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Temperature Conditions on the Scotian Shelf and in the southern Gulf of St. Lawrence during 2002 Relevant to Snow Crab

Conditions de température sur le plateau néo-écossais et dans le sud du golfe du Saint-Laurent en 2002 en regard du crabe des neiges

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Abstract

Temperatures during 2002 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 declined from 2001, was below the long-term mean and the second lowest value in the 32-year record. On the Scotian Shelf and on Sydney Bight, their habitat indices also decreased and in both cases fell to near their long-term averages. Bottom temperatures within the snow crab fishing areas of the southern Gulf of St. Lawrence were near average in 2002, and increased over the cold conditions that dominated in 2001. In Roseway and LaHave Basins in the southwestern Scotian Shelf, near-bottom temperatures were slightly below their long-term means. Crab caught during the annual snow crab surveys in all areas were found in warmer waters in 2002 than in 2001, which is believed to reflect the availability of warmer temperatures.

Resumé

Les températures de l'année 2002 des eaux des provinces Maritimes fréquentées par le crabe des neiges sont présentées. 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 les hauts fonds madeliniens, dans le golfe du Saint-Laurent. Un indice d'habitat du crabe des neiges, défini par la superficie du fond couverte d'eau entre –1 °C et 3° C, a été établi pour la partie sud du Golfe, Sydney Bight et la partie nord-est du plateau néo-écossais. L'indice pour le Golfe a diminué par rapport à 2001; il se situait au-dessous de la moyenne à long terme et constituait la deuxième plus faible valeur de la série d'indices s'échelonnant sur 32 ans. Sur le plateau néo-écossais et dans Sydney Bight, les indices ont aussi diminués, chutant presque jusqu'au niveau de leurs moyennes à long terme. Les températures au fond dans les zones de pêche du crabe des neiges du sud du Golfe du Saint-Laurent s'approchaient de la moyenne en 2002; elles étaient supérieures aux températures froides qui ont prédominé en 2001. Dans les bassins Roseway et LaHave, situés dans la partie sud-ouest du plateau néo-écossais, les températures près du fond étaient légèrement inférieures à leur moyenne à long terme. Les individus capturés dans toutes les régions dans le cadre des relevés annuels du crabe des neiges fréquentaient des eaux plus chaudes en 2002 qu'en 2001, ce qui semble refléter le fait que les températures des eaux étaient plus élevées.

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, in Sydney Bight and on the northeastern Scotian Shelf (Fig. 1). A small fishery also takes place on the southwestern Scotian Shelf in the vicinity of LaHave and Roseway Basins. Annual assessments of the stock abundance, fishing effort, biological characteristics and the environment of the snow crab are undertaken primarily by the Gulf Region of the Department of Fisheries and Oceans (DFO) and with cooperation from the snow crab fishing industry and DFO's Maritimes Region. The purpose of this paper is to provide information on the sea temperature conditions during 2002 in the snow crab fishing areas (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 2002 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 2002 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, 400 stations were occupied during the snow crab surveys conducted from July to September (Fig. 3a) with an additional 19 taken in April and May and 54 in June. The annual groundfish survey in the southern Gulf was carried out in September containing 175 stations (Fig. 3b). On the northeastern Scotian Shelf, the main snow crab survey was undertaken during July to September (312 stations, Fig. 4a) and the groundfish survey in July (Fig. 4b). Additional snow crab stations were collected from February to June and again in October. In particular, Areas 20-22 were surveyed in May, July and again in October. The snow crab surveys obtained near-bottom temperatures with a Vemco Minilog© attached to the trawl. Temperature and salinity data were collected with a conductivity-temperature-depth (CTD) instrument during the groundfish surveys. Approximately half of the 212 stations taken during the July groundfish survey were located on the northeastern Scotian Shelf or Sydney Bight in the vicinity of the major snow crab fishing areas. The remaining CTDs during the

July groundfish survey were taken in the central and southwest portions of the Shelf. The latter were augmented by bottom temperatures (174 stations) collected in the southwestern portion of the shelf during a fishermen conducted survey, also in July. Other temperature data from the snow crab areas in 2002 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-2002 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 examined the relationship between snow crab catch and bottom temperature. Comparison of results from 2002 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 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 tend to be 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 estimation using all available data for the years 1971-2000 in the historical temperature, salinity database at the Bedford Institute. These climatological means are then subtracted from the values derived from the 2002 survey. The differences are called temperature anomalies. A negative anomaly indicates that the 2002 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 2001 optimally estimated temperatures from the 2002 estimates. A negative value indicates that 2002 was cooler than 2001, 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 2002 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 2002 were determined using data from the BIO database within each of the snow crab areas and in the vicinity of LaHave and Roseway Basins (Fig. 2). 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.

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, both those where snow crabs were caught and those where they were not. Comparisons were also made between the results from 2002 and 2001 and between different snow crab areas.

Results

Southern Gulf of St. Lawrence

Bottom Temperatures

On the Magdalen Shallows, data from the September groundfish survey in 2002 showed bottom temperatures from <1ºC to over 18ºC (Fig. 5). As is typical, the majority of the bottom was covered by temperatures of <3ºC with the largest portion of the Shallows (50-80 m) covered by temperatures <1ºC. Bottom temperatures tend to increase from the center 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 via the Strait of Belle Isle. This transport varies annually but with a mean of approximately 35% of the total volume of the CIL (Petrie et al., 1988). In 2002, the warmest near-bottom temperatures and anomalies in the southern Gulf were in its shallowest regions, in particular in Northumberland Strait and St. Georges Bay, where they reached 15º-18ºC (Fig. 5).

Similar to 2001, temperature anomalies over most of the Shallows in 2002 were near to or just above normal (Fig. 5). The exception was a band of below average temperatures stretching along the north shore of Prince Edward Island and around the Magdalen Shallows. The highest positive anomalies (+4ºC) appeared off western Prince Edward Island with anomalies of near +3ºC in eastern Northumberland Strait. 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 of the close proximity 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 2001, bottom temperatures during the 2002 groundfish survey tended to be slightly warmer over much of the central Magdalen Shallows and in the nearshore regions surrounding Prince Edward Island (Fig. 6). There was, however, a significant area around the Magdalen Islands and extending towards the Baie des Chaleurs that was cooler in 2002 than in 2001.

The spatial pattern of the bottom temperatures from the snow crab survey in July-September 2002 (Fig. 7) is similar to that from the 2002 groundfish survey (Fig. 5). For example, there is a reasonably large area west of the Magdalen Islands that had bottom temperatures of <0ºC and the warmest temperatures were in the Laurentian Channel. Temperatures along the slope and in Laurentian Channel were slightly cooler during the snow crab survey, however. Also, there are no warm waters (nothing >5ºC on the Shallows) due to lack of shallow stations during the snow crab survey. For overlapping grid points between the two surveys, 48% had temperatures within ±0.5°C and 89% were within ±1.0°C. Possible causes of the differences in the bottom temperature field, in addition to differences in survey coverage, include seasonal warming, differences in instrument accuracy (the CTD being more accurate than the Minilog©), a relatively 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 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 70,039 km2 (847 grid points). We also estimated the average temperature within the area covered by temperatures in the range -1ºC to 3ºC and correlated these with the habitat index.

In 2002, the area of the bottom of the Magdalen Shallows covered by waters between -1ºC and 3ºC during the groundfish survey decreased compared to 2001. It was just over 48,200 km^2 and is below the long-term mean (1971-2000) of approximately 52,300 km^2 (Fig. 8). The 2002 value represents 68% of the total Shallows area, and was 6% lower than in 2001 but only slightly less than in 2000. The snow crab habitat index in 2002 was the second lowest value over the 32-year record, with only 1980 being smaller. Note, however, that the interannual 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 2002 rose slightly compared to 2001 (by > 0.1°C). Relatively high temperatures have been recorded during the past 4 years and the 2002 value is the highest it has been since 1983. The correlation between the habitat index and the mean temperature over the years 1971-2002 within this area is -0.38ºC 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 core temperature in 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

This section 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 or possibility because 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 2002 over the central Magdalen Shallows (**Area 12** in Fig. 2 excluding the southern portion just north of Prince Edward Island) were available for March to September as well as November. The monthly and annual anomaly profiles tend to show generally above-normal temperatures (anomalies <1°C) below 50 m (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 not significantly different from zero, based upon the error of the means. Below 100 m, which is primarily limited to the Laurentian Channel and the deep trough off Cape Breton, monthly temperature anomaly profiles were consistently positive and the annual anomaly was significantly above zero. The only month that was an exception was March when the temperatures down to 200 m were significantly colder-than-normal. In the top 20 m, temperature anomalies varied from month to month, but again with a tendency for positive values. Only at 10 m was the anomaly considered significantly different than zero. 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 the period from the mid-1980s to the late 1990s (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 2002, temperatures varied about the long-term mean being cold at the beginning of 2002 and then warming to above normal during the latter half of the year.

Within the southern portion of Area 12 (formerly Areas 25 and 26), just north of Prince Edward Island, data were available only in March, June, July (50 m only) and September. Monthly temperature anomalies at 20 to 50 m vary from cold in June, to warm in September and near normal in March and July (Fig. 11). This is reflected in the annual means that suggest positive but non-significant anomalies. In contrast to these subsurface conditions, at the surface and 10 m, the annual mean temperatures were significantly colder-than-normal. Most of this area contains bottom depths less than 60 m and is shallower than the rest of the snow crab areas. It also tends to contain fewer crabs than the other areas. The time series at 30 m shows high variability with a tendency towards above normal temperatures since the late 1980s (Fig. 12). At 50 m (not plotted) there was a tendency towards negative anomalies from the mid-1980s to the mid- to late 1990s but not as consistently as in the rest of Area 12. During the last four years, temperatures at 50 m have oscillated about, but generally above, the long-term mean. There are, however, much less data at 50 m then at 30 m for this Area. At these relatively 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 March, June, August, September and November in 2002. The mean profiles indicate significantly warmer-than-normal waters in the top 50 m, and below 100 m (Fig. 13). Maximum temperature anomalies appeared at 150 m, being upwards of 1°-2°C. The coldest anomaly (-2°C) was recorded in March at 75 m. Temperatures at 100 m were above normal during 2002 and were warmer than the temperatures recorded in either 2000 or 2001.

Data during June, August and September of 2002 were available from **Area F** (Fig. 15). The near surface (0-10 m) temperatures were below normal by around -0.5°C. From 30 to 300 m, temperatures were above the long-term means in all three months, resulting in a significant positive annual anomaly varying up to approximately 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, declined in 2001 but rose again in 2002 (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 5 months: March, June, August, September and November. Monthly mean temperatures in the near surface waters varied depending upon the month with a non-significant positive annual temperature anomaly. At 50 m and deeper, the monthly mean anomalies were all positive except in the 50-100 m layer during March. The preponderance of positive monthly values resulted in significant positive annual anomalies, upwards of 1°C throughout the lower water column (Fig. 17). 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 2002 contrast with the below normal values in 2001 but are similar to 2000.

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, showing the five-year running means of the temperature anomalies for Areas 12, 18-19 combined, E and F. These show the general warming trend since the early 1990s and the warmest conditions since the early 1980s in recent years.

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

The catches of snow crab as a function of temperature during the 2002 snow crab surveys in the Gulf are shown in Fig. 20. Over 94% of all of the crab were caught in temperatures between -1° and 3°C. As observed in other years, there is a tendency for snow crab to be captured in slightly colder waters than the temperatures available (Fig. 20). The snow crab in 2002 were generally caught in warmer temperatures in 2002 than in 2001, which reflects the available temperatures (Fig. 20). We also examined the differences by snow crab area. For this analysis we combined Areas E and F as well as 18 and 19. The results show the coldest waters are in Area 12 and hence the crabs are caught in the coldest temperatures in this Area (Fig. 21). Interestingly, in all three regions (Areas 12, 18-19 and E-F) the temperatures crab were caught in reflect the available temperatures but tend to be slightly colder than what was available (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. 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 (upwards of 9°C). Temperatures in the northeastern Scotian Shelf were mostly near their long-term means but varied spatially between slightly above or below normal (Fig. 22). The coldest anomalies (colder than -1°C) were in a band stretching from the continental slope off Sable Island towards Middle Bank and the coast of Nova Scotia. The warmest anomalies (2°C) were on Western Bank to the southwest of Sable Island. Temperatures increased relative to July 2001 over most of the Scotian Shelf (Fig. 23). This returns to the warm conditions during the late 1990s and 2000 and reverses the cooling trend observed in 2001.

Bottom temperatures from the snow crab survey in July-September display a similar spatial pattern to that from the groundfish survey (Fig. 24). This includes the coldest temperatures in the northeast and the warmest 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 with the exception of a slightly larger extension of temperatures <2°C. 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). In spite of these differences, the majority (54%) 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 76% were within ±1.0°C. Given these small differences, the two surveys are both considered as capturing 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 northeastern Scotian Shelf based upon optimally-estimated bottom temperatures from the July groundfish survey is available from 1970 to present. The grid occupies a total bottom water area of 70,426 km^2 (201 grid points) while on the Sydney Bight the area is 7,801 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 2002 was 30,013 km^2 representing approximately 43% coverage of the total grid area and a decrease relative to 2001 (Fig. 25). It is not significantly different from the long-term mean. The maximum coverage was reached in 1991 when the index represented 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. It returned to values above the long-term mean in 2001 before falling in 2002. The increase in the habitat index from the late 1980s 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 snow crab habitat 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 2002 when the habitat index decreased, the mean temperature increased.

On Sydney Bight, the snow crab habitat index in 2002 was 2,031 km^2 and declined slightly compared to 2001 (Fig. 26). It represents 26% coverage of the total grid area and is near the long-term average of 2,188 km^2. This index has varied between 21% to 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 2002 rose slightly relative to 2001 (Fig. 26). The correlation between the average temperature within the index area and the habitat index itself during 1970 to 2002 for Sydney Bight is -0.64 and is significant at the $p=0.05$ level.

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 northeastern 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 the chosen depths are considered representative of the near-bottom region within each of the fishing areas. Again, because of the limited amount of data within the areas over which the averages were made or because of 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.

Therefore interpretation of any anomalies must be viewed with caution and no significance should be placed on any individual month, 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 gradients 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 7 months of 2002. The dominant feature is the below normal temperatures throughout most of 2002 below 50 m (Fig. 27). The only exceptions were in March and the lone measurement at 175 m in June. The mean bottom temperature anomalies were approximately -3° to -6°C below 150 m. However, the mean in this region is largely reflected of the slope water characteristics at the edge of Sable Island Bank and also found 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. 27). The time series at 100 m shows high variability but generally below normal temperatures over most of 2002 (Fig. 28). This is in contrast to the above normal temperatures observed in 2001 but is similar to most of the 1990s.

In Area 23, temperatures were collected in 8 months of 2002 (Fig. 29). There is high variability both from month to month and with depth. This is reflected in the annual anomalies. Negative anomalies dominated in the top 10 m and at 175 m, whereas positive anomalies were observed in the 30-75 m depth range and below 200 m. However, the later were not significantly different than zero. Almost all of the anomalies had an absolute amplitude of <1°C. The time series at 100 m indicates anomalies near the long-term mean and warmer than in 2001 (Fig. 30).

The temperature data for snow crab fishing Areas 20 through 22 were combined in our analysis. For the 8 months of 2002 when observations were available, temperatures throughout the water column tended to show high variability about the long-term means (Fig. 31). This variability is reflected in the annual means, which, although tending to be on the positive side, were generally <0.5°C and not significant. Only at 150 m was the anomaly considered significantly different from zero, based on the error of the means. In the top 20-30 m, it appears as if temperatures were cool during the spring but increased to above normal by the summer, conditions that extended into the autumn. 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). They fell below average in 2001 and fluctuated about the long-term mean in 2002. Analysis 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 2002 snow crab surveys of the Scotian Shelf are shown in Fig. 33. Only 56% of all of the crab were caught in temperatures less than 3°C, almost the same percentage (52%) as the available temperatures in this range. No stations had temperatures of -1°C or below. More crab were found in warmer waters in 2002 compared to 2001, which in part reflects the available station temperatures in each of those years (Fig. 33). The depths that the crab were caught at were largely the same in both years. It appears that the crab on the northeastern Shelf maintain their depth, and while having a tendency to favour colder waters, their temperature habitat is largely determined by what temperatures are available to them. We also examined the differences between snow crab areas. These show that crab in Area 23 are in the coldest waters. Crab in the three areas (20-22, 23 and 24) generally were caught in colder temperatures than the available station temperatures.

Southwestern Scotian Shelf (Roseway and LaHave Basins)

A small snow crab fishery exists in the vicinity of Roseway and LaHave Basins in NAFO Division 4X. This year we have included a short summary of temperature conditions in these regions.

