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Northwest Atlantic Fisheries Organization

Serial No. N5196 **NAFO SCR Doc. 05/91**

SCIENTIFIC COUNCIL MEETING – OCTOBER-NOVEMBER 2005

The Distribution and Abundance of Northern Shrimp (*Pandalus borealis*) in Relation to Bottom Temperatures in NAFO Divisions 3LNO based on Multi-species Surveys from 1995-2005

by

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ABSTRACT

The spatial distributions and abundance of northern shrimp are presented in relation to their thermal habitat for NAFO Divisions 3LNO during spring surveys from 1998-2005 and for fall surveys from 1995-2004. The data indicates that the highest numbers of shrimp are generally found in the 2°-4°C temperature range during the spring with lower numbers in water with temperatures <2°^{o}C and >4°C. During the fall most shrimp are found in a colder temperature range of 1°-3°C. Cumulative frequency distribution of the number of shrimp caught and temperature indicates that <5% of the catches are associated with temperatures <1°C in the spring and up to 30% are associated with temperatures <1°C in the fall. 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. In terms of available thermal habitat, about 30% of the surveyed region was covered with water in the 2°-4°C-temperature range during the spring, while about 40% was covered by water in this temperature range in the fall. In 2004 the average spring bottom temperature increased significantly over 2003 to >2°C, the highest since the early 1980s but decreased to slightly <2°C in the spring of 2005. An apparent shift in the shrimp distribution towards colder temperatures further upon the Grand Bank and towards the inshore regions occurred during the fall and as a result, a greater proportion (30%) of the catch shifted into the 0^{o}-1^{o}C temperature range. Very low numbers of shrimp were found in temperatures <0°C and >4°C during both spring and fall. Shrimp catches were mostly zero in all surveys in the shallow waters (<100 m) of the southeast Grand Bank, where temperatures generally range from 2°-7°C. In general, during the spring most of the large catches were found in the warmer water along the slopes of Div. 3LN, while in the fall, larger catches were found in most areas of Div. 3L including the inshore areas of the bays along the east coast of Newfoundland. During the spring of 2005 most of the shrimp catches (>70%) were found in temperatures >3°C with an apparent increase in the overall catches over the previous year. Preliminary results indicate that the larger shrimp are associated with temperatures >3°C while smaller shrimp on average are found in temperatures <2°C. The total number of shrimp in sets dominated with small shrimp show a general association with bottom temperature with the higher numbers occuring in years with low bottom temperatures while the opposite seems to be the case for larger size shrimp.

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 (2004) 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 by examining the mean catch rates and the cumulative distributions of available temperature to the survey and catch numbers for the complete range of temperatures encountered in the region. 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°C.

Data on shrimp abundance and distribution were available for the years 1995-2004 for the fall and from 1998-2005 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 1 500 m (Fig. 1) (Brodie, 1996; McCallum and Walsh, 1996). The mean numbers and weight of northern shrimp for all sets within 1°C temperature bins for each survey were computed. 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. 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 1998-2005 and for the fall surveys for the years 1995 to 2004. 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 during the fall of 2004.

Results

The average number and weight of northern shrimp caught per fishing set in 1^{o}C-temperature bins are displayed in Fig. 2 and 3 for the spring and fall surveys, respectively. Significantly higher numbers and weight of shrimp were caught in the 2°-4°C-temperature range during the spring surveys, with much lower numbers in waters with temperatures <2°C and >4°C. During the spring of 2005 most of the shrimp catches (>70%) were found in temperatures >3°C with an apparent 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. There appeared to be a decrease in the catch rates in the lower temperature bins during the fall of 2004 however the survey coverage was incomplete. 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 (Fig. 2 and 3). 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. The observed seasonal change in distribution as determined by the surveys was most evident in the northern regions of NAFO Div. 3L. The largest observed catches of shrimp occurred in the fall of 2002 and spring of 2003 in the 2°-3°C-temperature range. In general, catch rates and the estimated biomass of northern shrimp has increased substantially during the past three or four years, compared to earlier years of the surveys (Orr *et al*., 2000, 2001, and 2002).

The average weight of shrimp per set in 1°C temperature bins indicates that the larger shrimp (6-7 g) are associated with temperatures >3°C while smaller shrimp (4-5 g) on average are found in temperatures <2°C (Fig. 4). The total number of shrimp in sets with average weights of <5 g show a general association with bottom temperature with the higher numbers occuring in years with low bottom temperatures. The opposite seems to be the case for shrimp with average sizes of 6-7 g (Fig. 5). It should be noted however that these are average numbers and the sets actually contain both males and females shrimp of all sizes, so more effort is probably need to confirm any size depentent relationship with changes in temperature.

To further partition the thermal habitat of northern shrimp in Div. 3LNO we computed annual and average cumulative distributions of available temperature and catch number temperature distributions based on data from the surveys for the years 1998-2005 for the spring (Fig. 6) and 1995-2004 for the fall (Fig. 7). The average distributions for spring and fall based on all data are displayed in Fig. 8. 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. These preliminary results indicate that <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. In the 1°-2°C range, around 10% were caught in the spring and about 20% in the fall surveys. 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 shrimp were caught in the both the spring and fall surveys in areas where the bottom temperatures were >3.5°C. Again a shift in the distribution towards warmer temperatures during the spring of 2005 is evident.

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. In the fall, about 30% of the surveyed region was covered with <0°C water, about 30% was in the 0^{o}-3^{o}C temperature range and about 40% of the bottom was covered by water with temperature >3°C (Fig. 8). These results indicate that on average the thermal habitat in the surveyed area of Div. 3LNO during both spring and fall is very similar. There are exceptions however, the most noteworthy being the spring of 2004 when most of the area had warmed significantly compared to the fall of 2003. It should be noted that these percentages are based on the relatively warm years of 1995-2005. The shift in the shrimp distribution towards colder temperature bins during the fall is clearly evident by comparing the cumulative distributions displayed in Fig. 6 to 8.

The areal extent of the bottom covered by water in various temperature ranges during spring for the Div. 3LNO region is displayed in Fig. 9 (top panel). In this region from 1975 to 1983 most of the bottom area was covered by water above 0°C with only approximately 20% covered by <0°C water. From 1984 to 1997 there was a large increase in the area of <0°C water with percentages reaching near 60% in some years. Since 1997 there was a significant decrease in the percentage area of the bottom covered by <0°C water and a corresponding increase in the area covered by water ≥1°C. During 2000 the area of cold water began to increase reaching 30% by 2002 and to 40% by 2003. This area decreased again in 2004 to <10% the lowest value in the record and increased slightly to about 10% in 2005. The area of the Grand Bank covered by water >3°C in 2004 and 2005 was about 20%, similar to that observed during the warm period of the late 1990s.

The average spring bottom temperature time series for the Div. 3LNO region shows large inter-annual variations of about 1℃ amplitude and a downward trend that started in 1984. This trend continued until the early-1990s. The highest temperature in the 25-year record occurred in 1983 when the average temperature was 3.2°C and the lowest temperature of 0.25°C occurred in 1990. Recently, temperatures have increased over the lows of the early-1990s with the average bottom temperature during the spring of 1999 and 2000 reaching 2^{o}C. During the spring of 2001 to 2003, the average bottom temperature decreased over the 2000 value to about 1℃ in 2003, the 11th coldest in the 28 year record (Fig. 9, bottom panel). In 2004 the average spring bottom temperature increased significantly over 2003 to >2°C, the highest since the early 1980s but decreased to slightly <2°C in the spring of 2005.

The spring and fall bottom temperature maps together with the number and weight of shrimp caught per set for NAFO Div. 3LNO are shown in Fig. 10 to 12. In general, spring bottom temperatures in the northern areas ranged from <0°C in the inshore regions of the Avalon Channel to >3°C at the shelf edge. Over the central and southern areas bottom temperatures ranged from 1°C to >3.5°C on the Southeast Shoal and >3°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 Div. 3NO was covered by <0°C water (Colbourne, 2000). Beginning around 1996 the area of <0°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°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°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°-3°C) as a result of summer surface heating (Colbourne, 2000; Colbourne and Murphy, 2000).

The numbers and weight of northern shrimp caught per set during each survey are displayed with the temperature contours in Fig. 10 and 11 for the spring surveys and in Fig. 12 and 13 for the fall surveys as expanding symbols. The size of the circle is proportional to the magnitude of the catch or weight in each set. The majority of fishing sets in the shallow regions (water depths <100 m) of southern Div. 3L and most of Div. 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. 12). 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°-7°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°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

Data on the spatial distributions and abundance of northern shrimp collected during the multi-species surveys in NAFO Div. 3LNO 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. Cumulative frequency distribution of the number of shrimp caught and temperature indicates that <5% of the catches are associated with temperatures <1°C in the spring and up to 30% are associated with temperatures <1^{o}C in the fall. 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. In terms of available thermal habitat, about 30% of the surveyed region was covered with water in the 2°-4°C-temperature range during the spring, while about 40% was covered by water in this temperature range in the fall. In 2004 the average spring bottom temperature increased significantly over 2003 to >2°C, the highest since the early 1980s but decreased to slightly <2°C in the spring of 2005. An apparent shift in the shrimp distribution towards colder temperatures further upon the Grand Bank and towards the inshore regions occurred during the fall and as a result, a greater proportion (30%) of the catch shifted into the 0°-1°C temperature range. Very low numbers of shrimp were found in temperatures <0°C and >4°C during both spring and fall. Shrimp catches were mostly zero in all surveys in the shallow waters (<100 m) of the southeast Grand Bank, where temperatures generally range from 2^{o}-7°C. In general, during the spring most of the large catches were found in the warmer water along the slopes of Div. 3LN, while in the fall, larger catches were found in most areas of Div. 3L including the inshore areas of the bays along the east coast of Newfoundland. During the spring of 2005 most of the shrimp catches (>70%) were found in temperatures >3°C with an apparent increase in the overall catches over the previous year. Preliminary results indicate that the larger shrimp are associated with temperatures >3°C while smaller shrimp on average are found in temperatures <2°C. The total number of shrimp in sets dominated with small shrimp show a general association with bottom temperature with the higher numbers occuring in years with low bottom temperatures while the opposite seems to be the case for larger size shrimp. Finally it is not known if the observed changes in the distribution from spring to fall are environmentally driven, feeding behaviour or due to other factors, such as changes in trawl catchability.

