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Temperature Conditions on the Scotian Shelf and in the southern Gulf of St. Lawrence during 2000 Relevant to Snow Crab

Conditions de température sur la plate-forme Scotian et dans le sud du golfe du Saint-Laurent en 2000 relativement au crabe des neiges

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Abstract

Temperatures during 2000 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 in the Gulf and Shelf regions was lower than normal and declined from 1999 values. In the Gulf the index was the lowest since 1980 and the second lowest in the 30-yr record while on the Shelf it was the lowest since 1984 and the fourth lowest in its 29-yr record. On Sydney Bight the habitat index increased slightly over 1999 and was 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 warmer-than-average in 2000, which was above 1999 temperatures and the cold conditions during most of the past 15 years. In the central Magdalen Shallows, while mean temperatures were up slightly, the amount of waters <0ºC also increased. The crabs caught during the annual snow crab surveys were found in warmer waters in 2000 than in previous years, which is believed to reflect in large part the availability of warmer temperatures.

Resumé

Les températures des eaux du Canada maritime habitées par le crabe des neiges sont présentées pour l'an 2000. Les données sont tirées de diverses sources, y compris des 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. L'indice d'habitat du crabe des neiges, défini par la superficie du fond où la température de l'eau se situe entre -1 °C et 3 °C, a été calculé dans les zones du sud du golfe, de la grande baie de Sydney et du nord-est de la plate-forme Scotian. L'indice, dans les zones du golfe et de la plate-forme, était inférieur à la normale et il avait diminué par rapport à celui de 1999. Dans le golfe, la valeur de l'indice était la plus basse depuis 1980 et la deuxième plus basse des valeurs enregistrées en 30 ans, alors que dans le cas de la plate-forme, la valeur de l'indice était la plus basse depuis 1984 et la quatrième plus basse des valeurs enregistrées en 29 ans. Dans la grande baie de Sydney, l'indice d'habitat a légèrement augmenté par rapport à celui de 1999 et il était légèrement supérieur à sa moyenne à long terme. De manière générale, les températures 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, étaient supérieures à la moyenne en 2000. Elles étaient supérieures aux températures de 1999 et à celles caractéristiques des conditions froides de la plupart des quinze dernières années. Dans la zone centrale des petits fonds des Îles de la Madeleine, bien que les températures moyennes étaient légèrement à la hausse, on a aussi observé un accroissement des eaux dont la température est inférieure à 0 °C. Les crabes pêchés en 2000, au cours des relevés annuels du crabe des neiges, se trouvaient dans des eaux plus chaudes que celles des années précédentes et on considère que ce fait reflète en grande partie la disponibilité de températures plus chaudes.

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 2000 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 2000 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 2000 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-September (Fig. 3a) and the annual groundfish survey in September (Fig. 3b). On the northeastern Scotian Shelf, the snow crab survey was undertaken during May-June (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 274 bottom temperature stations were occupied in the Gulf and 301 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 198 CTD stations were occupied in the Gulf and approximately 120 of the 218 stations taken during the July groundfish survey were located on the northeastern portion of the Shelf and on Sydney Bight where snow crab are traditionally fished. The remaining CTDs were taken in the central and southwest portions of the Scotian Shelf. The latter was also augmented by bottom temperatures (197 stations) collected during a fishermen conducted survey in July. Other temperature data from the snow crab areas in 2000 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-2000 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 also have included data on snow crab catch and examined their relationship to bottom temperature. Comparison of results from 2000 with previous years' surveys is 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 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 1961-1990 in the historical temperature, salinity database at the Bedford Institute. The 30-year period coincides with that used by the meteorologists and has been used in our previous reports. These climatological means are then subtracted from the values from the 2000 survey. The differences are called temperature anomalies. A negative anomaly indicates that the 2000 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 1999 optimally estimated temperatures from the 2000 estimates. A negative value indicates that 2000 was cooler than 1999, 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 2000 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 2000 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 by averaging the available monthly anomalies, regardless of whether this was 1 or 12 months. 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.

An addition this year is a presentation of the catch of snow crab as a function of temperature for the Gulf and Shelf areas. The temperature in 2000 at which the crabs were caught was partitioned into 0.5°C bins and the frequency distribution of the crab temperatures was expressed in percentages. 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 are made between these 2000 results and those from earlier surveys.

Results

Southern Gulf of St. Lawrence

Bottom Temperatures

On the Magdalen Shallows, data from September 2000 during the groundfish survey showed the typical bottom temperature pattern with a range of <0°C to over 10°C (Fig. 5). The majority of the bottom was covered by temperatures of <3°C with the coldest waters (<0°C) limited to a region to the north of Prince Edward Island (PEI). Most of the Shallows (50-80 m) are covered by temperatures <1°C. From there, bottom temperatures tend to increase 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 2000, the warmest near-bottom temperatures and anomalies in the southern Gulf were in its shallowest regions, in particular around PEI, in Northumberland Strait and in St. Georges Bay where the analysis suggests they reached upwards of 15°C (Fig. 5).

Temperature anomalies on the western half of the Shallows were primarily near to or below normal except in some of the nearshore regions (Fig. 5). The highest negative anomalies were located to the north of western Prince Edward Island. On the eastern half of the Shallows, temperatures were generally above normal with high values around the Magdalen Islands and off eastern Prince Edward Island. The warmest anomalies (above 3°C) were located in eastern Northumberland Strait and St. Georges Bay. This must be viewed with caution, however, since the largest uncertainties in the temperature fields are in the near shore 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 by oceanographers. 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 gradients.

Relative to 1999, bottom temperatures during the 2000 groundfish survey were warmer in regions to the east of the Gaspe, around the Magadalen Islands and off eastern PEI (Fig. 6). In contrast, an almost equal area of the bottom appeared colder than in 1999, principally in the central Shallows, off Cape Breton and in Chaleur Bay. This differs from the warming observed throughout most of the Shallows from 1998 to 1999.

The spatial pattern of the bottom temperatures from the snow crab survey in August-September are similar to that from the groundfish survey (Fig. 7). The major difference is the warmer values in most of the nearshore regions in 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 <0°C water recorded in the groundfish survey. However, over 70% 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. Given these differences, the similarity in the two surveys in the regions outside of the nearshore regions is encouraging.

<u>Snow Crab Habitat Index</u>

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 2000, the area of the bottom of the Magdalen Shallows covered by waters between -1°C and 3°C during the groundfish survey decreased compared to 1999. It was slightly over 48000 km^2 compared to the long-term mean (1971-90) of approximately 52000 km^2 (Fig. 8). The 2000 value represents 69% of the total Shallows area, and was 3% lower than in 1999. It was the lowest area since 1980 and the second lowest in the 30-yr record. Note, however, that the variability in the habitat index for the Shallows tends to be small. The index only varies between 66% and 84% of the total area available over all years. The mean temperature within the habitat area in 2000 fell slight compared to 1999 (by > 0.06°C) but is well above the much colder average temperatures that were recorded through most of the 1990s. The correlation between the habitat index and the mean temperature (1971-2000) 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 as first revealed by Gilbert and Pettigrew (1997) and updated in Drinkwater et al. (2000).

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 (1961-90) 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 8 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 30 m to 75 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 December when these deep temperatures were significantly colder-than-normal. In the top 20 m, temperatures varied from month to month with May and August experiencing colder-than-normal temperatures and the remaining months being warmer-than-normal. The average of all of the months indicate a warmer temperature in the surface layer than usual by around 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 since the mid-1980s, including most of 2000 (Fig. 10). Part of the high month-to-month variability is believed to be due to differences in the extent of the spatial sampling. Recent years, including 2000, indicate a slight warming trend although the temperatures have generally remained below normal. 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 generally positive anomalies (up to 2.5°C at 30 m) in the top 30 m (Fig. 11). 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 and recent years (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 May, June and September in 2000. The mean profiles indicate near normal or warmer-than-normal waters at most depths down to the maximum of 175 m (Fig. 13). Maximum temperature anomalies appeared at 20-30 m being upwards of 2°C. Below this the anomalies were between near normal and 1°C above normal except at 100 m when the anomalies were above 1°C. Above 20 m, temperature anomalies were positive but less than 1°C. The time series at 100 m shows above normal temperatures in 2000, but down from the warmer temperatures recorded in 1998 and 1999. However, they are up from the cold conditions that persisted from the late 1980s to 1997 (Fig. 14).

Data during June, August and September of 2000 were available from **Area F**. In all months, temperature anomalies throughout the water column were above normal. The warmest anomalies were around 20 m in all three months with the highest anomaly (4°C) occurring in August (Fig. 15). The only large negative anomaly was found at 300 m in August. Below 50 m temperatures were generally warmer-than-normal, except in the deepest waters (200 m and greater) during August. The time series at 100 m in Area F is similar to the combined Areas 18-19, i.e. a strong tendency towards below normal anomalies from the mid-1980s to the late 1990s, a general warming since the mid-1990s, and warmer-than-normal temperatures in 1999 and in 2000 (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: June, August, September, November and December. Monthly mean temperatures in the near surface waters varied depending upon the month but below 50 m were predominantly near to or above normal (Fig. 17). The major exception was December when temperatures in the 100-200 m depth range were below normal. The average of the monthly anomalies show significantly above normal values (by 0.3-0.9°C) to 150 m and just slightly below normal between 175-250 m. Maximum positive anomalies were upwards of 2°C. 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). For the first year since the mid-1980s the 100 m data showed significant above normal temperatures in 2000.

Snow Crab Catches by Temperature

The catch of snow crab as a function of temperature and depth during the snow crab survey are shown in Fig. 19. Ninety-four percent of all of the crabs caught in the 2000 Gulf survey were taken in temperatures between –1 to 3°C. While these temperatures were primarily those that were available to the crabs, at least in the stations surveyed, there was a slight tendency for the crabs to favour the colder waters. Comparing the percent frequency of the catch for 2000 for other years when temperature data were available during the Gulf surveys (1988-1995), a higher percentage of the catch in 2000 were found in warmer temperatures (>2°C; Fig. 20). Oddly enough, a higher percentage were also caught in temperatures <0°C. This pattern appears to reflect the distribution of the available temperatures to the crab as there was more warmer waters (>2°C) and more <0°C waters in 2000 than the average of the previous years' surveys.

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 <3°C (Fig. 21). Temperatures were almost exclusively warmer-than-normal with anomalies typically between 0° and 2°C (Fig. 21). They increased relative to July 1999 over almost the entire northeastern Scotian Shelf by upwards of over 1°C (Fig. 22). This is the second year in succession that the majority of the bottom has been covered by temperatures that are warmer than their long-term means after over a decade of colder-than-normal conditions. It also continues the trend of slow warming observed over the past few years in this area.

Bottom temperatures from the snow crab survey in May-June display a similar spatial pattern to that from the groundfish survey (Fig. 23). The major difference is the larger extension of the 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 64% 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 82% 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 2000 was 19870 km^2 representing approximately 28% coverage of the total grid area. This index had been relatively high from the mid-1980s to the early 1990s but has been declining ever since (Fig. 24). 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. 24). 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 2000 when the habitat index declined, the mean temperature increased, although only slightly.

On Sydney Bight, the snow crab habitat index in 2000 increased over the low of 1999 and matched the value observed in 1998 (Fig. 25). It represents slightly over 30% coverage of the total grid area and is again above normal having dropped below normal in 1999. This index has varied between 26-43% since the early-1980s. Prior to 1982, the index was low (generally <20%). The lower percent coverage 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 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 2000 was similar to 1999 and much higher than the values observed during the rest of the 1990s (Fig. 25). The correlation between the average temperature within the index area and the habitat index itself for Sydney Bight is -0.67.

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). Also 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.

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. 26). 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 from 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 2000. With the exception of August and November, temperatures from the surface to the bottom tended to be near to or above normal with the anomalies ranging from 0° to 4°C (Fig. 26). The above normal conditions are reflected in the average of the monthly anomaly profiles labelled as the "annual" mean profile (Fig. 26). The time series at 100 m shows high variability but generally above normal temperatures over most of 2000 (Fig. 27). This is in contrast to the below normal temperatures observed through most of the 1990s but does continue the warming trend observed since the mid-1990s.

On the northeastern Scotian Shelf in Area 23, temperatures were collected in 8 months of 2000 (Fig. 28). Temperatures throughout the water column were predominantly near to or above normal. The only significant negative anomalies were measured below 150 m in September. The "annual" mean again reflects these warm conditions throughout the water column. As in Area 24, the warm conditions in 2000 contrast with the cold conditions between the mid-1980s to 1998 but are consistent with the recent warming trend (Fig. 29).

The temperature data for snow crab fishing Areas 20 through 22 were combined in our analysis. From the 6 months of 2000 when observations were available, temperatures throughout the water column tended to be above normal (Fig. 30). 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. 31). 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 catch of snow crab as a function of temperature and depth during the May-June snow crab survey of the Scotian Shelf is shown in Fig. 32. More crabs were found in warmer waters (only 46% of the crabs were found in waters <3°C and 75% in waters <4°C) compared to the Gulf. This is in large part because of the larger area of warmer waters available to the crabs on the Shelf, although there is still the tendency for the frequency distribution of the crabs on the Shelf to favour the colder waters relative to what is available to them. Comparing the percent frequency of the catch for 2000 for the other year when temperature data were available during the Shelf survey (1997), a higher percentage of the catch in 2000 were found in warmer temperatures (Fig. 33) and may in part be due to the warmer temperatures available to them in 2000 compared to 1997.

