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Temperature Conditions on the Scotian Shelf and in the southern Gulf of St. Lawrence during 1998 Relevant to Snow Crab

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Abstract

Temperatures during 1998 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. 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 has been relative large since the late-1980s compared to the 1970s and early 1980s, indicative of more preferred habitat for snow crab. Temperature trends within each of the snow crab fishing areas of the southern Gulf of St. Lawrence to the northeastern Scotian Shelf were similar and have shown generally colder-than-normal conditions since the late-1980s. Whereas temperatures collected during the groundfish surveys (on the inner half of the northeastern Scotian Shelf in July and on the Magdalen Shallows in September) were cooler in 1998 than in 1997, supplementary temperature data indicate that the slow warming observed in recent years throughout much of the Magdalen Shallows and the northeastern Scotian Shelf generally continued into 1998.

Résumé

Les températures des eaux du Canada maritime habitées par le crabe des neiges sont présentées pour 1998. Des données ont été obtenues de diverses sources notamment des relevés du poisson de fond réalisés sur le plateau néo-écossais et dans la grande baie de Sydney en juillet et sur les hauts fonds des îles de la Madeleine, dans le golfe du Saint-Laurent, en septembre ainsi qu'à d'autres moments de l'année dans le cadre de relevés de pêche, de recherches ou de l'utilisation de navires occasionnels. La température au fond de grandes parties de ces zones de plateau se situait entre -1^{o} et 3^{o}C, une gamme jugée optimale pour le crabe des neiges. La superficie du fond où la température de l'eau se situait dans cette gamme dans chacune des zones du sud du Golfe, de la grande baie de Sydney et du nord-est du plateau néo-écossais a été relativement importante depuis la fin des années 1980, comparativement aux années 1970 et au début des années 1980, et correspondait donc à une augmentation de l'habitat préféré du crabe des neiges. L'allure de la température au sein de chacune des zones de pêche du crabe des neiges, du sud du golfe du Saint-Laurent au nord-est du plateau néo-écossais, était semblable et indiquait des valeurs généralement inférieures à la normale depuis la fin des années 1980. Les températures notées en 1998 pendant les relevés du poisson de fond (demie interne du nord-est du plateau néo-écossais en juillet et hauts fonds des îles de la Madeleine en septembre) étaient inférieures à celles de 1997, mais des données supplémentaires montrent que le lent réchauffement observé ces dernières années dans la plus grande partie des hauts fonds des îles de la Madeleine et du nord-est du plateau néo-écossais s'était généralement poursuivi en 1998.

Introduction

Snow crab (*Chionoecetes opilio*) is a cold-water species typically inhabiting bottom depths of 80-200 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. 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 1998 in areas occupied by snow crab and to compare these temperatures to their long-term means. As in last year's review (Drinkwater et al., 1998c), 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 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 1998 in our areas of interest were limited to 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. 2a). The second dataset was the Gulf of St. Lawrence annual groundfish survey in September that covered the Magdalen Shallows (Fig. 2b). Additional temperature data from 1998 were obtained from the Marine Environmental Data Service (MEDS) in Ottawa, Canada's national oceanographic data archive, and are derived from other fisheries surveys, research surveys and ships-of-opportunity. Pre-1998 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. Note that the January survey of the Laurentian Channel reported on in previous years was not undertaken in 1998 due to completion of the program.

Methods

The near-bottom temperatures from data collected during both 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 data were then smoothed and the bottom temperatures contoured. 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 tend to be weaker than 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 Northwest Atlantic Fisheries Organization (NAFO). The climatological means were then subtracted from the 1998 survey data to produce temperature differences from the long-term means, hereafter referred to as anomalies. A negative anomaly indicates that the 1998 value was colder than the long-term mean. We also examined the change in temperature since the previous year by subtracting the 1997 optimally-estimated temperatures from the 1998 estimates. A negative value indicates that 1998 was cooler than 1997.

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 1998 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 1998 were determined within each of the snow crab areas (Fig. 1) 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, 300 m). 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.

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. 3). Temperatures were principally below their long-term means with anomalies mostly between 0° and 1°C (Fig. 3). They decreased slightly relative to July 1997 over the inner half of the northeastern Scotian Shelf (Fig. 4) which differs from the trend of slow warming observed over the past few years in this area. In contrast, on the outer banks, such as Banquereau and Sable Island, bottom temperatures increased in July 1998 relative to July 1997.

Southern Gulf of St. Lawrence

On the Magdalen Shallows, bottom temperatures in September 1998 show a typical range of < 0°C to over 10°C (Fig. 5). The majority of the bottom is covered by temperatures of <3°C with the coldest waters (<0°C) extending over a large region north of Prince Edward Island (PEI) in depths of 50-80 m. 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 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 as well as by advection of cold Labrador Shelf water through the Strait of Belle Isle. In 1998, the warmest near-bottom temperatures and anomalies were in the shallowest regions, in particular in Northumberland Strait and along the north shore of PEI. The majority of the

Shallows was covered by bottom waters that were generally below normal by 0 to 1°C. The coldest anomalies (lower than -2°C) were located off northwestern PEI and the Magdalen Islands. Relative to 1997, bottom temperatures over most of the central region decreased slightly (Fig. 6). This reverses the trend that has been observed over the past several years of slowly increasing bottom temperatures.

Snow Crab Habitat Index

From the July 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 occupied a total area of 70426 km^2 (201 grid points) while on the Sydney Bight the total area was 7801 km^2 (23 grid points). On the Magdalen Shallows, the total area was 70039 km^2 (847 grid points) and surveys have been carried out since 1971. Note that the larger number of grid points in the Gulf was 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 estimated the average temperature within the area covered by -1°C to 3°C and correlated these with the areal index.

Northeastern Scotian Shelf and Sydney Bight

On the northeastern Scotian Shelf, the snow crab habitat index in 1998 was 32,856 km^2 representing approximately 47% coverage of the total grid area. This index has been relatively high since the mid-1980s but has been declining slowly since the early 1990s (Fig. 7). The maximum coverage was reached in 1991 (over 60% of the total grid area). These results are 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 are negatively correlated with the size of the area ($r=-0.88$, $p<.001$). 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 has been high in recent years, temperatures have generally been low. However, in 1998 both the habitat index and temperature declined relative to 1997.

On Sydney Bight, the snow crab habitat index in 1998 remained relatively high (representing slightly over 30% coverage of the total grid area) and was similar to 1997. This index has varied between 26-43% since the mid-1980s (Fig. 8). 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). Correlations between the average temperature within the index area and the habitat index itself for Sydney Bight were low and not significant. This is in

contrast to 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 lack of correlation.

Southern Gulf of St. Lawrence

The area of the bottom covered by waters between -1°C and 3°C on the Magdalen Shallows during the September groundfish survey also shows a relatively high value (around 55000 km^2) in 1998 (Fig. 9). This represents about 79% of the total Magdalen Shallows area. This value of the index was not significantly different from that for 1997. The variability in the habitat index for the Shallows tends to be small, although the past six years have seen a gradually increase. In recent years, mean temperatures within this area have been relatively low with a minimum in 1995. The 1998 mean temperature decreased by approximately 0.2°C from the 1997 value and reverses the trend of increasing temperatures observed over the past few years. The correlation between the habitat index and the mean temperature within this area ($r=-0.88$; $p<0.001$) matches that for the northeastern Scotian Shelf. 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. (1998a). The index for the Magdalen Shallows is slightly different from that shown in Drinkwater et al. (1998c) which was based upon data estimated from kriging. The present method using the optimal estimated temperatures is considered more representative because of the inclusion of the vertical data in the interpolation scheme. The major differences occurred prior to the late 1980s when there tended to be fewer hydrographic stations and the vertical resolution of the data was not as good.

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. 1 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.

Northeastern Scotian Shelf and Sydney Bight

In Area 24, data were available in 7 months of 1998. With the exception of April, temperatures below 20 m tended to be near or below normal with the largest anomalies (-1° to -3°C in depths > 50 m) after August (Fig. 10). The time series at 100 m shows below normal temperatures

over most of the 1990s but unlike many of the other fishing zones there is no evidence of the warming in 1998. Area 24 spands 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. 3). 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 the Warm Slope Water (temperatures >8°C) that occupied the region for most of the past 30 years were replaced by colder Labrador-type slope water with temperatures of 4-6°C (Drinkwater et al., 1998b). This cooling contributed substantially to the below normal bottom temperature anomalies observed in Area 24 during 1998. The effect of this cooling on snow crab, which was principally limited to the western portion of Area 24, may be minimal, however. 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 between 50 and 100 m were predominantly below normal in 1998 and the time series at 100 m shows the familiar pattern of cold temperatures since about the mid-1980s with recent years trending upwards (Fig. 11).

The temperature data for snow crab fishing Areas 20 through 22 were combined in our analysis. From the 5 months of 1998 when observations were available, temperatures below 100 m tended to be below normal, the exception being November (Fig. 12). In the upper 100 m, temperatures varied significantly from month to month but with a greater preponderance of warmer-than-normal temperatures. The only significant deviation from this trend was in July with strong negative cooling appeared below approximately 15 m. The time series at 100 m shows colder-than-normal waters since the mid-1980s and warming during recent years (Fig. 12). This same pattern is observed from 50 to 150 m and is consistent with that reported for Sydney Bight in last year's report (Drinkwater et al., 1998c).

Gulf of St. Lawrence

Data for 1998 over the central Magdalen Shallows (Area 12 in Fig. 1 excluding the southern portion just north of Prince Edward Island) were available during August to November, inclusive, although the October 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. 13). This depth range covers most of the bottom depths over the Magdalen Shallows. Below 100 m during August and November temperatures were warmer-than-normal by about 0.5°C. In September, temperatures in this depth range were nearer normal. Most of these deeper data are from the Laurentian Channel. In the top 20 m there is a tendency towards higher-than-normal

temperatures except in October. The combined higher anomalies in the surface layer and colder anomalies at intermediate depths indicate increased thermal stratification. The time series of monthly mean temperatures at 75 m in zone 12 shows high variability but a definite tendency for below normal temperatures since the mid-1980s (Fig. 13). Note that not all months of each year contain data. Recent years, including 1998, 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. 13 is believed to be due to differences in the extent of the spatial sampling.

