Fisheries and Oceans Canada | Pêches et Océans Canada
Science | Sciences

C S A S | S C C S

Canadian Science Advisory Secretariat | **Secrétariat canadien de consultation scientifique**

Research Document 2002/043

Document de recherche 2002/043

Not to be cited without permission of the authors *

Ne pas citer sans autorisation des auteurs *

Temperature Conditions on the Scotian Shelf and in the southern Gulf of St. Lawrence during 2001 Relevant to Snow Crab

Conditions de température sur la plate-forme Scotian et dans le sud du golfe du Saint-Laurent en 2001 en regard du crabe des neiges

K.F. Drinkwater, R.G. Pettipas and / et W.M. Petrie

Department of Fisheries and Oceans, Maritimes Region
Ocean Sciences Division, Bedford Institute of Oceanography
P.O. Box 1006, Dartmouth, N.S. B2Y 4A2

ISSN 1480-4883

Canada

Abstract

Temperatures during 2001 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 Gulf of St. Lawrence. 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 significantly from 2000, reaching near its long-term mean value. On the Scotian Shelf, the index increased by a factor of 2 and above its long-term average. On Sydney Bight the habitat index was the same as in 2000, remaining slightly above its long-term mean. Bottom temperatures within the snow crab fishing areas of the southern Gulf of St. Lawrence and the northeastern Scotian Shelf were generally cooler-than-average in 2001, reversing the trend of increasing temperatures observed over the past few years. Over the central Magdalen Shallows, while mean temperatures decreased in 2001, there was less water with temperatures <0ºC. The crabs caught during the annual snow crab surveys in all areas were found in colder waters in 2001 than in 2000, which is believed to reflect in large part the availability of cooler temperatures.

Résumé

Sont présentées pour 2001 des données sur la température des eaux des provinces Maritimes fréquentées par le crabe des neiges. Les données proviennent de diverses sources, y compris les relevés du crabe des neiges et du poisson de fond effectués sur la plate-forme Scotian et les petits fonds des Îles de la Madeleine, dans le golfe du Saint-Laurent. Un indice d'habitat du crabe des neiges, défini par la superficie du fond couverte par des eaux de –1 °C à 3 °C, a été calculé pour le sud du Golfe, la baie Sydney Bight et le nord-est de la plate-forme Scotian. L'indice pour le Golfe a nettement augmenté par rapport à 2000, pour atteindre presque sa valeur moyenne à long terme, tandis que sur la plate-forme Scotian, il a augmenté par un facteur de 2, pour se situer au-dessus de sa valeur moyenne à long terme, alors que dans la baie Sydney Bight, il était le même qu'en 2000, c'est-à-dire légèrement au-dessus de la moyenne à long terme. La température au fond dans les zones de pêche du crabe des neiges du sud du golfe du Saint-Laurent et du nord-est de la plate-forme Scotian était généralement plus basse que la moyenne en 2001, ce qui est un renversement de la tendance à une augmentation de la température observée au cours des dernières années. Bien que la température moyenne dans la partie centrale des petits fonds des Îles de la Madeleine ait diminué en 2001, il y avait moins d'eau de moins de < 0 ºC. Les crabes capturés dans le cadre des relevés annuels effectués dans toutes les zones ont été pris dans des eaux plus froides en 2001 qu'en 2000, ce que l'on croit reflète en grande partie la disponibilité d'habitats plus froids.

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). The purpose of this paper is to provide information on the sea temperature conditions during 2001 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 on 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 2001 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

Extensive geographic coverage of near-bottom temperatures during 2001 in the areas of snow crab fishing was available from two main surveys in both the Gulf of St. Lawrence and the Scotian Shelf. In the Gulf, the annual snow crab survey was conducted during August-October with a few additional stations taken in May (Fig. 3a) and the annual groundfish survey was carried out in September (Fig. 3b). On the northeastern Scotian Shelf, the snow crab survey was undertaken during May-September (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. A total of 327 bottom temperature stations were occupied in the Gulf and 377 stations on Sydney Bight and the northeastern Shelf. Temperature and salinity data were collected with a conductivity-temperature-depth (CTD) instrument during the groundfish surveys. A total of 148 CTD stations were occupied in the Gulf and approximately 93 of the 209 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 (154 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 2001 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-2001 data were taken from the historical hydrographic database maintained at the Bedford Institute of Oceanography (BIO). This database contains an edited version of the entire MEDS holdings for the region.

This year we again have examined the relationship between snow crab catch and bottom temperature. Comparison of results from 2001 with previous years' surveys is also present.

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 method is similar to other objective techniques such as kriging but offers the advantage that the interpolation is 4-dimensional; i.e. three space dimensions, two horizontal and one vertical, and the time dimension, rather than 2-dimensional (the two horizontal dimensions). In this study the surveys were treated as synoptic and no interpolation in time was carried out. 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. Note that the smoothing routine tends to spread out near-bottom temperature gradients (e.g. those near the coast), 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. Note that in previous reports we used the 30-year period 1961-1990. Updating to the most recent 30-year period is in compliance with meteorological convention. The difference in the two 30-year averaging periods tends to vary spatially but it generally lies within 0.5ºC, with the 1971-2000 period being slightly colder. The 1971-2000 climatological means are then subtracted from the values derived from the 2001 survey. The differences are called temperature anomalies. A negative anomaly indicates that the 2001 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 2000 optimally estimated temperatures from the 2001 estimates. A negative value indicates that 2001 was cooler than 2000, a positive value that it was warmer.

A snow crab habitat index, defined as the area of the bottom covered by temperatures between -1°C and 3°C, was calculated from the optimally estimated bottom temperatures from the groundfish surveys. Separate indices were calculated for the Scotian Shelf, Sydney Bight and the Magdalen Shallows. 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 2001 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 2001 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 are shown in the plots of these monthly means. They are the 5-year running averages of the “annual” anomalies.

Again this year we 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, both those where snow crabs were caught and those where they were not. Finally, comparisons were made between these 2001 results and those from 2000.

Results

Southern Gulf of St. Lawrence

Bottom Temperatures

On the Magdalen Shallows, data from September 2001 during the groundfish survey showed the typical bottom temperature pattern with a range of <1°C to over 15°C (Fig. 5). The majority of the bottom was covered by temperatures of <3°C with the largest portion of the Shallows (50-80 m) covered by temperatures <1°C. Bottom temperatures tend to increase from there towards the shallower, near shore 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 which originate from the slope water region off the continental shelf. These 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 an additional 35% from advection of cold Labrador Shelf water through the Strait of Belle Isle (Petrie et al., 1988). In 2001, the warmest near-bottom temperatures and anomalies 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 over 15°C (Fig. 5).

Temperature anomalies over most of the Shallows were primarily near to or just above normal (Fig. 5). The exception was a band of below average temperatures stretching offshore of Cape Breton Island, north of Prince Edward Island and northward towards the Gaspe. The highest negative anomalies appeared off eastern Prince Edward Island. The warmest anomalies (above 2°C) were located in Miramichi 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 lay 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 2000, bottom temperatures during the 2001 groundfish survey tended to be near to or slightly warmer over the central Magdalen Shallows north of Prince Edward Island (Fig. 6). In contrast, temperatures cooled slightly between the Magdalen Islands and Cape Breton Island, immediately to the north of Prince Edward Island, along the southern edge of the Laurentian Channel and off much of the Gaspe Peninsula. Cooling was greatest (upwards of 4º) off eastern Prince Edward Island.

The spatial pattern of the bottom temperatures from the snow crab survey in August-October 2001 are similar to that from the 2001 groundfish survey (Fig. 7). The major difference is the warmer values in the Bay of Chaleur during the groundfish survey, presumably due to the seasonal deepening and warming of the upper mixed layer. In the deeper regions (>~50 m), the temperature and temperature patterns are similar, although not identical. For example, there is slightly more <1°C water recorded in the snow crab survey. However, over 84% of the gridded temperatures from the two surveys differ by <0.5°C for the same grid point and 94% were within 1°C. 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 measurment (the thermistor is on bottom while the CTD will be a few to several m 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 present. 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 2001, the area of the bottom of the Magdalen Shallows covered by waters between -1°C and 3°C during the groundfish survey increased slightly compared to 2000. It was just over 52400 km^2 and compares closely to the long-term mean (1971-90) of approximately 52300 km^2 (Fig. 8). The 2001 value represents 75% of the total Shallows area, and was 6% higher than in 2000. 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 2001 fell slight compared to 2000 (by > 0.06°C), which is a similar to the decrease observed last year but is well above the much colder temperatures recorded through most of the 1990s. The correlation between the habitat index and the mean temperature over the years 1971-2001 within this area is -0.36 and is not statistically significant. The long-term temperature pattern from the snow crab habitat index on the Magdalen Shallows is consistent with that for the CIL waters throughout the Gulf of St. Lawrence. The CIL variability was first described by Gilbert and Pettigrew (1997) and updated in Drinkwater et al. (2001).

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 (1971-90) 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 or 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 2000 over the central Magdalen Shallows (**Area 12** in Fig. 2 excluding the southern portion just north of Prince Edward Island) were available for 9 months between April and December inclusive. The monthly and annual anomaly profiles tend to show generally below-normal temperatures (up to –0.3°C on average) from 50 m to 100 m (Fig. 9). Below 100 m, which is primarily limited to the Laurentian Channel and the deep trough off Cape Breton, monthly temperature profiles varied but tended to be near to or above normal. The exception was in April when these deep temperatures were significantly colder-than-normal. In the top 30 m, temperatures varied from month to month with May, June and August experiencing colder-than-normal temperatures and the remaining months being warmer-than-normal. The average of all of the months indicates a warmer temperature in the surface layer than usual by between 0.5° and 1°C. The time series of monthly mean temperatures at 75 m in Area 12 shows high variability but a definite tendency for below normal temperatures over most of the period since the mid-1980s (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 longer term pattern matches that observed elsewhere and is considered real. In 2001, temperatures oscillated about the long-term mean with the tendency to be cold in the first half of the year and then warming to above normal by the end of the year. Note that not all months of each year contain data.

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 (50 m only) and

September. Temperatures in June and September show opposite anomalies at 10 to 20 m being cold in June but warm in September (Fig. 11). At 30 m, temperatures were generally colder-than-normal. At 50 m all three months show values near the long-term mean. Most of this area contains bottom depths less than 60 m and is shallower than the rest of the snow crab Areas within the Magdalen Shallows. The time series at 30 m shows high variability with a tendency towards above normal temperatures in 2000, which contrasts with the cold of 2001 (Fig. 12). At 50 m (not plotted) there has been a tendency towards negative anomalies since the mid-1980s but not as consistently as in the rest of Area 12. The last four years, temperatures at 50 m have oscillated about and near the long-term mean. There are, however, much less data at 50 m then at 30 m for this Area. 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 undersampled. 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 June, July September and December in 2001. The mean profiles indicate warmer-than-normal waters in the top 20 m and colder or near normal below 50 m (Fig. 13). Maximum temperature anomalies appeared at 10-20 m being upwards of 2°-3°C. The coldest anomalies (-2°C) were recorded in June around 30 m and also at 125 m. The time series at 100 m shows below normal temperatures in 2001 until the end of the year and were colder than the temperatures recorded in 1998 through 2000. They were similar to the cold conditions that persisted from the late 1980s into the 1990s (Fig. 14).

Data during June, August and September of 2001 were available from **Area F** (Fig. 15). The near surface (0-20 m) temperatures were extremely warm in August but were below normal in June and September. Between 50 and 75 m, conditions were near normal but from 100 to 175 m temperatures tended to be cold with maximum anomalies (-1°C) around 125 m. Below 175 m, anomalies were generally positive but with magnitudes of <0.5°C. 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 and a general warming since the mid-1990s. Warmer-than-normal temperatures were observed in 1999 and 2000 but declined in 2001 (Fig. 16). 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 during 4 months: June, August, September and December. Monthly mean temperatures in the near surface waters varied depending upon the month but from 75 to 150 m were predominantly below normal (Fig. 17). Below 150 m, temperatures were about normal. The averages of the monthly anomalies were above to near normal down to 75 m and below normal between 175-250 m. Maximum negative anomalies were near 1°C in December. 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 above normal temperatures in 2000 were replaced in 2001 by below normal values.

The general trends in the temperature anomalies in the near-bottom waters throughout the Magdalen Shallows are similar. This is highlighted in Fig. 19 that shows the five year running means of the temperature anomalies for Areas 12, 19-20 combined, E and F.

Snow Crab Catches by Temperature

The catches of snow crab as a function of temperature during the 2001 snow crab survey in the Gulf are shown in Fig. 20. Over 98% of all of the crabs were caught in temperatures between -1° and 3°C. There was a tendency for the snow crabs to be captured in slightly colder waters than the temperatures available. For example, the catch-weighted mean temperature at stations between -1° and 3°C was 0.7°C whereas the un-weighted mean temperature for the same stations was 1.1°C. More snow crabs were caught in cooler temperatures in 2001 than in 2000 except at temperatures <-0.5°C, which reflects the available temperatures (Fig. 21).

Northeastern Scotian Shelf and Sydney Bight

Bottom Temperatures

From the July groundfish survey, near-bottom temperatures were estimated for the entire Scotian Shelf, although for snow crab we are primarily interested in the northeastern region and Sydney Bight. In these latter areas, bottom waters were generally <5°C with a significant portion <2°C (Fig. 22). Temperatures were mostly colder-than-normal with anomalies typically between 0° and 2°C (Fig. 22). Exceptions in the northeastern Scotian Shelf were around Sable Island, on the outer portions of Banquereau Bank and on Misaine Bank. Temperatures decreased relative to July 2000 over almost the entire northeastern Scotian Shelf by upwards of 1°-3°C (Fig. 23). This reverses the warming trend of the past couple of years when the majority of the bottom was covered by temperatures that were warmer than their long-term means and are now similar to the previous decade of colder-than-normal conditions.

