourne *et al.*, 2004).

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. Temporal and spatial changes in bottom temperatures have been linked in the literature to changes in catchability (see Winger and Walsh 2001 for a review). It generally implies that at low temperatures fish are more easily caught, i.e. a change in vulnerability, because of changes in swimming endurance brought on by reduced metabolic activity. However, Winger *et al.*, 2000 could not find a temperature effect on swimming endurance in cod when measured in swimming flume tank experiment. In addition, swimming endurance has been shown experimentally to increase with temperature in American plaice which could improve the herding response and hence catchability (Winger *et al.*, 1999).

Bottom temperatures have also been shown to influence the spatial pattern of yellowtail flounder (Simpson and Walsh, 2003) and cod (Swain and Kramer, 1995; Swain *et al.*, 2000). Simpson and Walsh, 2003 using a non-parametric General Additive Model of mean number per tow, with depth temperature, location and sediment type showed that when the population density was low in the early 1990s the spatial distribution of yellowtail flounder were concentrated in preferred habitats south of 45°N and temperature and depth played an influential role in their distribution. However, as the population densities increased during the mid -to-late 1990s the availability of preferred habitats declined and the spatial extent expanded northward with temperature exerting less influence. In both cases depth was a large contributing factor to the spatial pattern and sediment type represented less than 2%. Walsh et al.

2006 have examined in a cursory manner the areal extent of yellowtail distribution on the southern Grand Bank, Div. 3NO above 45°N (top of Southeast Shoal) from 1973 to 2005. When the stock size was high during the 1970s-1980s over 30% of the biomass was found north of 45°N and when the stock declined in the early 1990s less than 10% was found in that area, exception was 1993 (30%). Since the fall of 1995 the areal extent northward has shown an increase with the proportion of the biomass being higher in the spring (up to 45% in 2005) than in the fall, with one exception 2002. This implies that density may have an effect on catchability.

In summary there was a steady increase in the abundance of yellowtail flounder coinciding with a northward expansion of the stock from 1995 up to 2005 that coincided with a further increase in bottom temperatures. This 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. 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

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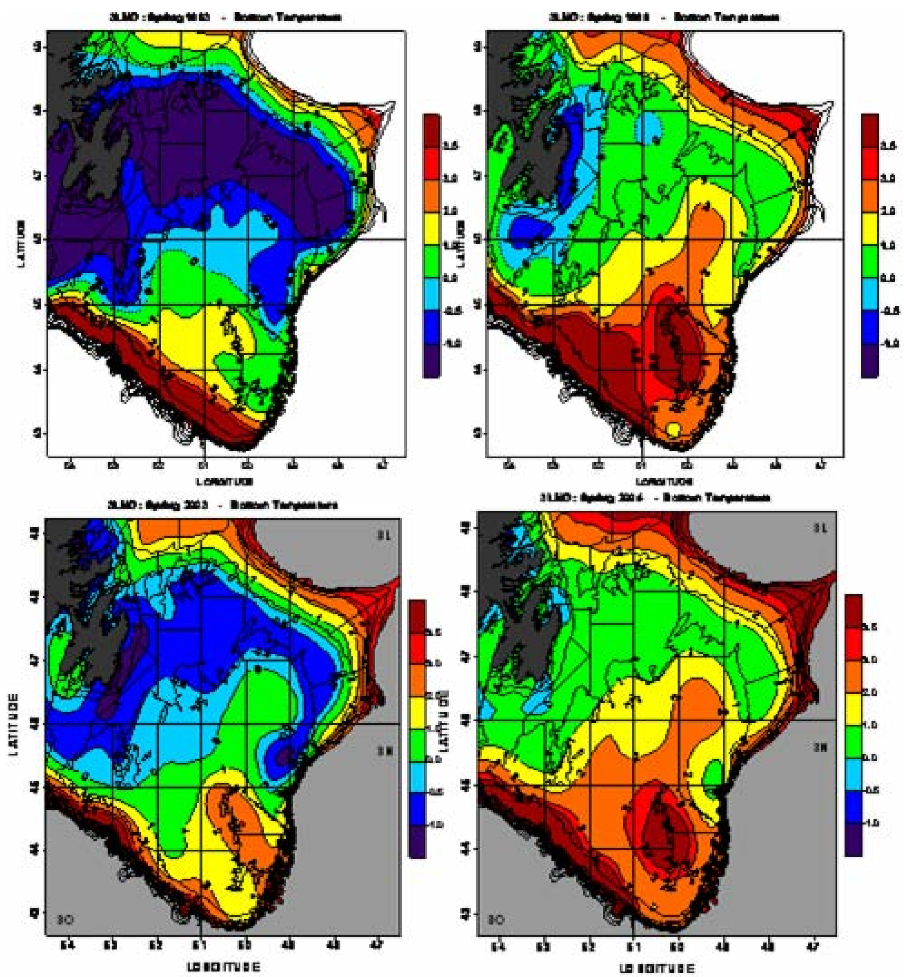


Fig. 1. Bottom temperature contour maps (in °C) for the **spring** of 1993, 1999, 2003 and 2004 from the annual 3LNO multi-species surveys.

