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

C S A S — **S C C S**

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

Research Document 2006/045 — **Document de recherche 2006/045**

Temperature Conditions in the Southern Gulf of St. Lawrence during 2005 Relevant to Snow Crab

Crabe des neiges et conditions de température dans le sud du golfe du Saint-Laurent en 2005

J. Chassé, R.G. Pettipas and W.M. Petrie

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

ISSN 1499-3848 (Printed / Imprimé)

Canada

Abstract

Temperatures during 2005 are presented for the waters of Southern Gulf of St. Lawrence inhabited by snow crab. Data were available from a number of sources including snow crab and multi-species surveys. In 2005, near bottom temperatures in the southern part of the Southern Gulf, from Miscou Island to western Cape Breton and all around PEI, were significantly below normal while the deeper parts of the Magdalen Shallows, including Chaleur Bay, exhibited warmer than normal conditions (average based on 1971-2000 period).

A snow crab habitat index, defined by the area of the bottom covered by waters between -1° to 3°C, was calculated for the southern Gulf region. The habitat index is now above the long-term average. However, the mean temperature within the habitat area in 2005 also significantly increased compared to 2004; this is an unusual situation as the two time series are negatively correlated. The mean temperature is above the long term mean, reaching a value similar to the ones observed during the 1999-2002 warm period and is the highest of the last 23 years.

The crabs caught during the annual snow crab surveys were found in warmer waters in 2005 than in 2004, which is believed to reflect in large part the warmer temperatures as opposed to 2004 when cooler conditions were observed.

Resumé

Les températures de 2005 sont présentées pour les eaux du sud du golfe du Saint-Laurent, où habite le crabe des neiges. Les données sont issues d'un certain nombre de sources, y compris les relevés sur le crabe des neiges et les relevés plurispécifiques. En 2005, les températures près du fond dans la partie méridionale du sud du Golfe, qui s'étend de l'île Miscou à l'ouest du Cap-Breton et autour de l'Î.-P.-É., ont été considérablement inférieures à la normale, tandis que dans les parties plus profondes du Plateau madelinien, y compris la baie des Chaleurs, les eaux ont été plus chaudes que la normale (d'après la moyenne établie pour la période allant de 1971 à 2000).

Un indice de l'habitat pour le crabe des neiges, qui est défini par l'aire sur le fond marin caractérisée par des eaux affichant une température qui oscillent entre –1 et 3 °C, a été établi pour la région sud du Golfe. L'indice de l'habitat est maintenant supérieur à la moyenne à long terme. Cependant, la température moyenne dans la zone d'habitat en 2005 a également augmenté de façon significative comparativement à 2004; il s'agit d'une situation inhabituelle du fait que les deux séries chronologiques affichent une corrélation négative. La température moyenne est supérieure à la moyenne à long terme, atteignant une valeur similaire aux températures observées au cours de la période chaude de 1999 à 2002; il s'agit des valeurs les plus élevées des 23 dernières années.

Les crabes capturés pendant les relevés annuels ciblant le crabe des neiges ont été trouvés dans des eaux plus chaudes en 2005 par rapport à 2004, ce qui devrait refléter en grande partie les températures plus chaudes enregistrées comparativement à l'année 2004, qui a été caractérisée par des conditions plus fraîches.

Introduction

Snow crab (*Chionoecetes opilio*) is a cold-water species typically inhabiting bottom depths of 20-400 m. It can be found in water with temperatures as low as -1°C. An active and very lucrative fishery presently exists in the Gulf of St. Lawrence (Fig.1), on Sydney Bight and on the northeastern Scotian Shelf. Annual assessments of the stock abundance, fishing effort, biological characteristics and the environment of the snow crab are undertaken by the combined efforts of the Gulf and Maritimes Regions of the Department of Fisheries and Oceans (DFO) and the snow crab fishing industry in some fishing areas. The purpose of this paper is to provide information on the sea temperature conditions during 2005 in snow crab fishing areas (12, 19, E and F) in the Southern Gulf (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. 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 2005 season is presented and compared to other years when temperature and catch data were available. We also present a timeseries of a new habitat index based on the preferred temperature habitat of commercial male crabs. 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.

Data

Near-bottom temperatures during 2005 in the areas of snow crab fishing were available from two main surveys in the Gulf of St. Lawrence. Around 354 stations were occupied during the snow crab survey conducted from July to September (Fig. 3). The annual multi-species survey (formerly, the groundfish survey) was carried out in September and 139 stations were occupied (Fig. 4). The snow crab survey obtained near-bottom temperatures with a thermistor recorder attached to the trawl. Temperature and salinity data were collected with a conductivity-temperature-depth (CTD) instrument during the multi-species survey. Other temperature data 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-2005 data were taken from the hydrographic database maintained at the Bedford Institute of Oceanography (BIO). This database contains an edited version of the entire MEDS holdings for the region. The catch information, i.e. the number of crabs per tow, is kept in a database maintained at the Gulf Fisheries Centre (GFC).

Methods

The near-bottom temperatures from data collected during the multi-species and snow crab surveys were interpolated onto a specified grid using an objective analysis procedure known as optimal estimation. This is a 4-dimensional interpolation technique; i.e. three space dimensions, two horizontal and one vertical, and the time dimension. In this study the surveys were treated as synoptic and no interpolation in time was carried out. 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 of the Laurentian Channel Shelf was taken as 500 m. The temperature grid has a mesh size of 0.1° x 0.1° latitude-longitude. The estimated bottom temperatures were slightly smoothed for the purpose of contouring, which tends to spread out the gridded values; thus the true gradients could 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 estimations using all available data for the years 1971-2000 in the temperature, salinity database at the Bedford Institute. The 1971-2000 climatological means are then subtracted from the values derived from the 2005 survey. The differences are called temperature anomalies. A negative anomaly indicates that the 2005 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 2004 optimally estimated temperatures from the 2005 estimates. A negative value indicates that 2005 was cooler than 2004, a positive value that it was warmer.

The snow crab habitat index, defined by Drinkwater et al (1998) as the area of the bottom covered by temperatures between -1°C and 3°C (favorable temperature range for the adults snow crabs), was calculated from the gridded temperature fields derived from the multi-species survey. The temperature at each grid point was assigned the area of bottom (0.1° by 0.1°) 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 2005 indices were compared to those derived from earlier surveys. The time series of the indices began in 1971 for the Southern Gulf.

In addition to the bottom temperatures and habitat indices, monthly mean temperature profiles for 2005 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). An "annual" anomaly profile was determined for each year by averaging the available monthly anomalies, regardless of how many months were available. Time series of monthly mean temperatures at representative depths for each area are also provided. Long-period trends represented by 5-year running averages of the "annual" anomalies are also shown.

We also examine the catch of snow crab as a function of temperature. The temperatures at which the crabs were caught were partitioned into 0.5°C bins and the depths into 20 m bins. The frequency distribution of the crab temperatures was expressed in percentages within each of the bins. These were then compared with the frequency distribution of the available temperatures at all of the stations sampled. Finally, comparisons were made between these 2005 results and those from 2004.

Results

Bottom Temperatures

Data acquired during the multi-species survey in September 2005 showed that bottom temperatures ranged from <0°C to over 17°C in the Southern Gulf of St. Lawrence (Fig. 5a). Most of the bottom was covered by waters <3°C with the largest portion of the Magdalen Shallows (50-80 m) covered by waters <1°C. Bottom waters, with temperature <1°C can also be seen in Chaleur Bay. As opposed to 2004, there was no large area showing sub-zero values over the Magdalen Shallows. Bottom temperatures tend to increase from the center of the Magdalen Shallows towards the shallower, nearshore regions and towards the deeper Laurentian Channel. This is because in the Gulf of St. Lawrence during summer, cold temperatures are found at intermediate depths (50-150 m), sandwiched between warm solar-heated upper layer waters and the relatively warm, salty deep waters in the Laurentian Channel. The latter originate from the slope water region off the continental shelf and are transported up the Channel. The cold waters are known as the cold intermediate layer (CIL). Although the deeper waters are warmer than the CIL, their density is greater because of higher salinities. In winter, the CIL merges with the upper layer as the latter cools. The primary origin of the waters in the CIL is from atmospheric cooling of the water within the Gulf of St. Lawrence in winter with additional input through advection of cold Labrador Shelf water through the Strait of Belle Isle. The latter varies annually but with a mean of approximately 35% of the total volume of the CIL (Petrie et al., 1988). In 2005, the warmest near-bottom temperatures in the southern Gulf were in Northumberland Strait and in St. Georges Bay where the analysis suggests they reached 15°-17°C (Fig. 5a).