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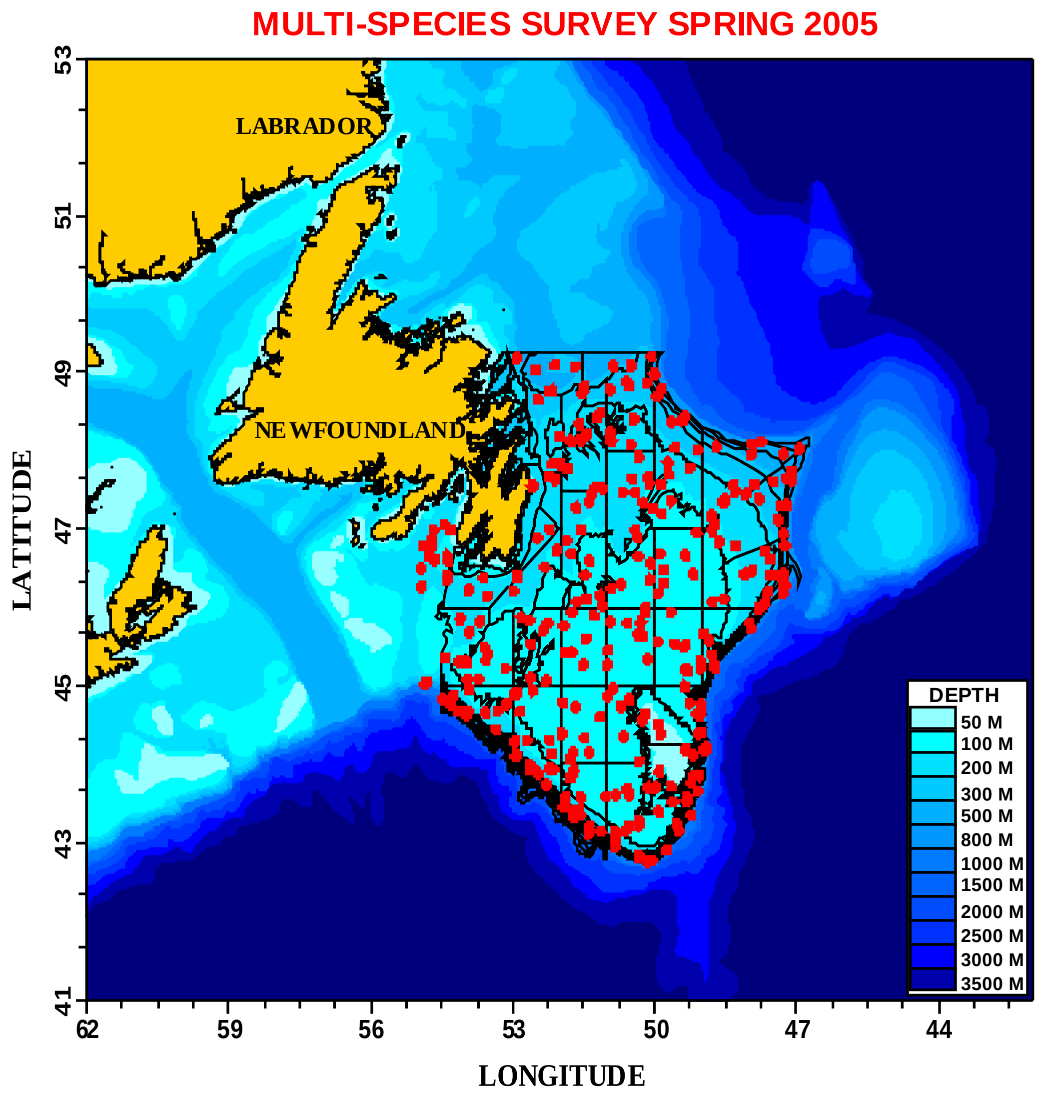
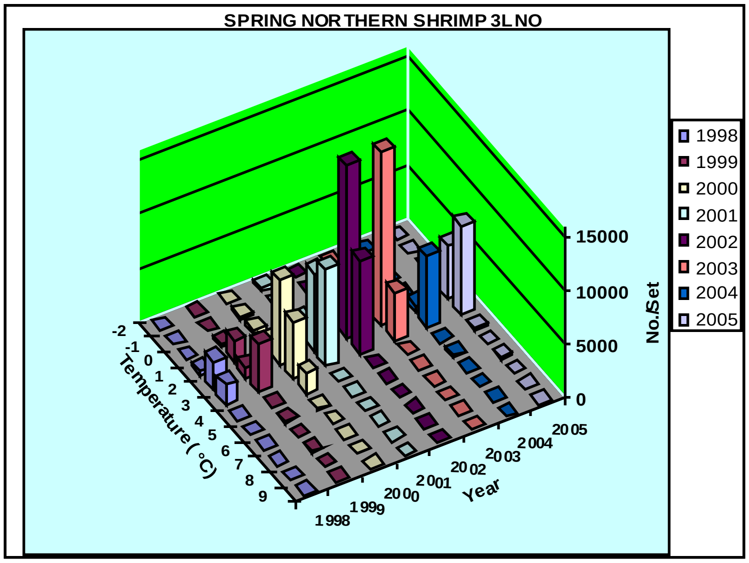


Fig. 1 Location map showing the stratified area and the positions of fishing sets during the Canadian research trawl survey in NAFO Div. 3LNO during the spring of 2005.



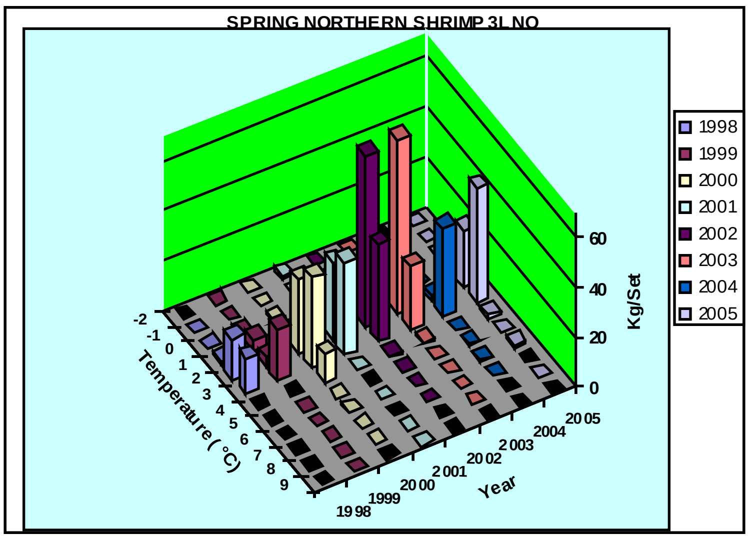


Fig. 2. The average number (top panel) and weight (bottom panel) of northern shrimp per fishing set in 1°C temperature bins for the **spring** surveys in NAFO Div. 3LNO for the years 1998-2005.