Bottom temperatures from the snow crab survey in May-September display a similar spatial pattern to that from the groundfish survey (Fig. 24). The major difference is the slightly larger extension of temperatures <3°C during the spring compared to summer. The reduction of this colder water in the summer, most noticeably farther offshore, is consistent with the known seasonal warming on and around Banquereau Bank (Petrie et al., 1996). In spite of these differences, approximately 57% of the grid points at which the data were extrapolated to using the optimal estimation procedures had values for the two surveys that were within ±0.5°C and 77% within 1°C. As in the Gulf, given these differences, the similarity in the two surveys in the regions is again encouraging in that the main temperature features are being captured by both surveys.

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. 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 2001 was 36358 km^2 representing approximately 52% coverage of the total grid area and was a dramatic increase (almost double) over 2000 (Fig. 25). This reverses the declining trend of the past 4 years and a return to above the long-term mean (29000 km^2; 41% of the total area). The maximum coverage was reached in 1991 (over 60% of the total grid area). In 1999, the index dropped below the long-term mean for the first time in over a decade and dropped further in 2000. 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 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 ($r=-0.87$, $p<0.001$; 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 2001 when the habitat index increased, the mean temperature decreased.

On Sydney Bight, the snow crab habitat index in 2001 remained the same as in 2000 (Fig. 26). It represents slightly over 30% coverage of the total grid area and is above the long-term average of 2188 km^2, which represents 28% of the total grid area. 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 2001 declined relative to 2000 and similar to the values observed during much of the 1990s (Fig. 26). The correlation between the average temperature within the index area and the habitat index itself during 1970 to 2000 for Sydney Bight is -0.65.

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 (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 (>8°C) in the southwest (Fig. 27). 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 calculated from the available data, therefore any apparent temperature trend for this Area must be viewed with caution. In Area 24, data were available in 10 months of 2001. The dominant feature is the below normal temperatures throughout almost all of 2001 below 50 m (Fig. 27). The mean bottom temperature anomalies were 5° to 7°C below 200 m. However, the mean in this region is largely reflected of the slope water characteristics at the edge of Sable Island Bank and also in Emerald Basin and the large anomalies likely reflect measurements taken in areas dominated by Shelf waters originating from the Gulf of St. Lawrence. Thus, while the negative anomalies are believed to be real, the magnitudes are not. In the top 50 m, temperatures were also below normal from February to July but warmed from then until the end of the year. Upper layer temperatures were also warmer-than-normal in January. The below normal conditions are reflected in the average of the monthly anomaly profiles labelled as the “annual” mean profile (Fig. 24). The time series at 100 m shows high variability but generally below normal temperatures over most of 2001 (Fig. 28). This is in contrast to the above normal temperatures observed in 2000 but is similar to most of the 1990s.

On the northeastern Scotian Shelf in Area 23, temperatures were collected in 8 months of 2001 (Fig. 29). Similar to Area 24, colder-than-normal temperatures dominated the year in the waters below 75 m. Also, while the first of the year appeared warm, cold conditions entered the region in late winter. In the surface layer, however, temperatures were variable with cold conditions from March to July, therefore warming to above normal, which continued through to November. The “annual” mean again reflects these cold conditions in the deeper sections of the water column. As in Area 24, the cold conditions in 2001 contrast with the warm conditions in 2000 and temperatures are closer to those in the mid-1980s to late 1990s (Fig. 30).

The temperature data for snow crab fishing Areas 20 through 22 were combined in our analysis. From the 7 months of 2001 when observations were available, temperatures throughout the water column tended to be above normal (Fig. 31). The maximum anomaly was over 3°C at 10 m in July. Exceptions to the warm conditions were in the 20-30 m depth layer in August, around 75 m in November and below 150 m in September. The time series at 100 m shows colder-than-normal waters from the mid-1980s to the late 1990s but with warming during recent years and above normal temperatures in 1999 and 2000 (Fig. 32). Analysis of the data has shown that this pattern in the time series is generally representative of conditions between 50 m and 150 m.

Snow Crab Catches by Temperature

The snow crab catches as a function of temperature during the 2001 May-June 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 2001 compared to 2000, which reflects the available temperatures in each of those years (Fig. 34). The depths that the crabs were caught at were largely the same in both years. It appears that the crabs on the northeastern Shelf maintain their depth, and while having a tendency to favour colder waters, their temperature habit is largely determined by what temperatures are available to them.

Summary

Near-bottom temperatures in the southern Gulf of St. Lawrence (Magdalen Shallows) and in the northeastern Scotian Shelf during 2001 were examined primarily from data collected during the snow crab and groundfish surveys. The snow crab surveys were conducted in May-September on the Scotian Shelf and in August-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 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 2001, conditions were variable but tended to have cooled throughout much of the region. The snow crab habitat index, based upon the area of bottom temperatures preferred by snow crab (-1°C to 3°C), increased relative to 2000, reversing the declining trend and returning to near normal values. The temperatures within the area of -1° to 3°C is above normal but fell slightly compared to last year, although not significantly. The vertical temperature profiles indicated a strong tendency to be warmer in the surface and in depths below about 200 m, whereas in the 50 to 150 m depth range, conditions were mainly colder than normal. In addition, the amount of water <0°C decreased compared to 2000 but there was more 0°-1°C water in 2001.

Even colder conditions occupied the northeastern Scotian Shelf region. Below normal conditions were found in the bottom waters of the northeastern Shelf during the July groundfish survey and especially in late winter to late autumn of 2001. The cold conditions reverse the warming trend observed since the mid-1990s and the above normal temperatures observed in 2000. The cold conditions are closer to the cold conditions 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 and R. Gautreau 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. D. Dearman helped in the analysis of the catch, temperature and depth 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., E. Colbourne and D. Gilbert. 2001. Overview of environmental conditions in the Northwest Atlantic in 2000. NAFO SCR Doc. 01/36, 85 p.

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.

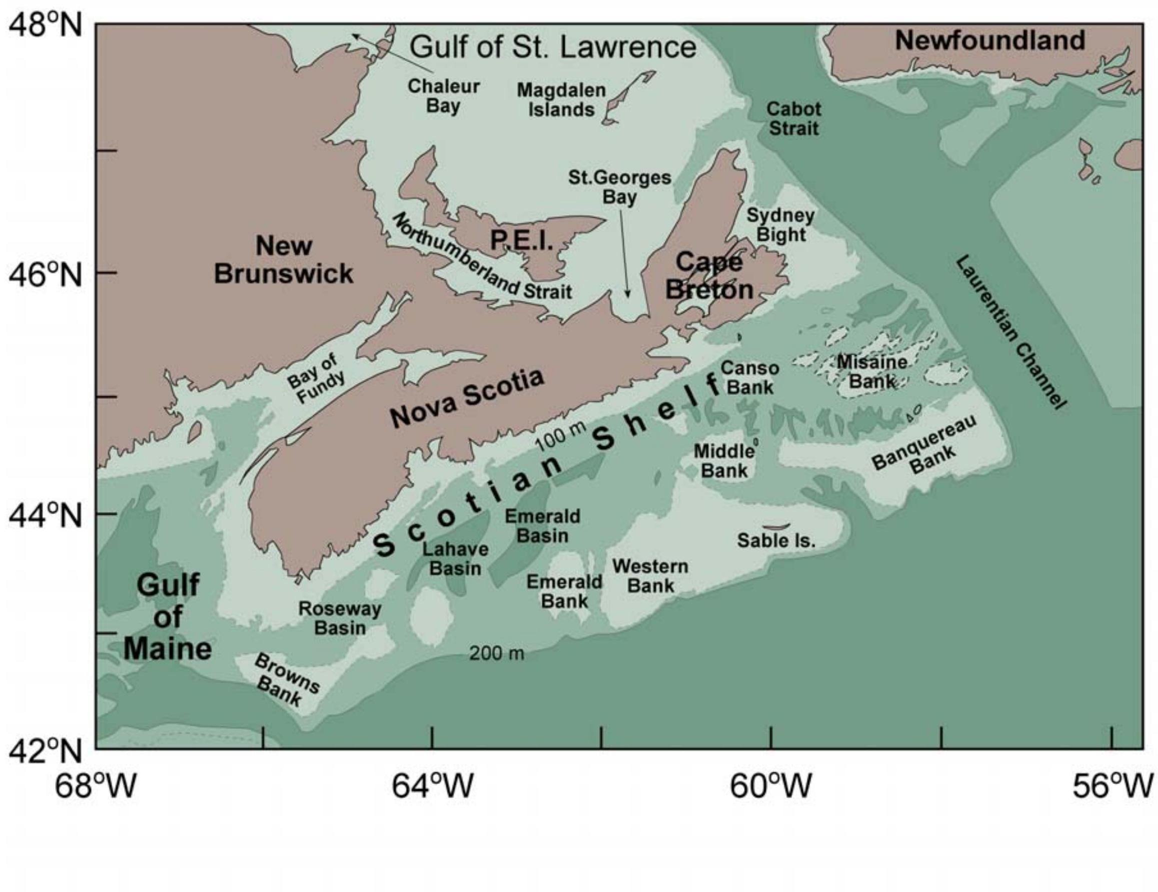


Fig. 1. Chart of the Scotian Shelf and the southern Gulf of St. Lawrence showing geographic and topographic features referred to in the text.

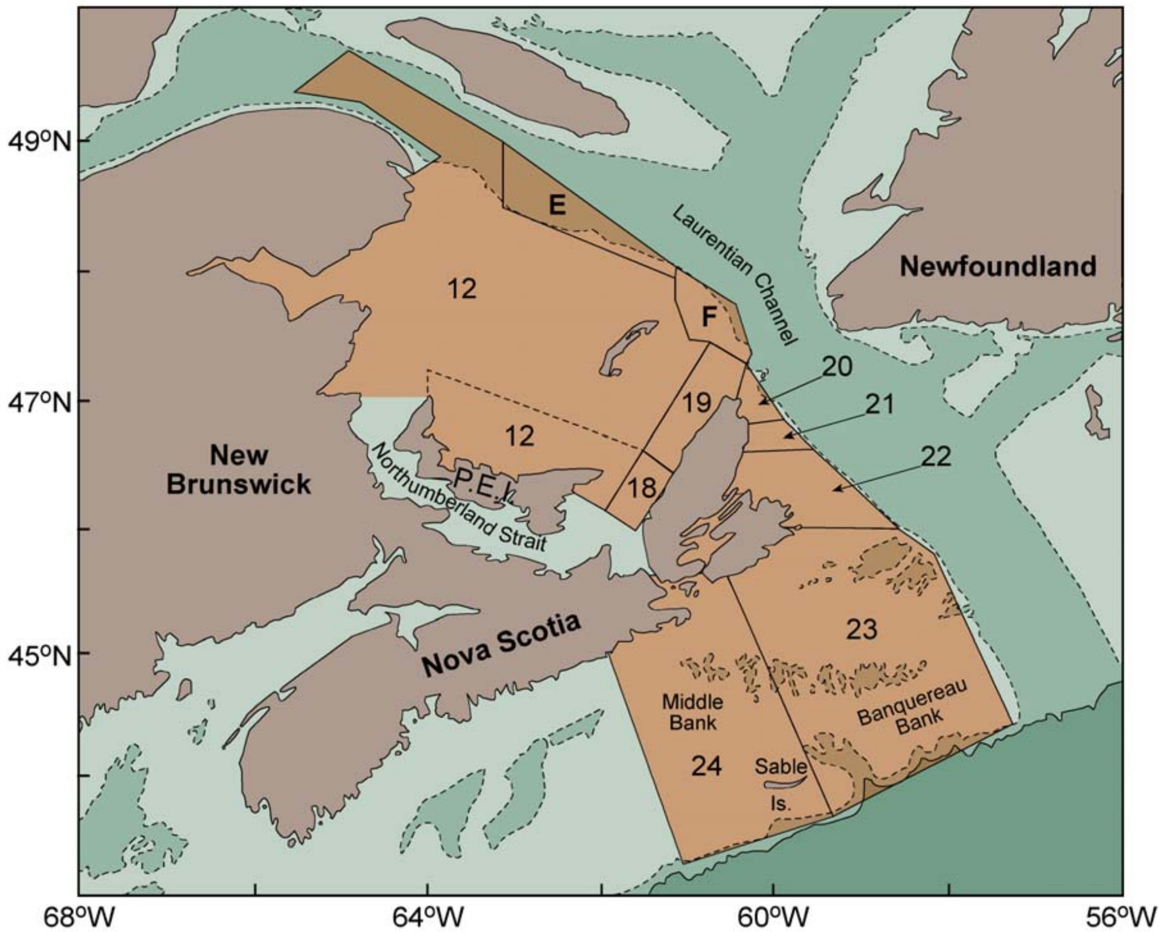


Fig. 2. The southern Gulf of St. Lawrence and Scotian Shelf showing the boundaries of snow crab fishing areas in which monthly mean temperature profiles were estimated. The section of Area 12, north of Prince Edward Island and denoted by the dashed line, contains former Areas 25 and 26.

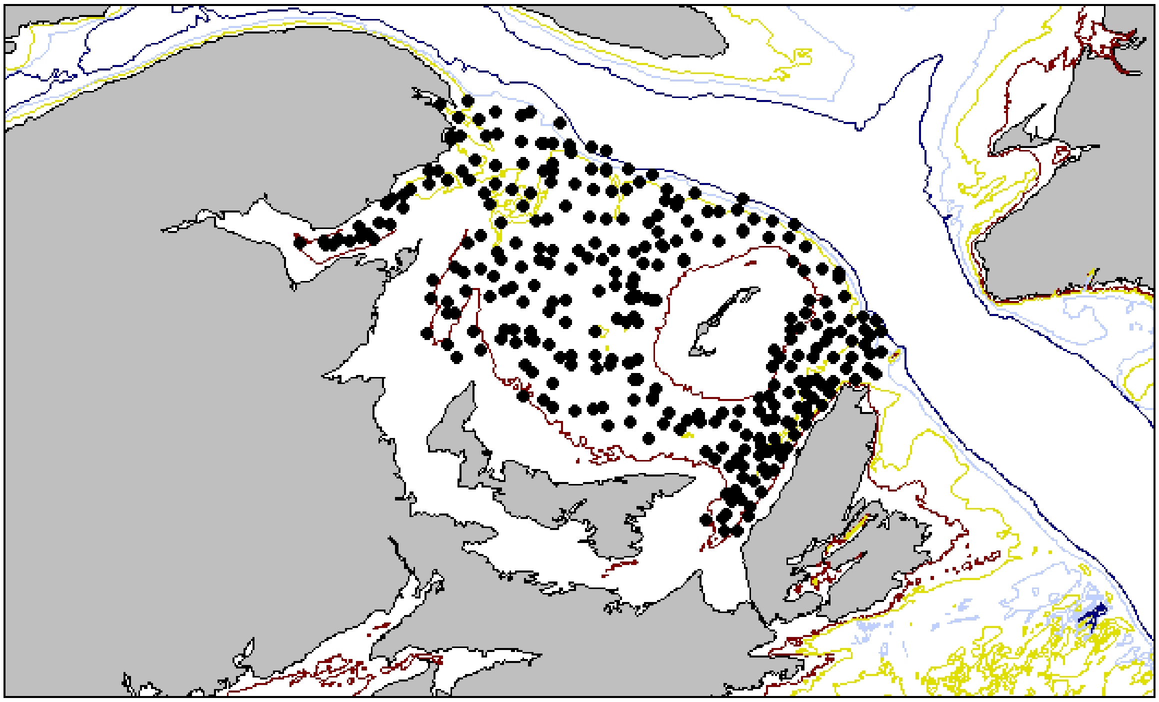


Fig. 3a. The location of the bottom temperature stations during the August-September 2001 snow crab survey.

