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Temperature Conditions on the Scotian Shelf and in the southern Gulf of St. Lawrence during 1999 Relevant to Snow Crab

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Abstract

Temperatures during 1999 are presented for the waters of Maritime Canada inhabited by snow crab. Data were available from a number of sources including groundfish surveys on the Scotian Shelf and Sydney Bight in July and on the Magdalen Shallows in the Gulf of St. Lawrence in September as well as at other times of the year from other fisheries surveys, research studies and ships-of-opportunity. Bottom temperatures in large portions of these shelf regions were between -1° and 3°C, conditions considered ideal for snow crab. However, the snow crab habitat index defined by the area of the bottom covered by waters between -1° to 3°C for each of the southern Gulf, Sydney Bight and northeastern Scotian Shelf declined from the relative high values that have persisted since the late-1980s. In all areas the habitat index was below the long-term mean for the first time in 4 years in the Gulf and in 11 years on the Bight and the Shelf. Although bottom temperatures within the snow crab fishing areas of the southern Gulf of St. Lawrence to the northeastern Scotian Shelf have been colder-than-average for most of the past 15 years, they have been warming since lows in the early to mid-1990s. This warming continued in 1999 and temperatures were above normal for the first time in a decade or more in most fishing areas. Exceptions were Areas 12 and F, where in spite of the warming they continued to have below normal average bottom temperatures, although they almost reached normal values during 1999. Temperature trends showed strong similarities between the Magdalen Shallows and the northeastern Scotian Shelf. Temperatures in LaHave and Roseway Basin where exploratory fishing for snow crab (NAFO Division 4X) was carried out in 1999 are also presented.

Résumé

Les températures des eaux fréquentées par le crabe des neiges aux Maritimes en 1999 sont présentées. Les données sont tirées de diverses sources, y compris des relevés du poisson de fond effectués sur le plateau néo-écossais et dans Sydney Bight en juillet et sur les petits fonds des Îles de la Madeleine, dans le golfe du Saint-Laurent, en septembre, ainsi que des relevés d'autres pêcheries, des études de recherche et des navires de passage couvrant d'autres moments de l'année. La température au fond dans de grandes parties de ces régions de la plate-forme se situait entre -1 °C et 3 °C, des conditions considérées comme idéales pour le crabe des neiges. Toutefois, l'indice d'habitat de l'espèce, défini par la superficie du fond où la température se situe entre -1 °C et 3 °C dans le sud du golfe, Sydney Bight et le nord-est du plateau néo-écossais, a diminué par rapport aux valeurs élevées relatives qui se sont maintenues depuis la fin des années 80. Dans toutes les régions, l'indice d'habitat se situait sous la moyenne à long terme pour la première fois depuis quatre ans dans le golfe et depuis onze ans dans Sydney Bight et sur le plateau néo-écossais. Bien que la température au fond dans les pêcheries du crabe des neiges s'étirant du sud du golfe au nord-est du plateau était plus basse que la moyenne pendant la plupart des quinze dernières années, elle est à la hausse, se relevant des bas niveaux observés du début au milieu des années 90. Ce réchauffement s'est poursuivi en 1999. Les températures se situaient au-dessus de la normale pour la première fois depuis une décennie ou plus dans la plupart des pêcheries, à l'exception des zones 12 et F, où, malgré le réchauffement, elles ont continué à se chiffrer sous la température moyenne normale, bien qu'elles ont presque atteint des valeurs normales en 1999. Les tendances de la température sur les petits fonds des Îles de la Madeleine et dans le nord-est du plateau néo-écossais se ressemblent beaucoup. Les températures enregistrées lors de la pêche exploratoire du crabe des neiges effectuée sur les bancs La Have et Roseway (division 4X de l'OPANO) en 1999 sont aussi présentées.

Introduction

Snow crab (*Chionoecetes opilio*) is a cold-water species typically inhabiting bottom depths of 60-200 m in water temperatures of -1 to 3°C. An active and very lucrative fishery presently exists on the northeastern Scotian Shelf, on Sydney Bight and in the Gulf of St. Lawrence (Fig. 1). Annual assessments of the stock abundance, fishing effort, biological characteristics and the environment of the snow crab are undertaken by the Maritimes Region of the Department of Fisheries and Oceans (DFO). The purpose of this paper is to provide information on the sea temperature conditions during 1999 in areas occupied by snow crab (Fig. 2) and to compare these temperatures to their long-term means. As in last year's review (Drinkwater et al., 1999a), we tailor the analyses to the snow crab temperature preferences and fisheries areas. 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 zones provide further information on sea temperature trends. We have also included an analysis of the temperature trends in those portions of 4X within which there was an exploratory fishery. 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

Extensive geographic coverage of near-bottom temperatures during 1999 in the areas of interest was available from two DFO groundfish surveys. These data were collected with a conductivity-temperature-depth (CTD) instrument. The first CTD dataset covered Sydney Bight and the northeastern Scotian Shelf and was part of the annual groundfish survey of the Scotian Shelf during July (Fig. 3a). In the southwest portion of the shelf it was augmented with data from a July survey undertaken by the fishing industry. The second dataset was the Gulf of St. Lawrence annual groundfish survey in September that covered the Magdalen Shallows (Fig. 3b). Temperature data from the snow crab areas for other months of 1999 were obtained from the Marine Environmental Data Service (MEDS) in Ottawa, Canada's national oceanographic data archive, and are derived from additional fisheries surveys, research surveys and ships-of-opportunity. Pre-1999 data were taken from the historical hydrographic database maintained at the Bedford Institute of Oceanography (BIO). This database contains an edited version of the MEDS holdings.

This year we also have included bottom temperature data collected by snow crab trap and trawl surveys. The majority of the data were obtained as part of an exploratory fishery in NAFO

(North Atlantic Fisheries Organization) Division 4X in the vicinity of LaHave and Roseway Basins. Temperatures were measured with thermograph recorders attached to the snow crab traps.

Methods

The near-bottom temperatures from data collected during the groundfish surveys were interpolated onto a specified grid using an objective analysis procedure known as optimal estimation, as described in Drinkwater and Pettipas (1996). 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 interpolation used the 15 nearest neighbours within a radius of up to 30 km in the horizontal (x,y) direction and within 15 m in the vertical (z) between 0-50 m and 25 m at depths > 50 m. These criteria are similar to that used by Petrie et al. (1996). The maximum profile depth 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 sharp near-bottom temperature gradients (e.g. those near the coast), thus the gradients depicted in the plots are not as sharp as in reality.

Long-term monthly climatological means of the near-bottom temperatures were estimated at each grid point based upon optimal estimations using all available data in the historical temperature, salinity database at the Bedford Institute for the years 1961-1990. The thirty-year period coincides with that used by the meteorologists and recommended by the Scientific Council of NAFO. The climatological means were then subtracted from the 1999 survey data to produce temperature differences from the long-term means, hereafter referred to as anomalies. A negative anomaly indicates that the 1999 value was colder than the long-term mean. We also examined the change in temperature since the previous year by subtracting the 1998 optimally estimated temperatures from the 1999 estimates. A negative value indicates that 1999 was cooler than 1998.

We also calculated snow crab habitat indices defined as the area of bottom covered by temperatures between -1°C and 3°C. These were derived using the optimally estimated bottom temperatures for July on the Scotian Shelf and Sydney Bight and September on 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 1999 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 the early 1970s for both the Scotian Shelf/Sydney Bight area and the Magdalen Shallows.

In addition to the bottom temperatures and habitat indices, monthly mean temperature profiles for 1999 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. Time series of monthly mean temperatures at representative depths for each area are plotted together with 5-year running averages of the data. The latter were estimated from annual anomalies, which in turn were simple arithmetic averages of the available monthly anomalies within the specific calendar year. The 5-year running averages are used to convey the longer-term temperature trends.

Thermograph data collected during the snow crab exploratory surveys in NAFO Division 4X were recorded continually during the survey. The data were processed at BIO to obtain the mean temperatures over the duration of the soak time of the trap for each station.

Results

Near-bottom Temperatures

Northeastern Scotian Shelf and Sydney Bight

In July, near-bottom temperatures were estimated for the entire Scotian Shelf, although for this study we were only interested in the northeastern region and Sydney Bight. In these latter areas, bottom waters were primarily <4°C with a significant portion <3°C (Fig. 4). Temperatures were mostly warmer-than-normal with anomalies generally between 0° and 1°C (Fig. 4). They increased relative to July 1998 over almost the entire northeastern Scotian Shelf by upwards of 2°C (Fig. 5). This is the first time in almost 15 years that the majority of the bottom has been covered by temperatures that are warmer than their long-term means. It also continues the trend of slow warming observed over the past few years in this area.

Southern Gulf of St. Lawrence

On the Magdalen Shallows, bottom temperatures in September 1999 show a typical range of <0°C to over 10°C (Fig. 6). The majority of the bottom is covered by temperatures of <3°C with the coldest waters (<0°C) limited to a small 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). In winter, the CIL merges with the upper layer as the latter cools. The primary origin of the waters in the CIL is thought to be 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 1999, the warmest near-bottom temperatures and anomalies in the southern Gulf were in its shallowest regions, in particular in Northumberland Strait, St. Georges Bay and Chaleur Bay. Temperature anomalies on the western half of the Shallows were primarily near to or below normal except in Chaleur Bay where temperatures were above normal. The coldest waters were located to the north of western Prince Edward Island. On the eastern half of the Shallows, temperatures were generally above normal except around the Magdalen Islands and a small area off eastern Prince Edward Island. The warmest anomalies (above 2°C) were located in Northumberland Strait, St. Georges Bay and along Southwestern Cape Breton Island. Relative to 1998, bottom temperatures over most of the central region increased slightly (Fig. 7). This differs from the cooling observed from 1997 to 1998 but reverts to the warming trend observed over the previous several years.

Snow Crab Habitat Index

From the July Scotian Shelf surveys, 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 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). From the September surveys on the Magdalen Shallows, a time series of the habitat index exists since 1971. The Magdalen Shallows grid contains a total area of 70039 km^2 (847 grid points). Note that the larger number of grid points in the Gulf compared to the Scotian Shelf is a result of the smaller grid size. 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. We also estimate the average temperature within the area covered by -1°C to 3°C and correlated these with the habitat index.

<u>Northeastern Scotian Shelf and Sydney Bight</u>

On the northeastern Scotian Shelf, the snow crab habitat index in 1999 was 25792 km^2 representing approximately 37% coverage of the total grid area. This index had been relatively high from the mid-1980s to the early 1990s but has been declining slowly since then (Fig. 8). 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. The increase in the habitat index through into the 1990s is consistent with 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 bottom area 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 was negatively correlated with the area itself ($r=-0.86$, $p<0.001$). 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 1999 when the habitat index declined, the mean temperature increased.

On Sydney Bight, the snow crab habitat index in 1999 declined significantly from 1998 to below the long-term mean (Fig. 9). It represents slightly over 21% coverage of the total grid area and is at its lowest level since 1981. This index had varied between 26-43% since the early-1980s (Fig. 9). 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 for the Bight being in deep regions (>200 m deep and hence in the relatively warm (>4°C) waters of the Laurentian Channel). The correlation between the average temperature within the index area and the habitat index itself for Sydney Bight was -0.67. This is lower than the Scotian Shelf but the reason for the difference is unknown. The lower spatial resolution on the Bight (i.e. a reduced number of grid points to average over) may contribute to the lower correlation.

Southern Gulf of St. Lawrence

Similar to the Scotian Shelf and Sydney Bight, the area of the bottom of the Magdalen Shallows covered by waters between -1°C and 3°C during the 1999 groundfish survey decreased compared to 1998. It dropped below the long-term mean to a value near 52000 km^2 (Fig. 10), which represents about 73% of the total Shallows area. The variability in the habitat index for the Shallows tends to be small, however. The index only varies between 66% and 84% of the total over all years. The mean temperature within the habitat area in 1999 rose significantly (by > 0.5°C) and continues the upward trend begun in 1996. It also rose above the long-term mean and was the highest value since 1983, although not statistically different from 1988. The correlation between the habitat index and the mean temperature within this area is -0.35 and is not statistically significant. The higher correlation coefficient reported last year (Drinkwater et al., 1999a) was in error. The long-term temperature pattern from the habitat index on the Magdalen Shallows is consistent with the very cold CIL waters throughout the Gulf of St. Lawrence since the mid-1980s as first revealed by Gilbert and Pettigrew (1997) and updated in Drinkwater et al. (1999b).

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 (see Fig. 2 for the area boundaries used in the temperature analysis). In addition, 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 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. 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.

Northeastern Scotian Shelf and Sydney Bight

In Area 24, data were available in 5 months of 1999. With the exception of November, temperatures between 75 m and 200 m tended to be near or above normal with the anomalies being 0° to 2°C (Fig. 11). The time series at 100 m shows below normal temperatures over most of the 1990s but there is definite warming in 1999 to above normal conditions. Area 24 spans a region of strong horizontal bottom temperature gradient from the relatively cold bottom temperatures (2-4ºC) in the northeast to warmer temperatures (>4ºC) in the southwest (Fig. 4). These two regions are separated by a series of shallow Banks, including Middle and Canso Banks. The origin of the colder waters 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. In 1998, the latter waters cooled substantially as Warm Slope Water (temperatures >8°C) that occupied the region for most of the past 30 years was replaced by colder Labrador-type slope water with temperatures of 4-6°C (Drinkwater et al., 2001). This cooling contributed substantially to the below normal bottom temperature anomalies observed in Area 24 during 1998. In 1999 Warm Slope Water again re-entered Emerald Basin and vicinity. The effect of these changes on snow crab may be minimal since the temperature changes were principally limited to the western portion of Area 24. This is because the absolute temperatures there are likely too high for snow crab, even subsequent to the cooling that occurred in 1998. The spatial distribution of data within Area 24 can greatly affect the monthly mean temperature, therefore any apparent temperature trend must be viewed with caution for this Area.

