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Temperature Conditions on the Scotian Shelf and in the southern Gulf of St. Lawrence during 2003 Relevant to Snow Crab

Conditions de température sur le plateau néo-écossais et dans le sud du golfe du Saint-Laurent en 2003 en regard du crabe des neiges

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Abstract

Temperatures during 2003 are presented for the waters of Maritime Canada inhabited by snow crab. Data were available from a number of sources including snow crab and groundfish surveys on the Scotian Shelf and the Magdalen Shallows in the Southern Gulf of St. Lawrence. Bottom temperatures within the snow crab fishing areas of the southern Gulf of St. Lawrence were generally cooler-than-average in 2003 except for the shallower regions where warmer-than-normal conditions were observed. Over the central Magdalen Shallows, temperatures decreased in 2003 compared to 2002 and there was more water with temperatures <0°C. In the northeastern Scotian Shelf, bottom waters were significantly colder than the long-term average (1971-2000) having cooled relative to observations in 2002. A snow crab habitat index, defined by the area of the bottom covered by waters between -1° to 3°C, was calculated for each of the southern Gulf, Sydney Bight and northeastern Scotian Shelf regions. The index for the Gulf rose compared to 2002, but it is still below the long-term mean value. On the Scotian Shelf, the index increased by 50% and it is above its long-term average with the highest value of the timeseries. In Sydney Bight the habitat index also increased compared to 2002 and is significantly above its long-term mean. The crabs caught during the annual snow crab surveys were found in colder waters in 2003 than in 2002, which is believed to reflect in large part the availability of cooler temperatures.

Resumé

Des données sur la température des eaux des provinces Maritimes fréquentées par le crabe des neiges sont présentées pour 2003. Les données proviennent de diverses sources, y compris les relevés du crabe des neiges et du poisson de fond effectués sur le plateau néo-écossais et le plateau madelinien dans le sud du golfe du Saint-Laurent. La température au fond dans les zones de pêche du crabe des neiges du sud du Golfe était généralement plus basse que la moyenne en 2003, sauf dans les secteurs peu profonds, où elle était plus élevée que la normale. Dans la partie centrale du plateau madelinien, la température a diminué en 2003 par rapport à 2002 car il y avait plus d'eau avec une température de moins de 0 °C. Dans le nord-est du plateau néo-écossais, la température au fond était nettement plus basse que la moyenne à long terme (1971-2000), ce qui démontre un refroidissement relativement aux conditions observées en 2002. Un indice d'habitat du crabe des neiges, défini par la superficie du fond couverte par des eaux de -1° à 3 °C, a été calculé pour le sud du Golfe, la baie Sydney Bight et le nord-est du plateau néo-écossais. L'indice pour le Golfe a augmenté par rapport à 2002, bien qu'il demeure inférieur à sa valeur moyenne à long terme, tandis que sur le plateau néo-écossais, il a augmenté par un facteur de 50 %, pour se situer au-dessus de sa valeur moyenne à long terme et constituer la valeur la plus élevée de la série chronologique. Dans la baie Sydney Bight, l'indice a aussi augmenté par rapport à 2002, pour se situer nettement au-dessus de sa valeur moyenne à long terme. Les crabes capturés dans le cadre des relevés annuels ont été pris dans des eaux plus froides en 2003 qu'en 2002, ce que l'on croit reflète en grande partie la disponibilité de par celles d'habitat plus froides.

Introduction

Snow crab (*Chionoecetes opilio*) is a cold-water species typically inhabiting bottom depths of 20-400 m. An active and very lucrative fishery presently exists in the Gulf of St. Lawrence, on Sydney Bight and on the northeastern Scotian Shelf (Fig. 1). Annual assessments of the stock abundance, fishing effort, biological characteristics and the environment of the snow crab are undertaken by the combined efforts of the Gulf and Maritimes Regions of the Department of Fisheries and Oceans (DFO) and the snow crab fishing industry. The purpose of this paper is to provide information on the sea temperature conditions during 2003 in areas occupied by snow crab (Fig. 2) and to compare these temperatures to their long-term means. This includes areal indices of the ocean bottom covered by water temperatures between -1°C and 3°C in Sydney Bight, over the northeastern Scotian Shelf and for the Magdalen Shallows in the Gulf of St. Lawrence. Monthly mean temperature profiles and time series of the monthly mean temperatures at specific depths within snow crab fishing areas provide further information on sea temperature trends. Finally, the catch of snow crab during the snow crab surveys as a function of temperature for the 2003 season is presented and compared to other years when temperature and catch data were available. We begin with a description of the temperature data, then provide details of the methods used to analyze the temperature fields and finally present the results. The results are given, first for the Gulf of St. Lawrence and then for the Scotian Shelf.

Data

Near-bottom temperatures during 2003 in the areas of snow crab fishing were available from two main surveys in both the Gulf of St. Lawrence and the Scotian Shelf. In the Gulf, 340 stations were occupied during the snow crab surveys conducted from July to early October (Fig. 3a). The annual groundfish survey in the southern Gulf was carried out in September but only 83 stations (Fig. 3b) were occupied due to vessel problems. On the northeastern Scotian Shelf, the main snow crab survey was undertaken from October to December (242 stations, Fig. 4a) and the groundfish survey in July (Fig. 4b). The snow crab surveys obtained near-bottom temperatures with a thermistor recorder attached to the trawl. Temperature and salinity data were collected with a conductivity-temperature-depth (CTD) instrument during the groundfish surveys. Approximately 93 of the 215 stations taken during the July groundfish survey were located on the northeastern portion of the Scotian Shelf and on Sydney Bight where snow crab are traditionally fished. The remaining CTDs during the groundfish survey were taken in the central and southwest portions of the Shelf. The latter were also augmented by bottom temperatures (136 stations) collected in the southwestern portion of the shelf during a fishermen conducted survey in July. Other temperature data from the snow crab areas in 2003 were obtained from the Marine Environmental Data Service (MEDS) in Ottawa, Canada's national oceanographic data archive, and were derived from additional fisheries surveys, research surveys and measurements from ships-of-opportunity. Pre-2003 data were taken from the hydrographic database maintained at the Bedford Institute of Oceanography (BIO). This database contains an edited version of the entire MEDS holdings for the region.

The relationship between snow crab catch and bottom temperature is examined again this year. A comparison of results from 2003 with previous years' surveys is also presented.

Methods

The near-bottom temperatures from data collected during all of the surveys were interpolated onto a specified grid using an objective analysis procedure known as optimal estimation. This is a 4-dimensional interpolation technique; i.e. three space dimensions, two horizontal and one vertical, and the time dimension. In this study the surveys were treated as synoptic and no interpolation in time was carried out. Only the temperature data from the September survey is used for the Southern Gulf while the data from July survey is used on the Scotian Shelf and in Sydney Bight. The details of the procedure are found in Drinkwater and Pettipas (1996). The maximum profile depth on the CTD for each station was assumed to be at the bottom. Checks against bathymetric charts were carried out to ensure no large errors occurred as a result of this assumption. The maximum depth in the grid for the slope water area off the Scotian Shelf was taken as 1000 m. The temperature grid for the Gulf of St. Lawrence was 0.1° x 0.1° latitude-longitude and for the northeastern Scotian Shelf and Sydney Bight was 0.2° x 0.2° latitude-longitude. The bottom temperature data were then smoothed for the purpose of contouring, which tends to spread out the gridded values, thus the true gradients are stronger than those depicted in the plots.

Long-term monthly climatological means of the near-bottom temperatures were estimated at each grid point based upon optimal estimations using all available data for the years 1971-2000 in the historical temperature, salinity database at the Bedford Institute. The 1971-2000 climatological means are then subtracted from the values derived from the 2003 survey. The differences are called temperature anomalies. A negative anomaly indicates that the 2003 temperature was colder than the long-term mean and a positive anomaly indicates that it was warmer than the long-term mean. We also examined the change in temperature since the previous year by subtracting the 2002 optimally estimated temperatures from the 2003 estimates. A negative value indicates that 2003 was cooler than 2002, a positive value that it was warmer.

The snow crab habitat index, defined by Drinkwater et al (1988) as the area of the bottom covered by temperatures between -1°C and 3°C (favorable temperature range for the adults snow crabs), was calculated from the gridded temperature fields derived from the groundfish surveys. Separate indices were calculated for the Magdalen Shallows, Scotian Shelf and Sydney Bight. The temperature at each grid point was assigned the area of bottom associated with that particular grid point. The areas with temperatures between -1° and 3°C, inclusive, were then summed. The mean temperature within this area was also estimated. The 2003 indices were compared to those derived from earlier surveys but augmented by any additional temperature data available for the particular year and month in question. The time series of the indices began in 1970 for the Scotian Shelf/Sydney Bight region and in 1971 for the Magdalen Shallows.

In addition to the bottom temperatures and habitat indices, monthly mean temperature profiles for 2003 were determined within each of the snow crab areas (Fig. 2) from the BIO database. All available data within each of these areas were averaged by month at standard depths (0, 10, 20, 30, 50, 75, 100, 125, 150, 175, 200, 250, and 300 m, where possible). Temperature data from areas 20 through 22, as well as 18 and 19 were combined for the presentation. An “annual” anomaly profile was determined for each year by averaging the available monthly anomalies, regardless of how many months were available. Time series of monthly mean temperatures at representative depths for each area are also provided. Long-period trends represented by 5-year running averages of the “annual” anomalies are also shown.

We also examine the catch of snow crab as a function of temperature and depth for the Gulf and Shelf areas. The temperatures at which the crabs were caught were partitioned into 0.5°C bins and the depths into 20 m bins. The frequency distribution of the crab temperatures was expressed in percentages within each of the bins. These were then compared with the frequency distribution of the available temperatures at all of the stations sampled. Finally, comparisons were made between these 2003 results and those from 2002 and earlier surveys.

Results

Southern Gulf of St. Lawrence

Bottom Temperatures

Data acquired during the groundfish survey in September 2003 showed that bottom temperatures ranged from <0°C to over 17°C over the Magdalen Shallows (Fig. 5a). The majority of the bottom was covered by waters <3°C with the largest portion of the Shallows (50-80 m) covered by waters <1°C. A large area, in the middle of the shallows, shows sub-zero values. The bottom temperatures in northeast part of the Southern Gulf are not shown due to the lack of data. Bottom temperatures tend to increase from the center of the Magdalen Shallows towards the shallower, nearshore regions and towards the deeper Laurentian Channel. This is because in the Gulf of St. Lawrence during summer, cold temperatures are found at intermediate depths (50-150 m), sandwiched between warm solar-heated upper layer waters and the relatively warm, salty deep waters in the Laurentian Channel. The latter originate from the slope water region off the continental shelf and are transported up the Channel. The cold waters are known as the cold intermediate layer (CIL). Although the deeper waters are warmer than the CIL, their density is greater because of higher salinities. In winter, the CIL merges with the upper layer as the latter cools. The primary origin of the waters in the CIL is from atmospheric cooling of the water within the Gulf of St. Lawrence in winter with additional input through advection of cold Labrador Shelf water through the Strait of Belle Isle. The latter varies annual but with a mean of approximately 35% of the total volume of the CIL (Petrie et al., 1988). In 2003, the warmest near-bottom temperatures in the southern Gulf were in its shallowest regions, in particular, in Northumberland Strait and in St. Georges Bay where the analysis suggests they reached 15°-17°C (Fig. 5).

Temperature anomalies over a large portion of the deeper part of the Magdalen Shallows were below normal while the shallower parts exhibit warmer than normal conditions (Fig. 5b). The highest negative anomalies (as low as -3°C) are located along the northeast coast of Prince Edward Island (PEI) and around Magdalen Islands. The highest positive anomalies (+3-4°C) appeared in Miramichi Bay, off northwestern PEI and in St. Georges Bay. However, these high anomalies must be viewed with caution since the largest uncertainties in the optimally estimated temperature fields are in the nearshore regions. There are two main reasons for this. First, there tends to be greater temporal variability at shallower depths because they lie close to the strong vertical gradient in temperature, called the thermocline. Indeed, in these regions the mixed layer may at times extend to the bottom in response to wind storms producing large variability in the near-bottom temperatures. Second, the optimal estimation routine extrapolates horizontal temperature gradients to the coast if there are no data inshore. This can lead to fictitious data, especially in regions of strong horizontal temperature gradients.

Relative to 2002, bottom temperatures during the 2003 groundfish survey were significantly cooler over much of the Magdalen Shallows (Fig. 6). The region off northwestern PEI was especially cooler with a temperature departure of -3°C. This cooling might be partially due to the lack of data for year 2003 as discussed in the previous paragraph. There was, however, a significant area off the north and east of PEI that was warmer in 2003 than in 2002.

The spatial pattern of the bottom temperatures from the snow crab survey in July-October 2003 is similar to that from the 2003 groundfish survey but shows significantly cooler waters in the shallower regions around the coastal regions, in Chaleur Bay and off the Magdalen Islands (Fig. 7). The cooler water in Chaleur Bay might be due to an earlier sampling (August) than in the case of the ground fish survey (September). Usually there is a seasonal deepening and warming of the upper mixed layer, especially in the shallower regions. The tail of the water patch with sub-zero temperature extend farther east in the pattern for the groundfish survey compared to the snow crab survey. This is probably due to advection of the cold water mass between August (snow crab survery) and September (grounfish survey). Other possible causes of the differences, besides seasonal warming in the shallow regions, may be differences in instrument accuracy (the CTD being more accurate than the thermistor recorder), a relative rapid point measurement (CTD) versus an average over a trawl distance (snow crab survey), and the difference in depth of the measurement (the thermistor is on bottom while the CTD will be a few to several meters above the bottom).

Snow Crab Habitat Index

From the September groundfish survey, a time series of the snow crab habitat index (area of bottom covered with waters between -1°C and 3°C) based upon optimally estimated bottom temperatures is available from 1971 to 2003. The Magdalen Shallows grid contains a total area of 70039 km^2 (847 grid points). We also estimated the average temperature within the area covered by temperatures in the range -1°C to 3°C and correlated these with the habitat index.

In 2003, the area of the bottom of the Magdalen Shallows covered by waters between -1°C and 3°C during the groundfish survey increased compared to 2002. It was just over 49570 km^2 and, as in 2002, was still below the long-term mean (1971-2000) of approximately 52300 km^2 (Fig. 8). The 2003 value represents 71% of the total Shallows area, and was 3% larger than in 2002 and 4% below the long-term mean. The snow crab habitat index in 2003 was the ninth lowest value over the 32-year record, with 1980 being the smallest followed by 2002. Note, however, that the variability in the habitat index for the Shallows tends to be small. The index only varied between 66% and 84% of the total area available over all years. The mean temperature within the habitat area in 2003 (0.47°C) decreased significantly compared to 2002 (by .51°C). This is a drastic change compared to the four previous years when warmer conditions were recorded. The 2003 mean temperature is the lowest of the last five years and is close to the 1998 value (0.44°C). The correlation between the habitat index and the mean temperature over the years 1971-2003 within this area is -0.35 and is not statistically significant.

Monthly Mean Temperature Anomaly Profiles and Time Series

The following provides the monthly mean temperature anomaly profiles within each of the snow crab fishing areas for the southern Gulf (see Fig. 2 for the area boundaries used in the temperature analysis). The monthly mean temperatures at standard depths were estimated by averaging all of the available data within the area regardless of when in the month it was measured. Similarly, no adjustments were made for the spatial distribution of data or the amount of data that contributed to the average. In some cases the "average" was based upon only one measurement while in other months it was over 200 stations. The long-term (1971-2000) mean was then subtracted to obtain a temperature anomaly. In addition to the profiles, temperature time series at depths considered representative of the near-bottom region within each of the fishing areas, are presented. Because of the limited amount of data within the areas over which the averages were made and the possibility of spatial variability in temperature within the areas, any one point or profile may not be truly representative of "average" conditions for the month. Interpretation of any anomalies therefore must be viewed with caution. While no significance should be placed on any individual monthly anomaly, persistent features are considered to be real.

Data for 2003 over the central Magdalen Shallows (Area 12 in Fig. 2 excluding the southern portion just north of PEI) were available for April to December. The monthly and annual anomaly profiles tend to show significantly below-normal temperatures from the surface to around 200 m, except for May, September and November which show slightly warmer than normal values in the surface layer (Fig. 9). Note that not all months of each year contain data. From 50 to 100 m, which covers most of the area of the Magdalen Shallows, the annual means are significantly different from zero even while considering the error of the means. Below 200 m, which is primarily limited to the Laurentian Channel and the deep trough off Cape Breton, monthly temperature anomaly profiles were slightly positive and the annual anomaly was above zero. An exception was in October when the temperatures below 200 m were significantly colder-than-normal. In the top 20 m, temperature anomalies varied from month to month, but again with a negative tendency. Negative anomaly profiles in 2003 contrast with the more positive ones that were observed in 2002; the water temperature in the whole water column was definitively colder in 2003 that in 2002 over the Magdalen Shallows (see Drinkwater et al. 2003 for temperatures in 2002). The time series of monthly mean temperatures at 75 m in Area 12 also shows high month-to-month variability with a definite tendency for below normal temperatures over most of the period since the mid-1980s to 1999 and closer to normal temperature since that time (Fig.