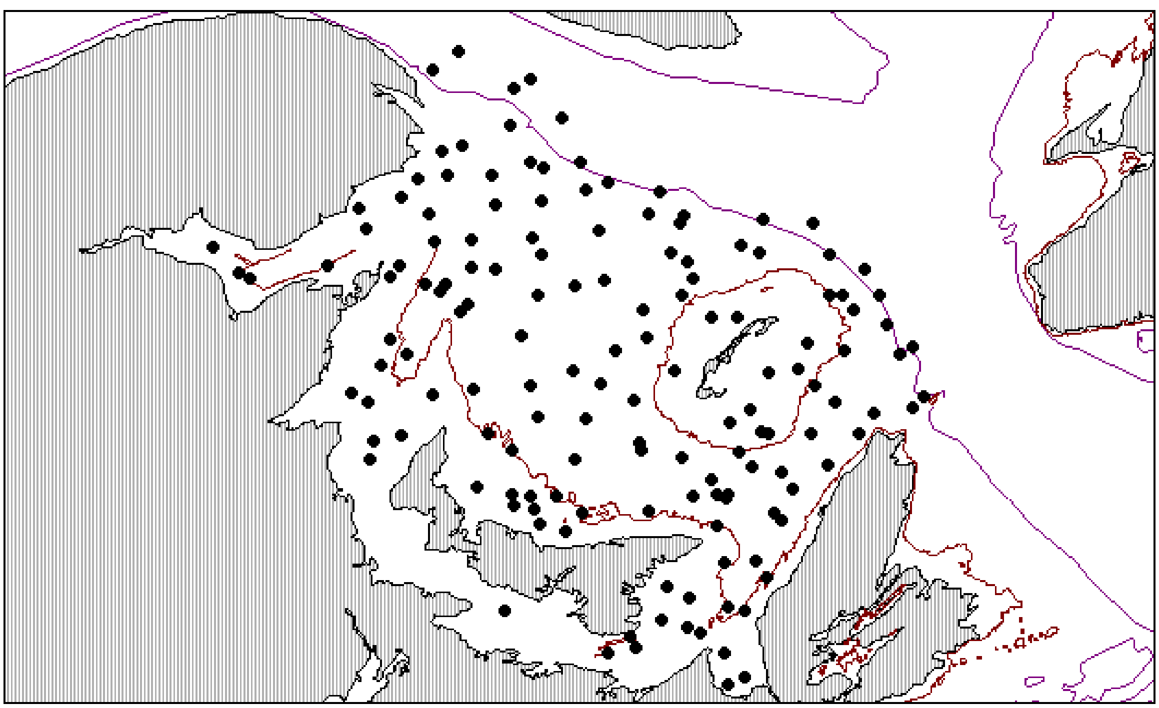


Fig. 3b. The location of the CTD stations during the September 2001 survey.

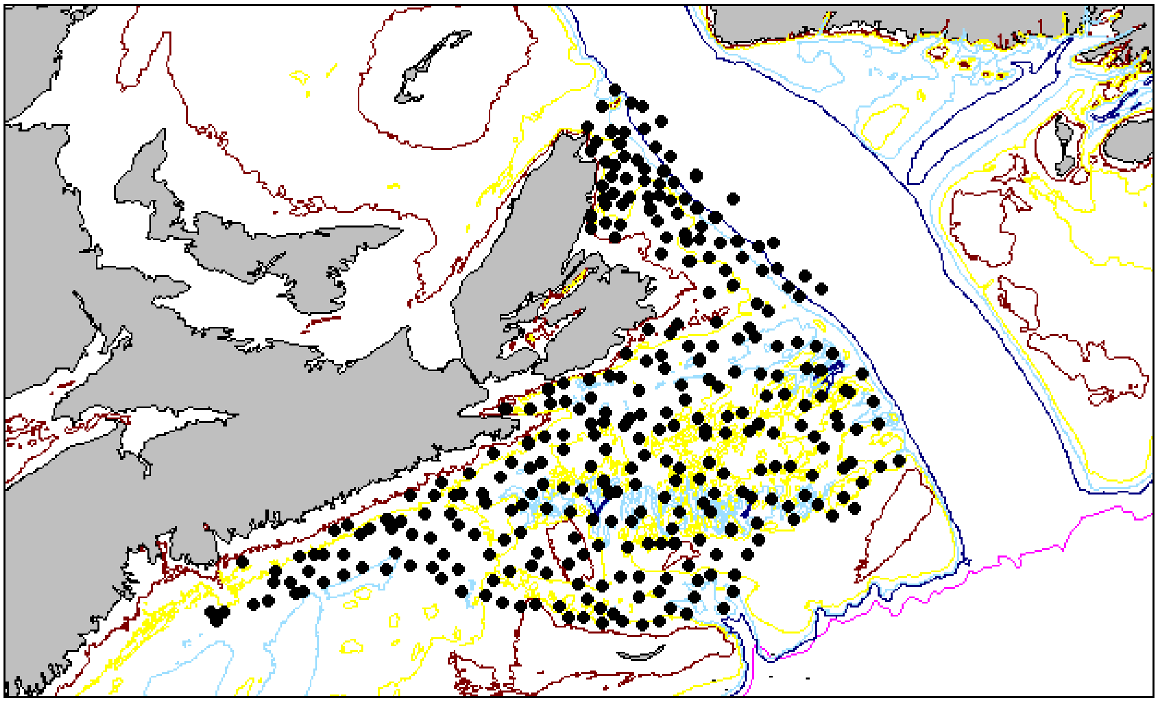


Fig. 4a. The location of the bottom temperature stations during the May-September 2001 snow crab survey.

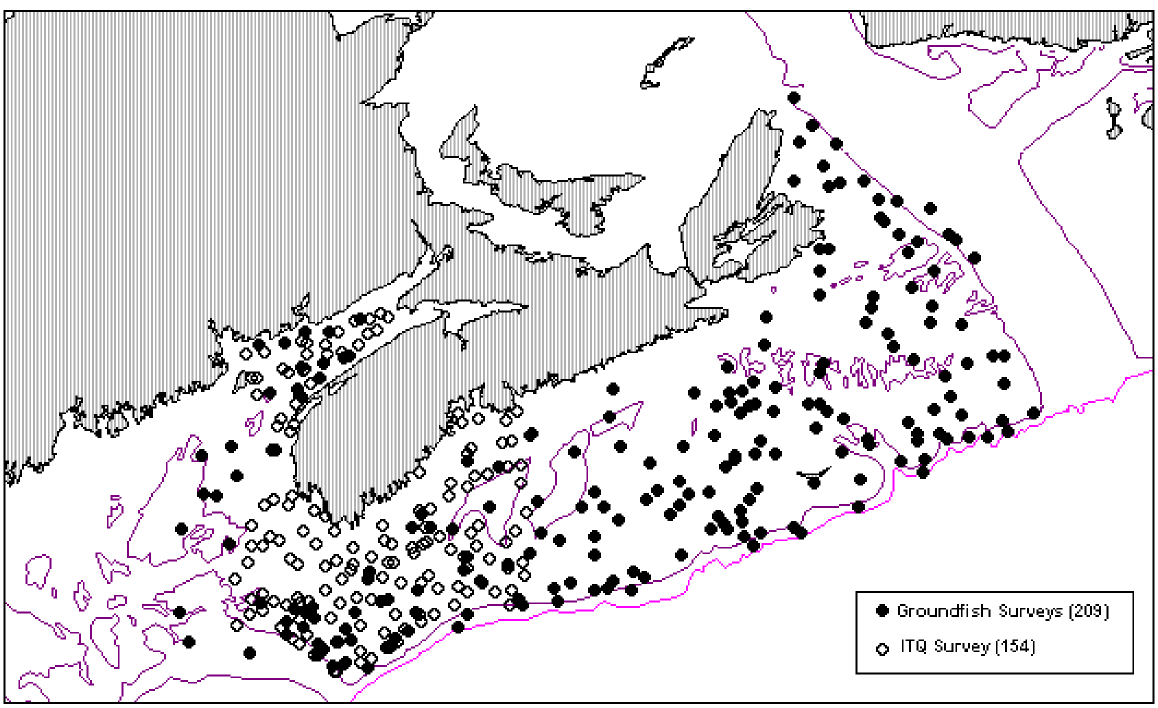


Fig. 4b. The location of the CTD stations during the July 2001 survey. The solid black dots represent the stations taken during the DFO groundfish survey and the open circles denote the stations taken during the fisherman run survey (labelled as ITQ Survey).

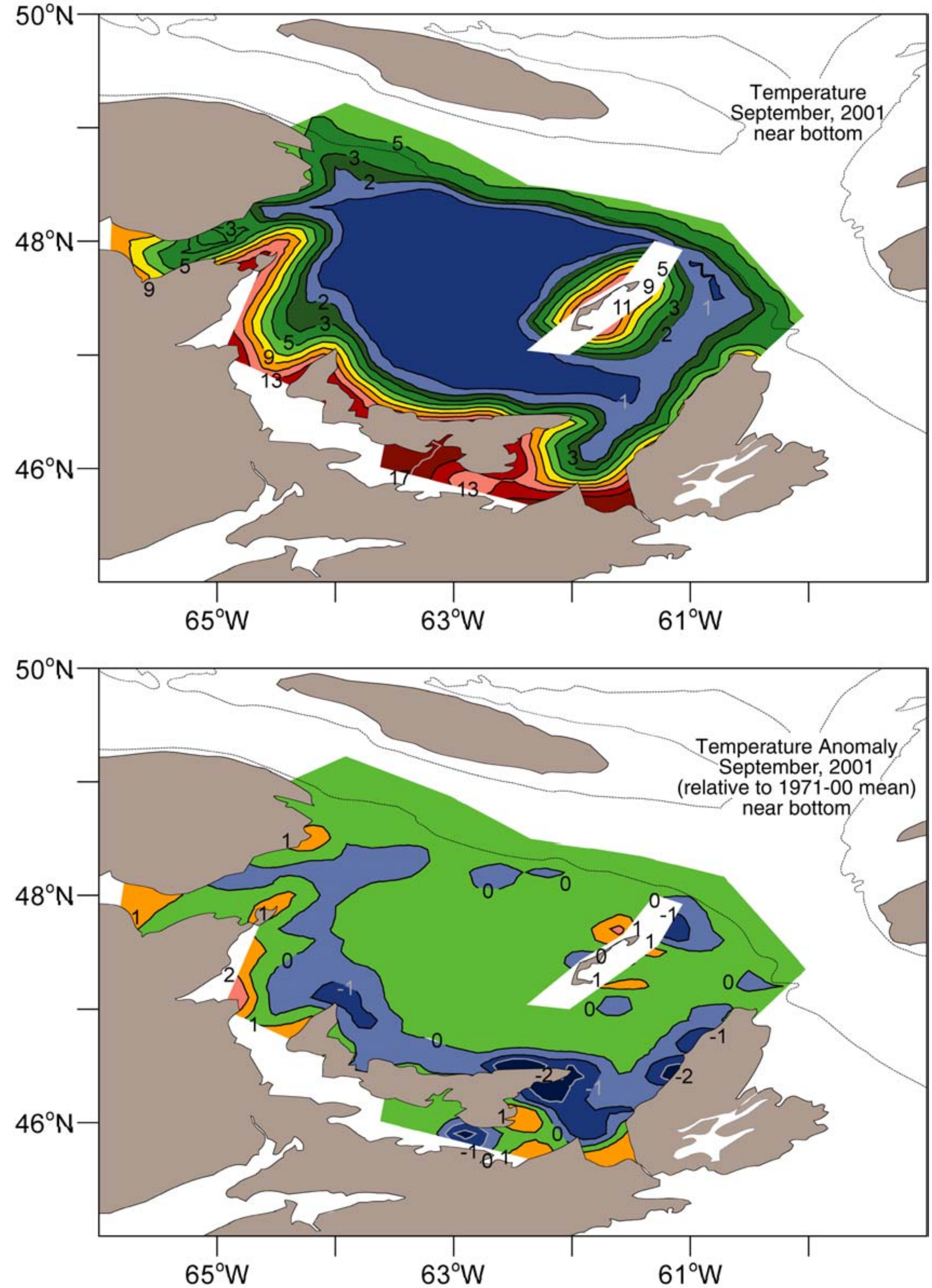


Fig. 5. Near-bottom temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) in the southern Gulf of St. Lawrence during the 2001 September groundfish survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

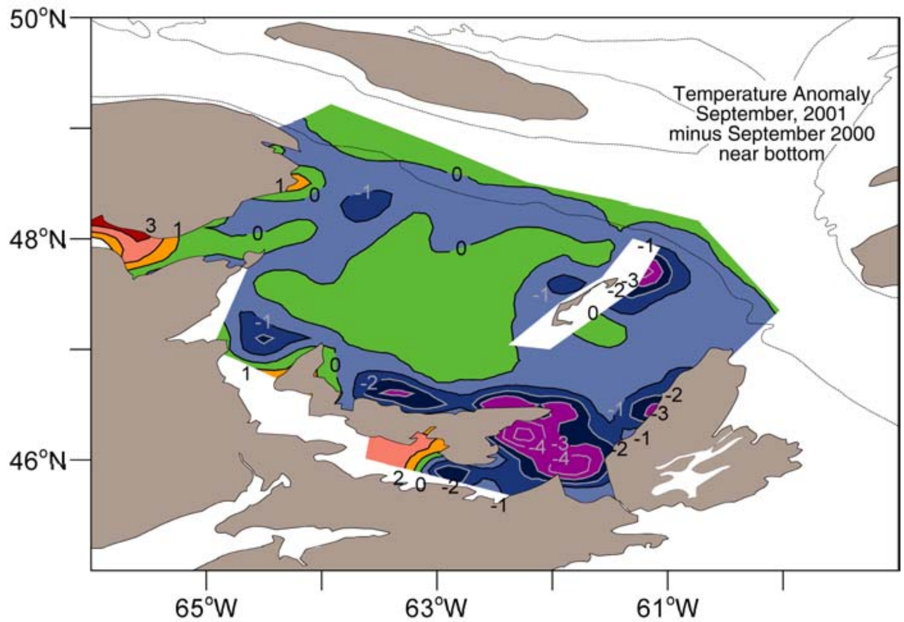


Fig. 6. The difference between the 2001 and 2000 temperature fields in the southern Gulf of St. Lawrence for the September groundfish surveys. Positive values (green and red) indicate temperatures in 2001 had warmed and negative values (blue and purple) that they had cooled.