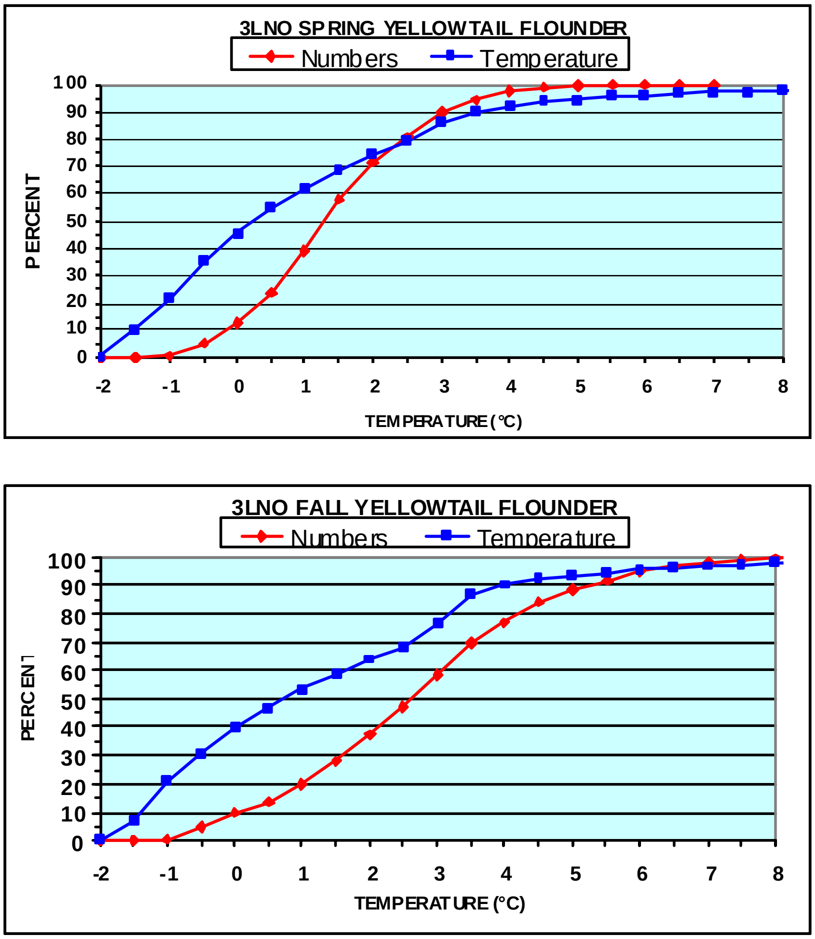


Fig. 2. Cumulative frequency distributions of the number of sets in the 3LNO survey in 1°C temperature bins and the cumulative frequency distribution of the number of fish caught in 1°C temperature bins for the **spring** (top panel) and **fall** (bottom panel) surveys.