Temperature anomalies, from the mouth of Chaleur Bay to western Cape Breton and all around PEI, were significantly below normal while the rest of the Southern Gulf, including Chaleur Bay and the deeper parts along the Laurentian Channel, exhibit warmer than normal conditions (Fig. 5b). The negative anomalies were reaching values above -3°C in the area offshore of Miramichi Bay and on the eastern side of Northumberland Strait. The large negative anomalies are unusual for these areas. The highest positive anomalies appeared in Chaleur Bay (+3°C), St. Georges Bay (+4°C) and on the eastern part of the Southern Gulf along the Laurentian Channel (+1-2°C). However, the anomalies in shallow water areas must be viewed with caution since the largest uncertainties in the optimally estimated temperature fields are in the nearshore regions. There are two main reasons for this. First, there tends to be greater temporal variability at shallower depths because they lie close to the strong vertical gradient in temperature, called the thermocline. Indeed, in these regions the mixed layer may at times extend to the bottom in response to wind storms producing large variability in the near-bottom temperatures. Second, the optimal estimation routine extrapolates horizontal temperature gradients to the coast if there are no data inshore. This can lead to fictitious data, especially in regions of strong horizontal temperature gradients.

Relative to 2004, bottom temperatures during the 2005 multi-species survey were significantly cooler in the coastal area extending from Miscou Island to St. Georges Bay, including the coastal waters north of PEI (Fig. 6). The remaining portion of the Southern Gulf, including Chaleur Bay, exhibit warmer conditions than in 2004. The region offshore of Miramichi Bay was especially cooler with a temperature departure of -4°C. As opposed to the situation observed during other years (Chassé et al., 2005), this cooling cannot be explained by under sampling of the area; the spatial coverage being sufficient in both 2004 and 2005. The eastern Northumberland Strait was significantly cooler in 2005 than in 2004 with a difference of over 5°C around Pictou Island.

The bottom temperatures from the snow crab survey in July-September 2005 are slightly cooler compared to those from the 2005 multi-species survey, especially in the shallower regions around the coast (Fig. 7). This might be due to an earlier sampling (some in July) in the case of the snow crab survey than for the case of the multi-species survey (all in September). Usually there is a seasonal deepening and warming of the upper mixed layer, especially in the shallower regions. The mechanism was amplified, in 2005, due to warmer air temperature in the second half of the year. Other possible causes of the differences, besides seasonal warming in the shallow regions, may be differences in instrument accuracy (the CTD being more accurate than the thermistor recorder), a relative rapid point measurement (CTD) versus an average over a trawl distance (snow crab survey), and the difference in depth of the measurement (the thermistor is on bottom while the CTD will be a few to several meters above the bottom).

Snow Crab Habitat Index

From the September multi-species 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 2005. The Southern Gulf 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 2005, the area of the bottom of the Magdalen Shallows covered by waters between -1°C and 3°C during the multi-species survey significantly increased compared to 2004. It was over 53640 km^2 and, for the first time since 2001, it was above the long-term mean (1971-2000) of approximately 52300 km^2 (Fig. 8). The 2005 value represents 77% of the total Shallows area, and was 7% larger than in 2004 and 2% above the long-term mean. The snow crab habitat index in 2005 was the tenth highest value over the 35-year record, with 1984 and 1992 being the highest values. The lowest values were reached in 1980, 1981 and 2002. Note, however, that the variability in the habitat index for the Shallows tends to be small. The index only varied between 66% and 84% of the total area available over all years. The mean temperature within the habitat area in 2005 (1.05°C) increased significantly compared to 2004 (by 0.41°C). The value is above the long term mean and values observed during the 1999-2002 warm period. This contrasts with 2003 when a drastic change was observed after four years when warmer conditions prevailed. The index was still below the long-term mean in September 2004. The 2005 mean temperature, within the habitat, is the highest of the last 23 years. Higher values where reached only in 1971, 1977, 1981, and 1982 (maximum at 1.31 °C). The minimum value (0.15°C) occurred in 1995. This is an unusual year in the sense that both the temperature and the aerial habitat index increased. Usually the two time series are negatively correlated. This brings the correlation between the habitat index and the mean temperature over the years 1971-2004 to a value of -0.45 and which is not statistically significant.

Monthly Mean Temperature Anomaly Profiles and Time Series

The monthly mean temperature anomaly profiles were determined for 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 a few measurements while in other months it was based on over 200 stations. The long-term (1971-2000) mean was then subtracted to obtain a temperature anomaly. In addition to the profiles, temperature time series at depths considered representative of the near-bottom region within each of the fishing areas, are presented. Because of the limited amount of data within the areas over which the averages were made and the possibility of spatial variability in temperature within the areas, any one point or profile may not be truly representative of “average” conditions for the month. Interpretation of any anomalies therefore must be viewed with caution. While no significance should be placed on any individual monthly anomaly, persistent features are considered real.

Data for 2005 over the central Magdalen Shallows (Area 12 in Fig. 2) were available for March to November with the exceptions of May and October (Fig. 9). During March, the anomalies were around normal in the first 100 m, and slightly positive below 100m. In April, the only measurement had a 1°C anomaly at 50 m. The anomalies were negative over most of the water column in June, except around 50 m where they were positive. During July, the anomalies were positive in the first 20 m and between 50 and 100 m, but were close to the normal at other depths. August shows cooler than normal waters in the surface layer (0-20 m) while around normal conditions are seen deeper in the water column. Warmer conditions were evident in September and November in the surface layer. The annual mean shows warmer than normal condition down to 75 m. From >75 to 210 m, which covers the deeper areas of the Magdalen Shallows and the slope of the Laurentian Channel, the annual means are significantly different from zero (lower) even while considering the error of the means. The annual anomaly was above zero below 210 m which is primarily limited to the Laurentian Channel. The time series of monthly mean temperatures at 75 m in Area 12 also shows high month-to-month variability with a definite tendency for below normal temperatures over most of the period since the mid-1980s to 1999 and closer to normal temperature since that time (Fig. 10). Part of the high month-to-month variability is believed to be due to differences in the extent of the spatial sampling but the long-term pattern matches that observed elsewhere and is considered real. In 2005, temperatures were cooler than the long-term mean at the beginning of the year but they were warmer than the average in the second half of the year.

Temperatures within fishing Area 19 along the Gulf side of Cape Breton Island were also used in this analysis. They include deep data (>150 m) from the Cape Breton Trough. Measurements were available for January, March to June, September and November in 2005 (Fig. 11). The conditions were very close to normal in the surface layer from January to June while deeper depths were cooler than normal during these months. The surface of the ocean was significantly warmer in September and November with an anomaly of over 4°C. The annual average shows warmer than normal conditions down to around 100 m, cooler than normal conditions between 100 and 180m and warmer than average in the deep portion. However, these averages are based on few data and should be interpreted cautiously. The time series at 100 m shows below normal temperatures during the first half of 2005 and above normal values in the second half (Fig. 12). The last value of the 5-year running mean at this depth is lower than for last year but is still close to zero, meaning that the average temperature for 2001-2005 was close to the 1971-2000 average temperature.

Data for January and June to September were available from Area F in 2005 (Fig. 13). No temperatures were recorded in the deeper part of this area (up to 300 m). Except for the very surface water in August and September, the water column was warmer than normal down to around 120 m for most of the months. The maximum (+4.2 °C) anomaly was observed in July at around 25 m. The rest of the water column was close to normal, except around 125 m, in August, when the water was cooler than normal. These conditions are also reflected in the annual mean profile. The time series at 100 m in Area F is similar to the one for Area 19 (Fig. 14), i.e. a strong tendency towards below normal anomalies from the mid-1980s to the late 1990s, a general warming starting around 1992 and a levelling off at the end of the 1990s and a slight cooling at the end of the time series. Warmer-than-normal temperatures were observed in 1999 and 2000, declined in 2001, rose in 2002, declined again in 2003, slightly rose in 2004 and peaked in 2005. The last value of the 5-year running mean is close to the long term mean. For most years, the data at 100 m are reasonably representative of conditions from 75 to 150 m in Area F.

To the north in Area E, data were available for 5 months: June, July, August, September and November (Fig. 15). Monthly mean temperatures were below normal in the surface layer in June but close to normal at greater depths. The largest cold anomaly of -1.5°C was observed at around 20 m (June). There was also a strong negative anomaly at the surface in September. All the other months exhibited warmer than normal condition down to 100 m. The largest positive anomaly (2.3°C) was observed in the surface layer in November. 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. 16). The above than normal temperatures at this depth in 2005 contrast with the lower than normal values observed in 2003 and 2004, but they were similar to the above normal values present in 2002.

The general trends in the temperature anomalies in the near-bottom waters throughout the Magdalen Shallows are quite similar. This is highlighted in Fig. 17 that shows the five-year running means of the temperature anomalies for Areas 12, 19, E and F. These show the continuously decreasing temperature from the last maximums in the early 1980s to the minimums in the early 1990s and then the general warming trend up to the early 2000s and a slight decrease at end of the time series, in recent years.

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

The catches (from the trawl survey) of snow crab as a function of temperature during the 2005 snow crab survey in the Gulf are shown in Fig. 18. Over 89% of all of the crabs were caught in temperatures between -1° and 3°C, which is slightly lower than in 2004 (92%). In 2005 and as for previous years, there was a tendency for the snow crabs to be captured in the cooler portion of the favourable habitat (which is defined as waters with a temperature range of -1°C to 3°C) but this is not as obvious as in 2003 and 2004 when cooler conditions were observed. However, the snow crabs in 2005 were generally caught in warmer waters than in 2004, a situation that reflects the ambient temperatures. The top panel in figure 18 and the cumulative percentages of snow crab catches and bottom temperatures (Fig. 19) clearly show that snow crabs have a tendency to be caught in the cooler waters.