Summary

Near-bottom temperatures in the southern Gulf of St. Lawrence (Magdalen Shallows) and in the northeastern Scotian Shelf during 2000 were examined primarily from data collected during the snow crab and groundfish surveys. The snow crab surveys were conducted in May-June on the Scotian Shelf and in August-September 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 (1961-90). Additional temperature data from other fisheries surveys and oceanographic studies in these same areas were also examined.

In the Gulf of St. Lawrence during 2000, warmer-than-normal conditions dominated throughout most of the region. The snow crab habitat index, based upon the area of bottom temperatures preferred by snow crab (-1°C to 3°C), declined relative to 1999 and was at it's 2nd lowest value in the 30-year record. The temperatures within the area of -1° to 3°C is above normal and rose compared to last year, although not significantly. Also in all of the snow crab Areas except 12, the temperatures throughout the water column were above normal. In Area 12, the bottom waters warmed in 2000, but still during most of the year they were around or slightly below the long-term mean. In addition the amount of water <0°C increased compared to 1999 but there was less 0°-2°C water in 2000. The temperatures at which the crabs were caught in 2000 during the snow crab survey appeared to reflect the warmer conditions. Larger numbers of crabs than usual were found in the warm waters, although almost all were still caught in temperatures <3°C.

Even warmer conditions seemed to occupy the northeastern Scotian Shelf region. Above normal conditions were found in the bottom waters of the northeastern Shelf during the July groundfish survey and in most other months of the 2000 where data were available. The warming trend since the early 1990s is continuing and the above normal condtions contrast with 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 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. Kabalen helped in the analysis of the catch and temperature data. Finally, we appreciate the comments of M. Biron on an earlier draft of this paper.

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. 2000. Overview of environmental conditions in the Northwest Atlantic in 1998. NAFO SCR Doc. 00/21, 89 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.

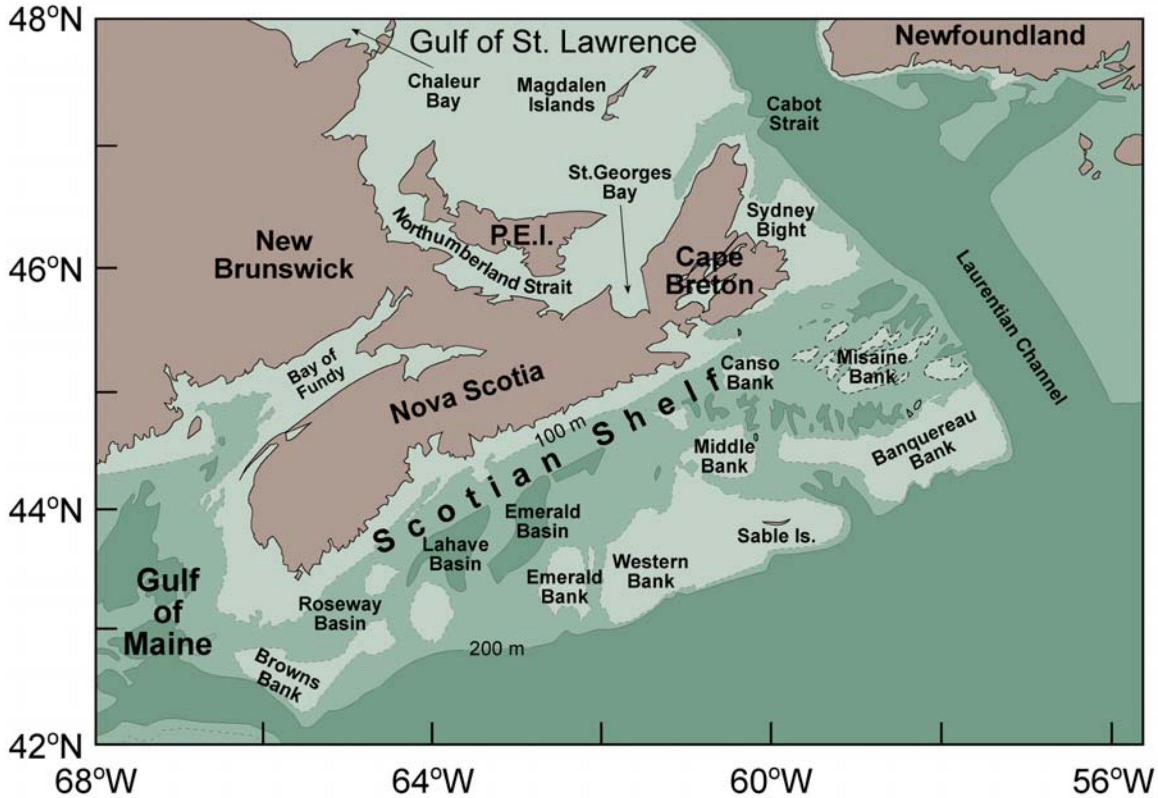


Fig. 1. Chart of the Scotian Shelf and the southern Gulf of St. Lawrence showing geographic and topographic features referred to in the text.

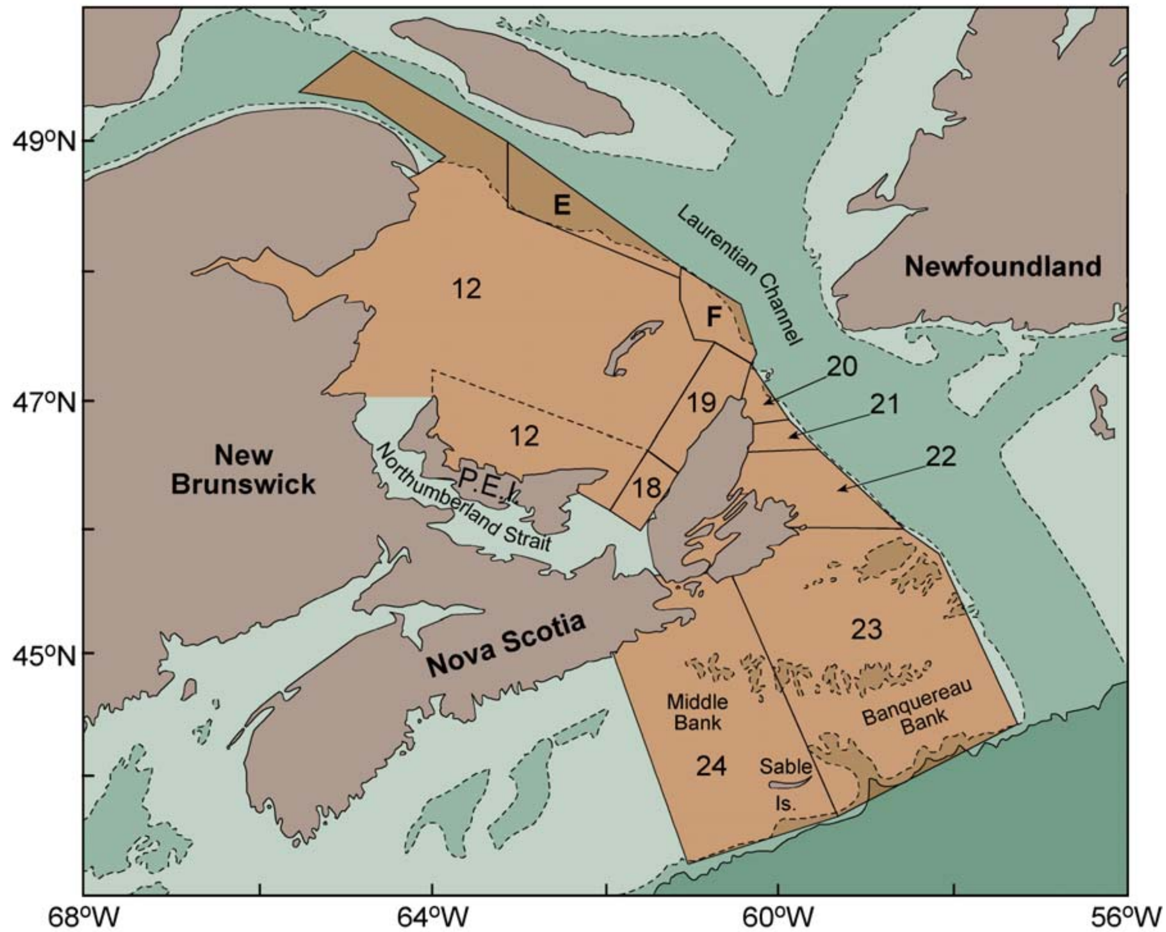


Fig. 2. The southern Gulf of St. Lawrence and Scotian Shelf showing the boundaries of snow crab fishing areas in which monthly mean temperature profiles were estimated. The section of Area 12, north of Prince Edward Island and denoted by the dashed line, is former Areas 25 and 26.

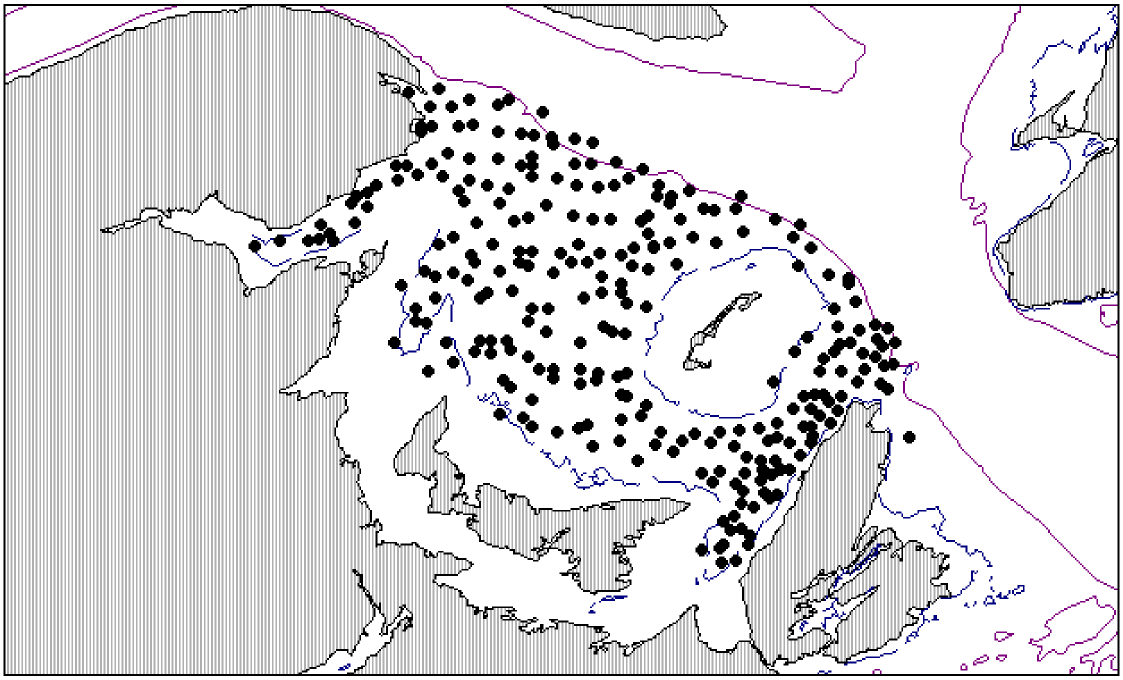


Fig. 3a. The location of the bottom temperature stations during the August-September 2000 snow crab survey.

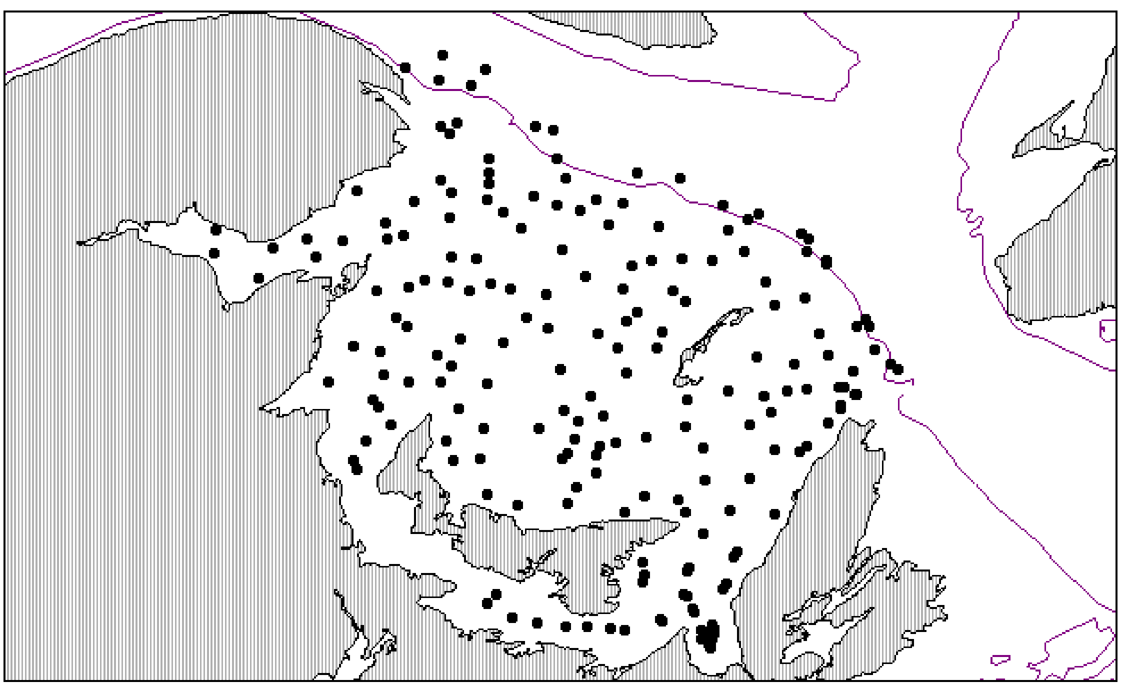


Fig. 3b. The location of the CTD stations during the September 2000 survey.