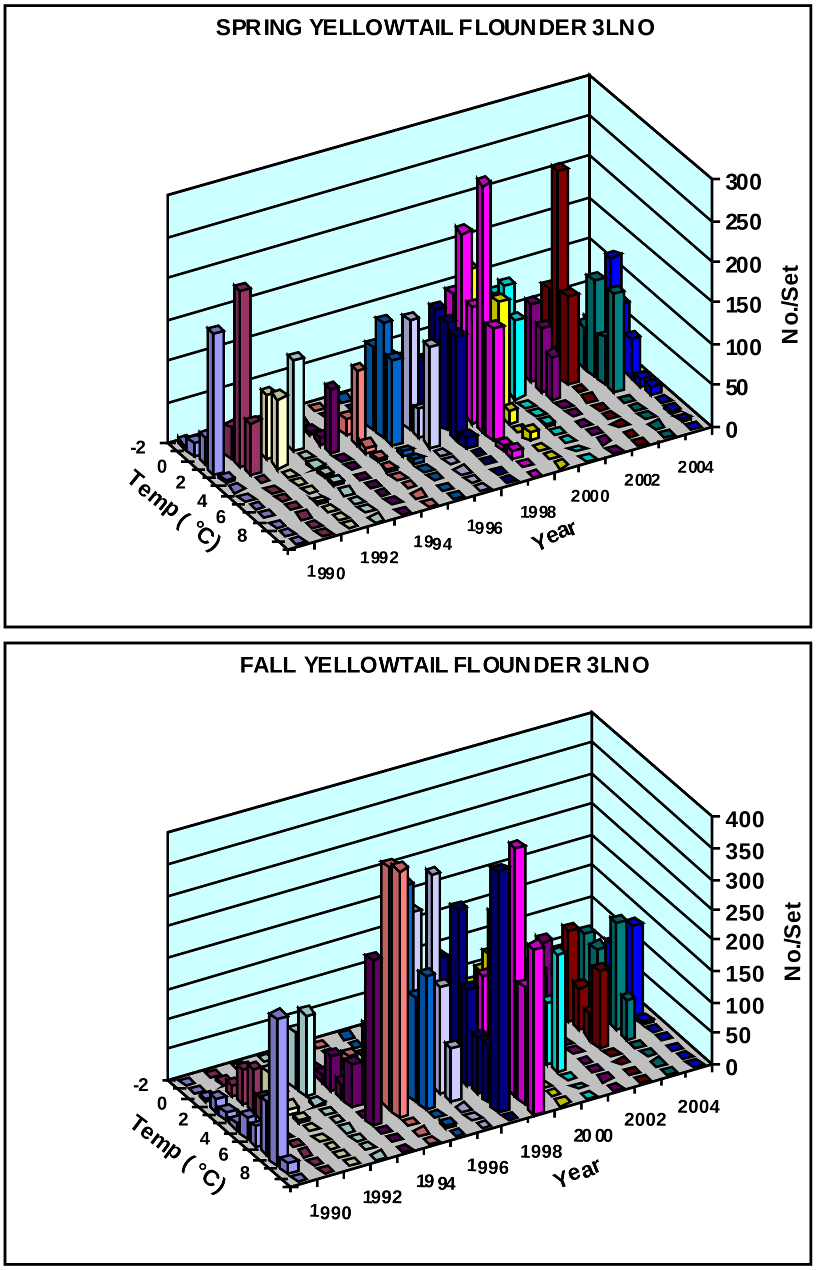
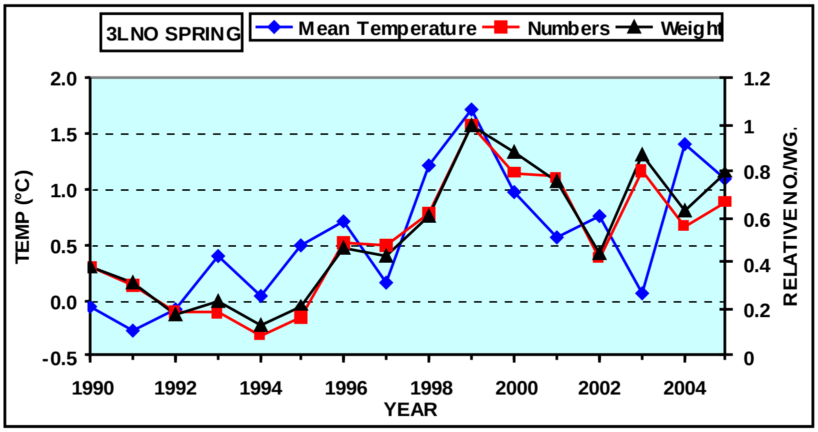


Fig. 3. The mean number of yellowtail flounder per fishing set in 1°C temperature bins for the spring surveys (top panel) and fall surveys (bottom panel).



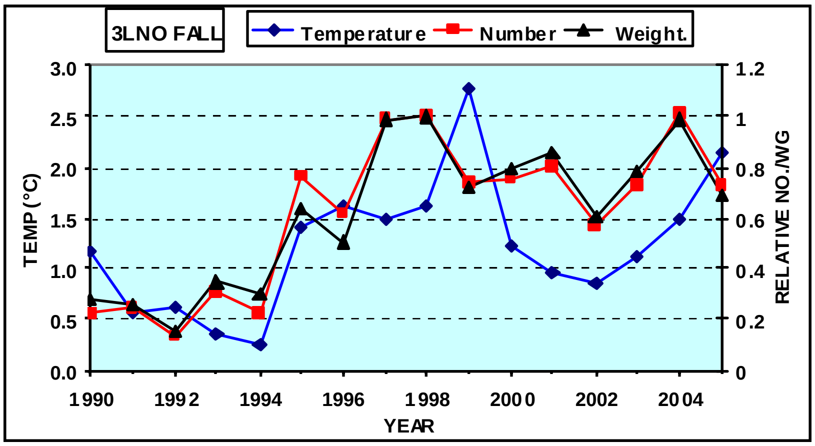


Fig. 4. Time series of the mean bottom temperature in NAFO Div. 3LNO for water depths ≤100-m together with the mean relative numbers and weight of yellowtail caught per set for the spring surveys (top panel) and fall surveys (bottom panel).