Within the southern portion of Area 12 (formerly Area 26), just north of Prince Edward Island, data were available only in September and November. September shows strong positive anomalies (up to 3°C) between 10 and 50 m with the peak at 30 m. By November, temperatures were near normal. 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. 14). 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. There are also much less data at 50 m then at 30 m. At the shallower 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 made during both September and November of 1998. The mean profiles indicate colder-than-normal waters at depths ranging from 20 m to 75 m in September but by November colder-than-normal conditions were restricted to 50 m to slightly deeper than 75 m (Fig. 15). Below approximately 75 m temperatures were above normal. The time series at 100 m shows above normal temperatures and a change from the cooler conditions that persisted since the late 1980s (Fig. 15). At shallower depths (50 and 75 m; not shown), the colder-than-normal conditions continued through 1998. At 150 m there are few data and no overall trend is observed.

Data during June, August and September of 1998 were available from Area F. In all three months, temperature anomalies from 50 m to 200 m were near normal but with a tendency to be slightly negative (Fig. 16). During September, the only month when data extended below 200 m, temperatures in this deep layer were slightly above normal. In the top 30 m, the temperature anomalies varied greatly from month to month, presumably due to atmospheric forcing. The time series at 100 m

in Area F is similar to both Area 12 and the combined 18&19, i.e. a strong tendency towards below normal anomalies since about the mid-1980s with general warming since the mid-1990s. This 100 m record is reasonably representative of conditions from 75 to 150 m in zone F.

To the north in Area E, data were available during August, September and November. Temperatures in September from 20 to 250 m were below normal with a maximum amplitude of near -3°C at 30 m (Fig. 17). Data from August and November show weaker temperature anomalies but with a tendency for depths of 50 to 200 m being below normal and deeper than 200 m being above normal. The temperature time series at 100 m for Area E shows the typical pattern of negative anomalies since the mid-1980s, a general upswing beginning in the mid-1990s and near normal temperatures by 1998. Deeper than 100 m there is also the tendency for below normal temperatures since the mid-1980s but with more measurements of warmer-than-normal conditions.

Comparison of Temperature Trends

The 5-year means show the major temperature trends. These are plotted together for each of the fishing areas for the Magdalen Shallows and for Sydney Bight/NE Scotian Shelf (Fig. 18). On the Magdalen Shallows the trends in all of the zones, 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 is 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 (Fig. 19). All show below normal temperatures through most of the 1990s.

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 zones 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. 20).

Summary

Near-bottom temperatures collected during groundfish surveys in July on the northeastern Scotian Shelf and in September on the Magdalen Shallows during 1998 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 1998, colder-than-normal conditions dominated throughout the region at bottom depths from approximately 50 m to 250 m, 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), remained relatively high throughout the region and the mean temperatures within these areas were low. Thus relatively large portions of the Magdalen Shallows, Sydney Bight and the northeastern Scotian Shelf continue to contain preferred habitat for snow crab. The index has been high since the late-1980s. In most snow crab fishing areas there has been a consistent pattern of colder-than-normal bottom temperatures since the mid- to late-1980s with slight warming in recent years. The only major exceptions are the section of Area 12 north of PEI (formerly Area 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 slope water into the region. Whereas temperatures collected during the groundfish surveys (on the inner half of the northeastern Scotian Shelf in July and on the Magdalen Shallows in September) were cooler in 1998 than in 1997, supplementary temperature data indicate that the slight warming observed in recent years throughout much of the Magdalen Shallows and the northeastern Scotian Shelf generally continued through 1998.

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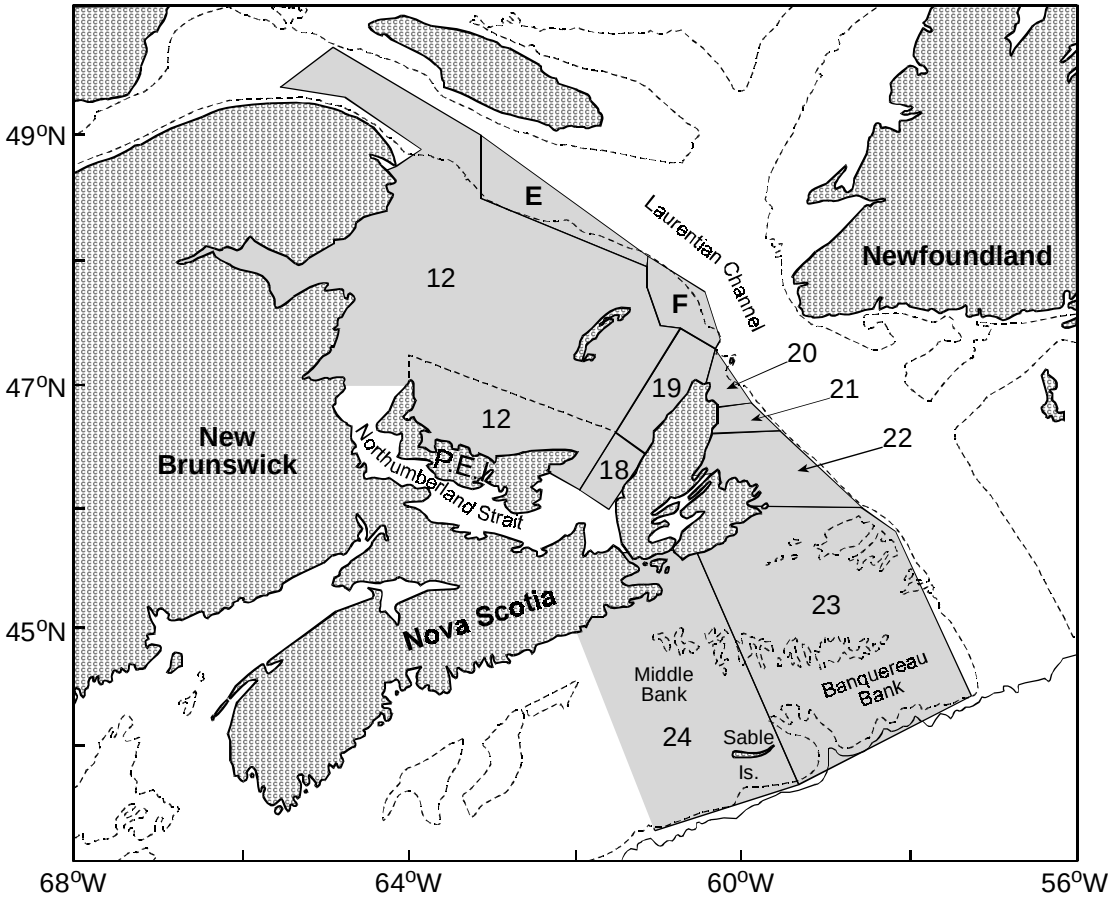

Fig. 1. The Gulf of St. Lawrence and Scotian Shelf showing boundaries of snow crab fishing areas in which monthly mean temperature profiles were estimated. The section of Area 12, north of Prince Edward Island and denoted by the dashed line, is former Area 26.

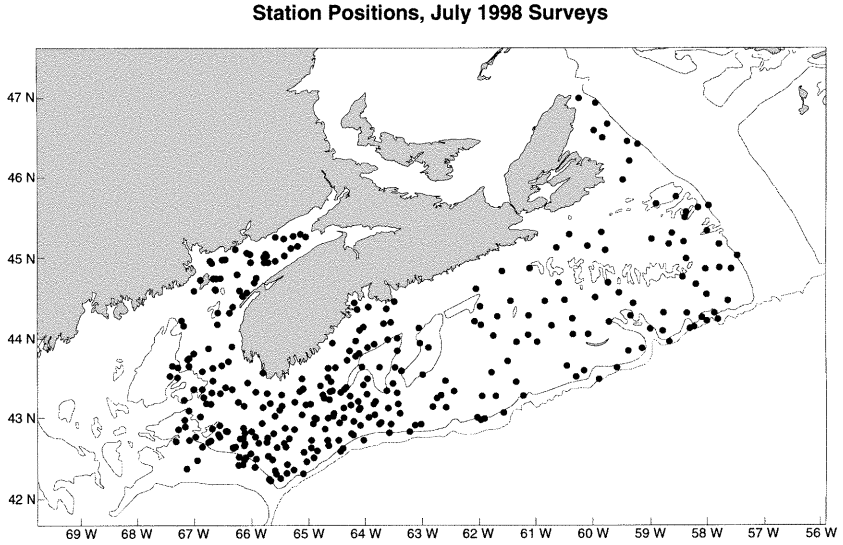

Fig. 2a. The CTD stations during the July 1998 survey.

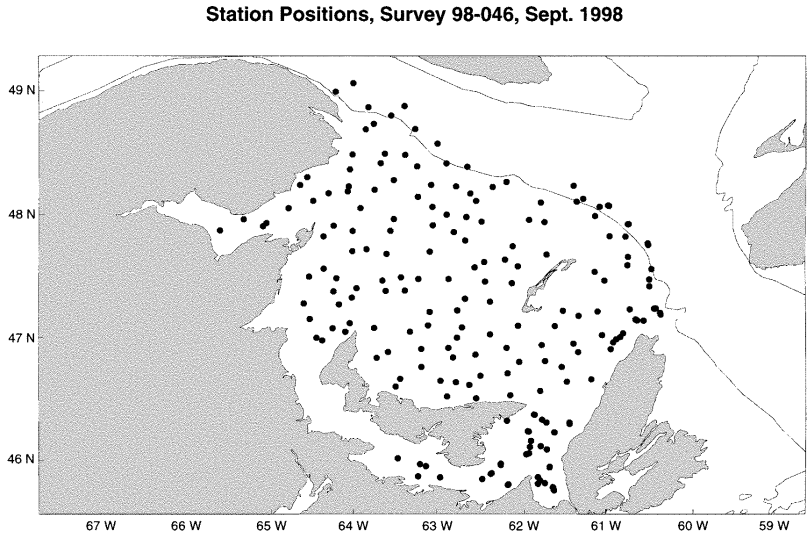

Fig. 2b. The CTD stations during the September 1998 survey.