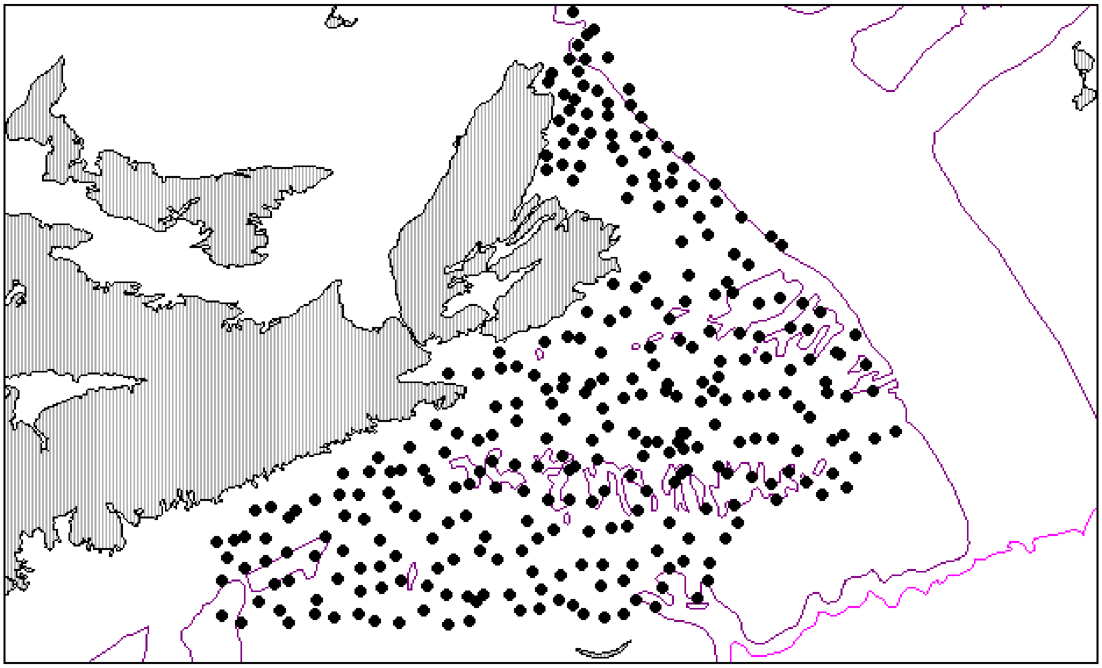


Fig. 4a. The location of the bottom temperature stations during the June 2000 snow crab survey.

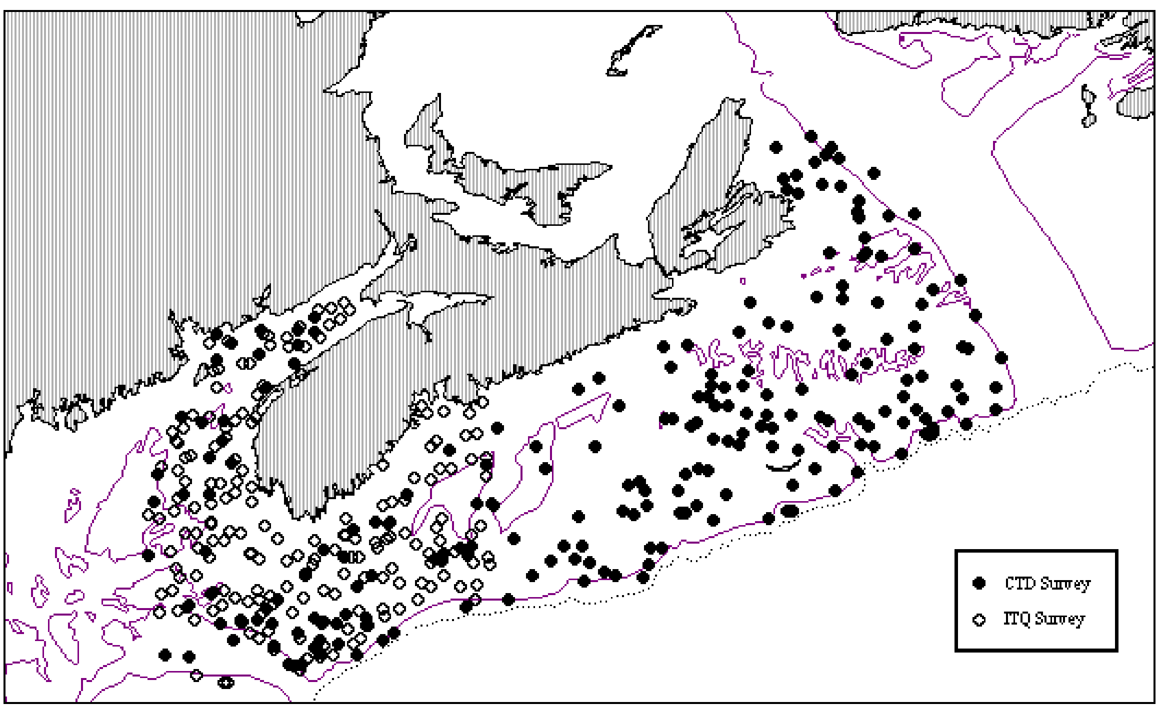


Fig. 4b. The location of the CTD stations during the July 1999 survey. The solid black dots represent the stations taken during the DFO groundfish survey and the open circles denote the stations taken during the fisherman run survey (labelled as ITQ Survey).

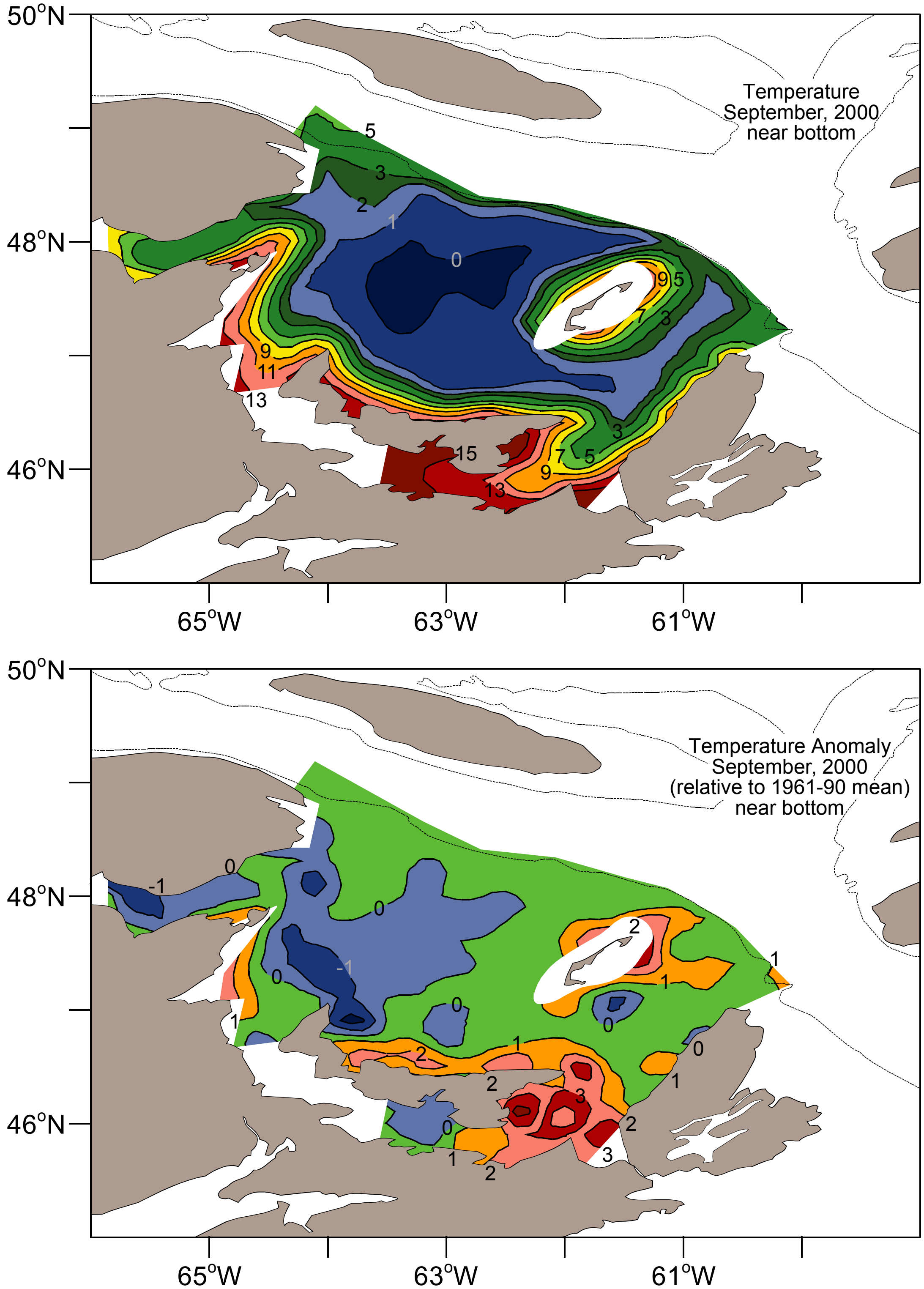


Fig. 5. Near-bottom temperatures (top panel) and their departure from the long-term (1961-1990) means (bottom panel) in the southern Gulf of St. Lawrence during the 2000 September groundfish survey. Regions of colder-than-normal temperatures are shaded in the bottom panel.

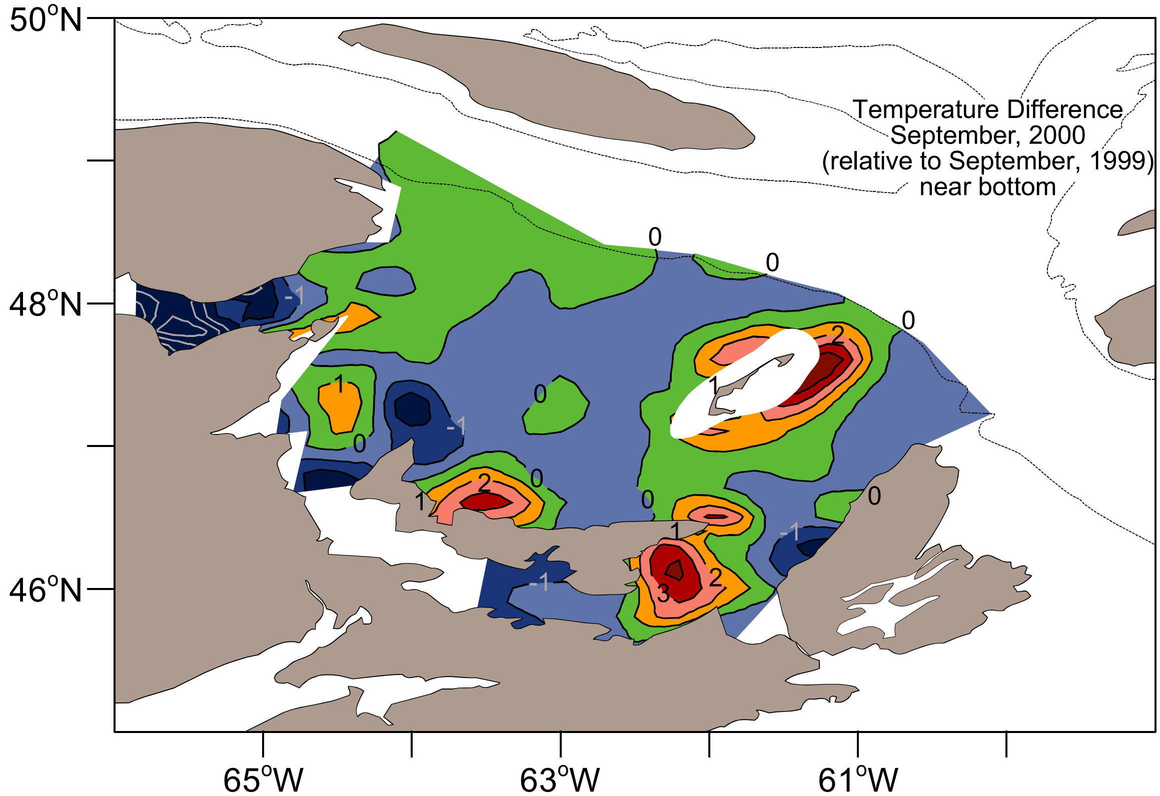


Fig. 6. The difference between the 2000 and 1999 temperature fields in the southern Gulf of St. Lawrence for the September groundfish surveys. Positive values indicate temperatures in 2000 had warmed and negative values that they had cooled. Regions where cooling occurred are shaded.