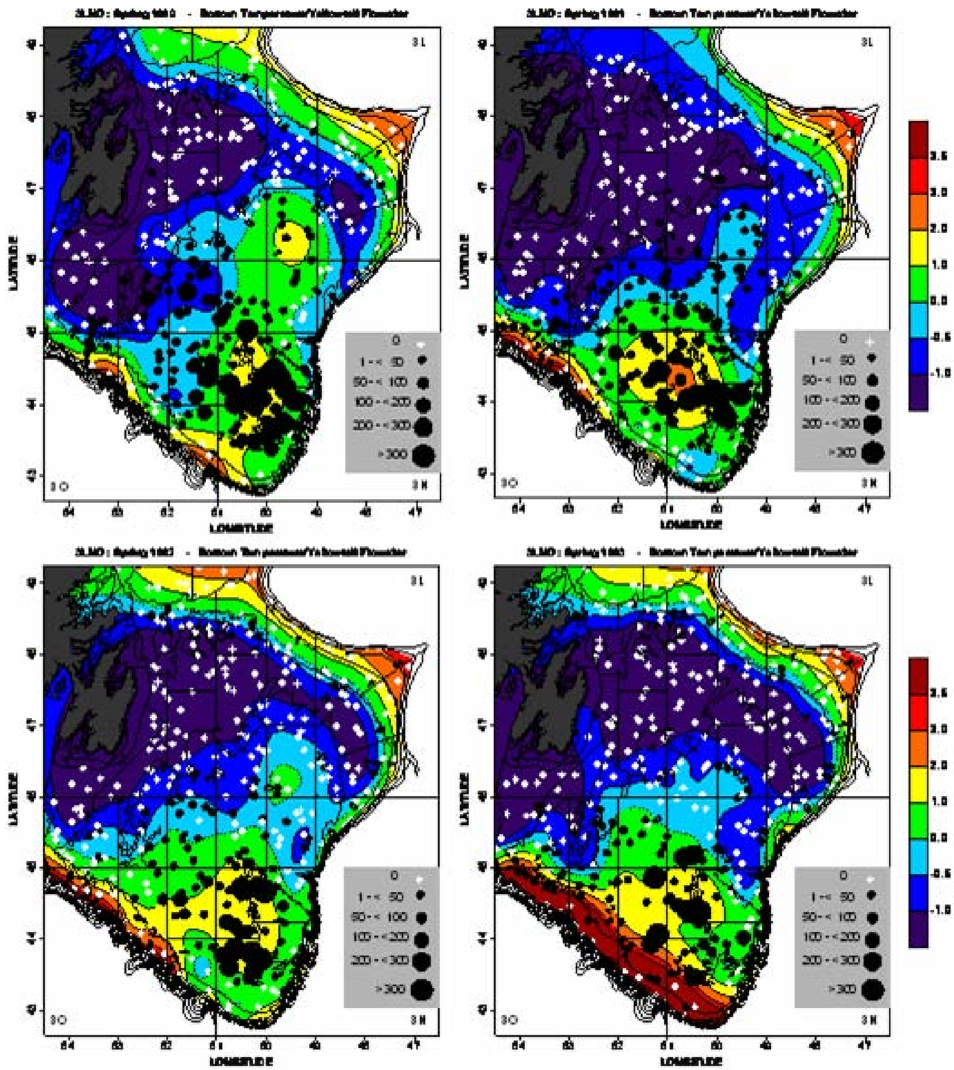


Fig. 5a. Bottom temperature contour maps (in °C) for the **spring** of 1990-1993 from the annual 3LNO survey. The numbers of yellowtail flounder in each fishing set are shown as solid circles. The crosses represent zero catches.

ig. 5b. 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.