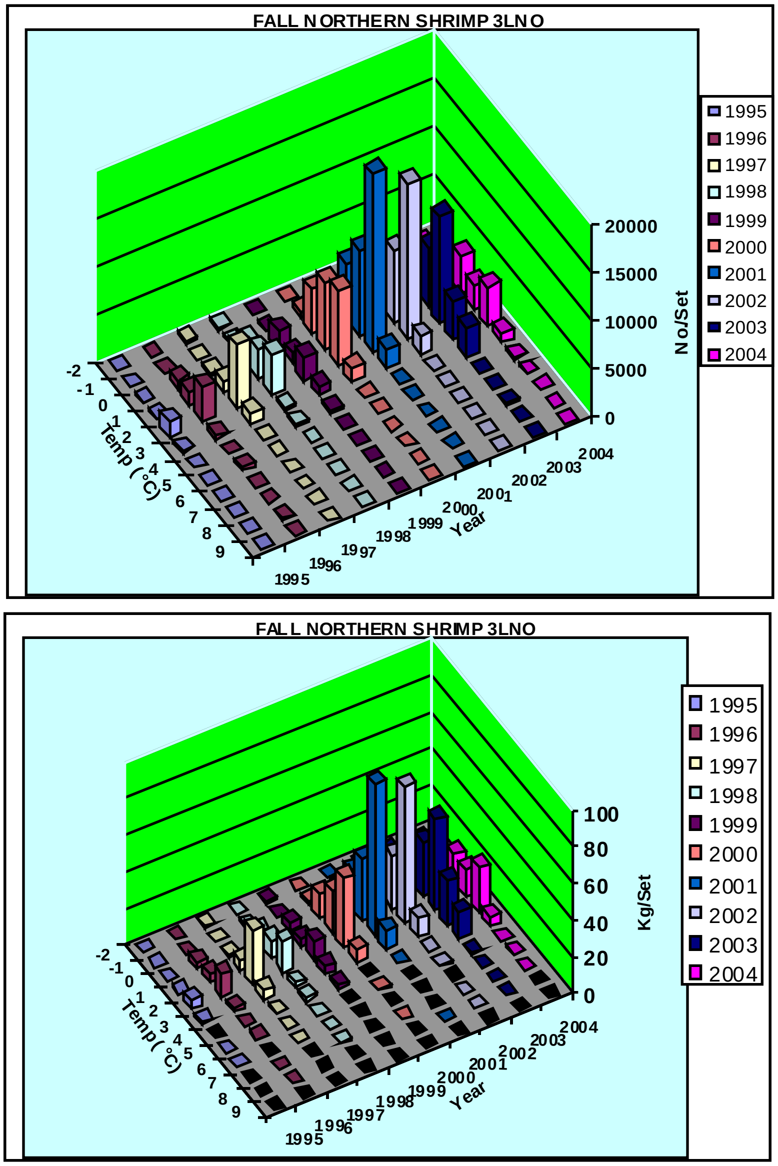


Fig. 3. The average number (top panel) and weight (bottom panel) of northern shrimp per fishing set in 1°C temperature bins for the **fall** surveys in NAFO Div. 3LNO for the years 1995-2004.

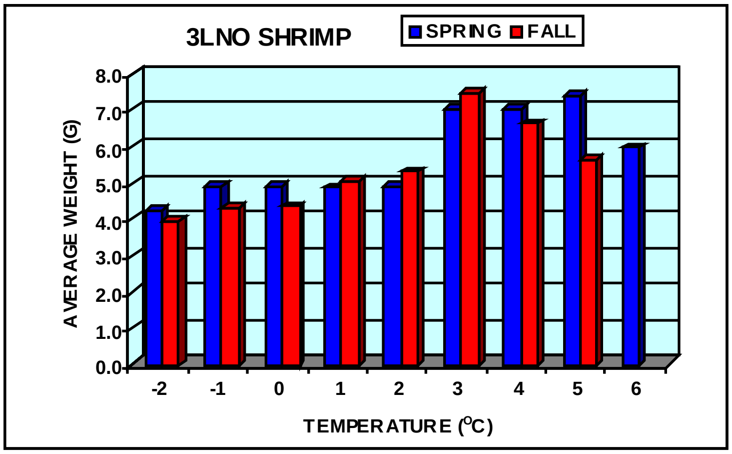
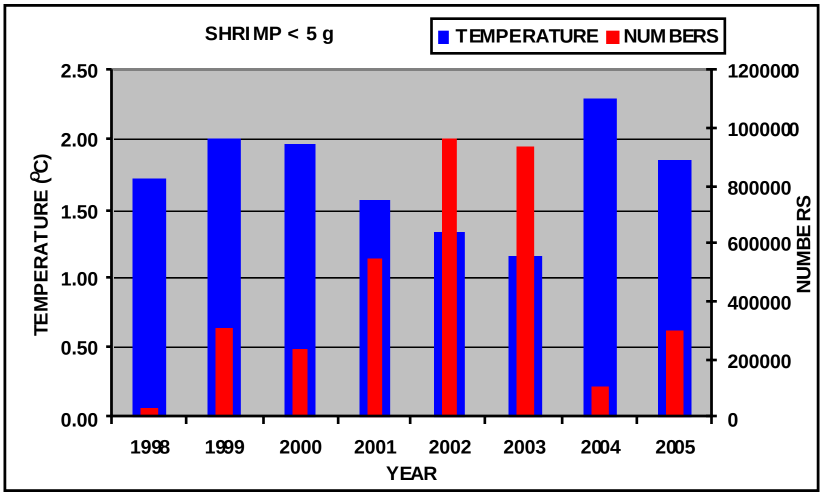


Fig. 4. The average weight (in g) of shrimp per set within 1°C temperature bins for the spring and fall surveys in NAFO Div. 3LNO.



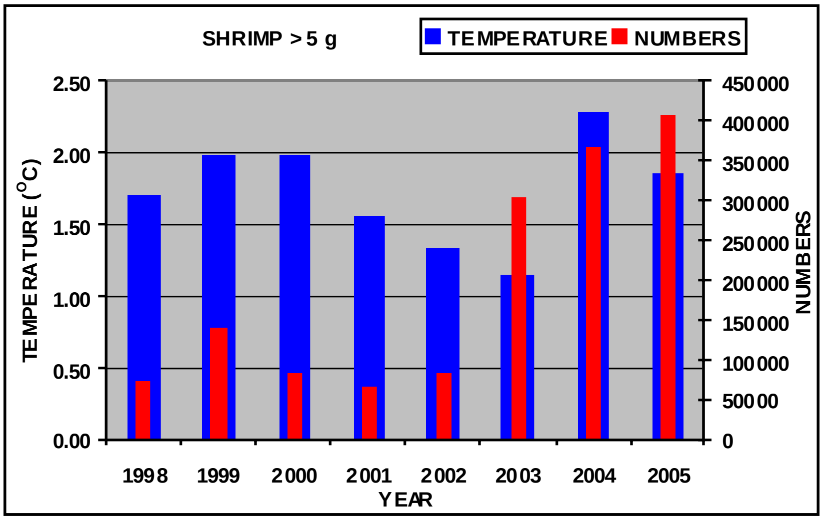


Fig. 5. The total number of shrimp in sets with average weights of <5 g (top panel) and >5 g (bottom panel) together with average spring bottom temperatures in NAFO Div. 3LNO.

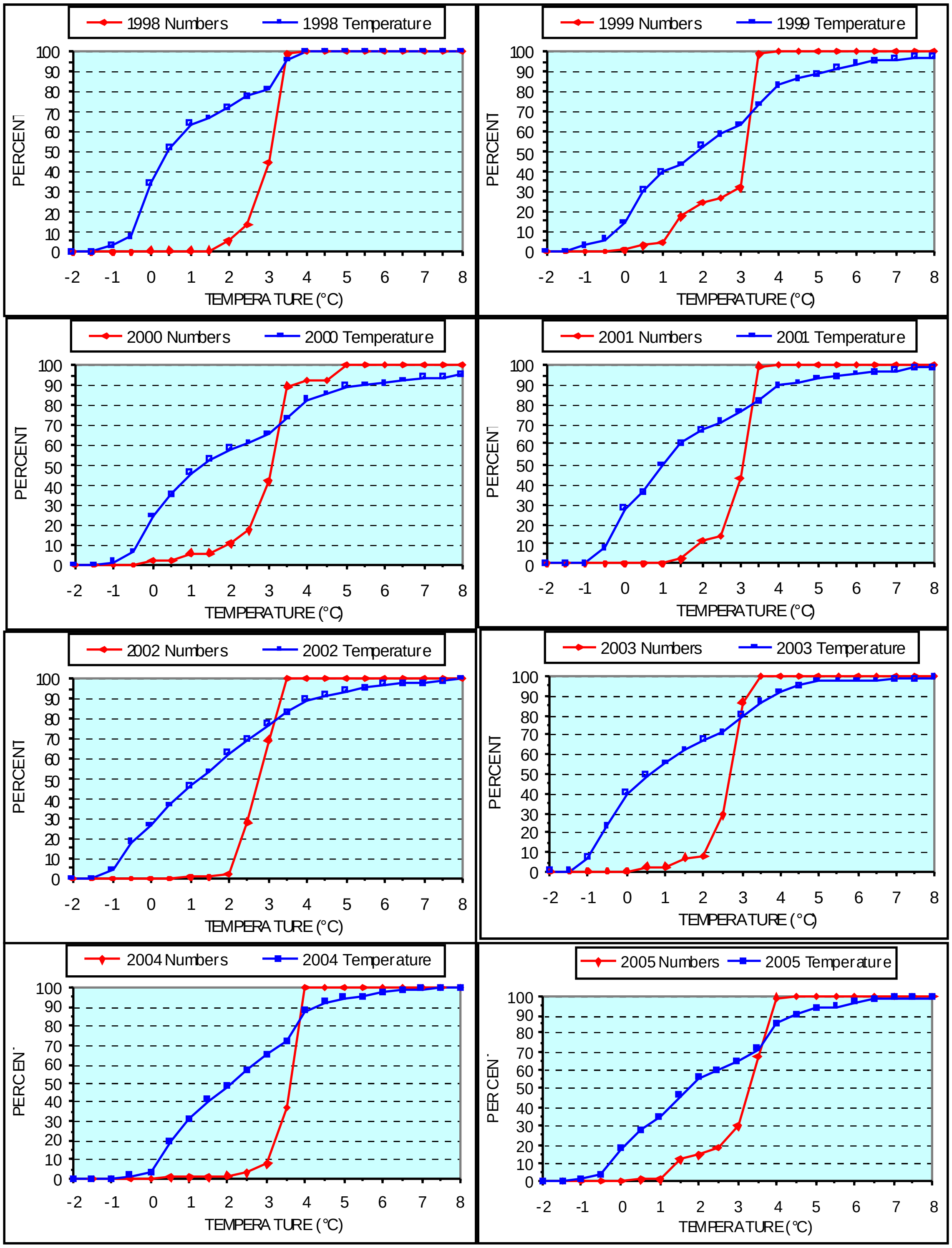


Fig. 6. Cumulative frequency distributions of the number of sets in the 3LNO survey in 1°C temperature bins and the cumulative frequency distribution of the number of shrimp caught in 1°C temperature bins for the **spring** surveys from 1998-2005.