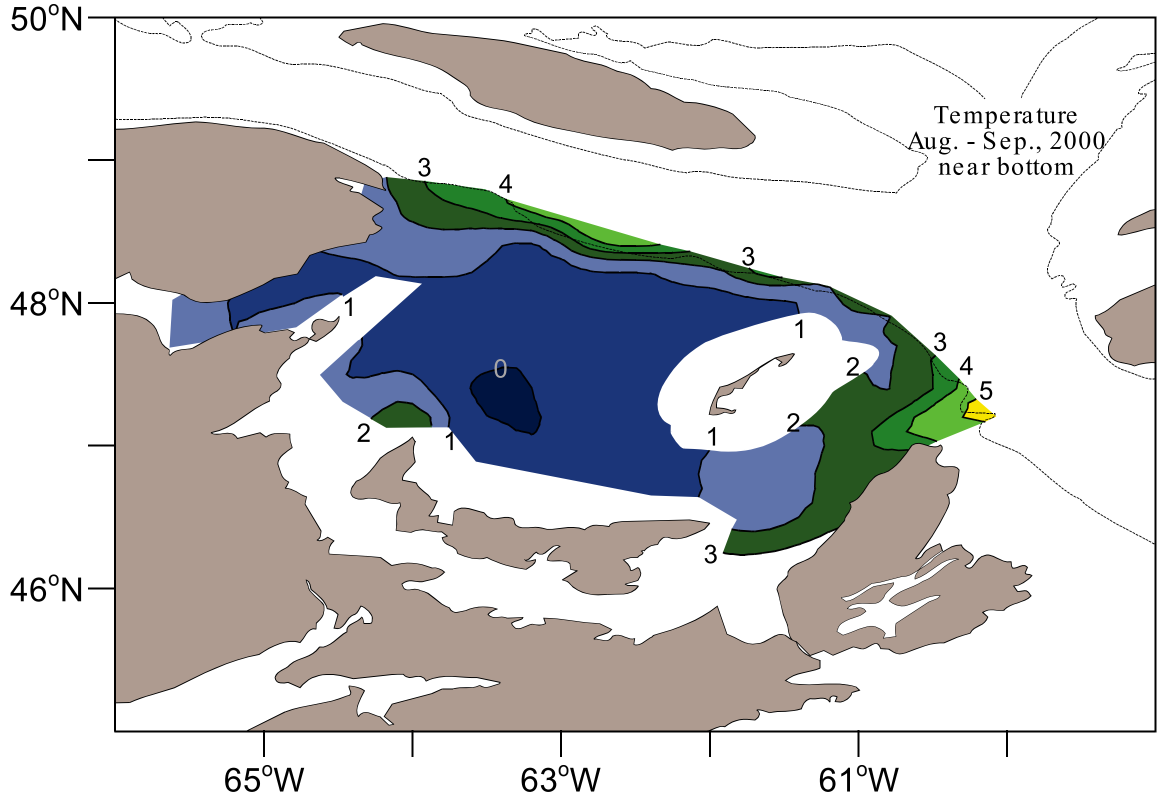


Fig. 7. Near-bottom temperatures in the southern Gulf of St. Lawrence during the 2000 August-September snow crab survey.

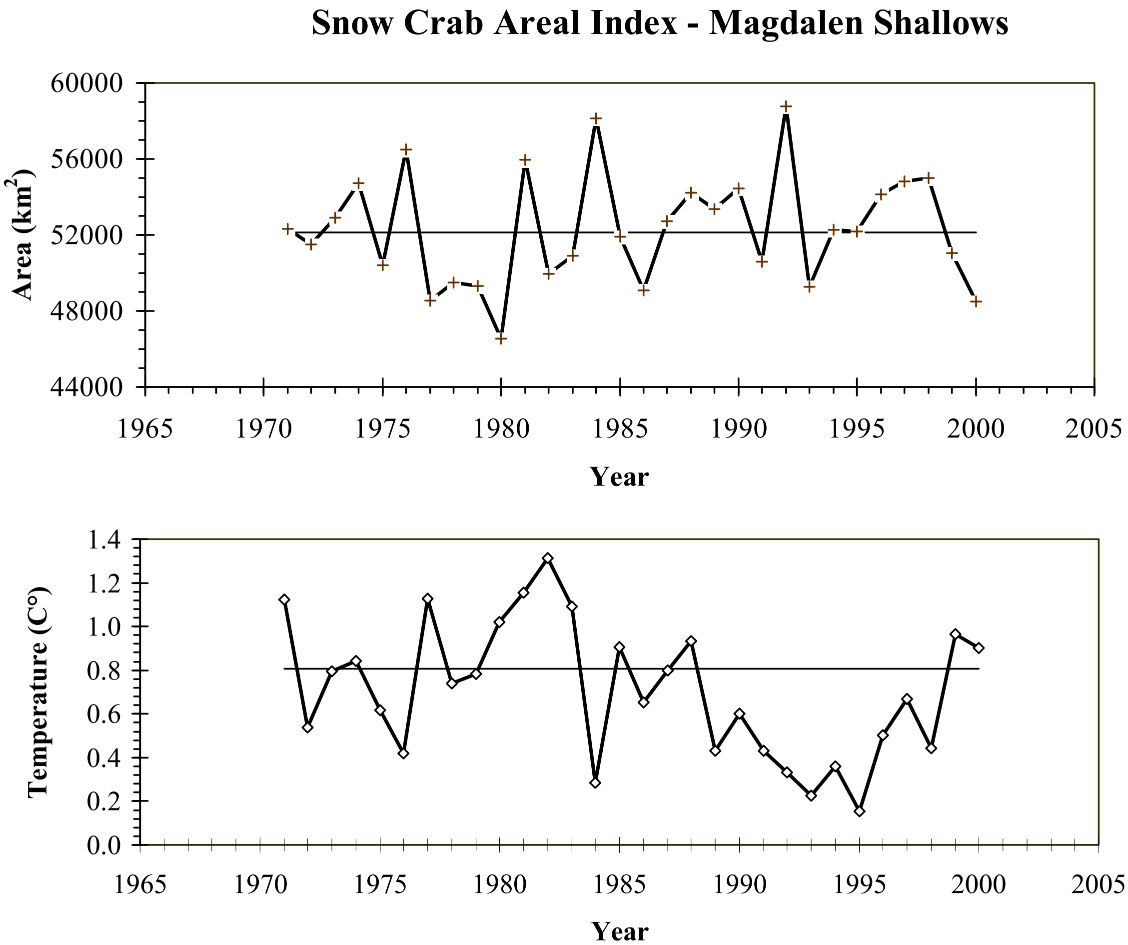


Fig. 8. Time series of the area of Magdalen Shallows covered by bottom temperatures between -1° and 3°C in September (top panel) and the mean temperature within that area (bottom panel). The horizontal lines represent the average over the time series.

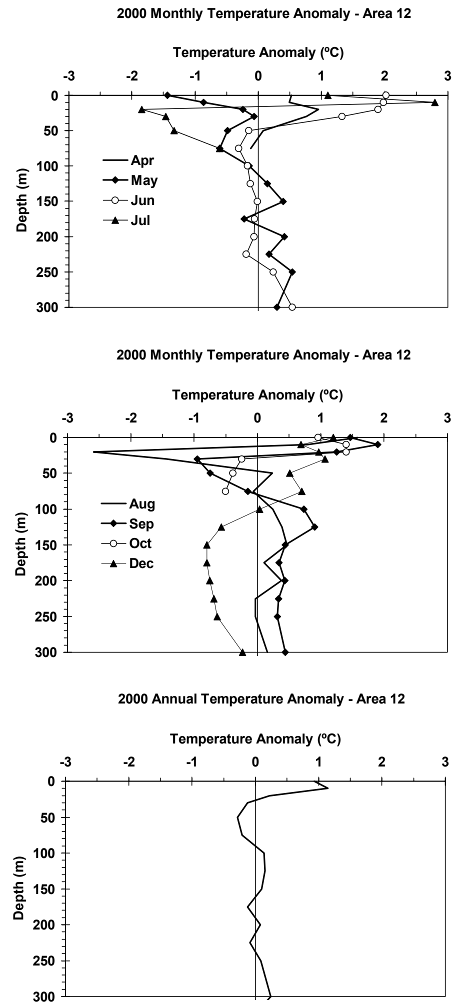


Fig. 9. Monthly (top two panels) and annual (bottom panel) mean temperature anomaly profiles during 2000 for snow crab fishing Area 12.

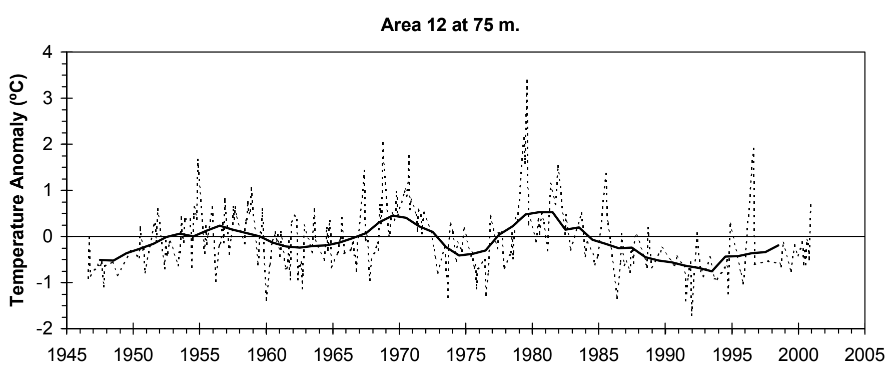


Fig. 10. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 75 m for snow crab fishing Area 12.

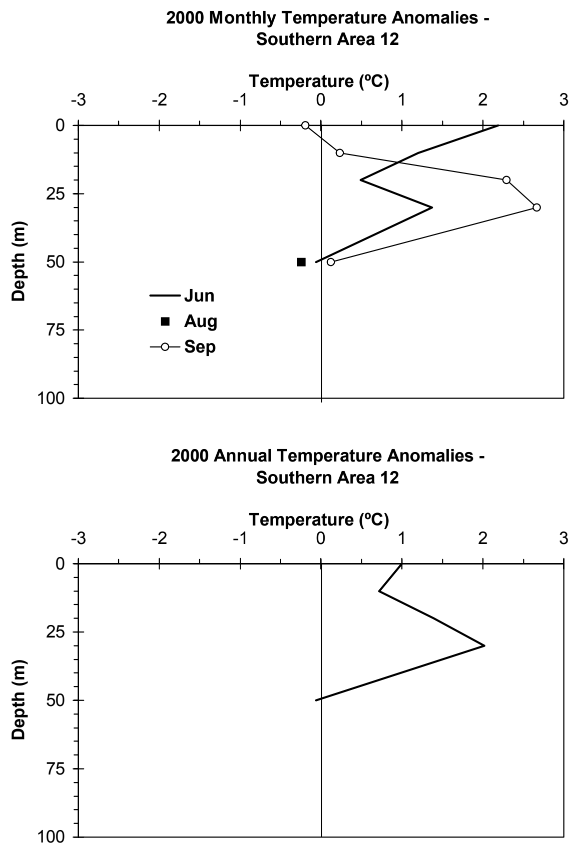


Fig.11. Monthly (top panel) and annual (bottom panel) mean temperature anomaly profiles during 2000 for the southern portion of snow crab fishing Area 12 (formerly Areas 25 and 26).

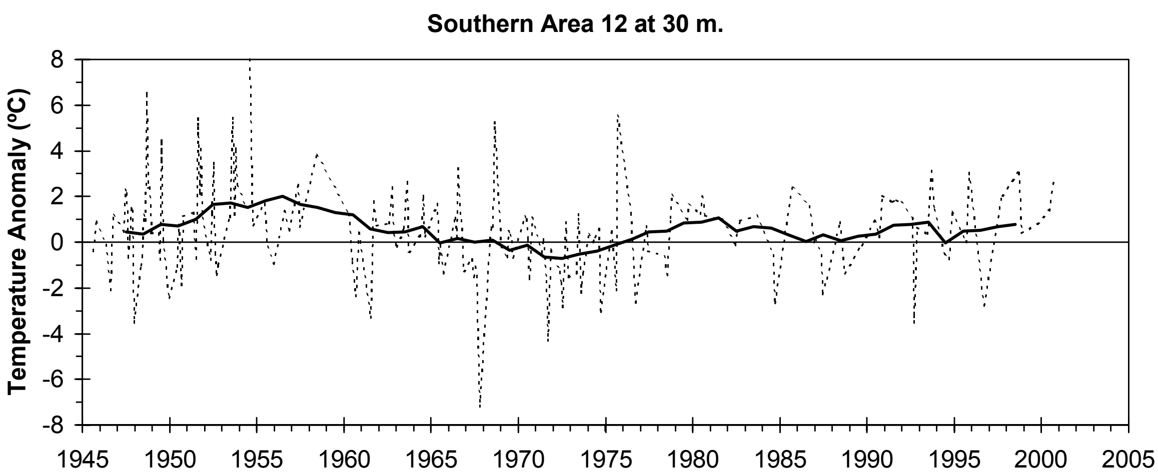
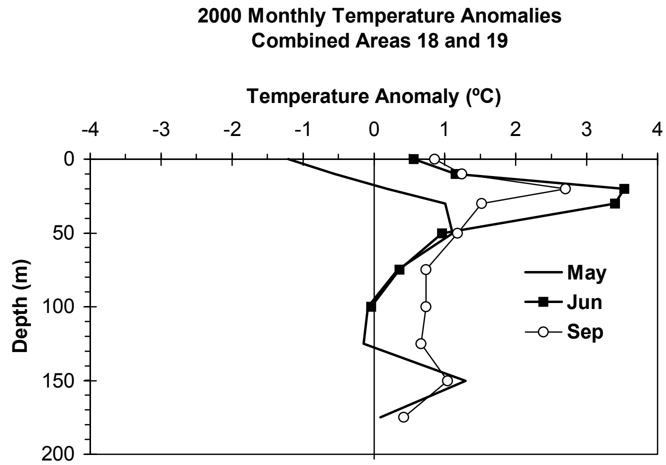


Fig. 12. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 30 m for the southern portion of snow crab fishing Area 12 (formerly Areas 25 and 26).



