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The Distribution and Abundance of Northern Shrimp (*Pandalus borealis*) in Relation to Bottom Temperatures in NAFO Divisions 3LNO based on Multi-species Surveys from 1995-2006

by

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ABSTRACT

The most recent oceanographic data from spring and summer surveys in NAFO Div. 3LNO during 2006 indicate that bottom temperature in the area continued to be above normal and increased over 2005 particularly in northern areas (3L). The area of the bottom covered by water with temperatures <0°C in the spring of 2006 was the 3rd lowest in 31 years. The cold-intermediate-layer (CIL) shelf water during the summer of 2006 was below-normal (implying warm conditions) across the Grand Bank for the 9th consecutive year, ranking the 5th lowest in the 56 year time series. The spatial distribution and abundance of northern shrimp indicate that the highest numbers of shrimp are generally found in the 2°-4°C temperature range during the spring with lower numbers in water <2°C and >4°C. During the fall most shrimp are found in a colder temperature range of 1°-3°C as a result of seasonal migration into the shallower colder water of the Grand Bank. The changes in distribution is not believed to be related to seasonal temperatures changes but may be related to reproductive cycles, other environmental factors, feeding behaviour or changes in trawl catchability. The average weight of individual shrimp indicates that larger shrimp (6-7 g) are associated with temperatures >3°C while smaller shrimp (4-5 g) are found in temperatures <2°C. Cumulative frequency distributions of available temperature and total catch indicate that about 90% of the shrimp were caught in the 2°-4°C temperature range during the spring, while only about 50% appeared in this temperature range during the fall. The distributions by age show that younger male shrimp are associated with the colder habitat in both spring and fall, although there is an overall shift into warmer waters in spring. The distributions by maturity stage show that ovigerous females are found in the deeper warmer waters along the slope of the Grand Banks compared to females that have either spawned or are developing eggs. The numbers of age-2 male shrimp from the fall surveys show a significant increase in 1999-2001 but then decreased to lower values in the most recent years. The 2-year lagged temperature measurements also show a similar pattern with spring bottom temperatures showing the strongest correlation. The numbers of fishable shrimp from the fall surveys and the Station 27 bottom temperatures at time lags of 4 and 5 years also show a significant positive correlation. The total fishable numbers of shrimp experienced a significant increase beginning in 2000 which coincided to the increase in bottom temperatures in 1996, a time lag approximately equal to the ages of commercial size shrimp. While these results indicate that the increase in temperature may have resulted in better shrimp survival in recent years, we note that the time series of survey data is too short to draw firm conclusions.

Introduction

Canada has been conducting stratified random groundfish trawl surveys in NAFO Div. 3LNO since 1971. Each division was stratified based on the depth contours from available standard navigation charts (Fig. 1). 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; Brodie, 1996).

Since the fall of 1995 the Canadian research vessel surveys in the Newfoundland and Labrador Region made use of a Campelen 1800 shrimp trawl (Mccallum and Walsh, 1996). As a result the annual spring and fall stratified random surveys now provides abundance and distribution data on northern shrimp (*Pandalus borealis*). In this manuscript we present an update to Colbourne and Orr (2005) where an analysis of the distribution and abundance of northern shrimp in relation to their thermal habitat in NAFO Div. 3LNO was presented. We begin first by updating the oceanographic environment in the area and then examine habitat preferences by temperature, season, maturity stage and age groups. We then present spatial distribution maps of northern shrimp in relation to the near-bottom temperature fields for both the spring and fall surveys.

Data and Methods

The historical oceanographic data set for the Newfoundland Shelf is available from archives at the Marine Environmental Data Service (MEDS) in Ottawa and from working databases maintained at the Northwest Atlantic Fisheries Centre (NAFC) in St. John's Newfoundland. Since 1989, net-mounted conductivity-temperature-depth (Seabird model SBE-19 CTD systems) recorders have replaced XBTs on the annual assessment surveys as the primary oceanographic instrument. This system records temperature and salinity data during trawl deployment and recovery and for the duration of the fishing 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. Expendable bathythermographs (XBTs) are only used when the net-mounted CTD fails during the tow, these are accurate to within 0.1^{o}C.

Data on shrimp abundance and distribution were available for the years 1995-2005 for the fall and from 1998-2006 for the spring surveys. Fishing sets of 15 minute duration at a towing speed of 3 knots were randomly allocated to strata covering the Grand Bank and slope waters to a depth of 1500 m (Fig. 1) (Brodie, 1996; McCallum and Walsh, 1996). The mean numbers and weight of northern shrimp for all sets within 1^{o}C temperature bins for each survey were computed. Cumulative frequency distributions of catch numbers, maturity stages and age groups for each temperature bin are compared to the available temperature distribution within the 3LNO region for all surveys. For the purpose of this preliminary analysis, these distributions were not weighted by sampling intensity or stratum area. Near-bottom temperature grids for NAFO Div. 3LNO were then produced from all available spring data for the years 1998-2006 and for the fall surveys for the years 1995 to 2005. All near-bottom temperature values for the time period of each survey were interpolated onto a regular grid and contoured using a geostatistical (2-dimensional Kriging) procedure. The numbers and total weight of northern shrimp per fishing set are displayed over the temperature contours as expanding solid circles proportional to the magnitude of the catch. It is noted that a significant portion of Div. 3L was not sampled in 2004 and a significant portion of Div. 3NO was not sampled during the spring of 2006.

Results

Bottom temperature and temperature anomaly maps for NAFO Divisions 3LNO during the spring of 2006 are displayed in Fig. 2. Spring bottom temperatures in Div. 3L ranged from <0^{o}-1^{o}C in the inshore regions of the Avalon Channel and parts of the Grand Bank and from 1^{o} to >3^{o}C at the shelf edge. Over the central and southern areas bottom temperatures ranged from 1^{o}C to 3^{o}C. The spring of 2006 had the 3rd lowest area of <0^{o}C water in Division 3L since the surveys began in the early 1970s (Fig. 2). In general, temperatures were above normal in most areas of the northern Grand Bank by 0.5^{o}C to 2^{o}C. Temperature anomalies in southern areas (3NO) were more variable. The below normal anomalies along the southern slopes of 3O are the result of grid extrapolation into areas where data were not available. From 1984 to 1997 there was a large increase in the area of <0^{o}C water on the Grand Banks with percentages reaching near 60% in some years. Since 1997 there was a significant decrease in the area <0^{o}C water and with the exception of 2003 this area has remained at <30% up to the spring of 2006.

The water mass characteristics on the Grand Banks are typical of sub-polar waters with sub-surface temperatures ranging from <0º to 2ºC. Surface temperatures during the summer of 2006 ranged from 10^{o} to 13^{o}C, while bottom temperature over most of the bank range from 0^{o}C to 1^{o}C (Fig. 3). Throughout most of the year, the cold shelf is separated from the warmer of the continental slope region by a strong temperature front where bottom temperatures increase from 0 to >3 in water depths >100 m. The most revealing feature of the shelf temperature structure, particularly during the summer, is the layer of cold <0°C water, commonly referred to as the Cold Intermediate Layer (CIL). This winter cooled water mass remains isolated during the summer and early fall months between the seasonally heated surface layer and warmer near bottom water originating from the continental slope region, although the CIL intersects the bottom over most of the shallow Grand Bank. In 2006 the CIL areas on the Grand Bank along the 47°N section was below normal for the 9th consecutive year ranking the 5th warmest year in the 56 year time series and the implying warmer-than-normal water temperatures on the continental shelf (Fig. 4).