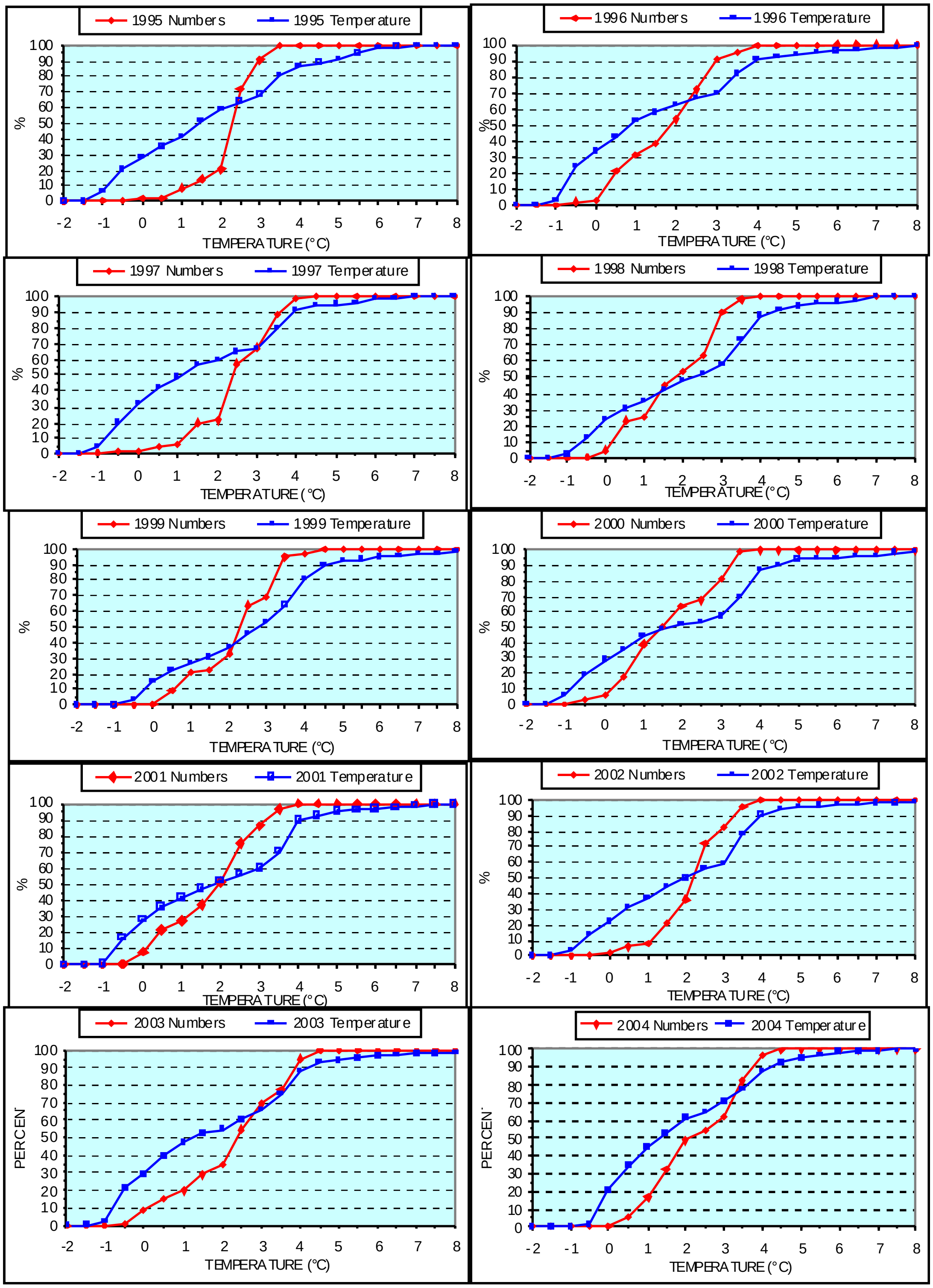


Fig. 7. Cumulative frequency distributions of the number of sets in the 3LNO survey in 1°C temperature bins and the cumulative frequency distribution of the number of shrimp caught in 1°C temperature bins for the **fall** surveys from 1995 to 2004.

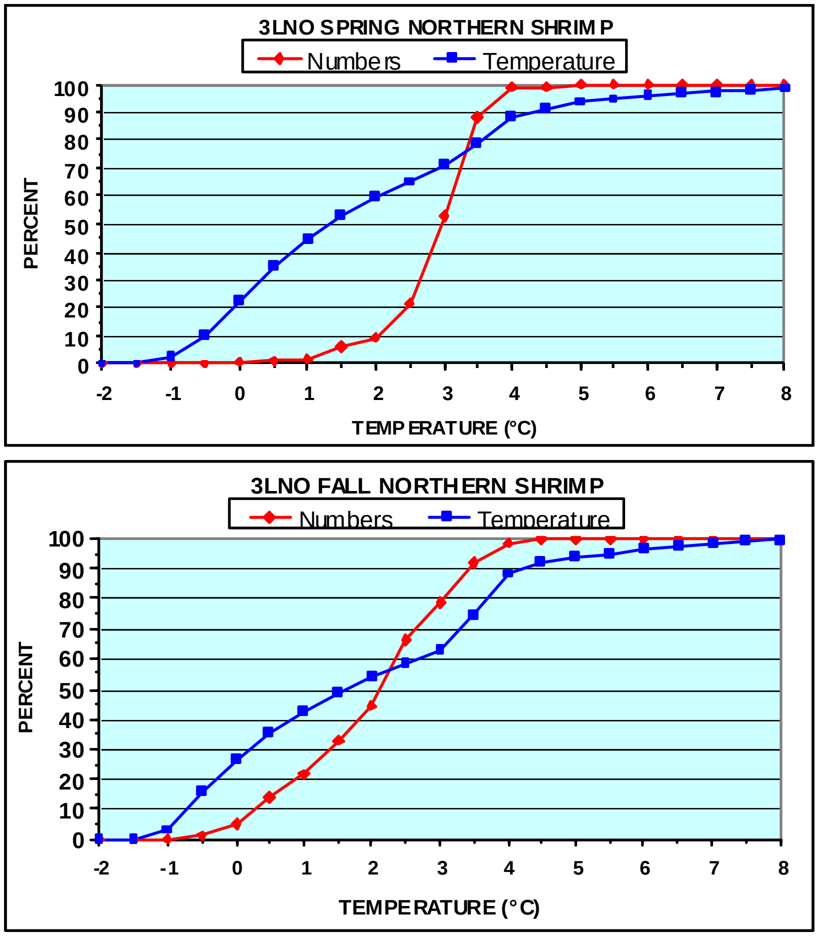


Fig. 8. Average cumulative frequency distributions of the number of sets in the 3LNO survey in 1°C temperature bins and the cumulative frequency distribution of the number of shrimp caught in 1°C temperature bins for all data in the **spring** (top panel) and **fall** (bottom panel) surveys

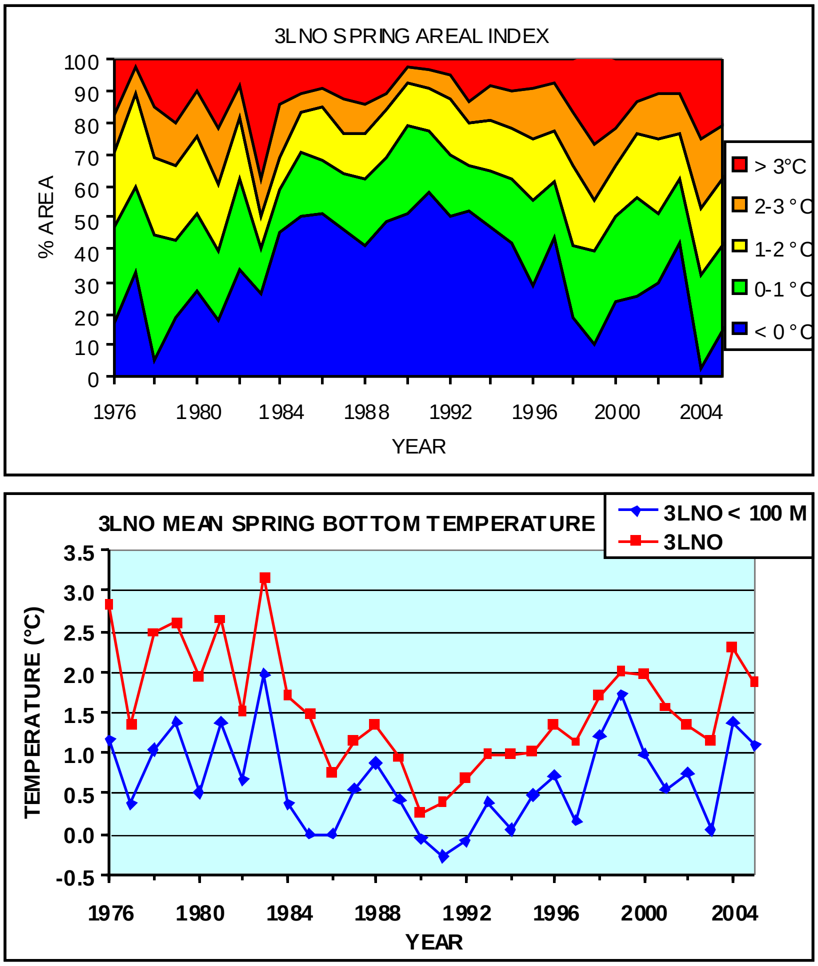


Fig. 9. Time series of the percentage area of the bottom in NAFO Div. 3LNO covered by water with temperatures ≤ 0°C, 0-1°C, 1-2°C, 2-3°C and ≥3°C during spring (top panel) and the spatially averaged spring bottom temperature (bottom panel).