Bottom Temperatures

As stated earlier, the July groundfish survey provides estimates of the near-bottom temperatures for the entire Scotian Shelf (Fig. 22). Bottom temperatures in the area of Roseway and LaHave Basins are much warmer (ranging from 3°-10°C) than the habitat of the snow crabs in the Gulf of St. Lawrence or the northeastern Scotian Shelf. During 2002, these temperatures were mostly near their long-term means with the anomalies varying spatially (Fig. 22). Compared to 2001, temperatures in these basins increased slightly, by upwards of 1°C (Fig. 23).

Monthly Mean Temperature Anomaly Profiles and Time Series

The monthly and “annual” mean temperature anomaly profiles for Roseway and LaHave were determined, as described above for the Gulf and the northeastern Scotian Shelf. For our purposes, the Roseway area covers most of the basin but the LaHave area tends to be inshore of the deep regions of its basin, which corresponds to locations where snow crab tend to be caught. The temperature time series at 150 m in Roseway and at 100 m in LaHave are considered representative of the near-bottom region within each of the fishing areas. The cautionary notes on the interpretation of the results also apply to these data. As before, anomalies were calculated relative to the 1971-2000 mean.

Data were available in 4 months during 2002 in Roseway Basin. They indicate variable temperature anomalies in July during the groundfish survey but during the 4 months the tendency was for warmer-than-normal temperatures over the top 125 m of the water column (Fig. 35). At 150 m the mean anomaly of the available months was slightly negative but not significantly different than the long-term average. The time series at 150 m indicates a switch from below normal in the first part of 2002 to above normal by the autumn (Fig. 36). Temperatures have been dominated by below normal anomalies since 1985, although they have oscillated about the long-term mean, especially since the early 1990s. Prior to 1985, temperatures tended to be above normal through the late 1970s and early 1980s and very cold from the late 1950s through the early 1970s.

In the vicinity of LaHave Basin, temperature data were collected in 7 months of 2002. In the top 50 m, temperatures through the year tended to be above normal with the maximum anomaly (>2ºC) occurring in July at 10 m (Fig. 37). The annual averages of the temperature anomalies, derived from the available 7 months, were also maximum at 10 m, being over 1ºC and considered significantly different than zero. The amplitude of the annual mean anomaly decreased with depth through to 75 m where it was near zero and became negative from 100 m and deeper. At 150 m, the temperature anomaly at the beginning of the year was strongly negative (approximately -2.5ºC) and decreased through the winter to reach positive but near zero values by April. It remained there through to September when the last data were collected in this region. The time series of the temperature anomalies at 100 m in LaHave (Fig. 38) show similar trends as Roseway (Fig. 36), although the details vary. This includes the cold conditions in 1950s and 1960s, above normal from the early 1970s through to the mid-1980s and a predominance of below normal temperatures from the late 1980s to present.

Snow Crab Catches by Temperature

The snow crab catches as a function of temperature and depth are shown in Fig. 39. Data were only available from the LaHave region. A total of 21 stations were sampled at which 110 crabs were caught. Given the small number of stations and limited numbers of crab, interpretation of the results must be made with caution. Unlike the Gulf and the northeastern Scotian Shelf, crab in the LaHave region were caught in much warmer temperatures, ranging from 3° to 10°C. Approximately 45% were caught in temperatures of 4°-5°C and an additional 38% were captured in very warm waters (9°-10°C). As to depths where the crab were caught, almost 50% were at 100-120 m. Most of the remaining crab were trapped in waters with depths from 120-200 m.

Summary

Near-bottom temperatures in the southern Gulf of St. Lawrence (Magdalen Shallows) and on the Scotian Shelf during 2002 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 2002, temperature conditions tended to warm 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), decreased relative to 2001 and was at its lowest level since the 1980s and the second lowest level in the 32-year record. The temperatures within the area of -1° to 3°C were above normal and increased compared to last year. The vertical temperature profiles indicated a strong tendency to be warmer than the long-term means in depths below about 50-100 m, whereas in the up 10-20 m, conditions varied spatially with no identifiable trend.

For the northeastern Scotian Shelf region, no consistent pattern emerged. Near normal conditions were found in the bottom waters of the northeastern Shelf during the July groundfish survey, and typically increased compared to 2001 conditions. Very cold waters were observed near bottom in Area 24 whereas in Area 23 and Areas 20-22 combined, subsurface conditions tended to be on the warm side but generally not significantly so. The latter reflects high month to month variability.

In Division 4X, in the vicinity of Roseway and LaHave Basins, temperatures are much warmer than in the northeastern Shelf or in the Gulf. Crab are caught in temperatures as warm as 9°-10°C. In 2002, near-bottom temperatures tended to be below normal and similar, or slightly warmer, than in 2001. Near-bottom

temperatures warmed through 2002 and by the autumn were above their long-term mean.

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. L. Tse helped in the analysis of the catch, temperature and depth data.

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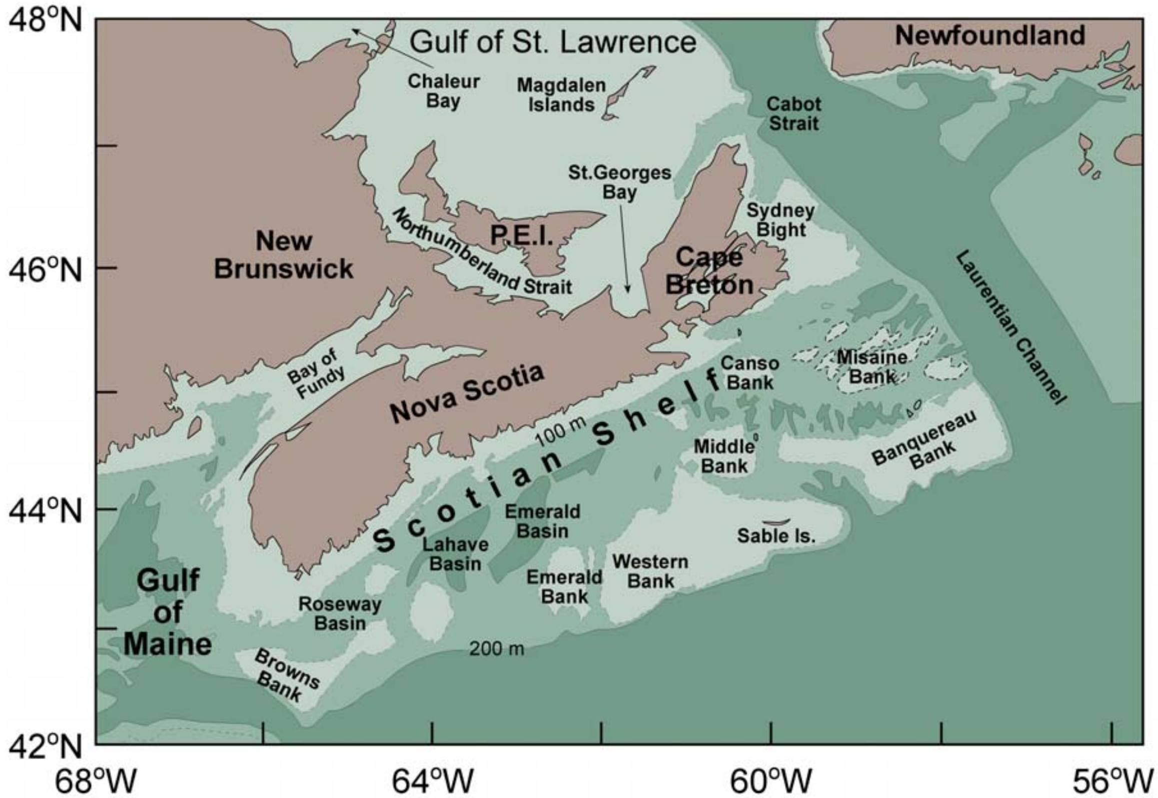

Fig. 1. Chart of the Scotian Shelf and the southern Gulf of St. Lawrence showing geographic and topographic features referred to in the text.

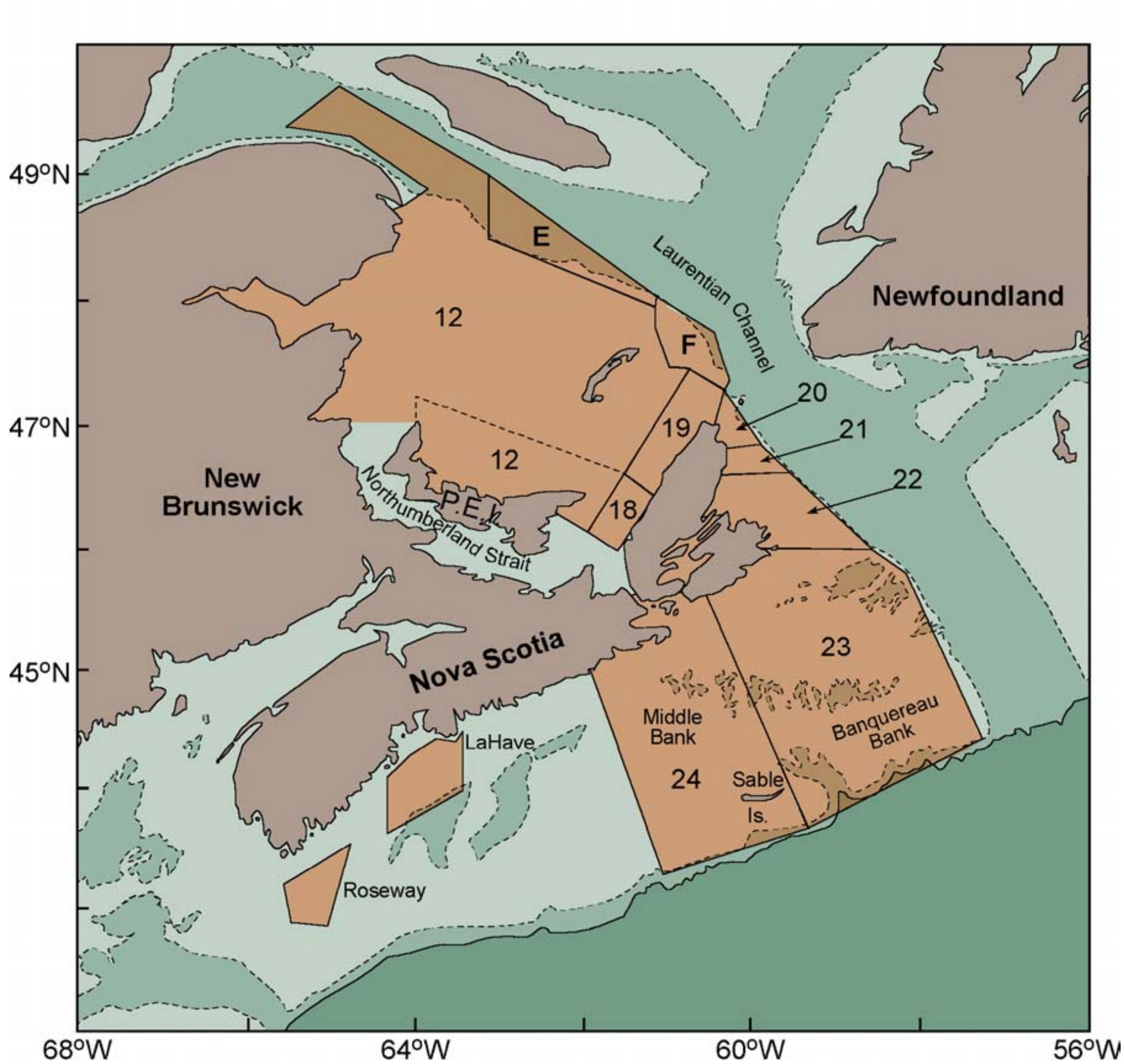

Fig. 2. The southern Gulf of St. Lawrence and Scotian Shelf showing the boundaries of snow crab fishing areas in which monthly mean temperature profiles were estimated. The section of Area 12, north of Prince Edward Island and denoted by the dashed line, contains former Areas 25 and 26.

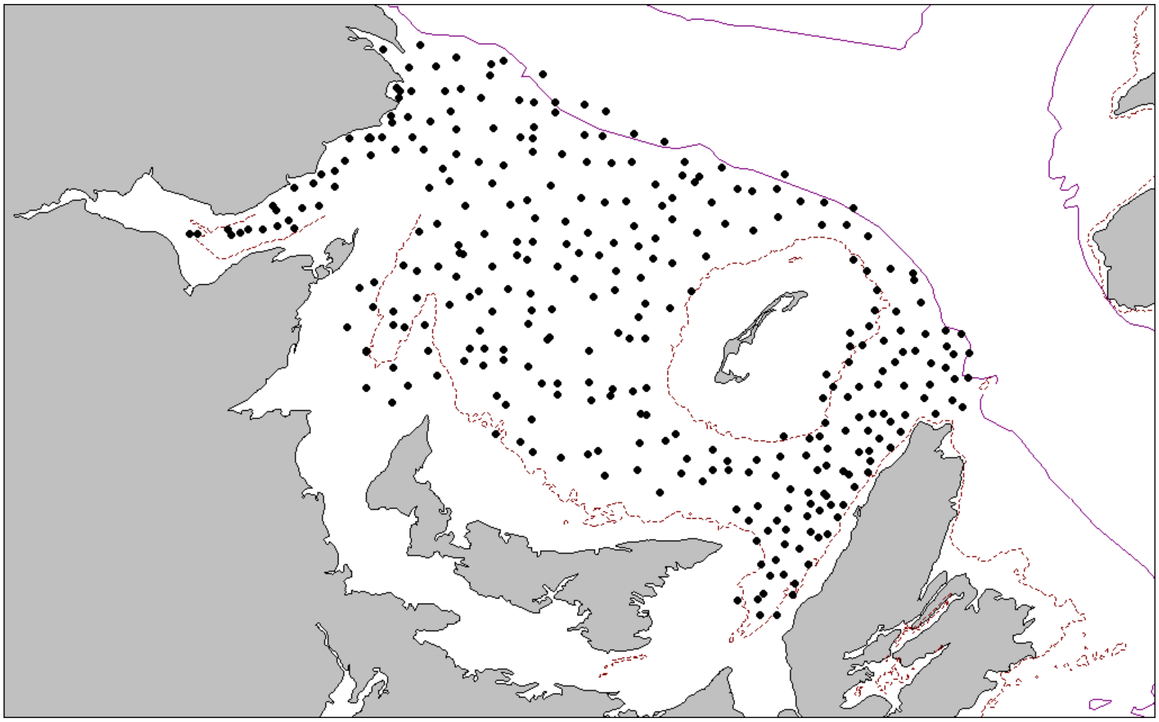

Fig. 3a. The location of the bottom temperature stations during the July-September 2002 snow crab survey.

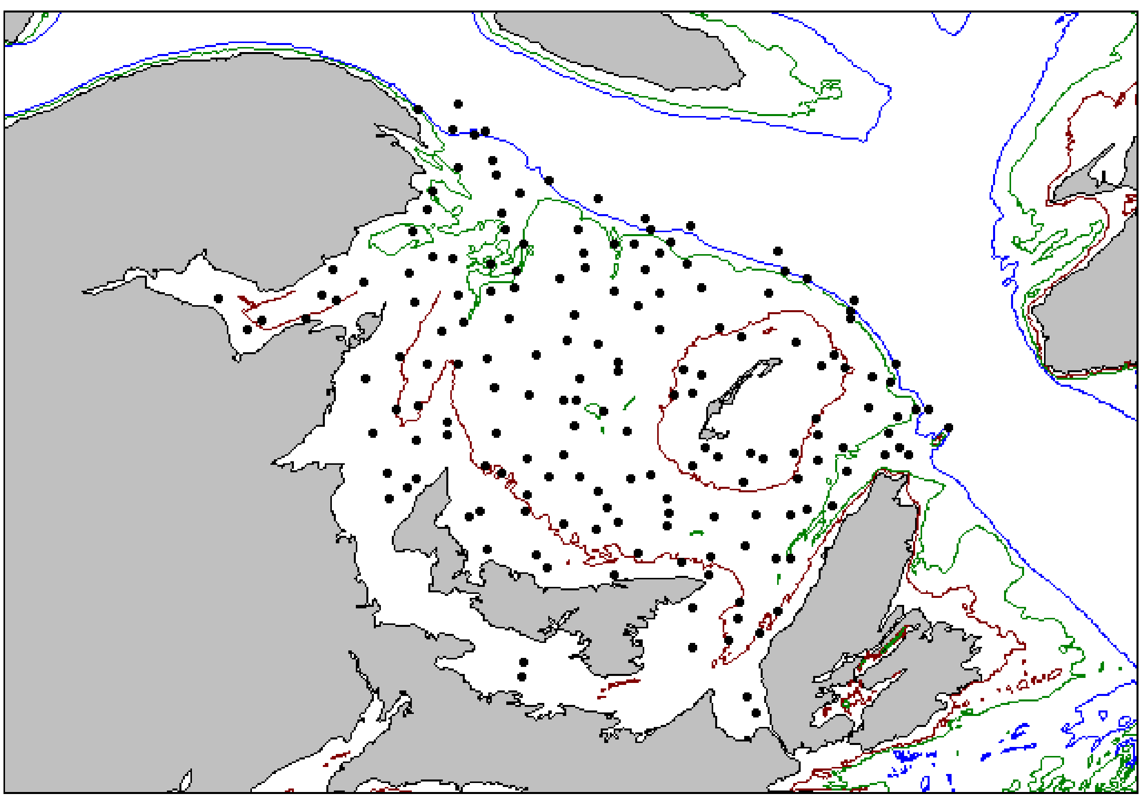

Fig. 3b. The location of the CTD stations during the September 2002 survey.