Summary

Near-bottom temperatures in the southern Gulf of St. Lawrence (Magdalen Shallows) and in the northeastern Scotian Shelf during 2005 were examined primarily from data collected during the snow crab and multi-species surveys. The snow crab survey was conducted in July-September while the multi-species survey was in September only. Data from the multi-species survey, which are available for a much longer period than those from the snow crab survey, 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 2005, near bottom temperatures in the southern part of area 12, from Miscou Island to Western Cape Breton and all around PEI, were significantly below the normal while the deeper parts of the Magdalen Shallows, including Chaleur Bay, exhibited warmer than normal conditions. The cooler coastal water is consistent with a significant increase in the Gulf wide snow crab habitat index (area of the bottom covered by water temperatures between –1 and 3 °C). The habitat index is now above the long-term average. However, the mean temperature within the habitat area in 2005 also significantly increased compared to 2004 and it is an unusual situation as the two time series are negatively correlated. The mean temperature is above the long term mean, reaching a value similar to the ones observed during the 1999-2002 warm period and is the highest of the last 23 years. The crabs caught during the annual snow crab surveys were found in warmer waters in 2005 than in 2004, which is believed to reflect in large part the availability of slightly warmer temperatures since 2003 when cooler conditions were observed. The catch analysis again shows that the adult snow crabs have a preference for cooler water.

Acknowledgements

We thank Dr K. Drinkwater for providing the schematic of this document. We acknowledge Tom Hurlbut for providing the CTD data from the multi-species surveys and Dr M. Moriyasu, M. Biron, E. Wade, T. Surette and C. Sabean for the crab and temperature data from the snow crab surveys. Also, a special thanks goes out to the scientists, technicians and crew who collected these data.

References

Chassé, J., K.F. Drinkwater, R.G. Pettipas and W.M. Petrie, 2005. Temperature Conditions on the Scotian Shelf and in the southern Gulf of St. Lawrence during 2004 Relevant to Snow Crab. DFO. Can. Sci. Advis. Sec. Res. Doc. 2005/002, 47p.

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

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

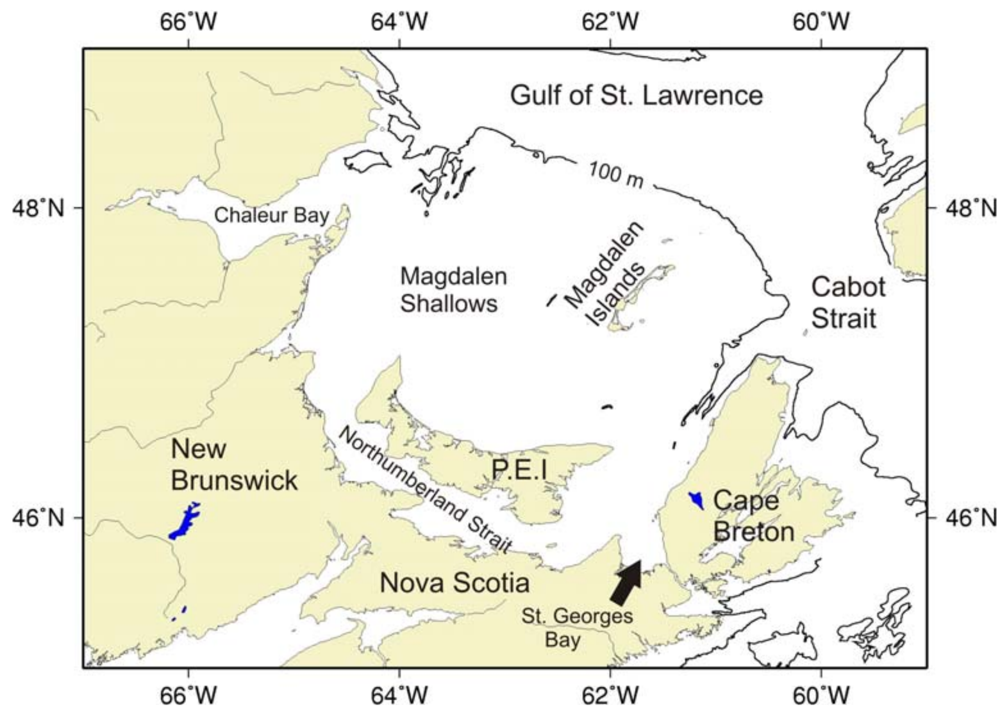


Fig. 1. Chart of the Southern Gulf of St. Lawrence showing geographic and topographic features referred to in the text.

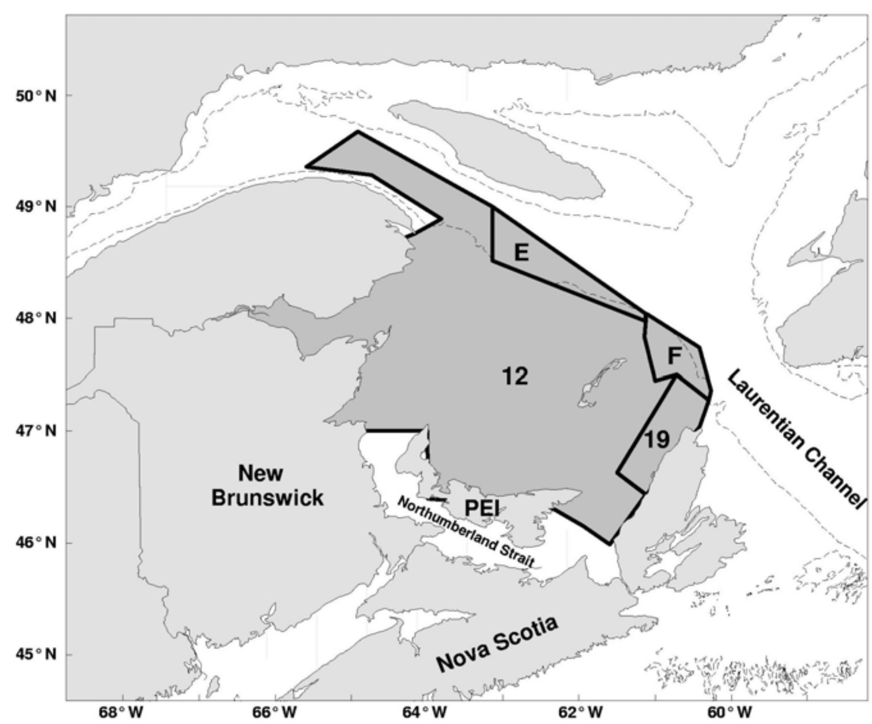


Fig. 2. The Southern Gulf of St. Lawrence showing the boundaries of snow crab fishing areas in which monthly mean temperature profiles were estimated.

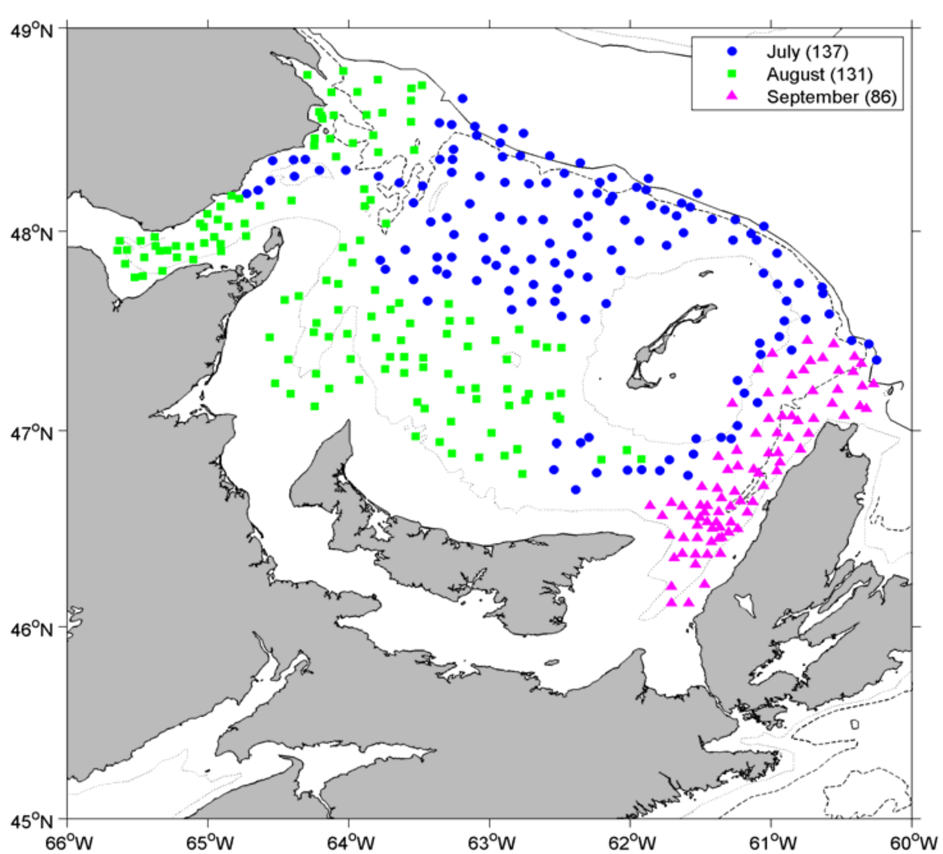


Fig. 3. The location of the bottom temperature stations during the July-September 2005 snow crab survey.