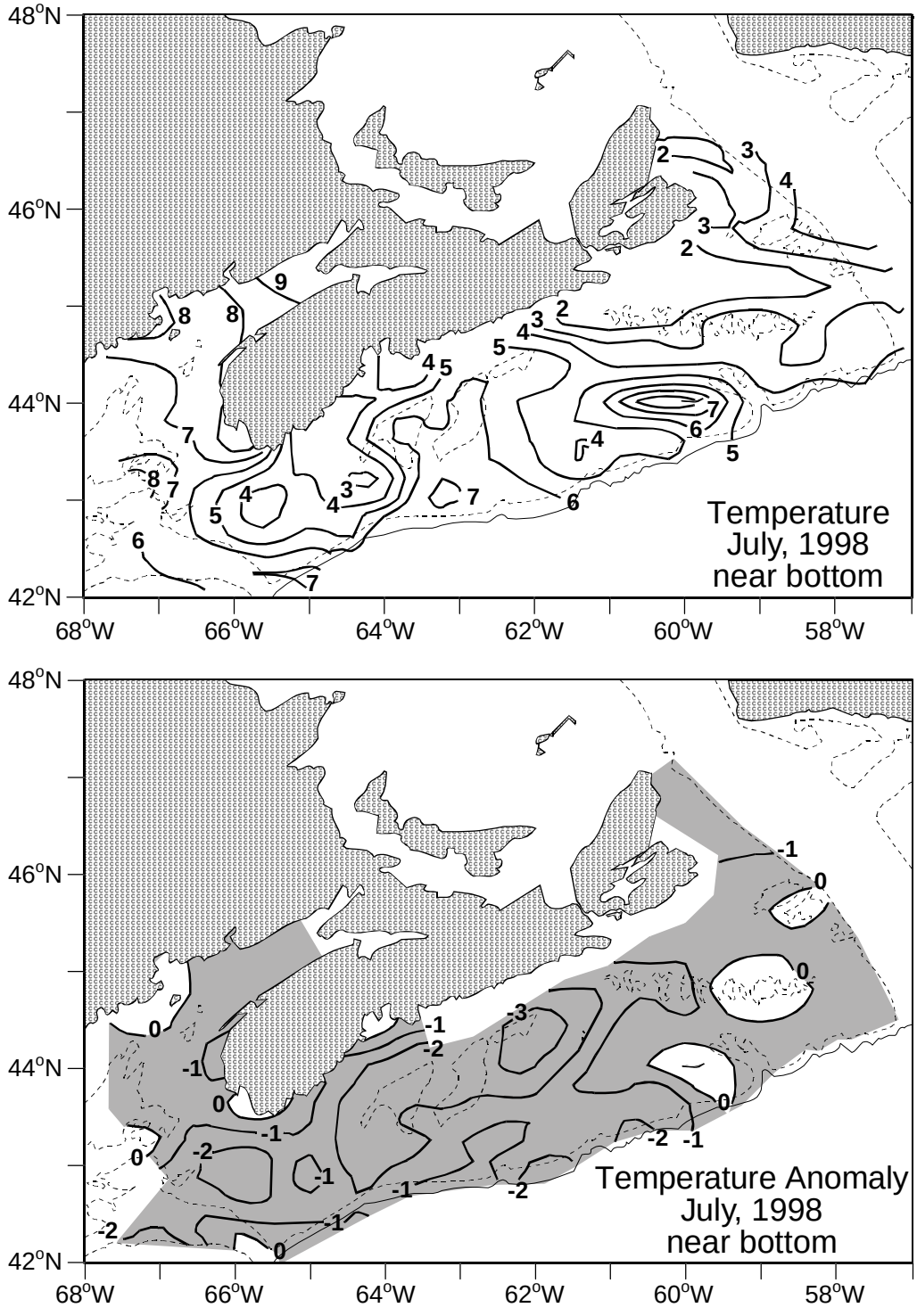

Fig. 3. Near bottom temperatures in 1998 (top panel) and their departure from the long-term (1961-90) means (bottom panel) during the July survey. Negative anomalies are shaded.

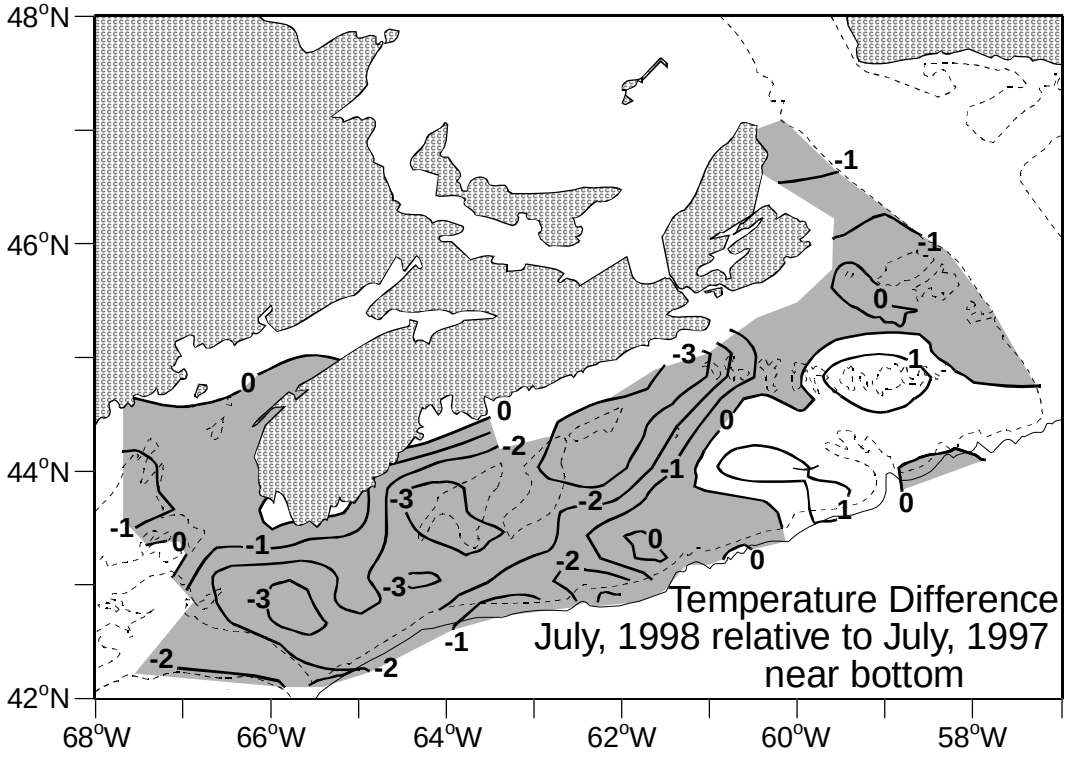

Fig. 4. The difference between the 1998 and 1997 temperature fields for the July survey. Positive values indicate warming in 1998 and negative a cooling. Negative differences are shaded.

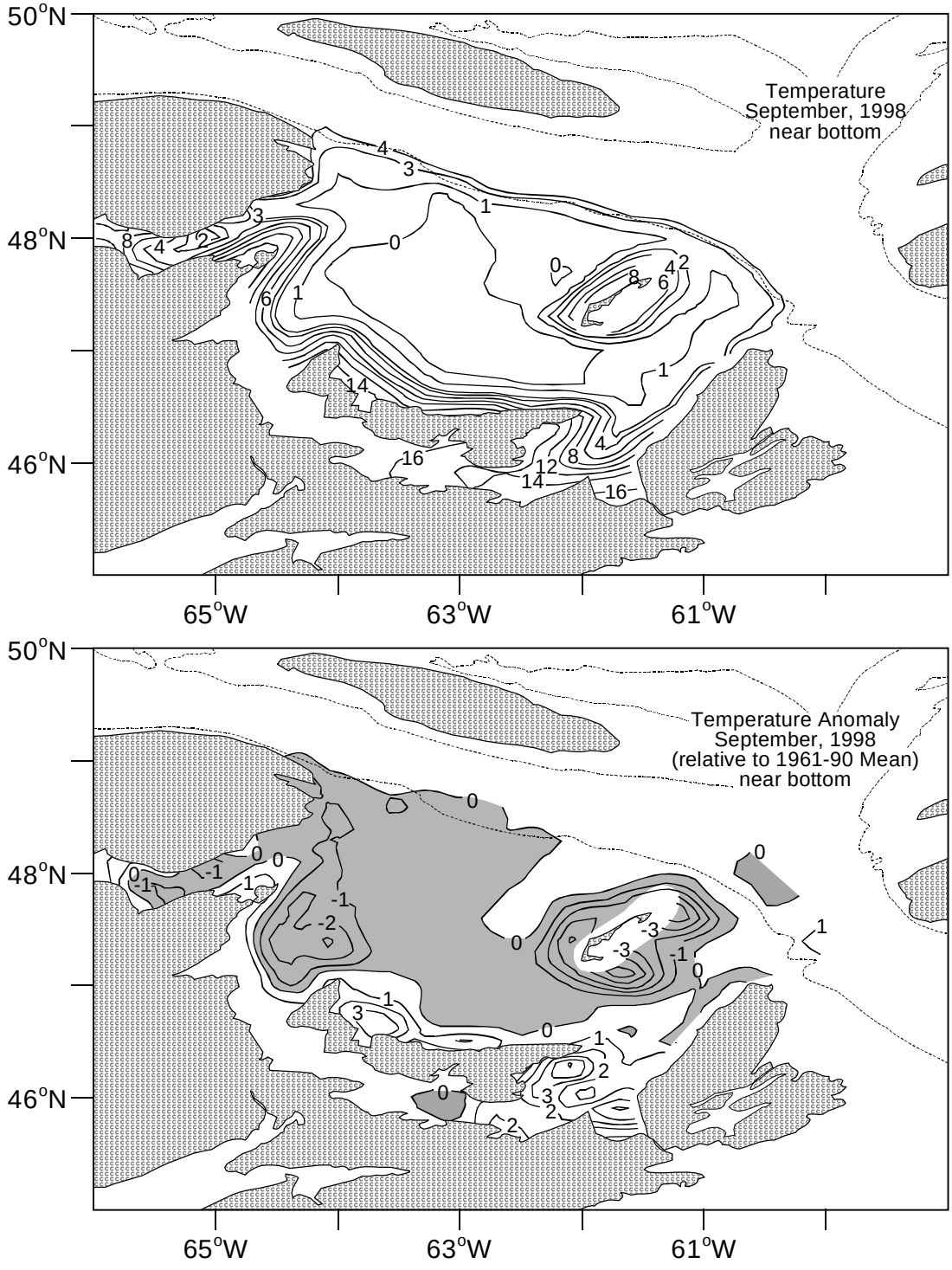

Fig. 5. Near bottom temperature (top panel) and temperature anomalies (bottom panel) in the southern Gulf of St. Lawrence in September 1998. Negative anomalies are shaded and the dotted line represents the 200 m isobath.