The average weight of northern shrimp caught per fishing set in 1°C-temperature bins are displayed in Fig. 5 for the spring and fall surveys, respectively. Significantly higher amounts of shrimp were caught in the 2°-4°C-temperature range during the spring surveys, with much lower amounts in waters with temperatures <2°C and >4°C with a significant increase in the overall catches over the previous year. Shrimp were also found in the –1.5°-1°C and 5-7°C temperature ranges but in very low numbers. During the fall surveys most of the shrimp catches were in the 1°-3°C-temperature range. Larger catches were observed in the 2°-4°C temperature range during the spring compared to the fall, while smaller catches were observed in 0°-1°C temperature range during the spring compared to the fall. This is the result of a shift in shrimp distribution further south and west in over the Grand Bank in colder water during the fall and is not believed to be related to seasonal temperatures changes. The observed seasonal change in distribution as determined by the surveys was most evident in the northern regions of Div. 3L. In general, catch rates and the estimated biomass of northern shrimp has increased substantially since the fall of 2001 compared to earlier years of the surveys with more variability in the spring surveys compared to fall (Orr *et al*., 2005). The average weight (total weight/total numbers) of shrimp per set in 1°C temperature bins indicate that larger shrimp (6-7 g) are associated with temperatures >3°C while smaller shrimp (4-5 g) are found in temperatures <2°C (Fig. 5 bottom panel). The increase in the distribution of shrimp in shallower-colder waters of 3L during fall compared to spring is dominated by smaller shrimp while large shrimp are associated with temperatures >4°C and are found mostly on the southern slopes of Div. 3O.

To examine whether shrimp habitat preferences change with season and maturity stage we examined shrimp distributions of total numbers, total weight, ages 1, 2 and 3+ , females with and without headroe and ovigerous females. The distributions displayed in Fig. 6 indicate that while age-2 shrimp are distributed in over the Grand Bank in temperatures <2°C the ovigerous females are almost exclusively found in the deeper warmer slope waters. The average cumulative distribution plots of available temperature, total catch, age groups and female maturity classes based on data from the surveys for the years 1998-2006 for the spring and 1995-2005 for the fall are displayed in Fig. 7. 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. The results indicate about 90% of the shrimp were caught in the 2°-4°C temperature range during the spring, while only about 50% appeared in this temperature range during the fall. Less than 5% of the catches are associated with temperatures <1°C in the spring while up to 20% of the catches are associated with temperatures <1°C in the fall. The shift in the distribution towards warmer temperatures during the spring compared to fall is evident (Fig. 7 top panels). The distributions by age show that the younger male shrimp are associated with the colder habitat in both spring and fall although there is an overall shift into warmer waters in spring (Fig. 7 middle panels). The distributions by maturity stage clearly show that ovigerous females are found in the deeper warmer waters along the slope of the Grand Banks compared to females that have either spawned or are developing eggs (Fig. 7 bottom panels). In terms of available near-bottom thermal habitat, in the spring about 20% of the surveyed region was covered with <0°C water, about 50% was in the 0°-3°C temperature range and about 30% of the bottom was covered by water with temperature >3°C with the fall distributions only slightly warmer than spring.

To examine recent temperature variability and the production of shrimp we examined the numbers of age-2 (12.5-17.0 mm CL) male shrimp from the fall surveys for 1995-2005 and compared it to several measures of temperature conditions in Divs. 3LNO at a time lag of 2-years (Fig. 8). The time series of total numbers of age-2 shrimp show a significant increase in 1999-2001 but then decreased to lower values in the most recent years. The 2-year lagged temperature measures also show a similar pattern with the survey spring bottom temperatures showing the strongest correlation with an adjusted r^2=0.55, p=0.009. The time series of the numbers of fishable (males and females ≥17.5 mm CL) shrimp from the fall surveys and the Station 27 bottom temperatures at time lags of 4 and 5 years also show a significant positive correlation (Fig.9). The total fishable numbers of shrimp experienced a significant increase beginning in 2000 which coincided to the increase in bottom temperatures in 1996. While it is tempting to attribute an increase in temperature to better shrimp survival we note that the time series is short and historically shrimp production (CPUE) were associated with cold conditions off Labrador (Parsons and Colbourne 2000).

The spring and fall bottom temperature maps together with the total numbers of shrimp caught per set for NAFO Div. 3LNO are shown in Fig. 10 and 11 respectively. In general, spring bottom temperatures in the northern areas ranged from <0^{o}C in the inshore regions of the Avalon Channel to >3^{o}C at the shelf edge. Over the central and southern areas bottom temperatures ranged from 1^{o}C to >3.5^{o}C on the Southeast Shoal and >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 (Colbourne, 2000). Beginning around 1996 the area of <0^{o}C water began to retract and by 1999 it was restricted to a small area in the Avalon Channel. During 2001 and 2003 the area of <0^{o}C water began to increase again covering most of the plateau of the Grand Bank in Div. 3L, however, during the spring of 2004 this area reached a record low. During the spring of 2005 the area of <0^{o}C water increased slightly over the previous year remained below normal. On average bottom temperatures in 3L during the fall are very similar to spring values with <0^{o}C water covering most of the area during cold years. During the warm years of 1998 and 1999 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^{o}-3^{o}C) as a result of summer surface heating (Colbourne, 2000; Colbourne and Murphy, 2000).

The total numbers of northern shrimp caught per set during each survey are displayed with the temperature contours in Fig. 10 and 11 using expanding symbols. The size of the circle is proportional to the magnitude of the catch in each set. The majority of fishing sets in the shallow regions (water depths <100-m) of southern 3L and most of 3NO show either zero catches or very low numbers. During the spring surveys most of the large catches were found in the warmer water along the slopes of Div. 3LN with very low catches in Div. 3O (Fig. 10). During the fall surveys, again large catches occurred along the outer areas and slopes of the Grand Bank, however as described above, larger catches were more widely distributed in Div. 3L, including the inshore areas of the bays along the east coast of Newfoundland (Fig. 11). It appears that during the fall, shrimp were caught in all available temperatures in Div. 3L, although in much lower numbers in the cold-intermediate-layer (CIL <0^{o}C) water of Div. 3L. Shrimp catches were mostly zero in all surveys both spring and fall in the shallow waters (<100 m) of the southeast Grand Bank where temperatures generally range from 2^{o}-7^{o}C. There were also many zero catches observed in the deepest sets (>1000 m) along the edges of the Grand Bank during the fall surveys in water with temperatures >3.5^{o}C. In general, as catch rates and the total biomass of shrimp increased during the most recent years of the surveys there were more non-zero catches occurring in most areas, particularly in Div. 3L during the fall.