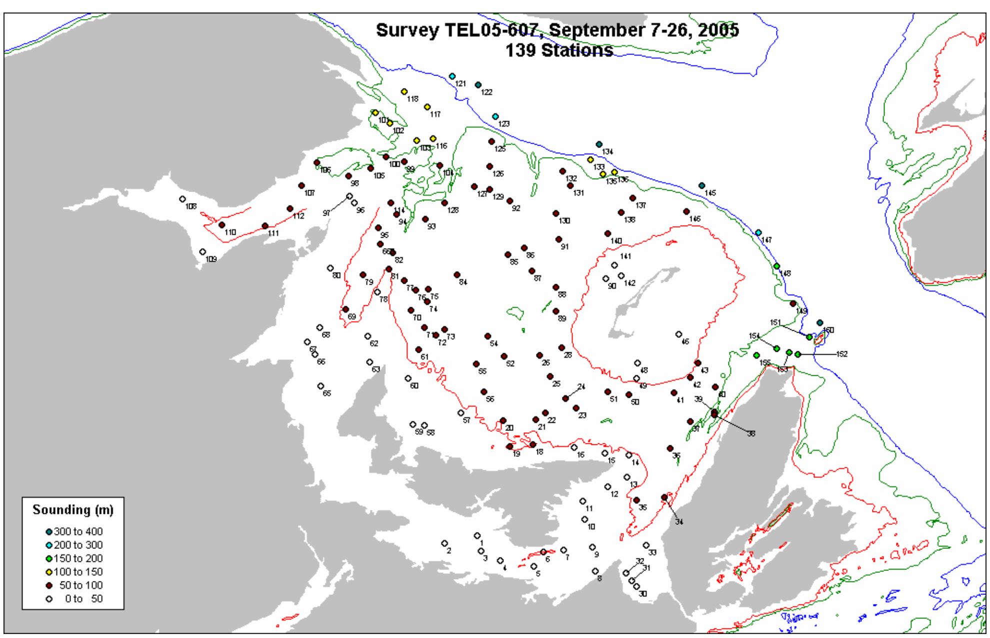


Fig. 4. The location of the CTD stations during the September 2005 multi-species survey.

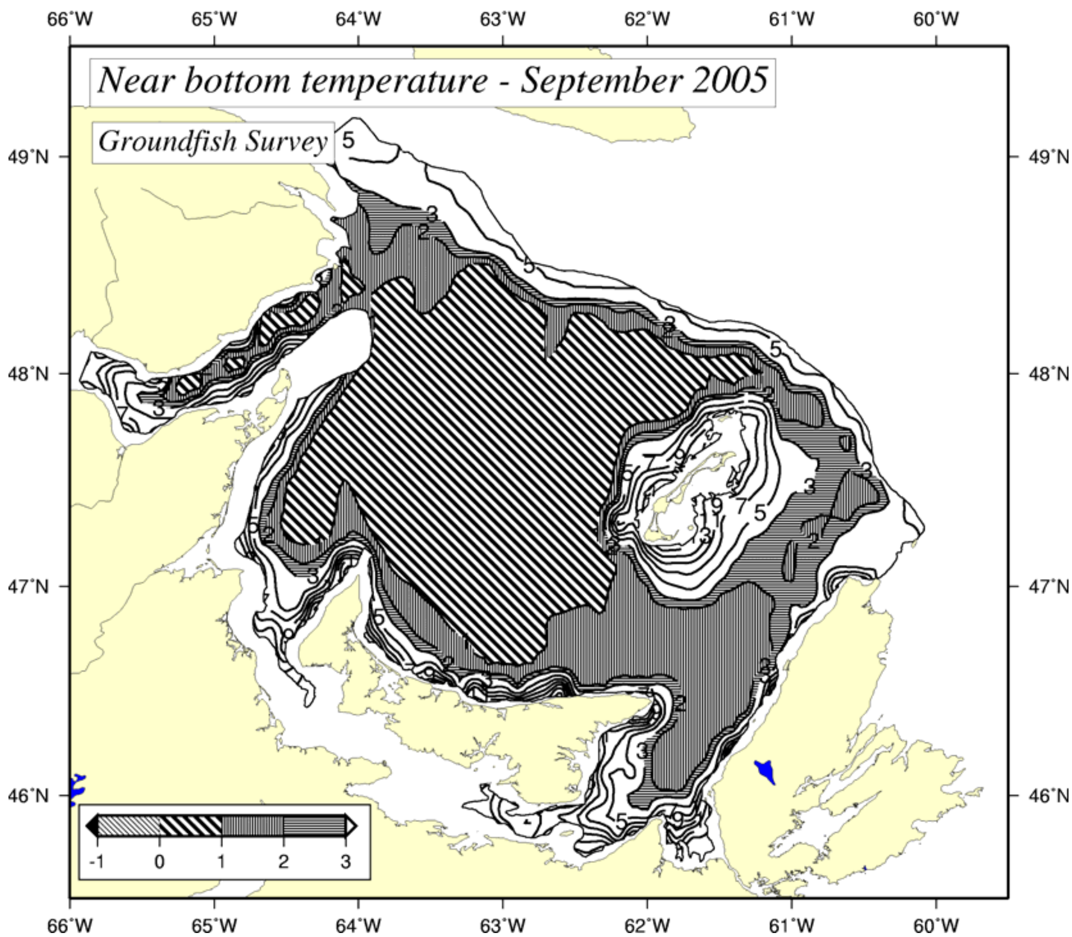


Fig. 5a. Near-bottom temperatures (°C) in the southern Gulf of St. Lawrence during the 2005 September multi-species survey. The hatch patterns show the suitable temperature range for the snow crab (-1 to 3°C).

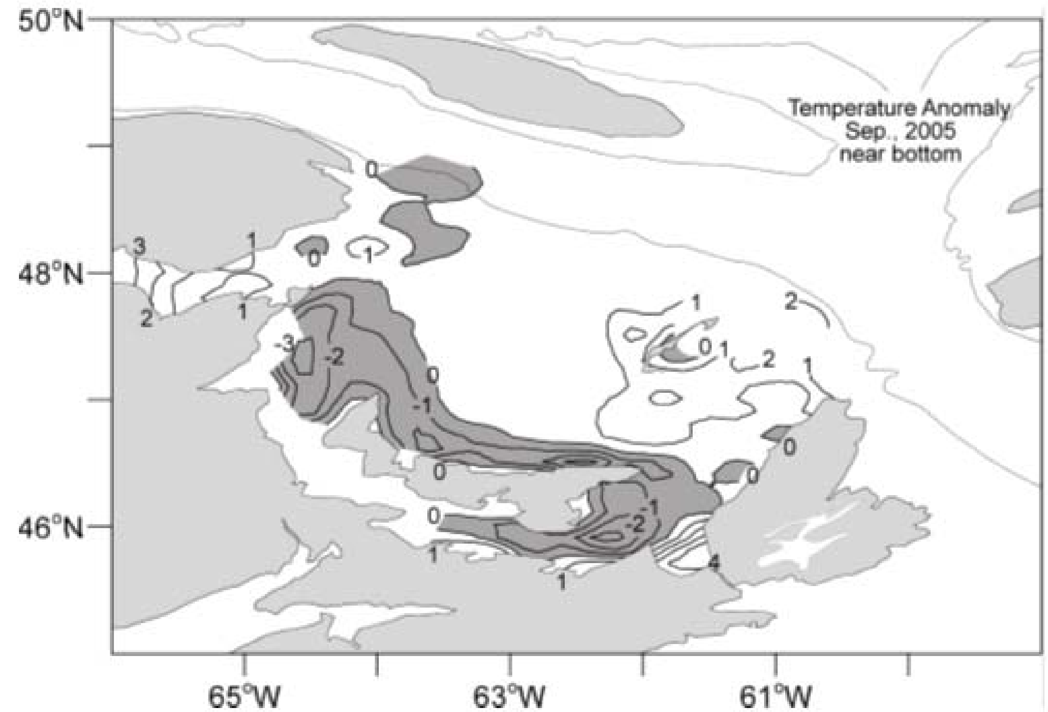


Fig. 5b. Near-bottom temperature departure (°C) from the long-term (1971-2000) means in the southern Gulf of St. Lawrence during the 2005 September multi-species survey. Shaded regions represent colder-than-normal temperatures.