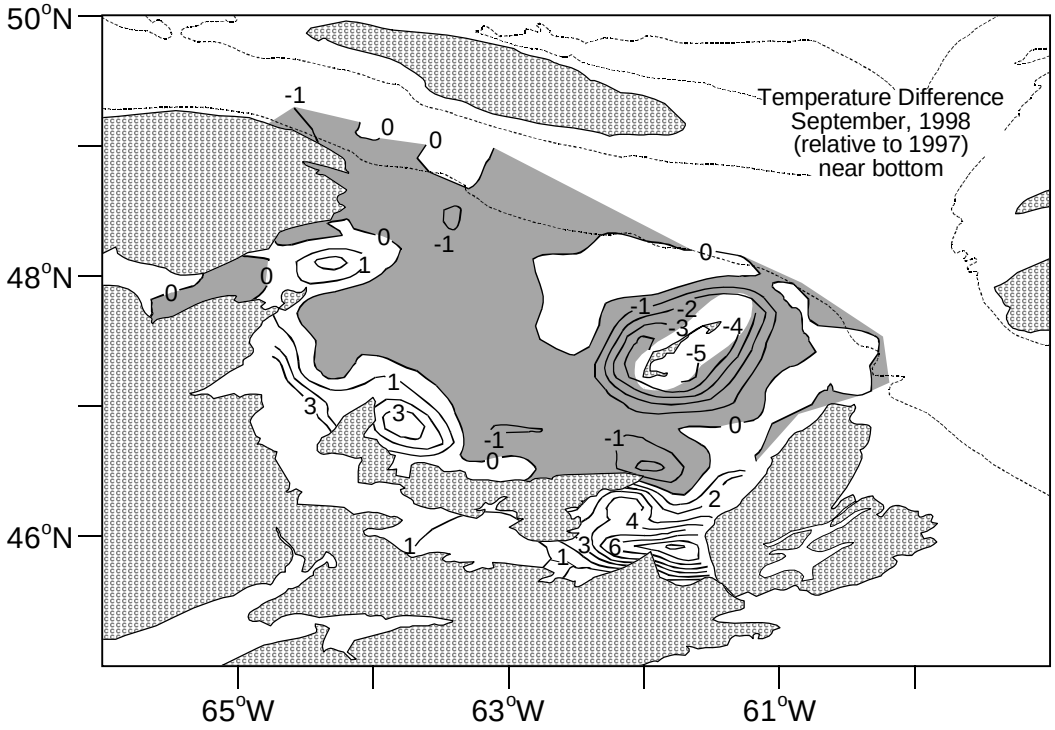

Fig. 6. The difference between the 1998 and 1997 temperature fields for the September survey. Positive values indicate warming in 1998 and negative a cooling. Negative differences are shaded.

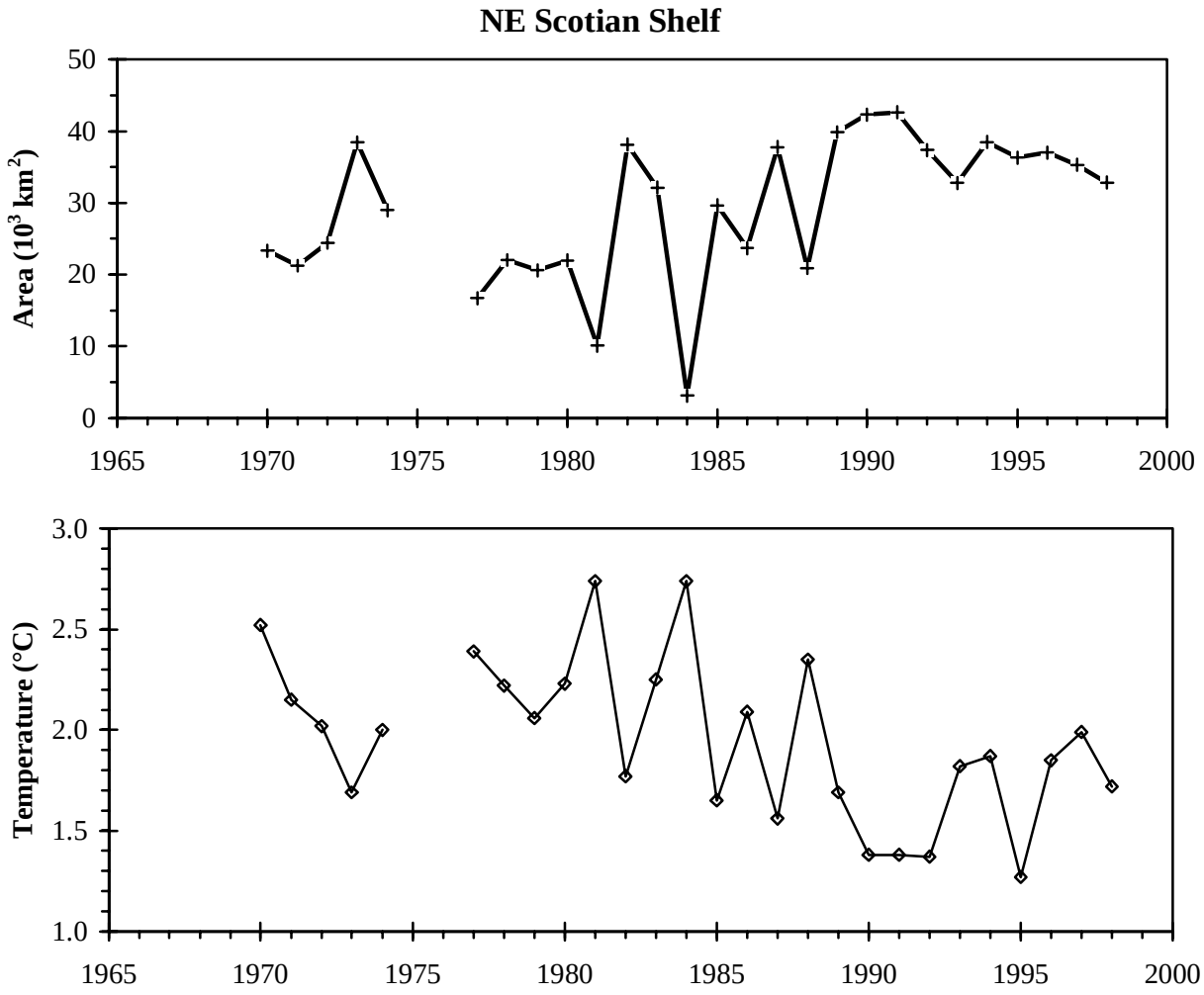

Fig. 7. Time series of the area of the northeast Scotian Shelf covered by bottom temperatures between -1° and 3°C in July (top panel) and the mean temperature within that area (bottom panel).

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

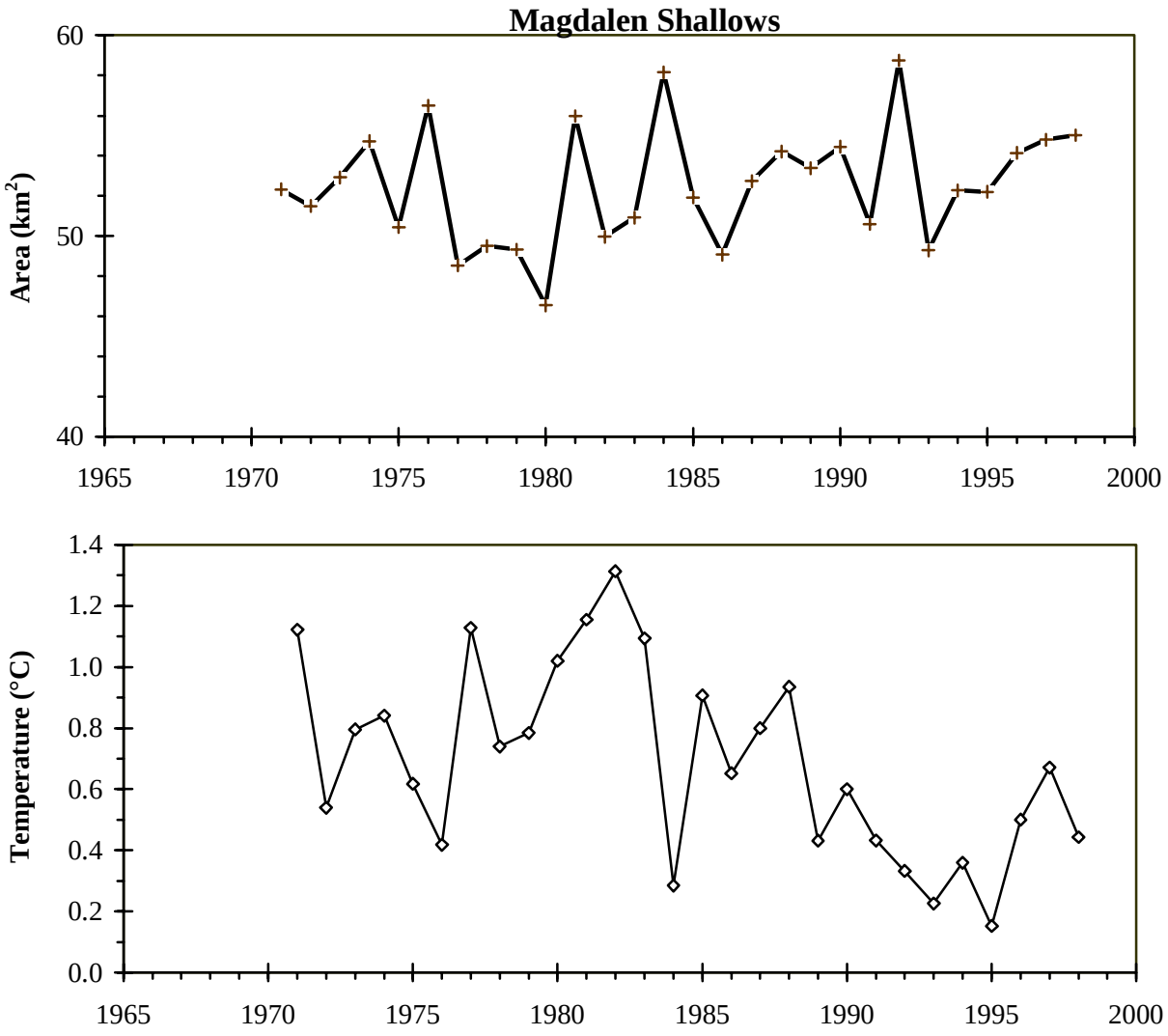

Fig. 9. Time series of the area of Magdalen Shallows covered by bottom temperatures between -1° and 3°C in September (top panel) and the mean temperature within that area (bottom panel).