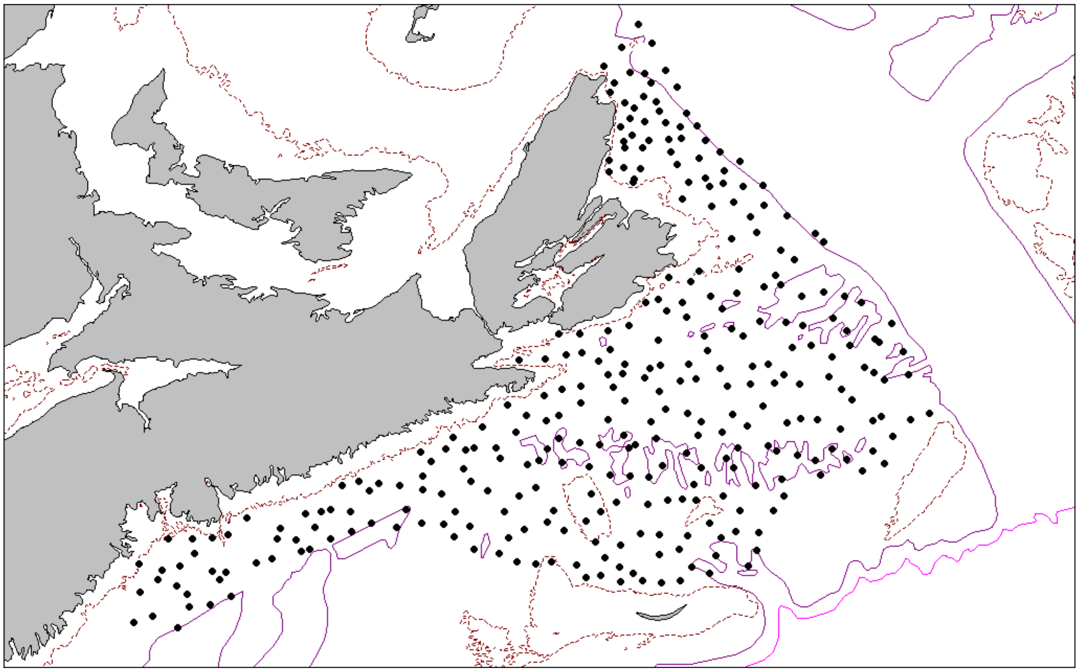

Fig. 4a. The location of the bottom temperature stations during the July-September 2002 snow crab survey.

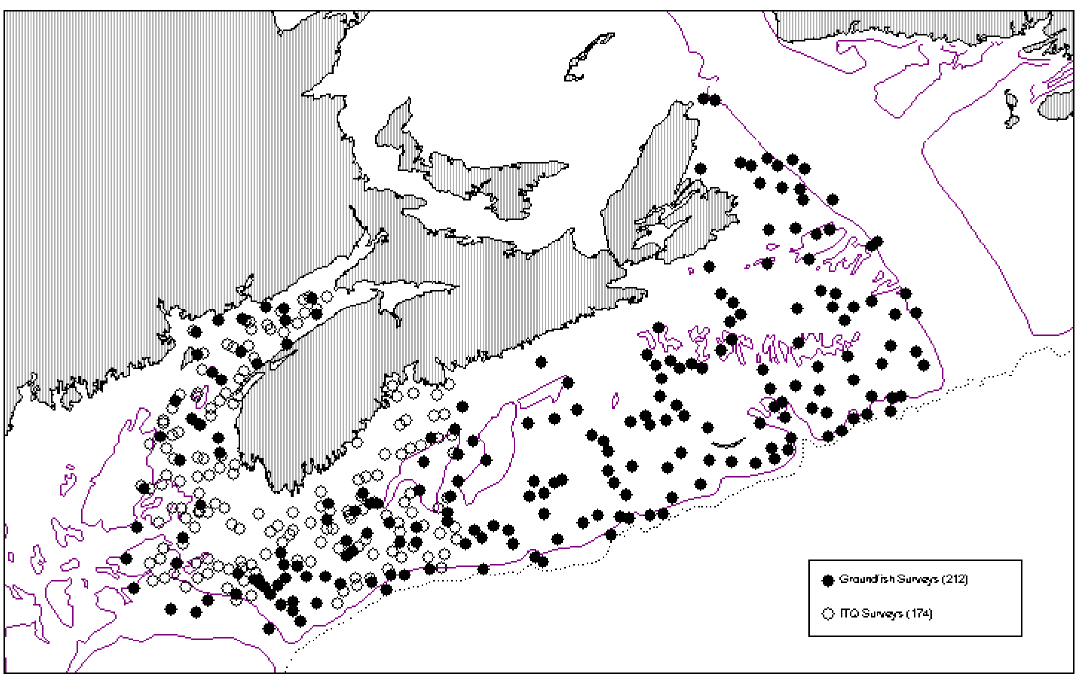

Fig. 4b. The location of the CTD stations during the July 2002 survey. The solid black dots represent the stations taken during the DFO groundfish survey and the open circles denote the stations taken during the fisherman run survey (labelled as ITQ Survey).

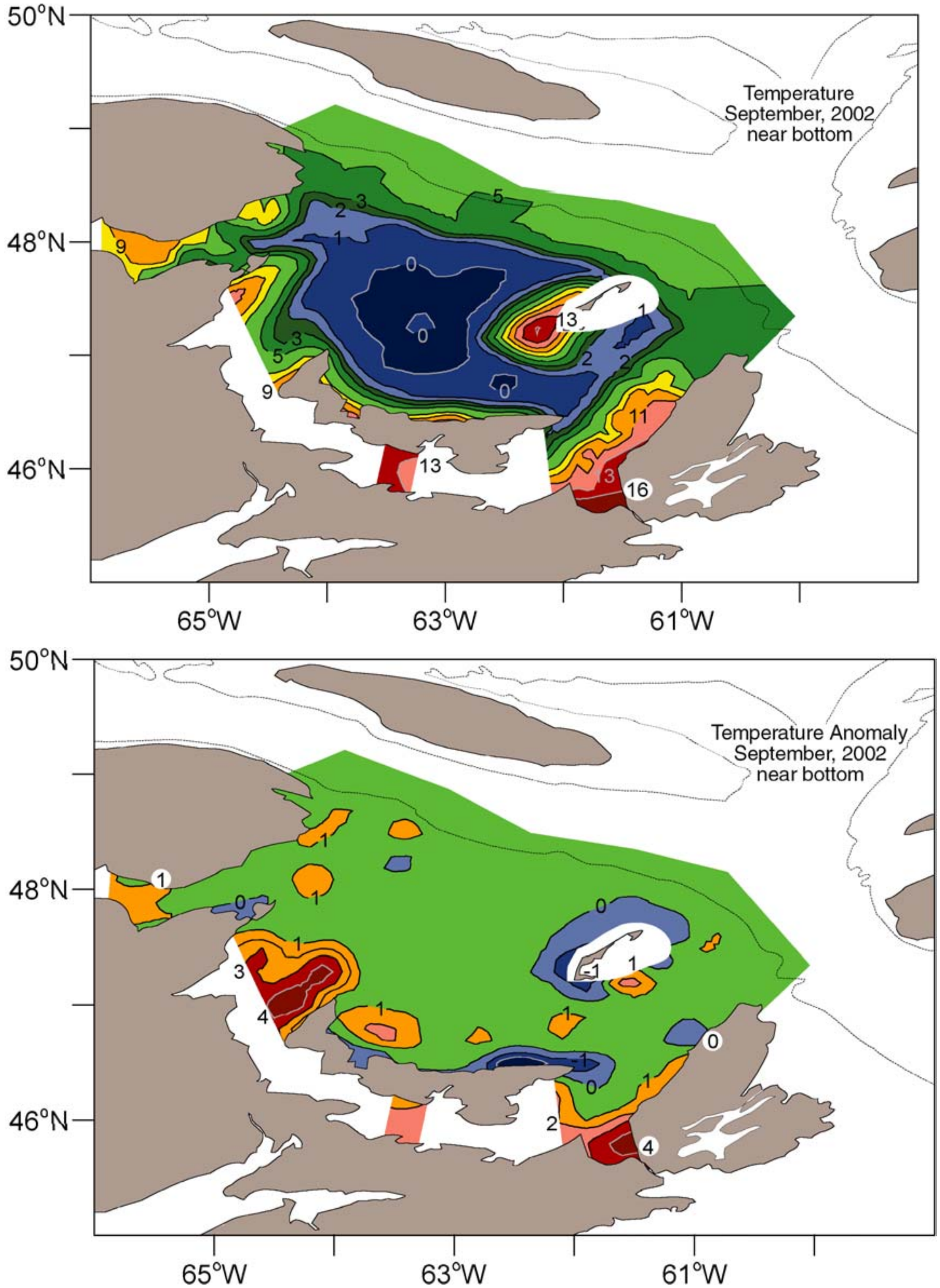

Fig. 5. Near-bottom temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) in the southern Gulf of St. Lawrence during the 2002 September groundfish survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

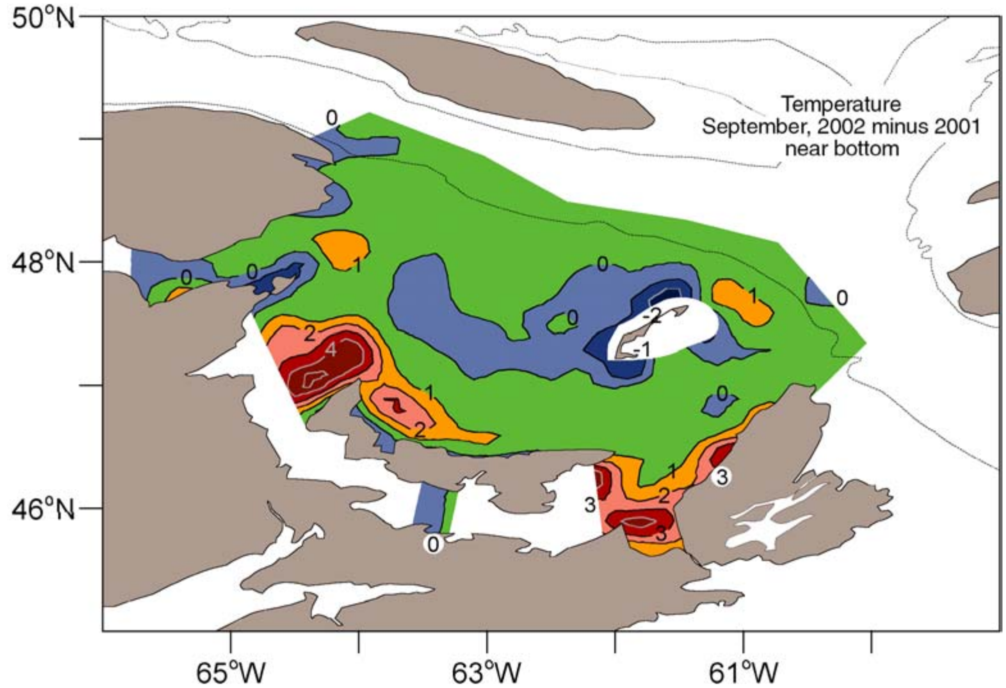

Fig. 6. The difference between the 2002 and 2001 temperature fields in the southern Gulf of St. Lawrence for the September groundfish surveys. Positive values (green and red) indicate temperatures in 2001 had warmed and negative values (blue and purple) that they had cooled.

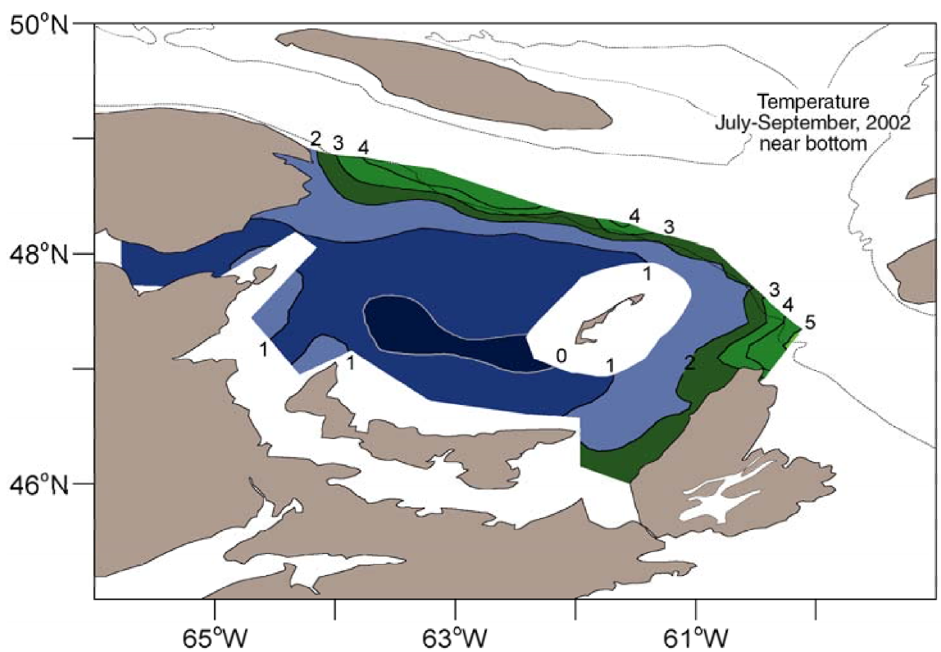

Fig. 7. Near-bottom temperatures in the southern Gulf of St. Lawrence during the 2002 July-September snow crab survey.

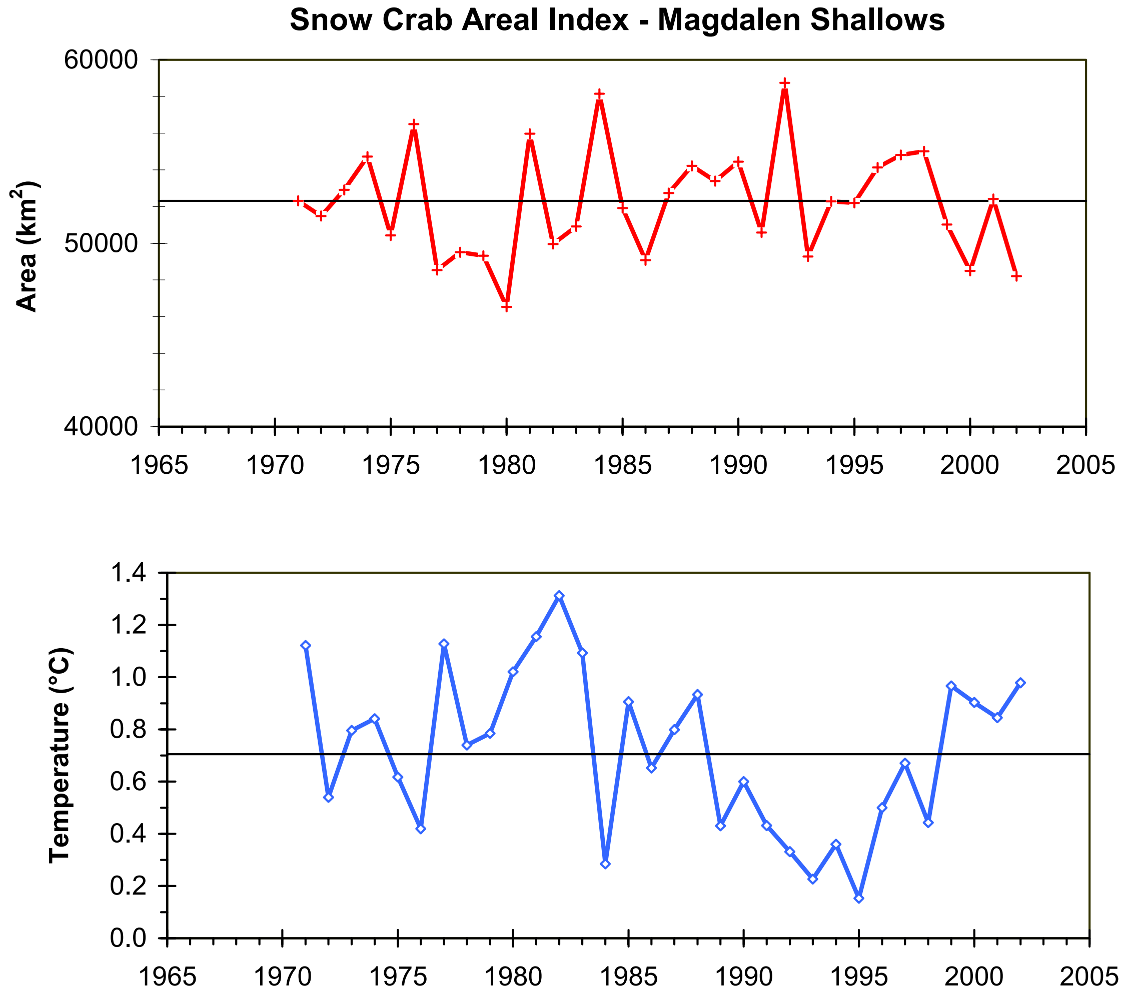

Fig. 8. Time series of the snow crab habitat index (area of Magdalen Shallows covered by bottom temperatures between -1° and 3°C) in September (top panel) and the mean temperature within that area (bottom panel).