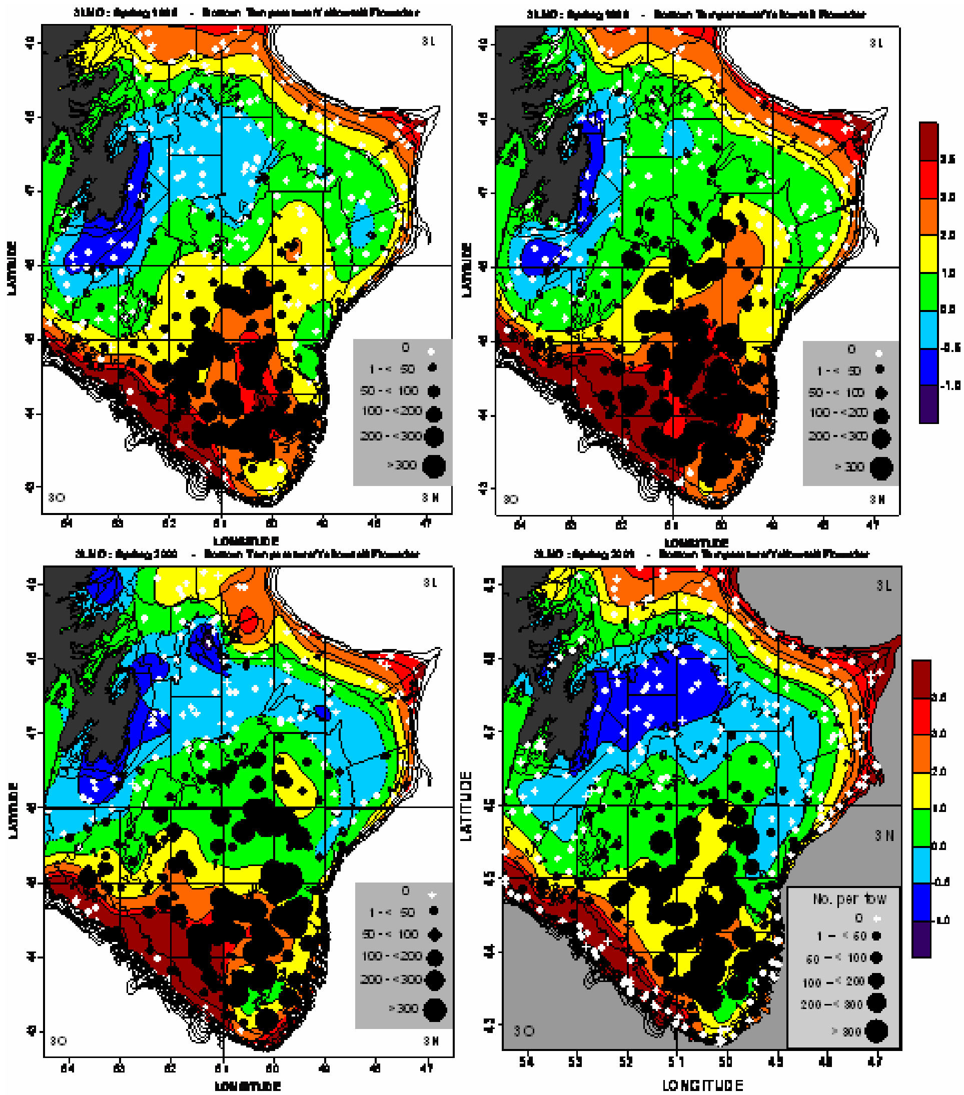


Fig. 5c. Bottom temperature contour maps (in °C) for the **spring** of 1998-2001 from the annual 3LNO survey. The numbers of yellowtail flounder in each fishing set are shown as solid circles. The crosses represent zero catches.

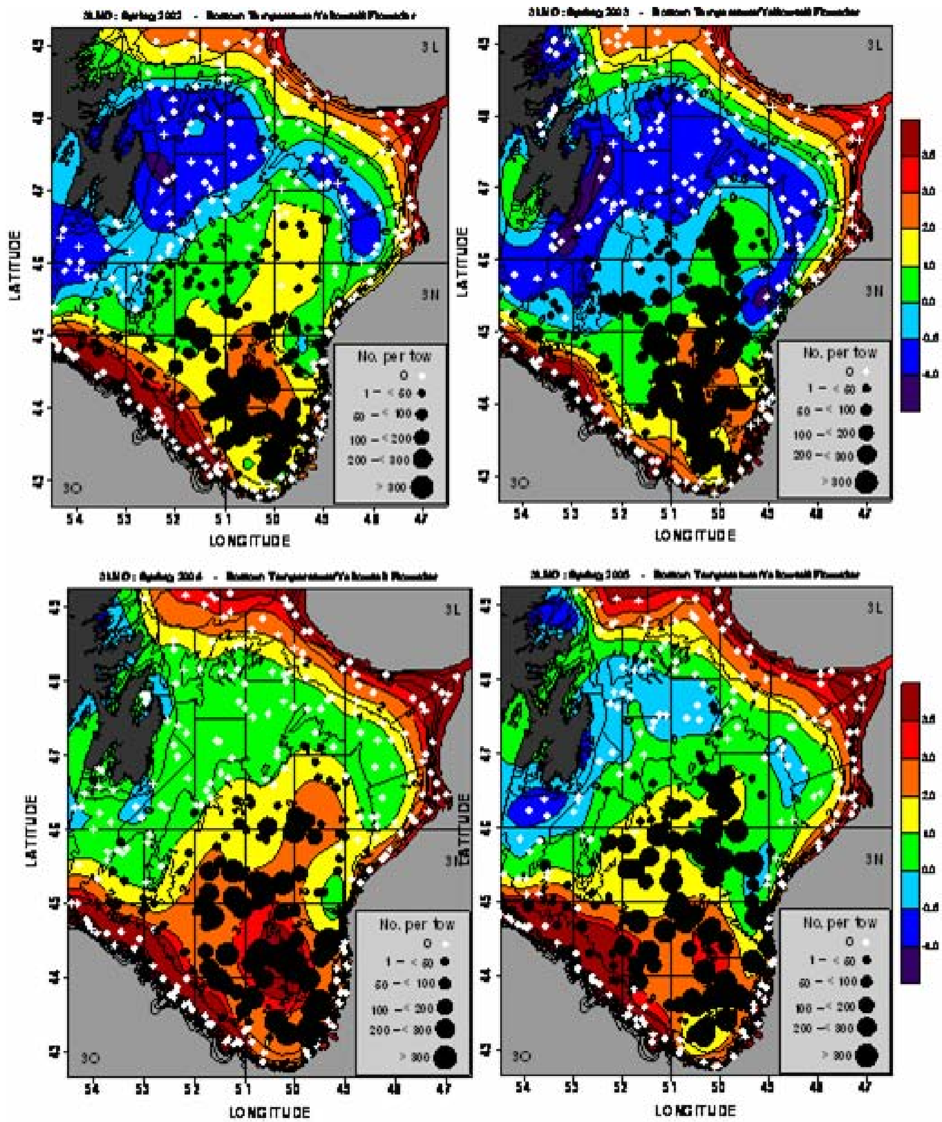


Fig. 5d. Bottom temperature contour maps (in °C) for the **spring** of 2002-2005 from the annual 3LNO survey. The numbers of yellowtail flounder in each fishing set are shown as solid circles. The crosses represent zero catches.