On the northeastern Scotian Shelf in Area 23, temperatures were collected in 8 months of 1999. Between 50 and 100 m they were predominantly above normal, which contrasts with the cold conditions between the mid-1980s to 1998 (Fig. 12). In recent years temperatures had, however, been trending upwards.

The temperature data for snow crab fishing Areas 20 through 22 were combined in our analysis. From the 6 months of 1999 when observations were available, temperatures below 50 m tended to be above normal (Fig. 13). The time series at 100 m shows colder-than-normal waters since the mid-1980s to the late 1990s but with warming during recent years and above normal temperatures in 1999 (Fig. 13). Analysis of the data has shown that this pattern is representative of conditions between 50 m and 150 m.

Gulf of St. Lawrence

Data for 1999 over the central Magdalen Shallows (Area 12 in Fig. 2 excluding the southern portion just north of Prince Edward Island) were available for 5 months between May and December inclusive, although the May and June data did not extend below 50 m. Expressed as deviations from the long term (1961-90) average, the anomaly profiles tend to show below-normal temperatures from 30 m to approximately 100 m (Fig. 14). This depth range covers most of the bottom depths over the Magdalen Shallows. Two of the three months that contained data below 100 m were warmer-than-normal by about 0.5°C while in December these deep temperatures were near the long-term mean with a tendency towards colder-than-normal. Most of these deeper data are from the Laurentian Channel. In the top 20 m, temperatures differed from month to month with August and December having colder-than-normal temperatures and May, June and September being warmer-than-normal. 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 1999 (Fig. 14). Note that not all months of each year contain data. Recent years, including 1999, have suggested a slight warming trend although the temperatures have generally remained below normal. The general pattern is consistent with the snow crab areal index results discussed above. Part of the high month-to-month variability shown in Fig. 14 is believed to be due to differences in the extent of the spatial sampling. For example, from the September groundfish survey, a large percentage of the Magdalen Shallows, including Area 12, showed above normal temperatures. However, temperatures averaged over the entire region indicate the spatial average still remains below normal.

Within the southern portion of Area 12 (formerly Areas 25 and 26), just north of Prince Edward Island, data were available only in September. September shows positive anomalies (up to 1.5°C at 20 m) throughout the water column (to maximum depths of 75 m). 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 recent years (Fig. 15). 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 three 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. At these relative shallow depths, temperature will be determined by local atmospheric processes and can change within 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 only available during September in 1999. The mean profiles indicate warmer-than-normal waters at all depths down to the maximum of 150 m (Fig. 16). From 50 to 125 m the temperature anomalies were around 1°C but increased at 150 m to approximately 1.7°C. Above 50 m, temperature anomalies were less than 1°C. The time series at 100 m shows above normal temperatures in 1999, similar to 1998, up from the cold conditions that persisted from the late 1980s to 1997 (Fig. 16).

Data during August and September of 1999 were available from Area F. In both months, temperature anomalies in the near surface (top 10 m) were well above normal by upwards of 3°C. In the 20 to 30 m layer, temperatures in September were much colder-than-normal (up to 2°C below normal) which contrast with August which was warmer-than-normal. 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 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. This 100 m record is reasonably representative of conditions from 75 to 150 m in Area F.

To the north in Area E, data were available during August, September and December. Temperatures below 50 m tended to be near the long-term mean with a tendency towards above normal in the first two months and slightly below normal in December (Fig. 18). Above 50 m, temperatures were generally much warmer-than-normal, especially in the summer months. Maximum anomalies were upwards of 3-4°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. Similar to Area 12 and unlike Areas 18-19 and F, 1999 temperatures remained near to but slightly below normal. Shallower than 50 m and deeper than 100 m in Area E, there is greater tendency for above normal temperatures in 1999.

Comparison of Temperature Trends

The 5-year means of the temperature anomalies show the major temperature trends. These are plotted separately for each of the fishing areas for the Magdalen Shallows and for Sydney

Bight/NE Scotian Shelf (Fig. 11-18). As discussed in last year's report (Drinkwater et al., 1999a), the temperature trends on the Magdalen Shallows in all of the Areas, except the southern portion of Area 12 off PEI, exhibit strong similarity especially since the mid-1960s. The difference between the area off PEI and the others is due to the shallowness of the former. As stated previously, the upper 30 m are influenced more by atmospheric forcing throughout the year whereas the deeper layers will reflect wintertime air-sea heat fluxes and will be less influenced by air conditions during the spring to autumn period. Since most of the snow crabs tend to be in waters deeper than 30 m, the temperature trends in the other areas will be more representative of conditions in regions traditionally occupied by the snow crabs. On Sydney Bight and the NE Scotian Shelf, there are also strong similarities in the temperature trends in terms of the timing of the peaks and troughs but not as tight as in the deep waters of the Magdalen Shallows.

To compare the Magdalen Shallows and the Sydney Bight/Scotian Shelf temperature trends, we average the 5-year running means for all of the fishing Areas in each region (except southern Area 12 was not included due to its shallowness). The two curves representative of the temperature trends over the Shallows and the Shelf are remarkably similar since the 1950s (Fig. 19).

Temperatures from Exploratory Survey

In 1999, exploratory snow crab surveys were carried out in NAFO Division 4X centred approximately in Roseway and LaHave Basins. The bottom temperatures are strongly dependent upon the depth (Fig. 20), especially in LaHave Basin. There, the snow crab survey recorded bottom temperatures >5°C at 100 m to almost 10°C at 200 m and deeper. These temperatures, taken in September and October, agree fairly well with those recorded during the 1999 July groundfish survey for the same region. The July temperatures suggested temperatures of 2-3°C at depths shallower than 75 m. At these depths, however, there is a strong seasonal signal and these temperatures will increase through the summer and into the autumn. At 50 m they typically rise to 6-7°C and at 75 m to 5°C. In Roseway Basin the depth dependence was weaker but still evident. Temperatures, taken in June, were 4-6°C in the depth range of 100-150 m while deeper than 150 m temperatures were typically 5-8°C. At 85 m, the snow crab survey observed temperatures of 3°C. Again, however, the shallower depths will undergo a seasonal cycle with the latter depths usually experiencing 5-6°C in the autumn.

Monthly mean temperature profiles for the two basins for 1999 were estimated in a manner similar to that for the snow crab Areas. For LaHave Basin where there were 10 months of data, the upper layer (to 75 m) tended to be warmer-than-normal throughout most of the year with the exception of April and July. Below 75 m, temperatures during early 1999 were colder-than-normal. Maximum temperature anomalies were 2-3°C below normal in the vicinity of 125 m during the first half of the year. As the year progressed, temperatures gradually warmed to near normal and slightly above towards the end of the year. Similar events were observed in Emerald Basin in the central

Scotian Shelf although the warming occurred earlier in the first half of 1999. The cool temperatures were a result of cold Labrador Slope water extending southward along the continental break of the Scotian Shelf during 1998, and displacing the Warm Slope Water that usually occupies this region. The cold Slope Water penetrated onto the Shelf and replaced the Warm Slope Waters that occupied the bottom layers of the deep basins on the Shelf. Drinkwater et al. (2001) has documented these events. In Roseway Basin data were available in only 5 months. These show warmer-than-normal conditions throughout most of the water column although most of the months were in the latter half of the year.

Time series of the temperatures at 100 m were also plotted. Both LaHave (Fig. 21) and Roseway (Fig. 22) Basins show very cold water in 1998 and warming into 1999, consistent with events in Emerald Basin described above. In Roseway Basin, the long-term temperature trend at 100 m is similar to those in the NE Scotian Shelf with colder-than-normal conditions from the mid-1980s to the late 1990s. In LaHave Basin, however, the cold conditions were not observed. This is also similar to trends in Emerald Basin.

Summary

Near-bottom temperatures collected during groundfish surveys in July on the northeastern Scotian Shelf and in September on the Magdalen Shallows during 1999 have been compared to their long-term means. Additional temperature data from other fisheries surveys and oceanographic studies in these same areas were also examined. In 1999, warmer-than-normal conditions dominated throughout the region at bottom depths from approximately 50 m to 250 m, which represents a change from the cold conditions that have persisted since the mid- to late-1980s. The snow crab habitat index, based upon the area of bottom temperatures preferred by snow crab (-1°C to 3°C), declined from the relatively high values of the earlier 1990s throughout the region and the mean temperatures within these areas rose. The habitat index was below normal in all regions in 1999 for the first time in 4 years on the Magdalen Shallows, and 11 years on Sydney Bight and the northeastern Scotian Shelf. While there continues to be large areas of all regions with habitat preferred by snow crab, these areas are declining. The largest declines are outside of the Gulf of St. Lawrence. In most snow crab fishing areas there has been a consistent pattern of colder-than-normal bottom temperatures extending from the mid- to late-1980s to 1998. Temperature minima were generally reached in the early to mid-1990s with gradual warming in recent years. The only major exceptions are the section of Area 12 north of PEI (formerly Areas 25 and 26) and Area 24. In the former, near-bottom temperatures have been above normal in recent years but this area contains mostly shallow depths (<60 m) with waters warmer than snow crab tend to prefer. In Area 24, extensive cooling was observed during 1998 in the southwestern sections due to an intrusion of colder-than-normal Labrador Slope Water into the region (Drinkwater et al., 2001). By 1999, warming continued to the point that the average temperature within most of the snow crab Areas had exceeded their long-term means. Exceptions were located in the western Gulf in Areas 12 and F. Temperature data collected during the snow crab exploratory fishing in LaHave and

Roseway Basins revealed temperatures generally >4°C. Cooler temperatures were found depths shallower than 100 m, but at these depths the waters will experience relatively strong seasonal warming in the autumn.

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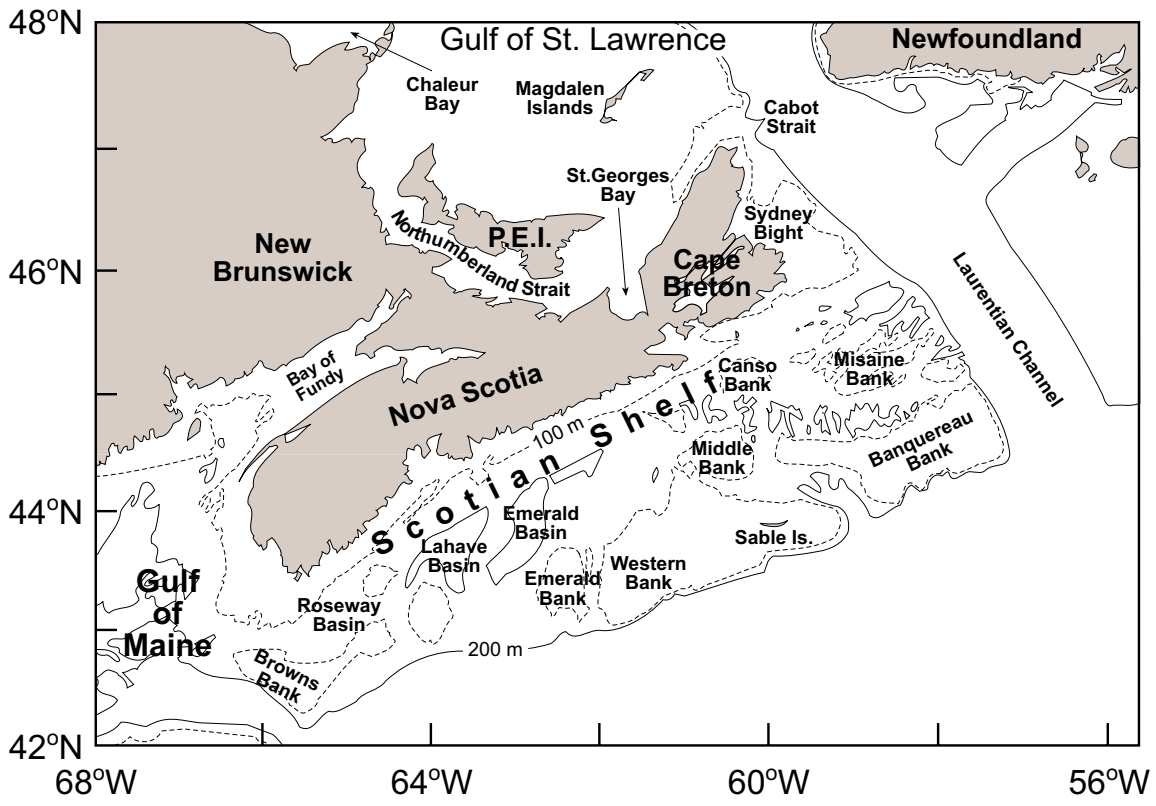

Fig. 1. Chart of the Scotian Shelf and the southern Gulf of St. Lawrence showing geographic and topographic features referred to in the text.