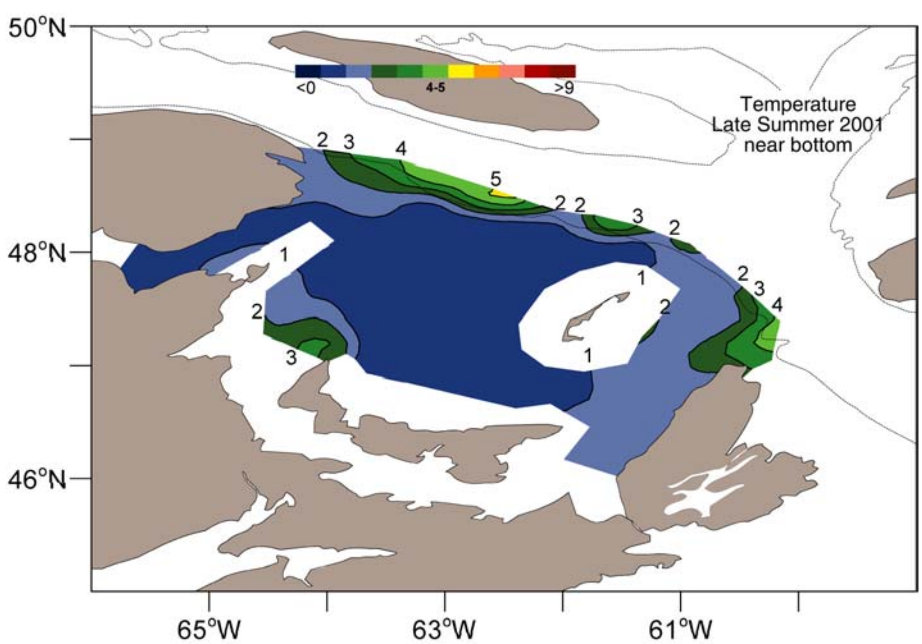


Fig. 7. Near-bottom temperatures in the southern Gulf of St. Lawrence during the 2001 July-September snow crab survey.

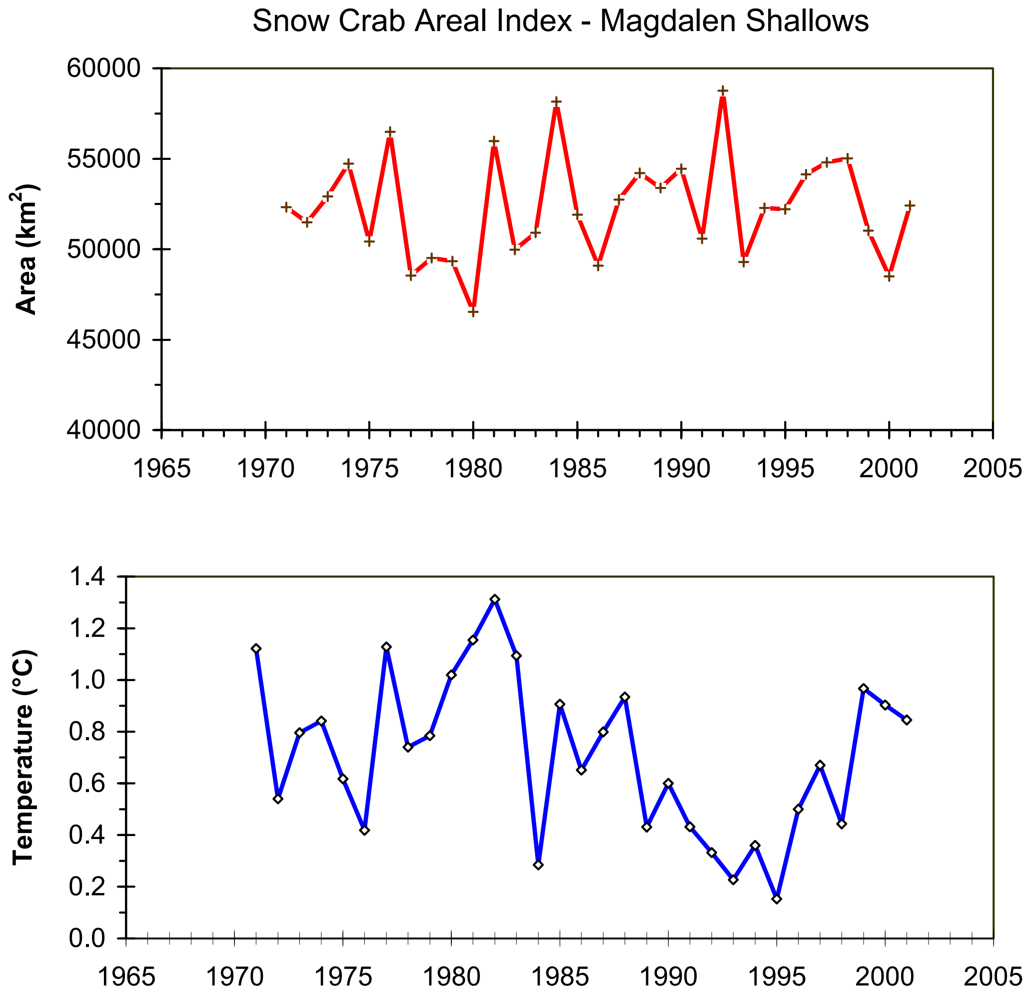


Fig. 8. Time series of the area of Magdalen Shallows covered by bottom temperatures between -1° and 3°C in September (top panel) and the mean temperature within that area (bottom panel).

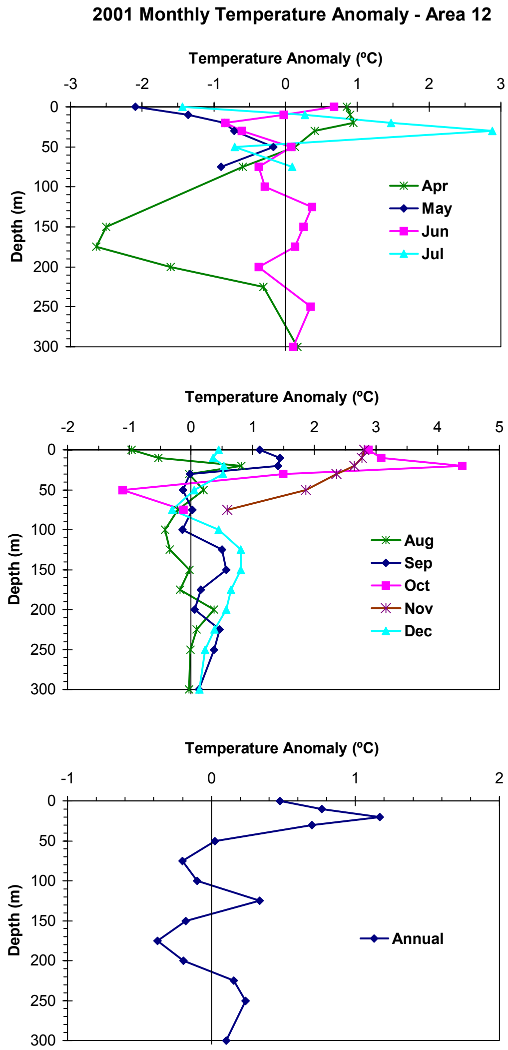


Fig. 9. Monthly (top two panels) and annual (bottom panel) mean temperature anomaly profiles during 2001 for snow crab fishing Area 12.

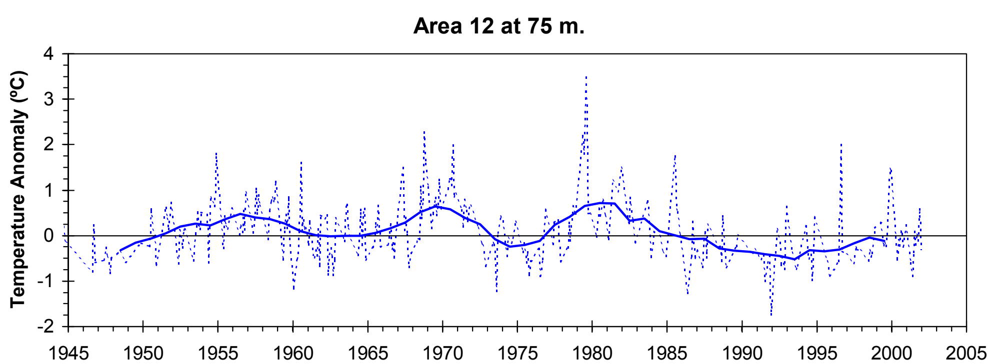
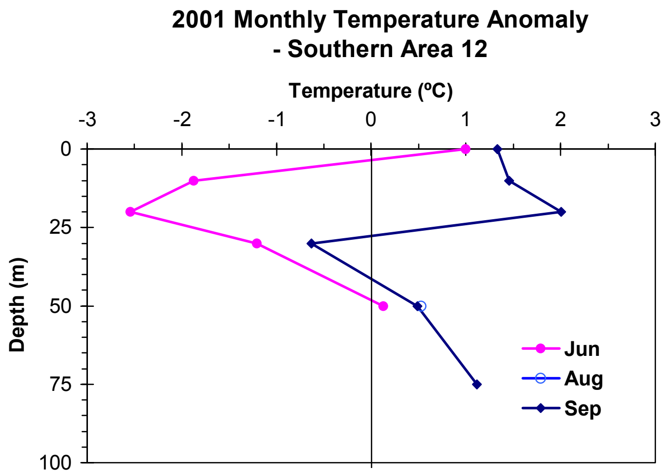


Fig.10. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 75 m for snow crab fishing Area 12.



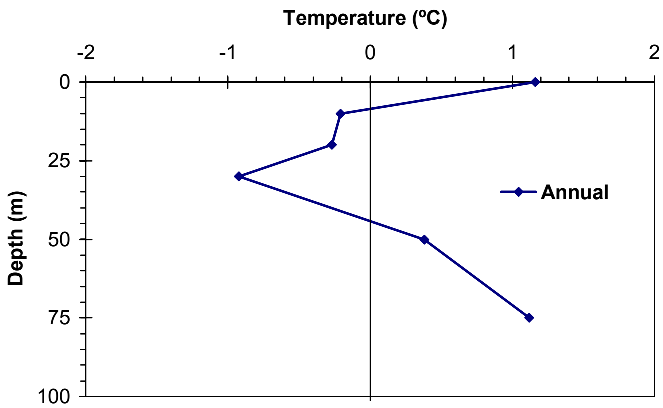


Fig.11. Monthly (top panel) and annual (bottom panel) mean temperature anomaly profiles during 2001 for the southern portion of snow crab fishing Area 12 (formerly Areas 25 and 26).

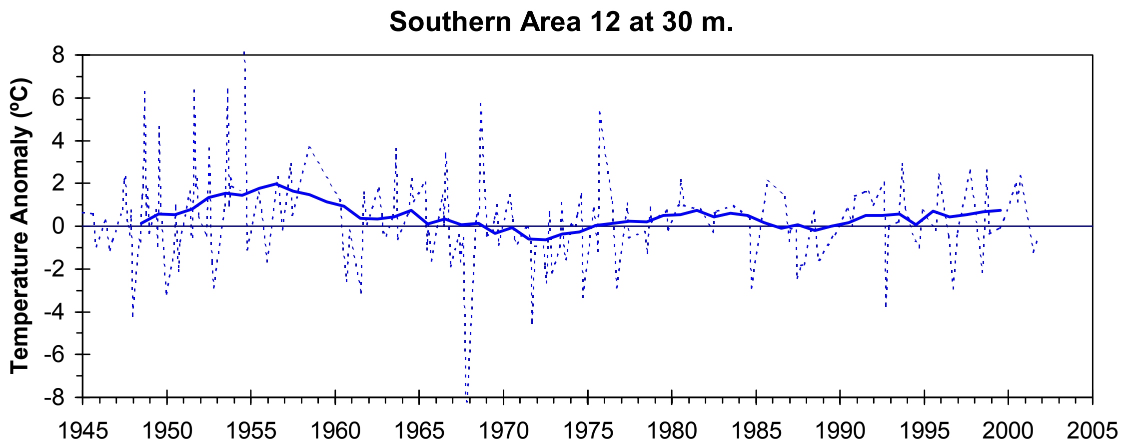


Fig.12. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 30 m for the southern portion of snow crab fishing Area 12 (formerly Areas 25 and 26).