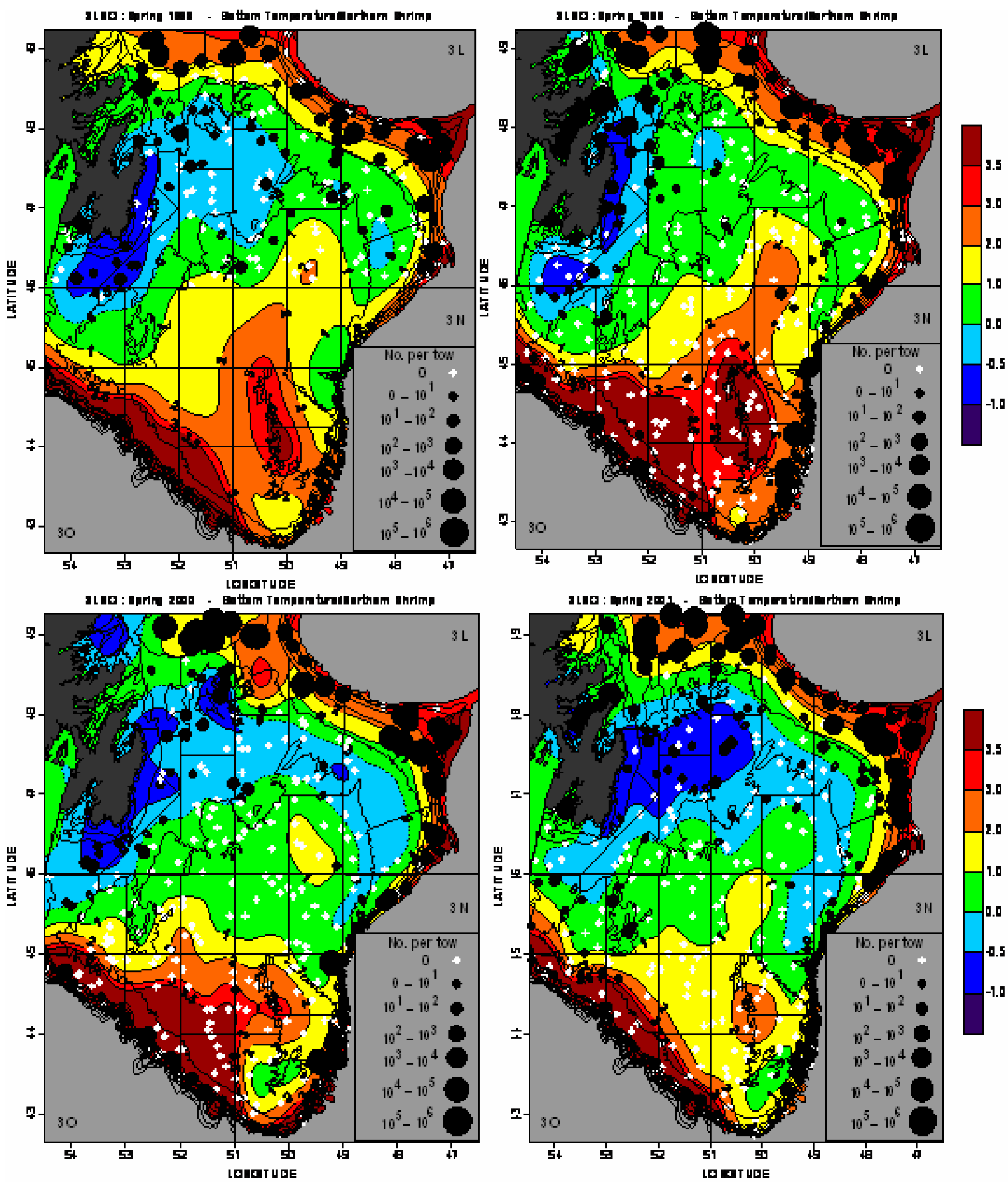


Fig. 10. Bottom temperature contour maps (in °C) for the **spring** of 1998-2001 from the annual 3LNO survey and the numbers of shrimp in each fishing set shown as solid circles. The white crosses represent zero catches.

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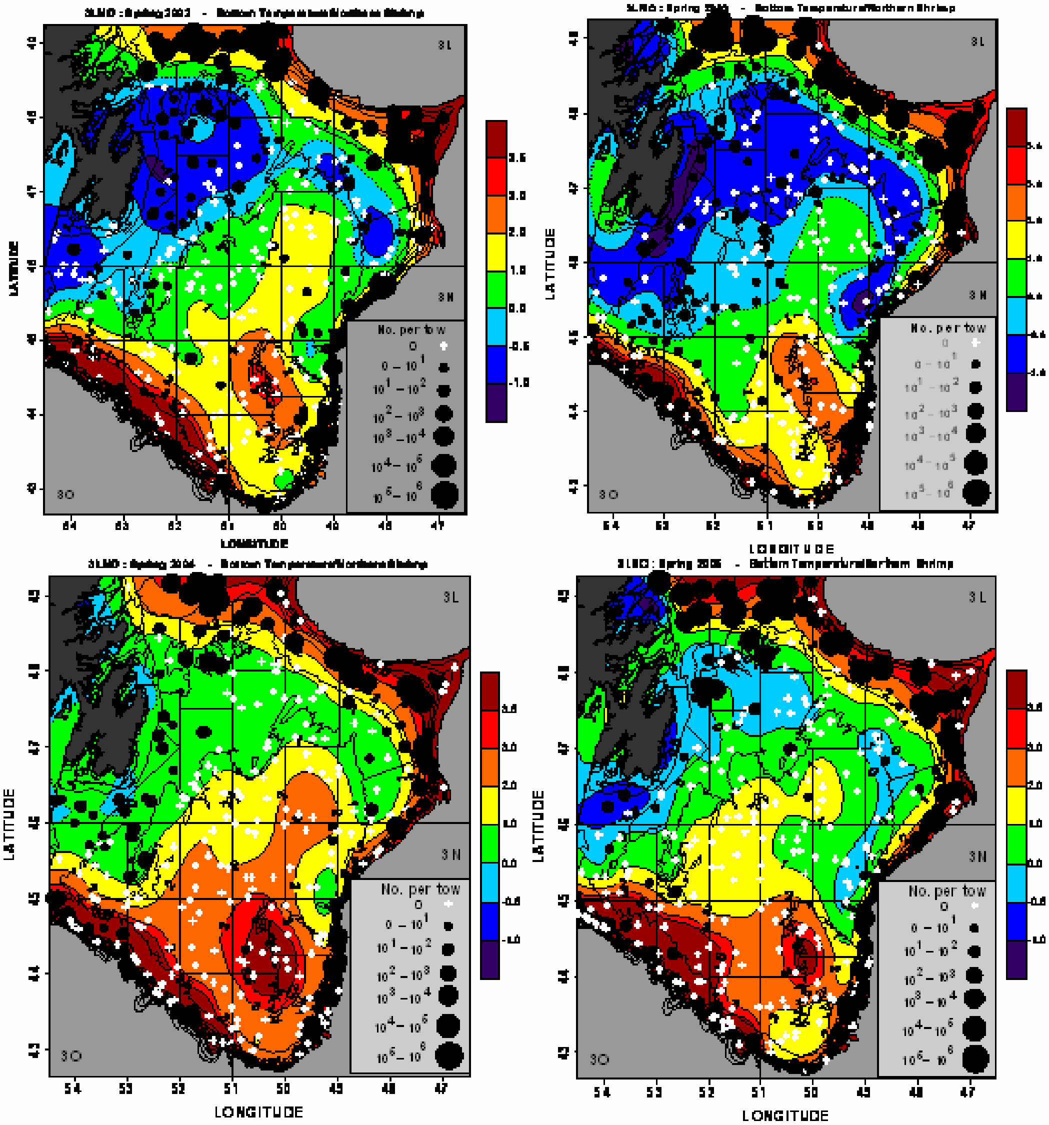

Fig. 10 (cont.). Bottom temperature contour maps (in C) for the **spring** of 2002-2005 from the annual 3LNO survey and the numbers of shrimp in each fishing set shown as solid circles. The white crosses represent zero catches.