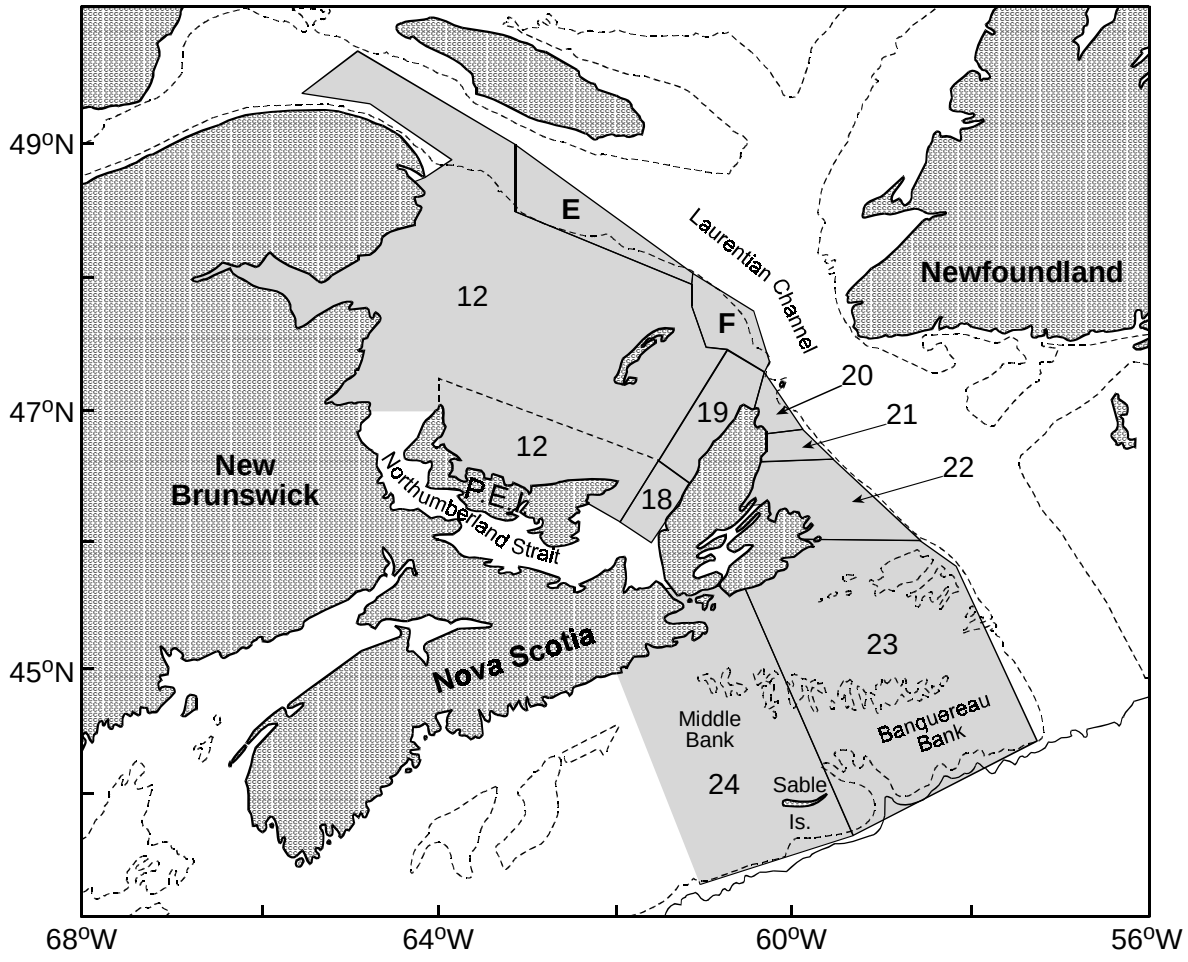

Fig. 2. The southern Gulf of St. Lawrence and Scotian Shelf showing the boundaries of snow crab fishing areas in which monthly mean temperature profiles were estimated. The section of Are 12, north of Prince Edward Island and denoted by the dashed line, is former Areas 25 and 26.

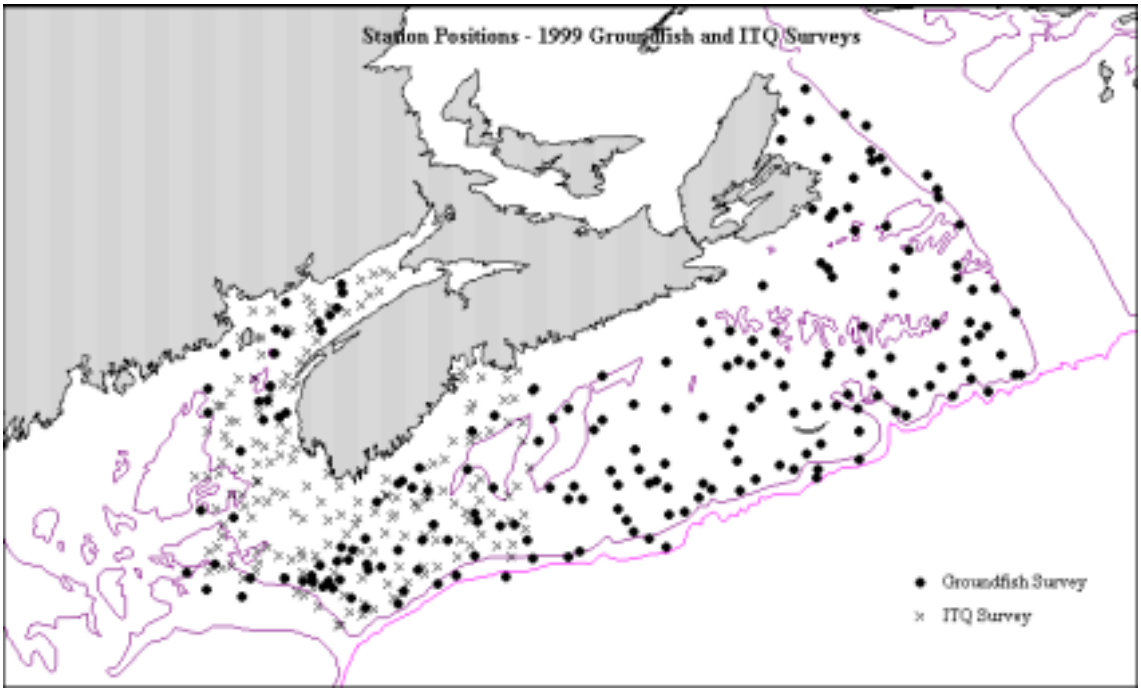

Fig. 3a. The CTD stations during the July 1999 survey.

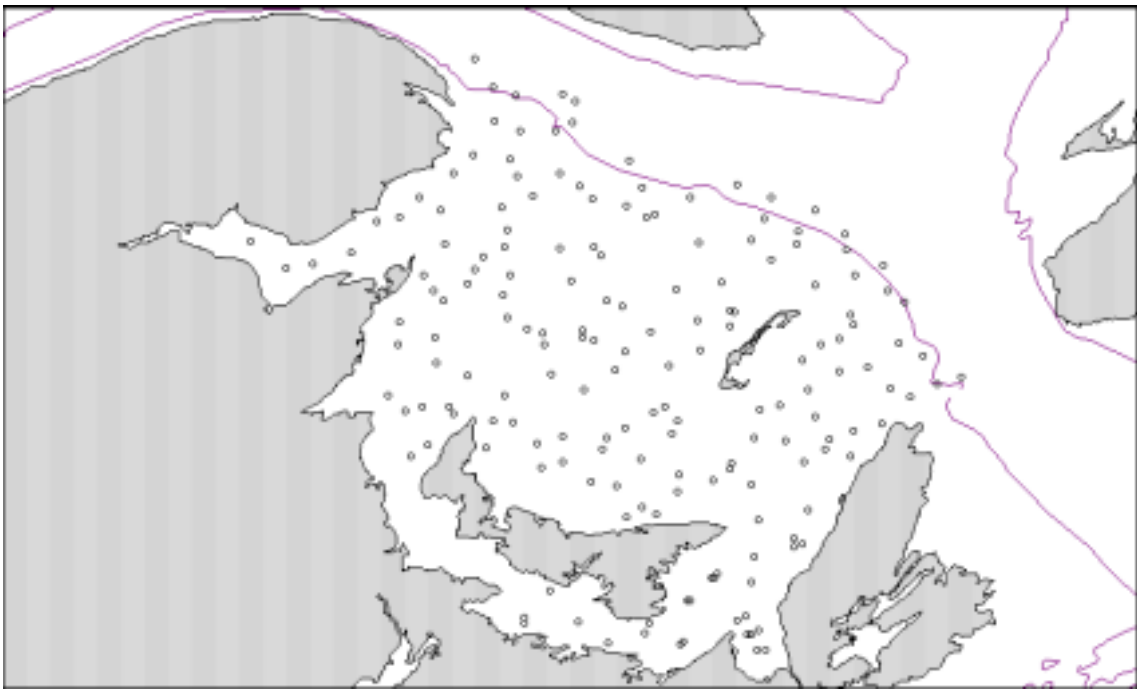

Fig. 3b. The CTD stations during the September 1999 survey.

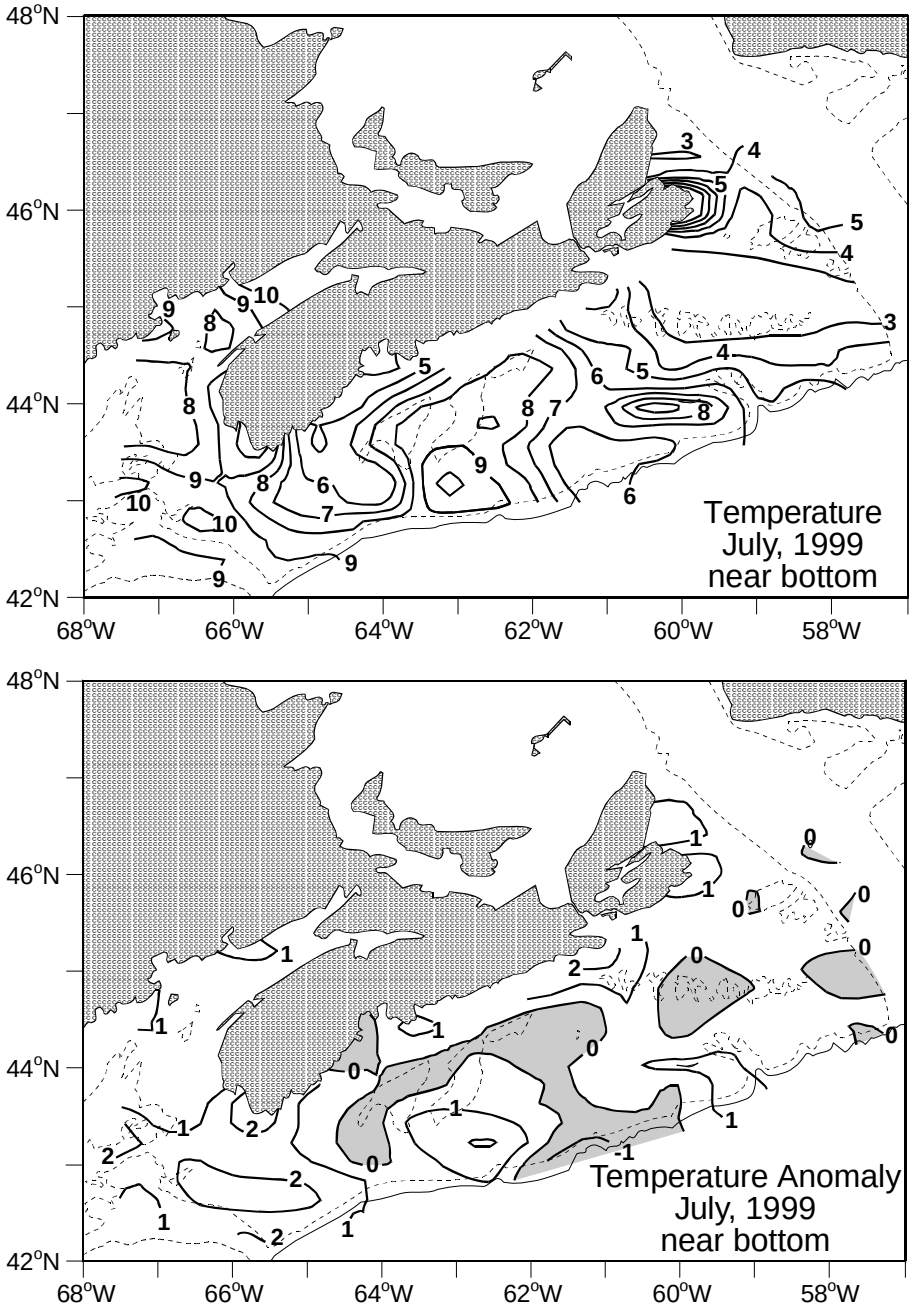

Fig. 4. Near-bottom temperatures (top panel) and their departure from the long-term (1961-1990) means (bottom panel) on the Scotian Shelf during the 1999 July surveys. Regions of colder-than-normal temperatures are shaded in the bottom panel.