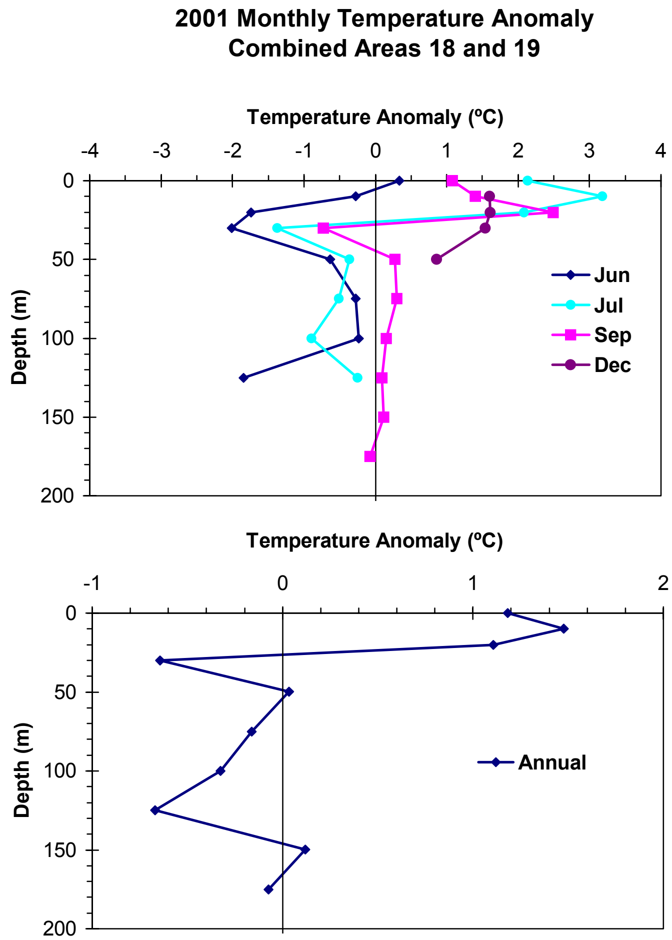


Fig.13. Monthly (top panel) and annual (bottom panel) mean temperature anomaly profiles during 2001 for snow crab fishing Areas 18-19 combined.

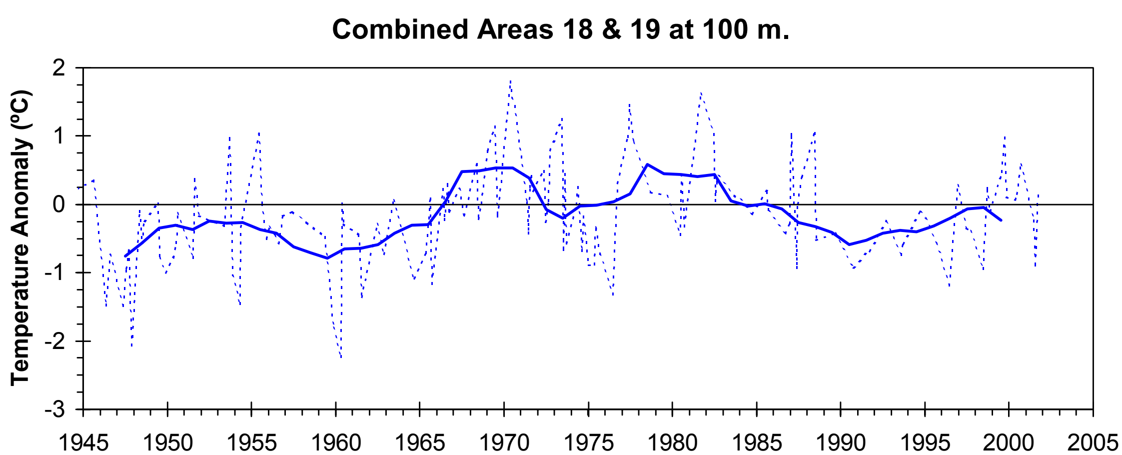


Fig.14. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Areas 18-19.

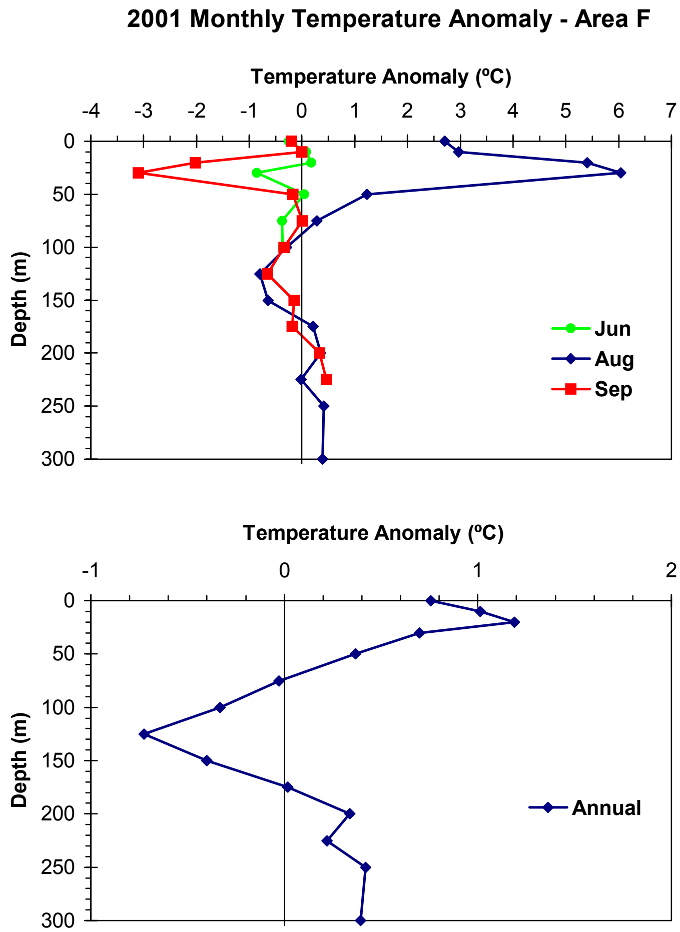


Fig.15. Monthly (top panel) and annual (bottom panel) mean temperature anomaly profiles during 2001 for snow crab fishing Area F.

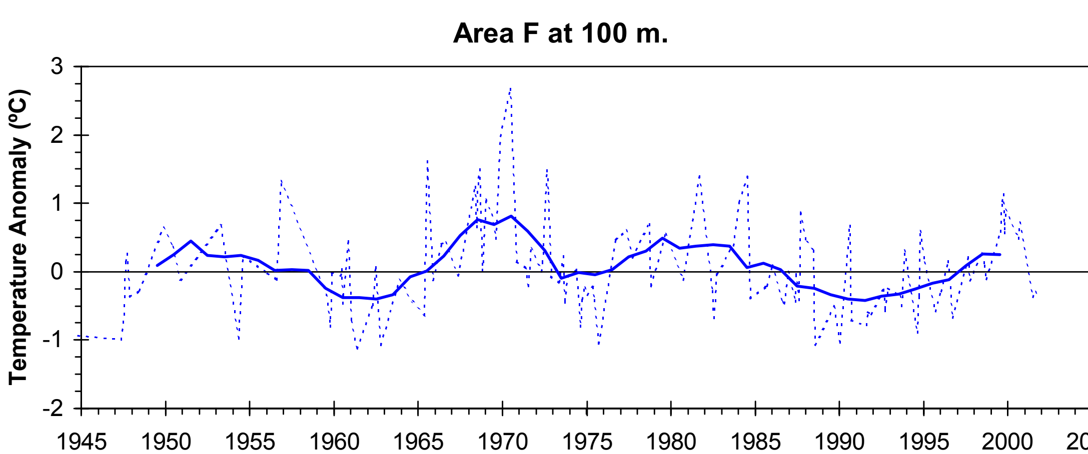


Fig.16. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Area F.

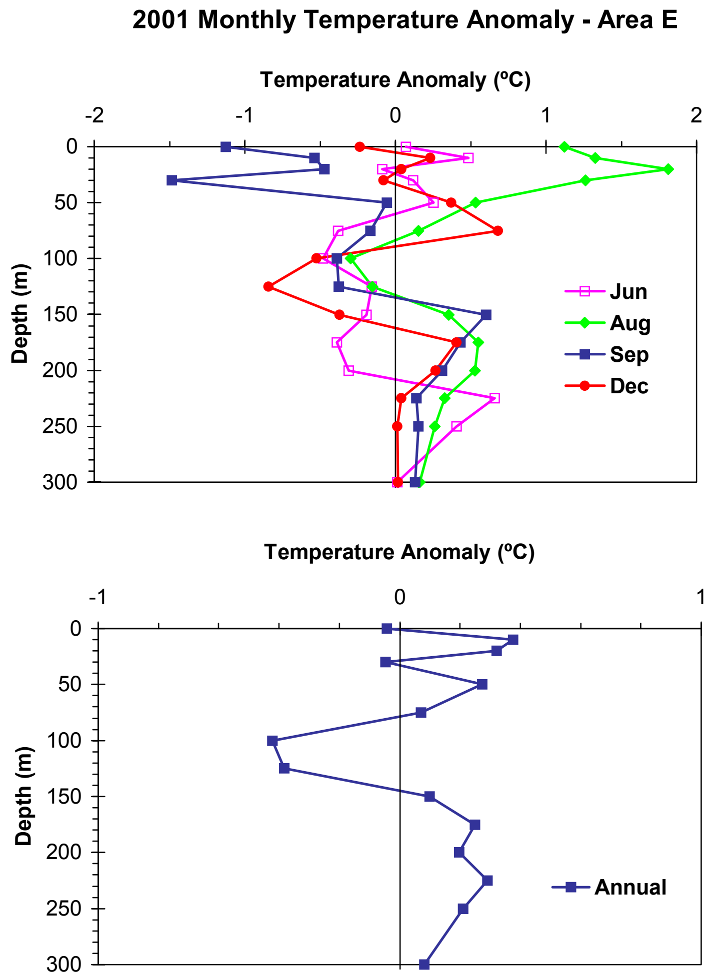


Fig.17. Monthly (top panel) and annual (bottom panel) mean temperature anomaly profiles during 2001 for snow crab fishing Area E.

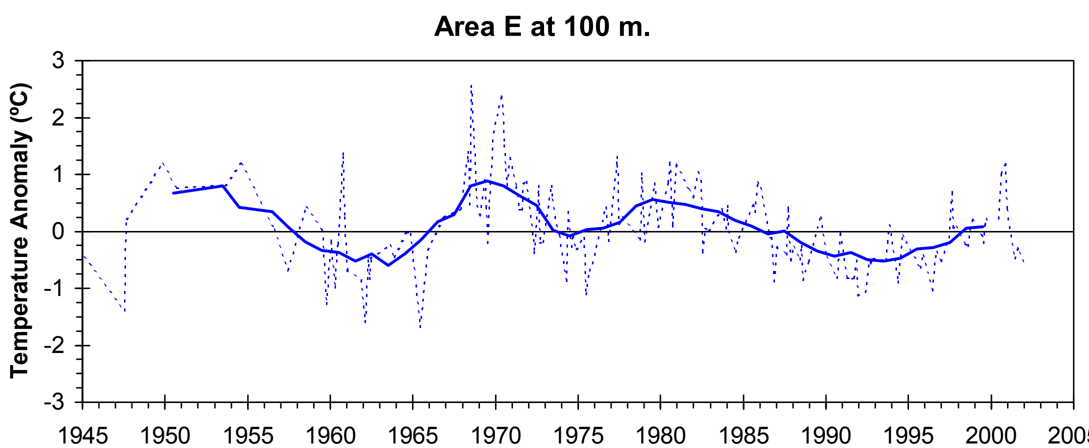


Fig.18. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Area E.

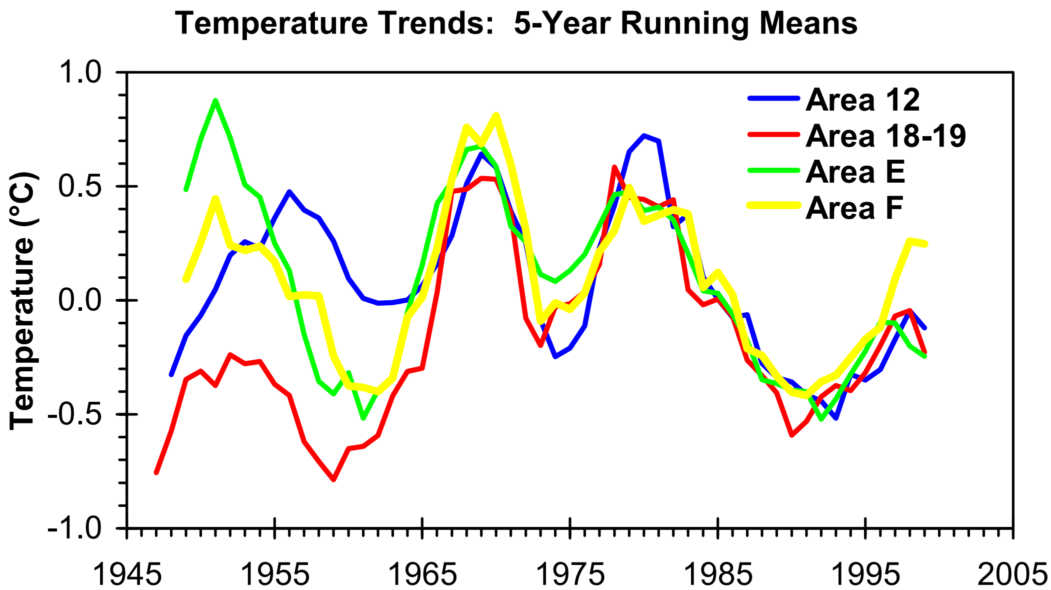


Fig.19. The five-year running means of the temperature anomalies for Areas 12, 18-19 (combined), E and F.