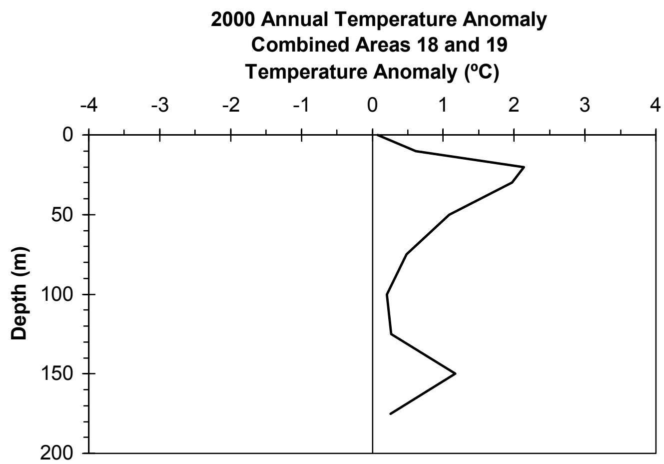


Fig.13. Monthly (top panel) and annual (bottom panel) mean temperature anomaly profiles during 2000 for snow crab fishing Areas 18-19 combined.

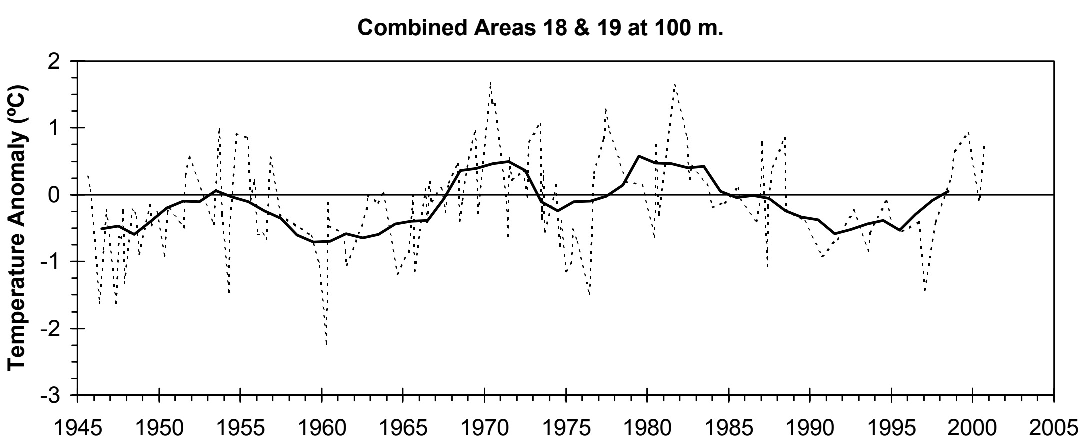
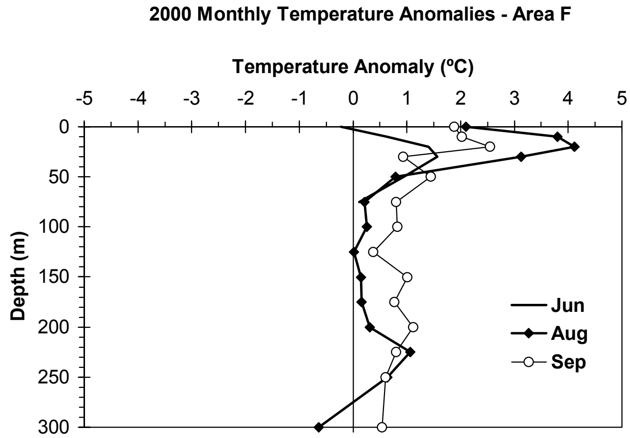


Fig.14. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Areas 18-19.



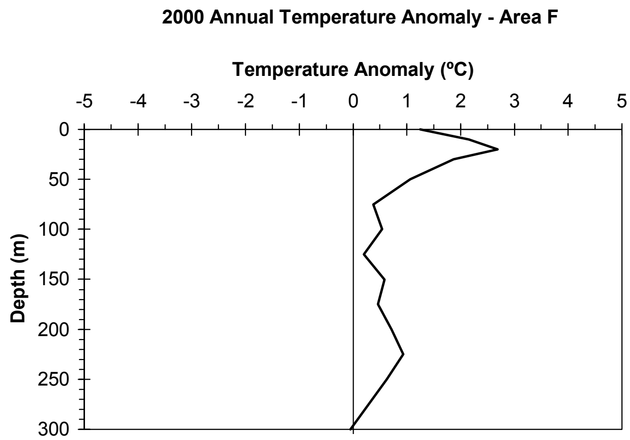


Fig.15. Monthly (top panel) and annual (bottom panel) mean temperature anomaly profiles during 2000 for snow crab fishing Area F.

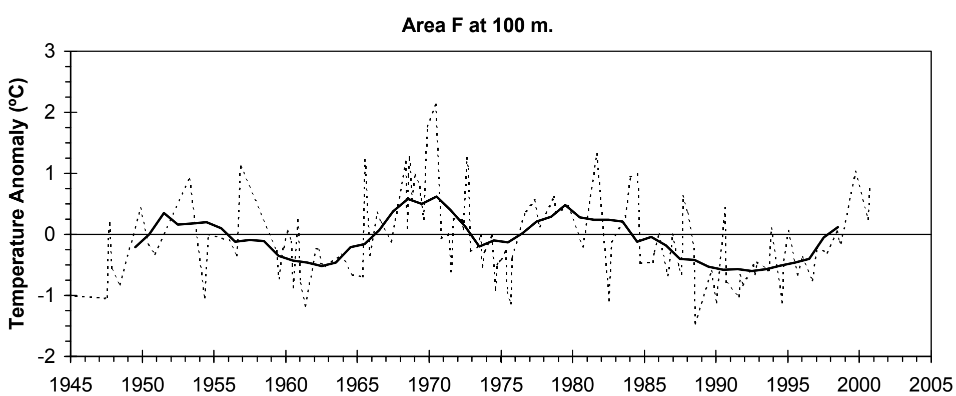
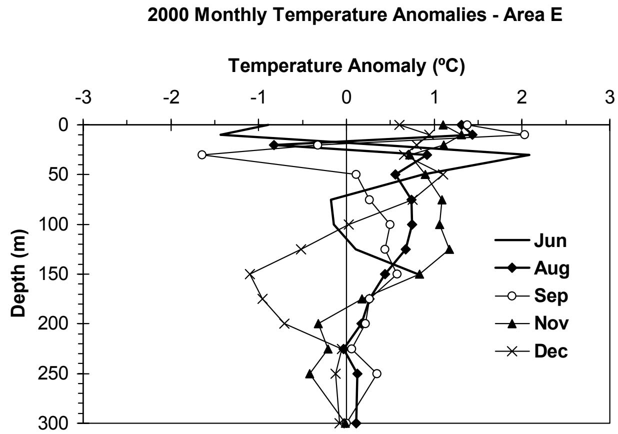


Fig.16. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Area F.



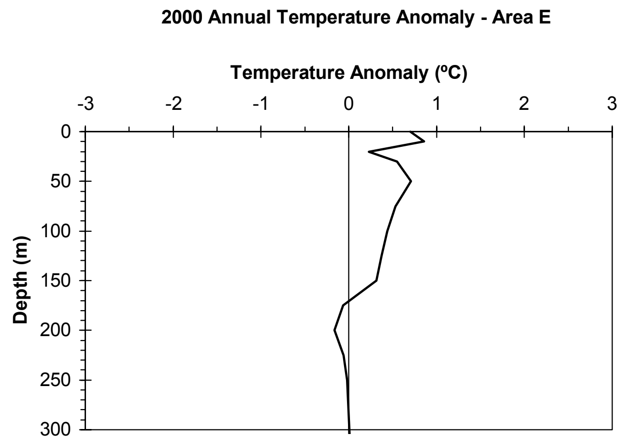


Fig.17. Monthly (top panel) and annual (bottom panel) mean temperature anomaly profiles during 2000 for snow crab fishing Area E.

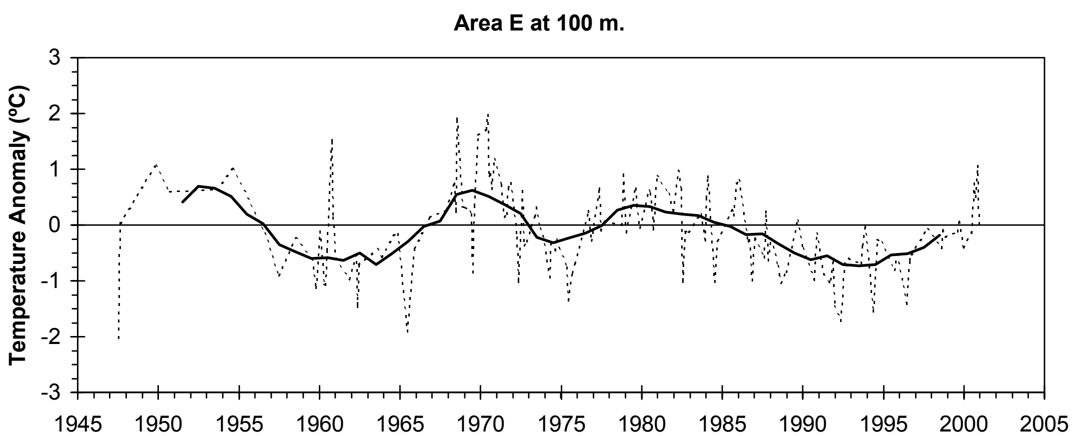


Fig.18. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Area E.

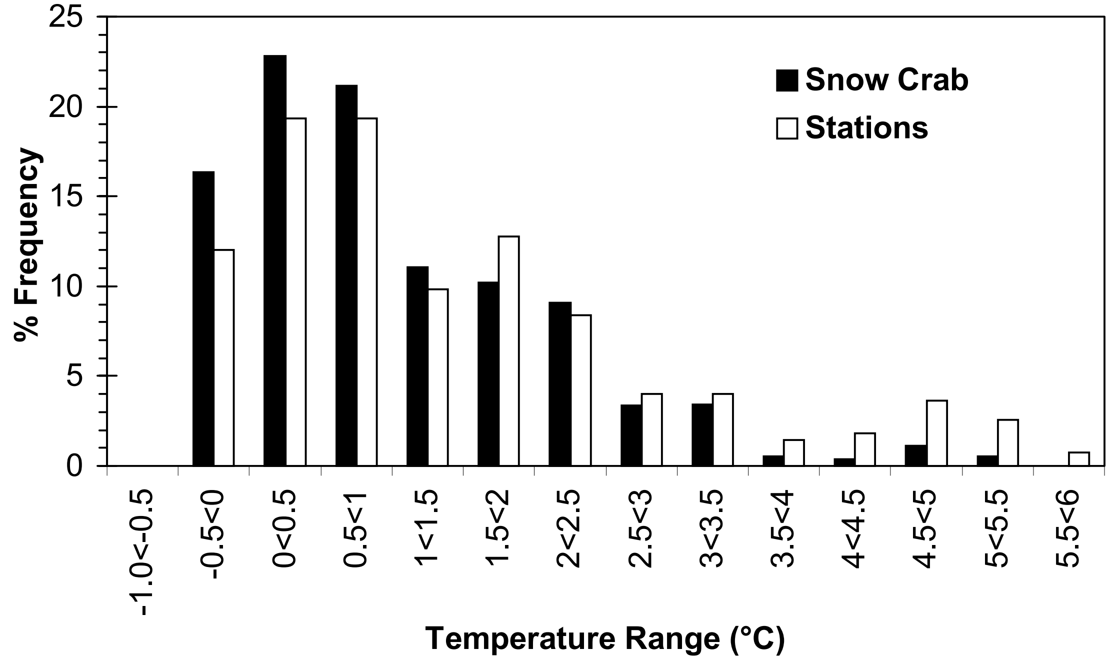


Fig. 19. The frequency distribution as a function of temperature for the snow crab catches and for all of the station locations.