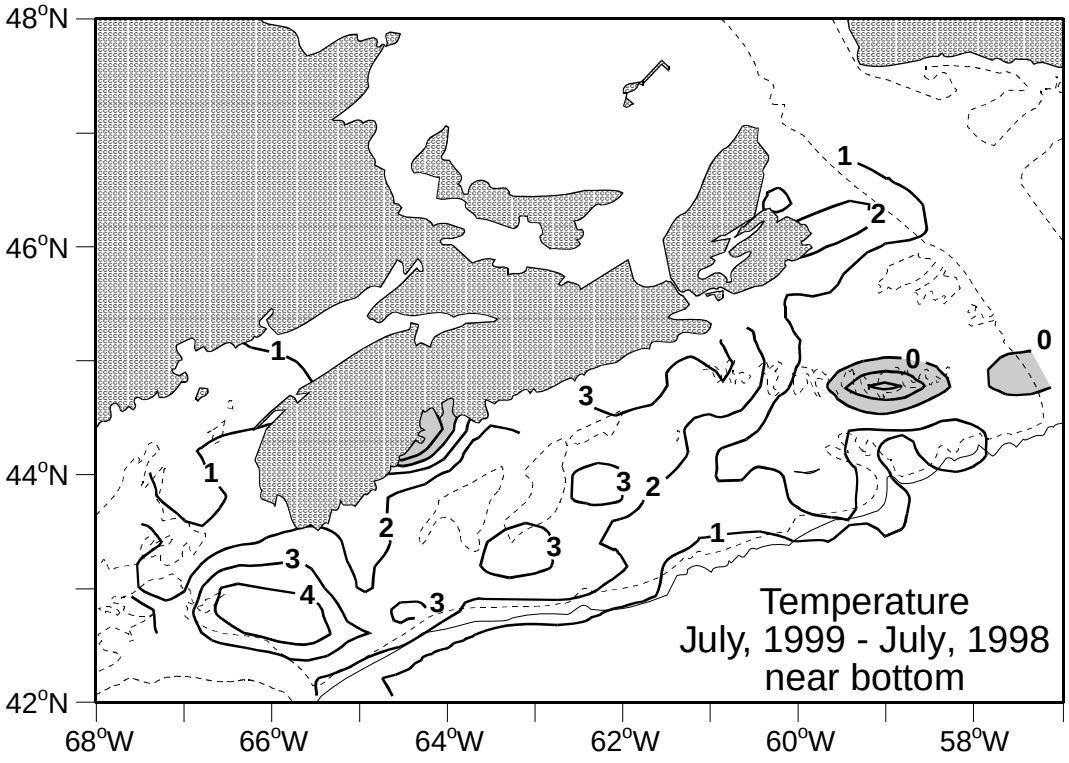

Fig. 5. The difference between the 1999 and 1998 temperature fields on the Scotian Shelf for the July surveys. Positive values indicate temperatures in 1999 had warmed and negative values that they had cooled. Regions were cooling occurred are shaded.

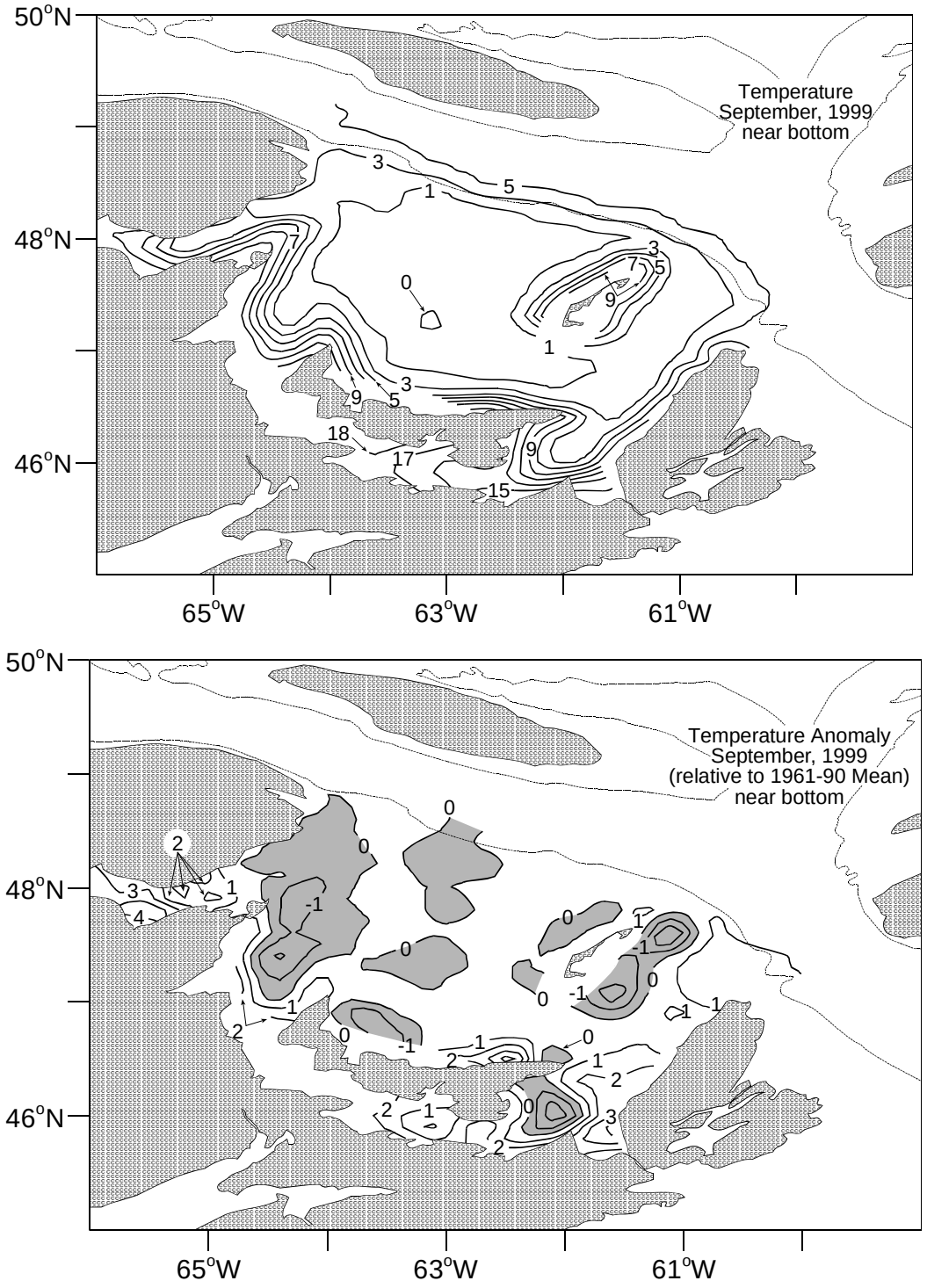

Fig. 6. Near-bottom temperatures (top panel) and their departure from the long-term (1961-1990) means (bottom panel) in the southern Gulf of St. Lawrence during the 1999 September survey. Regions of colder-than-normal temperatures are shaded in the bottom panel.

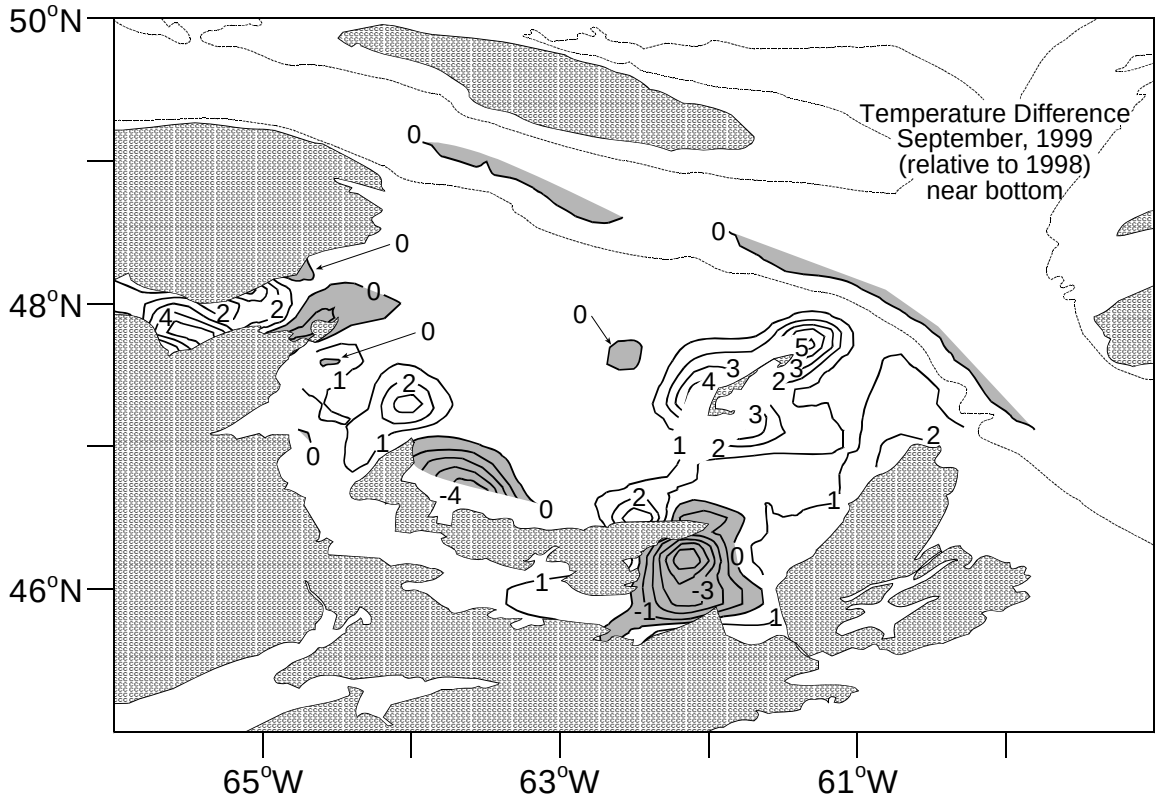

Fig. 7. The difference between the 1999 and 1998 temperature fields in the southern Gulf of St. Lawrence for the September surveys. Positive values indicate temperatures in 1999 had warmed and negative values that they had cooled. Regions were cooling occurred are shaded.

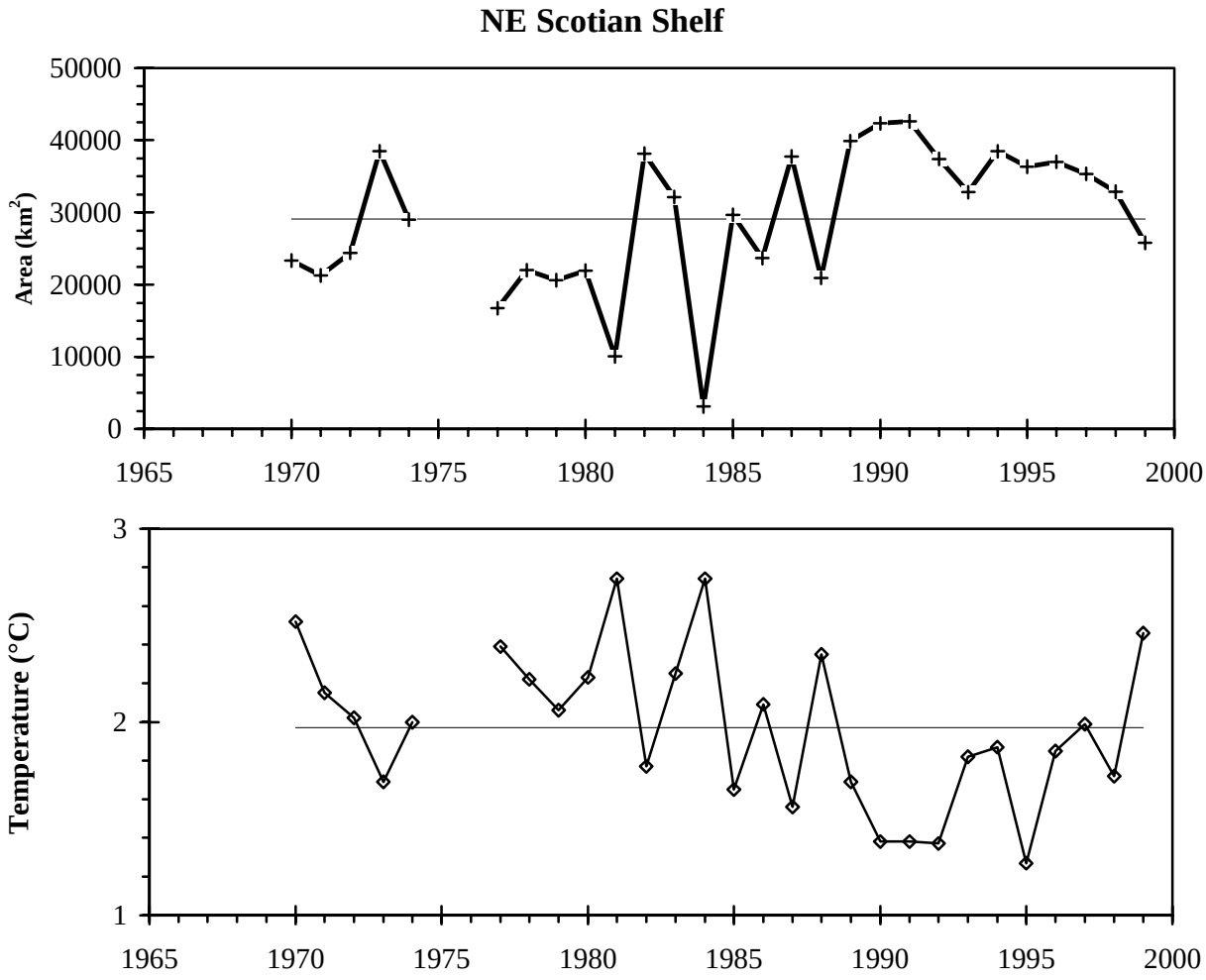

Fig. 8. Time series of the area of the northeast Scotian Shelf covered by bottom temperatures between -1° and 3°C in July (top panel) and the mean temperature within that area (bottom panel). The horizontal lines represent the average over the time series.