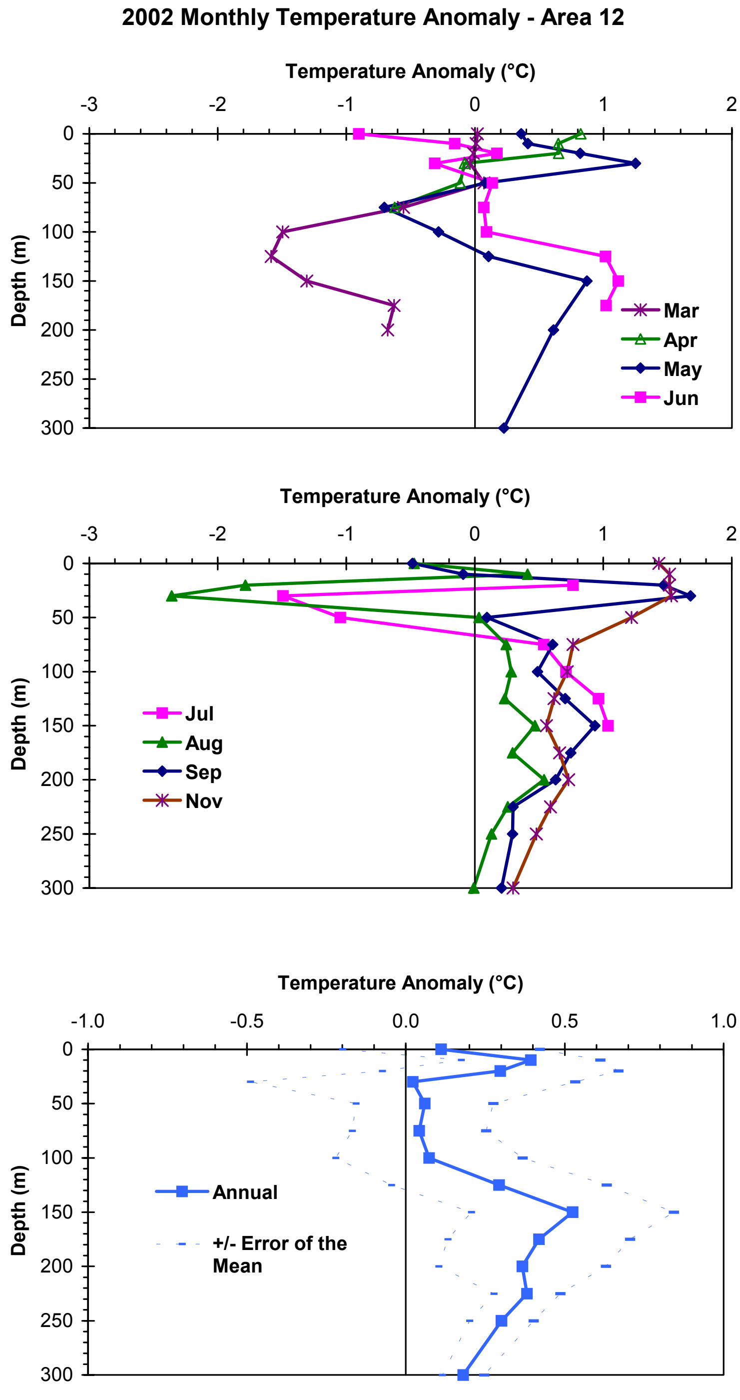

Fig. 9. Monthly mean temperature anomalies (top two panels) and annual temperature anomalies ± error of the mean (bottom panel) during 2002 for snow crab fishing Area 12.

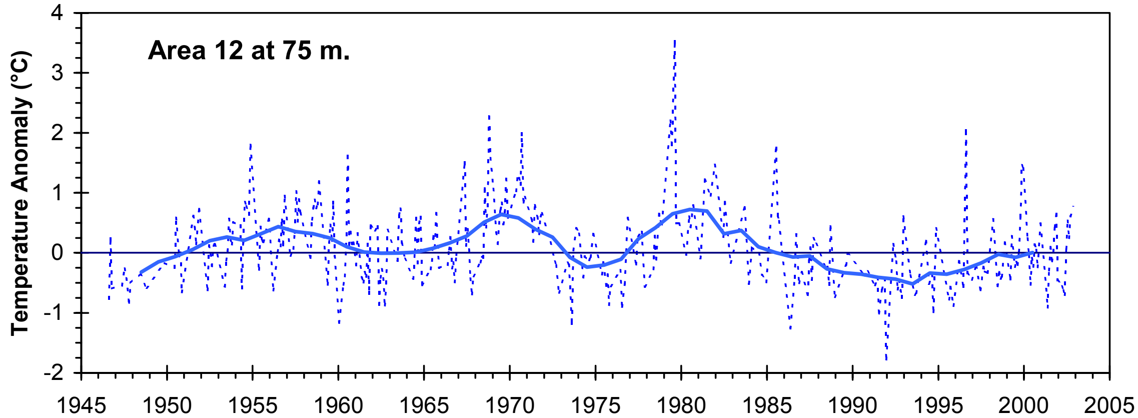

Fig.10. The time series of the monthly (dashed line) and the 5-year running mean (solid line) of the temperature anomalies at 75 m for snow crab fishing Area 12.

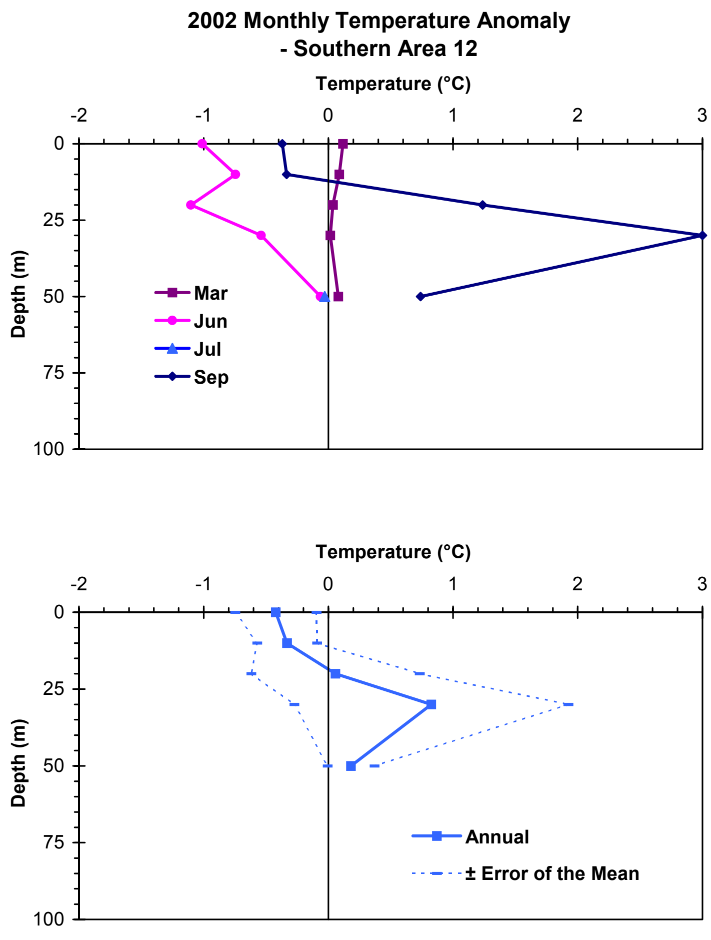

Fig.11. Monthly mean temperature anomalies (top two panels) and annual temperature anomalies ± error of the mean (bottom panel) during 2002 for the southern portion of snow crab fishing Area 12 (formerly Areas 25 and 26).

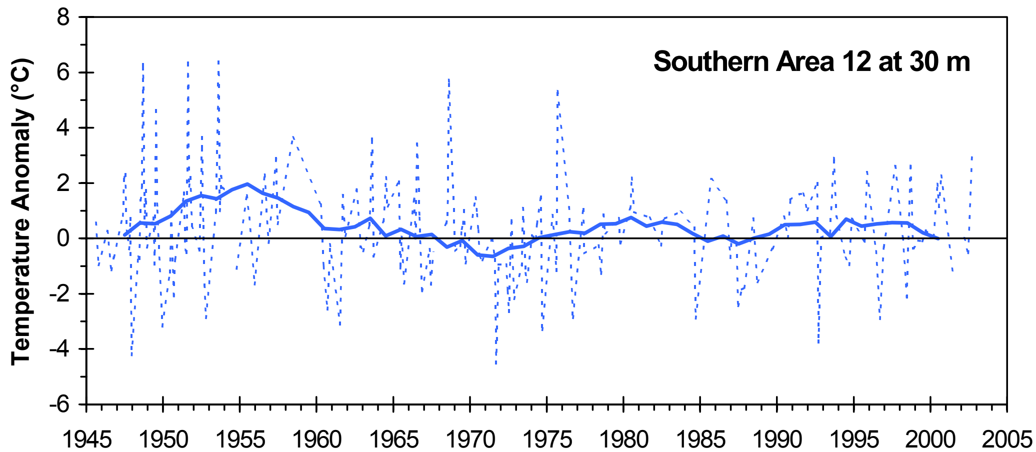

Fig.12. The time series of the monthly (dashed line) and the 5-year running means (solid line) of the temperature anomalies at 30 m for the southern portion of snow crab fishing Area 12 (formerly Areas 25 and 26).

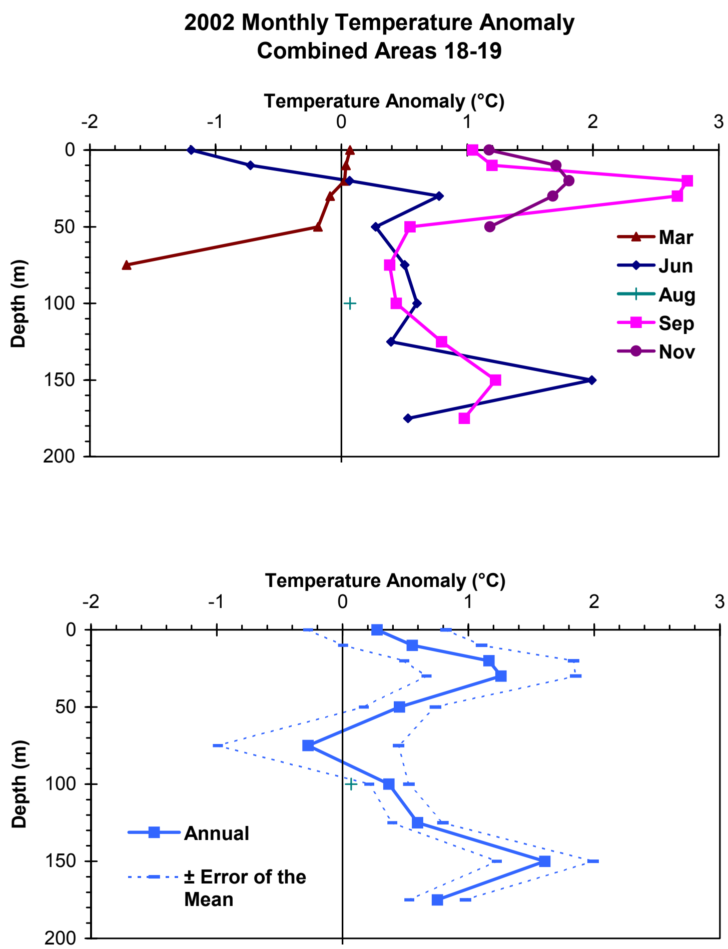

Fig.13. Monthly mean temperature anomalies (top panel) and annual temperature anomalies ± error of the mean (bottom panel) during 2002 for snow crab fishing Areas 18-19 combined.

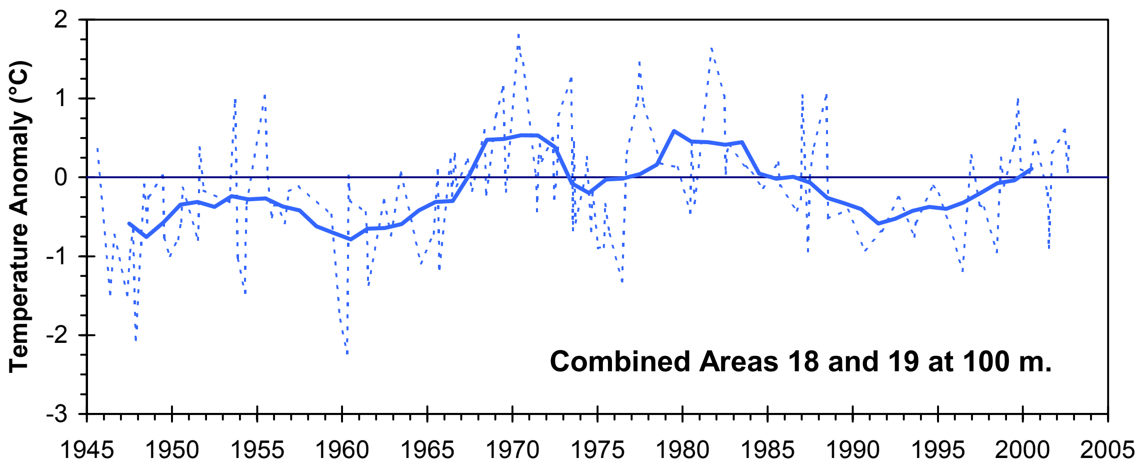

Fig.14. The time series of the monthly (dashed line) and the 5-year running means (solid line) of the temperature anomalies at 100 m for snow crab fishing Areas 18-19.

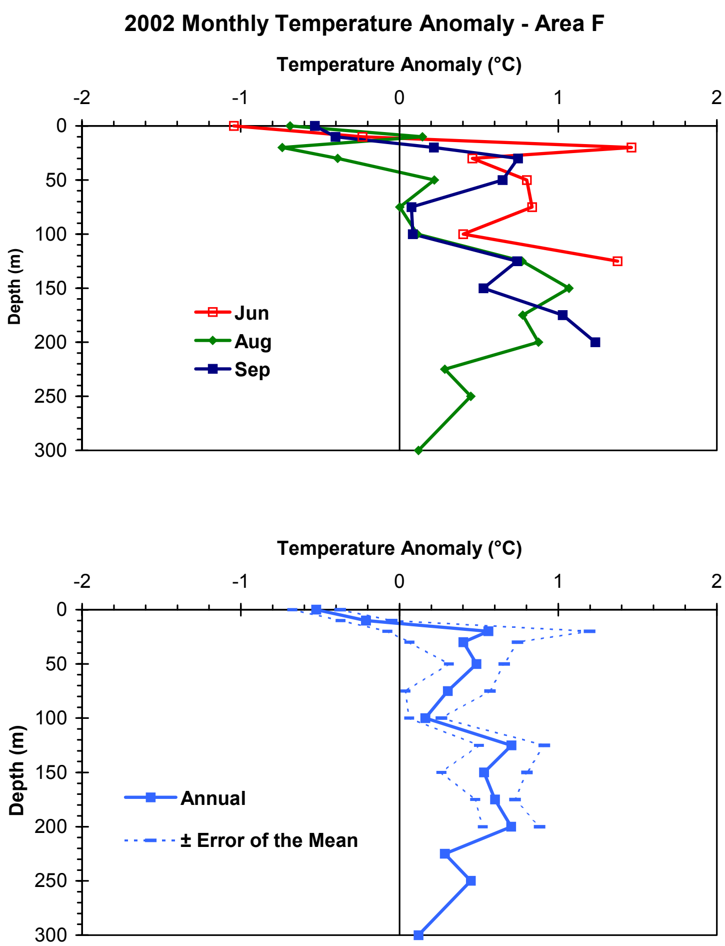

Fig.15. Monthly mean temperature anomalies (top panel) and annual temperature anomalies ± error of the mean (bottom panel) during 2002 for snow crab fishing Area F.