10). Part of the high month-to-month variability is believed to be due to differences in the extent of the spatial sampling but the long-term pattern matches that observed elsewhere and is considered real. In 2003, temperatures were cooler than the long-term mean except at the end of the year when they were warmer than the average.

Within the southern portion of Area 12 (formerly Areas 25 and 26), just north of Prince Edward Island, data were available only in June, August and September. Most of this area contains bottom depths less than 60 m and is shallower than the rest of the snow crab areas. Only bottom temperatures were available for the month of August. Monthly temperatures show that June was cooler than the normal from the surface to around 40 m. Then, in August and September the water column was warmer than the long term mean (Fig. 11). This is reflected in the annual means that suggest non-significant positive anomalies close to the surface, negative ones between 10 and 20 m and positive anomalies for the rest of the depths. It should be noted that there were fewer stations occupied during the groundfish survey in 2003 than in previous years and that the few stations close to PEI might have had more weight than usual in the means, resulting in apparent warmer-than-usual waters for this area. The time series at 30 m shows high variability with a tendency towards above normal temperatures since the late 1980s (Fig. 12). For the last five years, monthly mean temperatures at 30 m have oscillated about but generally above the long-term mean. At these relative shallow depths, temperature will be determined by local atmospheric processes and can change over relatively short (< a month) time scales. This contrasts with the deeper waters on the Magdalen Shallows (>50 m), which are more isolated from the effects of short-term storms and reflect instead the overall winter conditions. Because of the short-term temperature variability in these shallower waters and the general lack of data in any one month, this region is considered to be under sampled. Therefore, the time series of monthly mean temperatures for this area may not reflect true trends and any results must be interpreted with extreme caution.

Temperatures within fishing Areas 18 and 19 along the Gulf side of Cape Breton Island were combined for this analysis. They include deep data (>150 m) from the Cape Breton Trough. Measurements were available during April, June, August, September and October in 2003. After showing warmer-than-average conditions in April (when data were limited to the top 50 m), the mean profile indicates colder-than-normal waters in the whole water column in June (Fig. 13). Then, in September, the water column was warmer-than-normal in the first 50 m, cooler between 70 and 140 m and warmer-than-normal again in the deeper layer. The cooler node between 70 and 140 m is consistent with the increased CIL volume during 2003. Maximum temperature anomalies appeared at 30 m being upwards of 2°C in September. The coldest anomaly (-3°C) was recorded in June at 170 m. The year average shows warmer conditions than the normal between 10 and 60 m while the rest of the water column shows cooler-than-normal waters. However, it should be noted that these means are based on few data and the warm surface waters are not considered to be significant regardless. The time series at 100 m shows below normal temperatures during 2003 and they were colder than the temperatures recorded in 2002 and closer to the values observed in 2001 (Fig. 14). The last value of the 5-year running mean at this depth is now close to zero, meaning that the average temperature was close to the 1971-2000 average temperature.

Data during only June, July and October were available from Area F in 2003 (Fig. 15). No temperatures were recorded in the deeper part of this area (up to 300 m). Most water temperatures were below the normal, except at 15 m in June and at 120 m in July. This results in a significant negative annual anomaly varying up to approximately -2.0°C at a depth of 30 m where the minimum temperature was recorded in June. The time series at 100 m in Area F is similar to the combined Areas 18-19, i.e. a strong tendency towards below normal anomalies from the mid-1980s to the late 1990s, a general warming starting around 1992 and a levelling off at the end of the 1990s and a slight cooling at the end of the timeseries. Warmer-than-normal temperatures were observed in 1999 and 2000, declined in 2001, rose in 2002 and declined again in 2003 (Fig. 16). For most years, the data at 100 m are reasonably representative of conditions from 75 to 150 m in Area F.

To the north in Area E, data were available for 7 months, April and June to November. Monthly mean temperatures in the surface waters varied depending upon the month with a non-significant positive temperature anomaly (Fig. 17). Clearly the monthly mean values for June and October were below normal for depths between 60 and 100 m. On average, there is indication of cooler-than-normal waters were present between 60 and 160 m while deeper waters were warmer-than-normal. The temperature time series at 100 m for Area E shows the typical pattern of negative anomalies since the mid-1980s and a general upswing beginning in the mid-1990s (Fig. 18). The below normal temperatures in 2003 contrast with the above normal values in 2002 and they were cooler that those observed in 2001.

The general trends in the temperature anomalies in the near-bottom waters throughout the Magdalen Shallows are quite similar. This is highlighted in Fig. 19 that shows the five-year running means of the temperature anomalies for Areas 12, 18-19 combined, E and F. These show the continuously decreasing temperature from the last maximums in the early 1980s to the minimums in the early 1990s and then the general warming trend up to the early 2000s and a slight decrease at end of the timeseries, in recent years.

Snow Crab Catches by Temperature

The catches of snow crab as a function of temperature during the 2003 snow crab survey in the Gulf are shown in Fig. 20. Over 94% of all of the crabs were caught in temperatures between -1° and 3°C. In 2003, there was a tendency for the snow crabs to be captured in the cooler portion of the favourable habitat (which is defined as waters with a temperature range of -1°C to 3°C) as observed in previous years. The snow crabs in 2003 were generally caught in cooler temperatures than in 2002, a situation that reflects the ambient temperatures. The cumulative percentages of snow crab catches and bottom temperatures (Fig. 21) clearly show that snow crabs have a tendency to be caught in the cooler waters.

Northeastern Scotian Shelf and Sydney Bight

Bottom Temperatures

From the July groundfish survey, near-bottom temperatures were estimated for the entire Scotian Shelf. In the northeastern region and Sydney Bight, bottom waters were generally <5°C with a significant portion <2°C (Fig. 22). Higher temperatures were observed in the western parts of Area 24 and in Emerald Basin (upwards of 9°C). In the northeastern area and in Roseway Basin, temperatures were mostly below their long-term means while the waters in Lahave Basin were warmer-than-normal as well as a band of water on the southern part of Western Bank (Fig. 22). The coldest anomalies (lower than -2°C) were observed over Middle Bank. Temperatures decreased significantly relative to July 2002 over most of the Scotian Shelf (Fig. 23). The cooling difference (-3°C) is particularly noticeable over Misaine Bank. The 2003 temperatures contrast with the warmer conditions that were observed in 2002 and are closer to those observed in 2001.

Bottom temperatures from the snow crab survey in October-December display a similar spatial pattern to that from the groundfish survey (Fig. 24). This includes the colder temperatures in the northeast and the warmer temperatures towards the southwest, with the highest values in the Emerald Basin region. The major difference in the temperatures between the two surveys is that the temperatures tended to be warmer during the snow crab survey, except for the Laurentian Channel and Emerald Basin areas. Part of the reduction of the colder water in the snow crab survey is consistent with the known seasonal warming on and around several of the banks (Petrie et al., 1996). The snow crab survey was conducted later than usual during 2003 explaining in part why the observed warming between the two surveys is greater than for the previous years. For example, in 2002, the majority of the grid points had differences between the two surveys that were within ±0.5°C while in 2003 the majority of the points show a warming of 1 to 2 °C. Even with these differences, the two surveys are considered to capture the main bottom temperature patterns.

Snow Crab Habitat Index

A time series of the snow crab habitat index (area of the bottom covered with waters between -1°C and 3°C) for the Scotian Shelf based upon optimally estimated bottom temperatures from the July groundfish survey is available from 1970 to present. For the northeastern Scotian Shelf the grid occupies a total bottom water area of 70426 km^2 (201 grid points) while on the Sydney Bight the area is 7801 km^2 (23 grid points). Note that the smaller number of grid points on the Scotian Shelf compared to the Gulf is a result of the grid resolution being lower for the Shelf, although covered surfaces are similar. Due to insufficient data coverage no index was estimated for 1975 and 1976 on the Scotian Shelf and 1971, 1973-1976 and 1984 for Sydney Bight. Again as for the Gulf, the average temperature within the area covered by -1°C to 3°C was estimated and correlated with the habitat index.

On the northeastern Scotian Shelf, the snow crab habitat index in 2003 was 44073 km^2 representing approximately 63% coverage of the total grid area and was the largest area since the beginning of the timeseries, 1991 being the second highest value with coverage of 60% (Fig. 25). This represents a value significantly higher than the long-term mean. In 1999, the index dropped below the long-term mean for the first time in over a decade and dropped further in 2000. The return to values above the long-term mean has lasted since 2001 although there was a slight decline in 2002. The increase in the habitat index through into the 1990s supports the hypothesis of Tremblay (1997) that the expansion of the areal distribution of snow crab on the Scotian Shelf (with also an increase in biomass) during the 1990s was related to an increase in their preferred habitat. The minimum area of the bottom covered by temperatures between -1°C and 3°C occurred in 1984 (only 4.5% of the total area) and it was relatively small during the late 1970s and early 1980s (< 30% of the total). On the Scotian Shelf, the average temperatures within this area are negatively correlated with the area itself ($r=-0.88$, $p<0.001$; see Fig. 25). Therefore, when the area of the preferred snow crab habitat increases there is usually a decrease in the temperature within this area, e.g. while the habitat index was high in the early 1990s, temperatures were generally low. Consistent with this, in 2003 when the habitat index increased, the mean temperature decreased significantly to reach the minimum value (1.14 °C) of the timeseries while years 1995, 1992, 1991 and 1990 were the next four coldest years. Years 1981 and 1984 show the warmest average temperature in the snow crab habitat.

On Sydney Bight, the snow crab habitat index in 2002 was 3049 km^2 and increased significantly compared to 2002 (Fig. 26). It represents 39% coverage of the total grid area and is above the long-term average of 2188 km^2. This index has varied between 21-43% since the early-1980s. Prior to 1982, the index was lower (generally <20%). The lower percentage of the bottom with temperatures between -1°C and 3°C on Sydney Bight compared to the Scotian Shelf is due to the greater percentage of the Sydney Bight grid area being in deep regions (>200 m deep and hence in the relatively warm (>4°C) waters of the Laurentian Channel). The mean temperature within the area covered by -1°C and 3°C waters in 2003 decreased significantly relative to 2002 and is now the lowest value since 1993 (Fig. 26). The correlation between the average temperature within the index area and the habitat index itself during 1970 to 2003 for Sydney Bight is -0.66.

Monthly Mean Temperature Anomaly Profiles and Time Series

The monthly and “annual” mean temperature anomaly profiles within each of the snow crab fishing areas on the Scotian Shelf and Sydney Bight were determined as described above under the Gulf section (see Fig. 2 for the area boundaries used in the temperature analysis). As for the Gulf, temperature time series at depths considered representative of the near-bottom region within each of the fishing areas are presented. Again, because of the limited amount of data within the areas over which the averages were made or because of possibility of spatial variability in temperature within the areas, any one point or profile may not be truly representative of “average” conditions for the month. Therefore interpretation of any anomalies must be viewed with caution and no significance should be placed on any individual monthly anomaly, although persistent features are considered real. Anomalies were calculated relative to the 1971-2000 mean.

Area 24 spans a region of strong horizontal bottom temperature gradient from the relatively cold bottom temperatures (2-4°C) in the northeast to warmer temperatures (>7°C) in the southwest (Fig. 22). These two regions are separated by a series of shallow banks, including Middle and Canso Banks. The origin of the colder water is primarily from the Gulf of St. Lawrence while the warmer waters derive from offshore slope waters that penetrate onto the shelf between Emerald and Lahave Banks and move up through Emerald Basin. The spatial distribution of data within Area 24 can greatly affect the estimated monthly mean temperatures, therefore any apparent temperature trend for this Area must be viewed with caution. In Area 24, data were available in 7 months of 2003. The dominant feature is the below normal temperatures throughout most of 2003 at all depths except for the month of March when warmer temperatures were observed at depths greater than 150m (Fig. 27). The mean temperature anomalies were approximately –1° to -3°C from the surface to 200 m until July then, afterward, the surface layer (0-40 m) warmed up during the fall, consistent with positive air temperature anomalies. The below normal conditions are reflected in the average of the monthly anomaly profiles labelled as the “annual” mean profile (Fig. 27). The time series at 100 m shows low variability with below normal temperatures during most of 2003 (Fig. 28). This represents cooling compared to 2002; the years 2001 and 2003 contrast with the above normal temperatures observed in 1999-2000 but are similar to conditions through most of the 1990s.

On the northeastern Scotian Shelf in Area 23, temperatures were collected in 11 months of 2003 (Fig. 29). Except for February, the waters between the surface and 160 m were definitively colder-than-normal until the end of September, although the first few meters were close to normal. However, above average temperatures were present during the rest of the year. Below 160 m, the warmer-than-normal conditions were recorded until the end of July and changed to colder-than-normal conditions by the end of the year. The "annual" mean shows warmer than average waters between 0 and 25 m but they were not significant. Cooler-than-average temperatures were observed down to 150 m. From there to the bottom, temperatures changed from colder-than-normal to warmer-than-normal but these were not considered statistically significant. As in Area 24, the cold conditions in 2003 show some similarities with 2001 and contrast with the warm conditions observed in 1999, 2000 and 2002. The 2003 colder temperature conditions are closer to those in the mid-1980s to late 1990s although the 5-year running mean is still above average (Fig. 30).

The temperature data for snow crab fishing Areas 20 through 22 were combined in our analysis. From the 7 months of 2003, when observations were available, temperatures throughout the water column showed more variability than for other areas (Fig. 31). Although that there was a tendency for most months to exhibit colder-than-average conditions, there was a positive anomaly of 2.7°C at the surface in July and 4°C in November. The latter anomaly extended down to 50 m depth. Warmer-than-normal conditions were also present in deep water (140-180 m) during the months of April and November. The only significant temperature change appeared to be in the depth range from 75-150 m where temperatures were colder-than-normal. The time series at 100 m shows colder-than-normal waters from the mid-1980s to the late 1990s, then a warming with above normal temperatures in 1999 and 2000, a cooling in 2001, a rise again in 2002 and significantly cooler conditions in 2003 (Fig. 32). This lowers the 5-year running mean to the level of the long-term average (1971-2000). Analysis of the data has shown that this pattern in the time series is generally representative of conditions between 50 m and 150 m.

<u>Snow Crab Catches by Temperature</u>

The snow crab catches as a function of temperature during the 2003 October-December snow crab survey of the Scotian Shelf are shown in Fig. 33. Almost 89% of all of the crabs were caught in temperatures less than 3°C whereas only 67% of the stations visited had temperatures in that range. No stations had temperatures of below -1°C. More crabs were found in colder waters in 2003 compared to 2002, which reflects the ambient temperatures in each of those years. The depths that the crabs were caught at were largely the same in both years (not shown). It appears that the crabs on the northeastern Shelf maintain their depth, and while having a tendency to favour colder waters, their temperature habitat is largely determined by local conditions, i.e. it seems that they do not move a lot to seek more favourable conditions. As for the southern Gulf of St. Lawrence, the cumulative percentages of snow crab catches and bottom temperatures (Fig. 34) show that snow crabs have a tendency to be caught in the cooler waters.

Summary

Near-bottom temperatures in the southern Gulf of St. Lawrence (Magdalen Shallows) and in the northeastern Scotian Shelf during 2003 were examined primarily from data collected during the snow crab and groundfish surveys. The snow crab surveys were conducted in October-December on the Scotian Shelf and in July-October in the Gulf while the groundfish surveys were in July on the northeastern Scotian Shelf and in September on the Magdalen Shallows. The groundfish surveys, for which we have much more long-term data than for the snow crab surveys, were compared to their normal conditions (1971-2000). Additional temperature data from other fisheries surveys and oceanographic studies in these same areas were also examined.

In the Gulf of St. Lawrence during 2003, conditions were variable but tended to have cooled throughout much of the region. Near bottom temperatures over a large portion of the deeper parts of the Southern Gulf were below (colder) the long-term (1971-2000) average, while the shallower parts exhibit warmer than normal conditions. The snow crab habitat index, based upon the area of bottom temperatures preferred by snow crab (-1°C to 3°C), increased relative to 2002, but is still below the long-term average. The temperatures within the area of -1° to 3°C is below normal and fell significantly compared to last year.