Summary

Averaged bottom temperatures in NAFO Divs. 3LNO during the spring of 2004 reached 2.5°C, the highest in 22 years, decreased slightly in 2005 but increased again during the spring of 2006 in 3L. Since 1997 there was a significant decrease in the area of the bottom covered by water with temperatures <0^{o}C and with the exception of 2003 this area has remained <30% up to the spring of 2006, which had the 3rd lowest (<10%) in 31 years. The winter formed CIL water mass which is a robust index of ocean climate conditions, was below-normal (implying warm conditions) across the Grand Bank for the 9th consecutive year in 2006, ranking the 5th lowest in the 56 year time series.

Data on the spatial distribution and abundance of northern shrimp collected during the multi-species surveys in NAFO Divs. 3LNO indicate that the highest numbers of shrimp are generally found in the 2^{o}-4^{o}C temperature range during the spring with lower numbers in water <2^{o}C and >4^{o}C. During the fall most shrimp are found in a colder temperature range of 1^{o}-3^{o}C as a result of seasonal migration into the shallower colder water of the Grand Bank. The changes in distribution is not believed to be related to seasonal temperatures changes but may be related to reproductive cycles, other environmental factors, feeding behaviour or changes in trawl catchability. The average weight of individual shrimp indicates that larger shrimp (6-7 g) are associated with temperatures >3°C while smaller shrimp (4-5 g) are found in temperatures <2°C.

Cumulative frequency distributions of available temperature and total catch indicate that about 90% of the shrimp were caught in the 2^{o}-4^{o}C temperature range during the spring, while only about 50% appeared in this temperature range during the fall. The distributions by age show that younger male shrimp are associated with the colder habitat in both spring and fall although there is an overall shift into warmer waters in spring. The distributions by maturity stage clearly show that ovigerous females are found in the deeper warmer waters along the slope of the Grand Banks compared to females that have either spawned or are developing eggs.

The numbers of age-2 male shrimp from the fall surveys show a significant increase in 1999-2001 but then decreased to lower values in the most recent years. The 2-year lagged temperature measurements also show a similar pattern with the spring bottom temperatures showing the strongest correlation. The time series of the numbers of fishable shrimp from the fall surveys and the Station 27 bottom temperatures at time lags of 4 and 5 years also show a significant positive correlation. The total fishable numbers of shrimp experienced a significant increase beginning in 2000 which coincided to the increase in bottom temperatures in 1996, a time lag approximately equal to the ages of commercial size shrimp. While these results indicate that the increase in temperature may have resulted in better shrimp survival we note that the time series is too short to draw firm conclusions.

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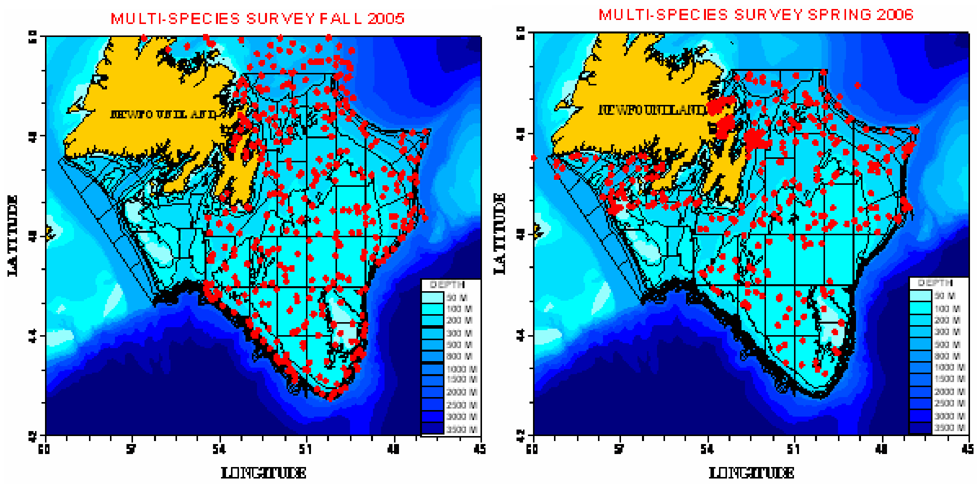

Fig. 1. Location maps showing the stratified area and the positions of fishing sets during the Canadian research trawl survey in NAFO Div. 3LNO during the fall of 2005 and spring of 2006.

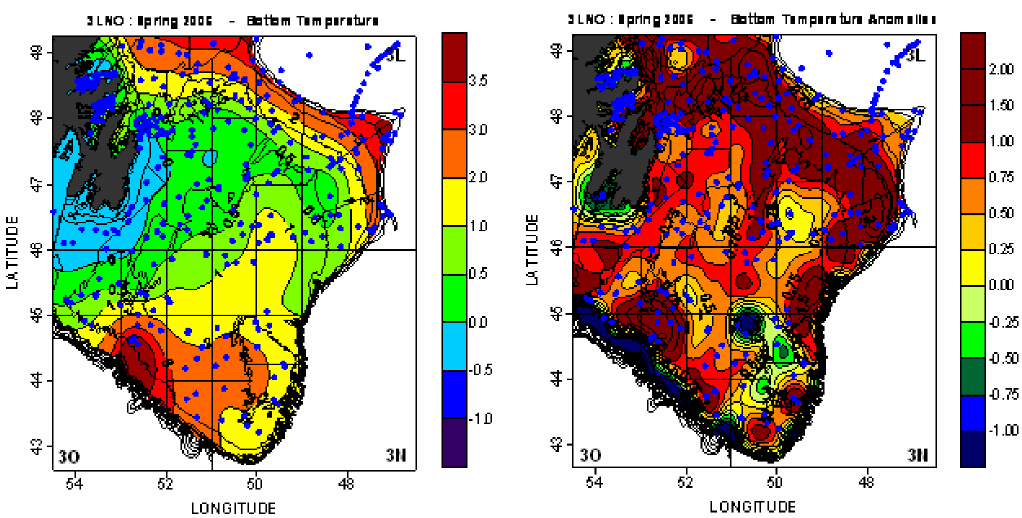

Fig.2. Bottom temperature maps in °C (left panel) and temperature anomalies (right panels) derived from the spring 2006 multi-species survey in NAFO Div. 3LNO. The blue dots indicate positions where temperature measurements were available.

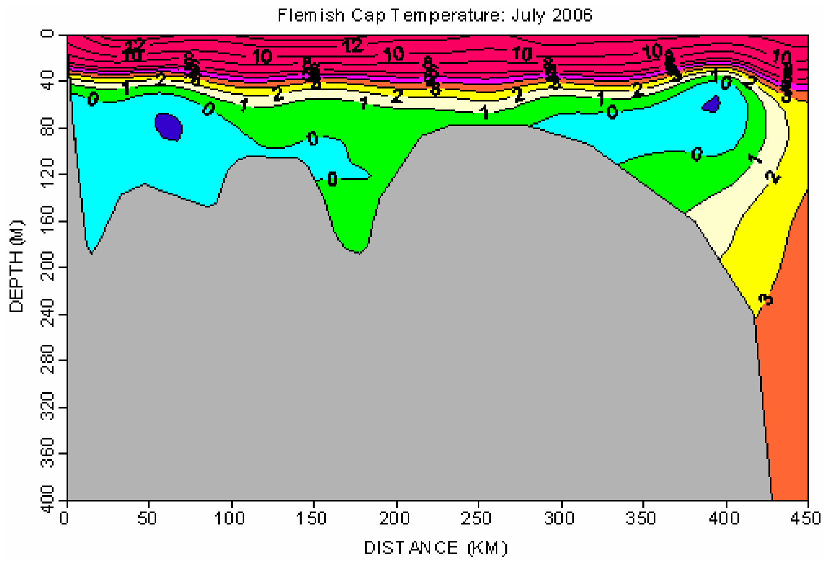

Fig.3. Vertical temperature cross-section (in °C) from the summer 2006 across the Grand Bank along the 47°N standard NAFO oceanographic section.