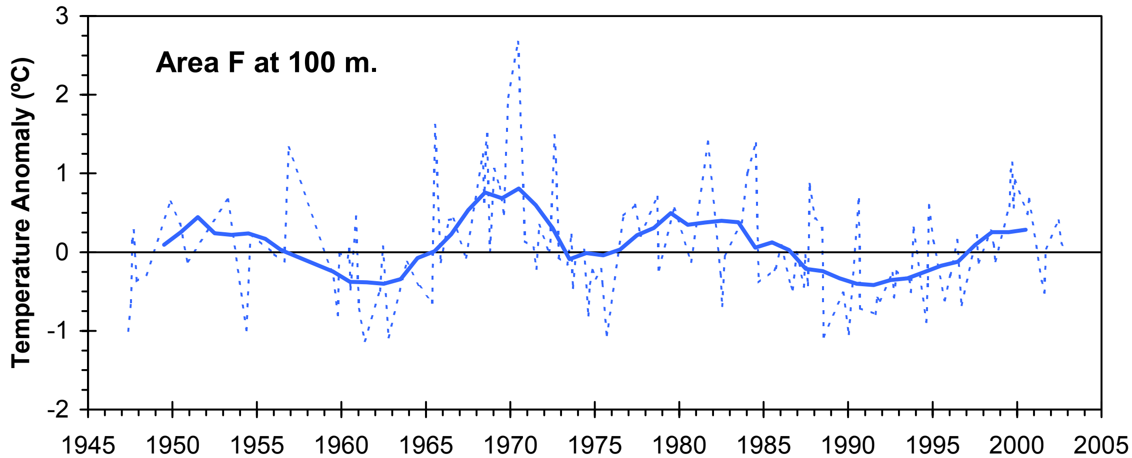

Fig.16. The time series of the monthly (dashed line) and the 5-year running means (solid line) of the temperature anomalies at 100 m for snow crab fishing Area F.

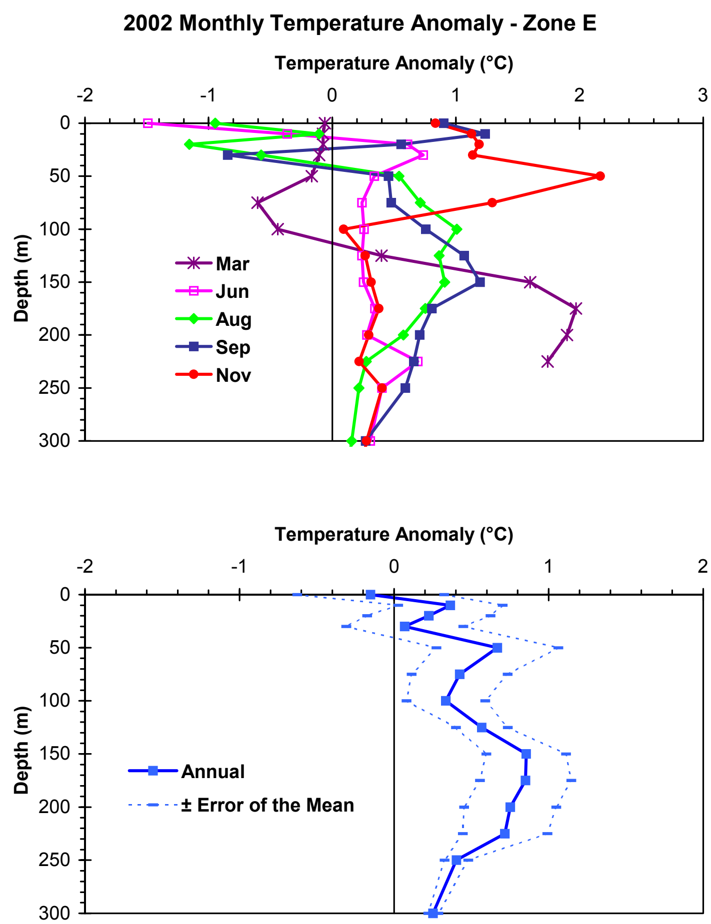

Fig.17. Monthly mean temperature anomalies (top panel) and annual temperature anomalies ± error of the mean (bottom panel) during 2002 for snow crab fishing Area E.

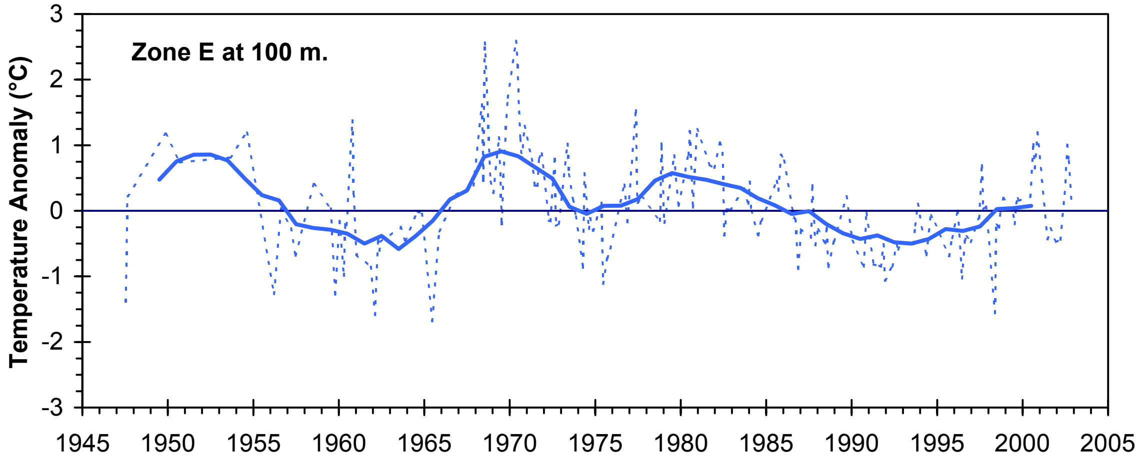

Fig.18. The time series of the monthly (dashed line) and the 5-year running means (solid line) of the temperature anomalies at 100 m for snow crab fishing Area E.

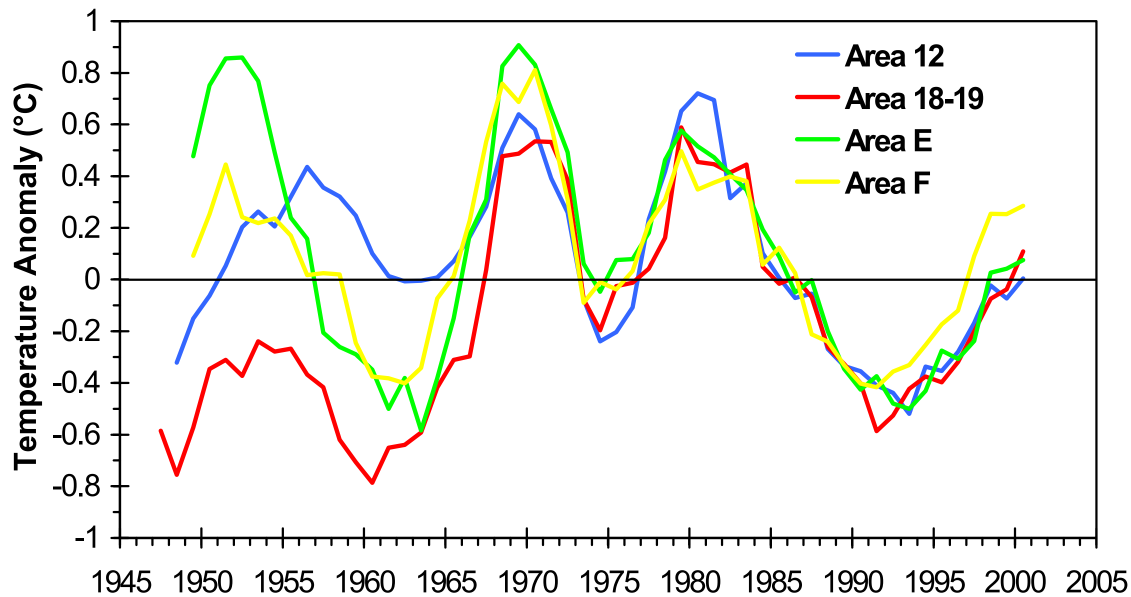

Fig.19. The five-year running means of the temperature anomalies for Areas 12, 18-19 (combined), E and F.

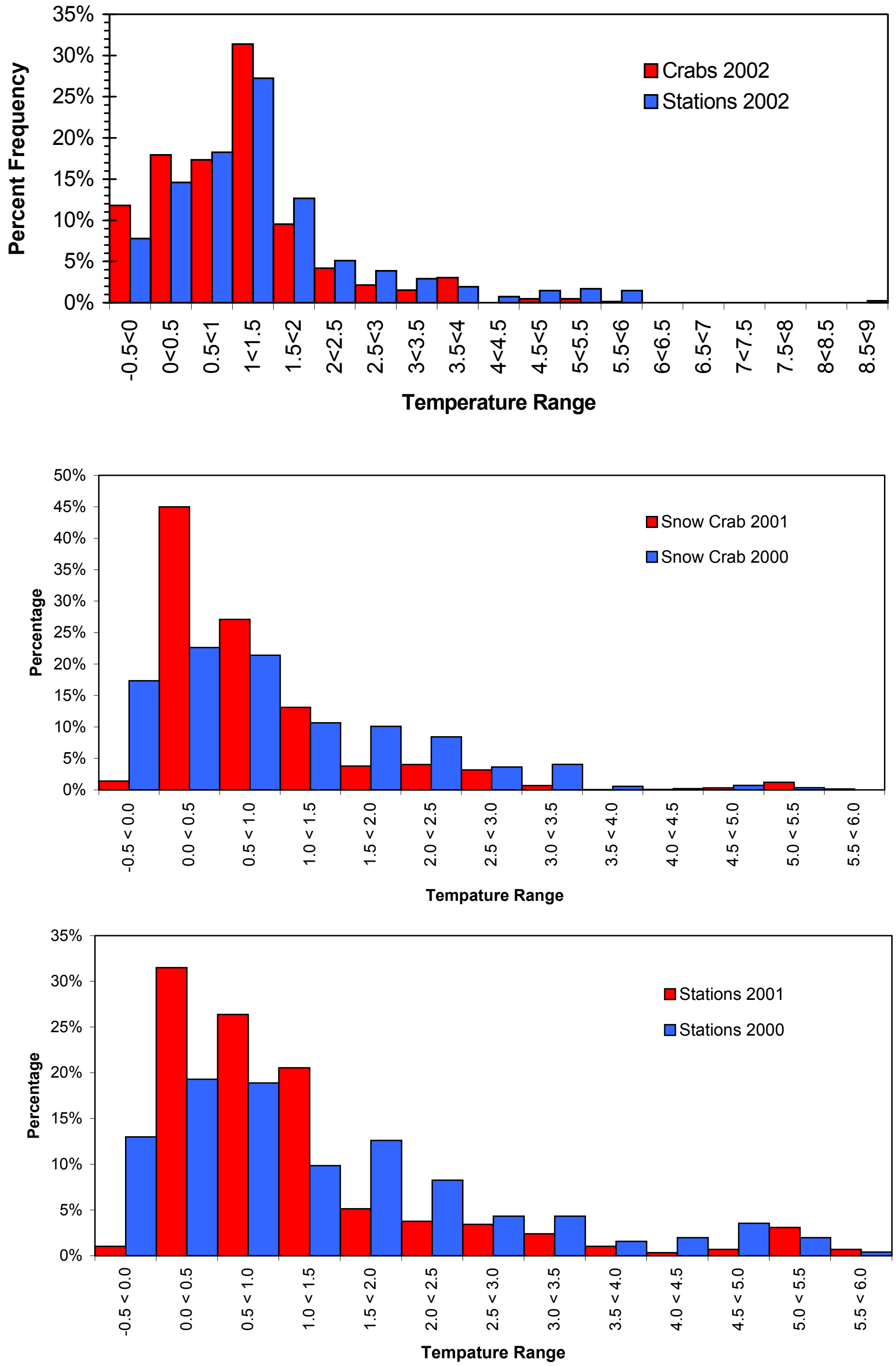

Fig.20. The frequency distribution as a function of temperature for the snow crab catches and for all of the stations occupied during the 2002 Gulf of St. Lawrence snow crab survey (top panel). The frequency distribution as a function of temperature for the stations occupied (middle panel) and for the snow crab catches (bottom panel) from the 2001 and 2002 Gulf of St. Lawrence surveys.

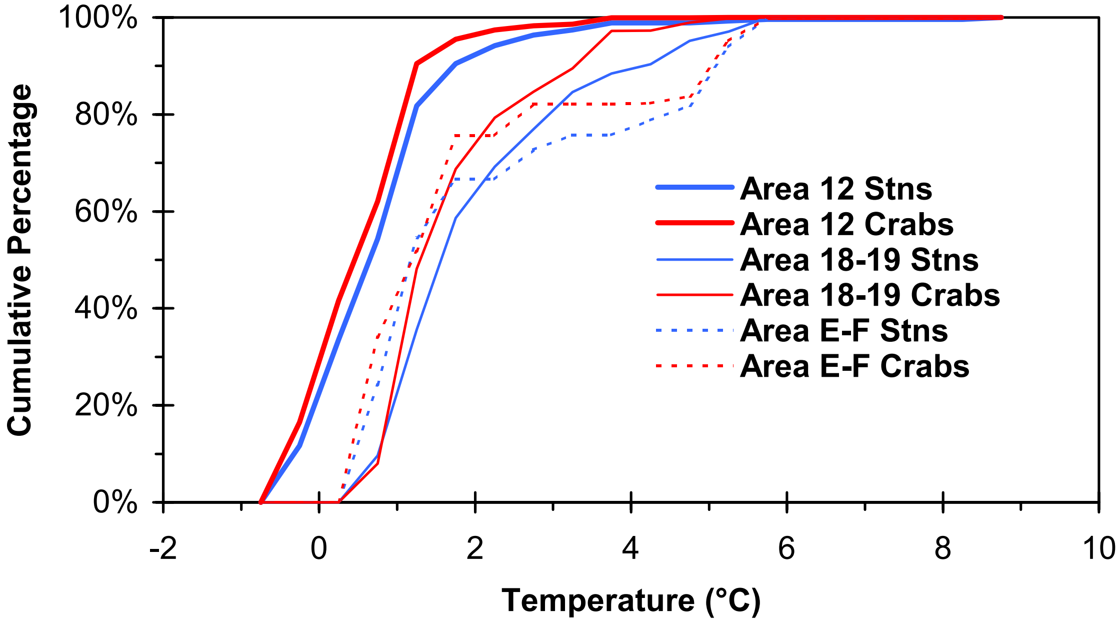

Fig. 21. The cumulative frequency distribution as a function of temperature for the stations and for the snow crab catches by snow crab fishing area within the Gulf of St. Lawrence during 2002.