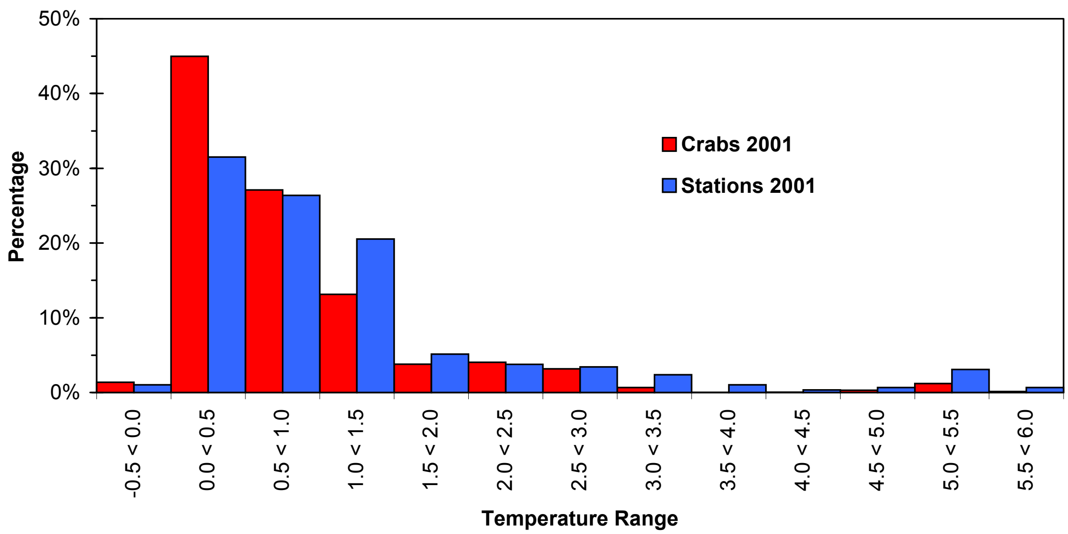


Fig.20. The frequency distribution as a function of temperature for the snow crab catches and for all of the station locations during the 2001 Gulf of St. Lawrence snow crab survey.

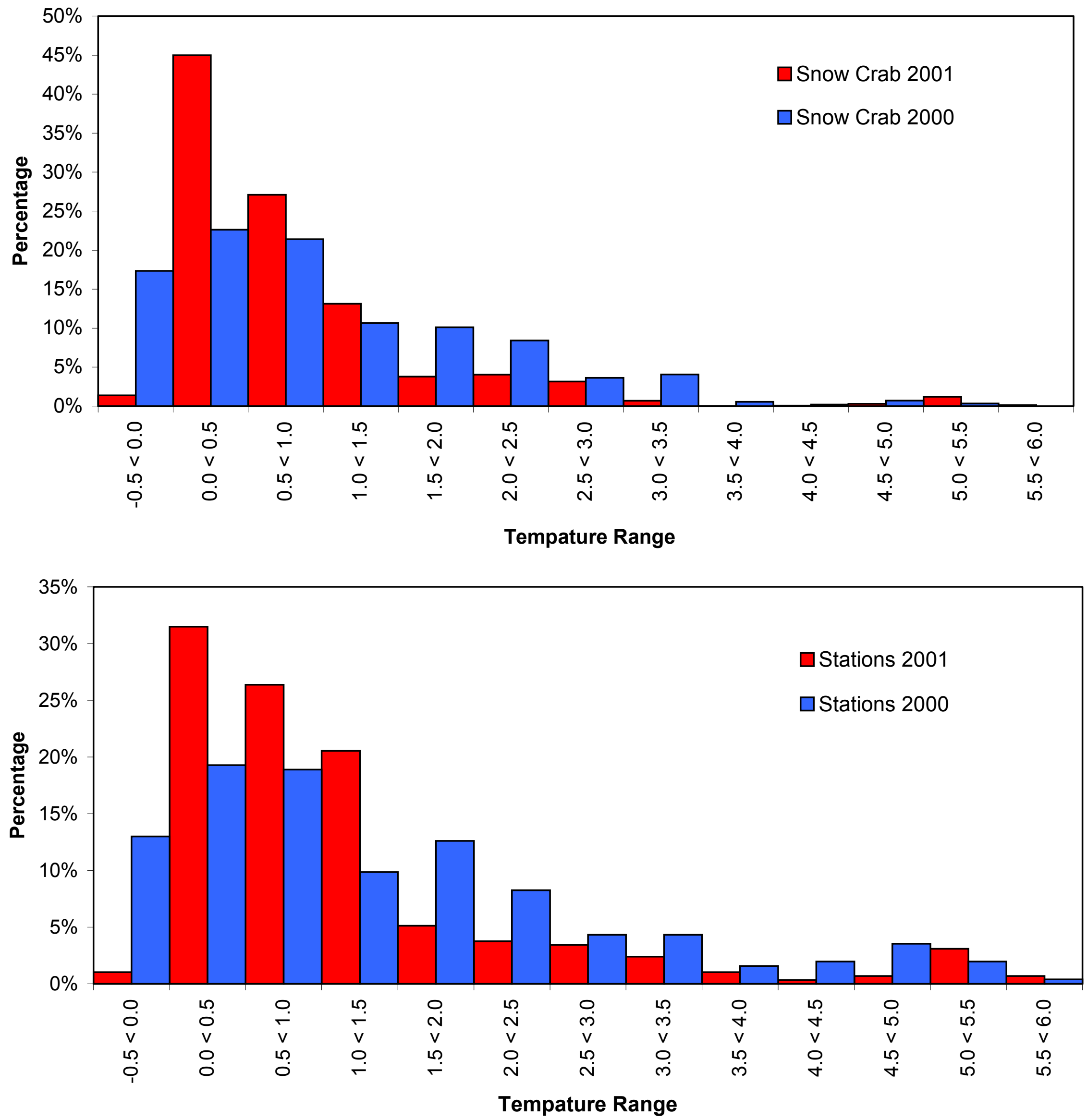


Fig.21. The frequency distribution as a function of temperature for the snow crab catches (top panel) and for all of the station locations (bottom panel) from the 2000 and 2001 Gulf of St. Lawrence surveys.

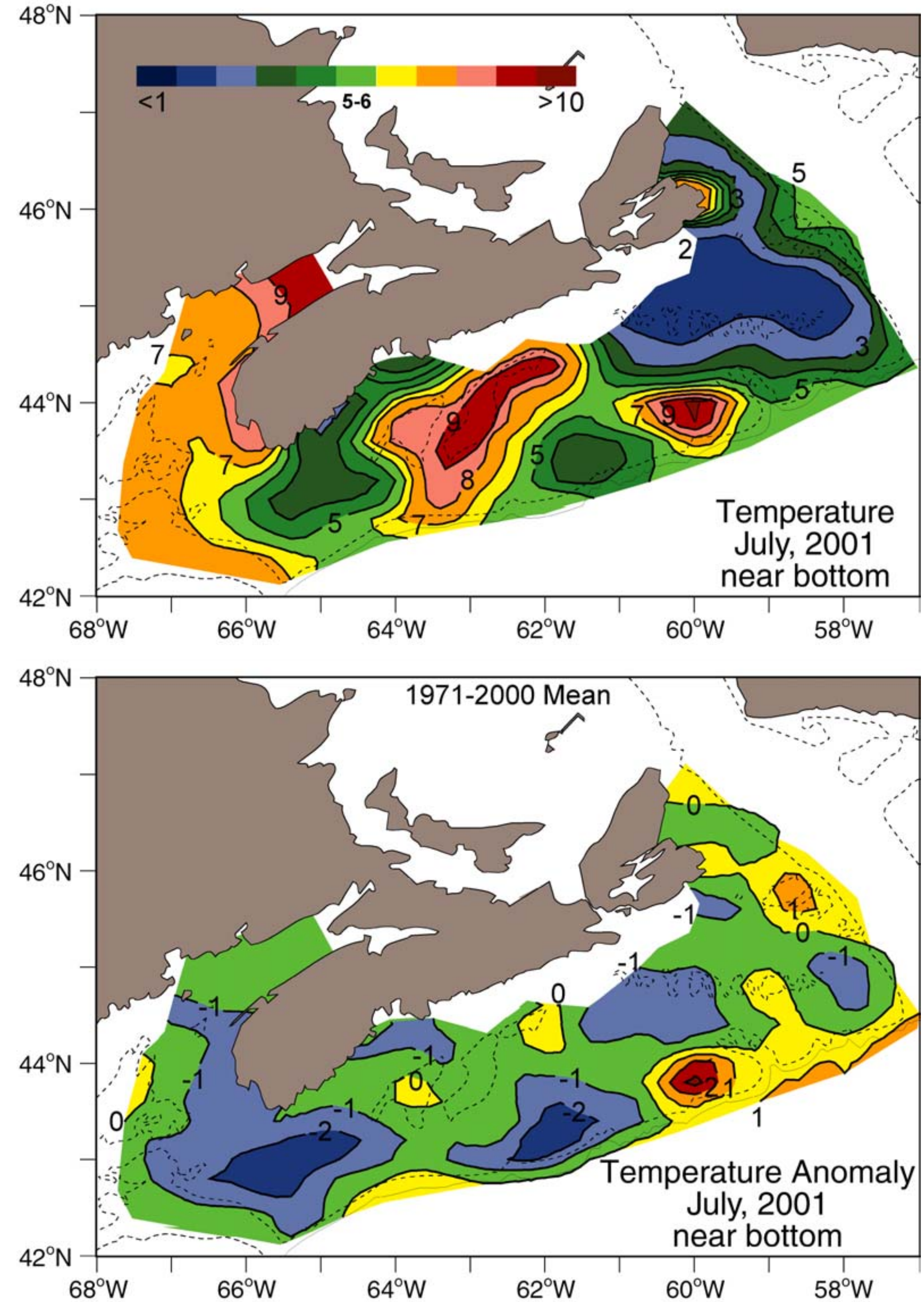


Fig.22. Near-bottom temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) on the Scotian Shelf during the 2001 July groundfish survey. Warmer-than-normal bottom temperatures (positive anomalies) are denoted by yellows through reds and colder-than normal (negative anomalies) by greens and blues.

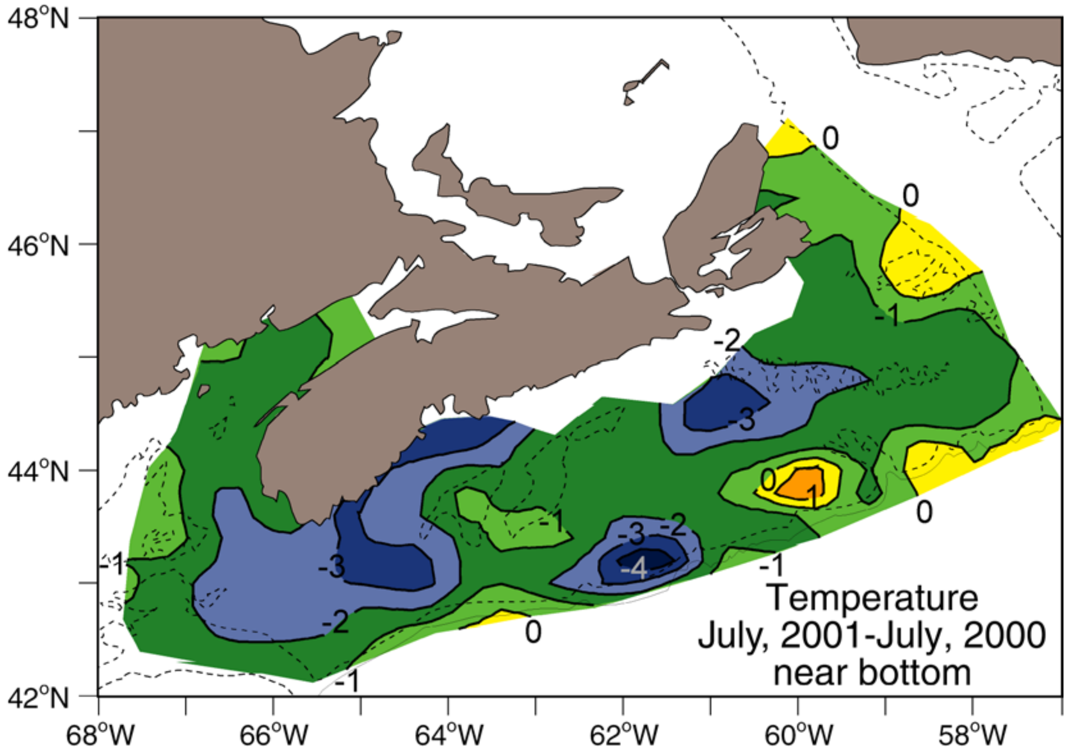


Fig.23. The difference between the 2001 and 2000 temperature fields on the Scotian Shelf for the July surveys. Positive values (yellow and oranges) indicate areas where temperatures in 2001 had warmed and negative values (greens through blues) where they had cooled.

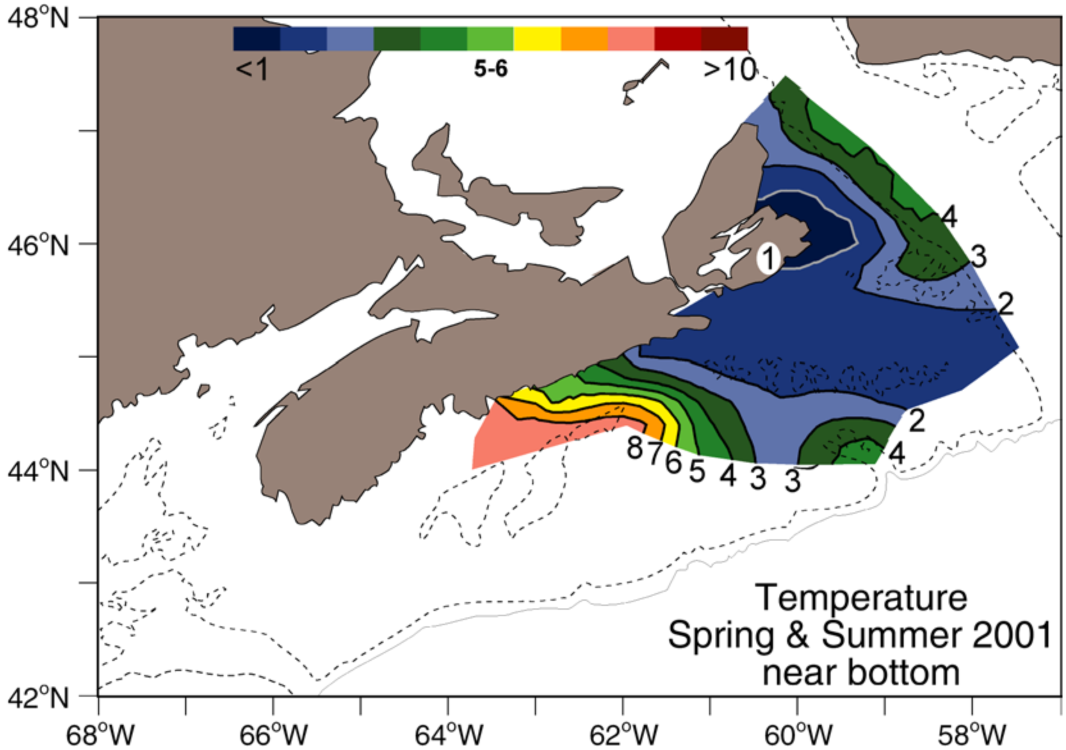


Fig.24. Near-bottom temperatures in the northeastern Scotian Shelf during the 2001 May-October snow crab survey.