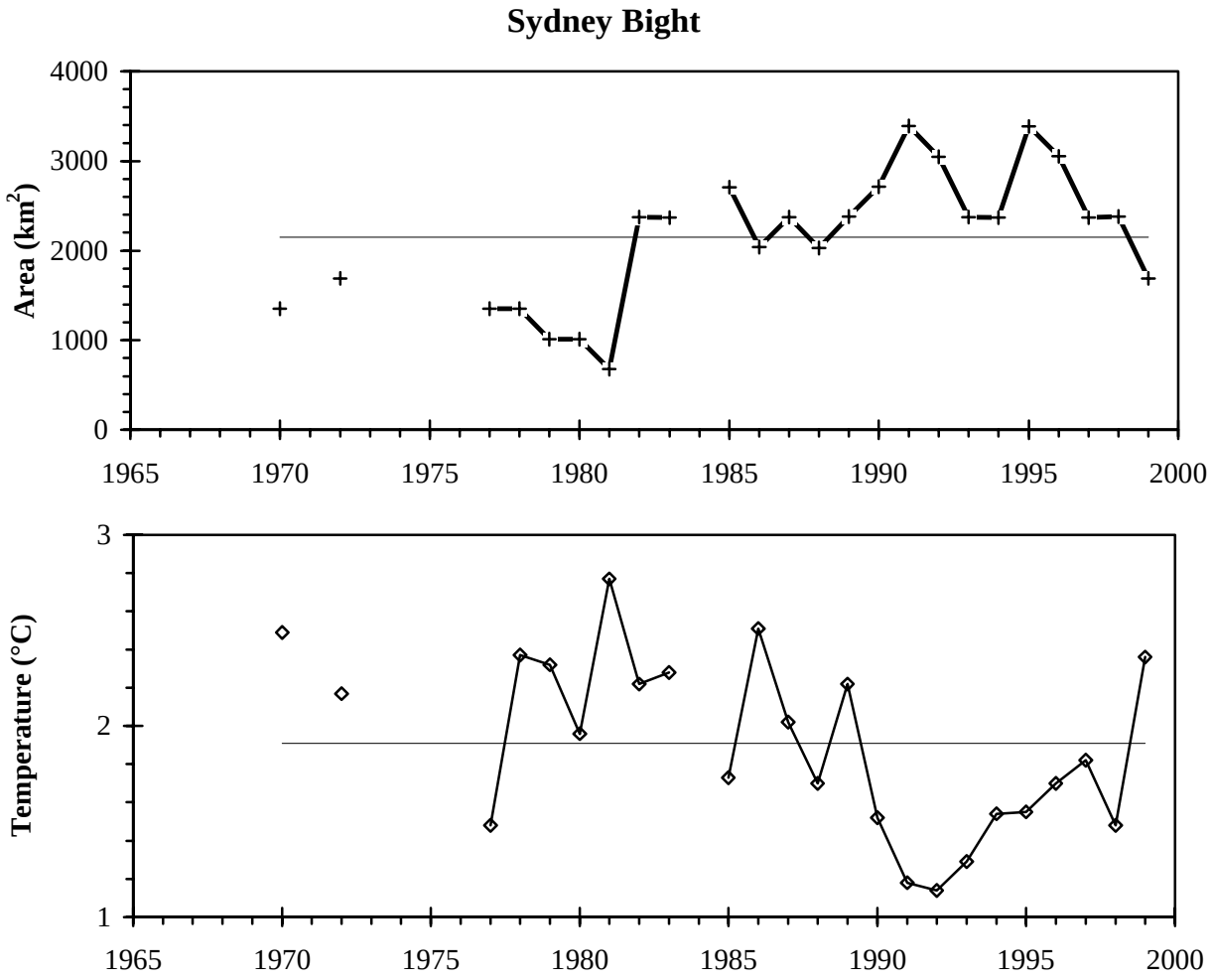

Fig. 9. Time series of the area of Sydney Bight covered by bottom temperatures between -1° and 3°C in July (top panel) and the mean temperature within that area (bottom panel). The horizontal lines represent the average over the time series.

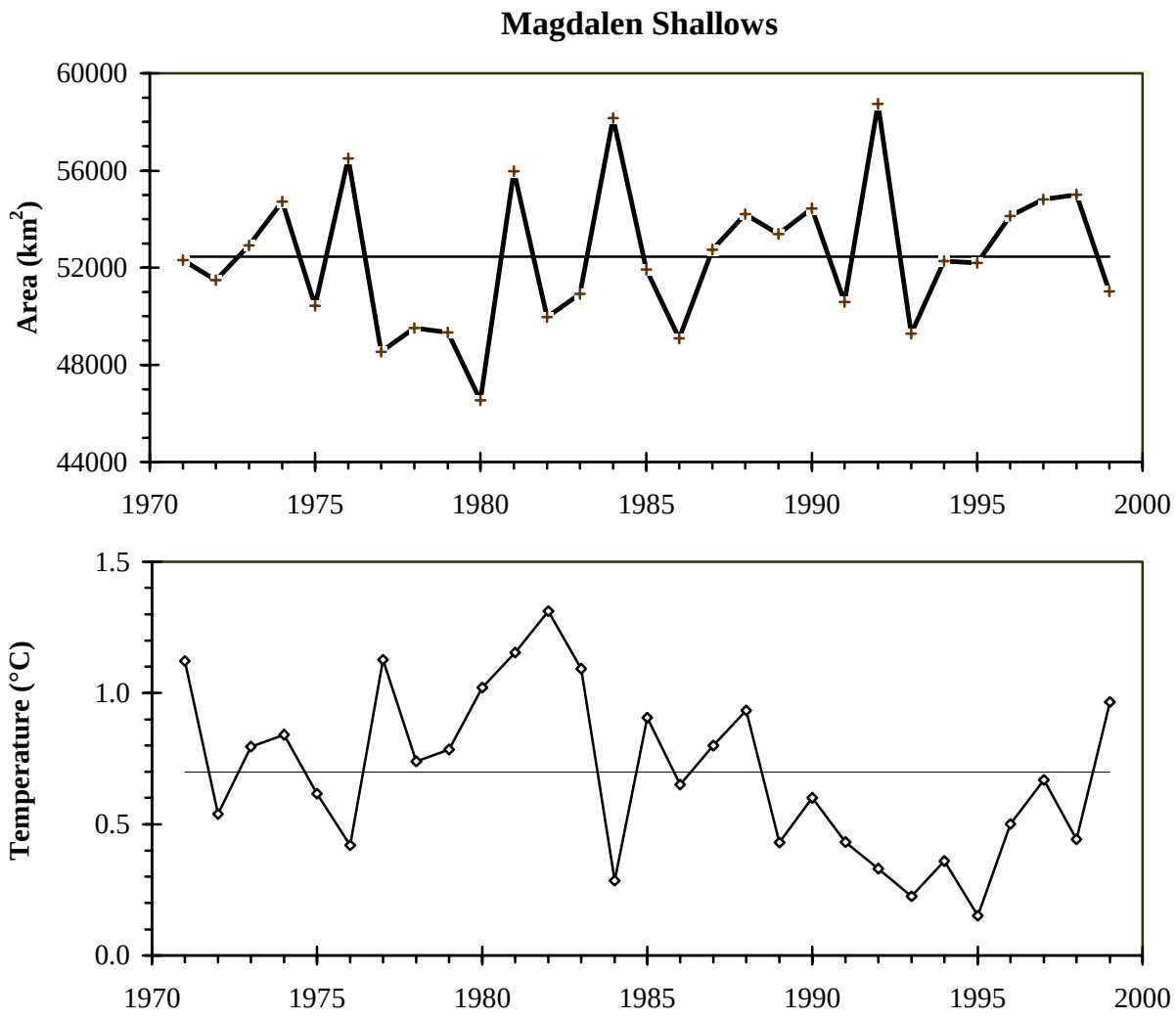

Fig.10. Time series of the area of Magdalen Shallows covered by bottom temperatures between -1° and 3°C in September (top panel) and the mean temperature within that area (bottom panel). The horizontal lines represent the average over the time series.

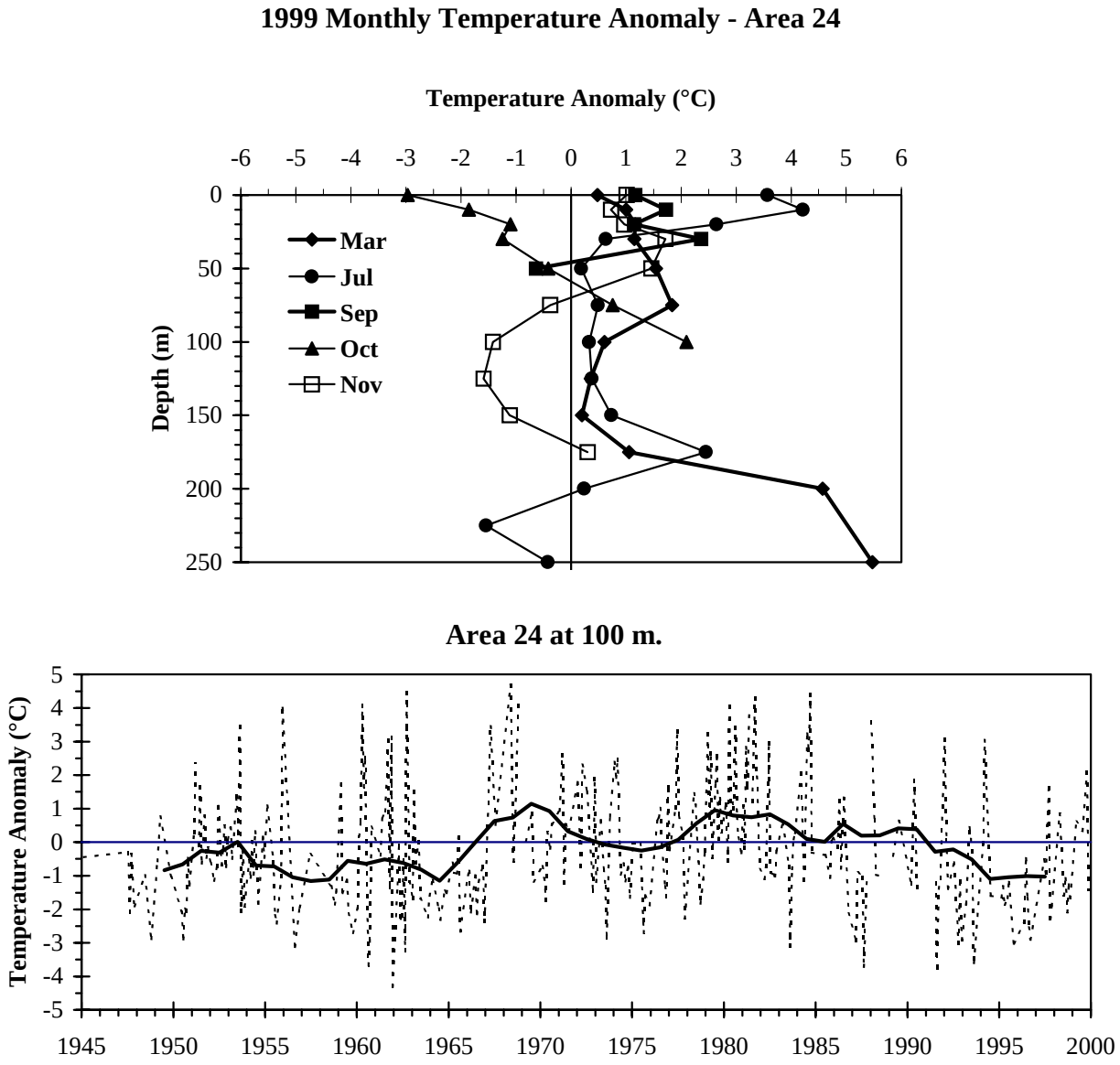

Fig.11. Monthly mean temperature anomaly profiles during 1999 (top panels) and the time series of monthly temperature anomalies at 100 m (bottom panel) for snow crab fishing Area 24.