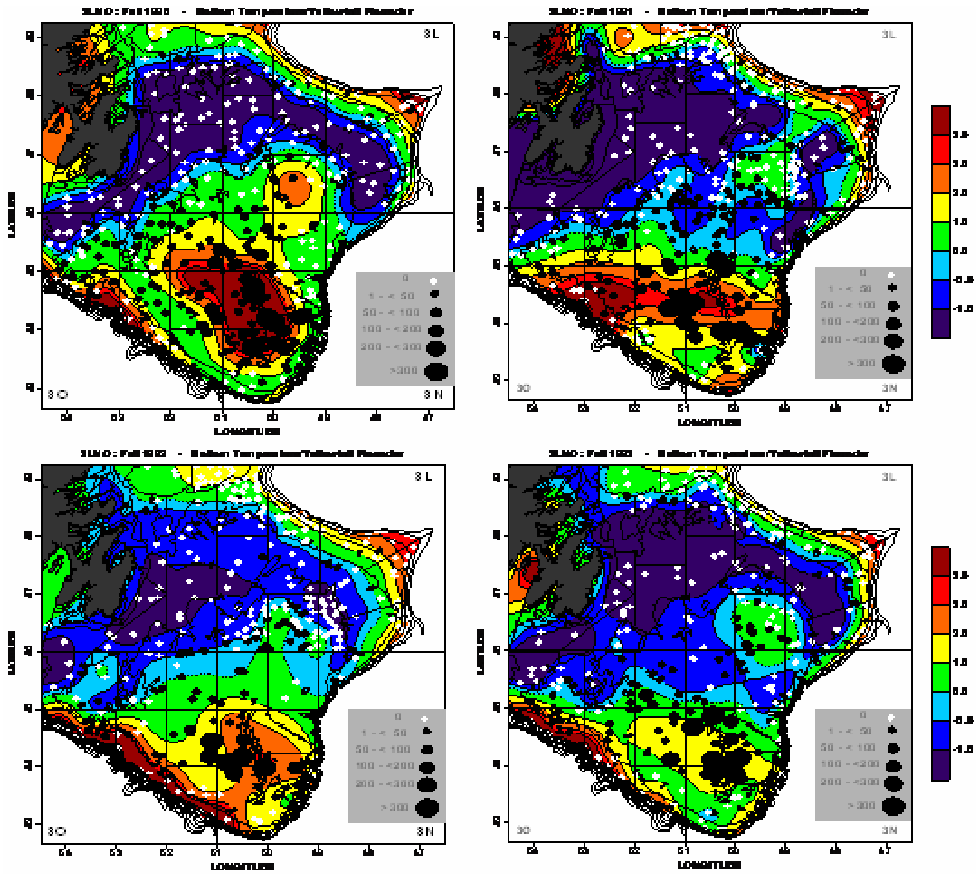


Fig. 6a. Bottom temperature contour maps (in °C) for the **fall** of 1990-1993 from the annual 3LNO survey. The numbers of yellowtail flounder in each fishing set are shown as solid circles. The crosses represent zero catches.