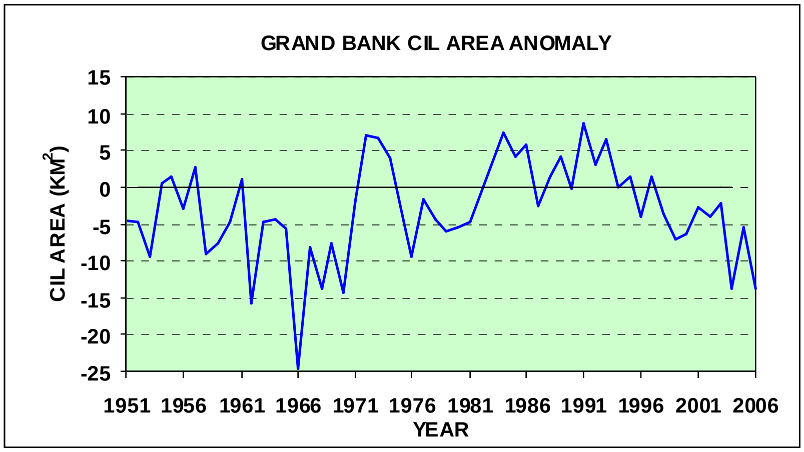

Fig.4. Time series of Cold Intermediate Layer (CIL) area anomalies based on summer surveys across the Grand Bank along the 47°N standard NAFO oceanographic section. Anomalies are referenced to the 1971-2000 base period.

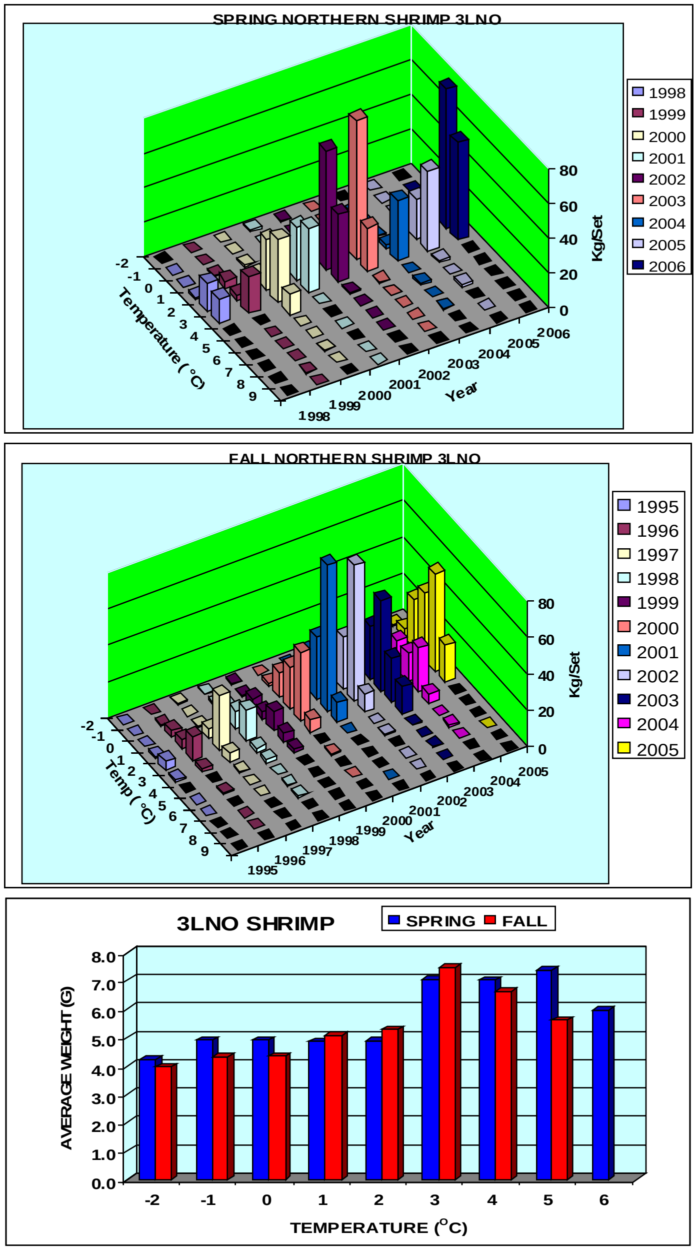

Fig. 5. The average weight of northern shrimp per fishing set in 1°C temperature bins for the spring (top panel) and fall (middle panel) surveys in NAFO Div. 3LNO for the years 1995-2006 and the average weight (in g) of shrimp per set within 1°C temperature bins for the spring and fall surveys (bottom panel).