Compared to previous years, even colder conditions occupied the northeastern Scotian Shelf region in 2003 although the region is warmer that the Southern Gulf. Below normal conditions were found in the bottom waters of the northeastern Shelf during the July groundfish survey in 2003. The snow crab habitat index shows the highest value of the timeseries in 2003. The cold conditions reversed the warming seen in 2002 and contributed to a general cooling trend observed since 2000. This cooling period opposes the warming trend seen from the mid-1990s to the above normal temperatures observed in 2000. The cold conditions in 2003 are closer to those observed in the period 1985 to the late 1990s.

Acknowledgements

We acknowledge J. McRuer for providing the CTD data from the groundfish surveys and M. Moriyasu, M. Biron, E. Wade, R. Landry and C. Sabean for the crab and temperature data from the snow crab surveys. Also, a special thanks goes out to the scientists, technicians and crew who collected these data.

References

Drinkwater, K.F. and R. Pettipas. 1996. Near-bottom temperatures on Sydney Bight and the northeastern Scotian Shelf during 1995. DFO Atlan. Fish. Res. Doc. 96/136, 14 p.

Drinkwater, K.F., R. Pettipas, L. Petrie and D.P. Swain. 1998. Temperature conditions in the Gulf of St. Lawrence and on the Scotian Shelf during 1997 relevant to snow crab. DFO Can. Stock Assess. Sec. Res. Doc. 98/56, 30p.

Drinkwater, K.F., E. Colbourne and D. Gilbert. 2001. Overview of environmental conditions in the Northwest Atlantic in 2000. NAFO SCR Doc. 01/36, 85 p.

Drinkwater, K.F., R.G. Pettipas and W.M. Petrie. 2003. Temperature Conditions on the Scotian Shelf and in the southern Gulf of St. Lawrence during 2002 Relevant to Snow Crab. DFO Can. Sci. Adv. Sec. Res. Doc. 2003/014.

Gilbert, D. and B. Pettigrew. 1997. Interannual variability (1948-1994) of the CIL core temperature in the Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. Vol. 54 (Suppl. 1): 57-67.

Petrie, B., K. Drinkwater, D. Gregory, R. Pettipas, and A. Sandström. 1996. Temperature and salinity atlas for the Scotian Shelf and the Gulf of Maine. Can. Tech. Rep. Hydrogr. Ocean Sci. 171: 398 p.

Petrie, B., B. Toulany and C. Garrett. 1988. The transport of water, heat and salt through the Strait of Belle Isle. Atmosphere-Ocean 26: 234-251.

Tremblay, M.J. 1997. Snow crab (*Chionoecetes opilio*) distribution limits and abundance trends on the Scotian Shelf. J. Northw. Atl. Fish. Sci. 21: 7-22.

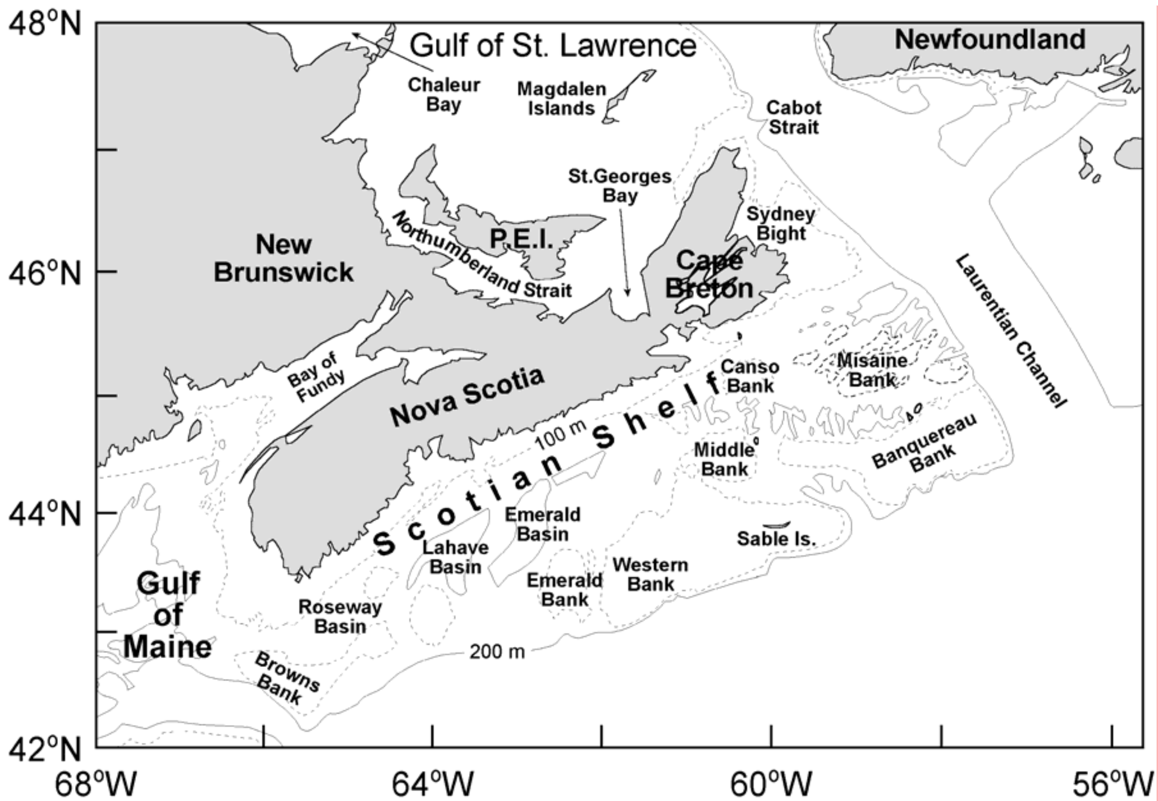


Fig. 1. Chart of the Scotian Shelf and the southern Gulf of St. Lawrence showing geographic and topographic features referred to in the text.

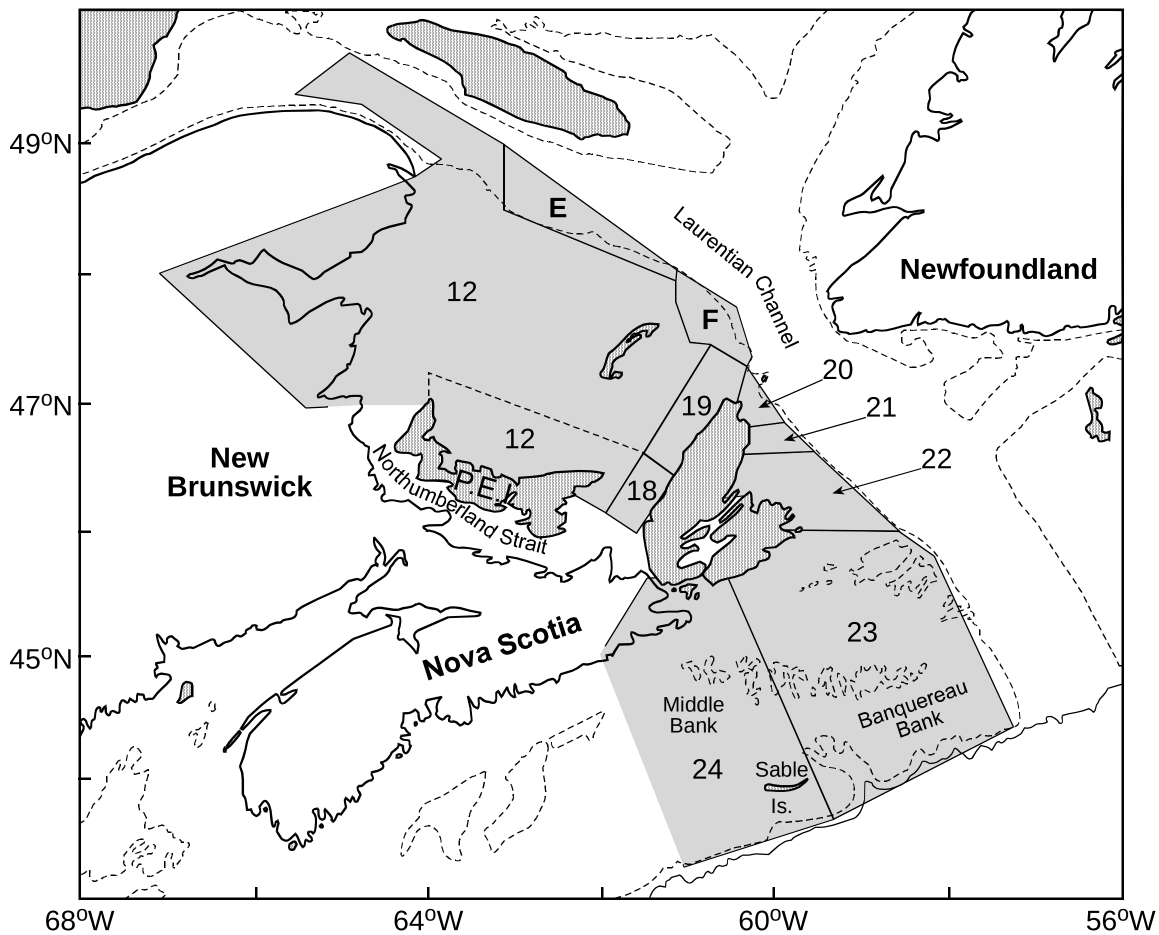


Fig. 2. The southern Gulf of St. Lawrence and Scotian Shelf showing the boundaries of snow crab fishing areas in which monthly mean temperature profiles were estimated. The section of Area 12, north of Prince Edward Island and denoted by the dashed line, contains former Areas 25 and 26.

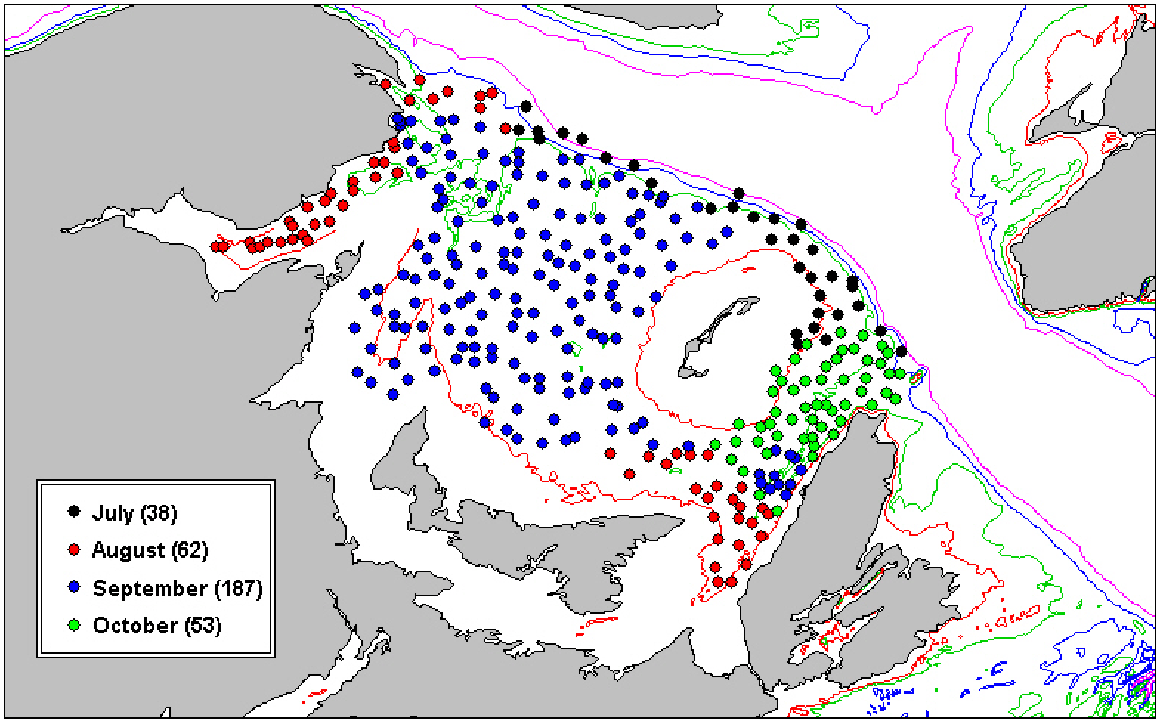


Fig. 3a. The location of the bottom temperature stations during the July-September 2003 snow crab survey.

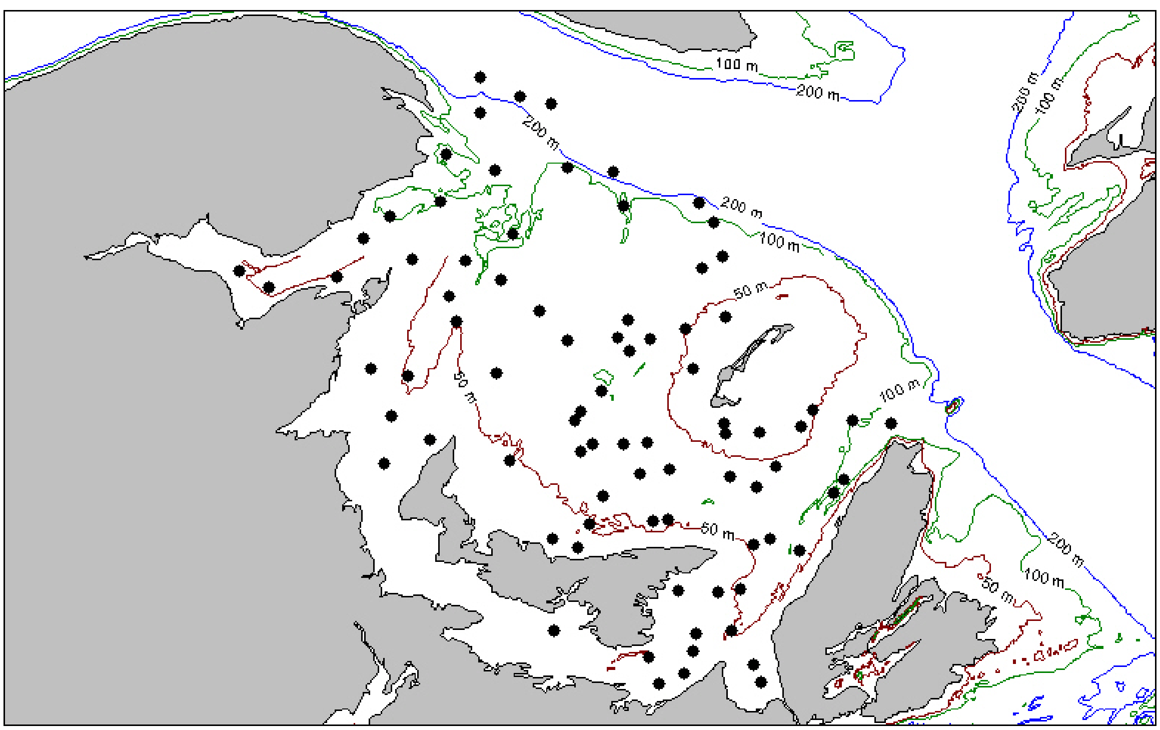


Fig. 3b. The location of the CTD stations during the September 2003 survey.

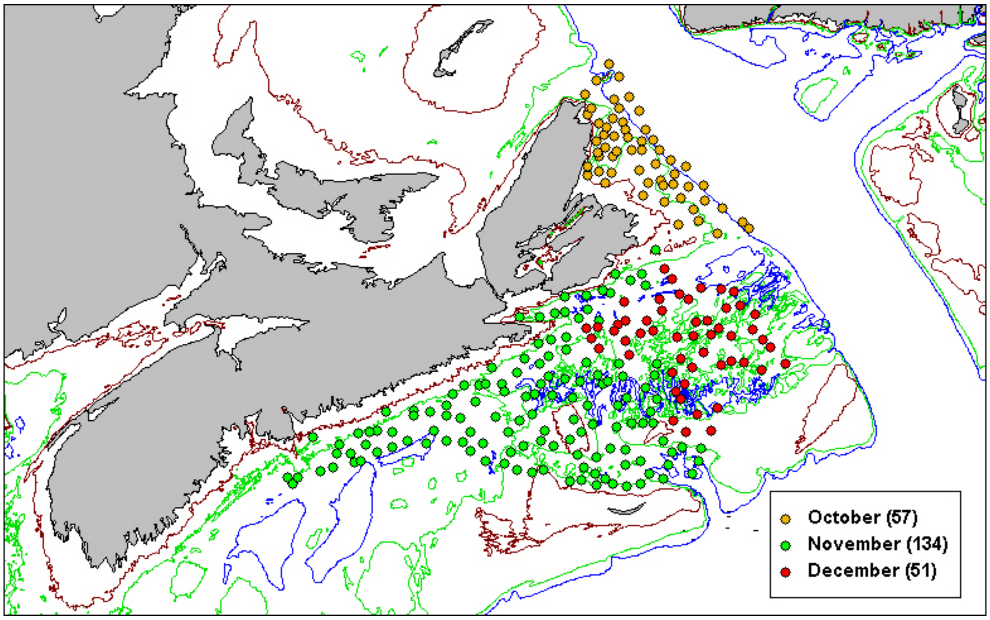


Fig. 4a. The location of the bottom temperature stations during the October-December 2003 snow crab survey.