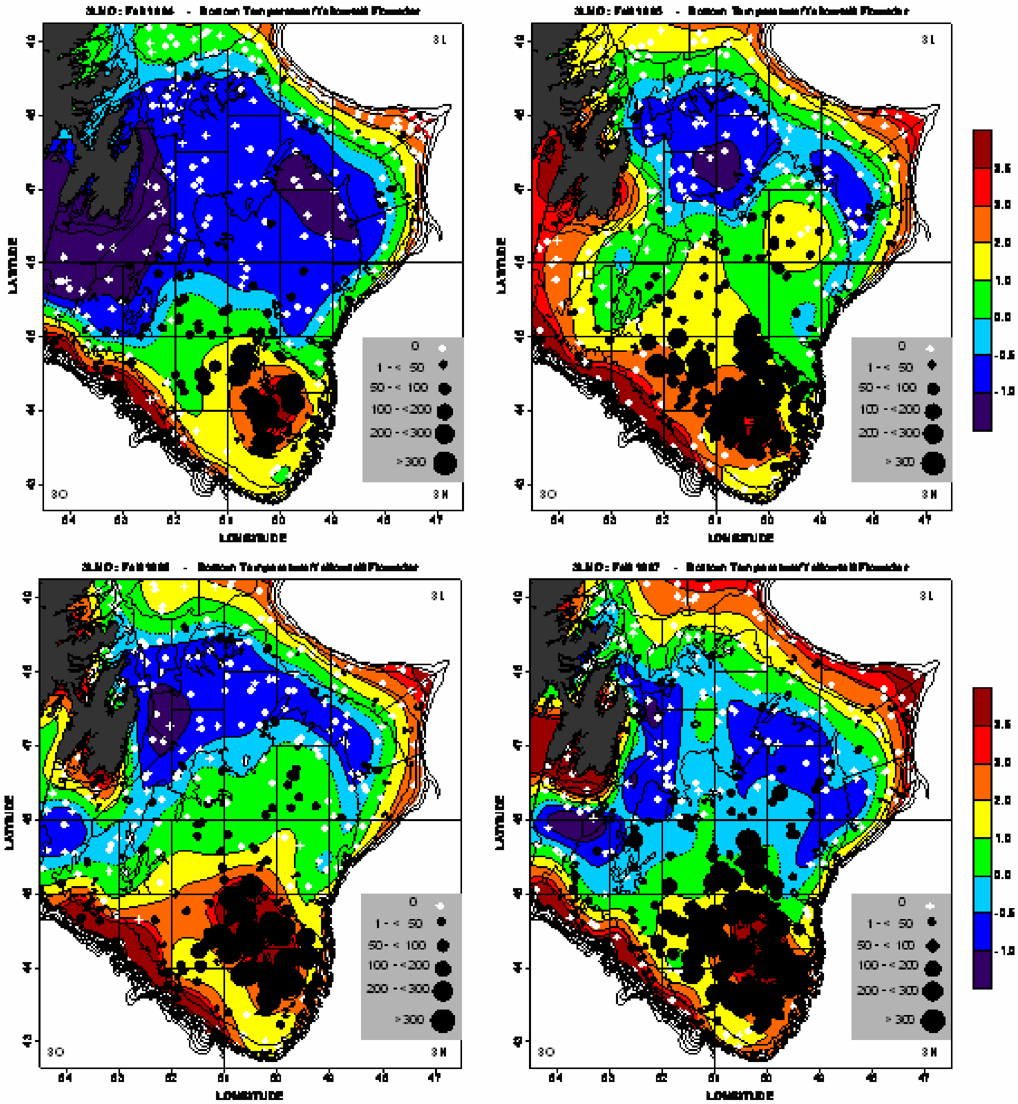


Fig. 6b. Bottom temperature contour maps (in °C) for the fall of 1994-1997 from the annual 3LNO survey. The numbers of yellowtail flounder in each fishing set are shown as solid circles. The crosses represent zero catches.