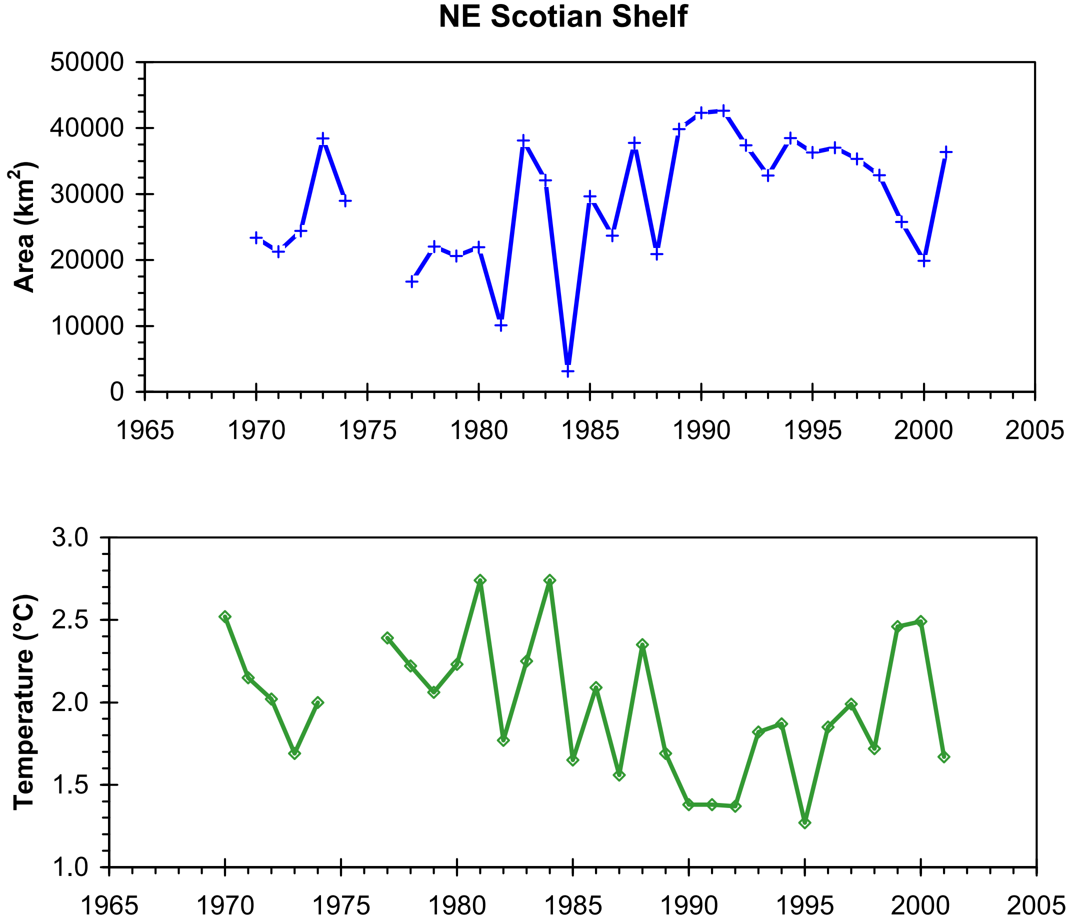


Fig.25. Time series of the area of the northeast Scotian Shelf covered by bottom temperatures between -1° and 3°C in July (top panel) and the mean temperature within that area (bottom panel).

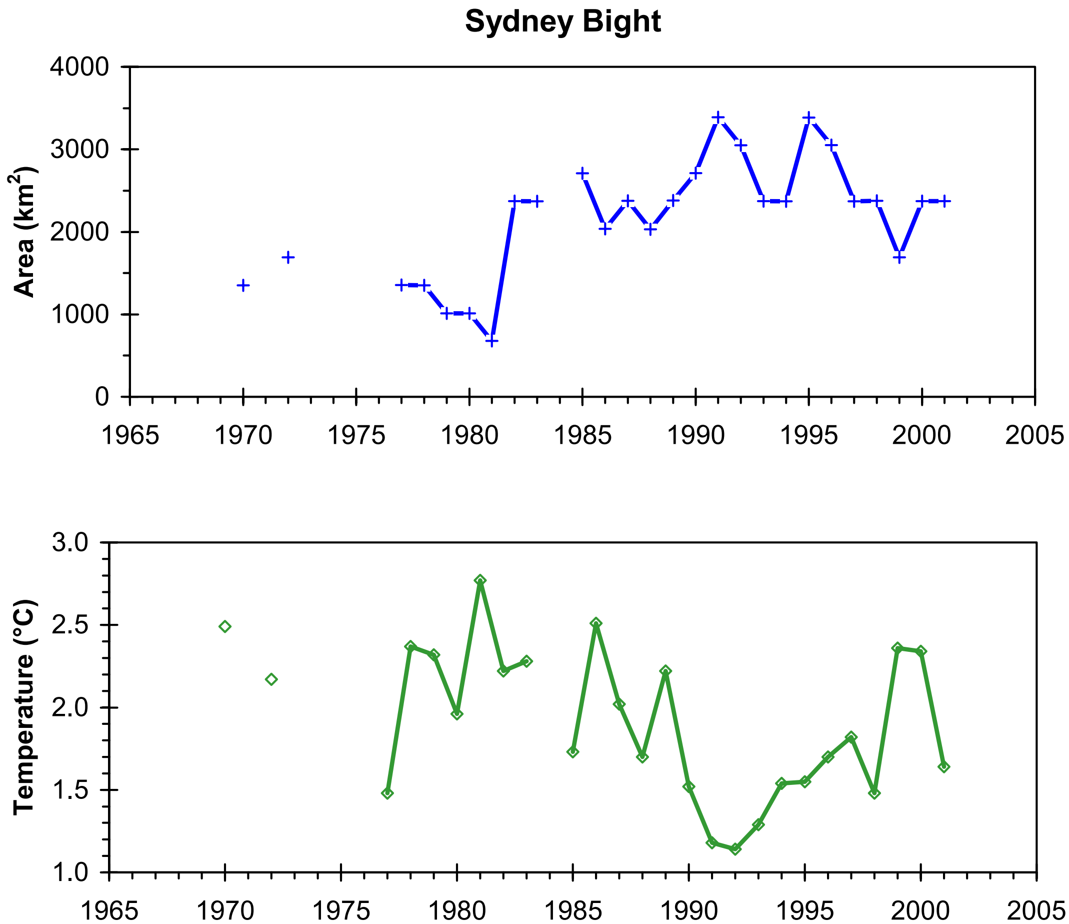


Fig.26. Time series of the area of Sydney Bight covered by bottom temperatures between -1° and 3°C in July (top panel) and the mean temperature within that area (bottom panel).

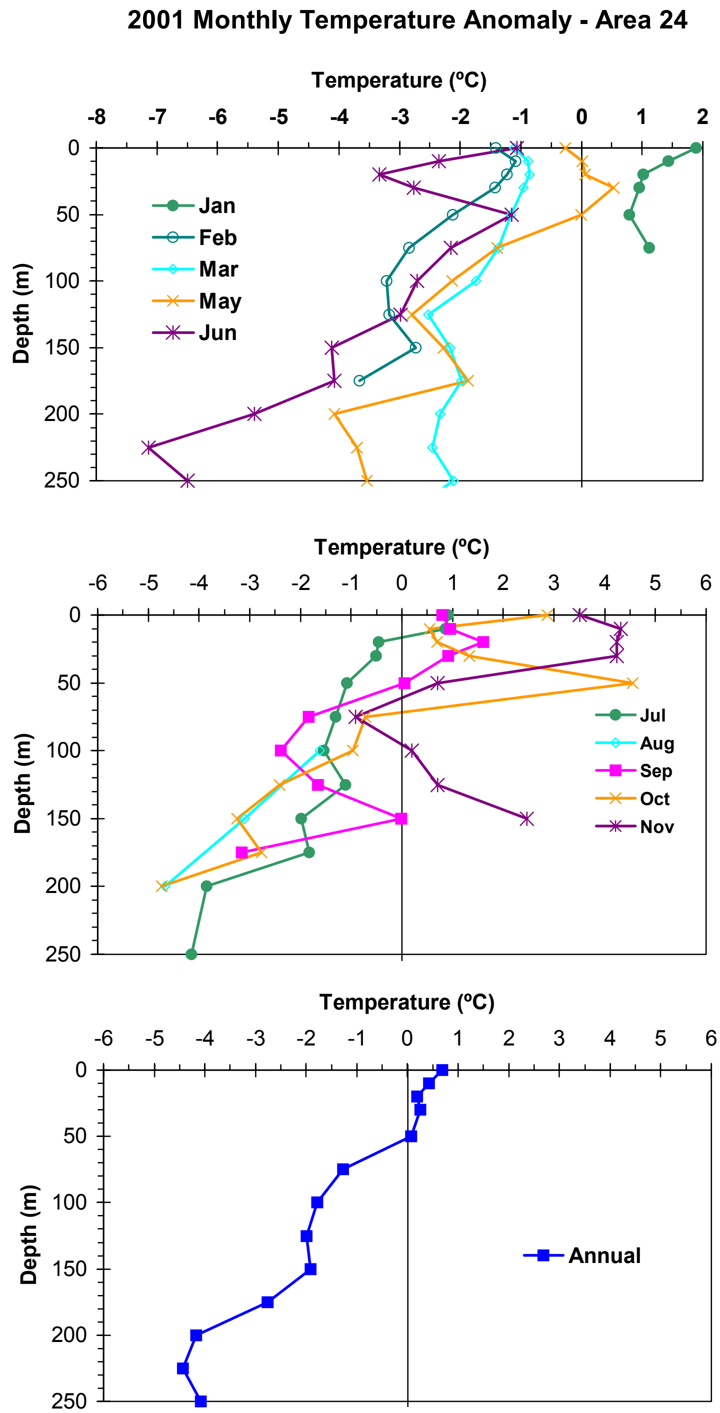


Fig.27. Monthly (top two panels) and annual (bottom panel) mean temperature anomaly profiles during 2001 for snow crab fishing Area 24.

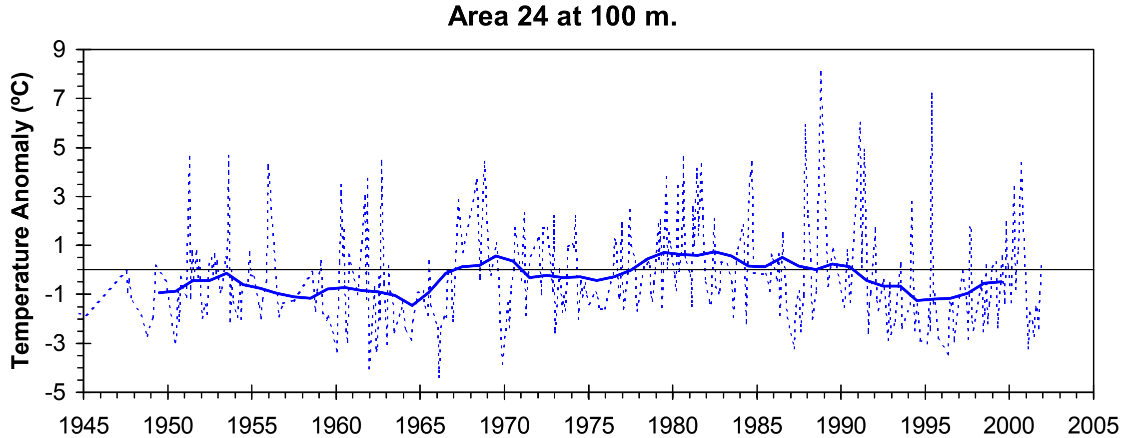


Fig.28. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Area 24.