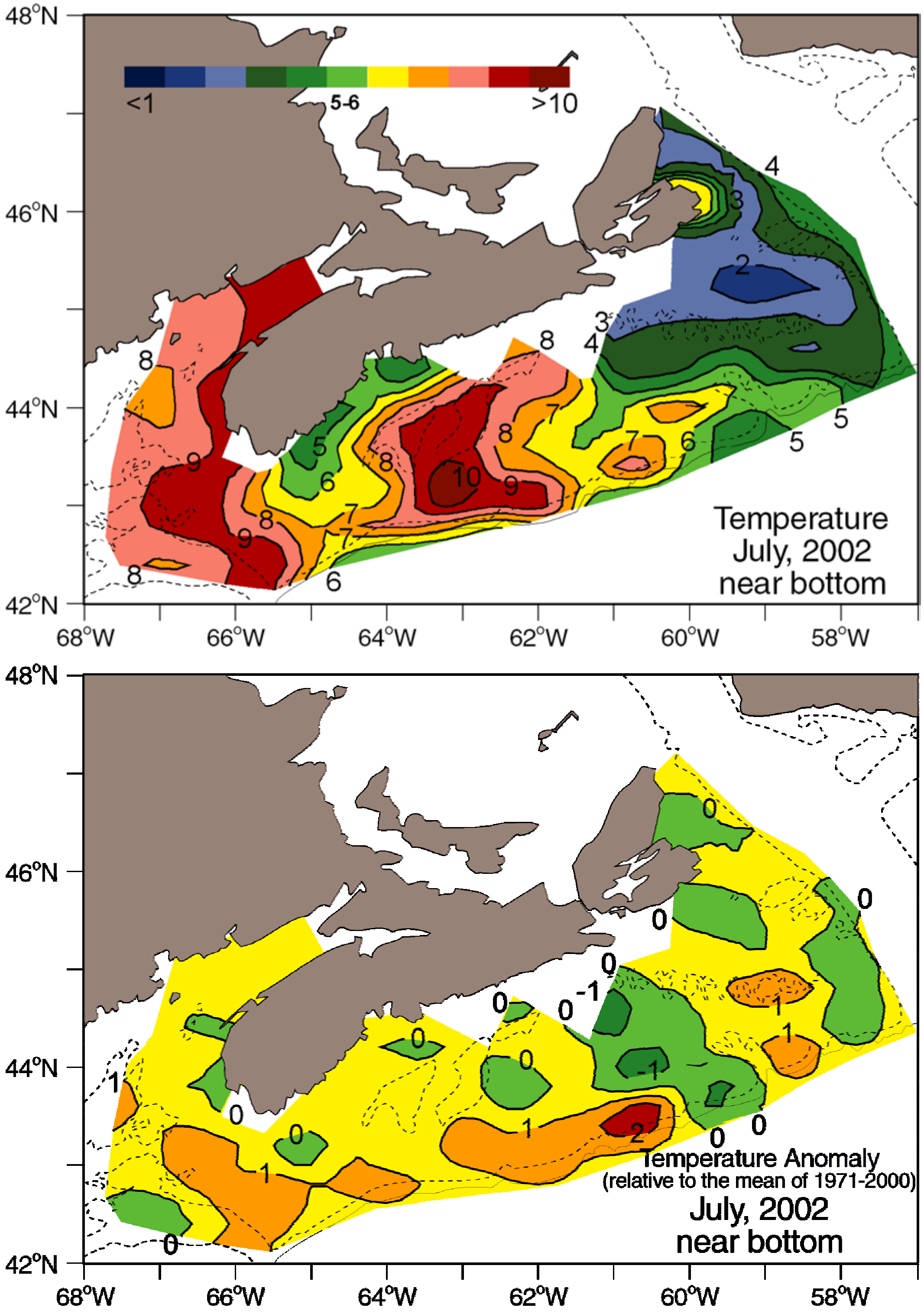

Fig.22. Near-bottom temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) on the Scotian Shelf during the 2002 July groundfish survey. Warmer-than-normal bottom temperatures (positive anomalies) are denoted by yellows through reds and colder-than normal (negative anomalies) by green.

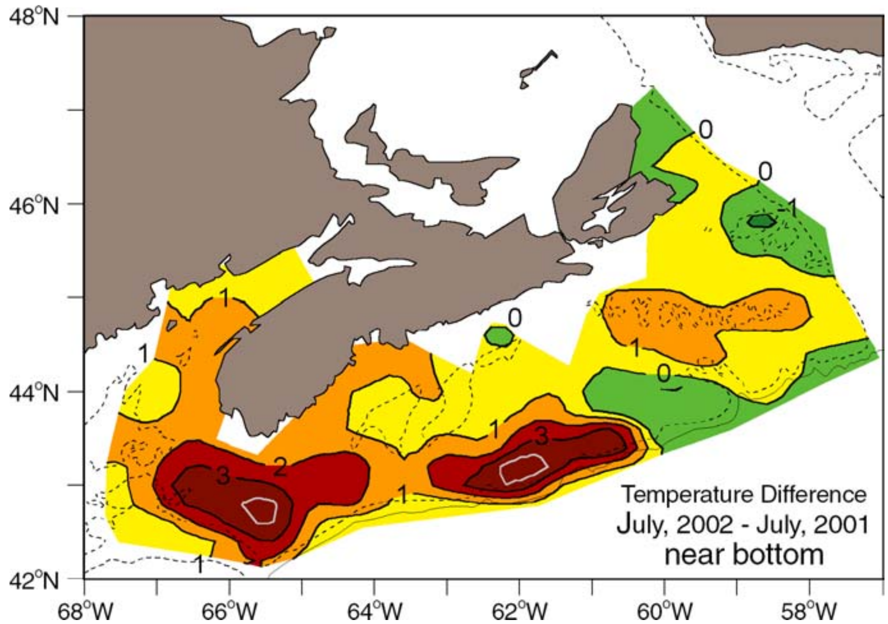

Fig.23. The difference between the 2002 and 2001 temperature fields on the Scotian Shelf for the July surveys. Positive values (yellow to reds) indicate areas where temperatures in 2002 had warmed and negative values (greens) where they had cooled.

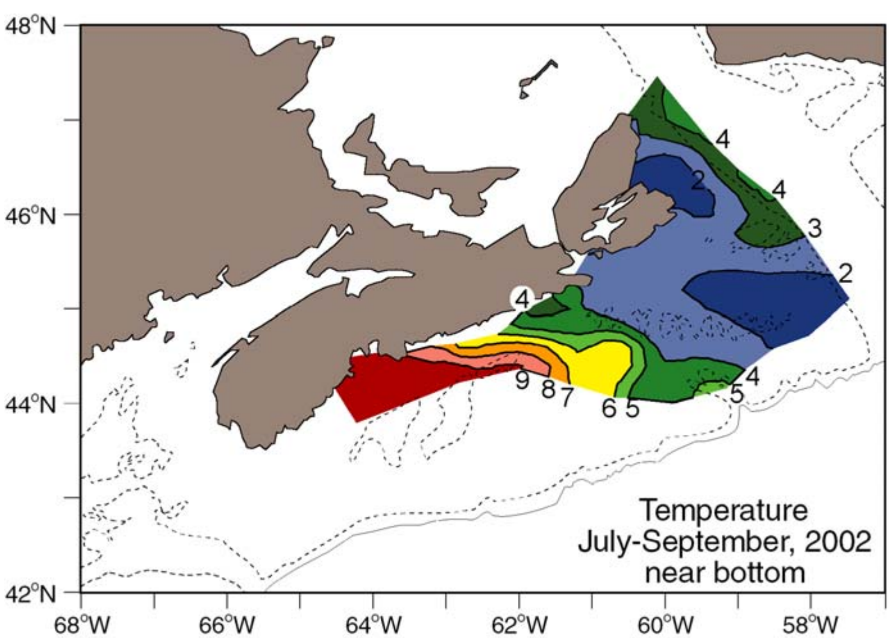

Fig.24. Near-bottom temperatures in the northeastern Scotian Shelf during the 2002 July-September snow crab survey.

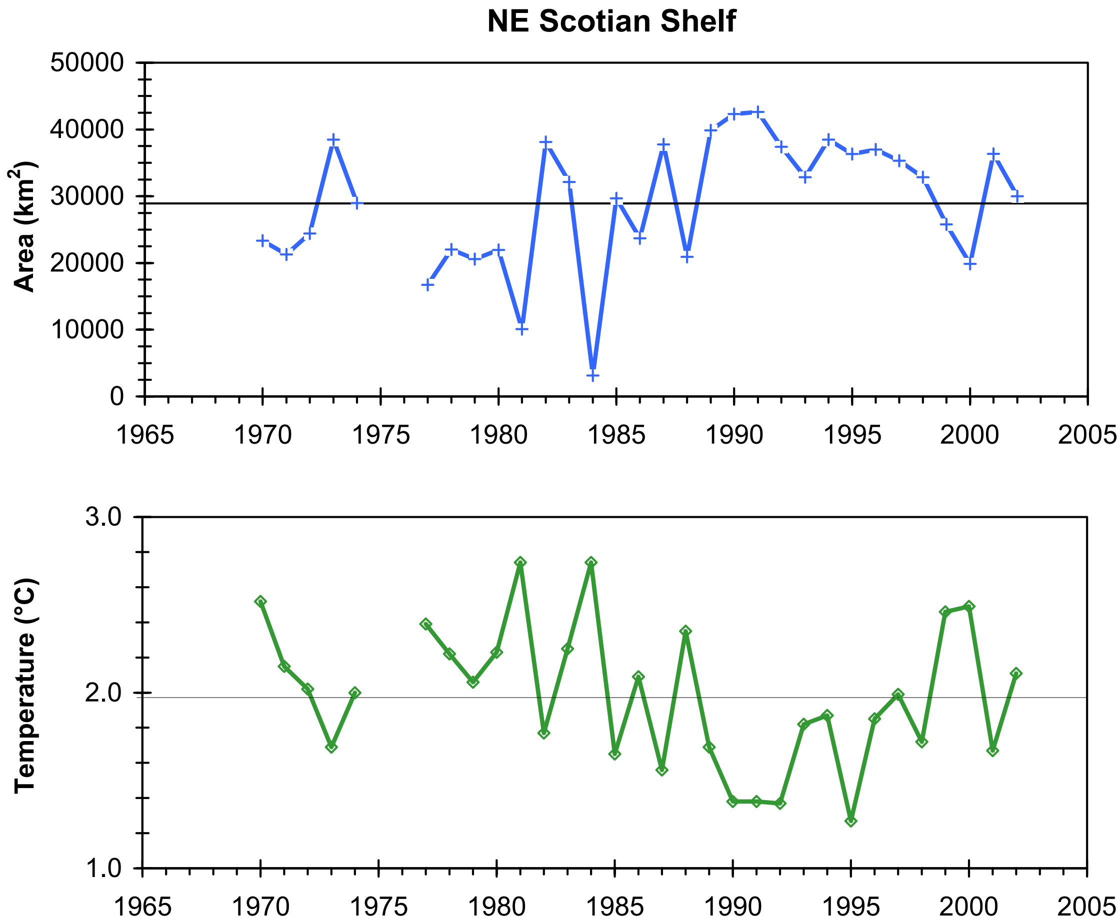

Fig.25. Time series of the snow crab habitat index (area covered by bottom temperatures between -1° and 3°C) for the northeast Scotian Shelf (Areas 23 and 24) in July (top panel) and the mean temperature within that area (bottom panel). The horizontal lines represent the 1971-2000 mean.

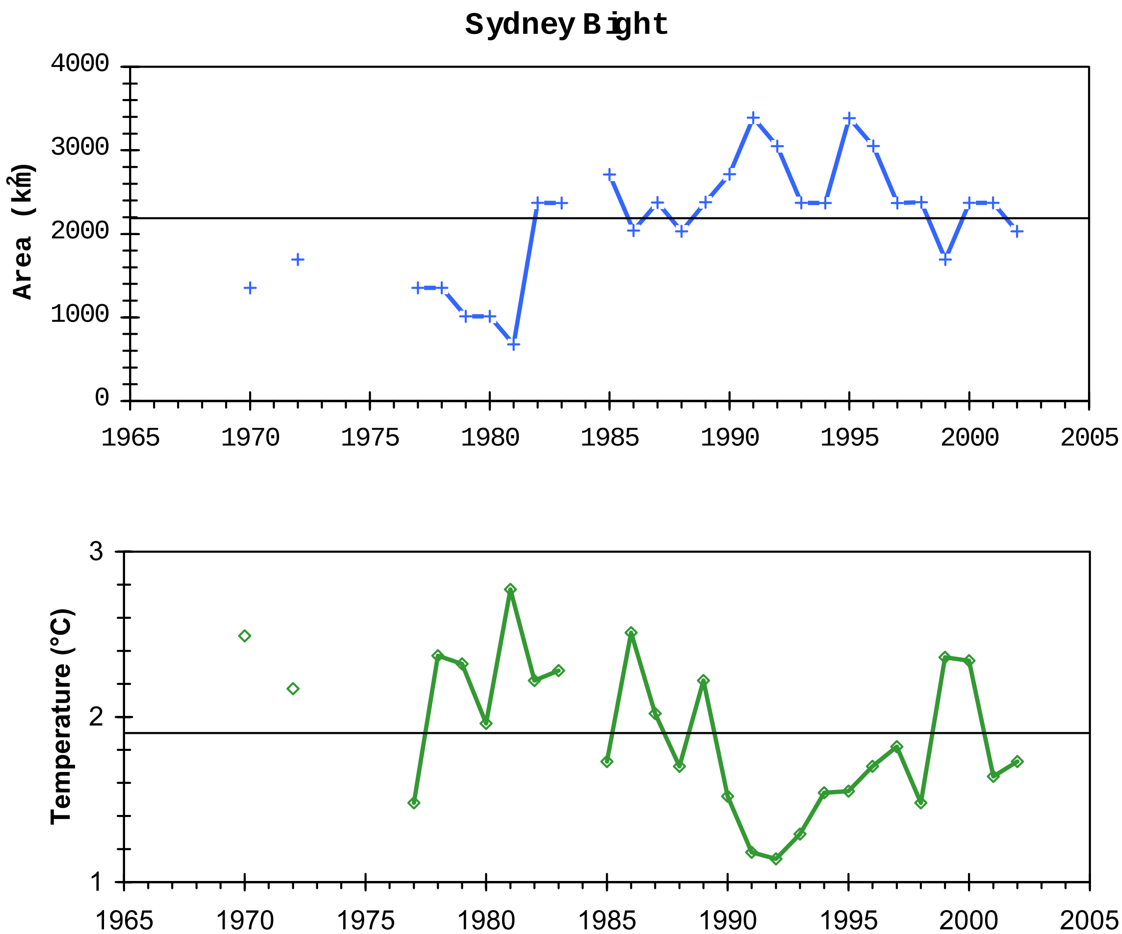

Fig.26. Time series of the snow crab habitat index for Sydney Bight in July (top panel) and the mean temperature within that area (bottom panel). The horizontal lines represent the 1971-2000 mean.

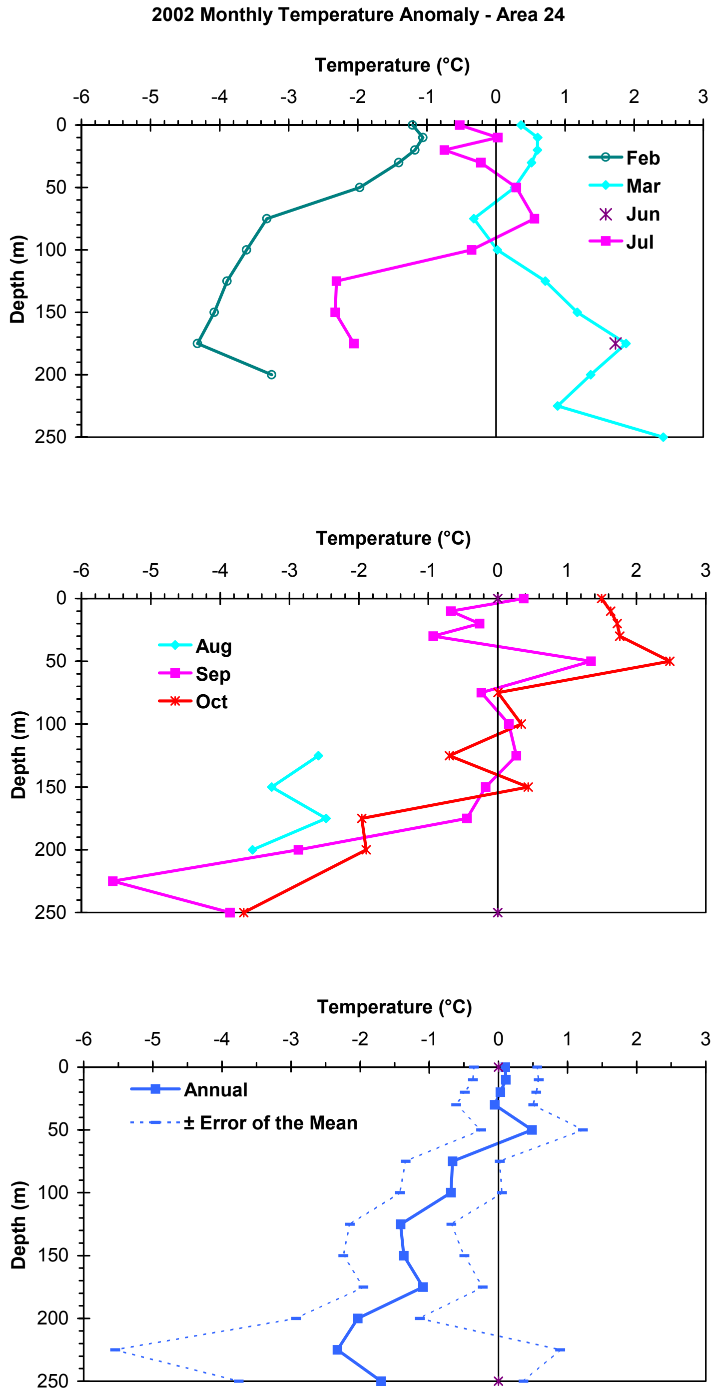

Fig.27. Monthly mean temperature anomalies (top two panels) and annual temperature anomalies ± error of the mean (bottom panel) for snow crab fishing Area 24.

