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A Spatial Analysis of Near-bottom Temperatures in NAFO Subareas 2 and 3 on the Newfoundland and Southern Labrador Shelves

by

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Abstract

Interannual variations in the near-bottom thermal habitat for NAFO Sub-areas 2 and 3 on the Newfoundland Shelf were examined by calculating the areal extent of the bottom covered with water in different temperature ranges. The areal extent of subzero ^{o}C bottom water during the fall in divisions 2J, 3KLNO decreased during 1995 and have remained relatively low up to 1998, with a corresponding increase in bottom water above 1^{o}C. The analysis revealed a significant decrease in the areal extent of subzero ^{o}C water and a corresponding increase of about 70% in the areal extent of water above 1^{o}C during the spring of 1998 compared to 1997 in NAFO Divs. 3LNO. The 1998 value represents the largest area of relatively warm water on the Grand Bank since 1983. In division 3P, the areal extent of subzero ^{o}C bottom water covering the banks shows a dramatic increase since the mid-1980s, very low values in 1996 and 1998, while in 1997 it represented approximately 60% of the total area. The areal extent of bottom water with temperatures above 1^{o}C was about 50% of the total area of the banks in the 3P region during 1998, also the first significant amount since 1984. In all areas considered, variations in the areal index were more pronounced on the banks and in the near shore regions, where the cold-intermediate-layer (CIL) intersects the bottom, compared to the deeper continental slope water.

Introduction

Canada has been conducting stratified random groundfish trawl surveys in NAFO Sub-areas 2 and 3 beginning in 1971. Each NAFO Div. has been stratified based on the depth contours of available standard navigation charts. Areas within each division, with a selected depth range, were divided into strata and the number of fishing stations in an individual stratum are based on an area weighted proportional allocation (Doubleday 1981). The stratification scheme is constantly being revised as more accurate navigation charts become available and efforts are being made to extend the stratification scheme shoreward and into deeper water along the shelf edge (Bishop 1994 and Murphy 1996).

Surveys have been conducted for the following NAFO Divs., time periods and depth ranges: 3P winter and/or Spring from 1972 to 1999, in water depths of 366 m until 1979 and to 548 m since then; 3L spring from 1971-1999, except 1983 and 1984; 3NO spring from 1971-1999, except 1983 in 3N and 1972, 1974 and 1983 in 3O, in water depths to 366 m in most years and more recently to 548 m; 2J fall from 1977-1998; 3K fall from 1978-1998; 3L fall from 1981-1998; 3N fall from 1990-1998; 3O fall from 1990-1998. During all of these surveys oceanographic data were collected at each station and archived in oceanographic databases as well as included in the trawl set details.

These data are available from archives at the Marine Environmental Data Service (MEDS) in Ottawa, the Bedford Institute of Oceanography in Dartmouth, Nova Scotia and at the Northwest Atlantic Fisheries Center (NAFC) in St. John's Newfoundland. From 1971 to 1988 temperature data on these surveys were collected using bottles at standard depths and/or MBT/XBTs, which were deployed usually at the end of each fishing set. Since 1989 net-mounted conductivity-temperature-depth (Seabird model SBE-19 CTD systems) recorders have replaced XBTs. This system records temperature and salinity data during trawl deployment and recovery and for the duration of the tow. Data from the net-mounted SBE-19 CTDs are not field calibrated, but are checked periodically and factory calibrated annually maintaining an accuracy of 0.005^{o}C in temperature and 0.005 psu in salinity. The XBTs are accurate to within 0.1^{o}C. In addition to these data, all available historical data were used to establish the long-term means.

In this report the average near-bottom temperature fields for NAFO Divs. 2J, 3KLNOP on the Newfoundland Shelf are presented for the spring and fall time periods. Their interannual variations are then considered by examining the areal extent of the bottom covered with water in various temperature bins. The purpose of this analysis is to provide some indication of potential changes in temperature dependent habitat of various fish species. This work was initiated by Narayanan et al. (1992) for the Newfoundland Shelf and by Drinkwater et al. (1998) on the Scotian Shelf.