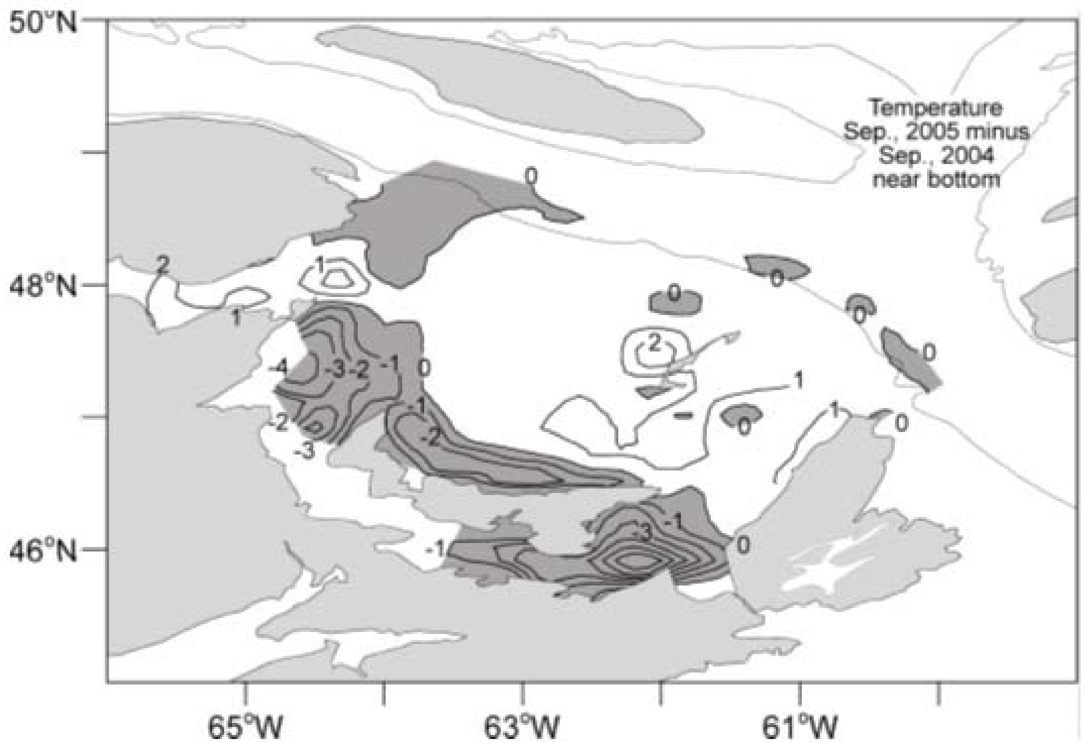


Fig. 6. The difference between the 2005 and 2004 temperature fields in the southern Gulf of St. Lawrence for the September multi-species survey. Positive values indicate temperatures in 2005 had warmed and negative values (shaded) that they had cooled.

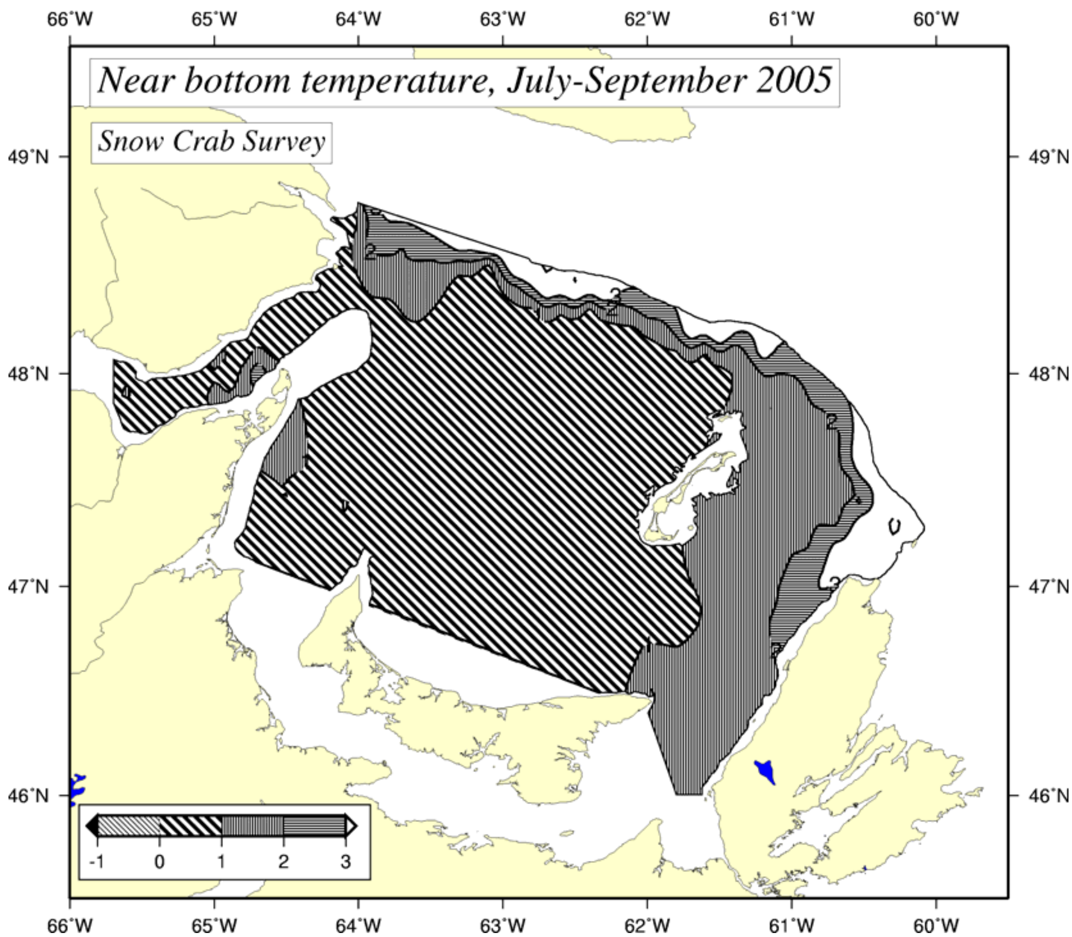


Fig. 7. Near-bottom temperatures in the southern Gulf of St. Lawrence during the 2005 July-September snow crab survey.

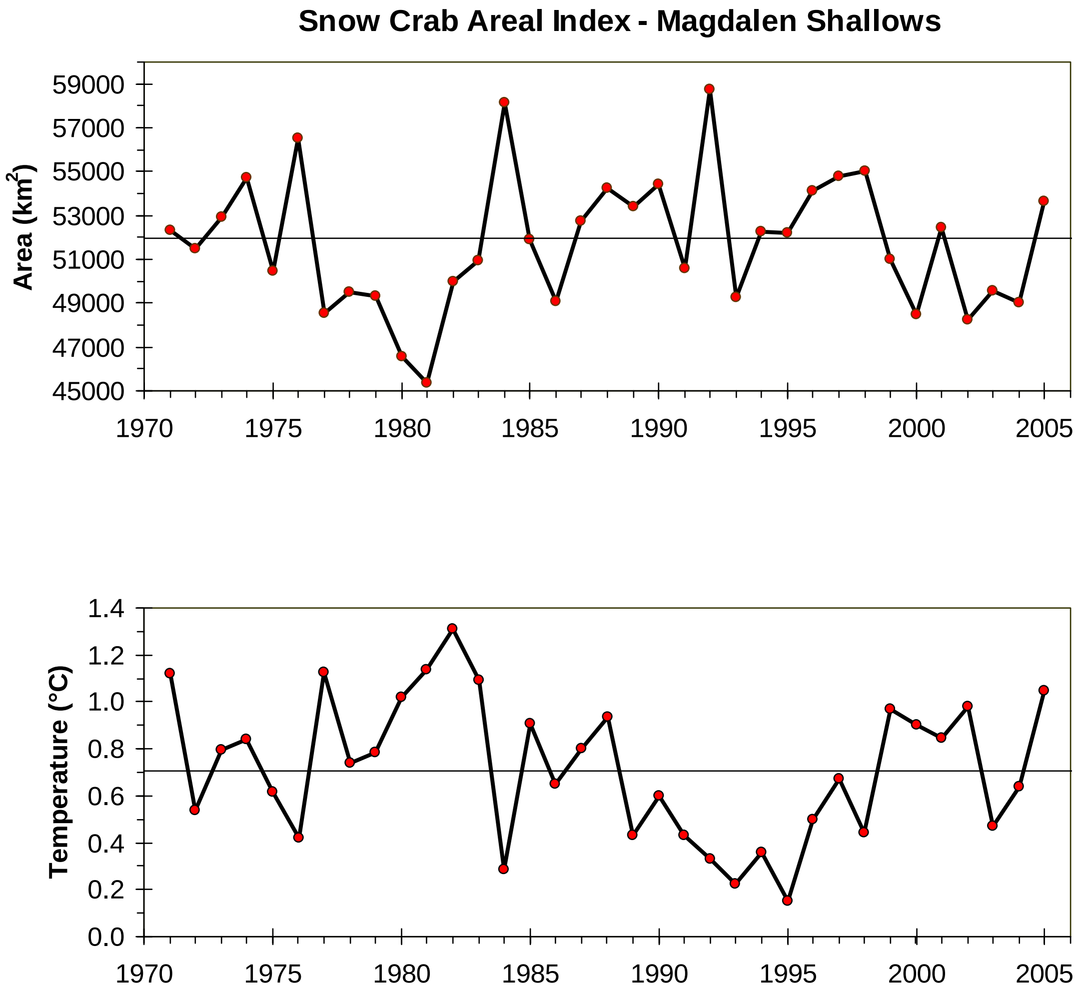


Fig. 8. Time series of the area of Magdalen Shallows covered by bottom temperatures between -1° and 3°C in September (top panel) and the mean temperature within that area (bottom panel).