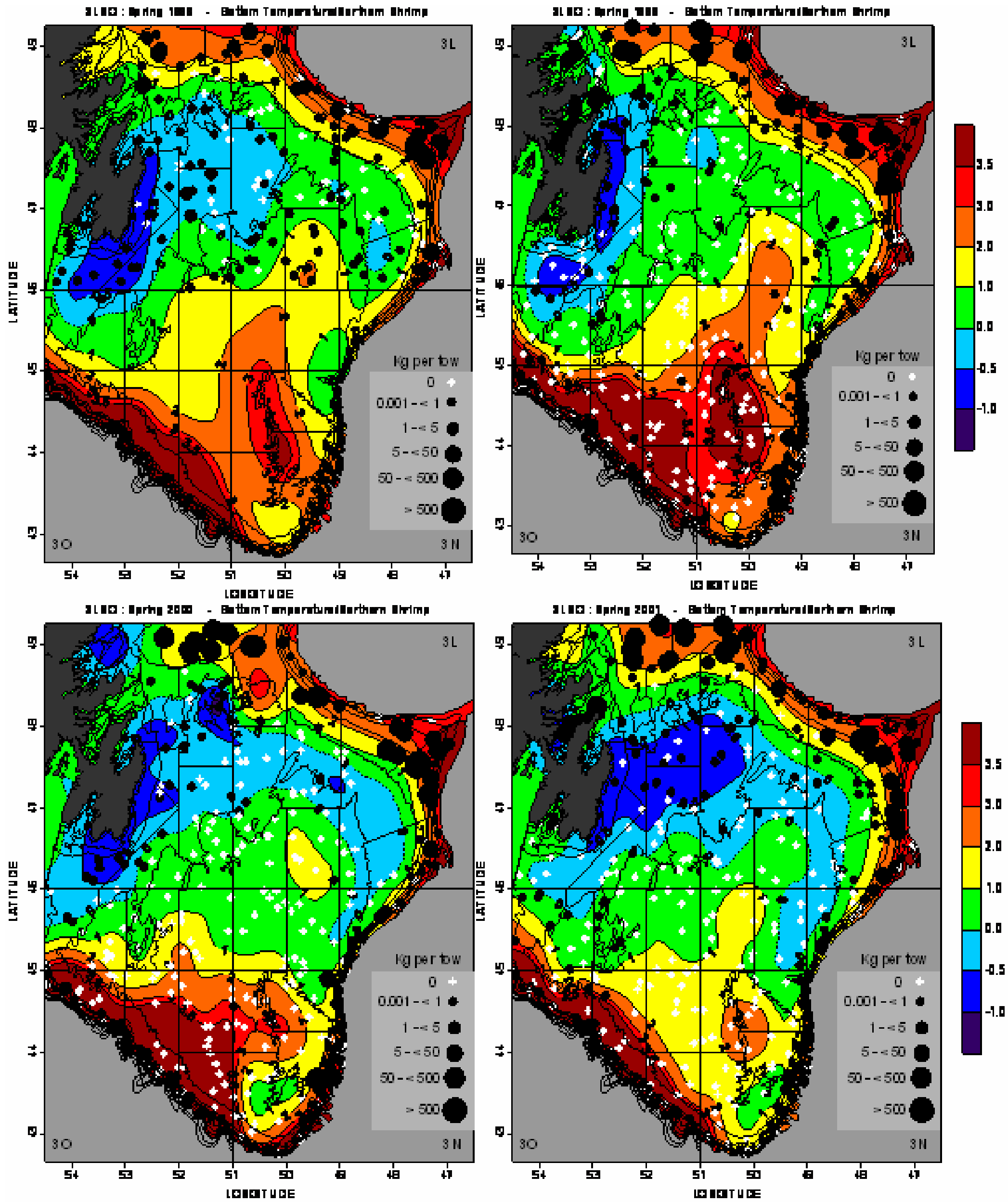

Fig. 11. Bottom temperature contour maps (in °C) for the **spring** of 1998-2001 from the annual 3LNO survey and the total weight of shrimp in each fishing set shown as solid circles. The white crosses represent zero catches.

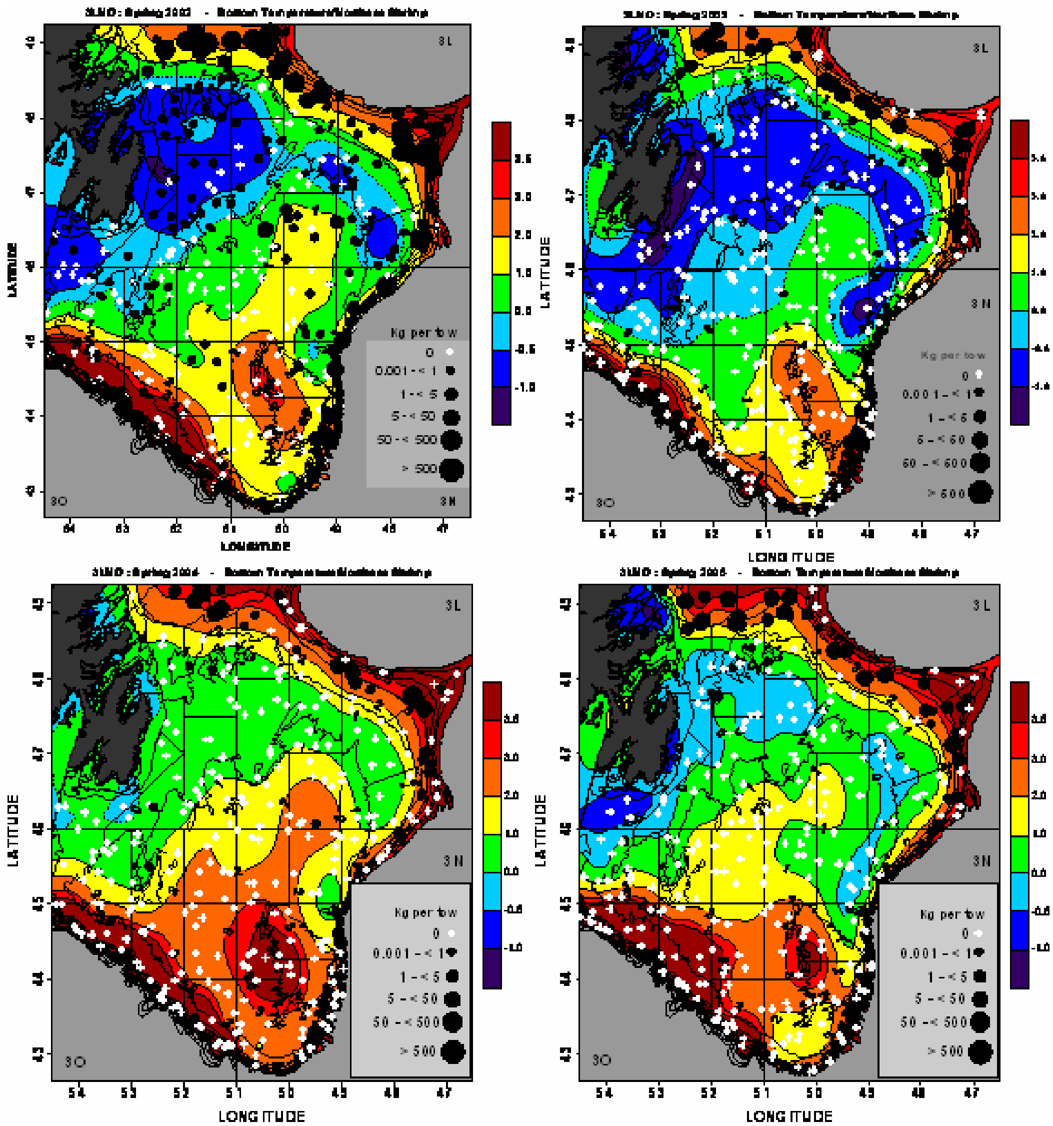

Fig. 11. (Cont.). Bottom temperature contour maps (in C) for the **spring** of 2002-2005 from the annual 3LNO survey and the total weight of shrimp in each fishing set shown as solid circles. The white crosses represent zero catches.