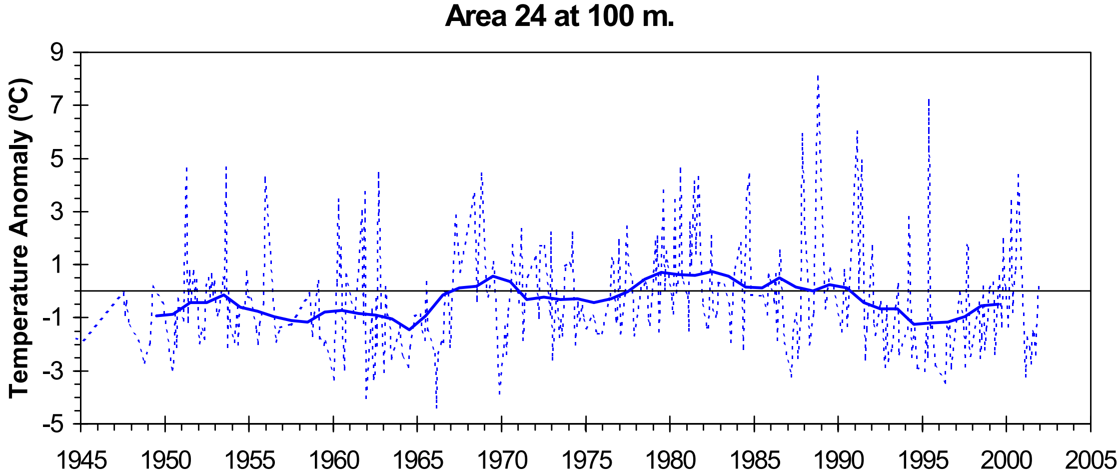

Fig.28. The time series of the monthly (dashed line) and the 5-year running mean (solid line) of the temperature anomalies at 100 m for snow crab fishing Area 24.

2001 Monthly Temperature Anomaly - Area 23

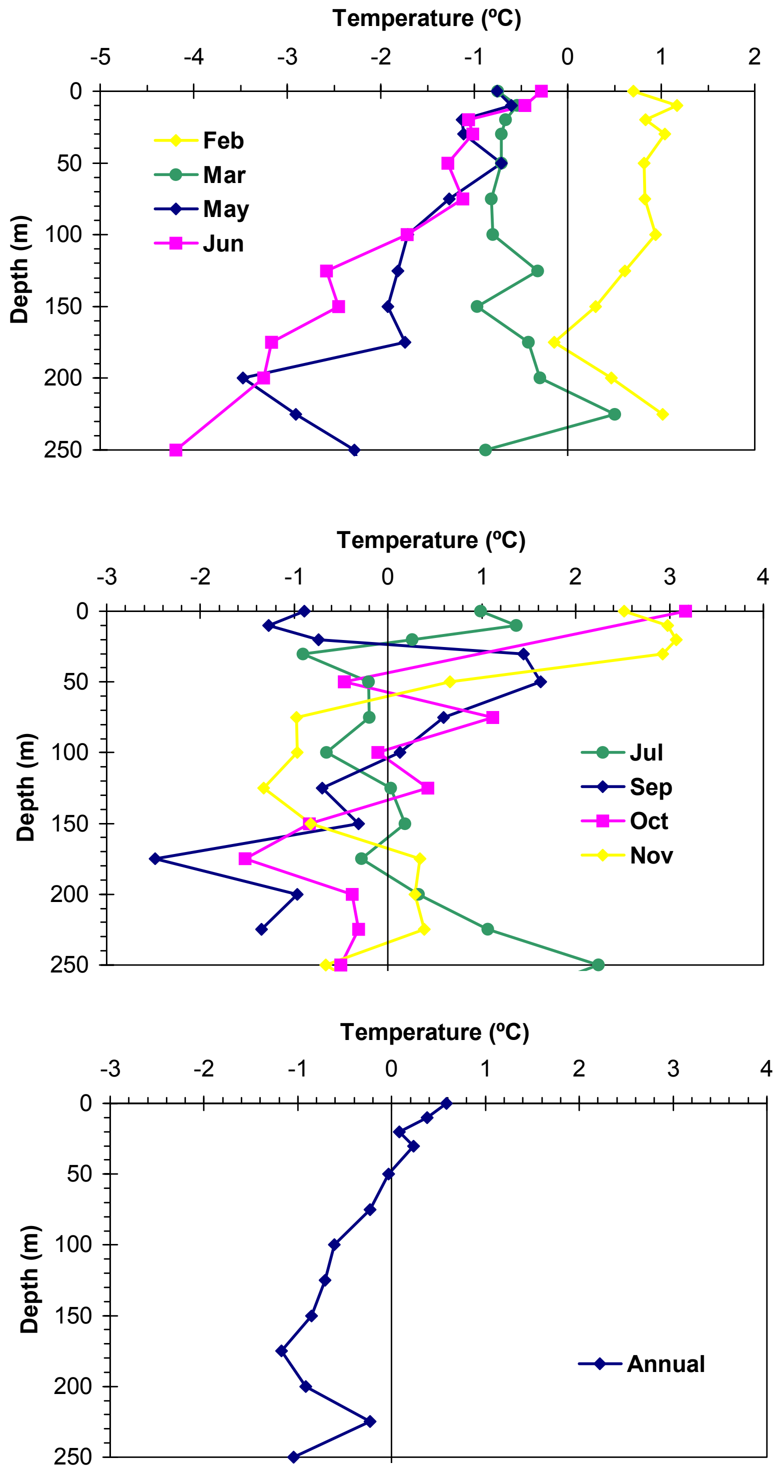

Fig.29. Monthly mean temperature anomalies (top two panels) and annual temperature anomalies ± error of the mean (bottom panel) during 2002 for snow crab fishing Area 23.

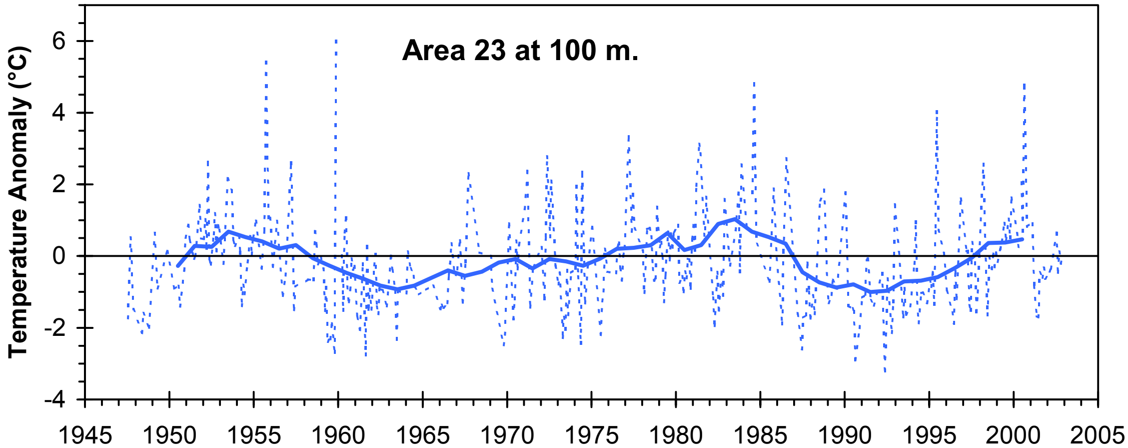

Fig.30. The time series of the monthly (dashed line) and the 5-year running mean (solid line) of the temperature anomalies at 100 m for snow crab fishing Area 23.

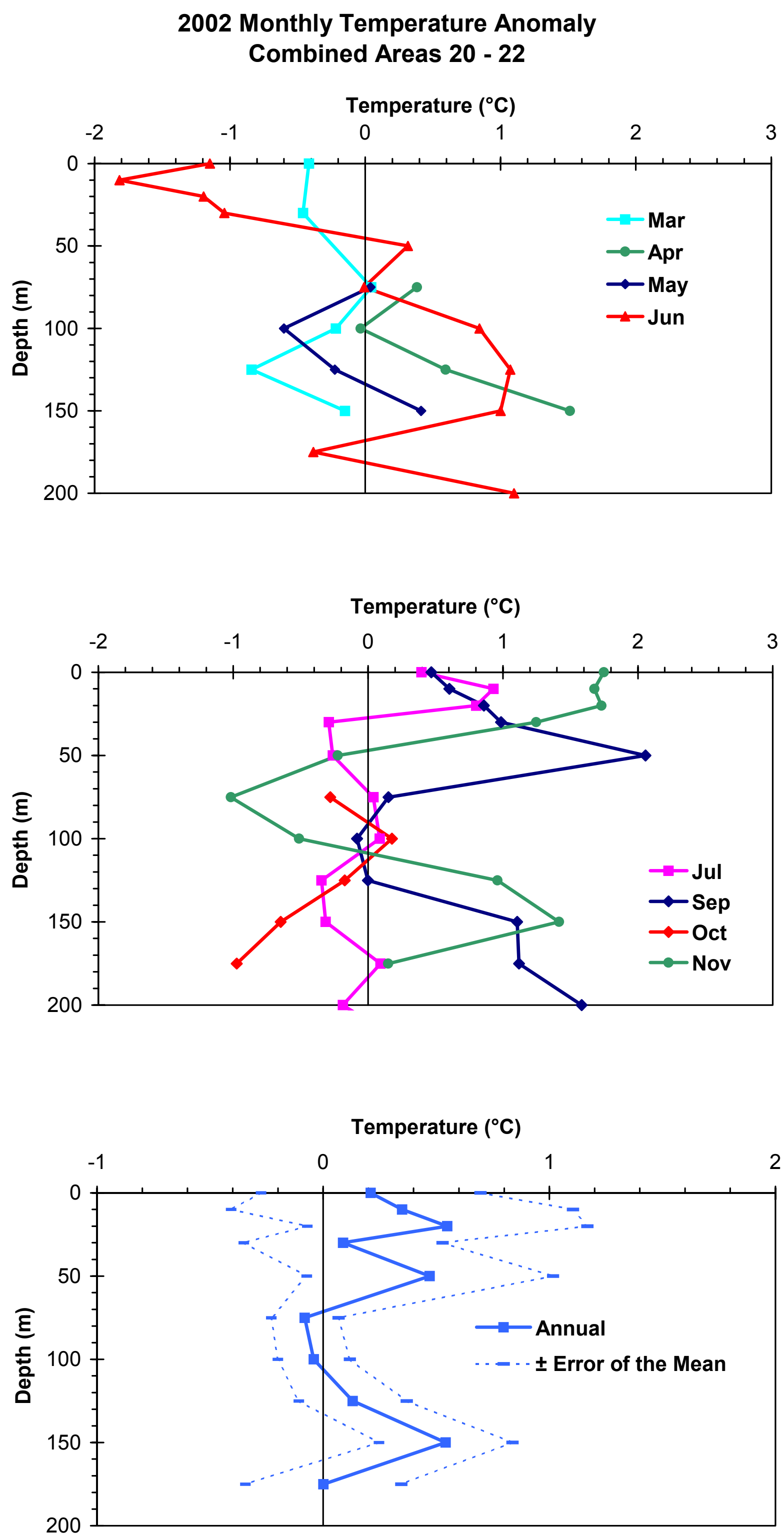

Fig.31. Monthly mean temperature anomalies (top panel) and annual temperature anomalies ± error of the mean (bottom panel) during 2002 for snow crab fishing Areas 20-22 combined.

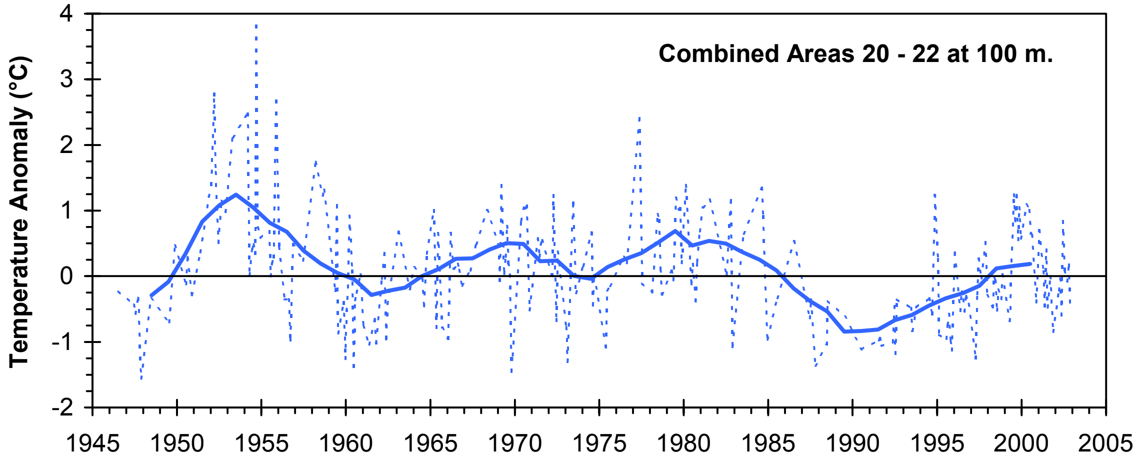

Fig.32. The time series of the monthly (dashed line) and the 5-year running mean (solid line) of the temperature anomalies at 100 m for snow crab fishing Area 20-22 combined.

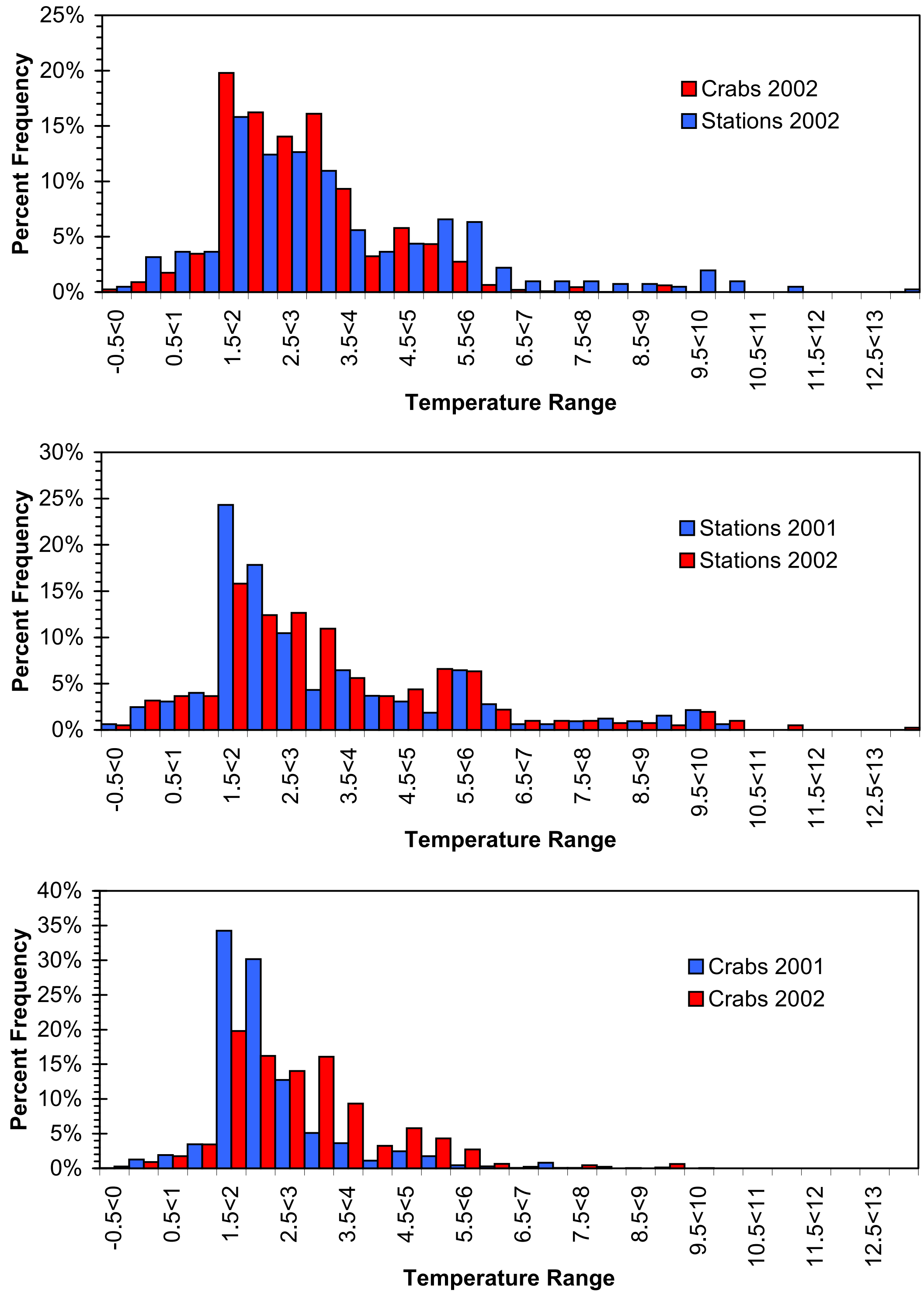

Fig.33. The frequency distribution as a function of temperature for the snow crab catches and for the station occupied during the 2002 Scotian Shelf snow crab surveys (top panel). The frequency distribution as a function of temperature for the stations (middle panel) and for the snow crab catches (bottom panel) from the 2001 and 2002 Scotian Shelf surveys.