2005 Monthly Temperature Anomaly - Area 12

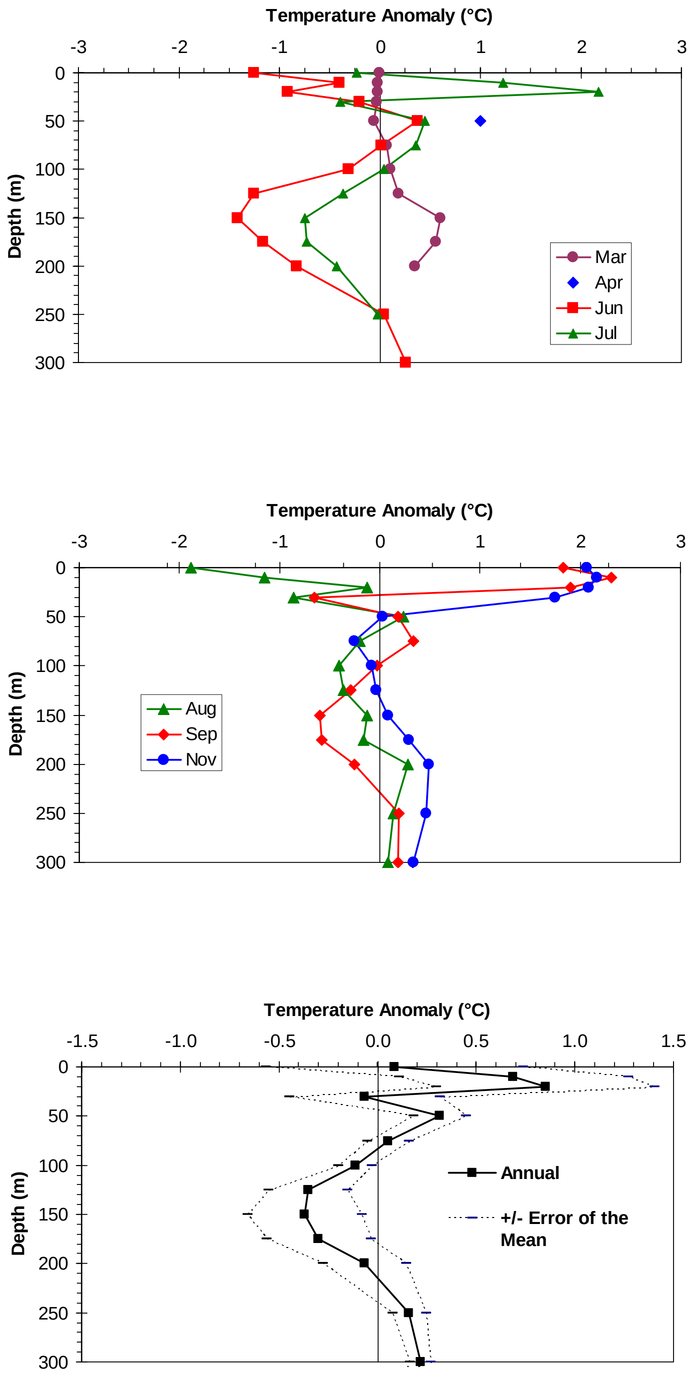


Fig. 9. Monthly (top two panels) mean temperature anomalies and annual temperature anomalies ± error of the mean (bottom panel) during 2005 for snow crab fishing Area 12.

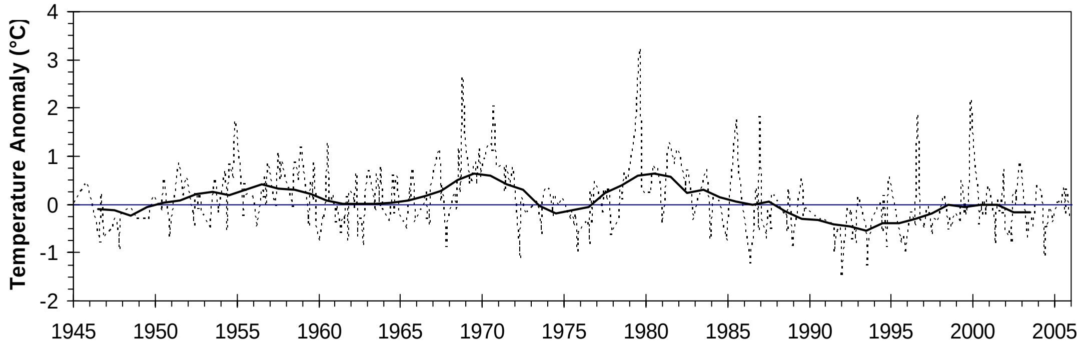


Fig.10. The time series of the monthly (dashed line) and the 5-year running mean of the annual temperature anomalies (solid line) at 75 m for snow crab fishing Area 12.

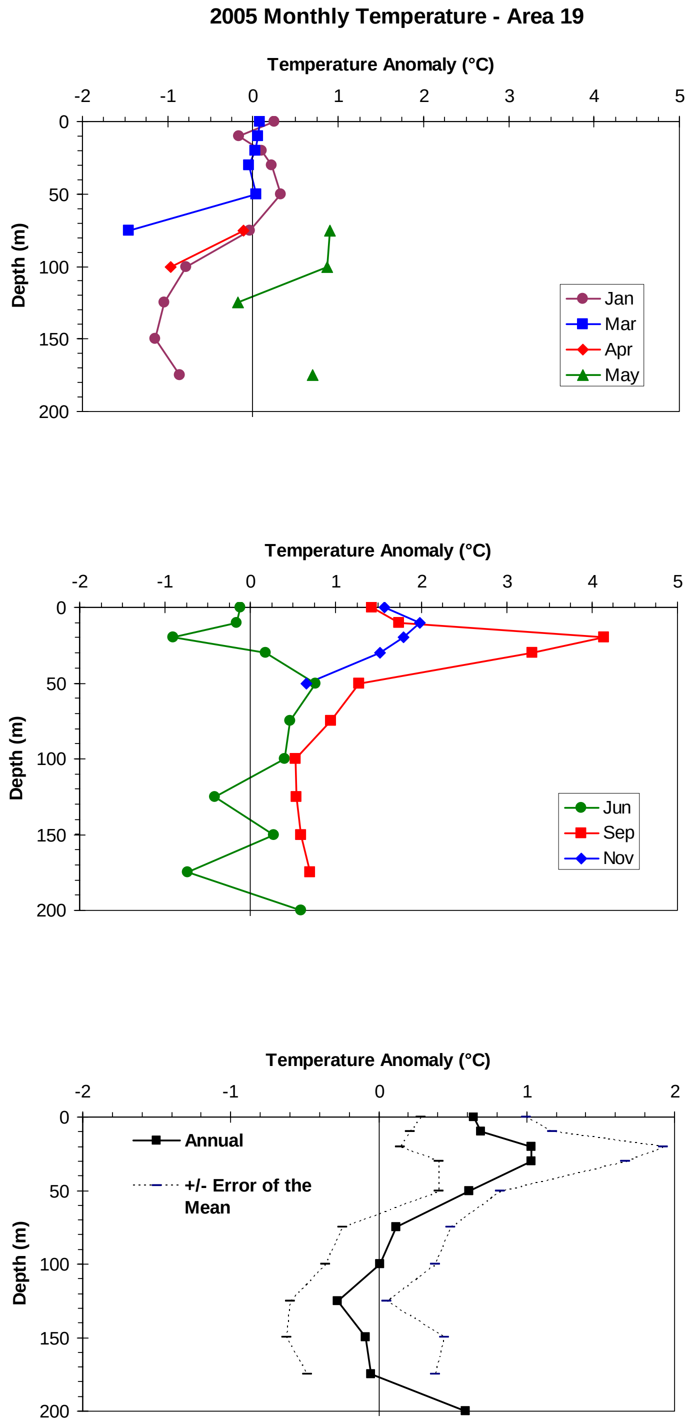


Fig.11. Monthly mean temperature anomalies (top panel) and annual temperature anomalies ± error of the mean (bottom panel) during 2005 for snow crab fishing Area 19.

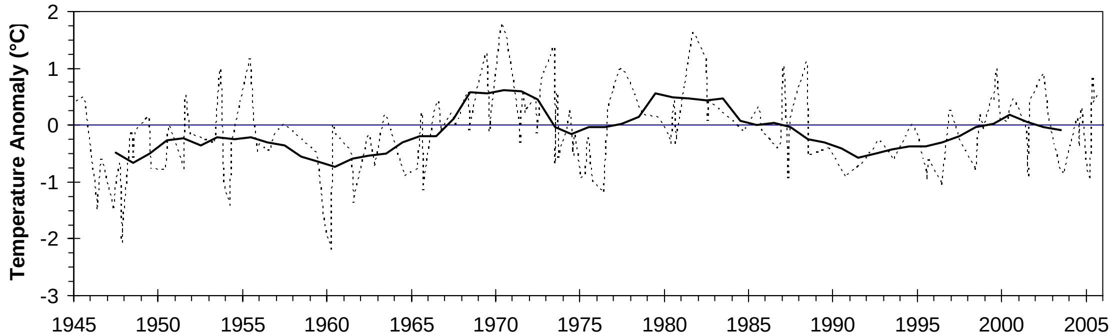


Fig.12. The time series of the monthly (dashed line) and the 5-year running means (solid line) of the annual anomalies at 100 m for snow crab fishing Area 19.