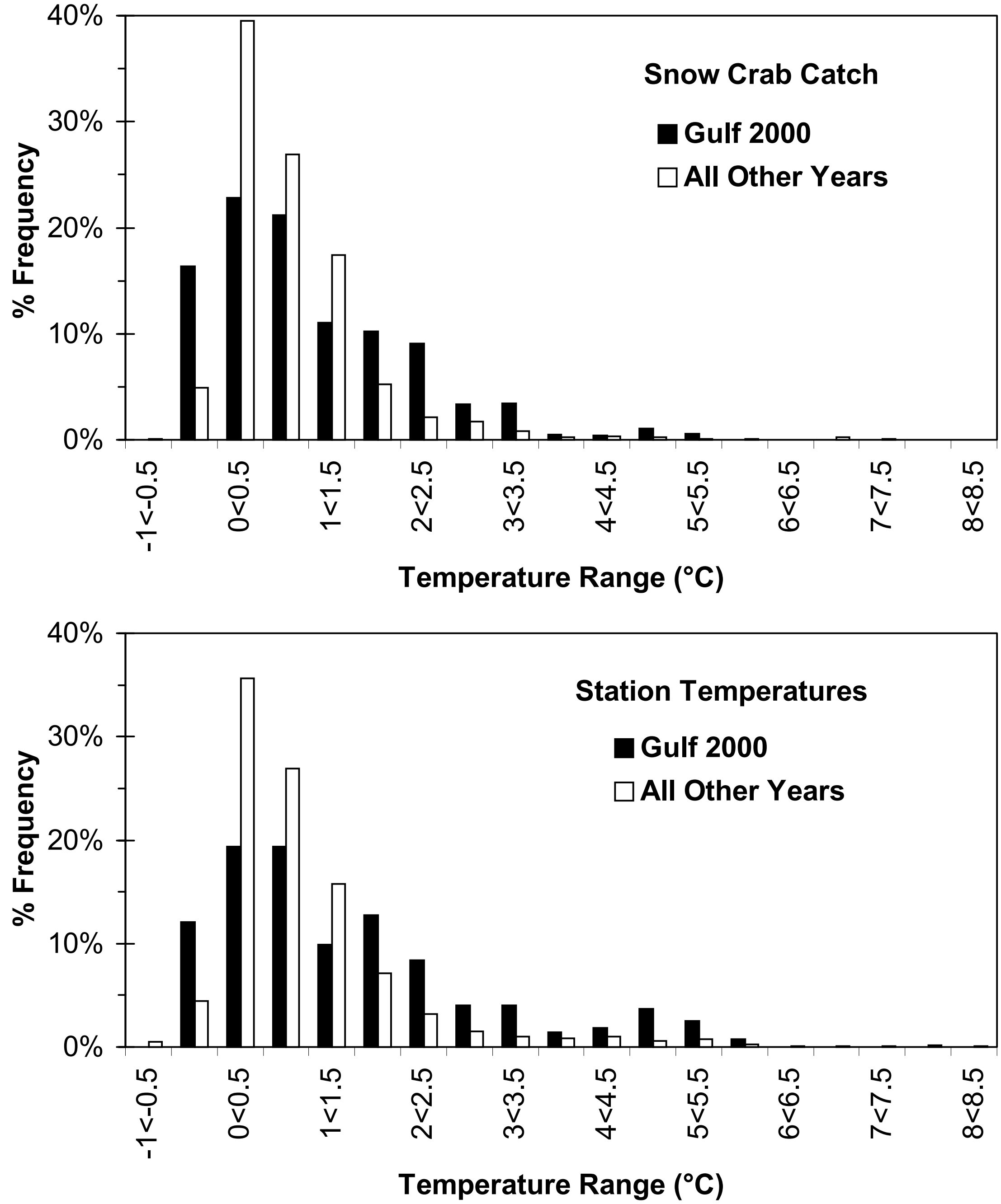


Fig. 20. The frequency distribution as a function of temperature for the snow crab catches (top panel) and for all of the station locations (bottom panel) from the 2000 survey and from all of the other surveys combined.

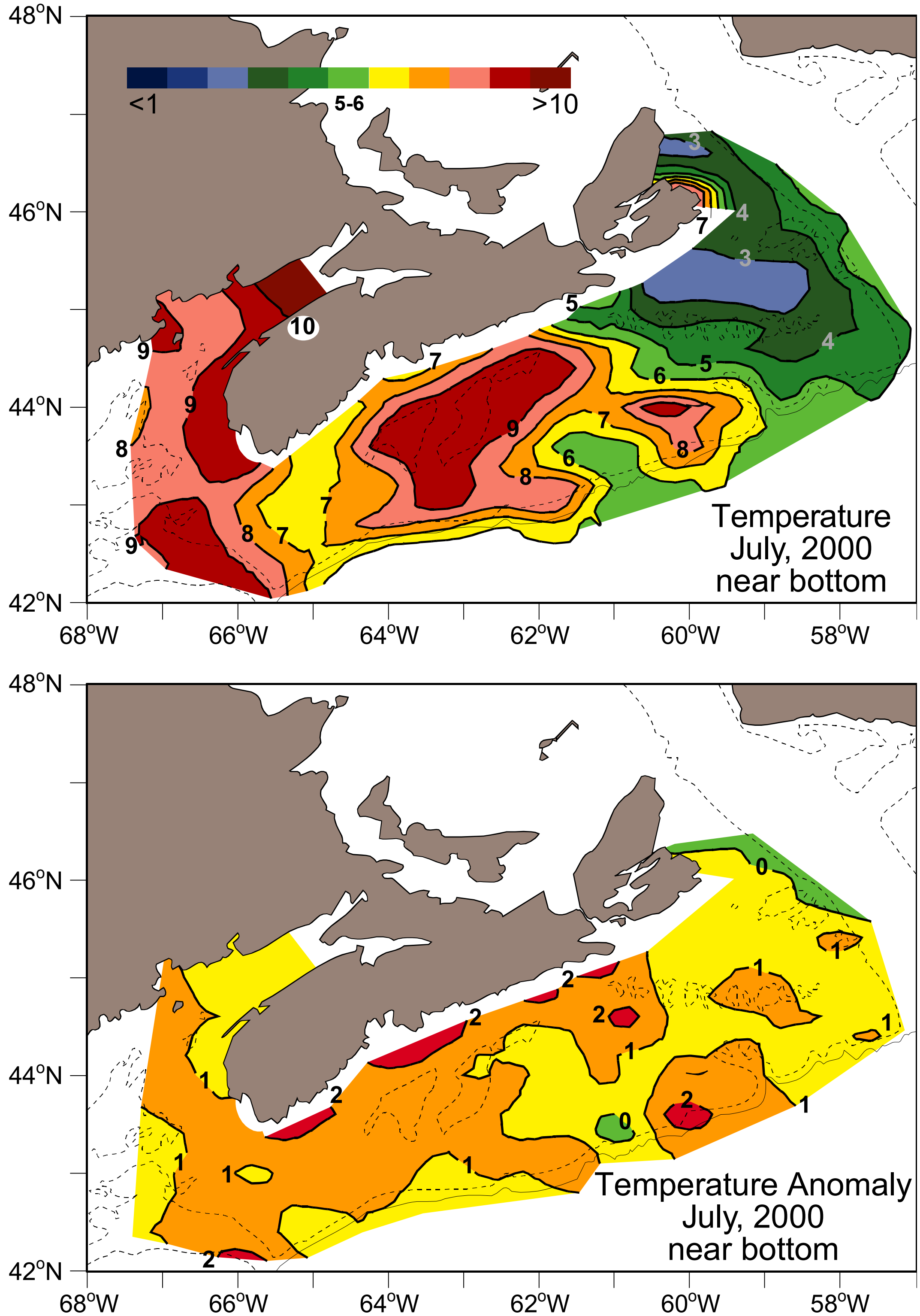


Fig. 21. Near-bottom temperatures (top panel) and their departure from the long-term (1961-1990) means (bottom panel) on the Scotian Shelf during the 2000 July groundfish survey. Note the predominance of warmer-than-normal bottom temperatures (positive anomalies).

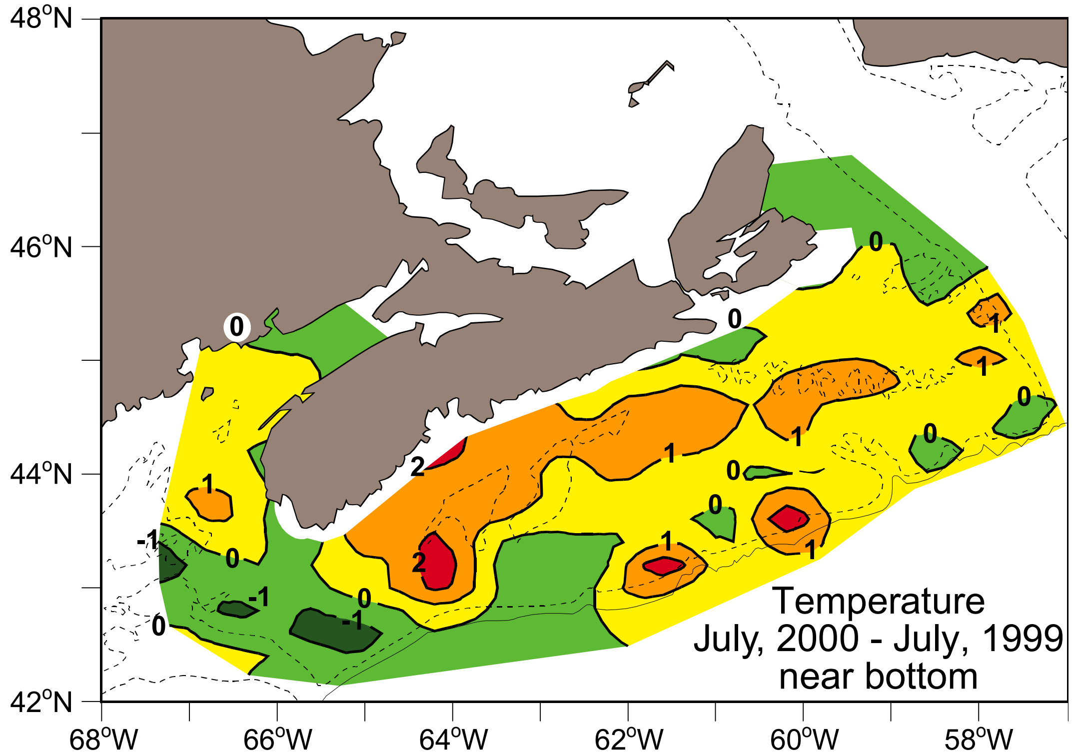


Fig. 22. The difference between the 2000 and 1999 temperature fields on the Scotian Shelf for the July surveys. Positive values (yellow, orange and reds) indicate temperatures in 2000 had warmed and negative values (greens) that they had cooled.

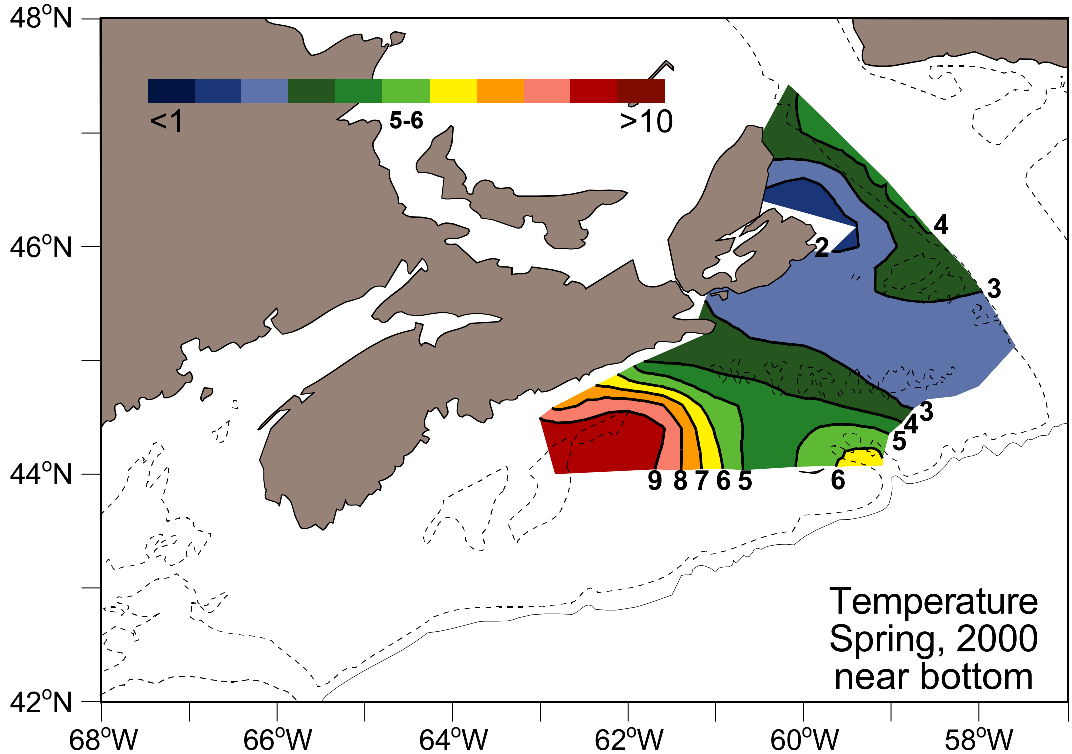


Fig. 23. Near-bottom temperatures in the northeastern Scotian Shelf during the 2000 May-June snow crab survey.