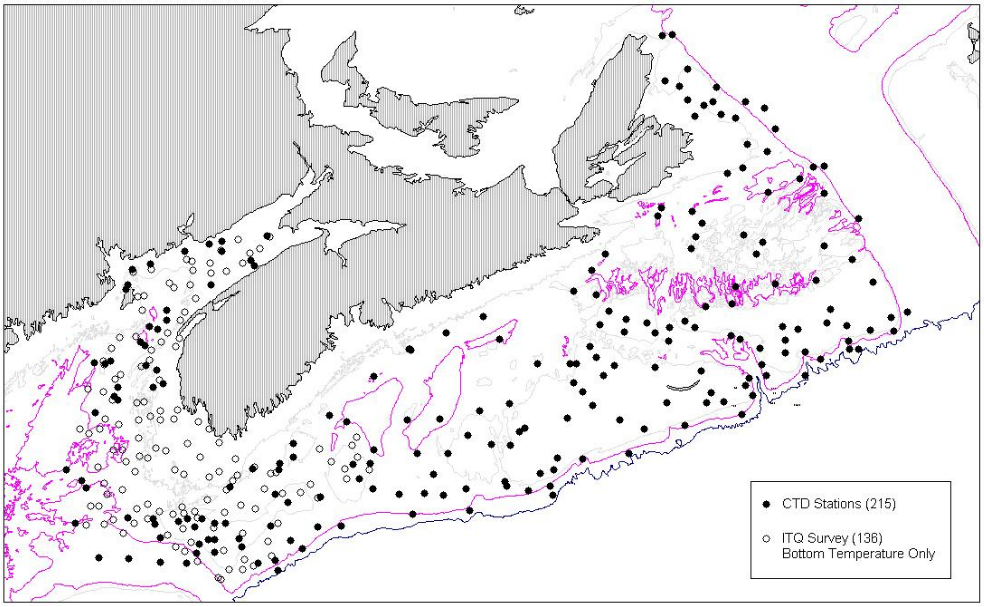


Fig. 4b. The location of the CTD stations during the July 2003 survey. The solid black dots represent the stations taken during the DFO groundfish survey and the open circles denote the stations taken during the fisherman run survey (labelled as ITQ Survey).

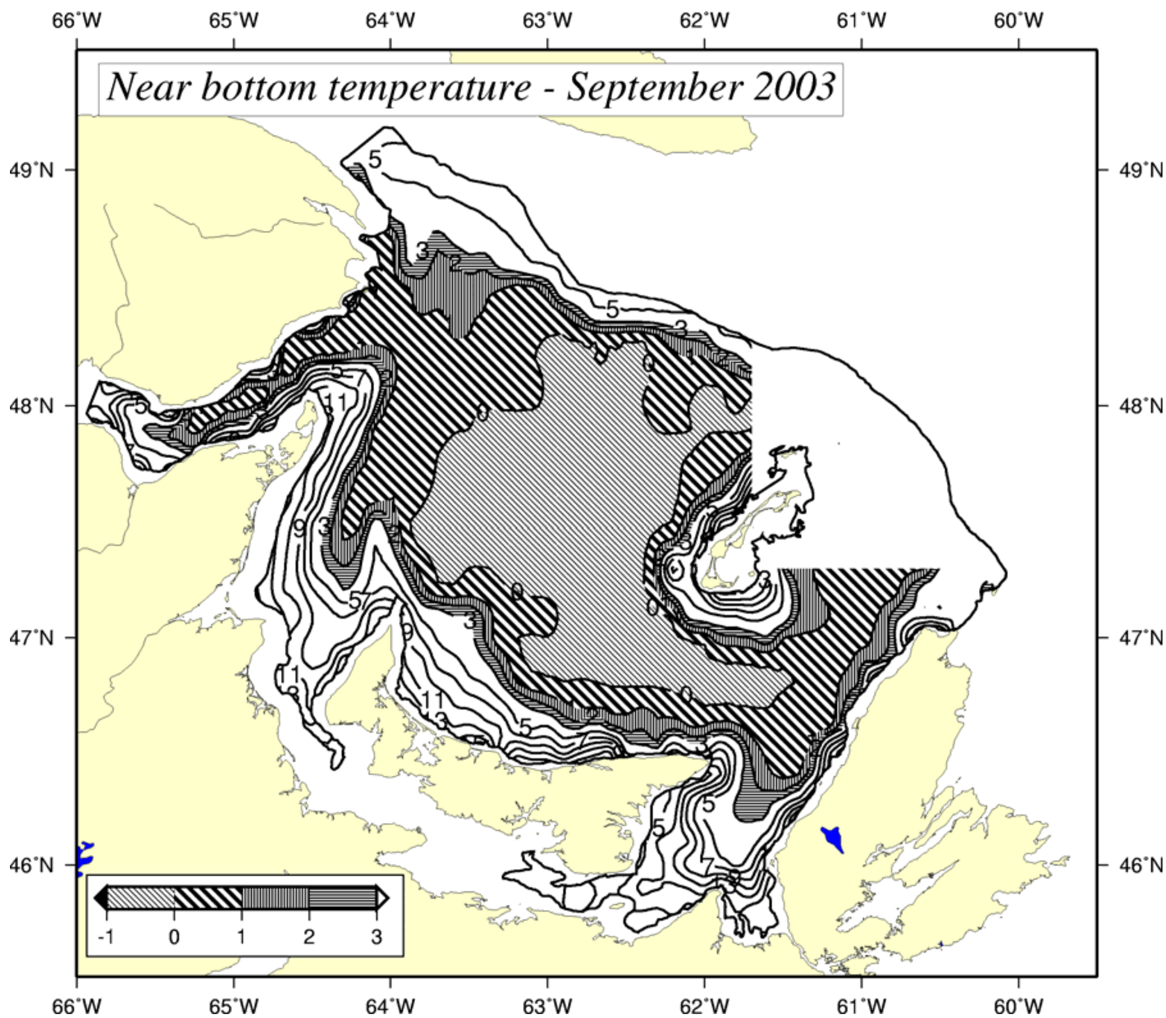


Fig. 5a. Near-bottom temperatures (°C) in the southern Gulf of St. Lawrence during the 2003 September groundfish survey. The hachure patterns show the suitable temperature range for the snow crab (-1 to 3°C).

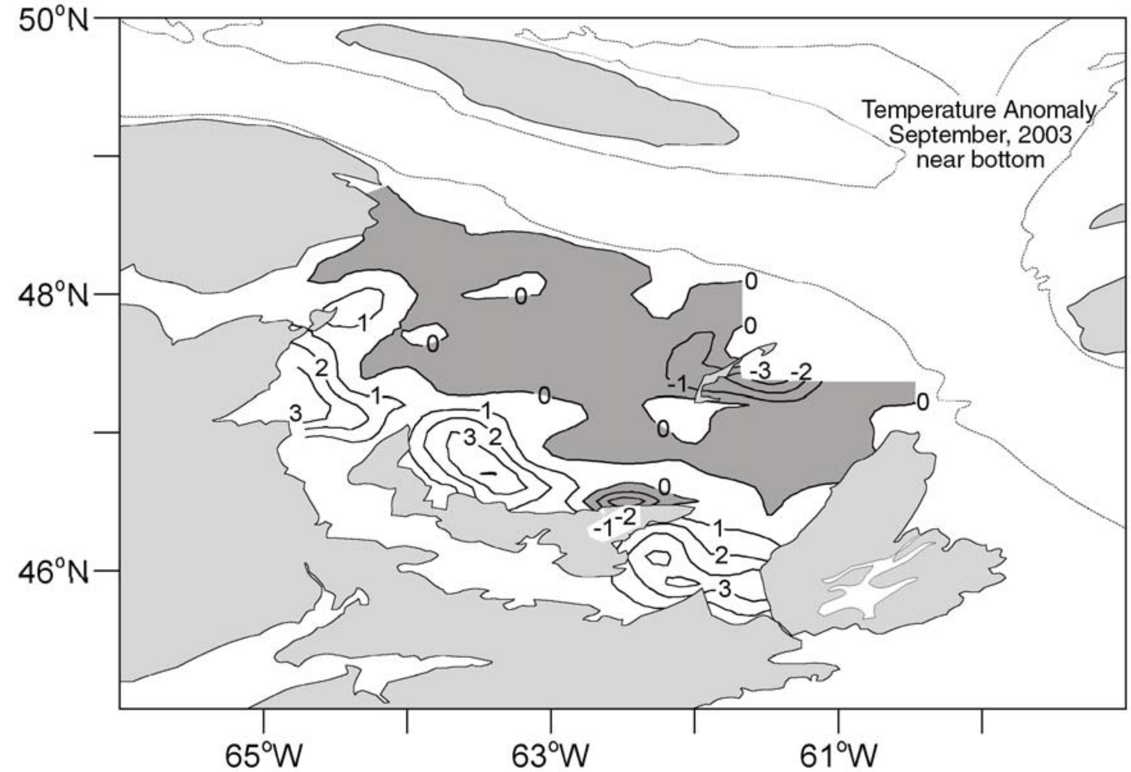


Fig. 5b. Near-bottom temperature departure (°C) from the long-term (1971-2000) means in the southern Gulf of St. Lawrence during the 2003 September groundfish survey. Shaded regions represent colder-than-normal temperatures.

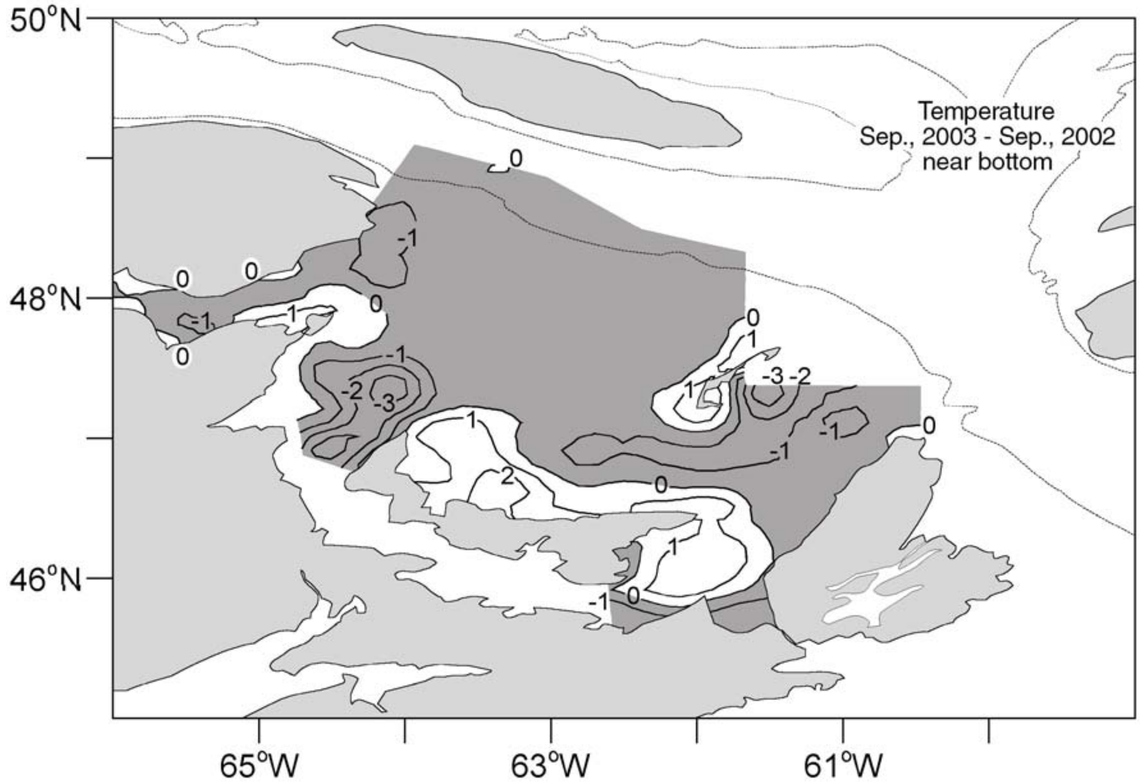


Fig. 6. The difference between the 2003 and 2002 temperature fields in the southern Gulf of St. Lawrence for the September groundfish surveys. Positive values indicate temperatures in 2003 had warmed and negative values (shaded) that they had cooled.

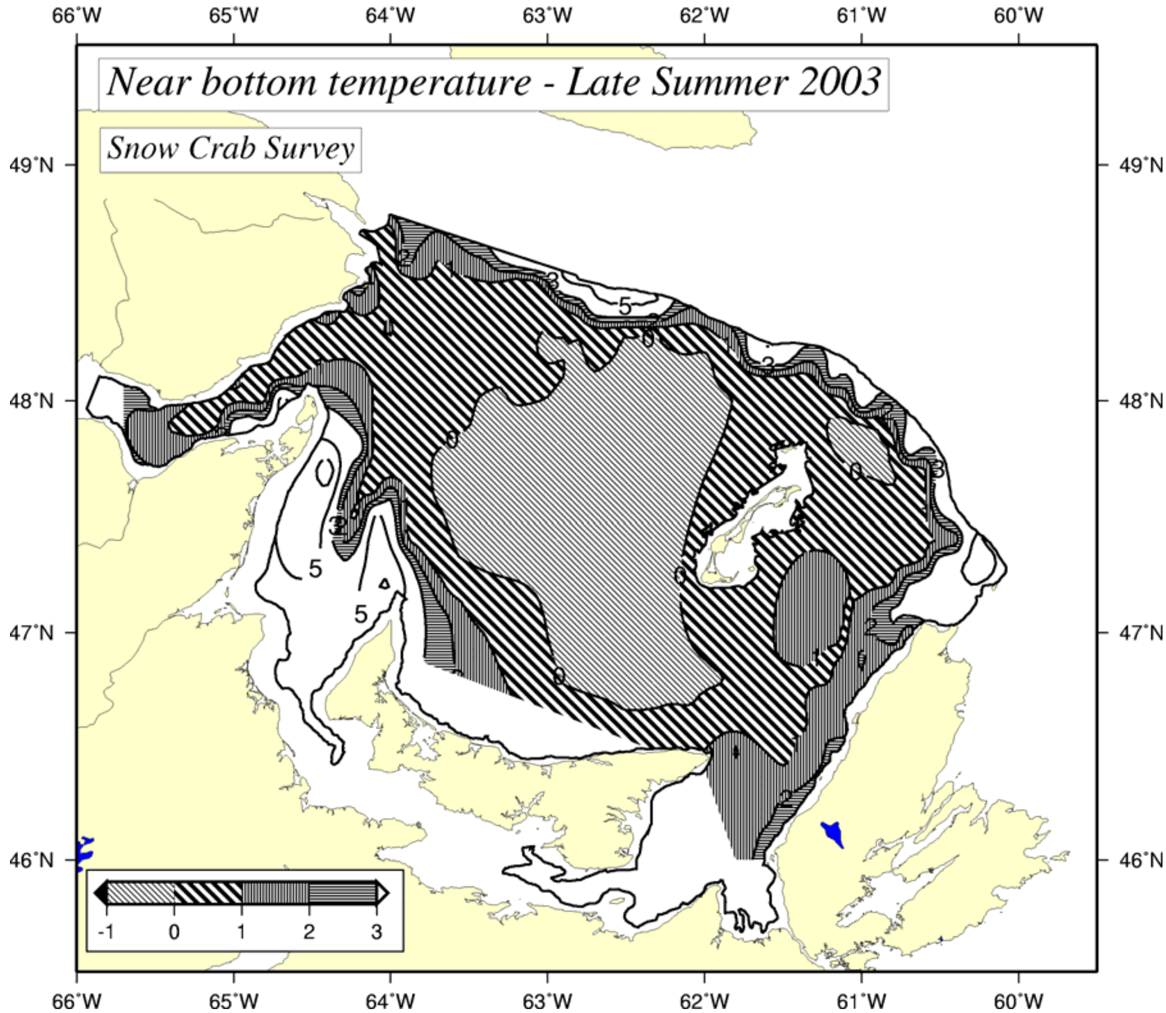


Fig. 7. Near-bottom temperatures in the southern Gulf of St. Lawrence during the 2003 July-October snow crab survey.