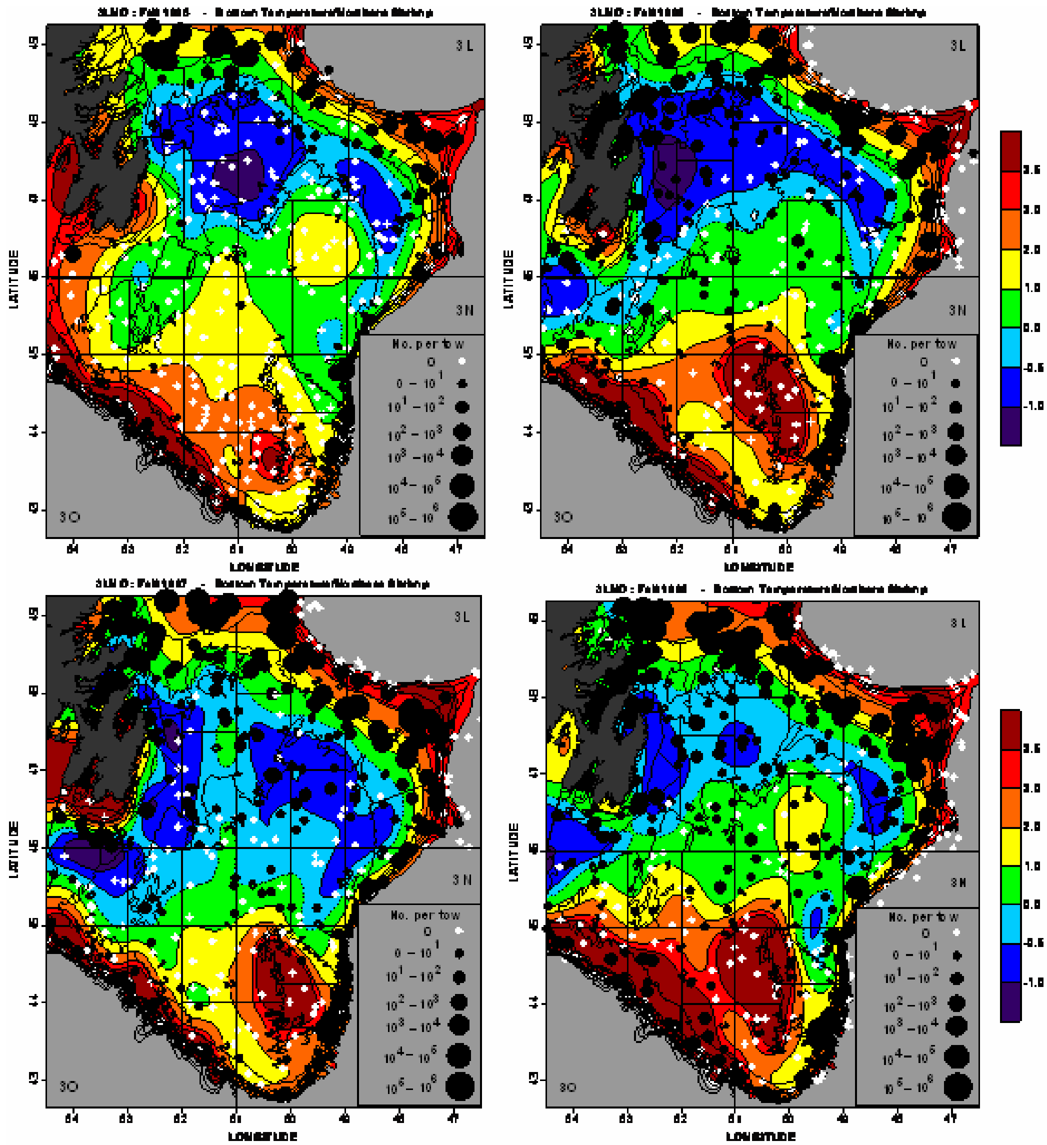

Fig. 12. Bottom temperature contour maps (in °C) for the **fall** of 1995-1998 from the annual 3LNO survey. The numbers of shrimp in each fishing set are shown as solid circles. The white crosses represent zero catches.

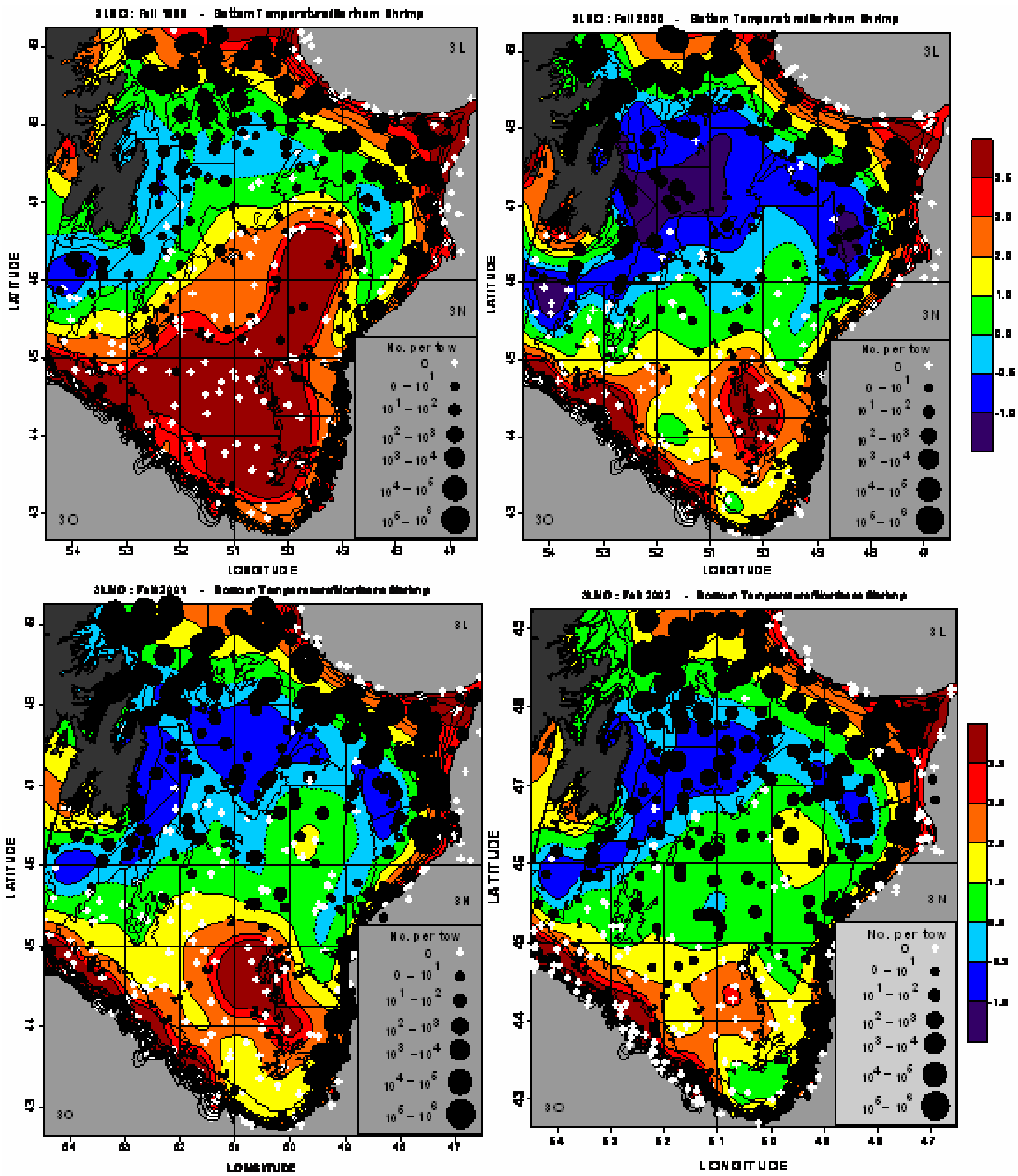

Fig. 12. (Cont.). Bottom temperature contour maps (in °C) for the **fall** of 1999-2002 from the annual 3LNO survey and the numbers of shrimp in each fishing set shown as solid circles. The white crosses represent zero catches

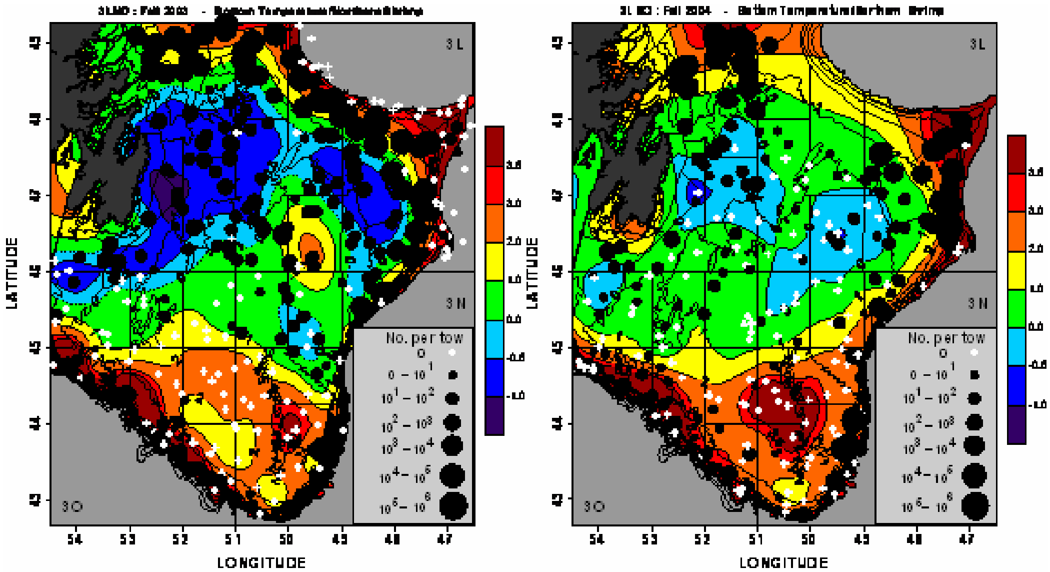

Fig. 12. (Cont.). Bottom temperature contour maps (in °C) for the **fall** of 2003 and 2004 from the annual 3LNO survey and the numbers of shrimp in each fishing set shown as solid circles. The white crosses represent zero catches.