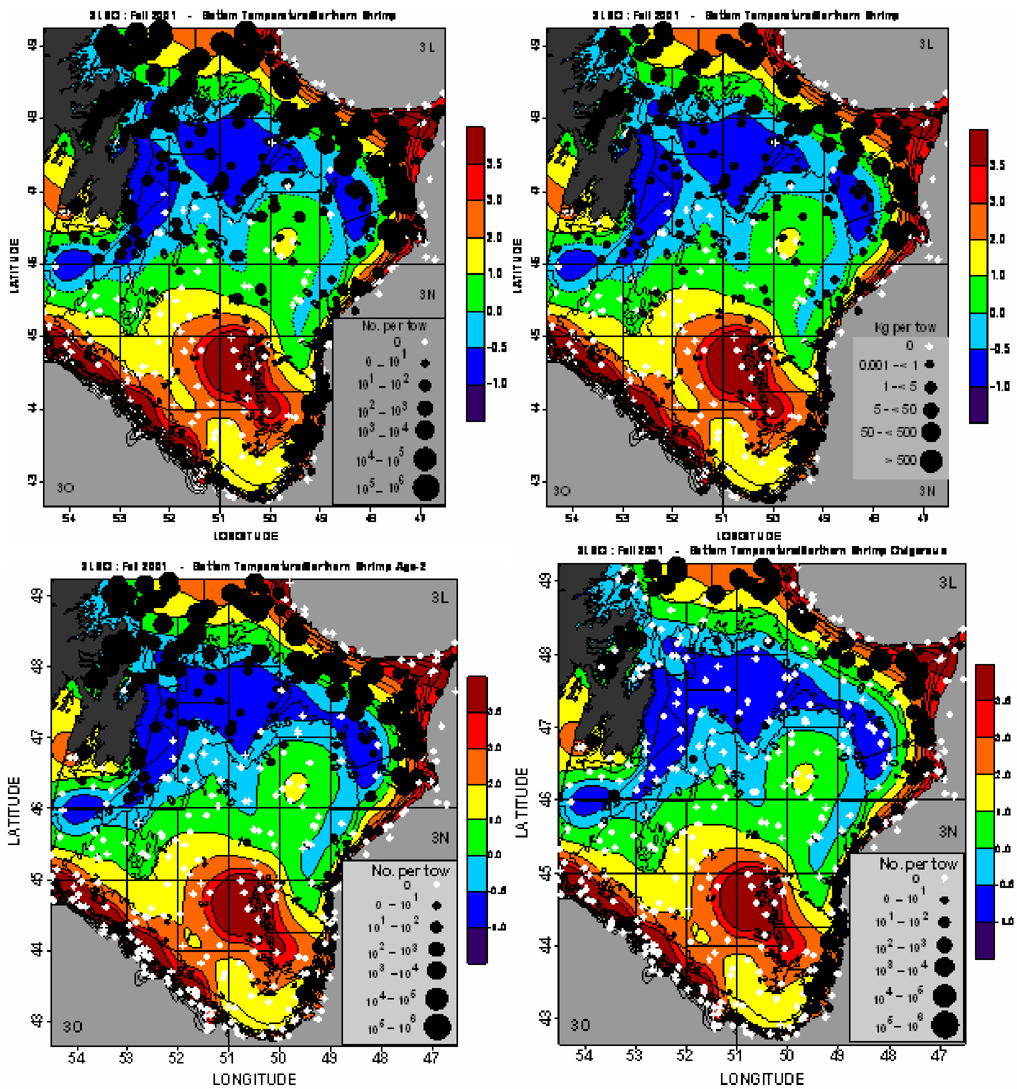

Fig. 6. Bottom temperature contour maps (in °C) for the fall of 1998 from the annual 3LNO survey and the total numbers, total weight, age-2 and ovigerous female shrimp in each fishing set shown as solid circles. The white crosses represent zero catches.

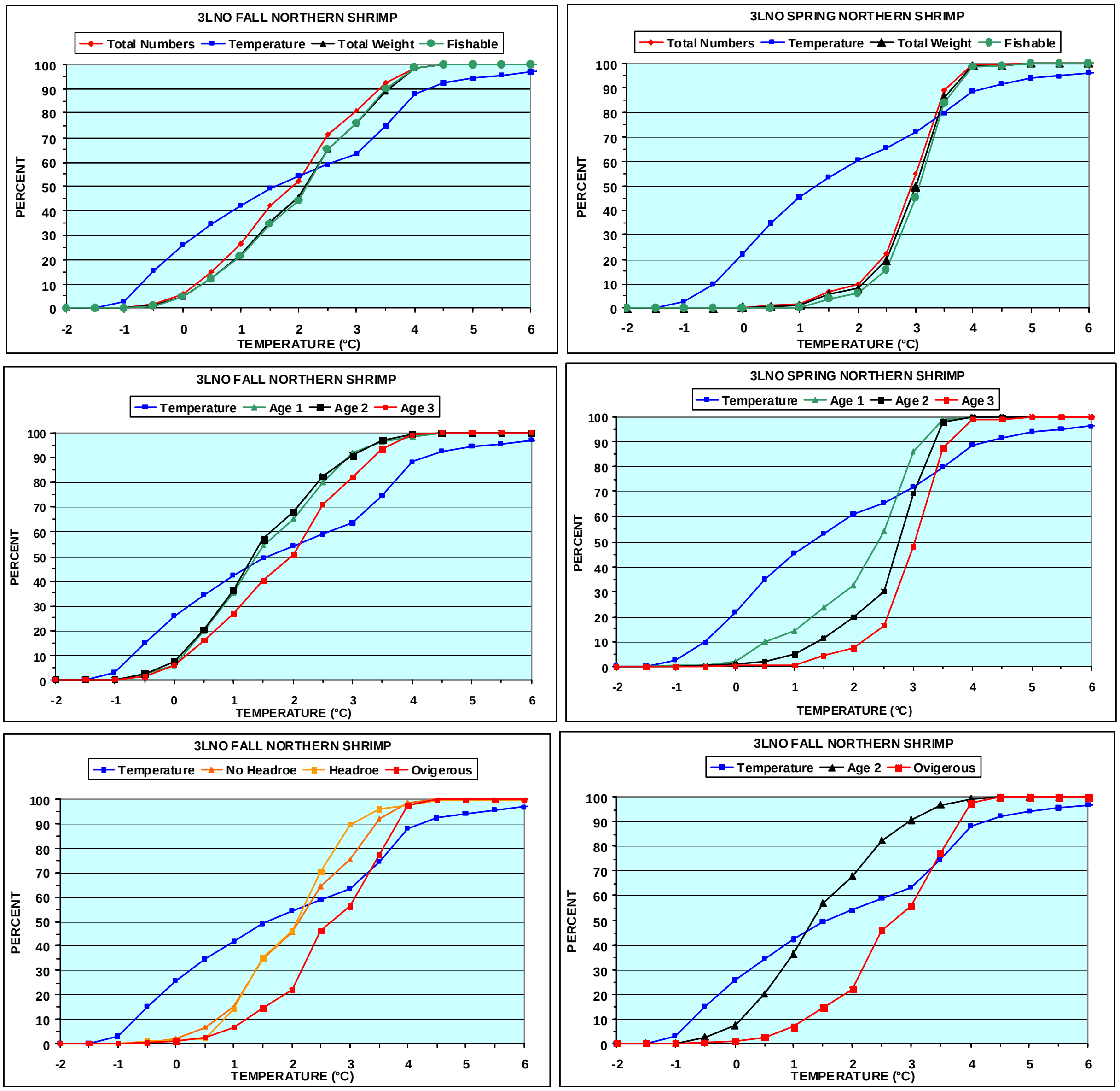

Fig. 7. Cumulative frequency distributions of the number of sets in the 3LNO survey in 1°C temperature bins and the cumulative frequency distribution of shrimp caught in 1°C temperature bins for the spring (1998-2006) and fall (1995-2005) surveys.

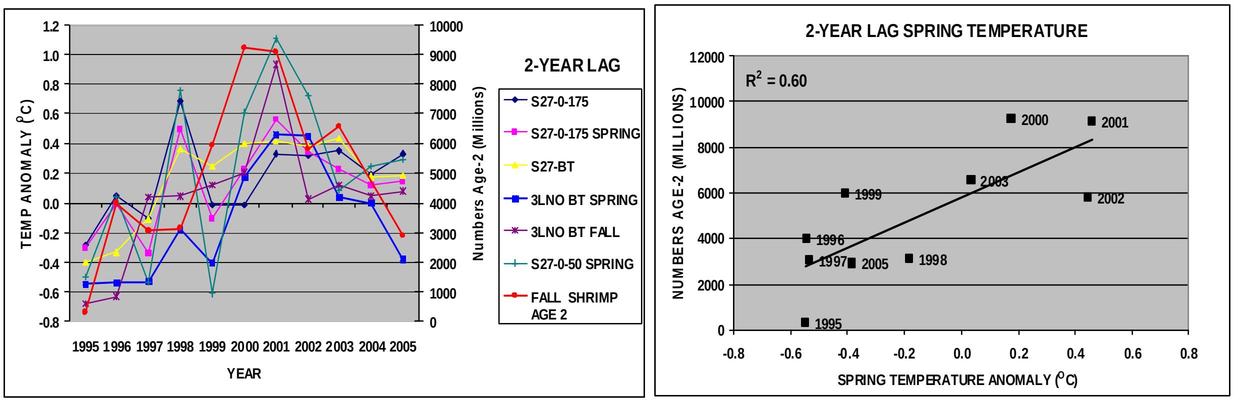

Fig.8. Time series of the numbers of age-2 shrimp from fall surveys in NAFO Divs. 3LNO and various temperature indices at a time lag of 2-years (left panel) and the correlation between age-2 shrimp numbers and spring temperatures 2 years earlier.