2005 Monthly Temperature Anomaly - Area F

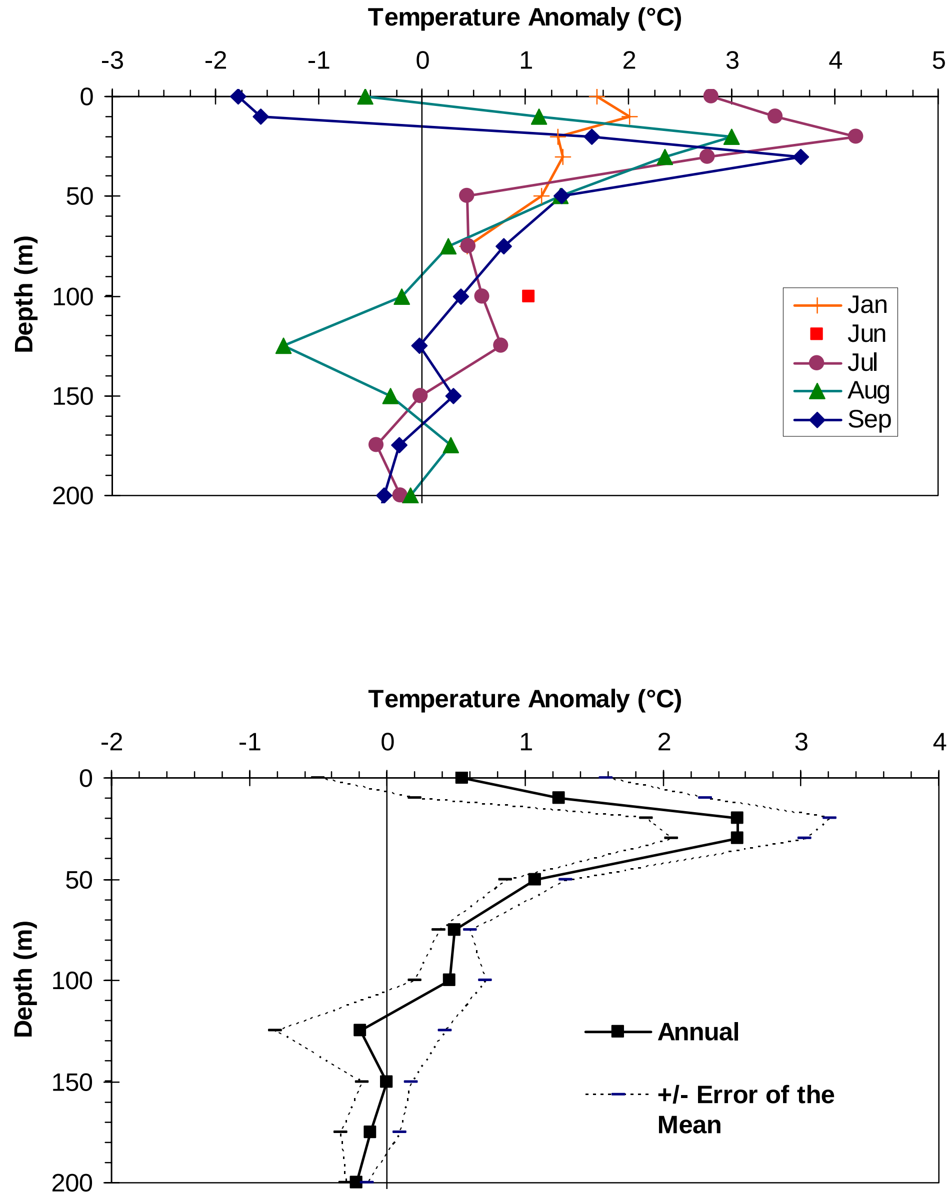


Fig.13. Monthly mean temperature anomalies (top panel) and annual temperature anomalies ± error of the mean (bottom panel) during 2005 for snow crab fishing Area F.

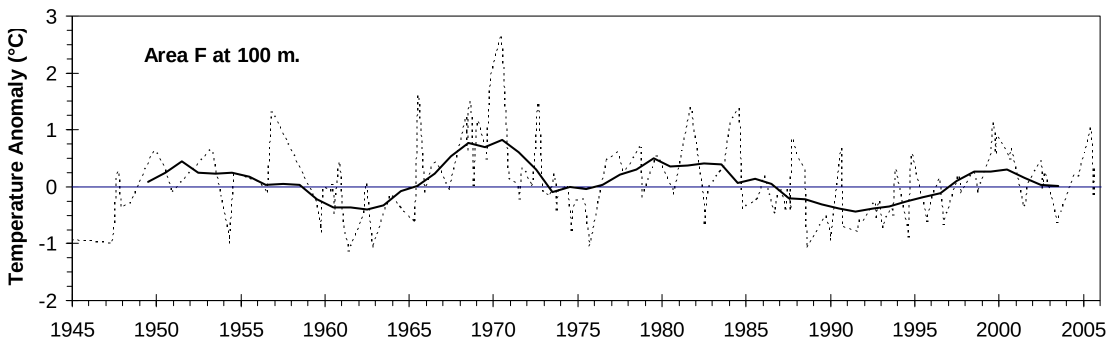
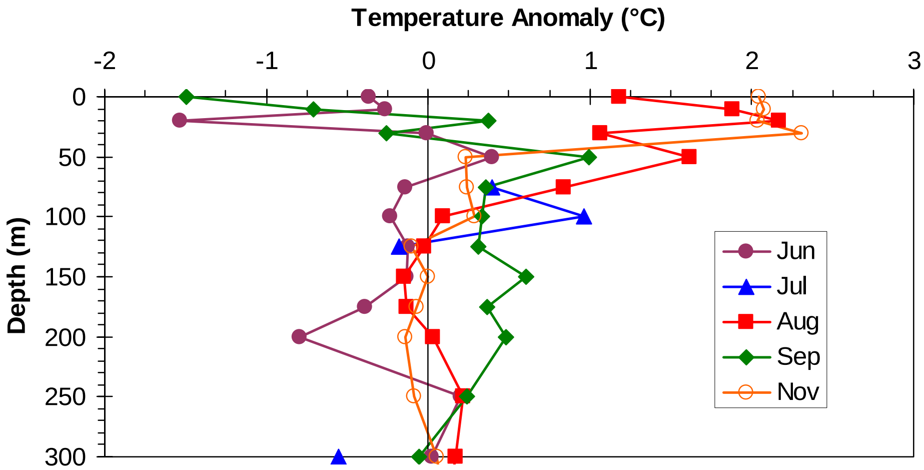


Fig.14. The time series of the monthly (dashed line) and the 5-year running means (solid line) of the annual temperature anomalies at 100 m for snow crab fishing Area F.

2005 Monthly Temperature Anomaly - Area E



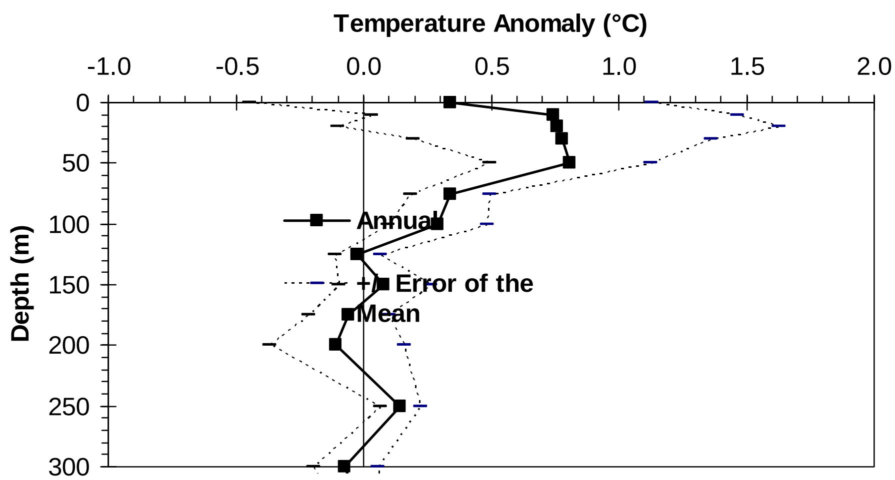


Fig.15. Monthly mean temperature anomalies (upper and mid panels) and annual temperature anomalies ± error of the mean (bottom panel) during 2005 for snow crab fishing Area E.