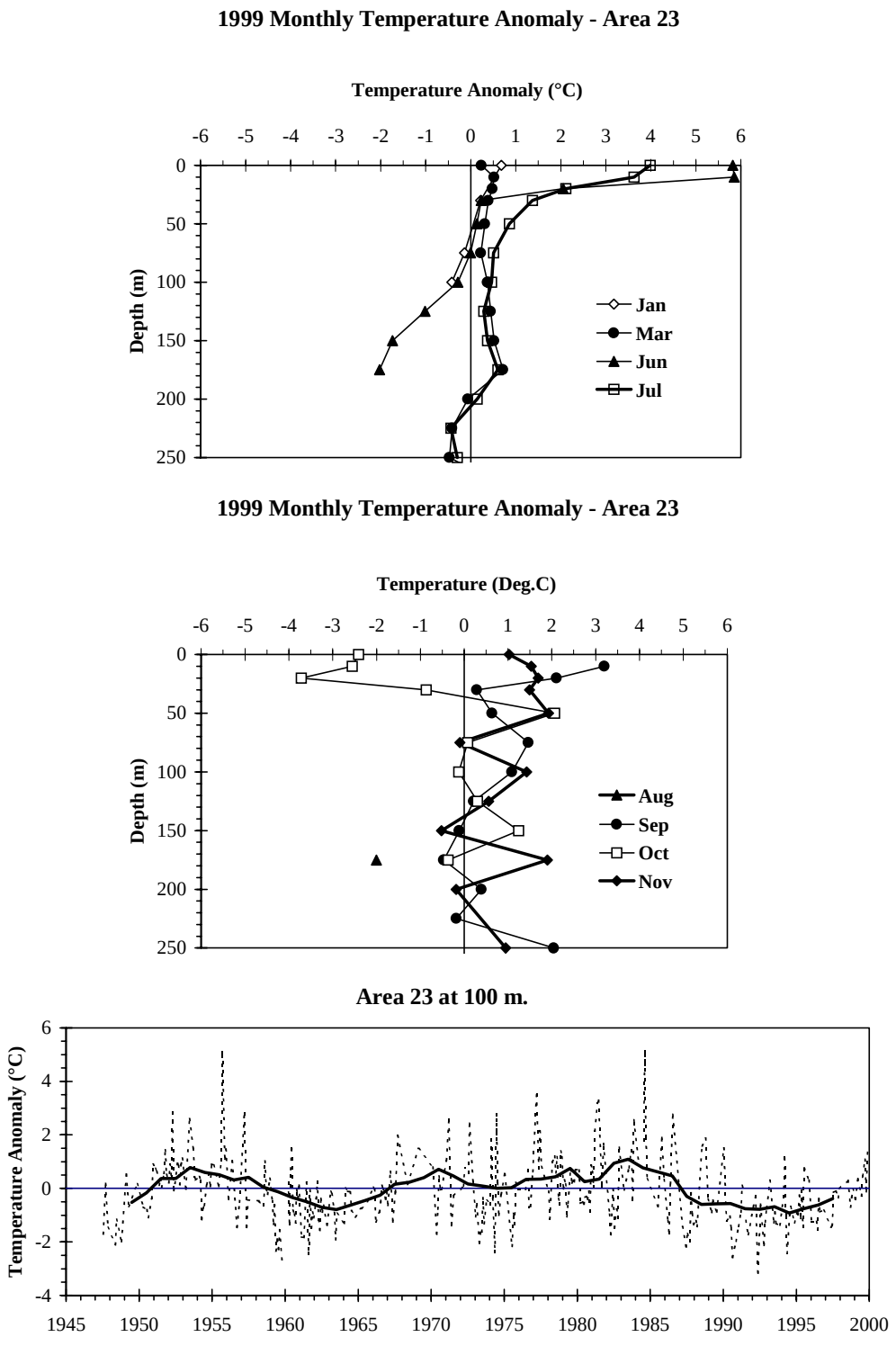

Fig.12. Monthly mean temperature anomaly profiles during 1999 (top panel) and the time series of monthly temperature anomalies at 100 m (bottom panel) for snow crab fishing Area 23.

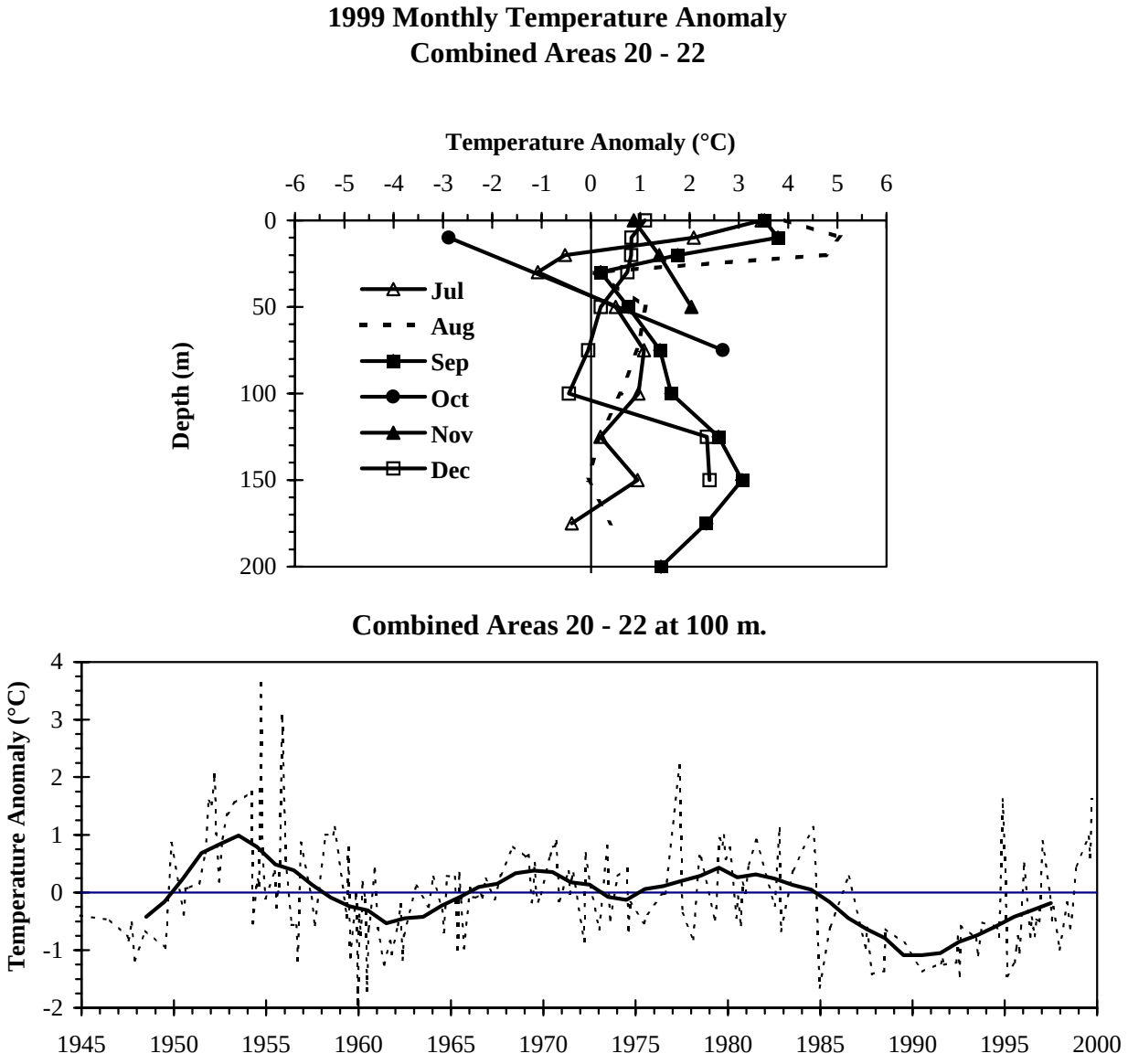

Fig.13. Monthly mean temperature anomaly profiles during 1999 (top panel) and the time series of monthly temperature anomalies at 100 m (bottom panel) for snow crab fishing Areas 20-22 combined.

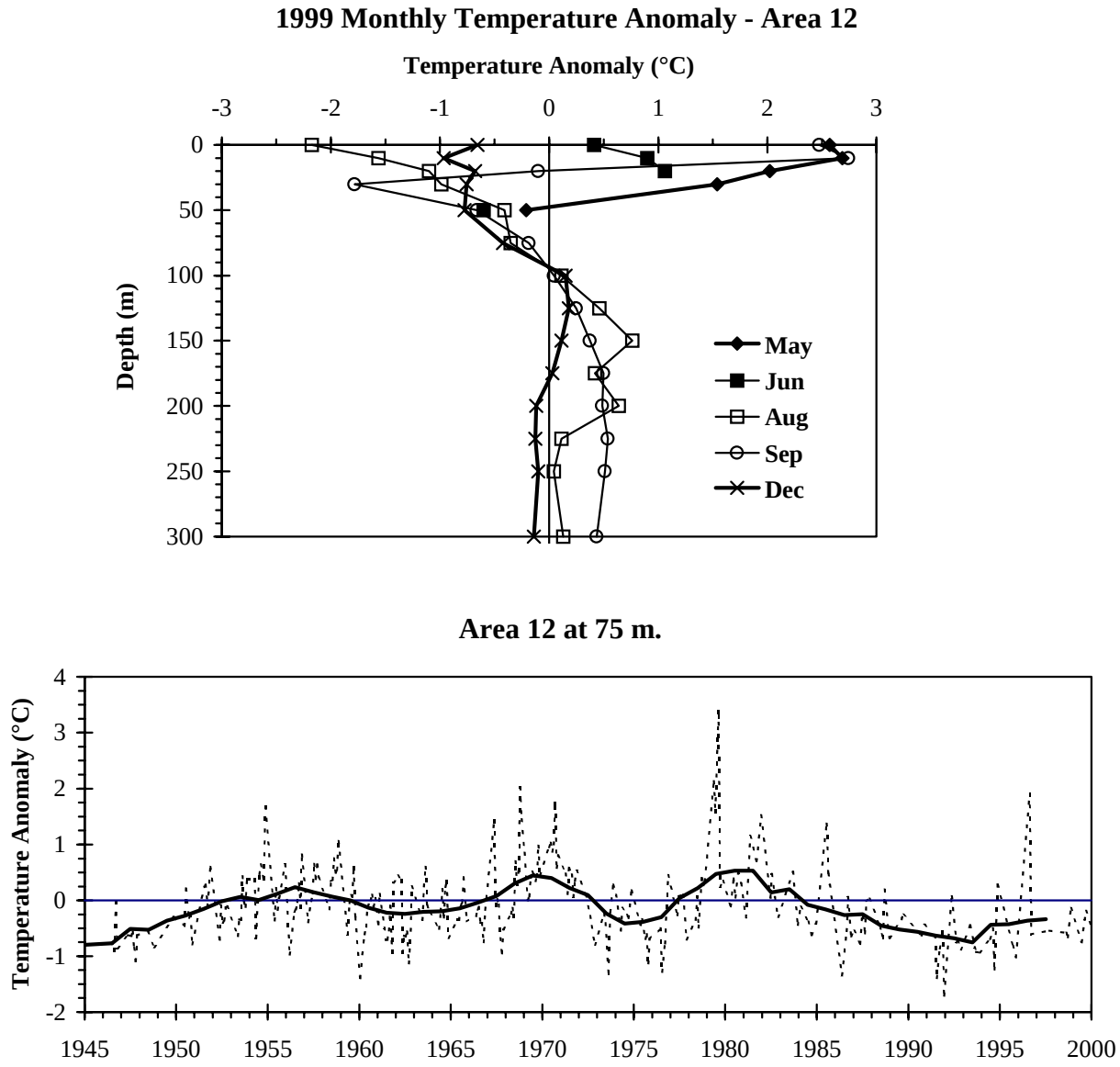

Fig.14. Monthly mean temperature anomaly profiles during 1999 (top panel) and the time series of monthly temperature anomalies at 75 m (bottom panel) for snow crab fishing Area 12.

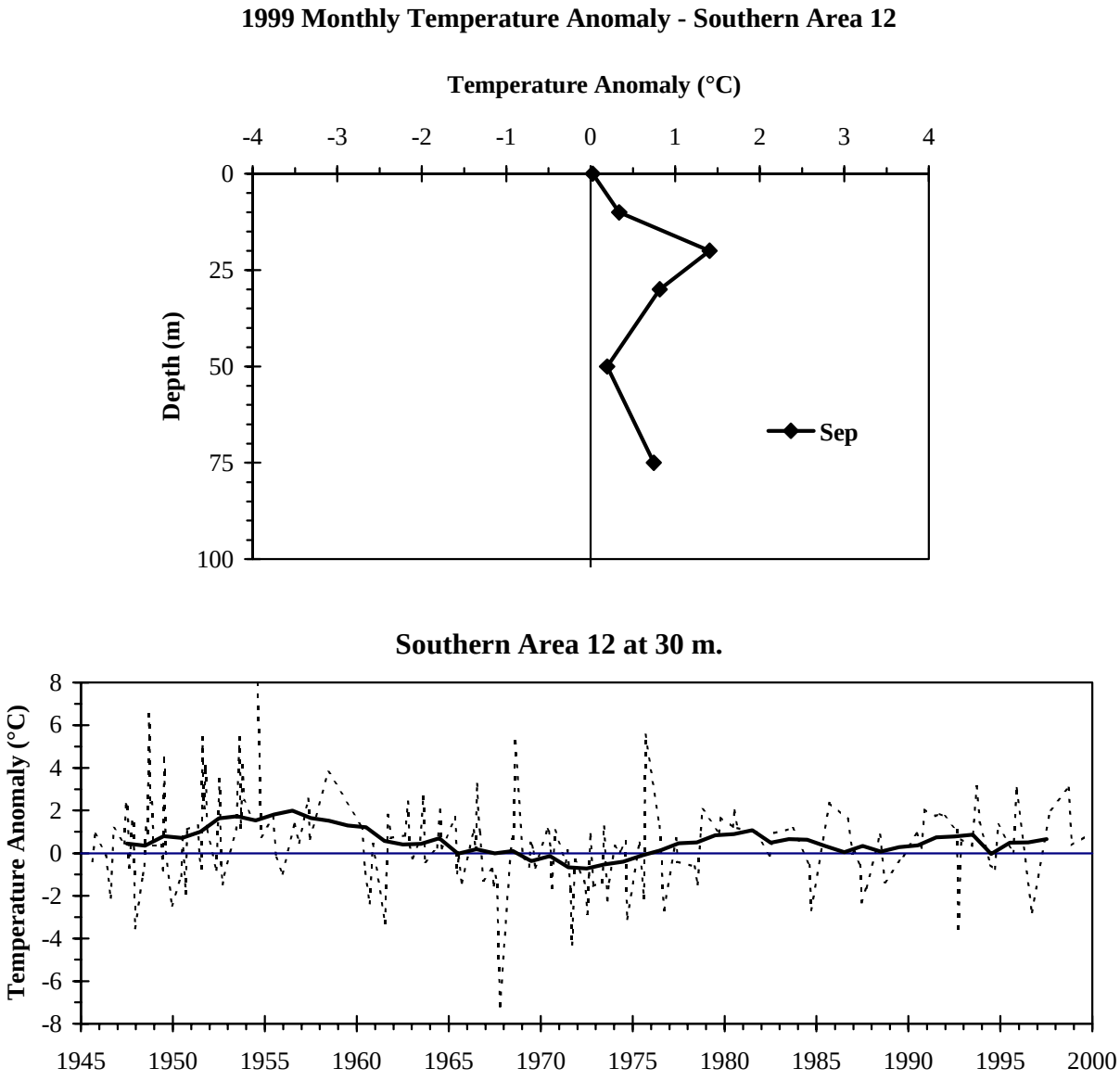

Fig.15. Monthly mean temperature anomaly profiles during 1999 (top panel) and the time series of monthly temperature anomalies at 30 m (bottom panel) in the southern portion of snow crab fishing Area12 (formerly Area 26).