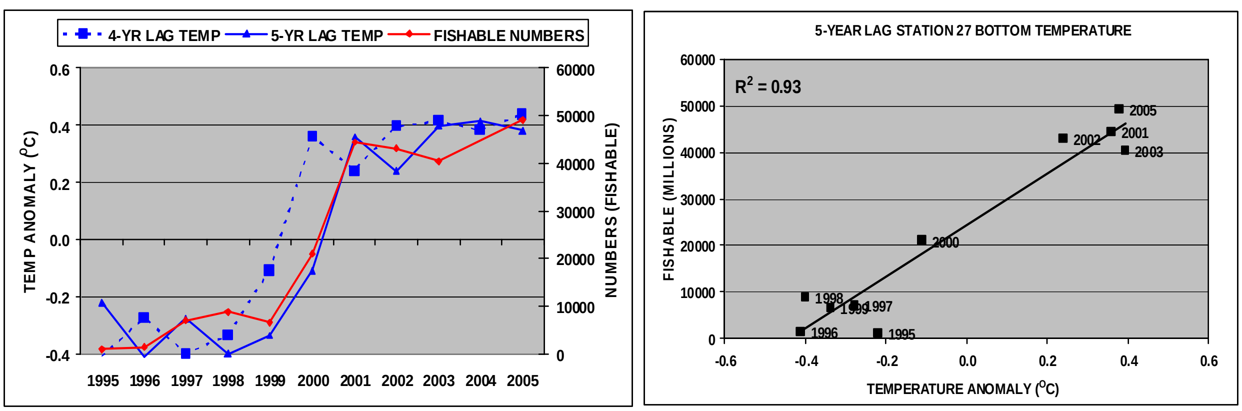

Fig.9. Time series of the numbers of fishable (>17.5 mm cl) shrimp from fall surveys in NAFO Divs. 3LNO and the Station 27 bottom temperatures at time lags of 4 and 5 years (left panel) and the correlation between fishable shrimp numbers and Station 27 bottom temperatures 5-years earlier.

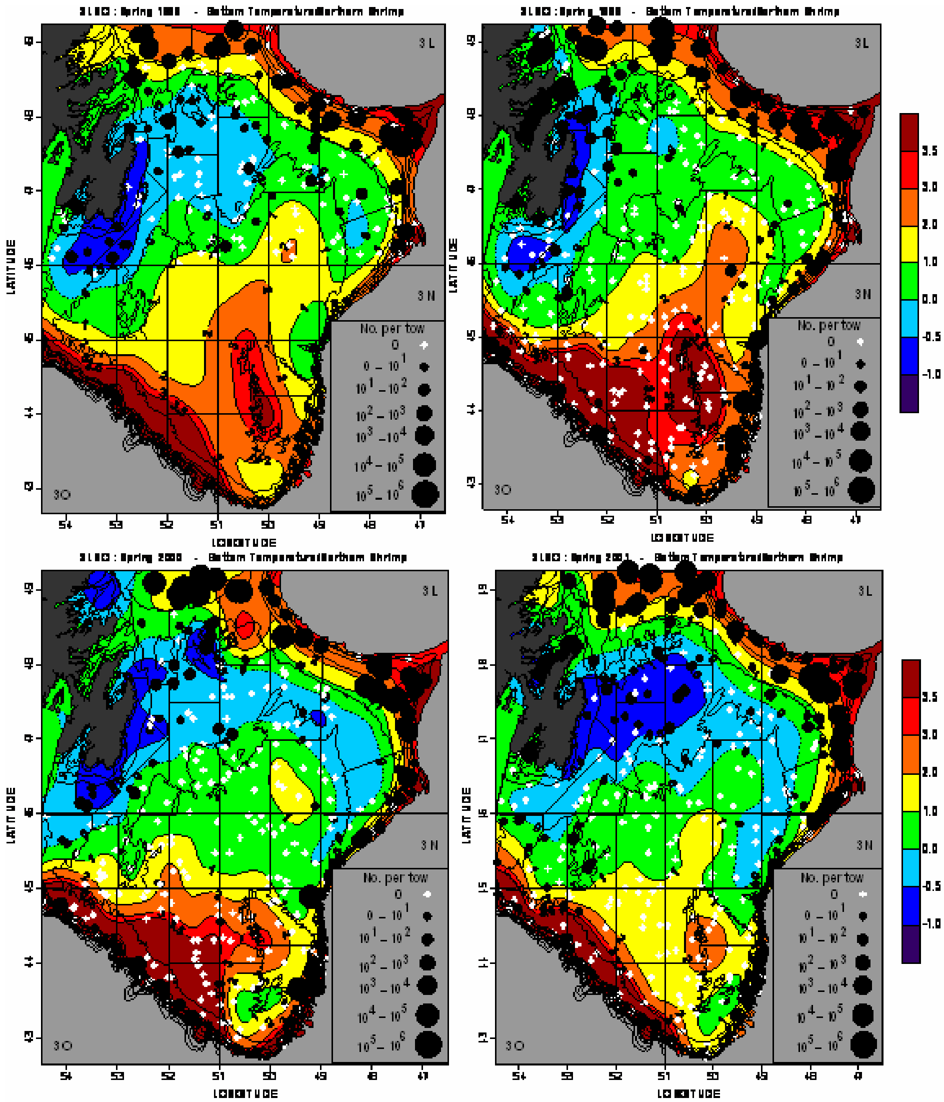

Fig. 10. Bottom temperature contour maps (in °C) for the **spring** of 1998-2001 from the annual 3LNO survey and the numbers of shrimp in each fishing set shown as solid circles. The white crosses represent zero catches.