Average Bottom Temperatures

2J Fall

The fall average near-bottom temperature map for NAFO division 2J based on all available data from 1961 to 1990 is shown in Fig. 1. The average bottom temperature on Hamilton Bank is between 1^{o}C to 2^{o}C over the central portions, greater than 3^{o}C on the offshore edge and around 0^{o}C on the shoreward edge of the bank. Near the coast in water depths typically less than 150-m, temperatures are normally subzero ^{o}C, except in proximity to the shore where they rise above 1^{o}C in water depths less than 50-m. Relatively warm slope water with temperatures between 2^{o}C to 3^{o}C floods through the deep trough between northern Belle Isle Bank and southern Hamilton Bank. Near the edge of the continental shelf in water depths below 500-m temperatures are generally around 3.5^{o}C.

3K Fall

The fall average near-bottom temperature map for NAFO Div. 3K based on all available data from 1961 to 1990 is shown in Fig. 2. Most of this area has water depths greater than 200-m, which is generally below the CIL except near shore where the CIL intersects the bottom. Thus along the coast, typically within 100-m depth temperatures are normally subzero ^{o}C. Relatively warm slope water with temperatures between 2^{o}C to 3^{o}C floods through the deep troughs between the northern Grand Bank and southern Funk Island Bank and between northern Funk Island Bank and southern Belle Isle Bank. The average bottom temperature on these banks is between 2^{o}C to 3^{o}C. Near the edge of the continental shelf in water depths below 500-m temperatures are generally around 3.5^{o}C.

3LNO Spring and Fall

Spring and fall average near-bottom temperature maps for NAFO Divs. 3LNO based on all available data from 1961 to 1990 are shown in Figs. 3 and 4. The average spring (April-May) bottom temperature ranges from subzero ^{o}C on the northern and western Grand Bank and in the Avalon Channel to above 3.5^{o}C at the shelf edge. Over the central and southern areas average bottom temperatures ranges from 0^{o}C to above 2^{o}C on the Southeast Shoal and to above 3.5^{o}C along the edge of the bank. In general, bottom temperatures are nearly uniform at constant depth exhibiting onshore-offshore gradients over most areas. The annual cycle in bottom temperatures over most areas has a very low magnitude, however, they under go significant interannual variations. For example, the areal extent of subzero ^{o}C water is restricted to a small area in the Avalon Channel and northern Grand Bank during a warm year (1998), but during a cold year (1991)) subzero ^{o}C water covers most of the Grand Bank (Colbourne 1999 and 1994a). The average fall bottom

temperature in division 3L is very similar to spring conditions with temperatures ranging from subzero °C in the Avalon Channel and on the northern Grand Bank to above 3.5°C offshore at the shelf break. The fall average temperature in Divs. 3NO ranges from subzero °C over the northern areas and up to 3.5°C over southeastern regions and at the shelf break.

3Pn and 3Ps Spring

The 1961-1990 average bottom temperature for April in Sub-Divs. 3Ps and 3Pn is shown in Fig. 5. The average temperature ranges from 5°C in the Laurentian, Burgeo and Hermitage Channels to about 3° to 4°C on Rose Blanche and Burgeo Banks. On St. Pierre Bank temperatures range from 0°C on the eastern side at the entrance to Placentia Bay, to about 1° to 2°C along the central portions of the bank and to above 3°C on the western side. In general, bottom temperatures are nearly uniform at constant depth following the bathymetry around the Laurentian Channel and the southwestern Grand Bank decreasing from 2°C at 200-m depth to 5°C in the deeper water. During cold years subzero °C water covers most of St. Pierre Bank within 100-m depth (Colbourne 1994b).