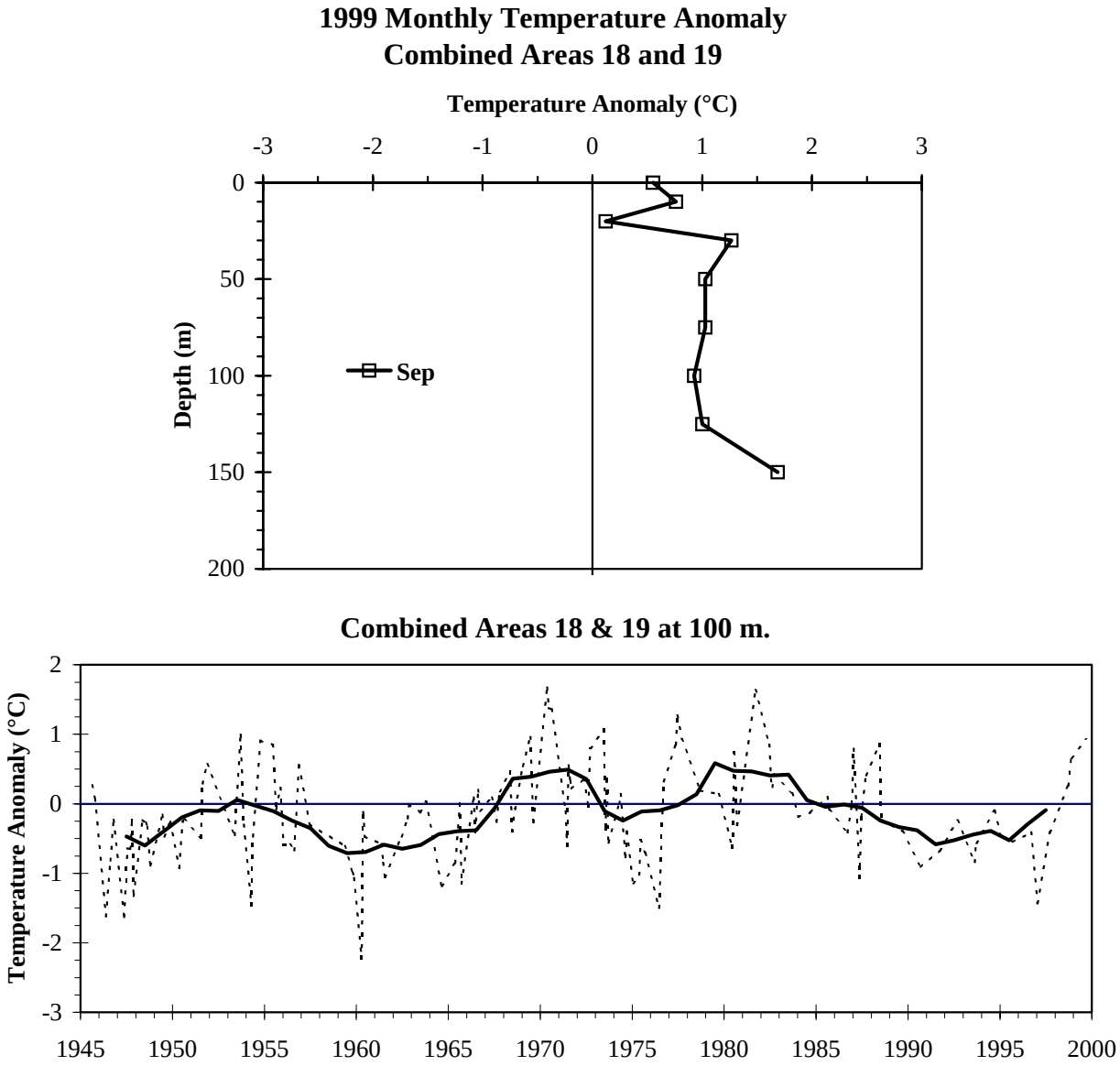

Fig.16. Monthly mean temperature anomaly profiles during 1998 (top panel) and the time series of monthly temperature anomalies at 100 m (bottom panel) for snow crab fishing Areas 18-19.

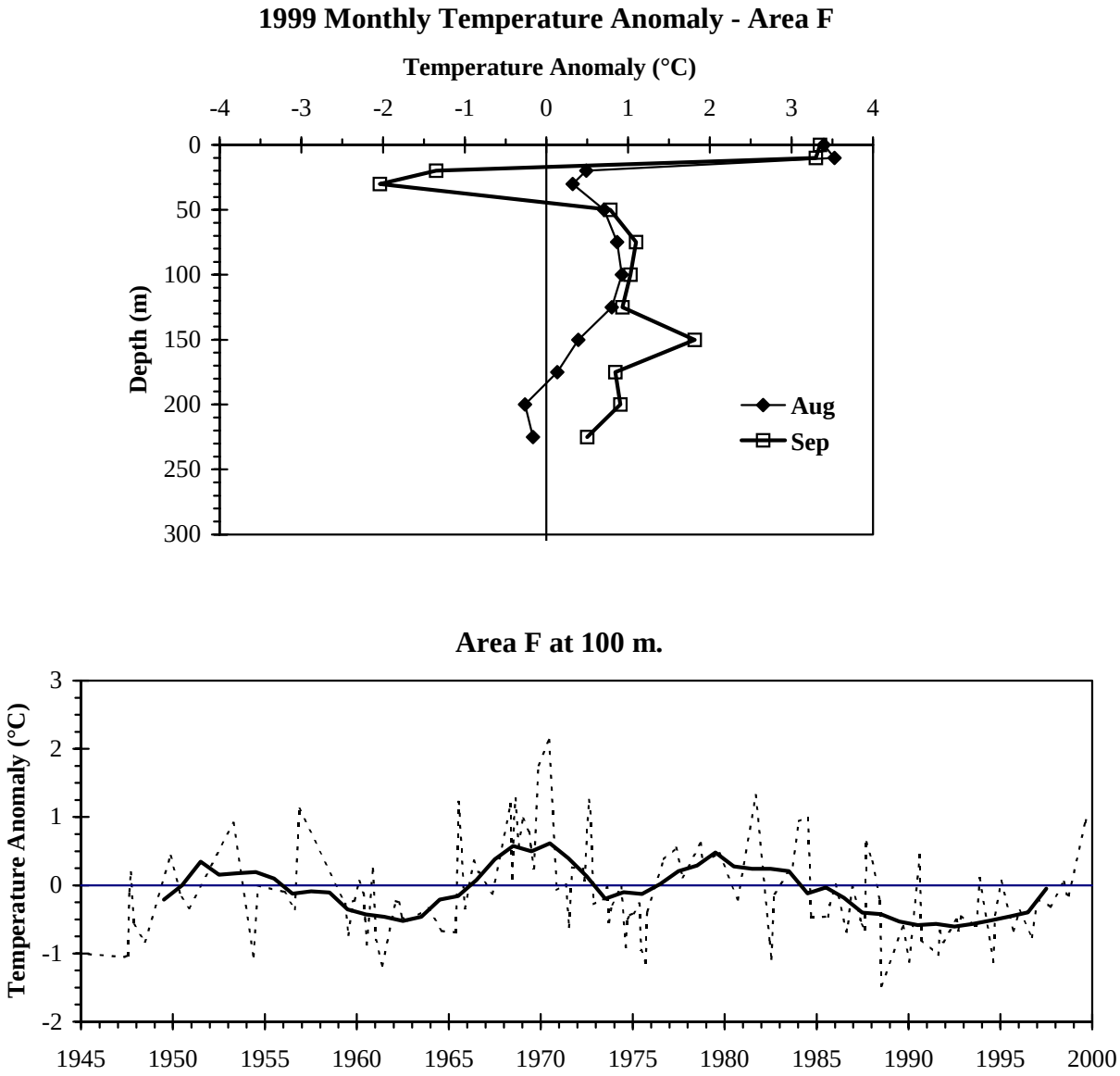

Fig.17. Monthly mean temperature anomaly profiles during 1999 (top panel) and the time series of monthly temperature anomalies at 100 m (bottom panel) for snow crab fishing Area F.

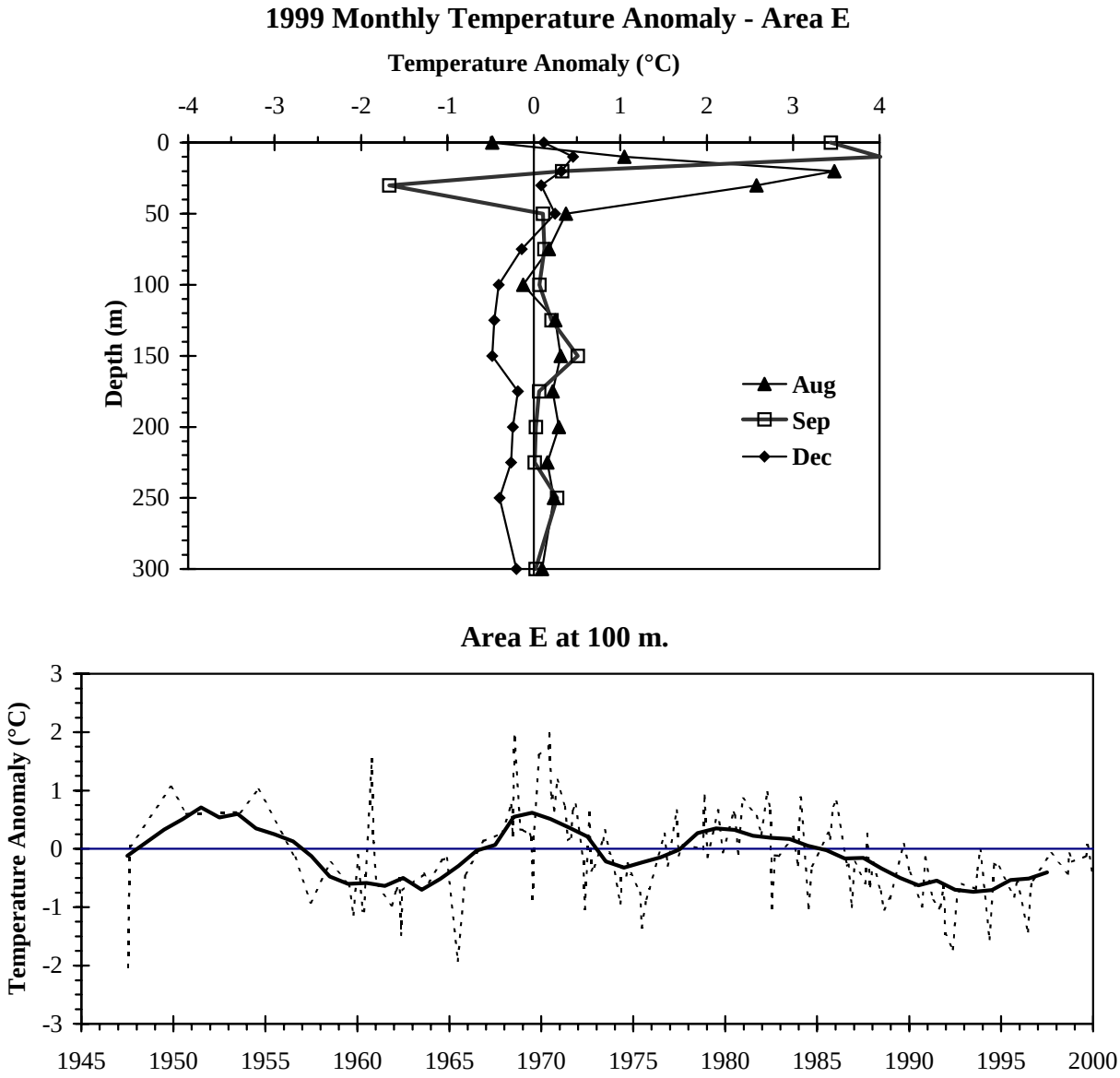

Fig.18. Monthly mean temperature anomaly profiles during 1999 (top panel) and the time series of monthly temperature anomalies at 100 m (bottom panel) for snow crab fishing Area E.