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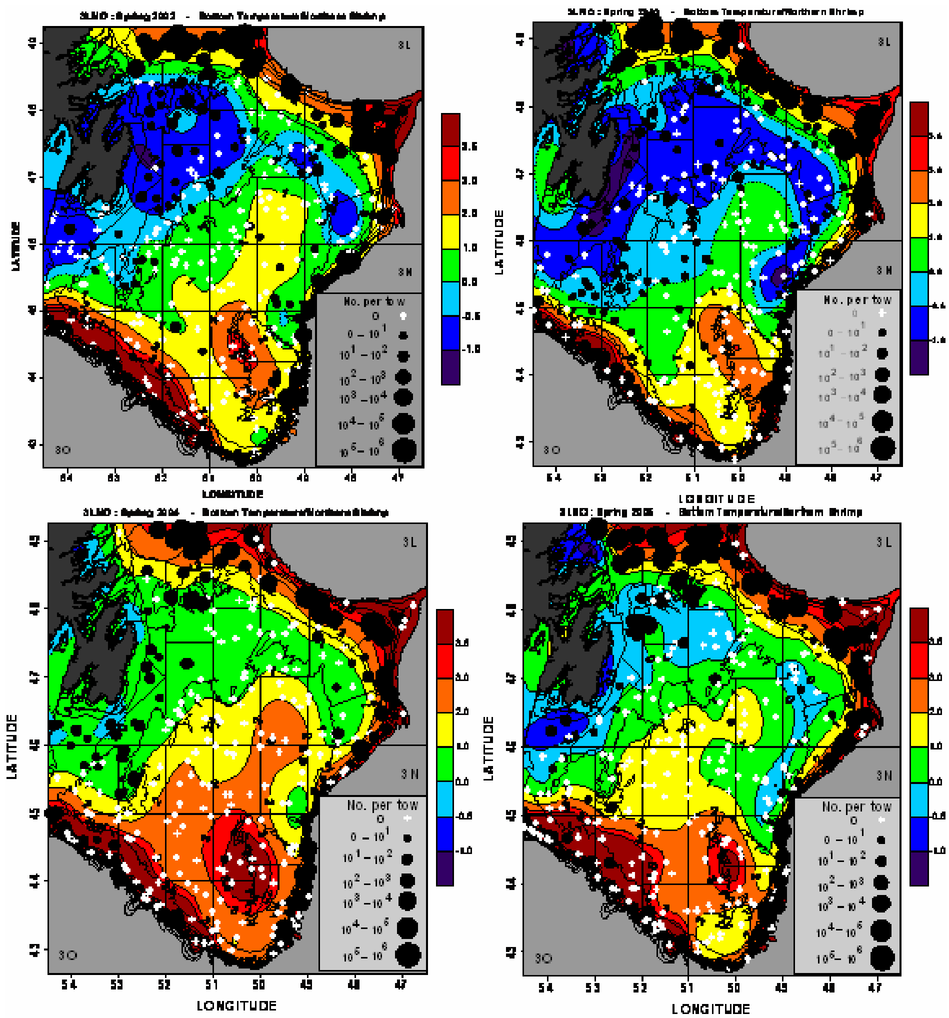

Fig. 10 (cont.). Bottom temperature contour maps (in C) for the **spring** of 2002-2005 from the annual 3LNO survey and the numbers of shrimp in each fishing set shown as solid circles. The white crosses represent zero catches.

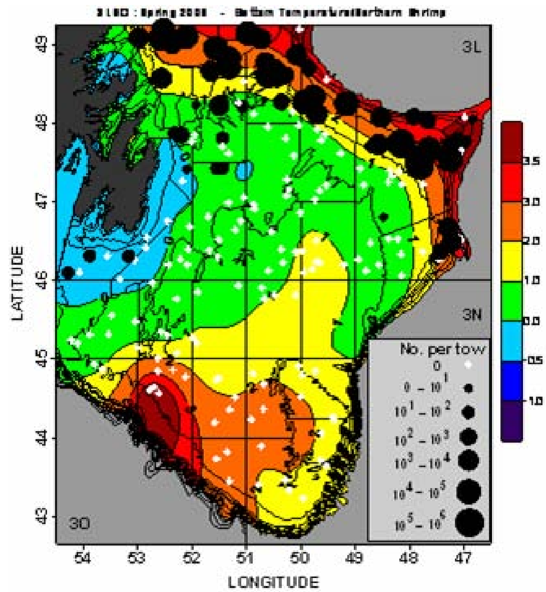

Fig. 10 (cont.). Bottom temperature contour maps (in °C) for the **spring** of 2006 from the annual 3LNO survey and the numbers of shrimp in each fishing set shown as solid circles. The white crosses represent zero catches.

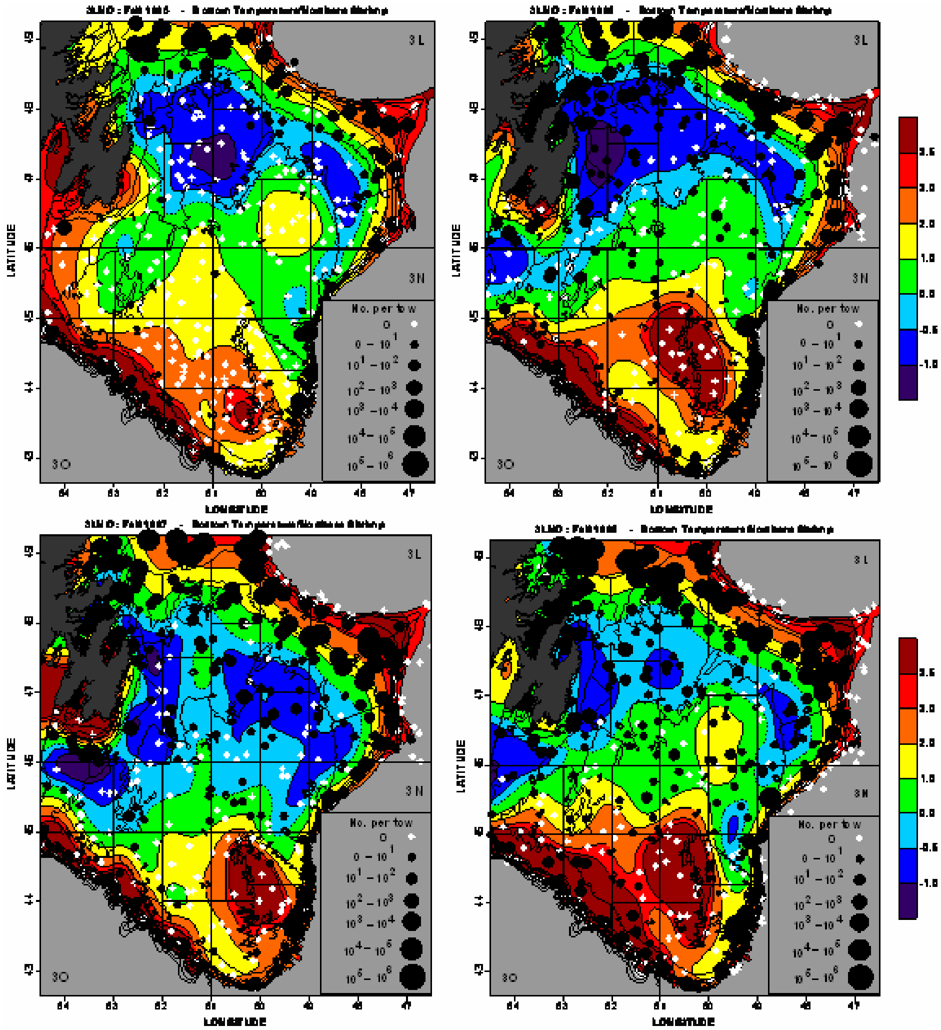

Fig. 11. Bottom temperature contour maps (in °C) for the **fall** of 1995-1998 from the annual 3LNO survey. The numbers of shrimp in each fishing set are shown as solid circles. The white crosses represent zero catches.