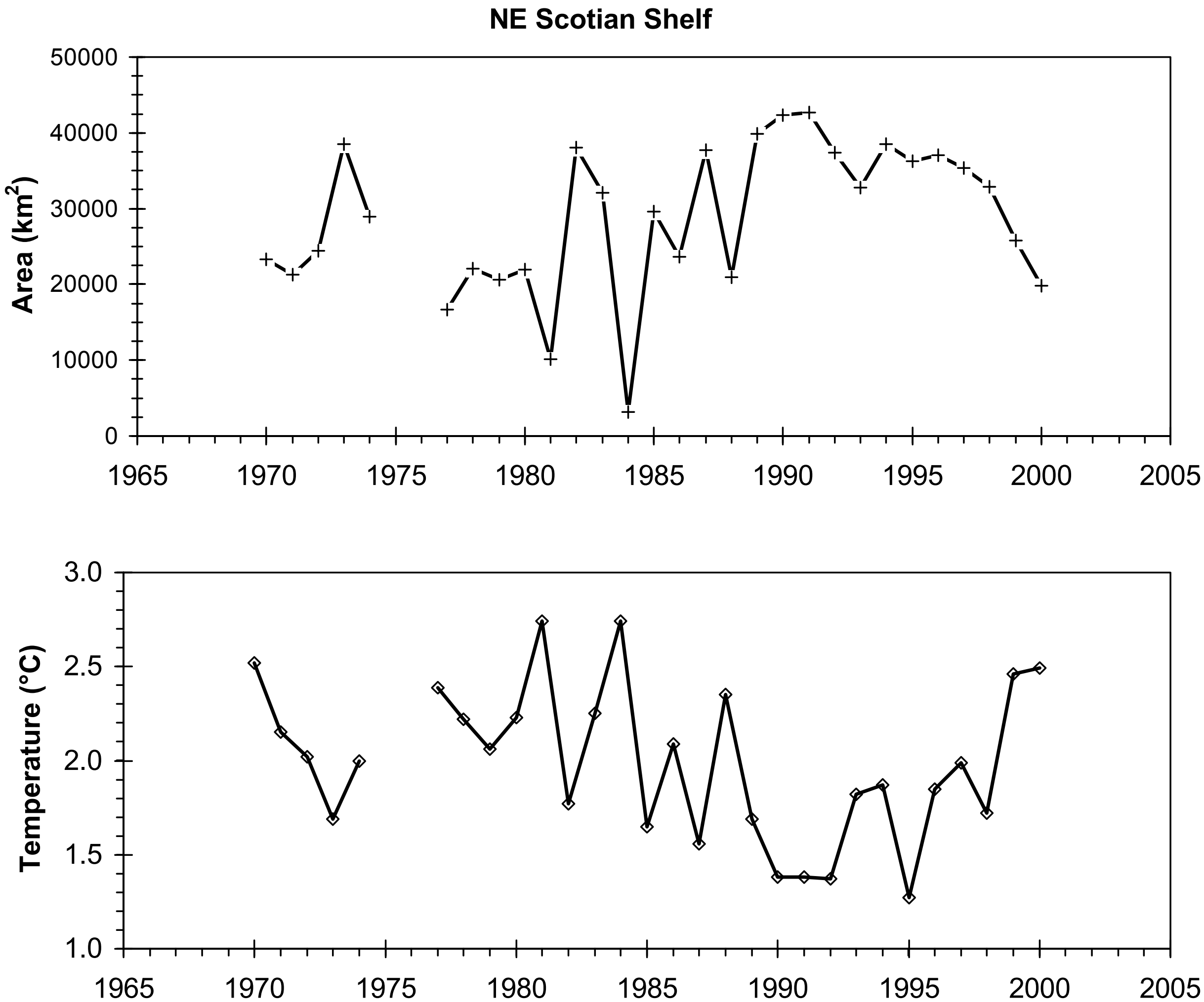


Fig. 24. Time series of the area of the northeast Scotian Shelf covered by bottom temperatures between -1° and 3°C in July (top panel) and the mean temperature within that area (bottom panel). The horizontal lines represent the average over the time series.

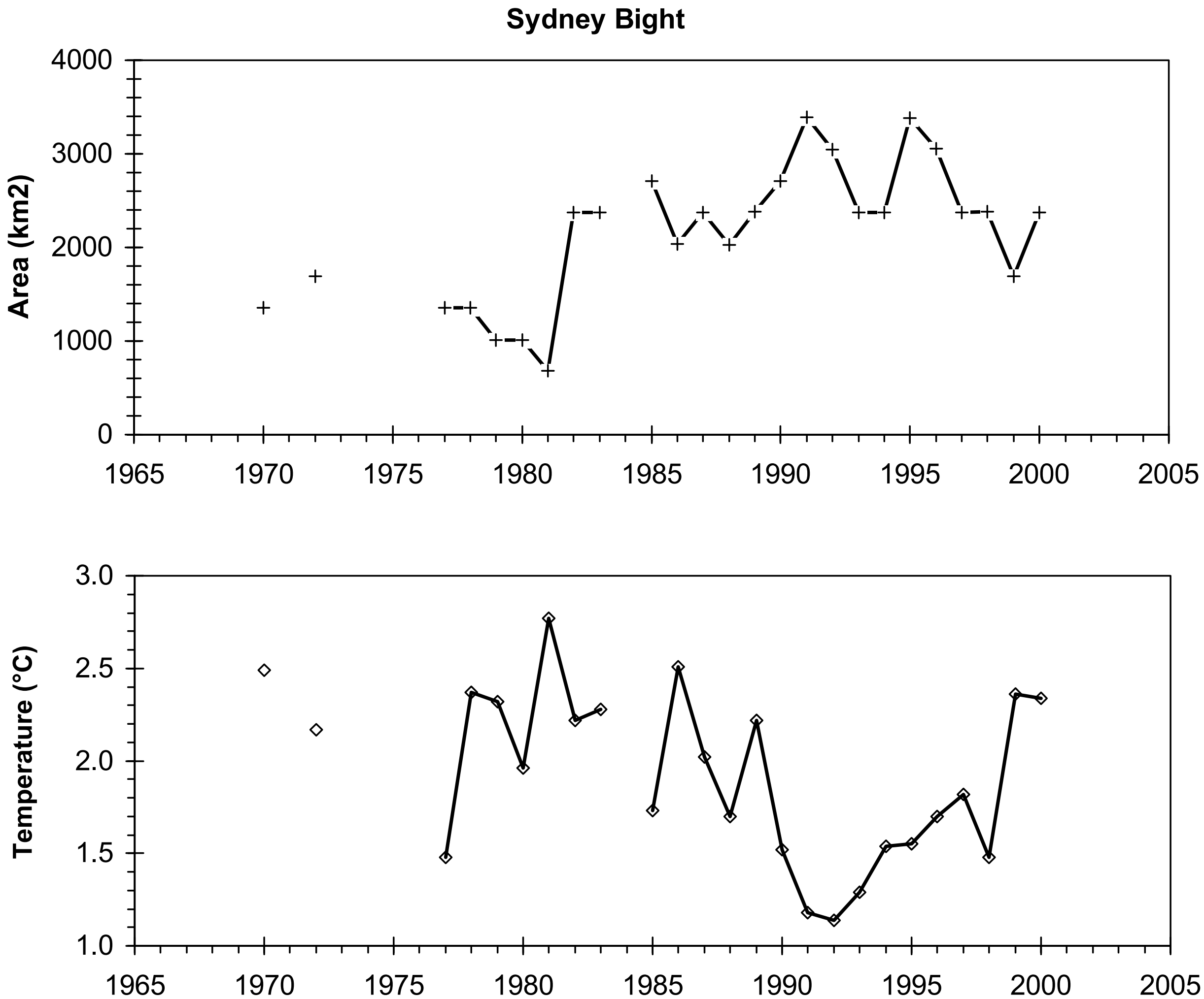


Fig. 25. Time series of the area of Sydney Bight covered by bottom temperatures between -1° and 3°C in July (top panel) and the mean temperature within that area (bottom panel). The horizontal lines represent the average over the time series.

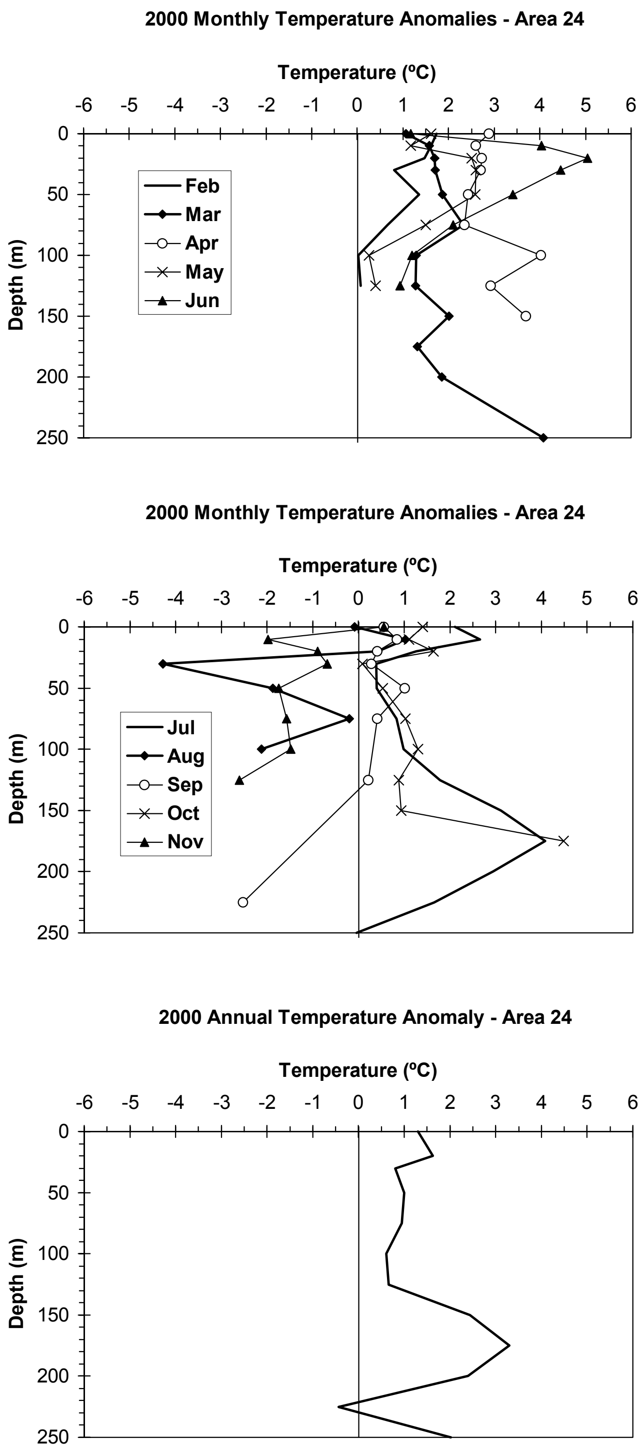


Fig.26. Monthly (top two panels) and annual (bottom panel) mean temperature anomaly profiles during 2000 for snow crab fishing Area 24.

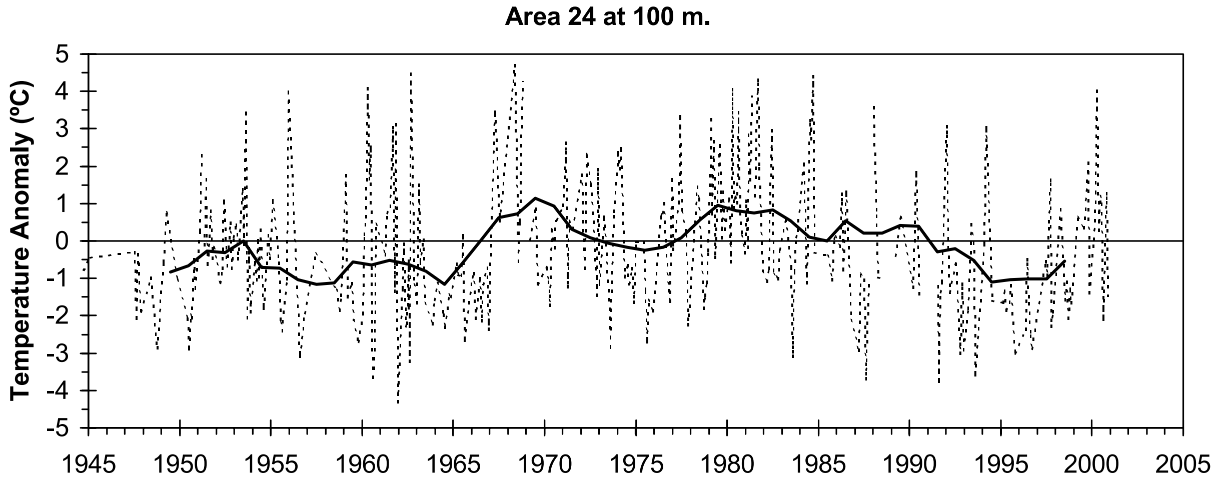


Fig.27. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Area 24.