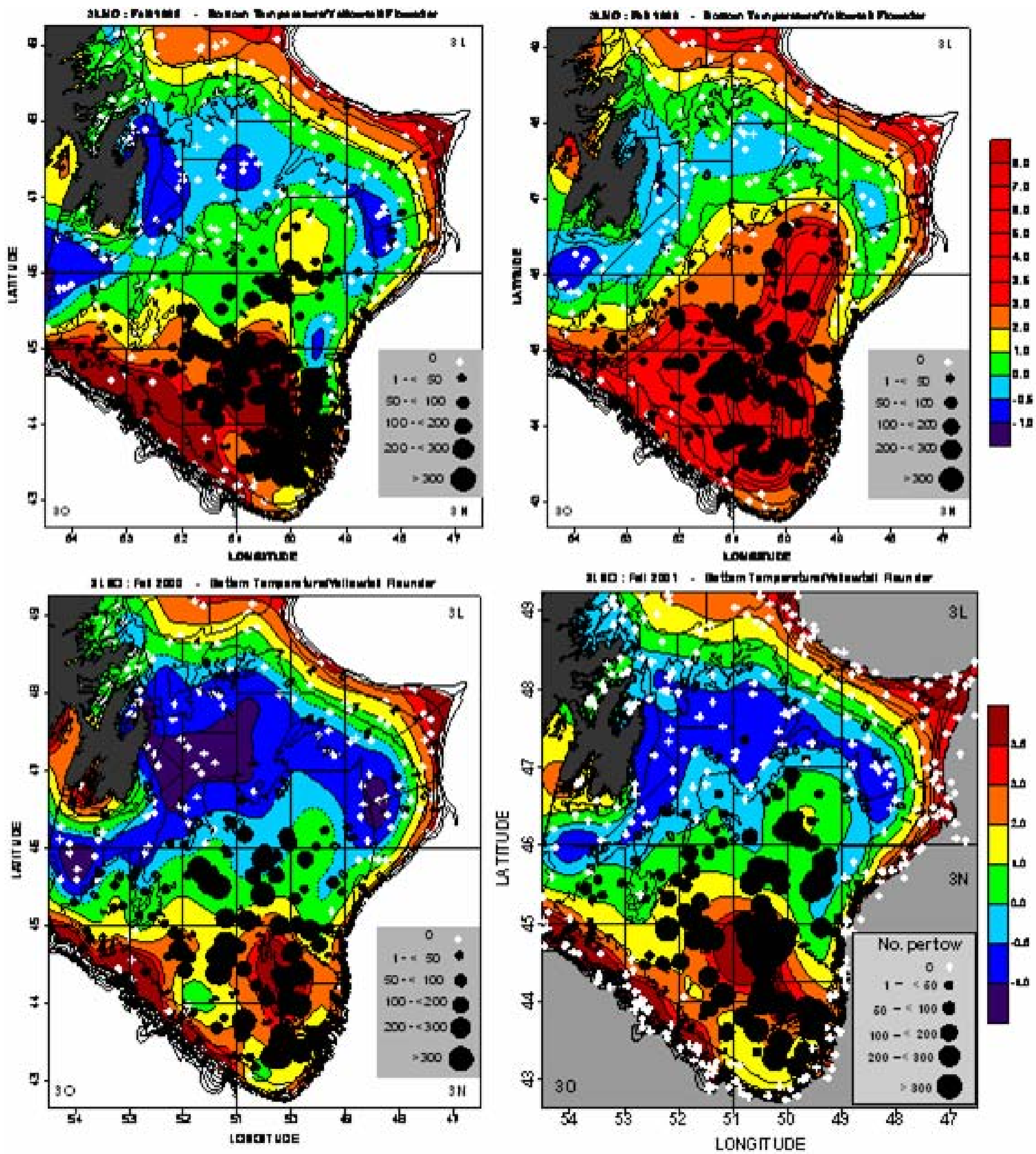


Fig. 6c. Bottom temperature contour maps (in °C) for the **fall** of 1998-2001 from the annual 3LNO survey. The numbers of yellowtail flounder in each fishing set are shown as solid circles. The crosses represent zero catches.

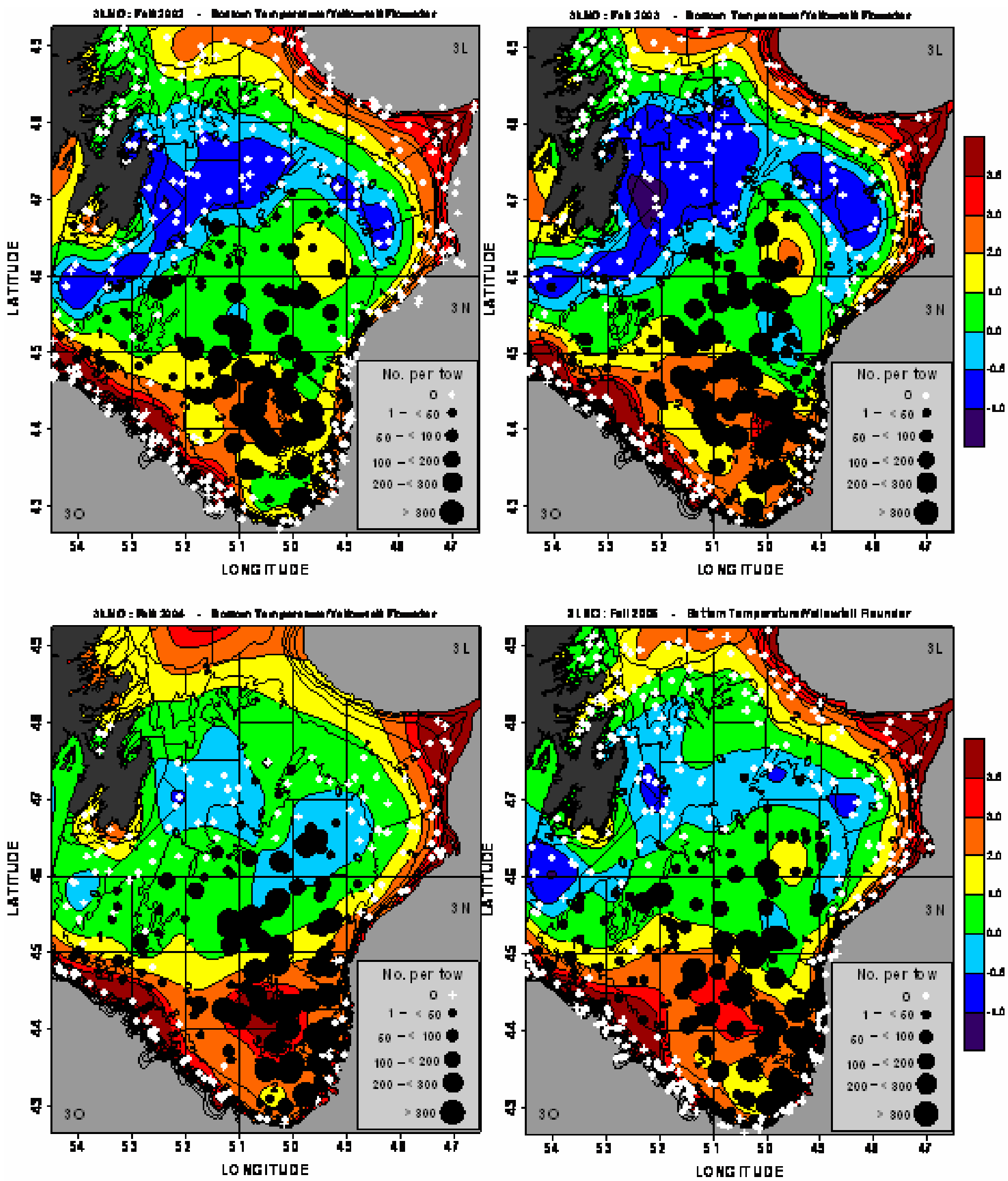


Fig. 6d. Bottom temperature contour maps (in °C) for the **fall** of 2002-2005 from the annual 3LNO survey. The numbers of yellowtail flounder in each fishing set are shown as solid circles. The crosses represent zero catches.