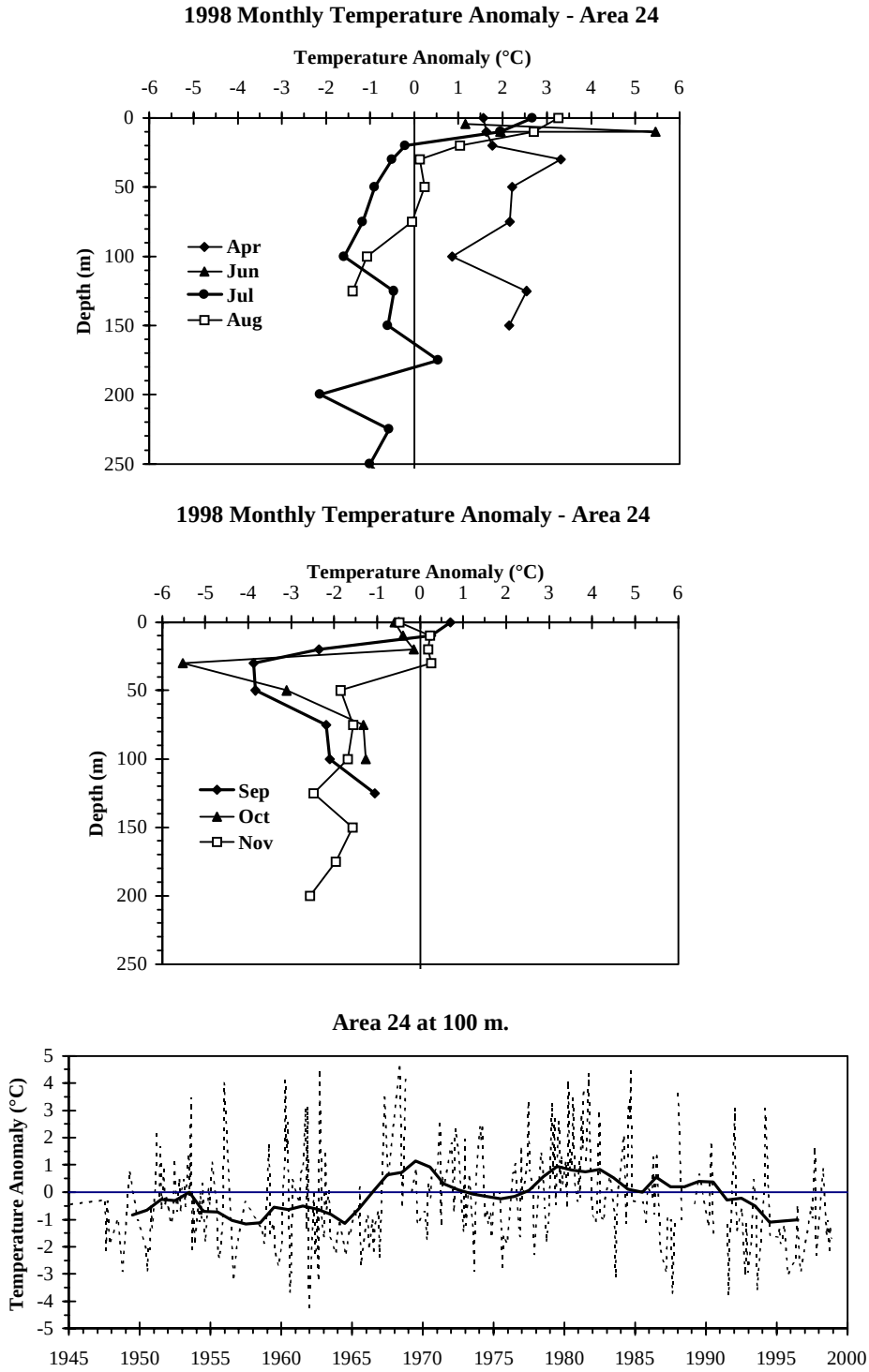

Fig.10. Monthly mean temperature anomaly profiles during 1998 (top panels) and the time series of monthly temperature anomalies at 100 m (bottom panel) for snow crab fishing Area 24.

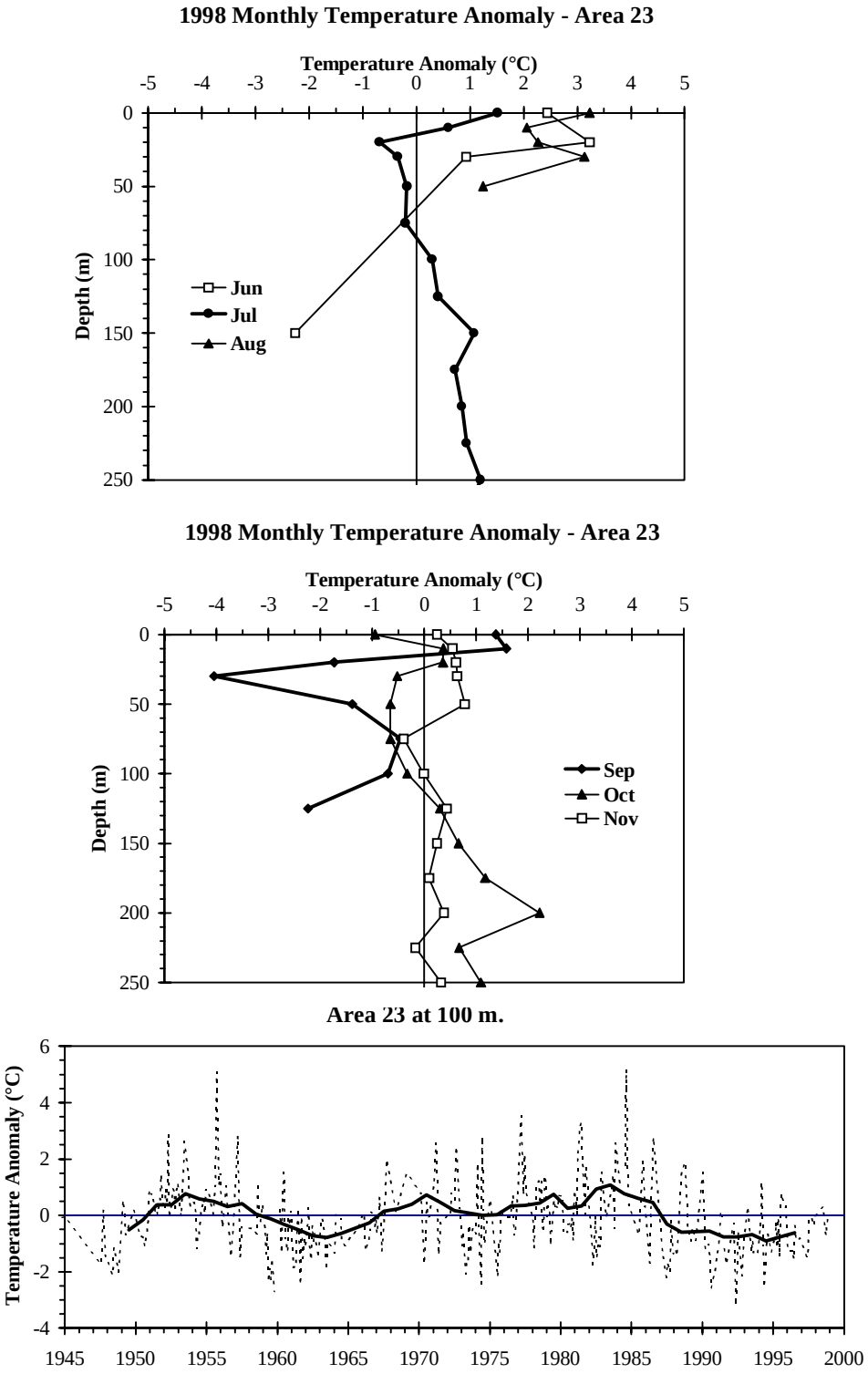

Fig.11. Monthly mean temperature anomaly profiles during 1998 (top panel) and the time series of monthly temperature anomalies at 100 m (bottom panel) for snow crab fishing Area 23.