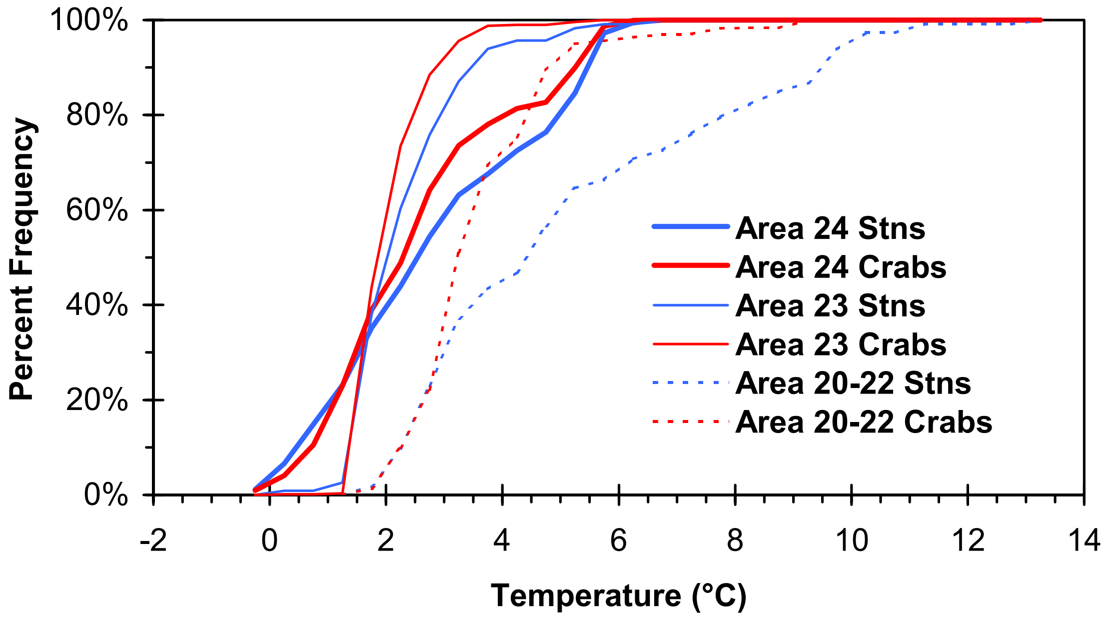

Fig.34. The cumulative frequency distribution as a function of temperature for the stations and for the snow crab catches by fishing area on the Scotian Shelf and Sydney Bight during 2002.

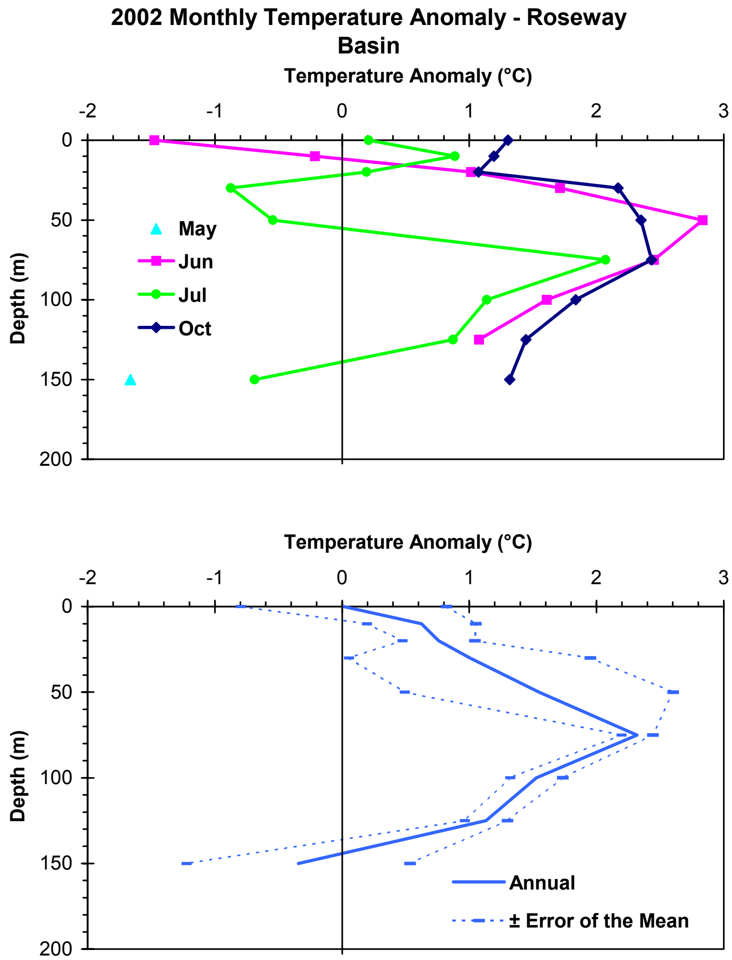

Fig. 35 Monthly mean temperature anomaly profiles (top two panels) and annual temperature anomalies ± error of the mean (bottom panel) for Roseway Basin.

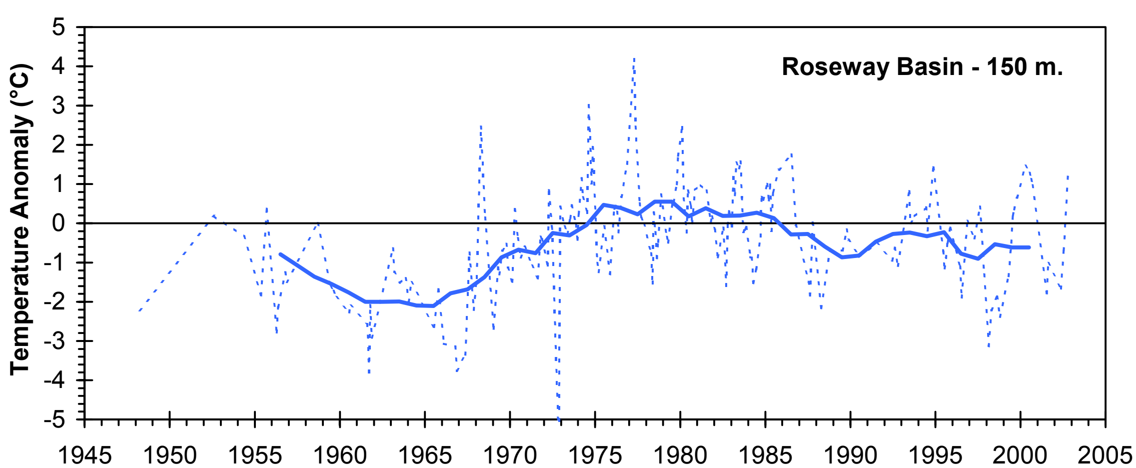

Fig.36. The time series of the monthly (dashed line) and the 5-year running mean (solid line) of the temperature anomalies at 150 m in Roseway Basin.

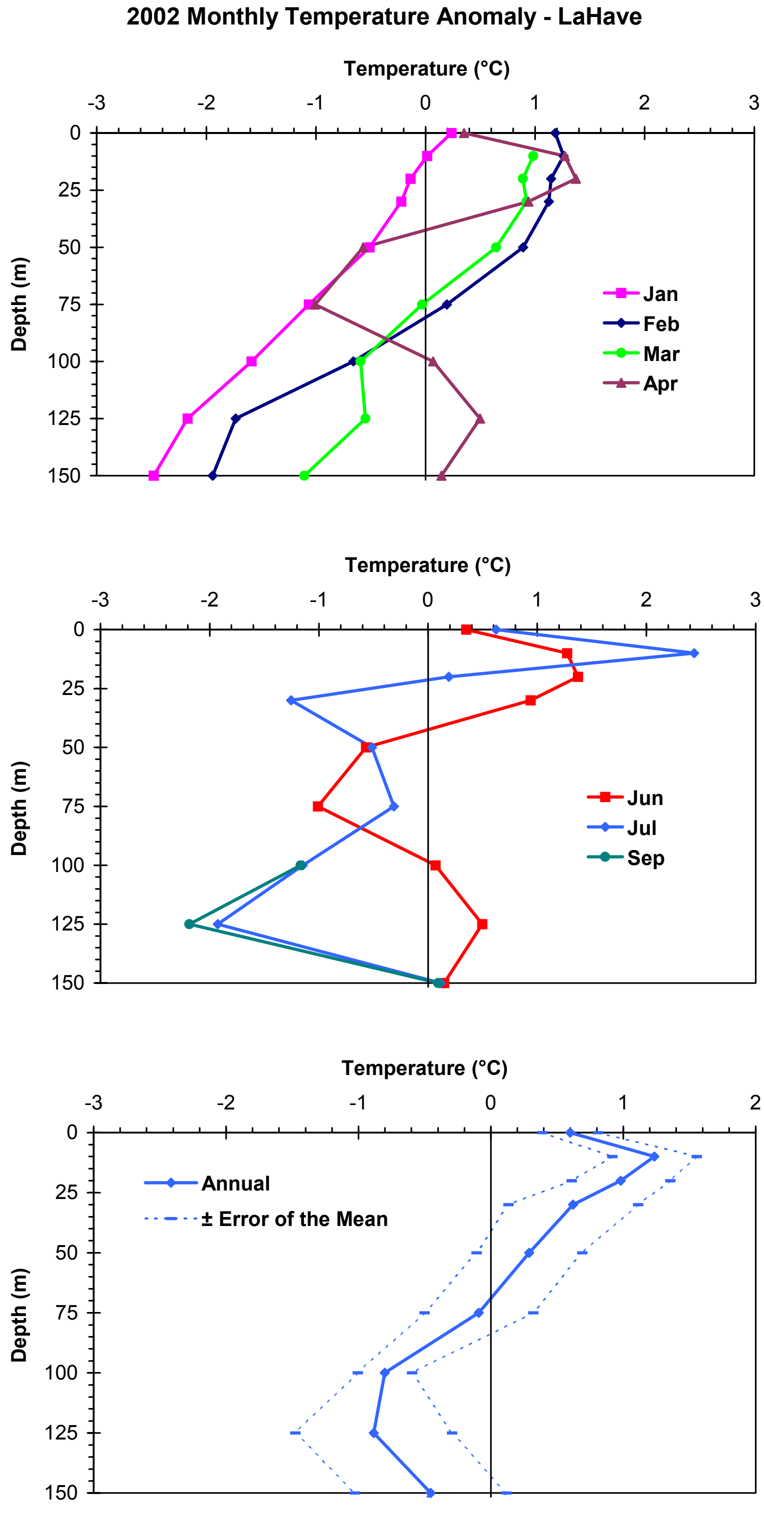

Fig. 37 Monthly mean temperature anomaly profiles (top two panels) and annual temperature anomalies ± error of the mean (bottom panel) for LaHave Basin.

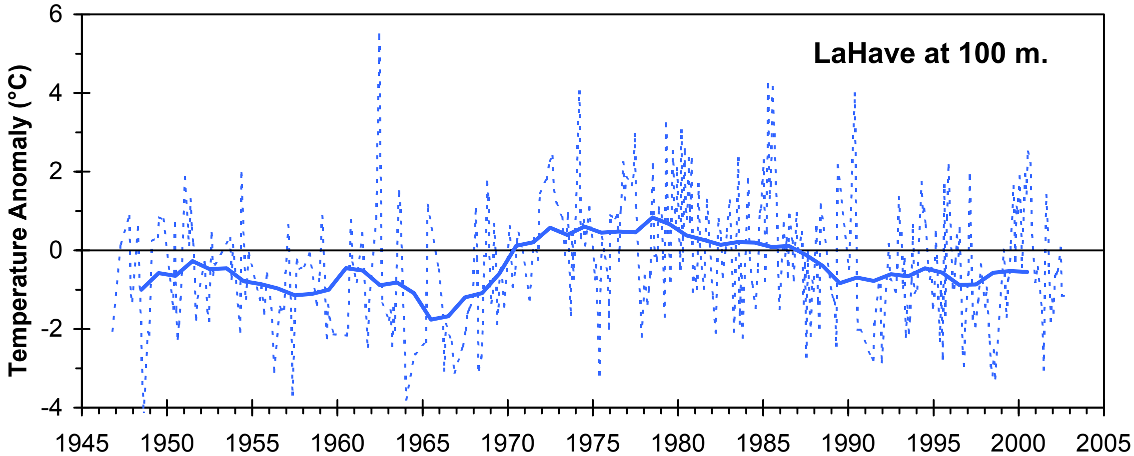

Fig.38. The time series of the monthly (dashed line) and the 5-year running mean (solid line) of the temperature anomalies at 100 m in LaHave Basin.

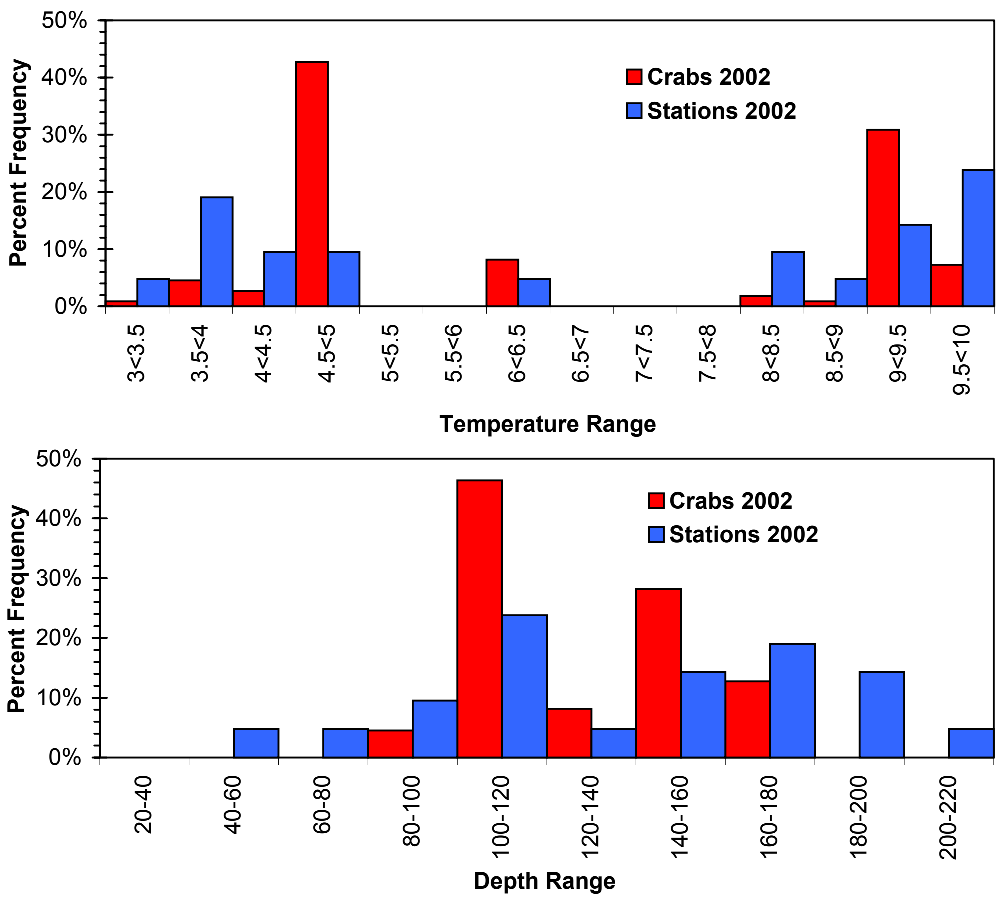

Fig.39. The frequency distribution as a function of temperature (top panel) and depth (bottom panel) for the snow crab catches and for the stations occupied in the vicinity of LaHave Basin during the 2002 snow crab surveys.