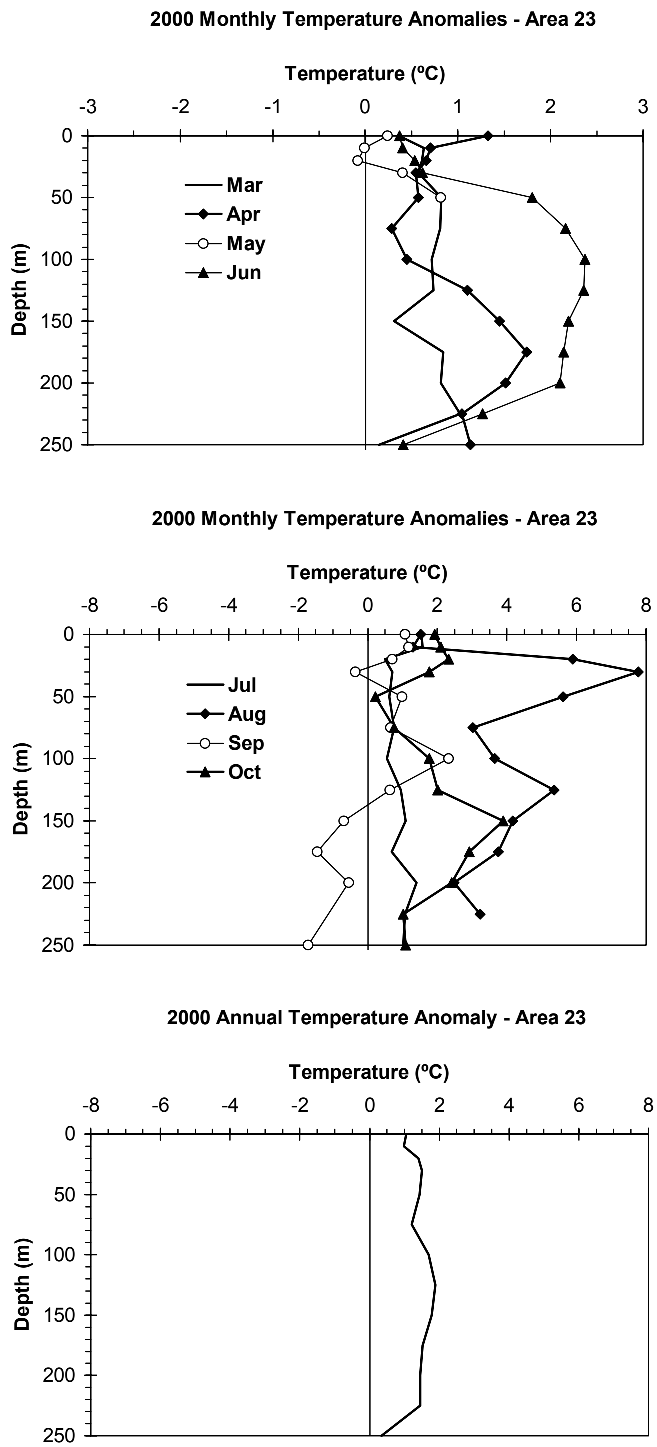


Fig.28. Monthly (top two panels) and annual (bottom panel) mean temperature anomaly profiles during 2000 for snow crab fishing Area 23.

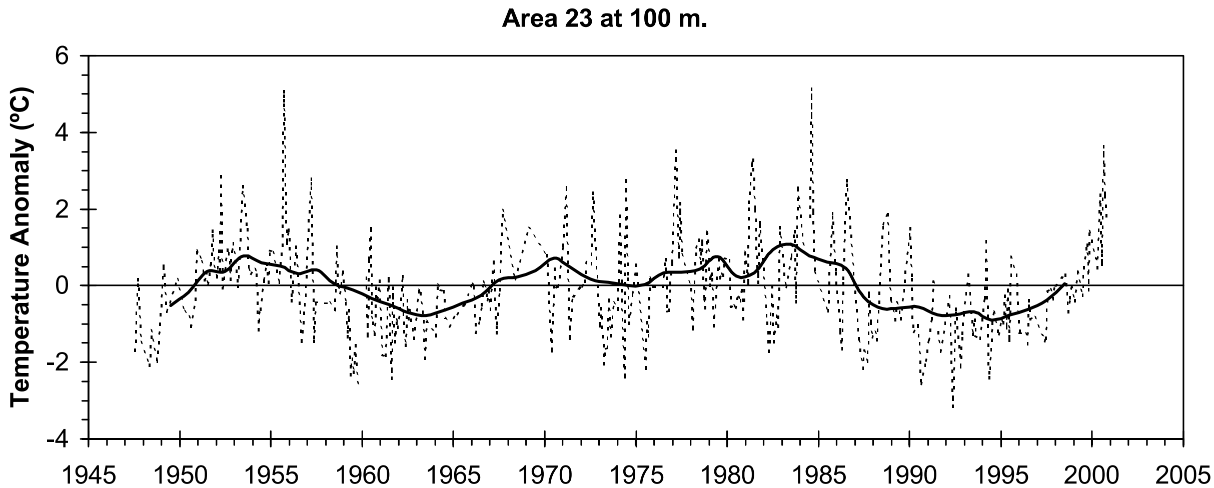


Fig.29. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Area 23.

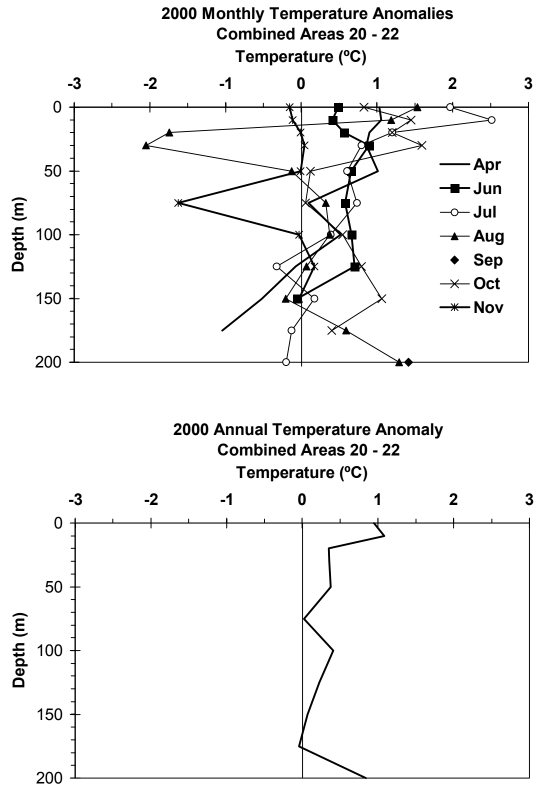


Fig.30. Monthly (top two panels) and annual (bottom panel) mean temperature anomaly profiles during 2000 for snow crab fishing Area 20-22.

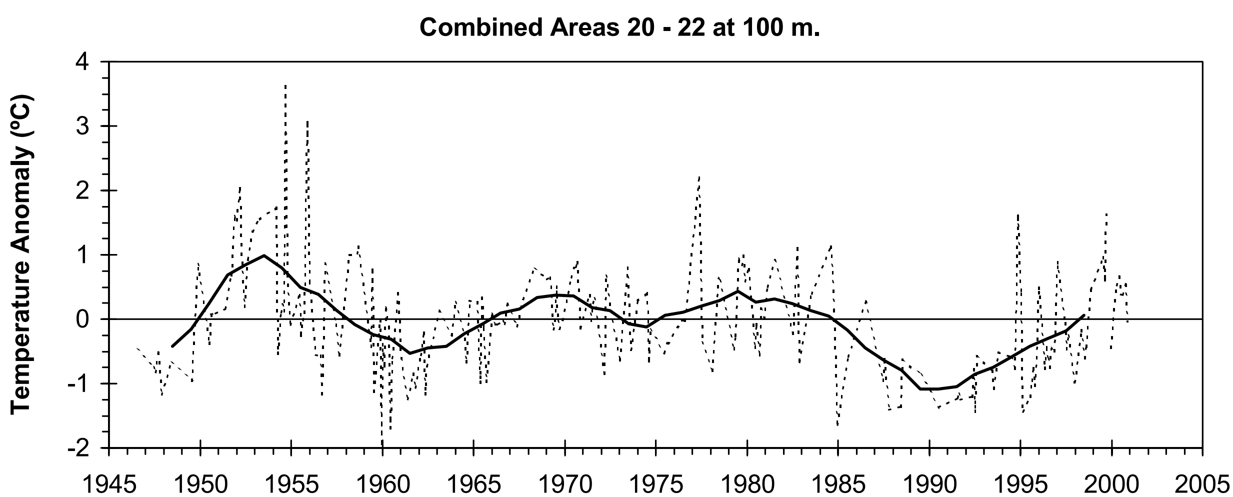


Fig.31. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Area 20-22.

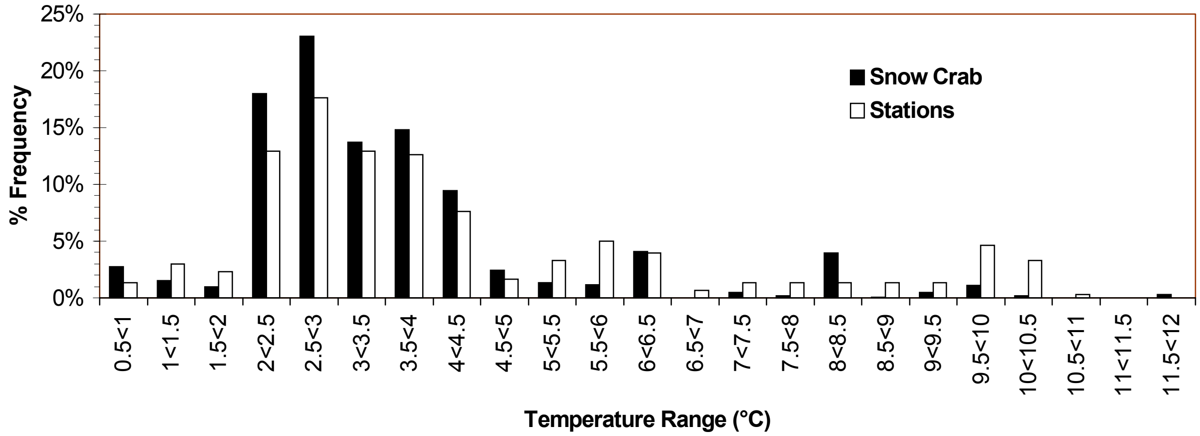


Fig. 32. The frequency distribution as a function of temperature for the snow crab catches and for all of the station locations during the May-June snow crab survey in 2000.

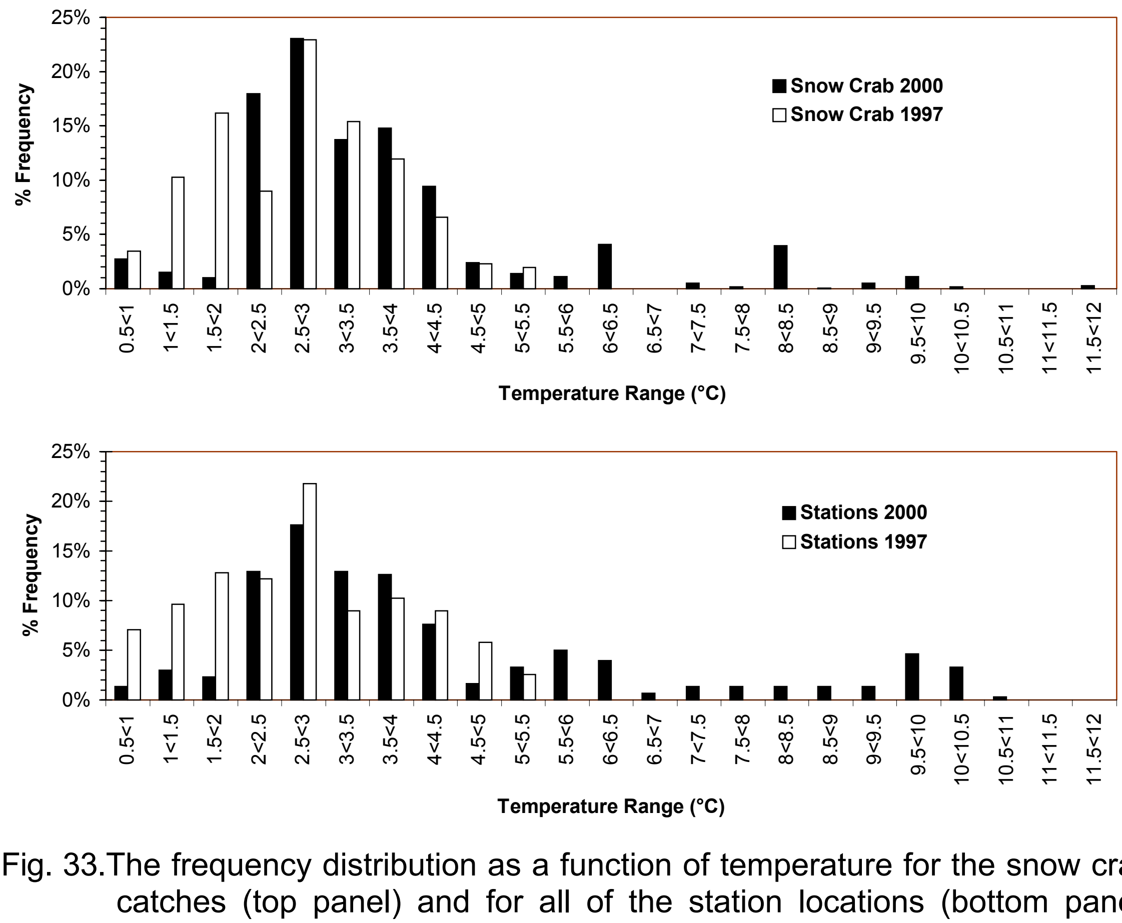


Fig. 33.The frequency distribution as a function of temperature for the snow crab catches (top panel) and for all of the station locations (bottom panel) from the May-June 2000 survey and from the 1997 survey.