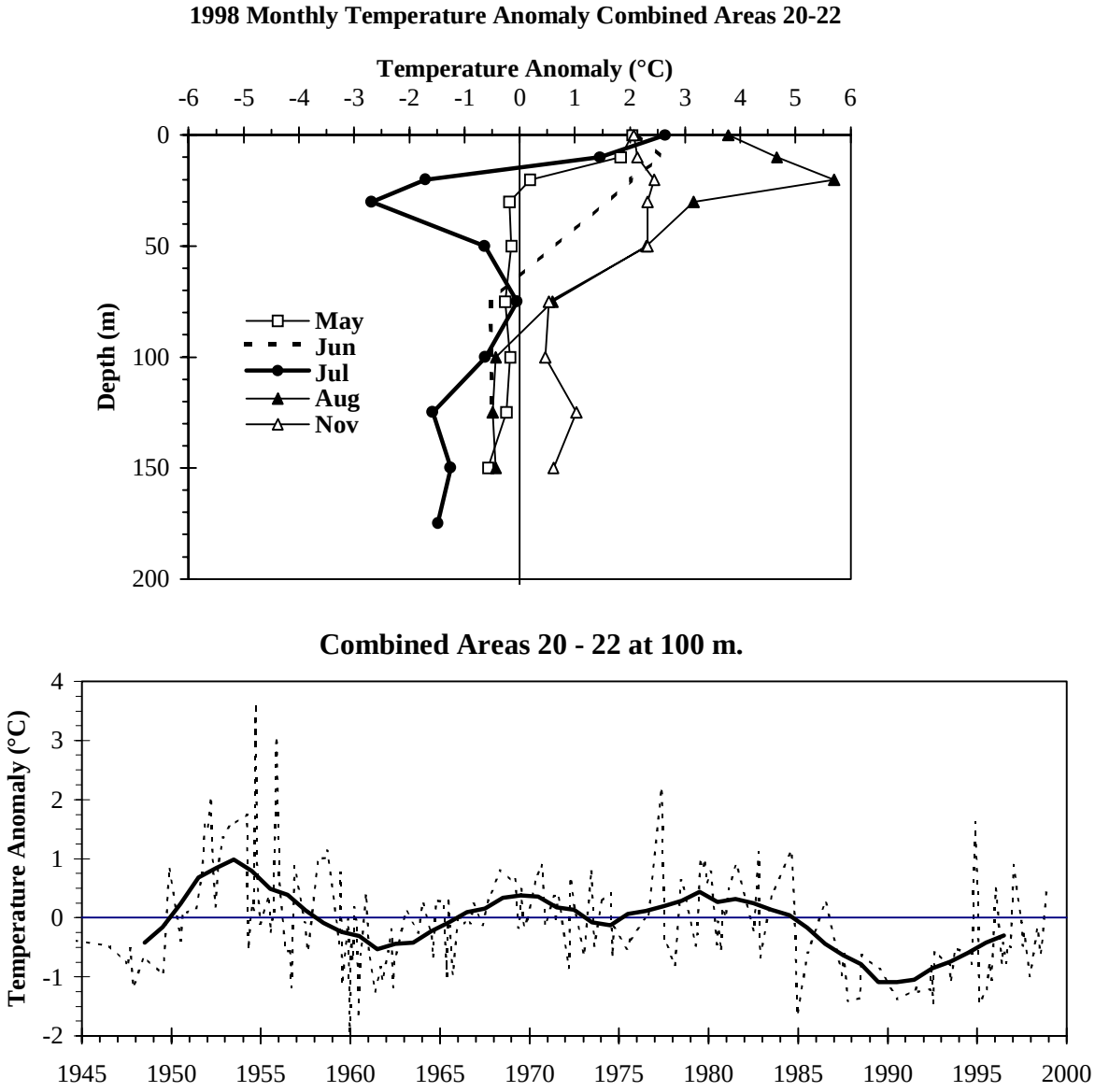

Fig.12. Monthly mean temperature anomaly profiles during 1998 (top panel) and the time series of monthly temperature anomalies at 100 m (bottom panel) for snow crab fishing Areas 20-22 combined.

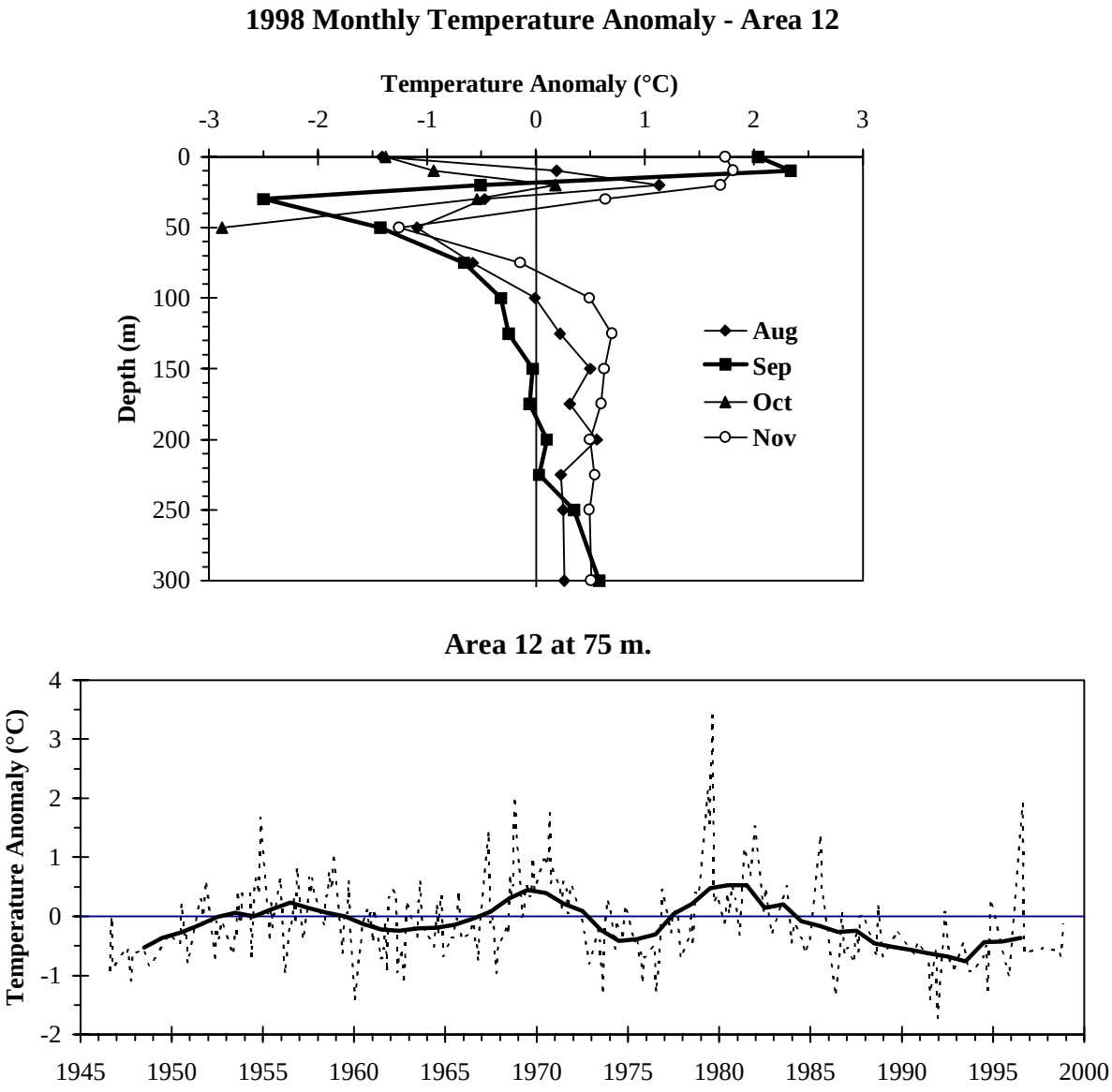

Fig.13. Monthly mean temperature anomaly profiles during 1998 (top panel) and the time series of monthly temperature anomalies at 75 m (bottom panel) for snow crab fishing Area 12.

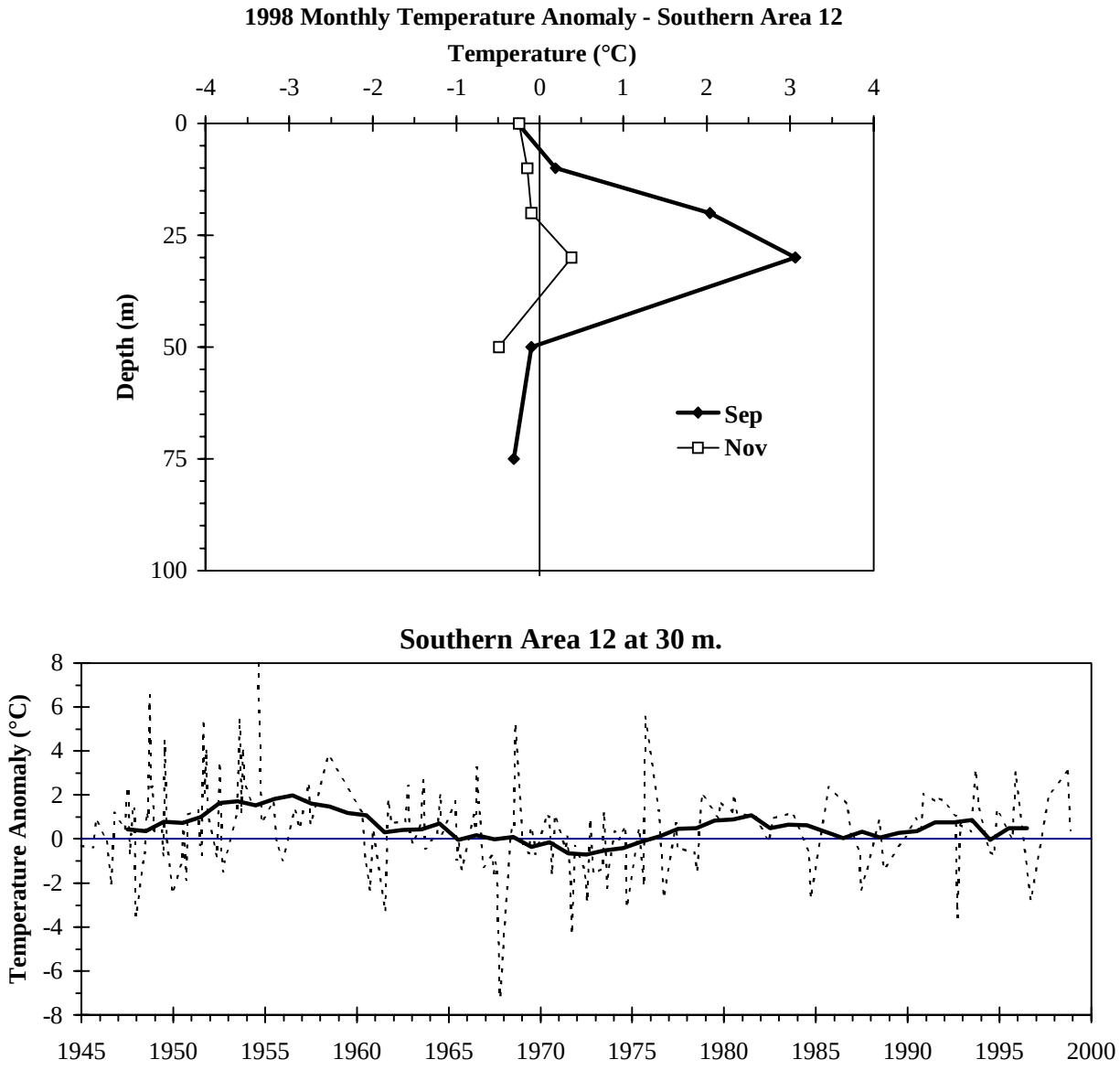

Fig.14. Monthly mean temperature anomaly profiles during 1998 (top panel) and the time series of monthly temperature anomalies at 30 m (bottom panel) in the southern portion of snow crab fishing Area 12 (formerly Area 26).