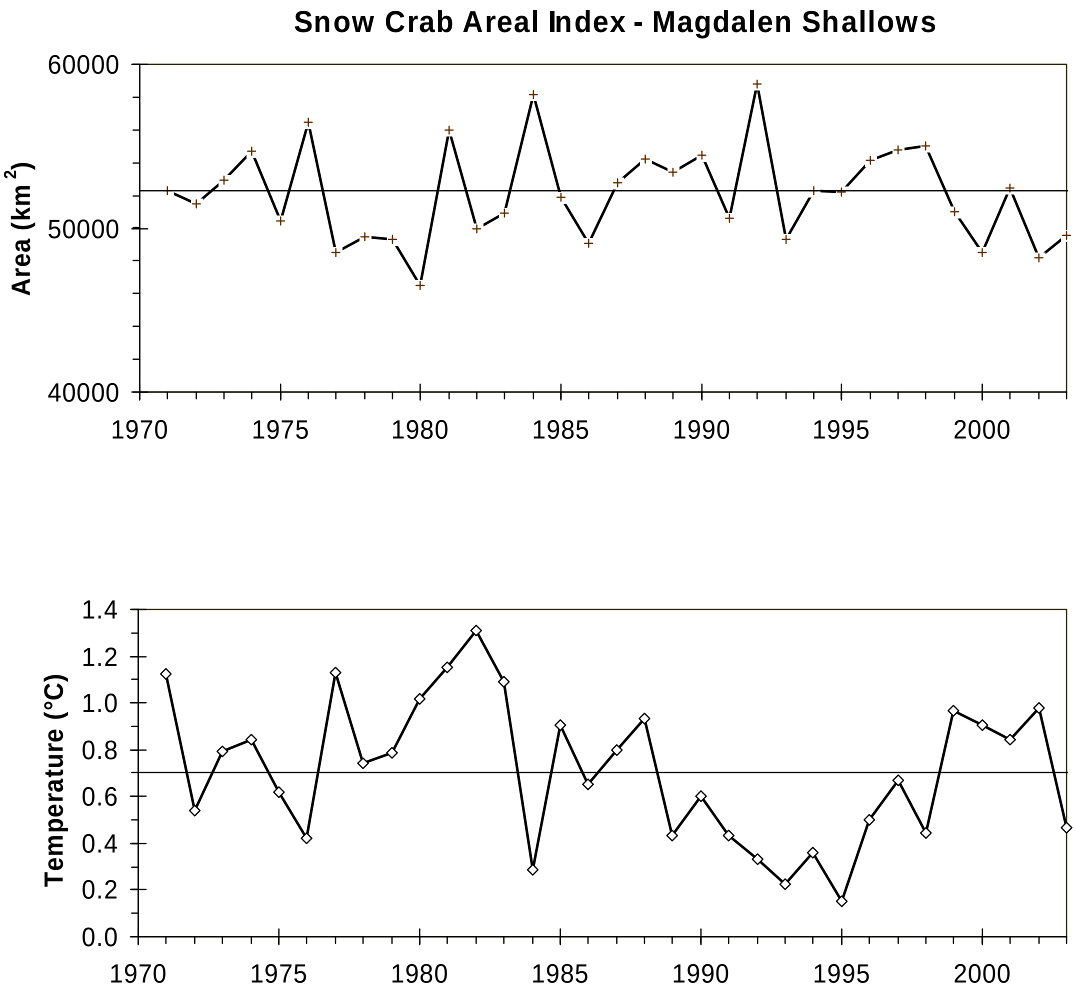


Fig. 8. Time series of the area of Magdalen Shallows covered by bottom temperatures between -1° and 3°C in September (top panel) and the mean temperature within that area (bottom panel).

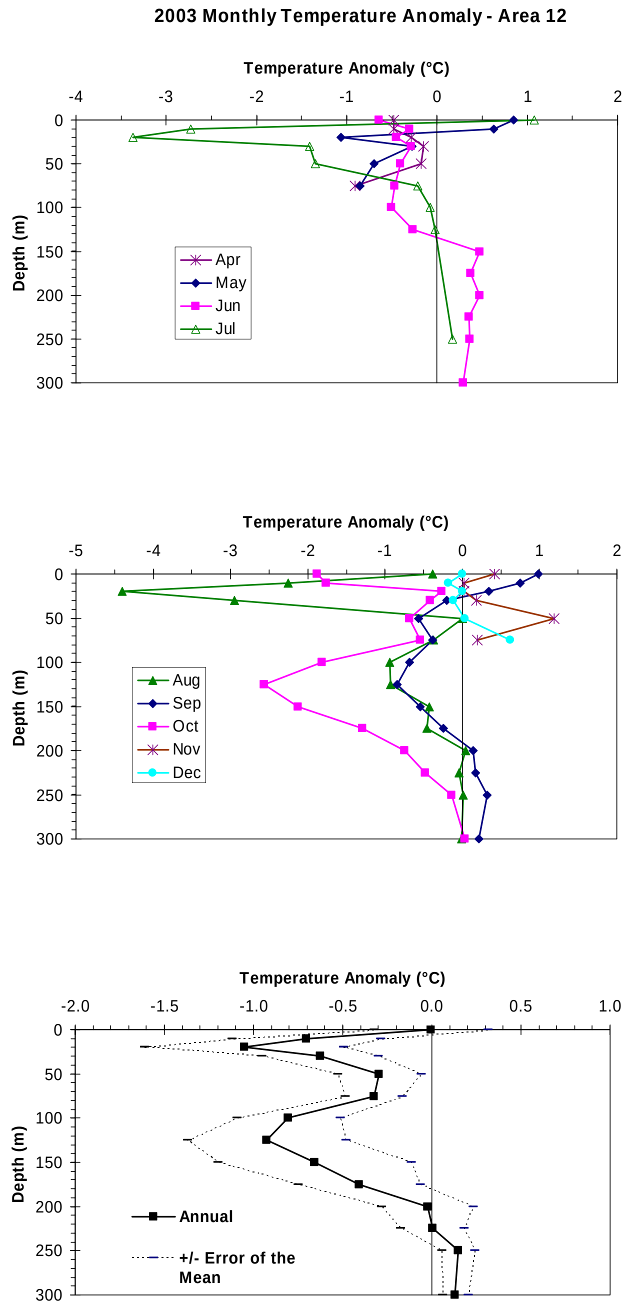


Fig. 9. Monthly (top two panels) mean temperature anomalies and annual temperature anomalies ± error of the mean (bottom panel) during 2003 for snow crab fishing Area 12.

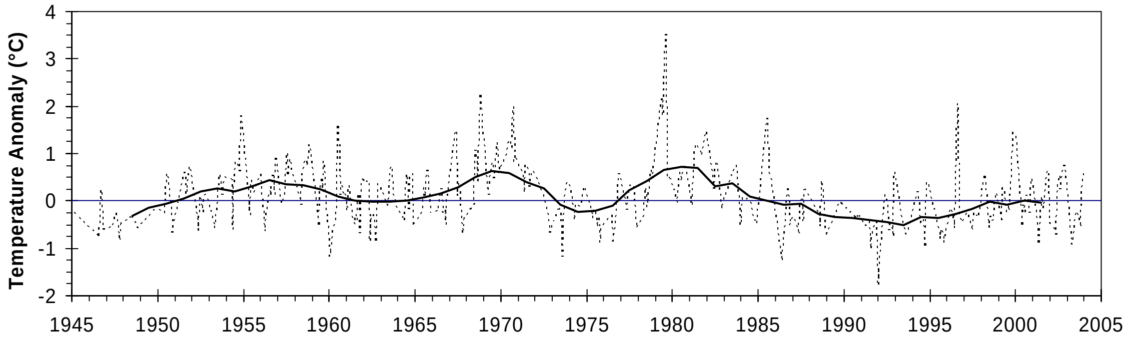


Fig.10. The time series of the monthly (dashed line) and the 5-year running mean of the annual temperature anomalies (solid line) at 75 m for snow crab fishing Area 12.

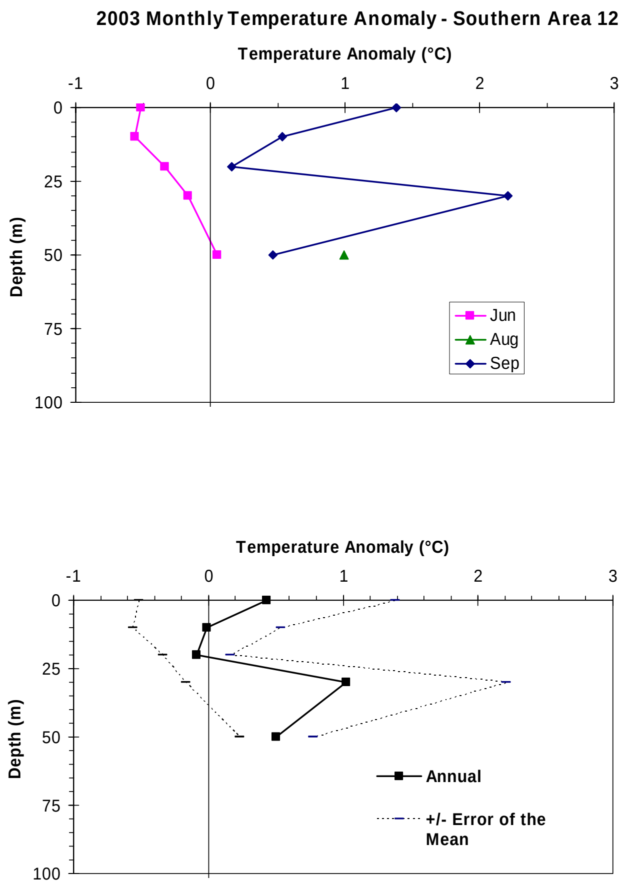


Fig.11. Monthly mean temperature anomalies (top two panels) and annual temperature anomalies ± error of the mean (bottom panel) during 2003 for the southern portion of snow crab fishing Area 12 (formerly Areas 25 and 26).

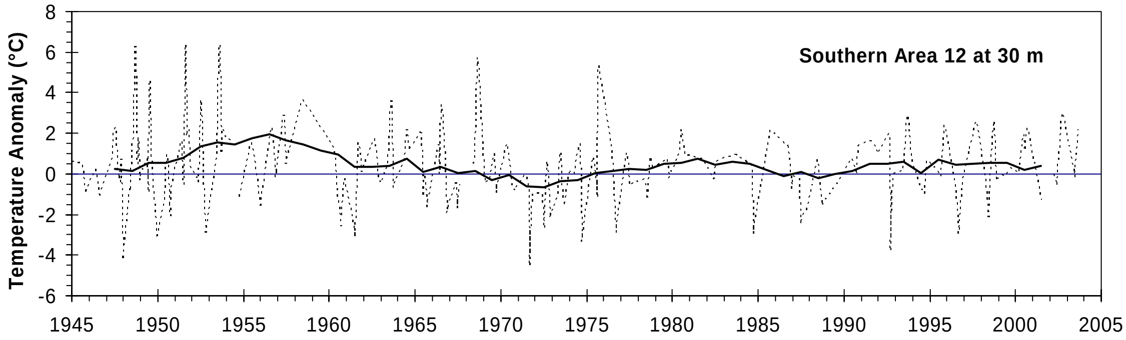
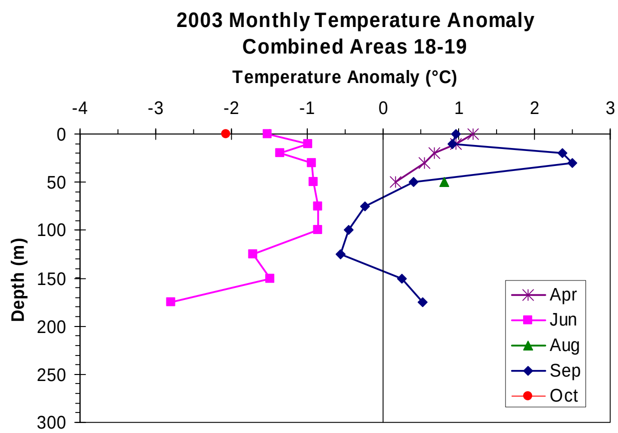


Fig.12. The time series of the monthly (dashed line) and the 5-year running means (solid line) of the annual temperature anomalies at 30 m for the southern portion of snow crab fishing Area 12 (formerly Areas 25 and 26).



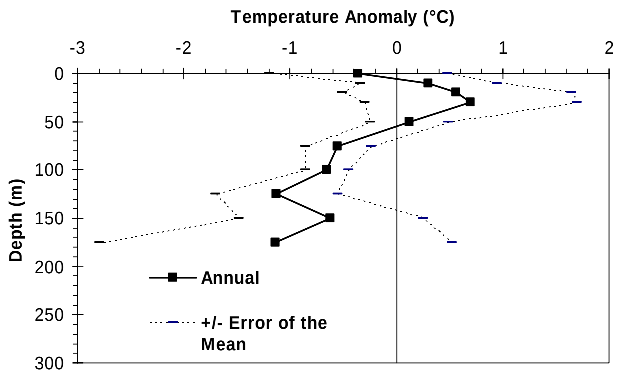


Fig.13. Monthly mean temperature anomalies (top panel) and annual temperature anomalies ± error of the mean (bottom panel) during 2003 for snow crab fishing Areas 18-19 combined.

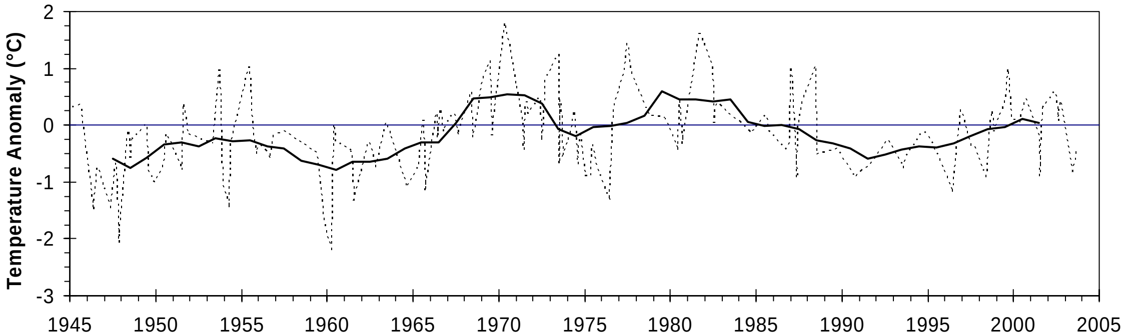
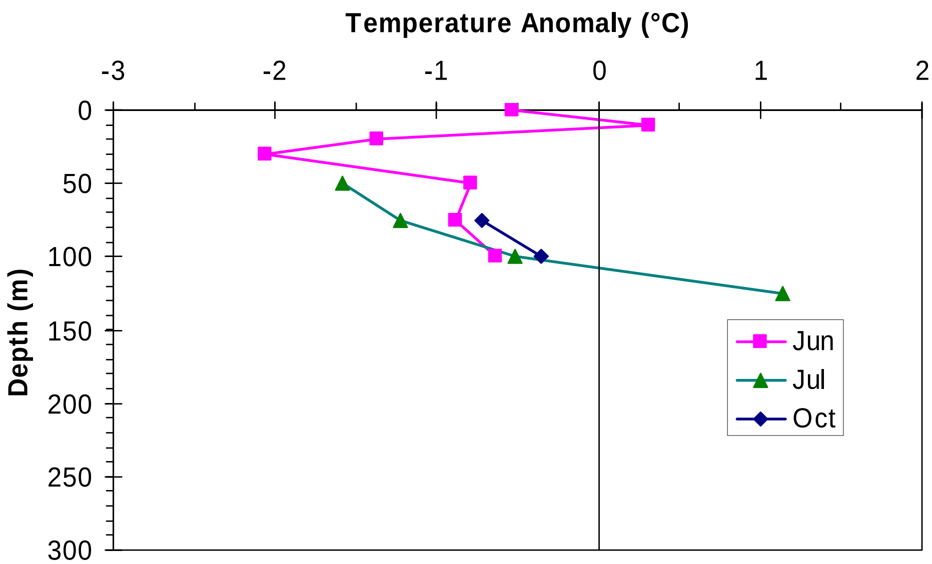


Fig.14. The time series of the monthly (dashed line) and the 5-year running means (solid line) of the annual anomalies at 100 m for snow crab fishing Areas 18-19.