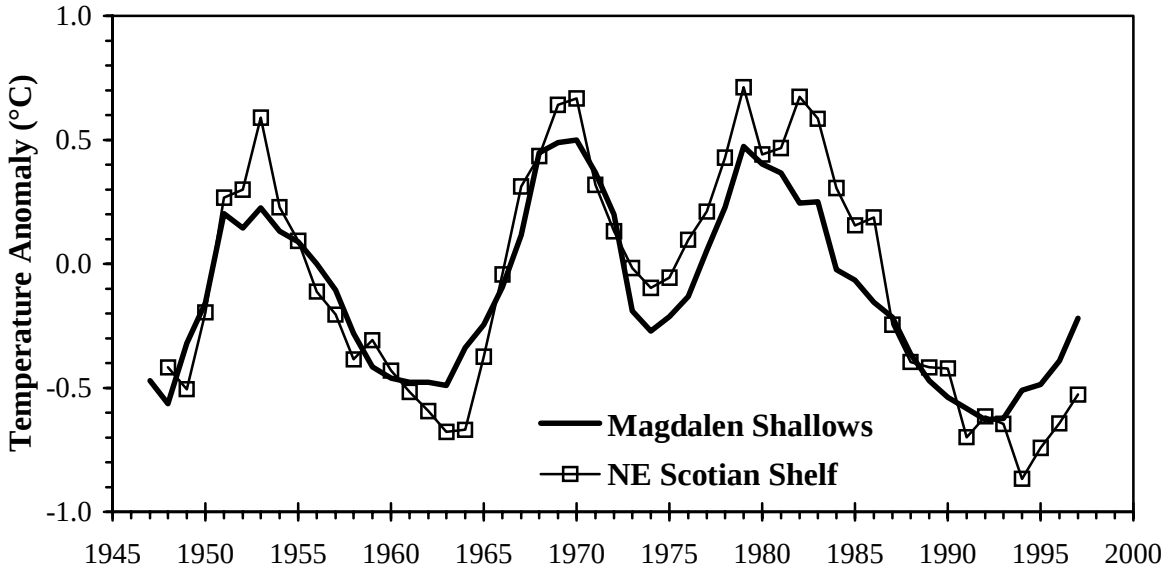

Fig. 19. The 5-year running mean of the average annual bottom temperature anomalies within the snow crab fishing Areas on the Magdalen Shallows and Sydney Bight/NE Scotian Shelf at depths of 75-100 m.

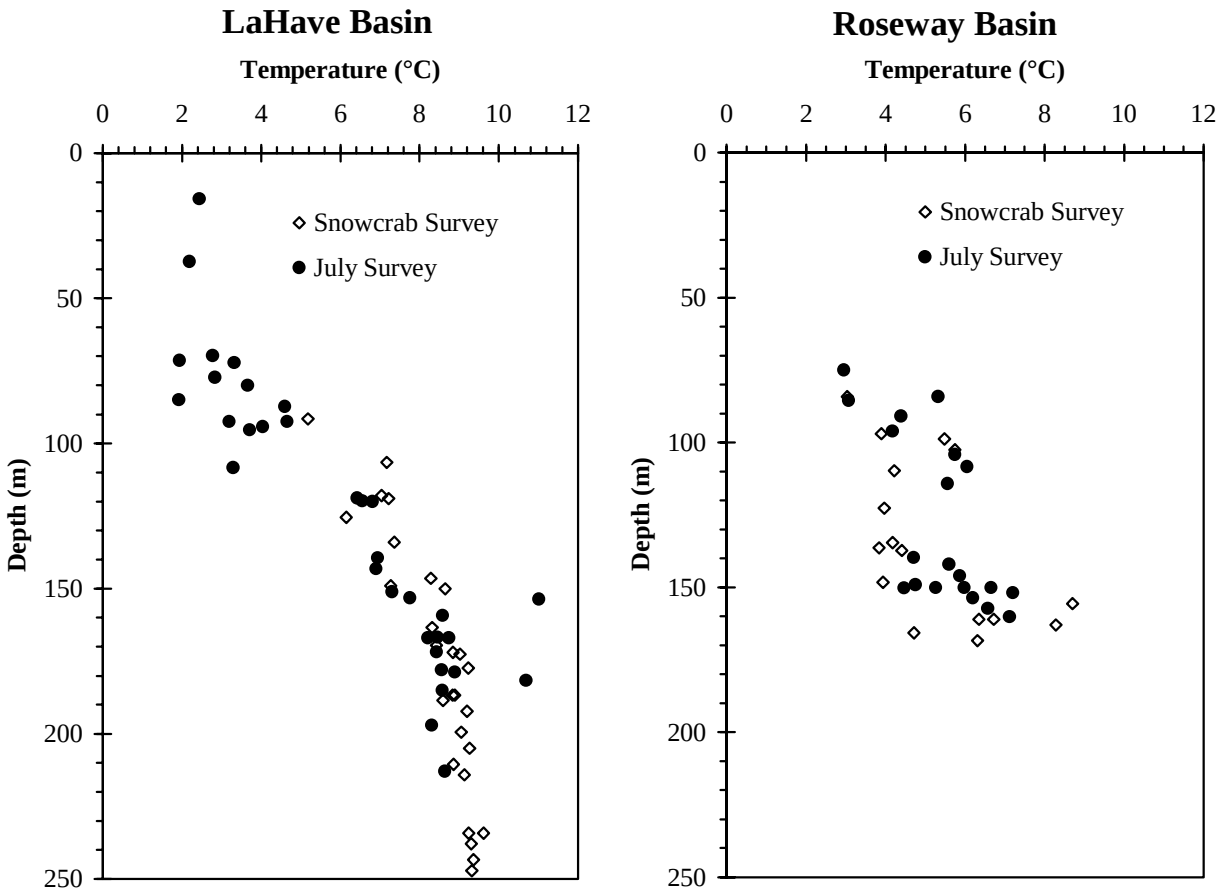

Fig. 20. The bottom temperatures as a function of depth from the July groundfish surveys and the September-October snow crab surveys in LaHave Basin (left panel) and the June snow crab survey in Roseway Basin (right panel).

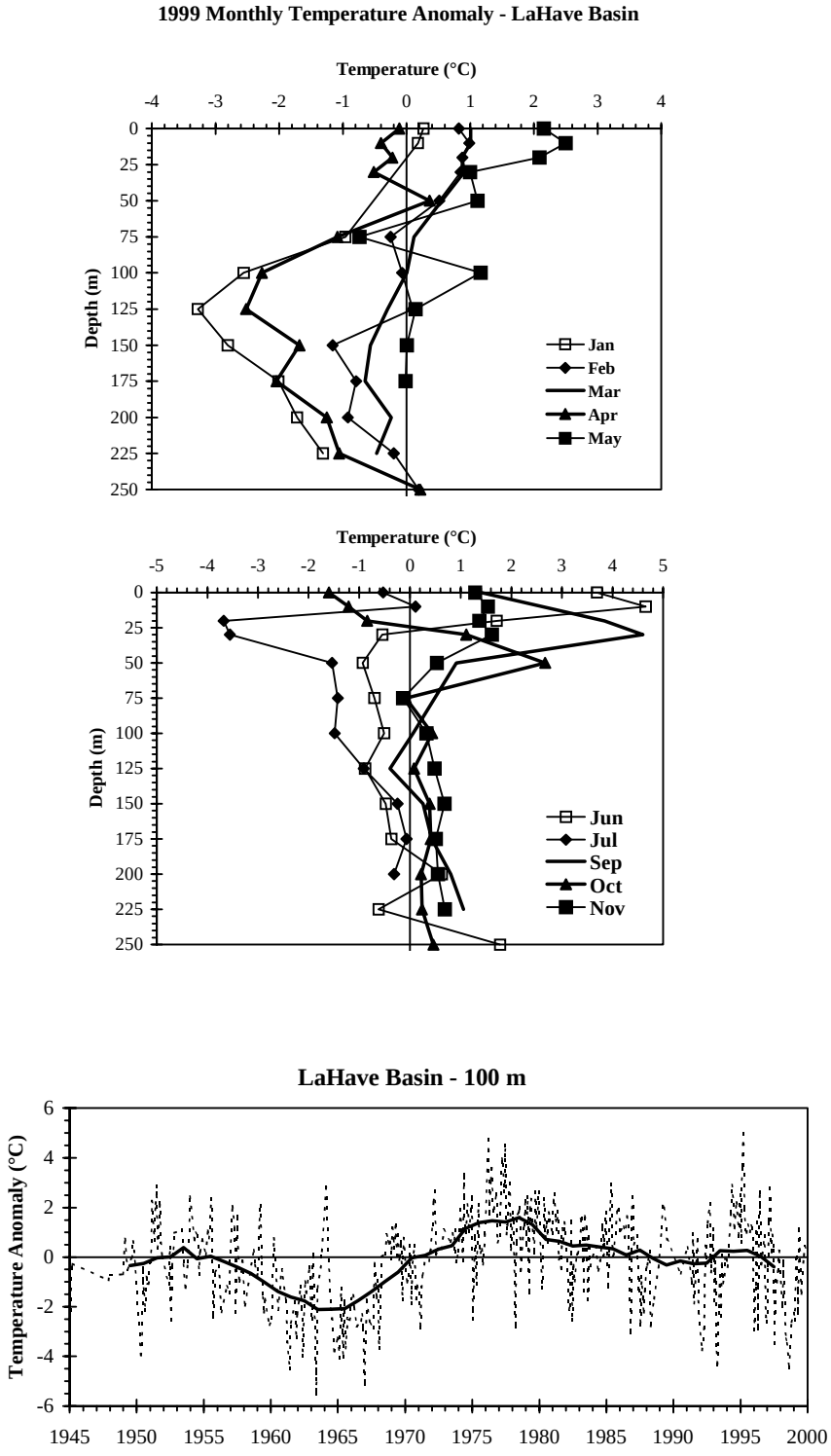

Fig.21. Monthly mean temperature anomaly profiles during 1999 (top panel) and the time series of monthly temperature anomalies at 100 m (bottom panel) for LaHave Basin.

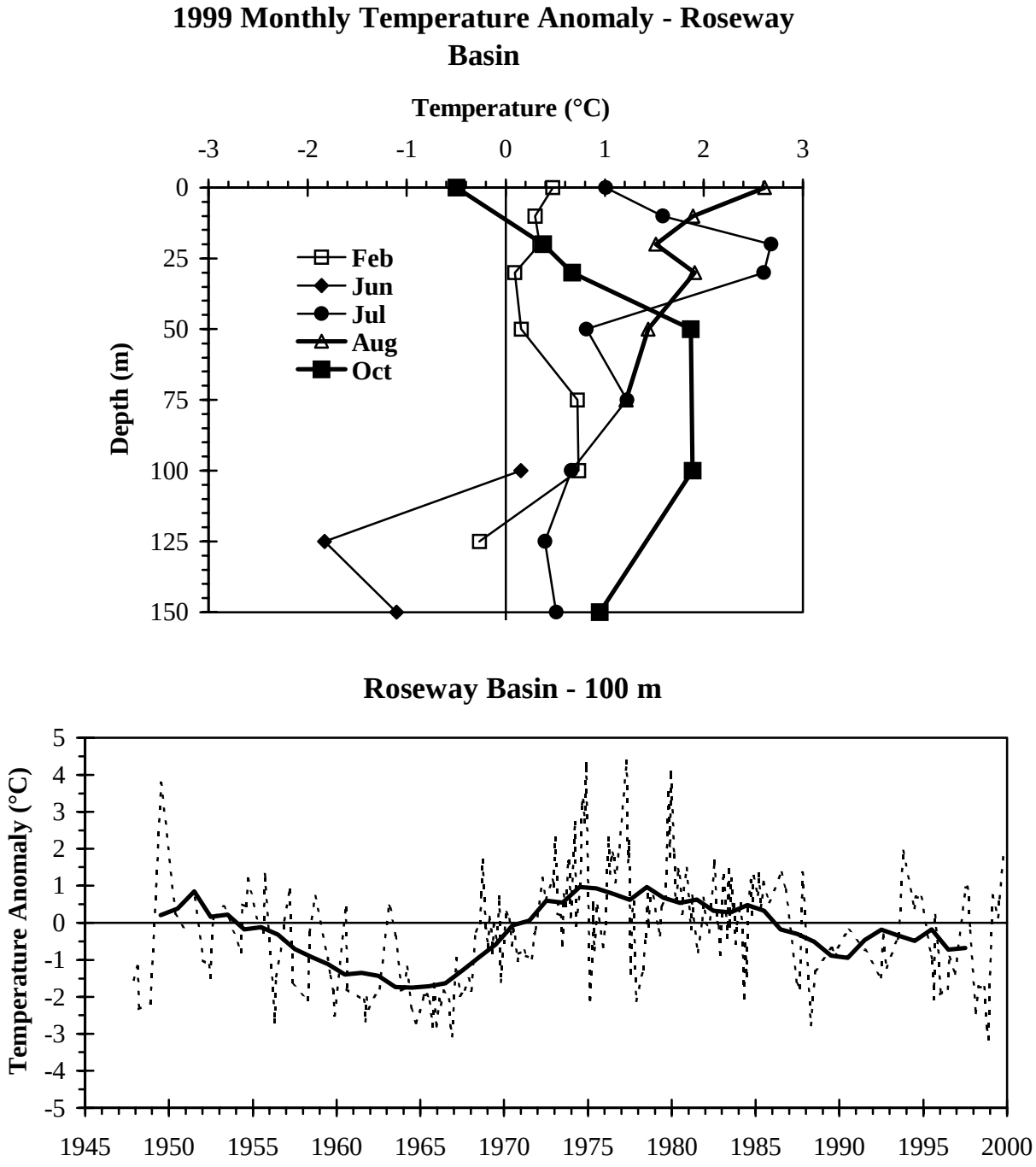

Fig.22. Monthly mean temperature anomaly profiles during 1999 (top panel) and the time series of monthly temperature anomalies at 100 m (bottom panel) for Roseway Basin.