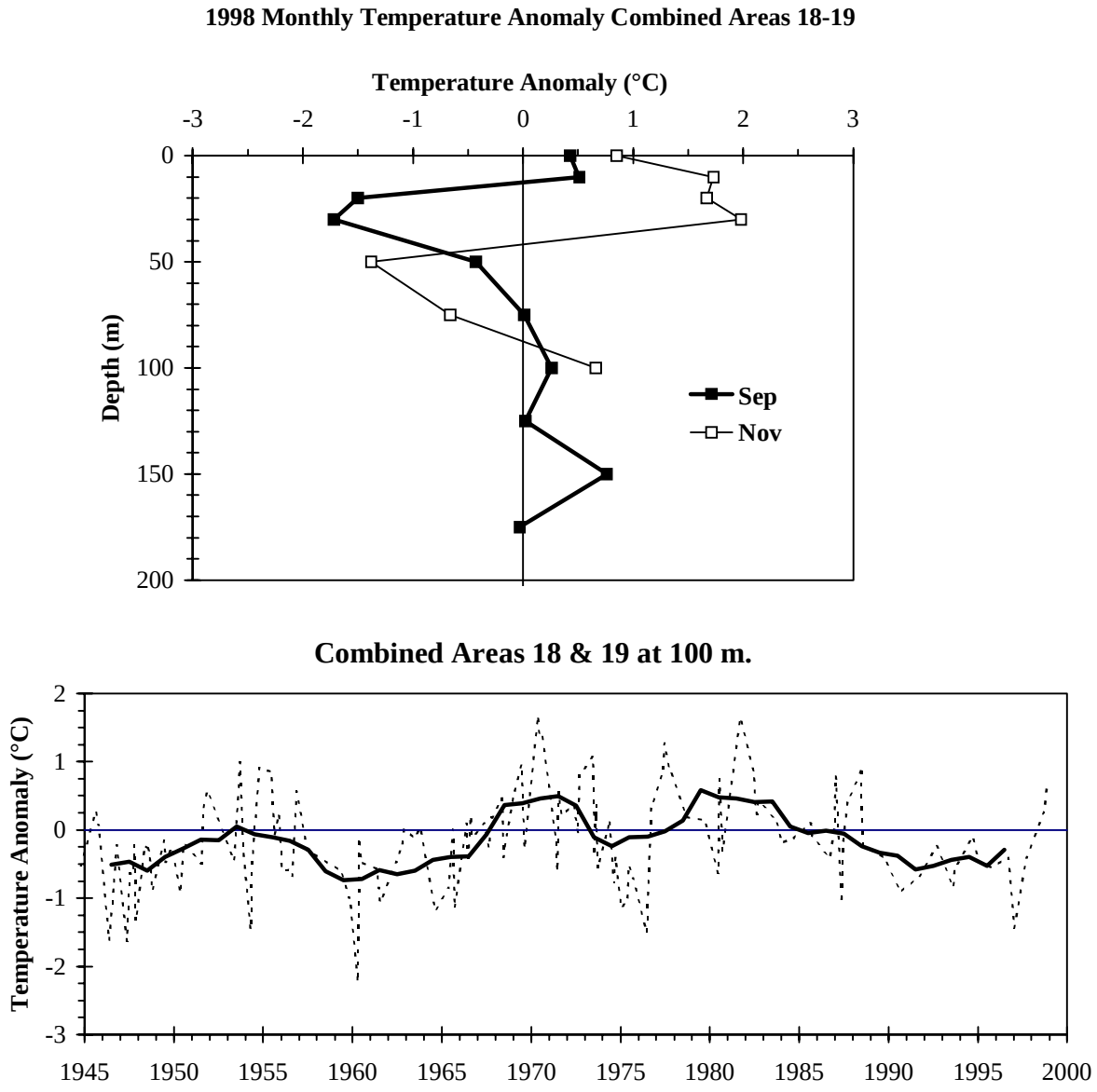

Fig.15. Monthly mean temperature anomaly profiles during 1998 (top panel) and the time series of monthly temperature anomalies at 100 m (bottom panel) for snow crab fishing Areas 18-19.

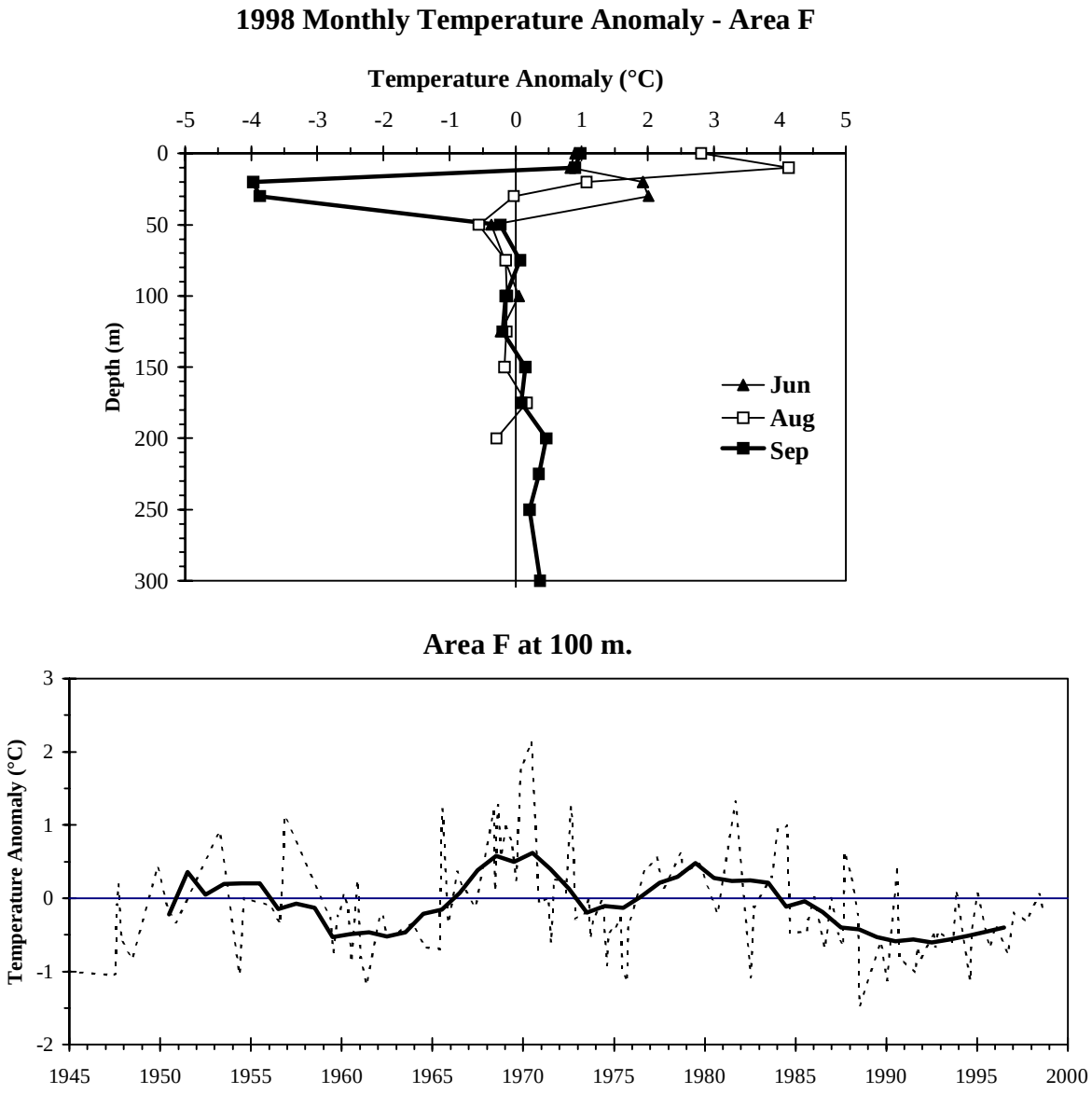

Fig.16. Monthly mean temperature anomaly profiles during 1998 (top panel) and the time series of monthly temperature anomalies at 100 m (bottom panel) for snow crab fishing Area F.