2003 Monthly Temperature Anomaly - Area F



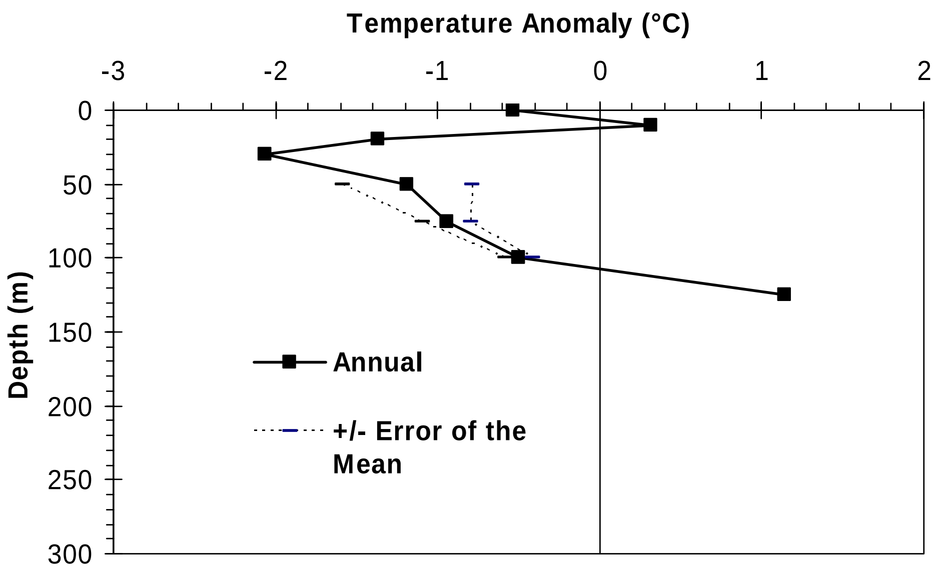


Fig.15. Monthly mean temperature anomalies (top panel) and annual temperature anomalies ± error of the mean (bottom panel) during 2003 for snow crab fishing Area F.

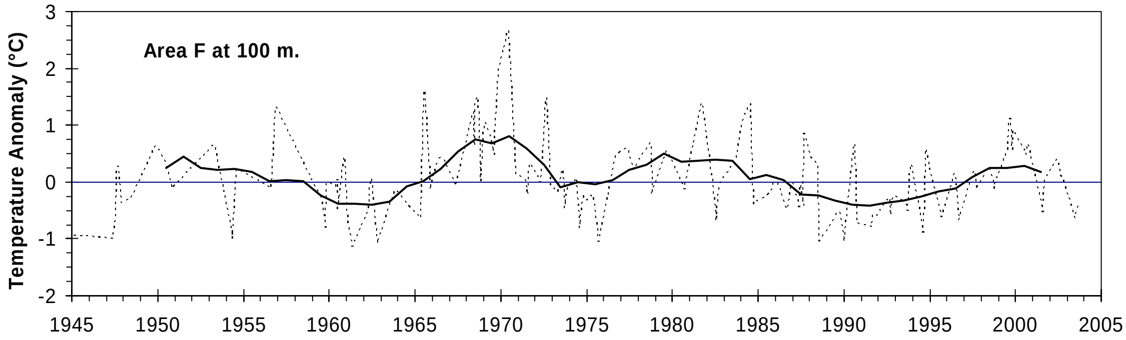


Fig.16. The time series of the monthly (dashed line) and the 5-year running means (solid line) of the annual temperature anomalies at 100 m for snow crab fishing Area F.

2003 Monthly Temperature Anomaly - Area E

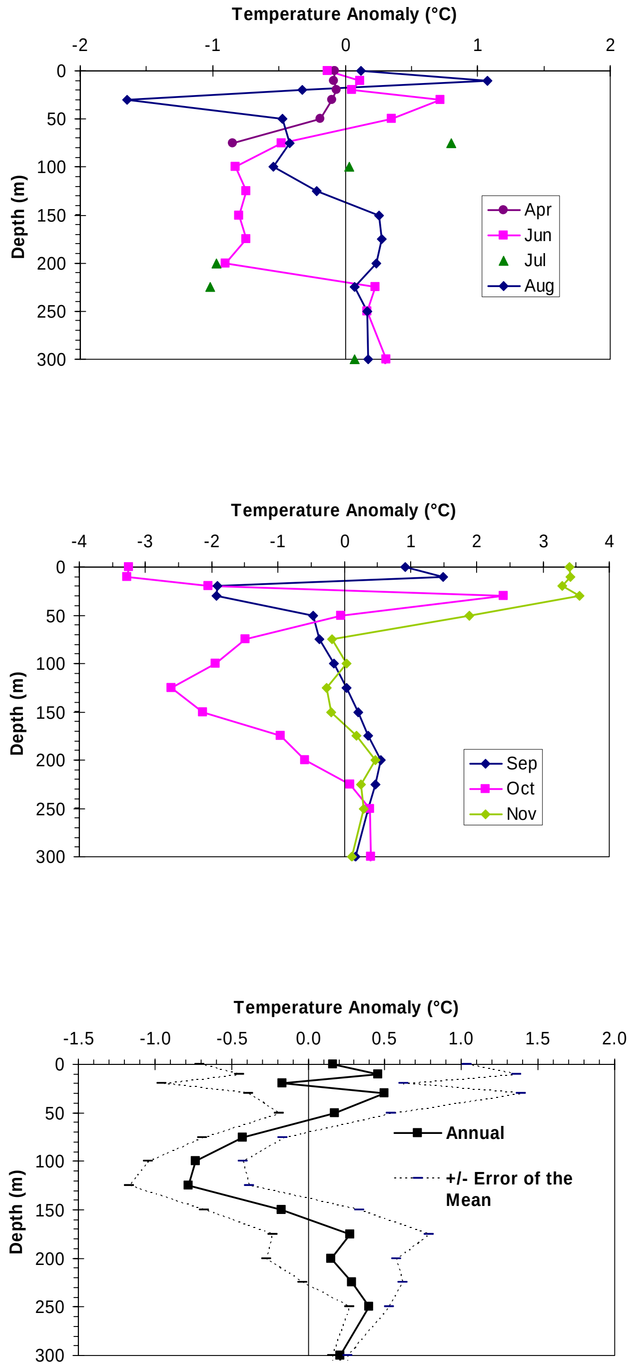


Fig.17. Monthly mean temperature anomalies (upper and mid panels) and annual temperature anomalies ± error of the mean (bottom panel) during 2003 for snow crab fishing Area E.

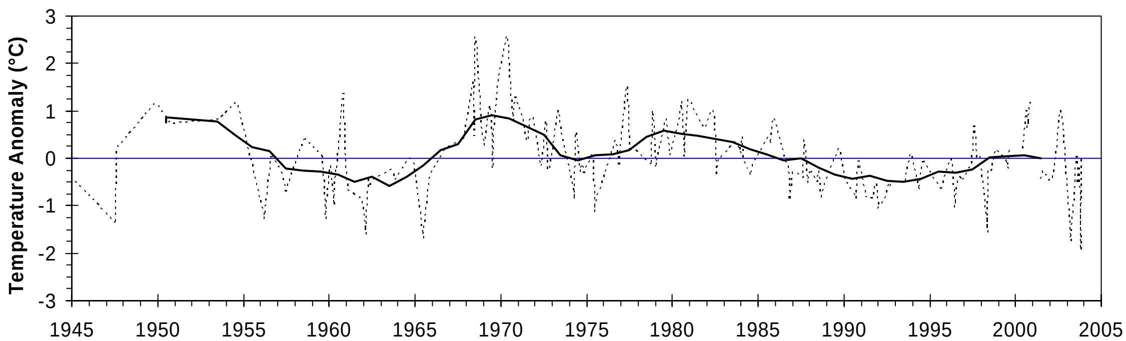


Fig.18. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Area E.

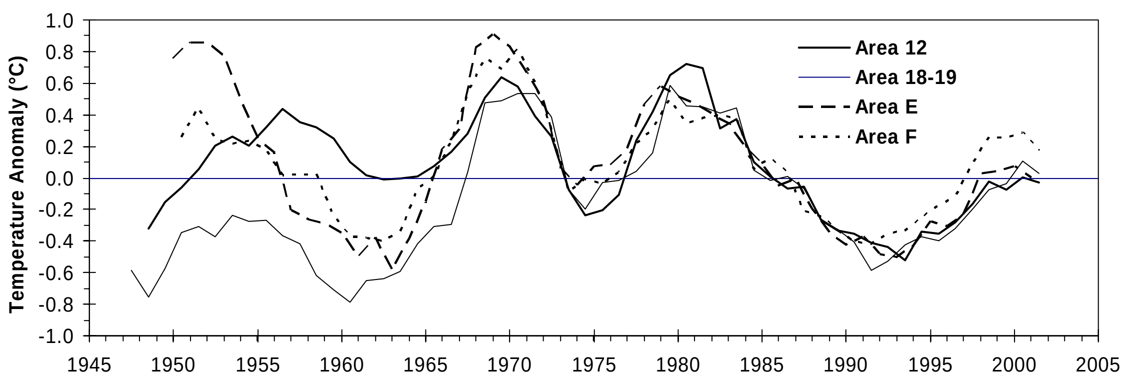


Fig.19. The five-year running means of the temperature anomalies for Areas 12, 18-19 (combined), E and F.

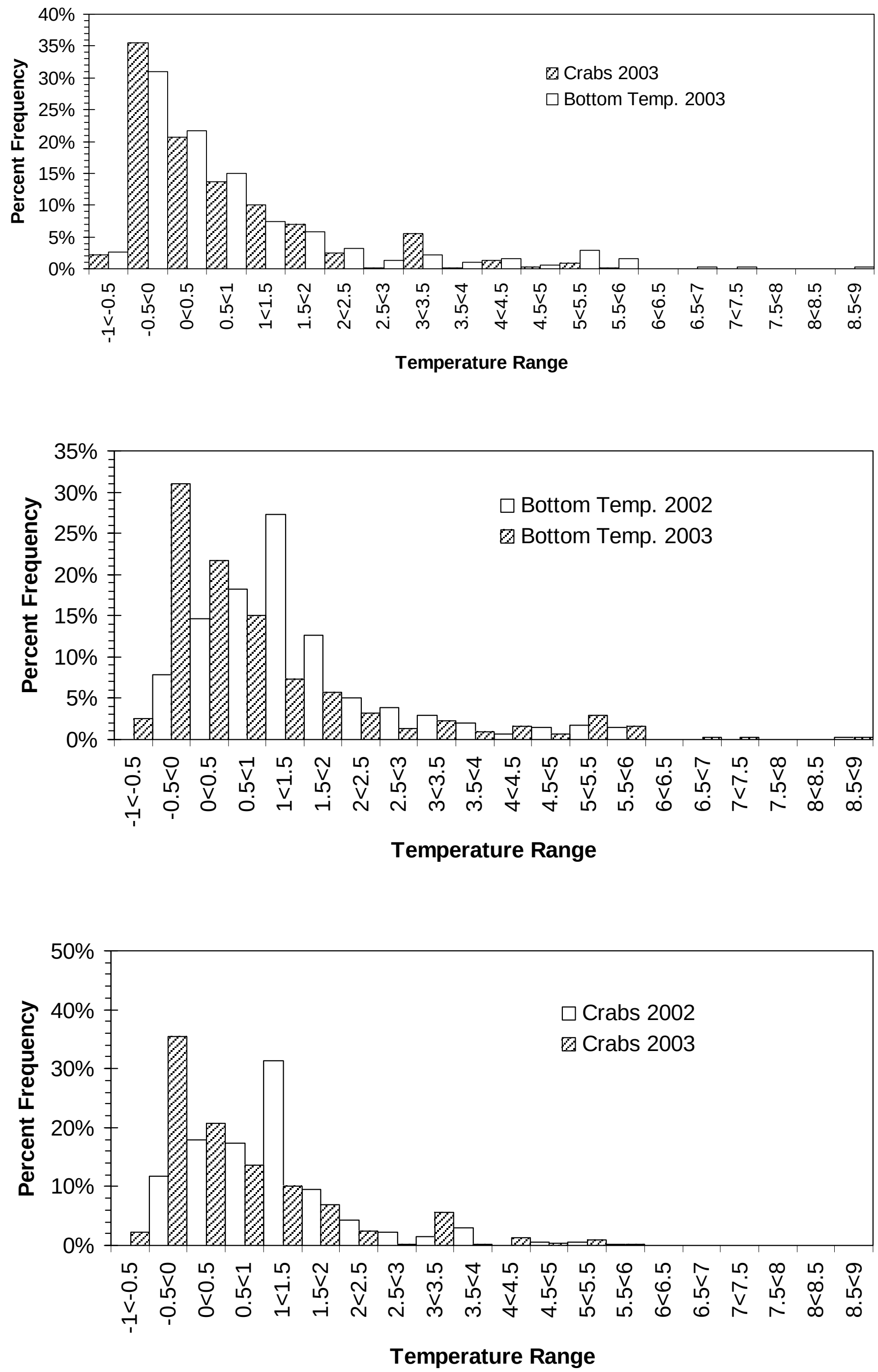


Fig.20. The frequency distribution as a function of temperature for the snow crab catches and for all of the station locations during the 2003 Gulf of St. Lawrence snow crab survey (top panel). The frequency distribution as a function of temperature for the stations occupied (middle panel) and for the snow crab catches (bottom panel) from the 2002 and 2003 Gulf of St. Lawrence snow crab surveys.

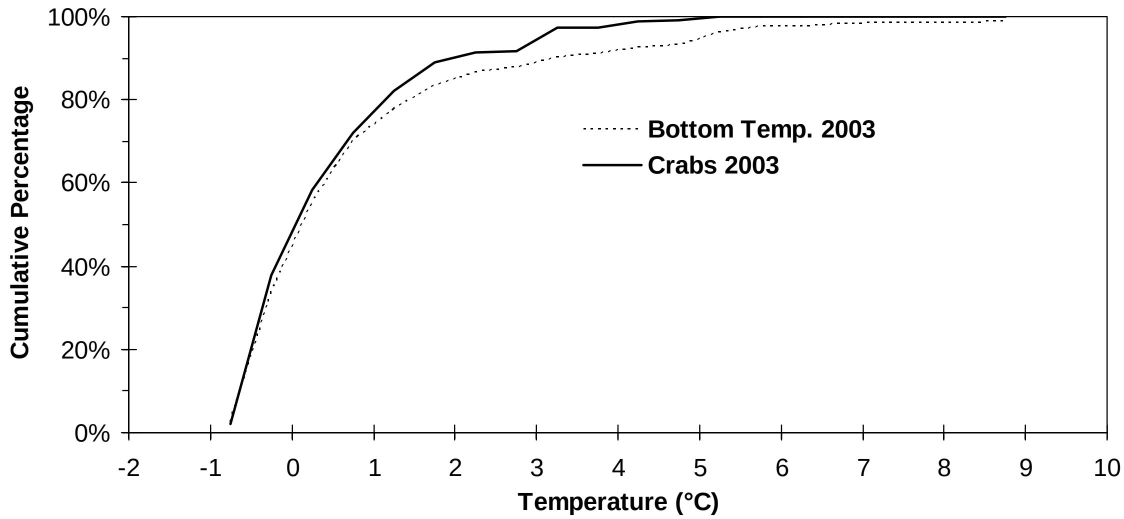


Fig.21. The frequency distribution as a function of temperature for the snow crab catches and for all of the station locations occupied during the snow crab survey in 2003.