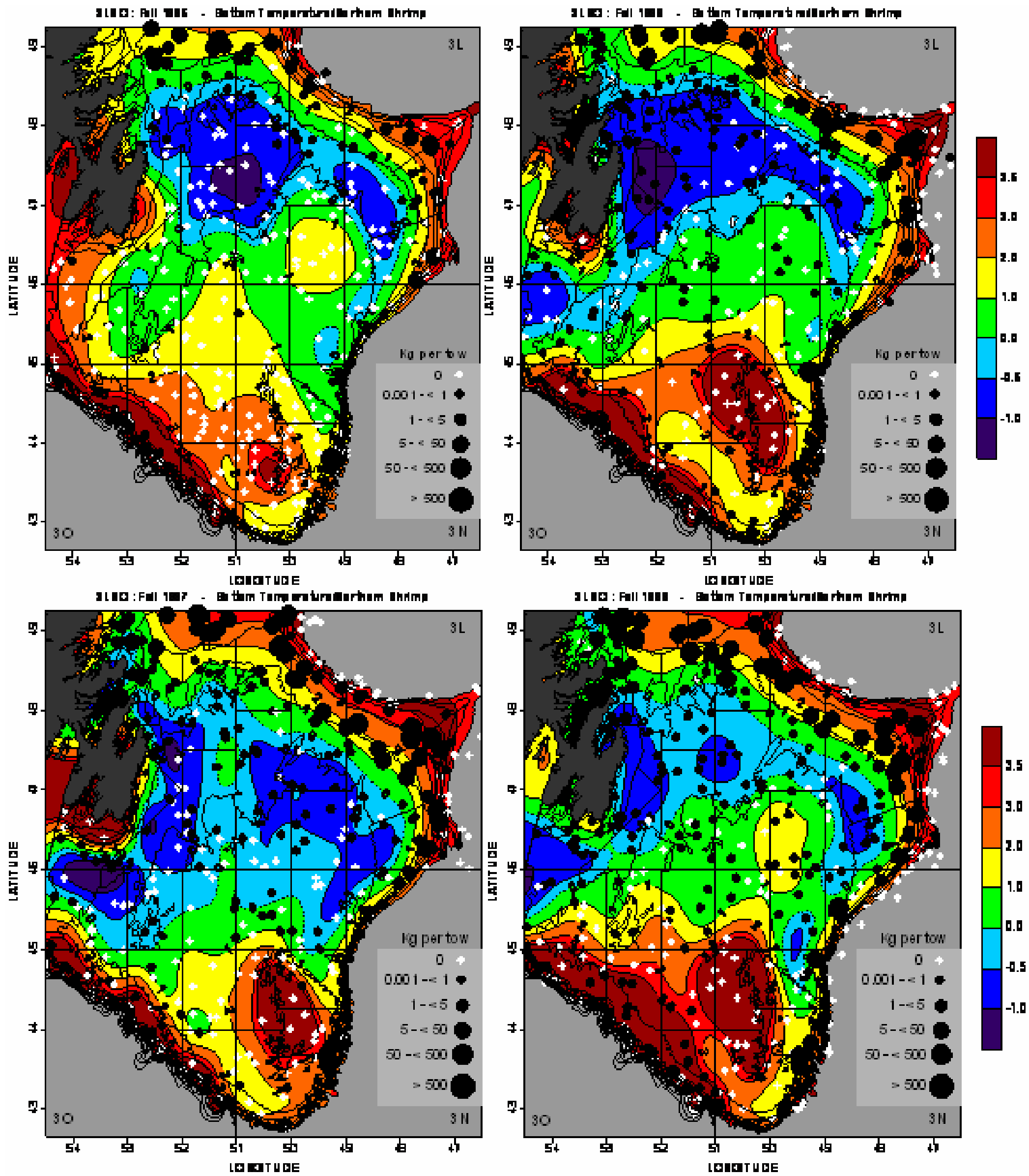

Fig. 13. Bottom temperature contour maps (in °C) for the **fall** of 1995-1998 from the annual 3LNO survey and the weight of shrimp in each fishing set shown as solid circles. The white crosses represent zero catches

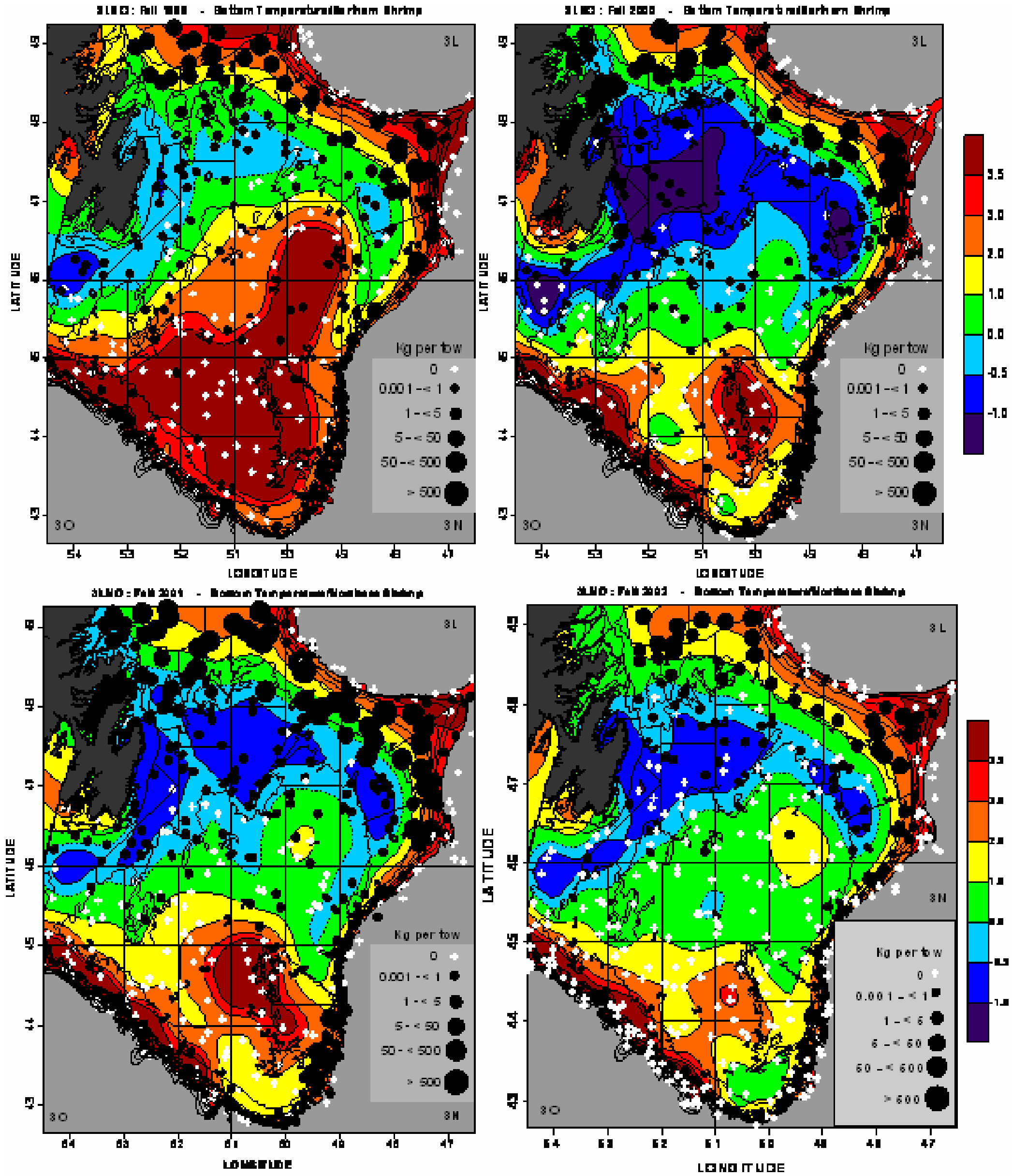

Fig. 13. (Cont.). Bottom temperature contour maps (in °C) for the **fall** of 1999-2002 from the annual 3LNO survey and the weight of shrimp in each fishing set shown as solid circles. The white crosses represent zero catches.

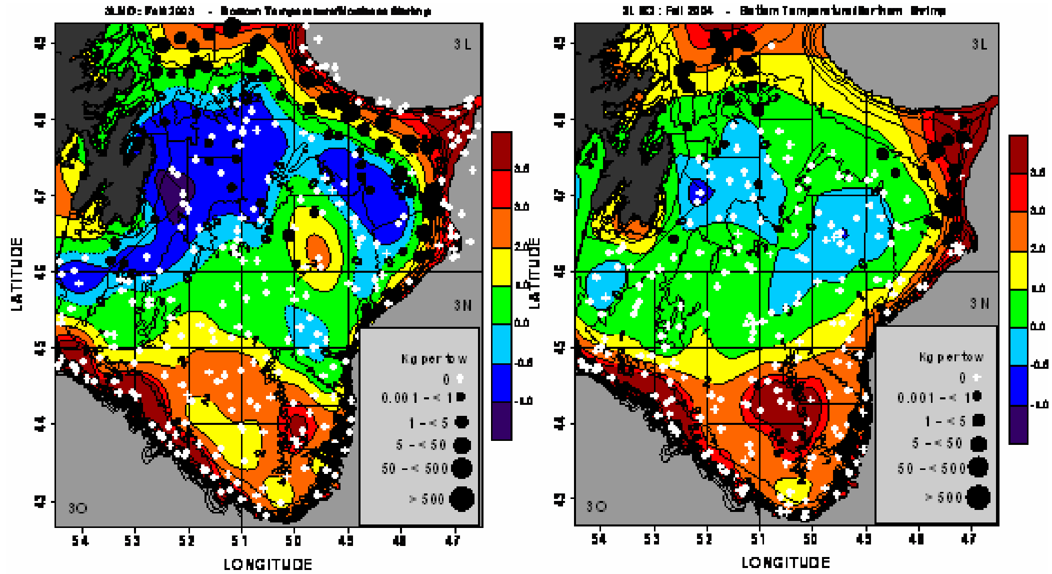

Fig. 13. (Cont.). Bottom temperature contour maps (in °C) for the **fall** of 2003 and 2004 from the annual 3LNO survey and the weight of shrimp in each fishing set shown as solid circles. The white crosses represent zero catches