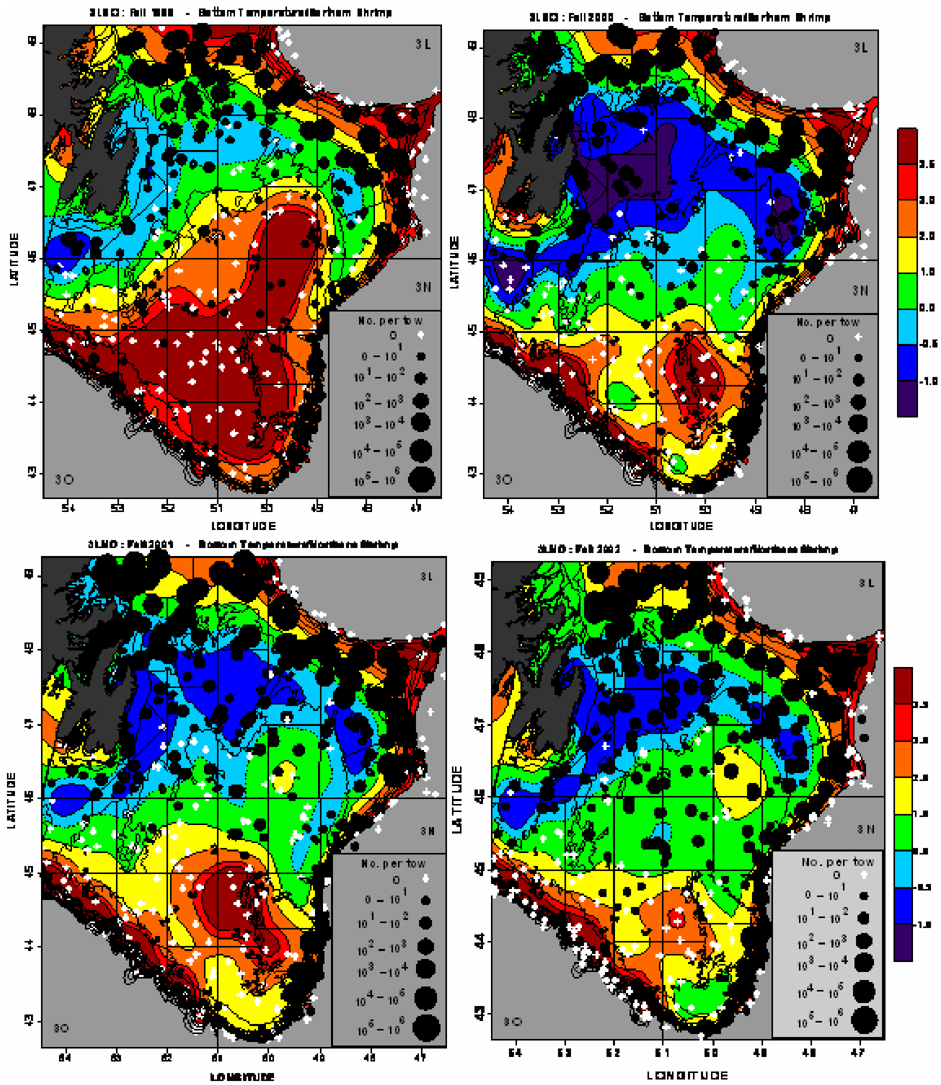

Fig. 11. (Cont.). Bottom temperature contour maps (in °C) for the **fall** of 1999-2002 from the annual 3LNO survey and the numbers of shrimp in each fishing set shown as solid circles. The white crosses represent zero catches

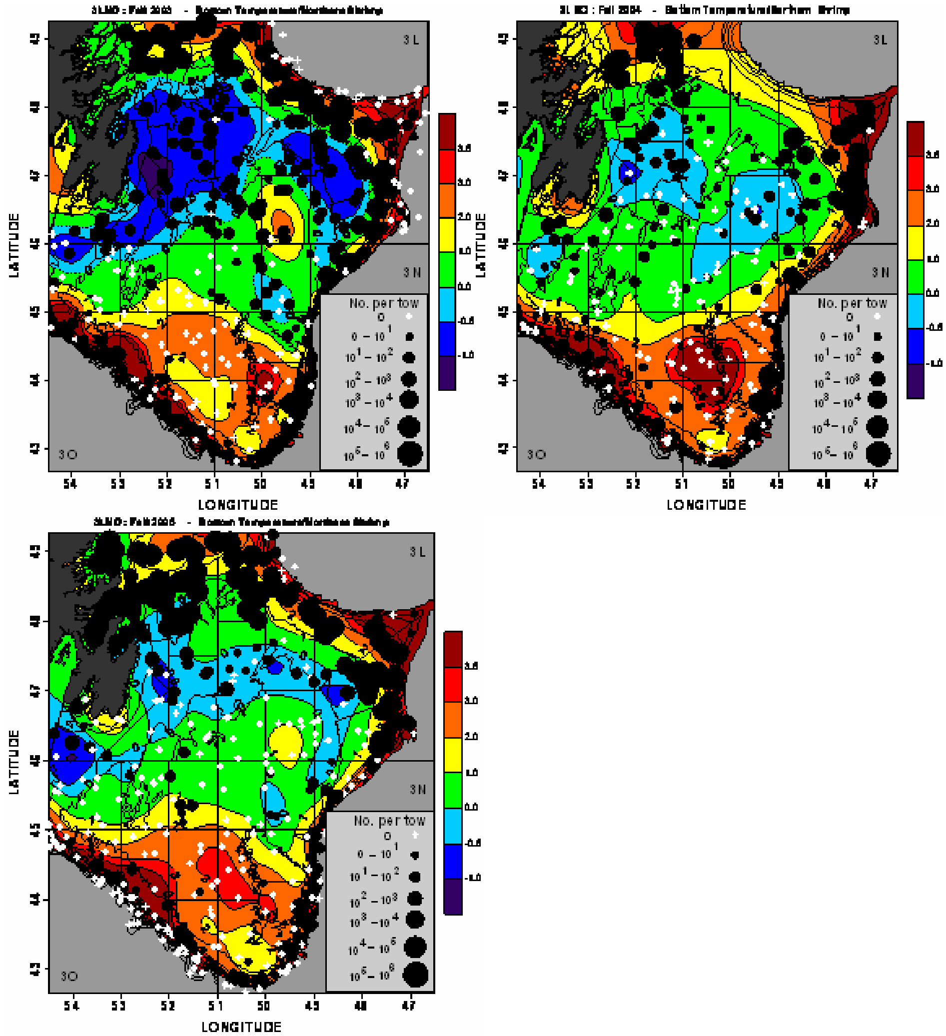

Fig. 11. (Cont.). Bottom temperature contour maps (in °C) for the **fall** of 2003 and 2005 from the annual 3LNO survey and the numbers of shrimp in each fishing set shown as solid circles. The white crosses represent zero catches.