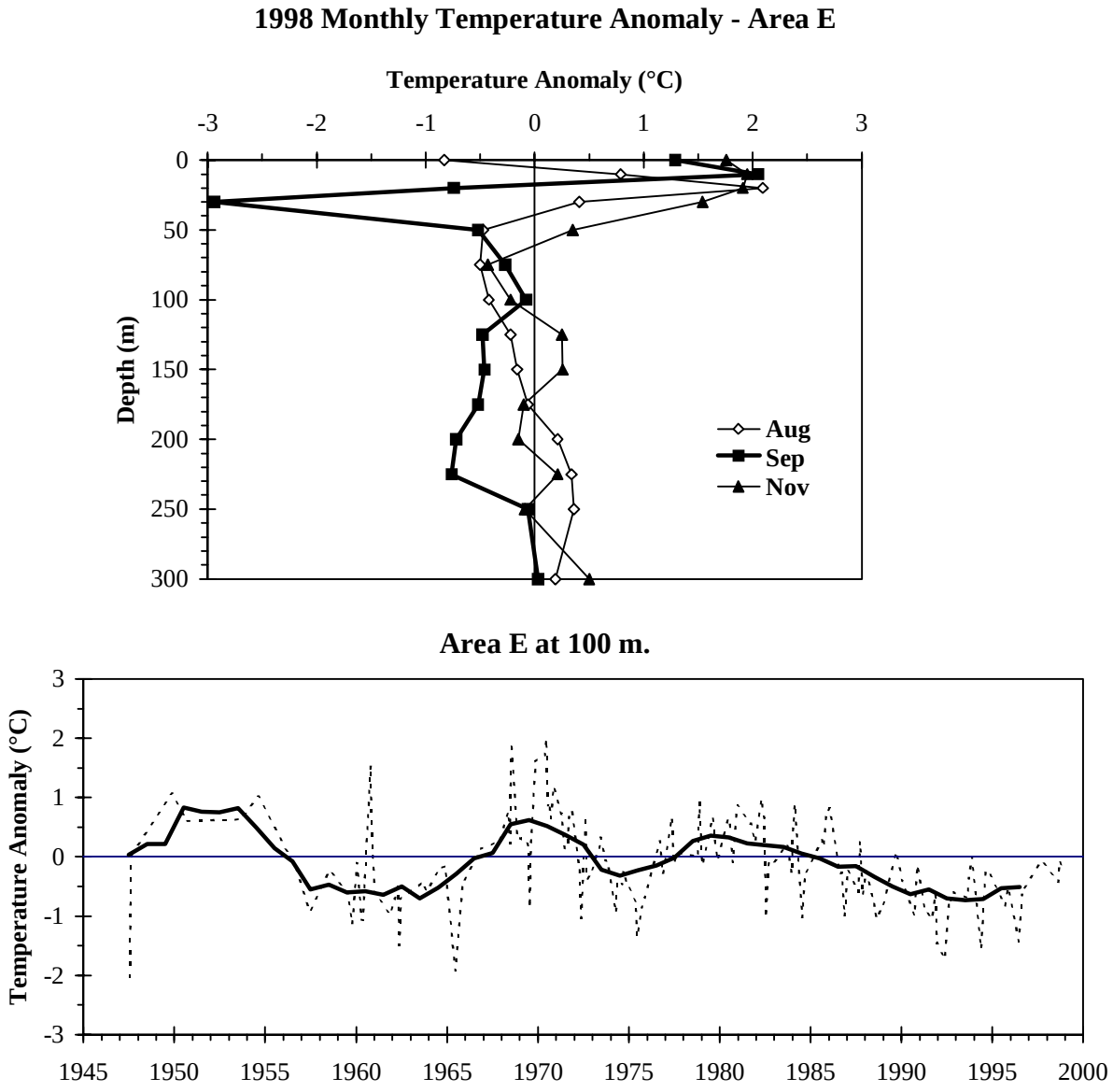

Fig.17. Monthly mean temperature anomaly profiles during 1998 (top panel) and the time series of monthly temperature anomalies at 100 m (bottom panel) for snow crab fishing Area E.

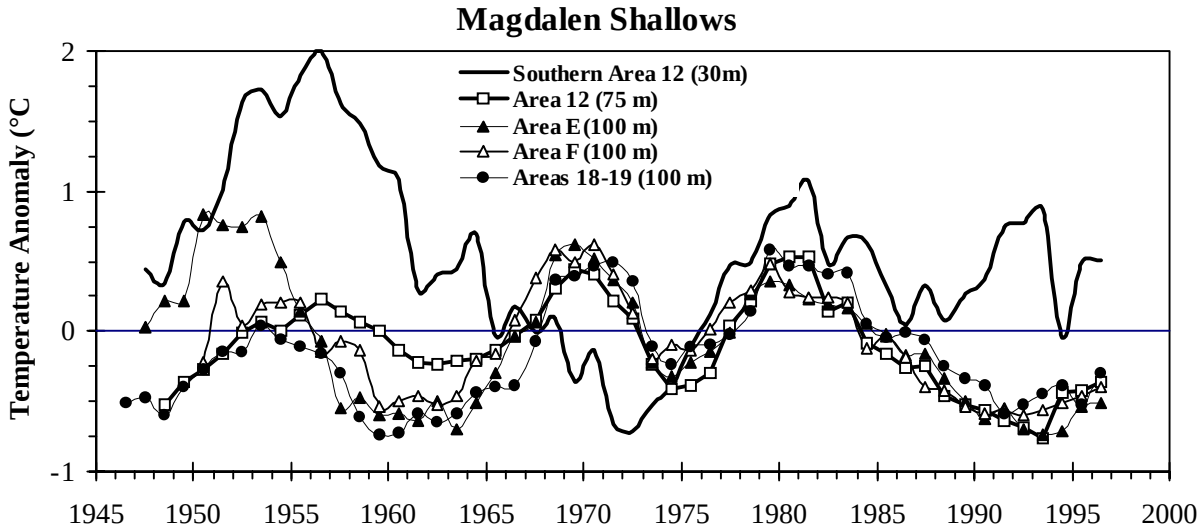

Fig. 18. The 5-year running mean of the annual bottom temperature anomalies on the Magdalen Shallows for each of the snow crab fishing areas.

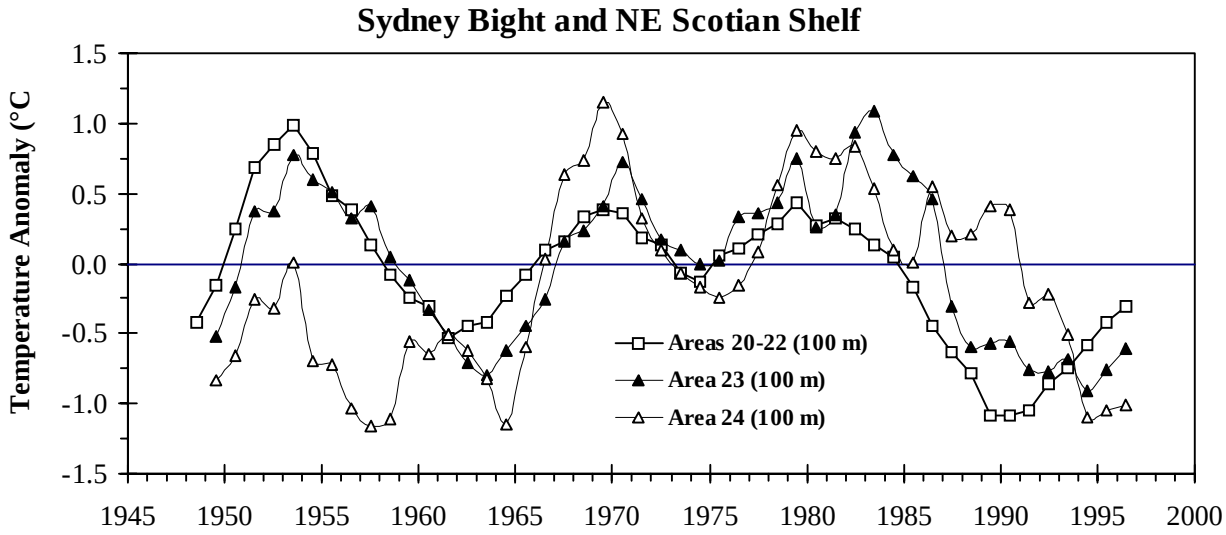

Fig. 19. The 5-year running mean of the annual bottom temperature anomalies on Sydney Bight and the northeastern Scotian Shelf for various snow crab fishing areas.

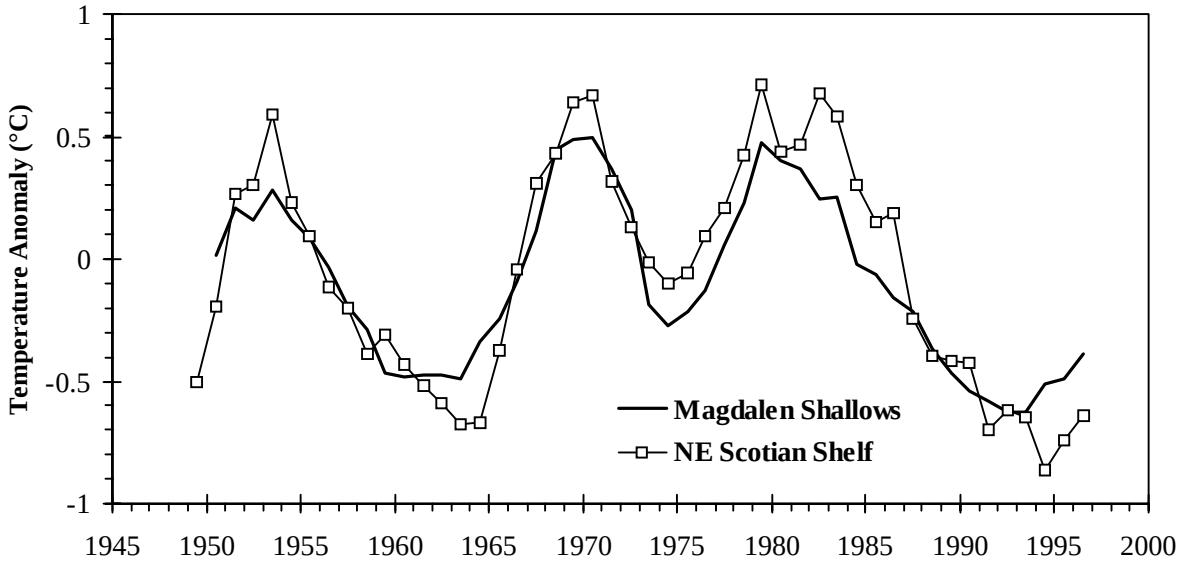

Fig. 20. The 5-year running mean of the average annual bottom temperature anomalies within the snow crab fishing zones on the Magdalen Shallows and Sydney Bight/NE Scotian Shelf at depths of 75-100 m.