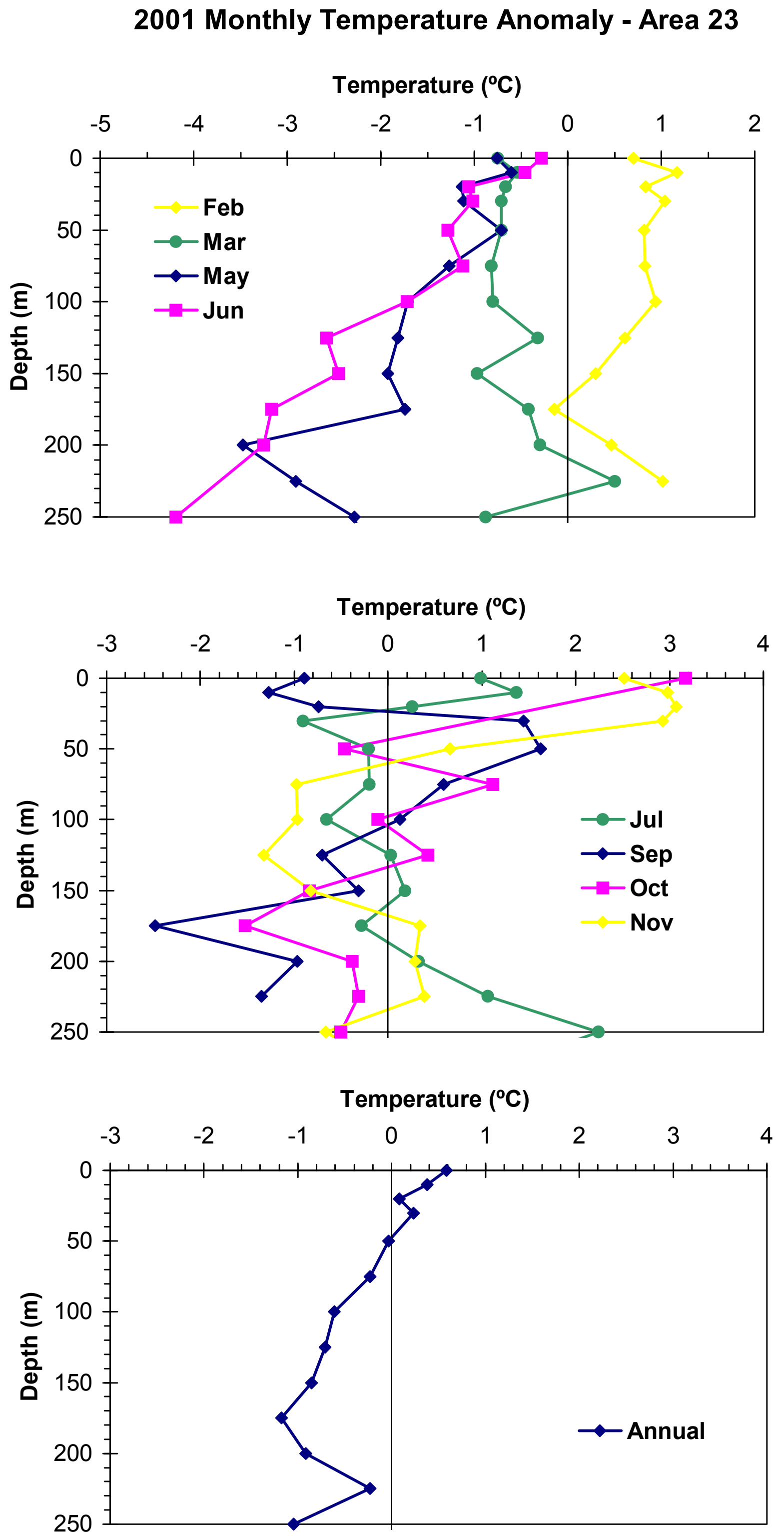


Fig.29. Monthly (top two panels) and annual (bottom panel) mean temperature anomaly profiles during 2001 for snow crab fishing Area 23.

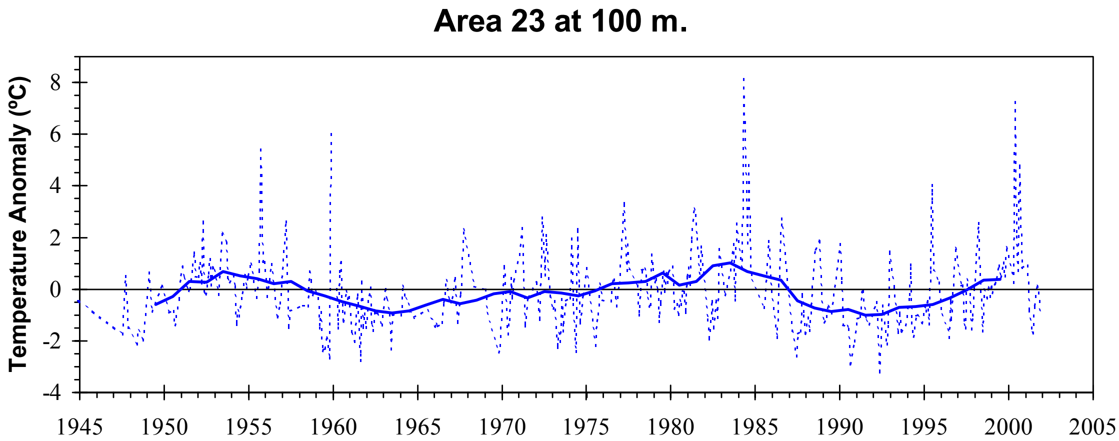


Fig.30. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Area 23.

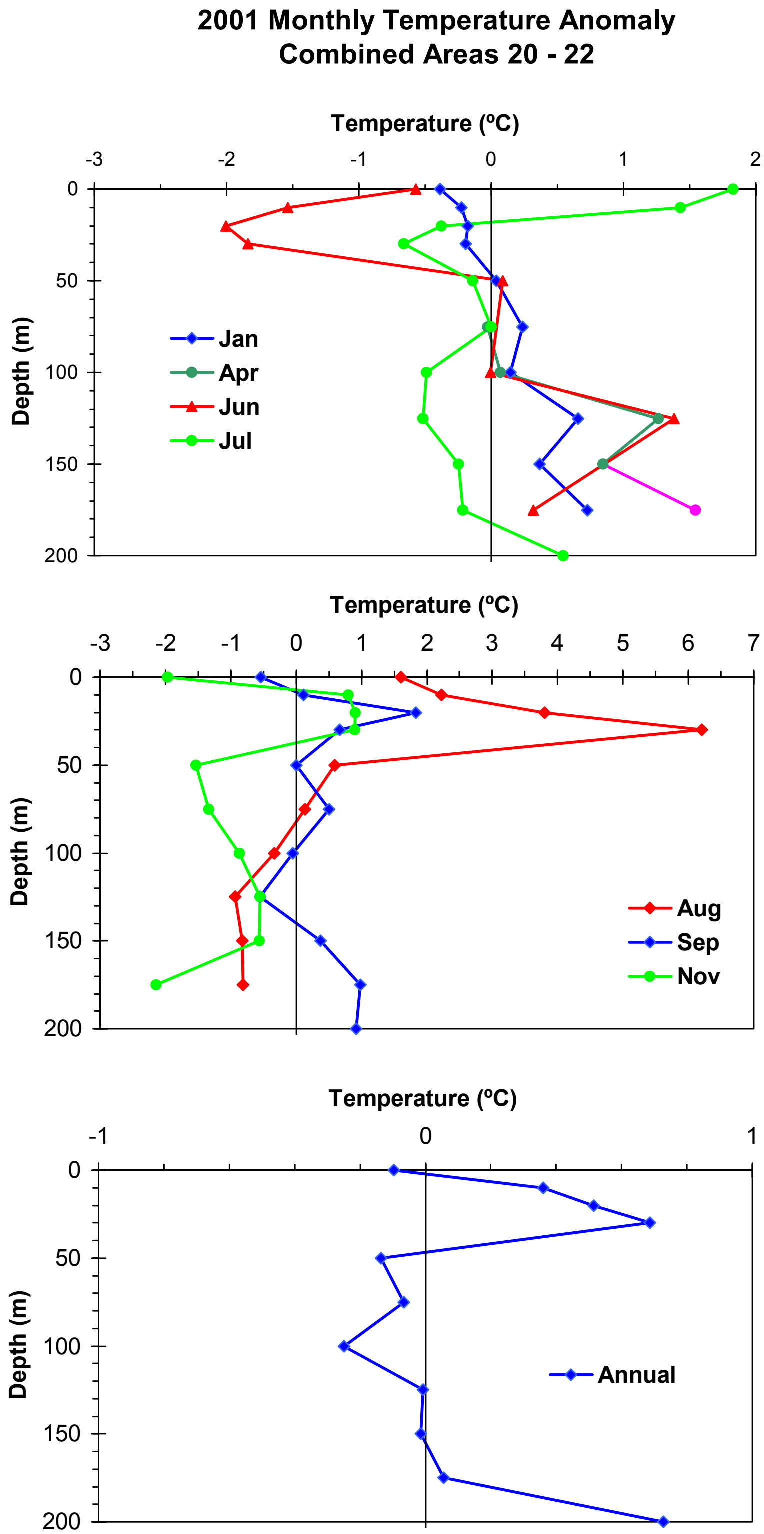


Fig.31. Monthly (top two panels) and annual (bottom panel) mean temperature anomaly profiles during 2001 for snow crab fishing Area 20-22.

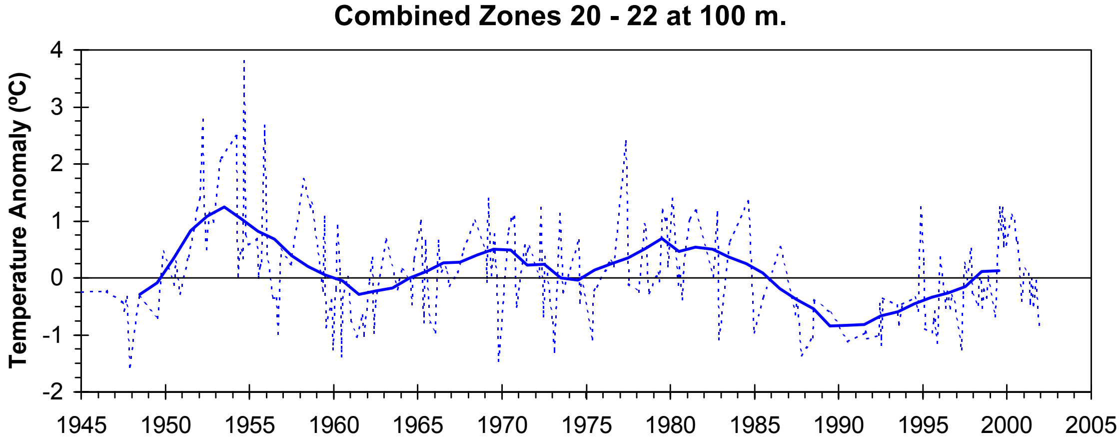


Fig.32. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Area 20-22.

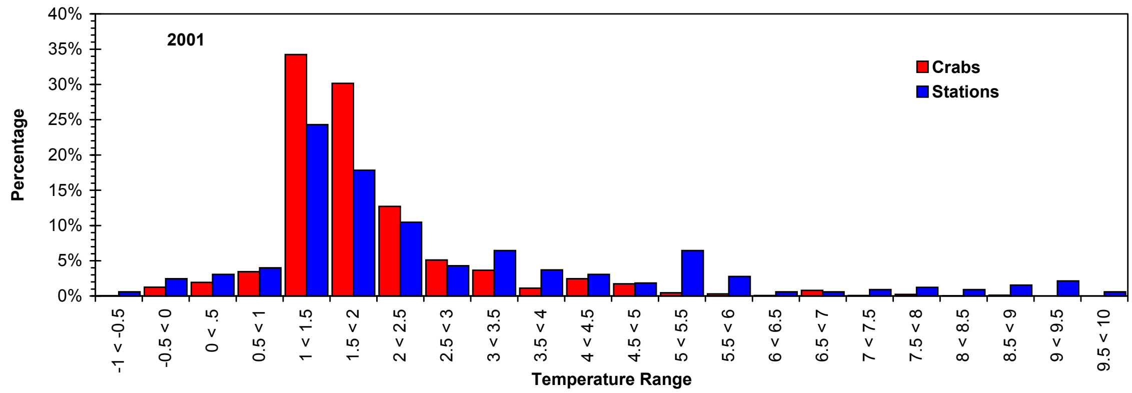


Fig.33. The frequency distribution in percentage as a function of temperature for the snow crab catches and for all of the station locations during the May-June snow crab survey on the Scotian Shelf in 2001.

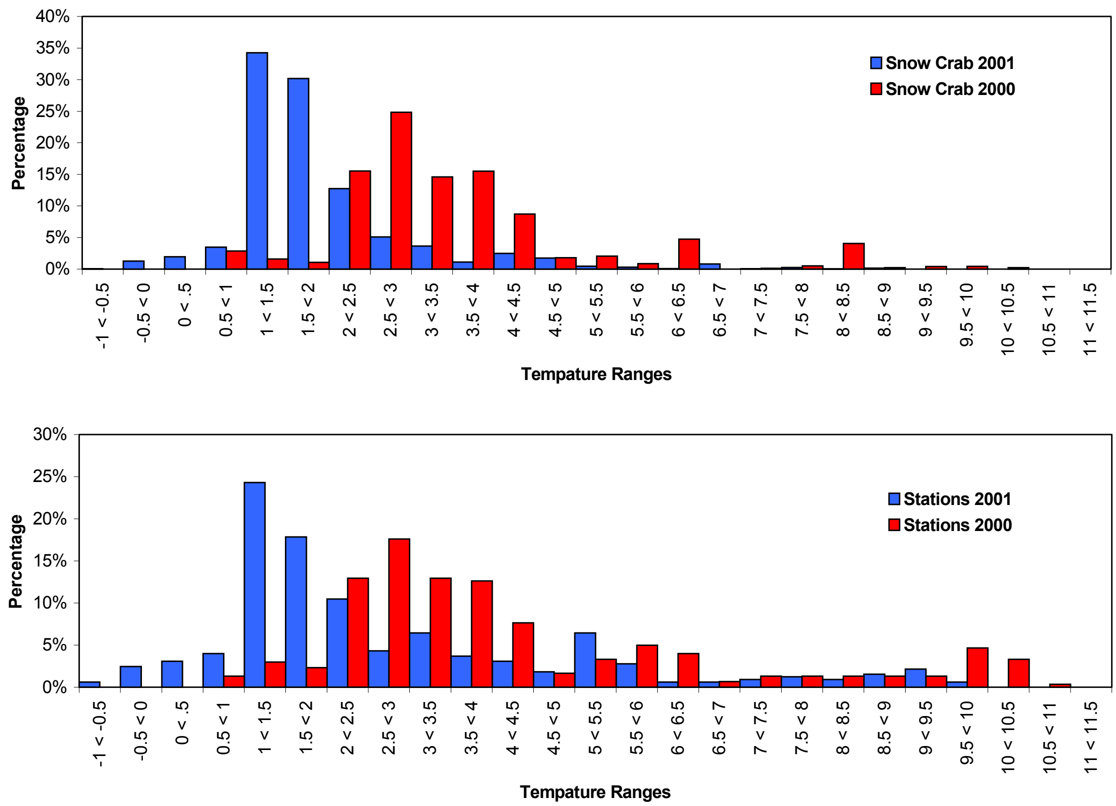


Fig.34. The frequency distribution in percentage as a function of temperature for the snow crab catches (top panel) and for all of the station locations (bottom panel) from spring 2000 and 2001 surveys.