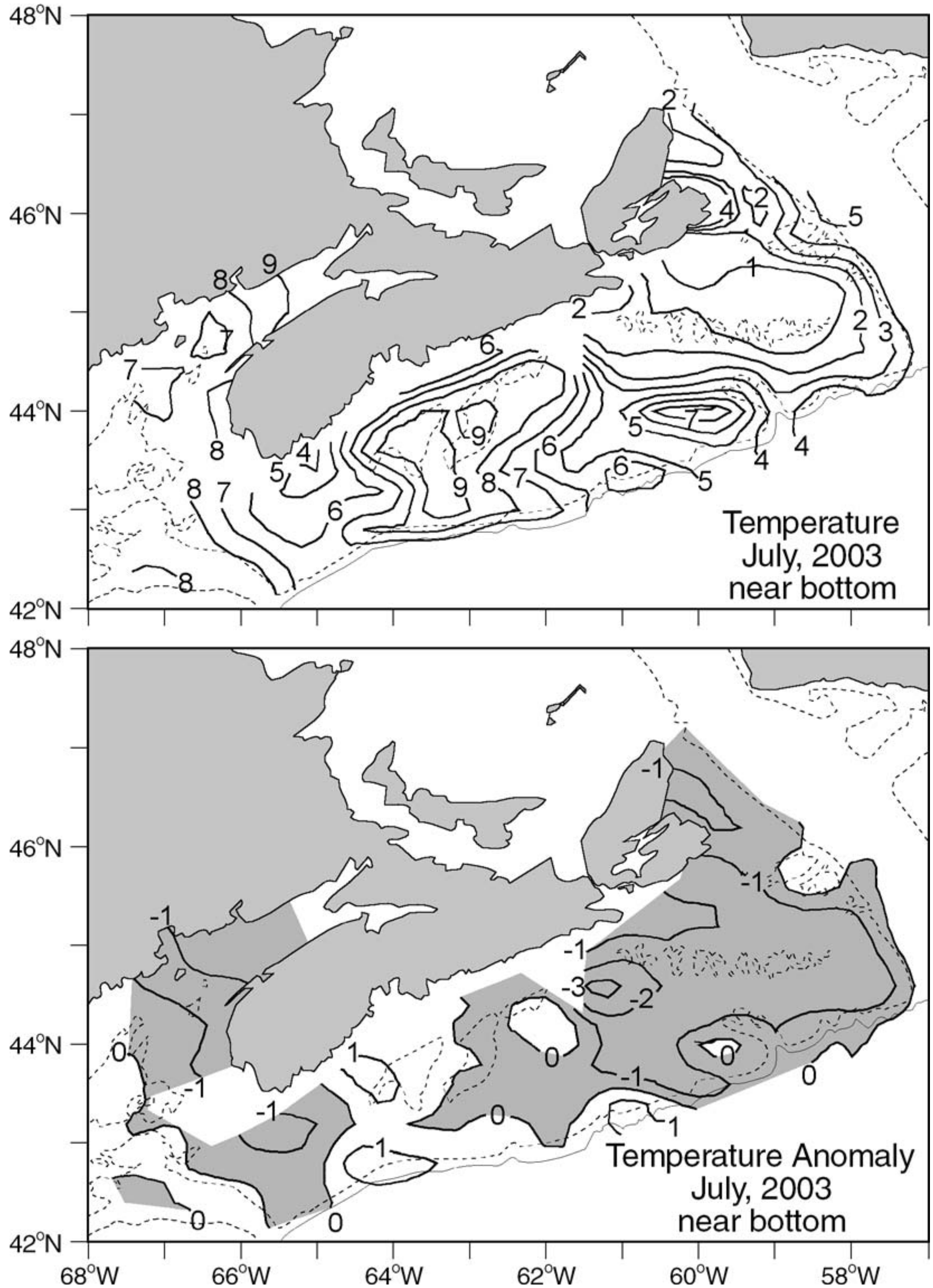


Fig.22. Near-bottom temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) on the Scotian Shelf during the 2003 July groundfish survey. Colder-than normal (negative anomalies) are shaded.

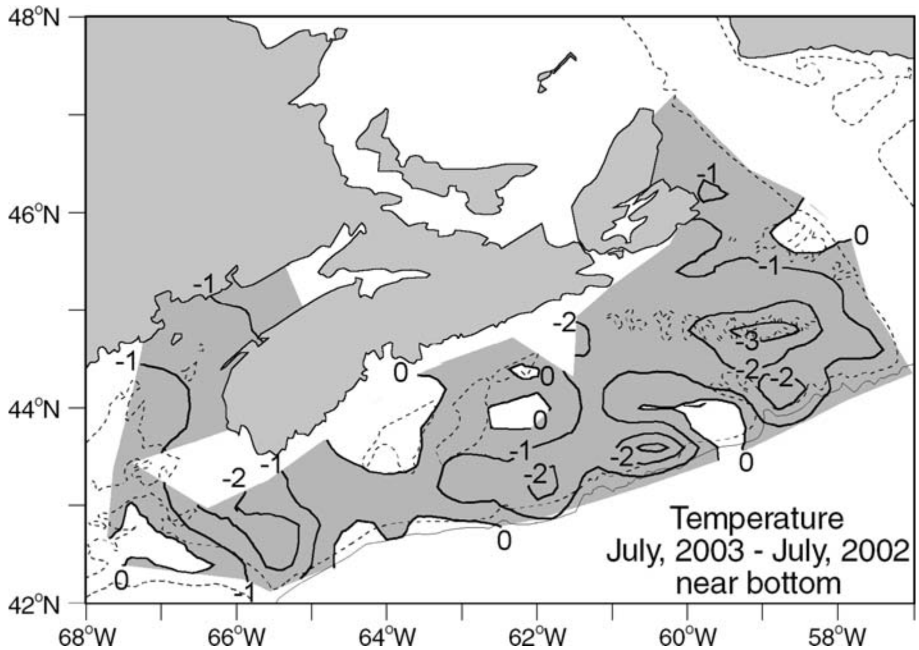


Fig.23. The difference between the 2003 and 2002 temperature fields on the Scotian Shelf for the July surveys. Positive values indicate areas where temperatures in 2003 had warmed and negative values (shaded) where they had cooled.

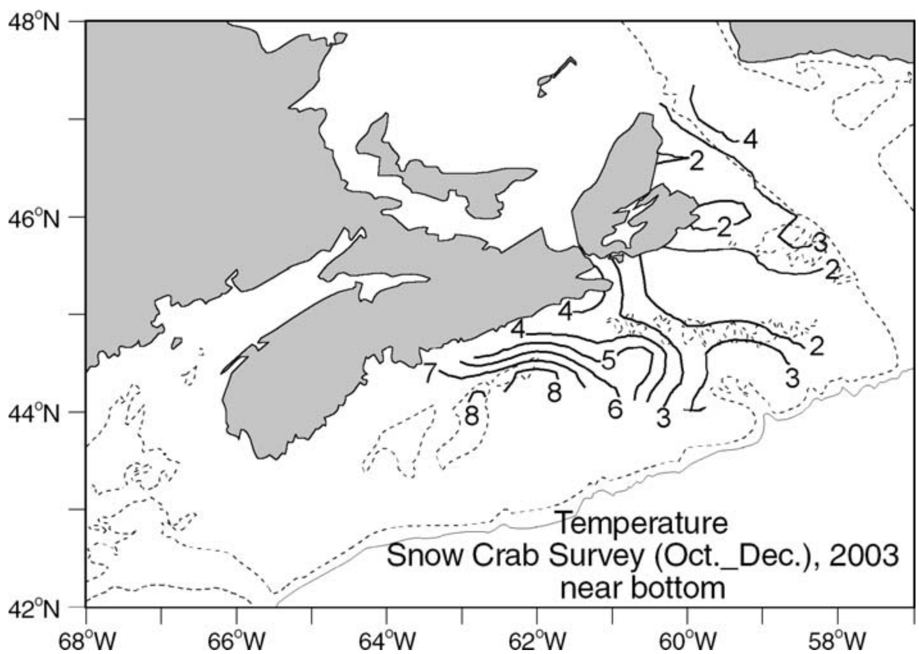


Fig.24. Near-bottom temperatures in the northeastern Scotian Shelf during the 2003 October-December snow crab survey.

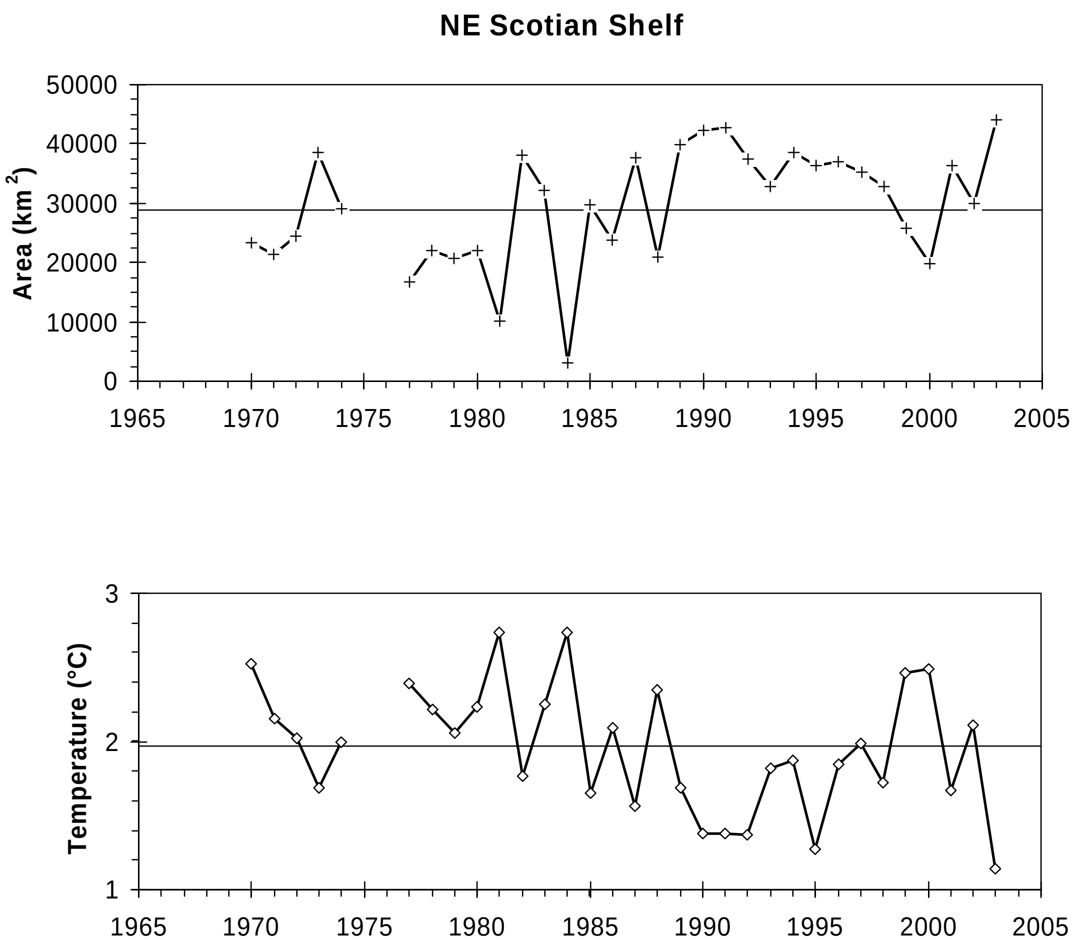


Fig.25. Time series of the area of the northeast Scotian Shelf covered by bottom temperatures between -1° and 3°C in July (top panel) and the mean temperature within that area (bottom panel). The horizontal lines represent the 1971-2000 mean.

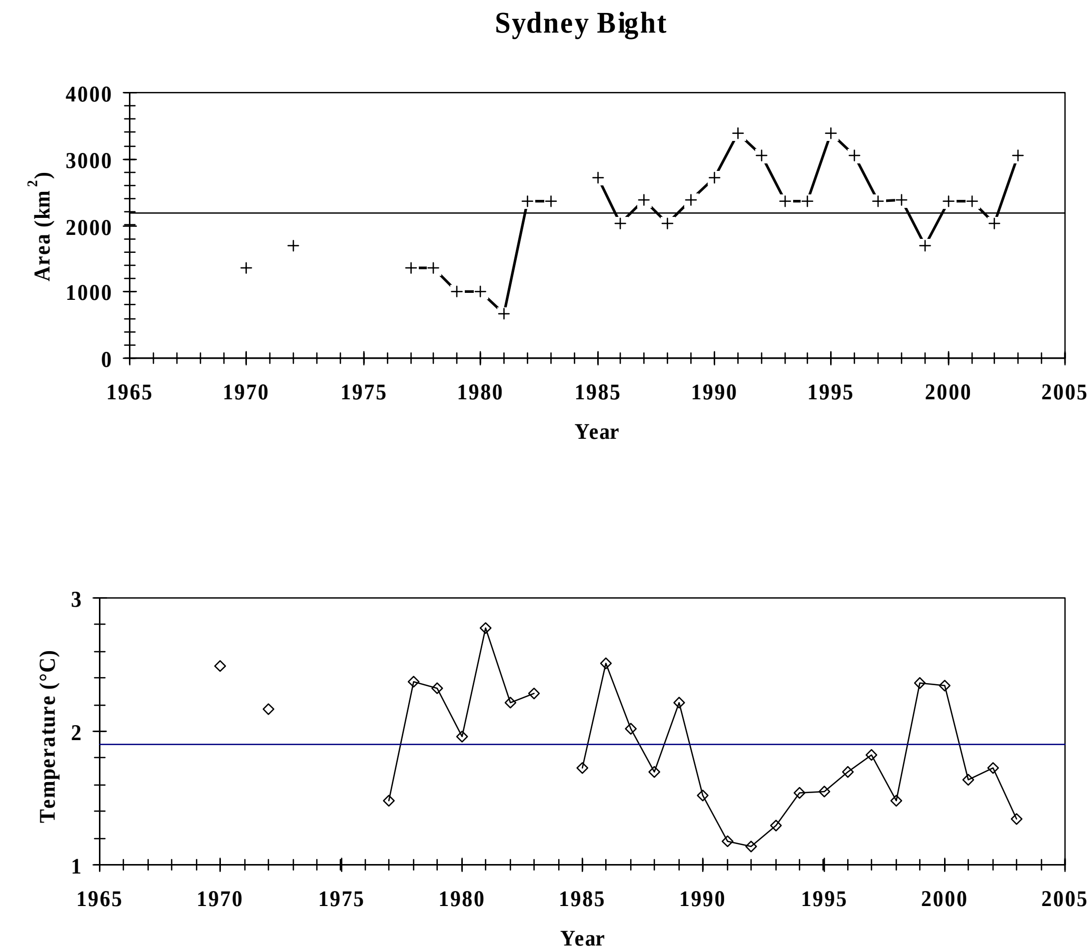


Fig.26. Time series of the area of Sydney Bight covered by bottom temperatures between -1° and 3°C in July (top panel) and the mean temperature within that area (bottom panel). The horizontal lines represent the 1971-2000 mean.

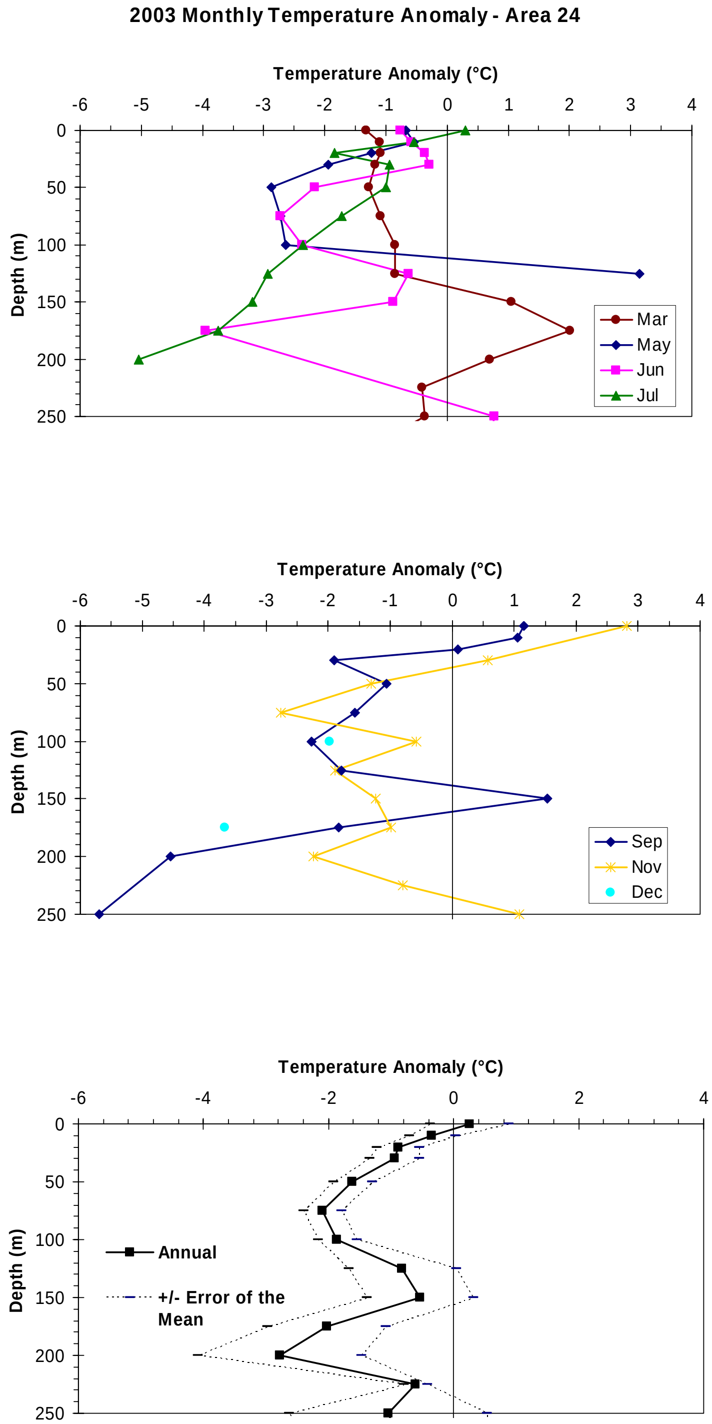


Fig.27. Monthly mean temperature anomalies (top two panels) and annual temperature anomalies ± error of the mean (bottom panel) for snow crab fishing Area 24 during 2003.