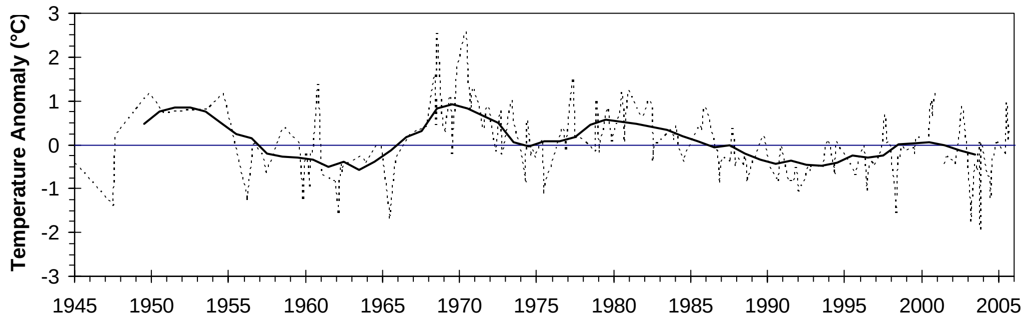


Fig.16. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) temperature anomalies at 100 m for snow crab fishing Area E.

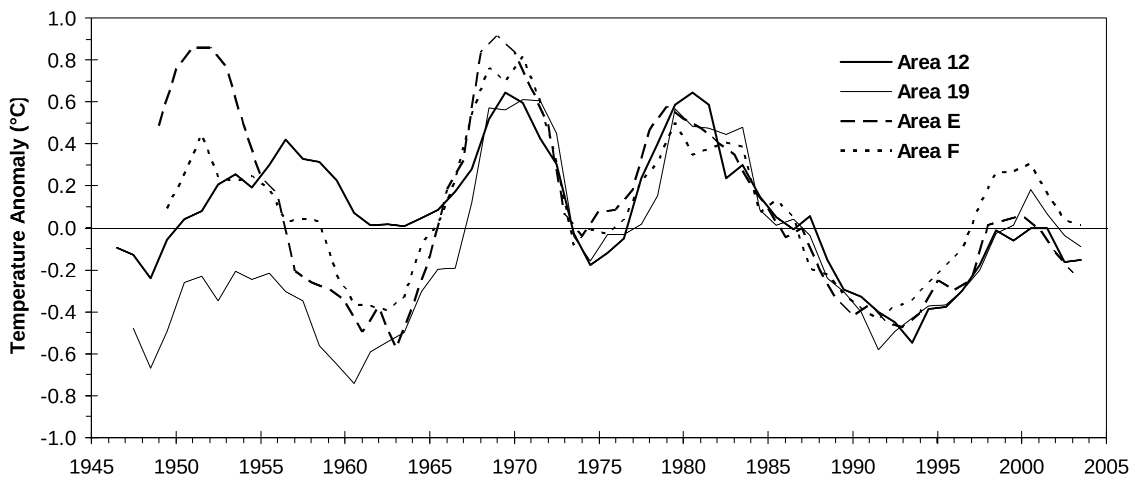


Fig.17. The five-year running means of the near bottom temperature anomalies for Areas 12, 19, E and F.

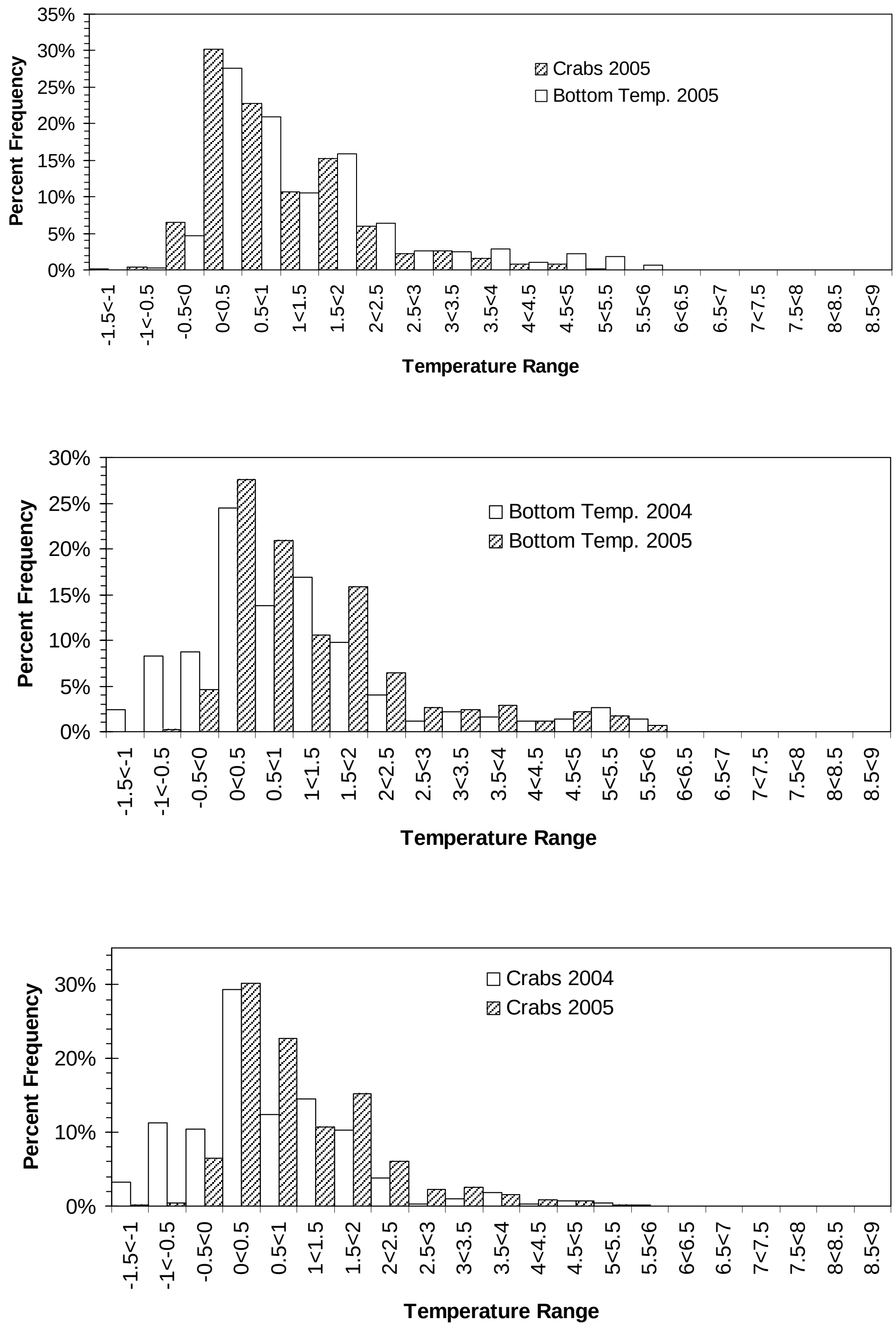


Fig.18. The frequency distribution as a function of temperature for the snow crab catches and for all of the station locations during the 2005 Gulf of St. Lawrence snow crab survey (top panel). The frequency distribution as a function of temperature for the stations occupied (middle panel) and for the snow crab catches (bottom panel) from the 2004 and 2005 Gulf of St. Lawrence snow crab surveys.

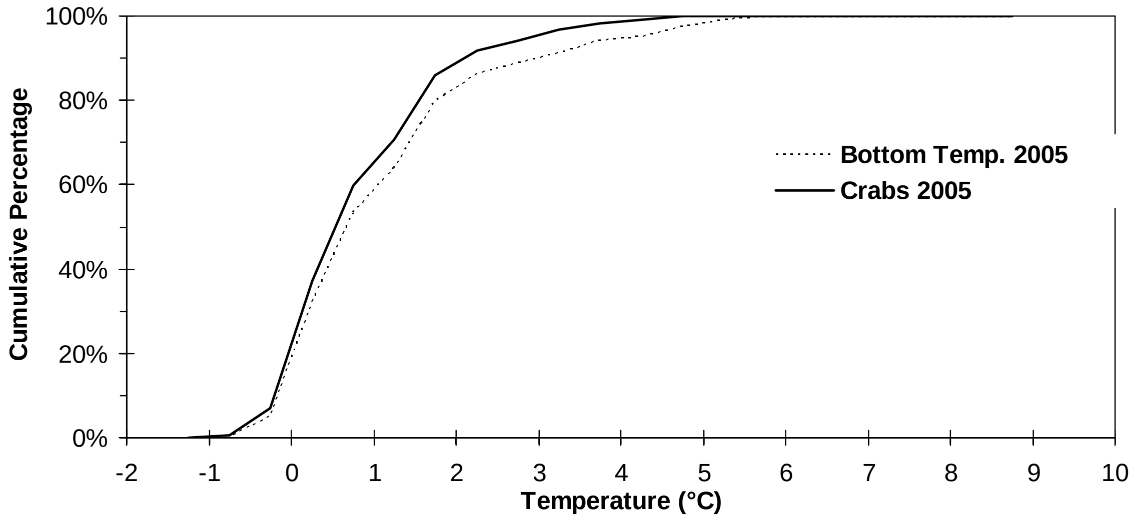


Fig.19. The frequency distribution as a function of temperature for the snow crab catches and for all of the station locations occupied during the snow crab survey in 2005.