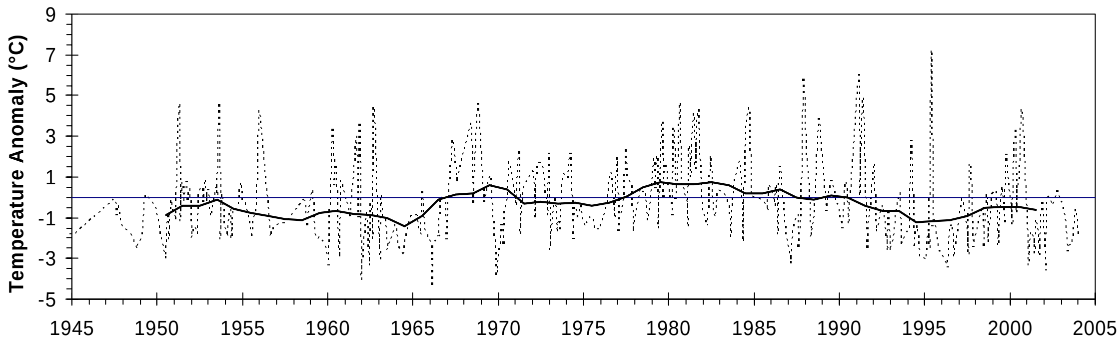


Fig.28. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Area 24.

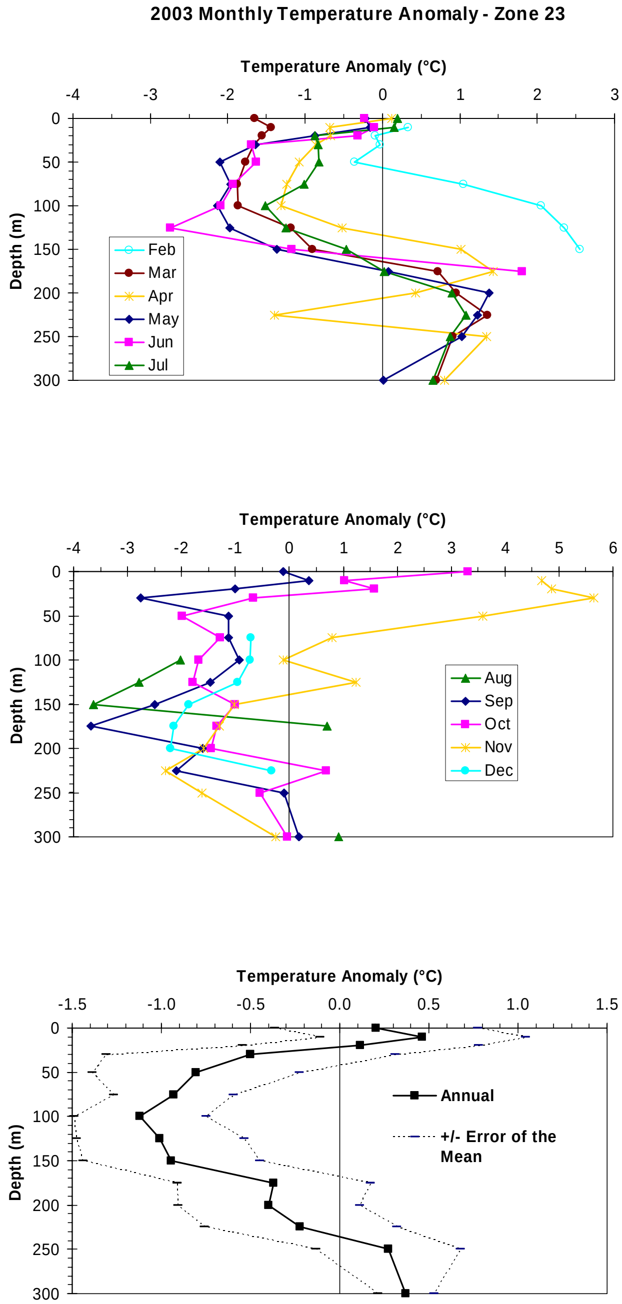


Fig.29. Monthly mean temperature anomalies (top two panels) and annual temperature anomalies ± error of the mean (bottom panel) during 2003 for snow crab fishing Area 23.

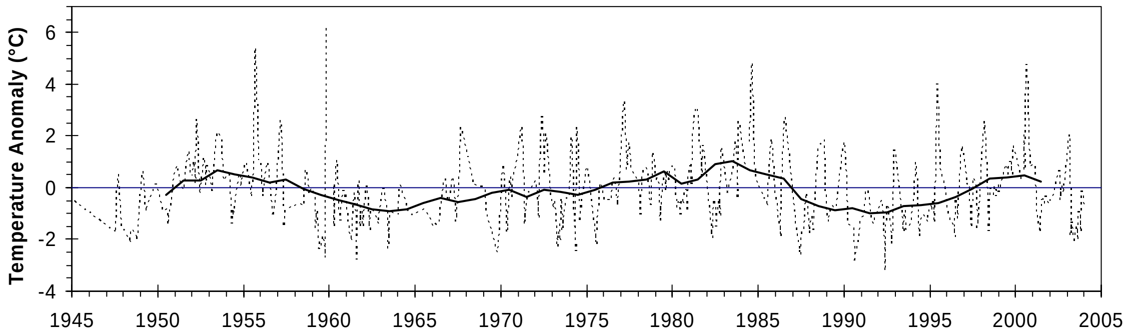


Fig.30. The time series of the monthly (dashed line) and the 5-year running mean of the annual temperature anomalies (solid line) at 100 m for snow crab fishing Area 23.

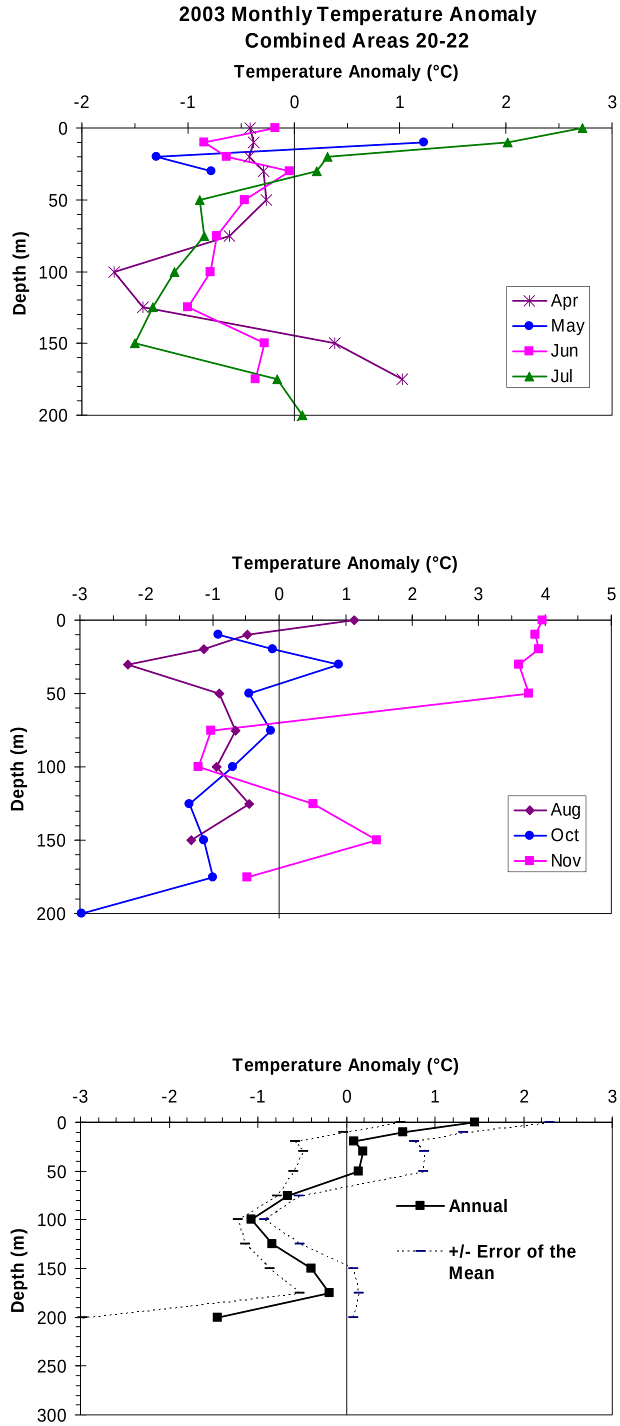


Fig.31. Monthly mean temperature anomalies (top panel) and annual temperature anomalies ± error of the mean (bottom panel) during 2003 for snow crab fishing Area 20-22 combined.

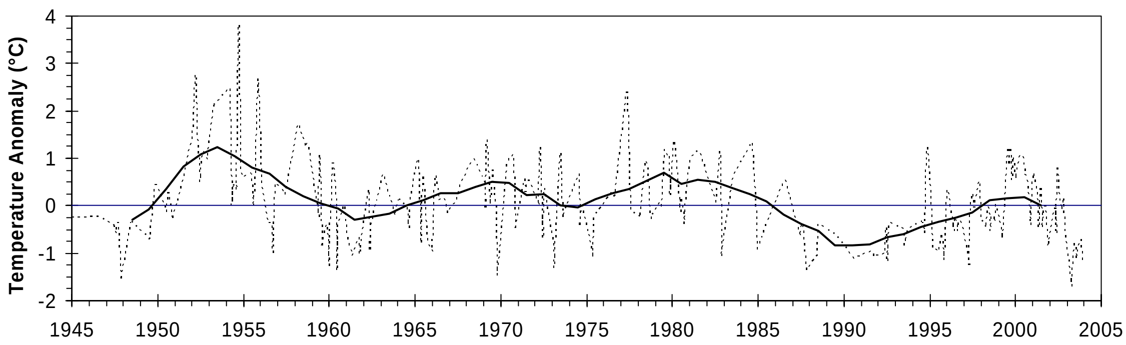


Fig.32. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Area 20-22 combined.

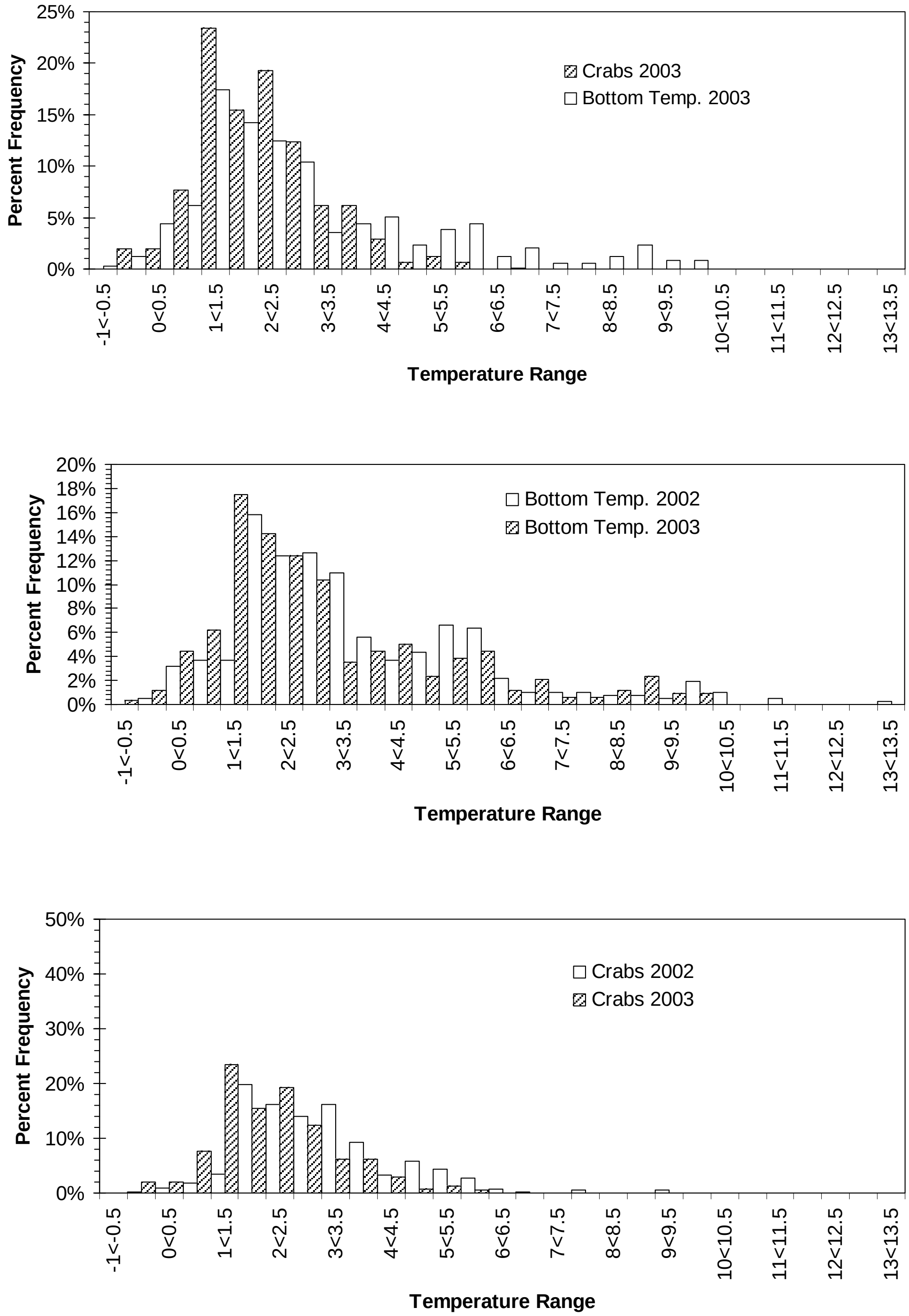


Fig.33. The frequency distribution in percentage as a function of temperature for the snow crab catches and for all of the station locations during the October-December snow crab survey on the Scotian Shelf in 2003.

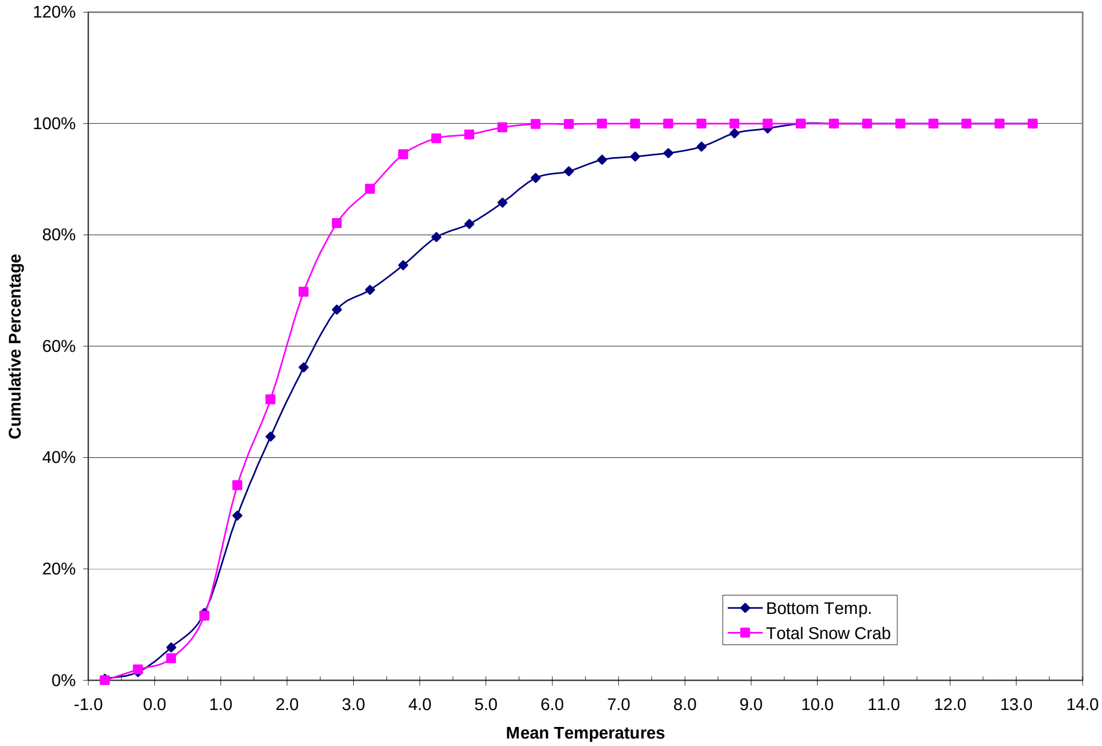


Fig.34. The frequency distribution in percentage as a function of temperature for the snow crab catches and for all of the station locations from 2003 surveys on the Scotian Shelf.