Areal Index

Near-bottom temperature data from the annual groundfish assessment surveys were used to compute a time series of the area covered by water in selected temperature ranges. The mean near-bottom temperature for each grid element was calculated and its area integrated to produce a yearly estimate of the total area within each temperature range. The areas are expressed as a percentage of the total surveyed area. The mean bottom temperature time series was also constructed for each region. The selected temperature ranges were ≤ 0 °C, 0 to 1°C and ≥ 1°C. Potential sources of error in this analysis include temporal biasing, arising from the wide time interval during which a typical survey is conducted. This source of error is probably small however, given the low magnitude of the annual cycle over most of the water depths. An additional source of error that can potentially affect the results, particularly along the shelf edge, occurs when the spatial scales of temperature variations are shorter than the grid size. This effect however will probably be small, particularly over the Banks where the landscape is relatively flat.

2J fall

Shown in Fig. 6 are time series of the areal extent of the bottom covered by water with temperatures ≤ 0°C, 0°C to 1°C, and ≥ 1 °C for NAFO Div. 2J during the fall period and for Hamilton Bank and the near shore regions in 2J with water depths ≤ 200-m. The percentage area of the bottom covered by subzero °C in this region is very low during the fall with significant amounts appearing only during the cold periods of the early to mid 1980s and early 1990s, when the percentage area ranged between 20% to 40%. On Hamilton Bank and in the near shore region in water depths less than 200-m however, the percentage area of subzero °C water reached a maximum of 80% in 1984 and 90% in 1993. The area covered by water in the 0° to 1°C temperature range varied from a low of about 0% in 1977 to near 40% in 1982, but in water depths ≤ 200-m these percentages were much higher, reaching near 100% in 1989. In the temperature range ≥ 1°C the bottom area ranged from 0% during cold periods to 100% in 1777. Since 1995 the area of the bottom covered with water above 0°C have increased considerably since the early 1990s, while the area of subzero °C water have decreased to near 0%. In general, the trends are more extreme in water depths ≤ 200-m.

Bottom temperatures in Div. 2J during the fall averaged about 2°C, overall, and less than 1°C on the banks with subzero °C values during the cold periods of the early to mid 1980s and early 1990s. Since 1996 average bottom temperatures have increased to above average values from the record low in 1993 (Fig. 6c).

3K fall

Shown in Fig. 7 are time series of the areal extent of the bottom covered by water with temperatures ≤ 0°C, between 0°C to 1°C, and ≥ 1°C for NAFO Div. 3K during the fall and for water depths ≤ 300-m in 3K, which includes most of the inner part of the Northeast Newfoundland Shelf, Funk Island Bank and southern Belle Isle Bank. The percentage area of the bottom covered by subzero °C in this region is generally less than 30%,

again with significant amounts appearing only during the cold periods of the early to mid 1980s and early 1990s. In water depths ≤ 300-m the percentage area is higher but generally less than 50%. Since 1995, the area covered by subzero ^{o}C has been insignificant. The area covered by water in the 0^{o} to 1^{o}C temperature range has remained relatively constant, generally less than 25% with no significant trends. In the temperature range ≥ 1^{o}C the bottom area covered ranged from about 55% in 1982 to near 90% in 1986 and around 80% since 1995. Again in water depths ≤ 300-m the cold periods of the early 1980s and 1990s are evident with percentages less than 40% during these time periods. Since 1995 however this area has recovered to near 75% and has remained relatively high at about 65% up to 1998.

Bottom temperatures in Div. 3K during the fall ranged from 1^{o}C in 1982 to 2.3^{o}C in 1986 with an overall average of about 2^{o}C. In water depths ≤ 300-m temperatures were near 0^{o}C during the cold periods of the mid-1980s and early 1990s, but since 1995 they have increased to above average values (Fig. 7c).

3LNO fall

Temperature data from the assessment surveys in NAFO Divs. 3LNO during the fall were interpolated onto a regular grid at a spatial resolution of approximately 390 km^{2}. A total of 640 grid points or 250,000 km^{2} were used within the boundaries of the region. Shown in Fig. 8 are time series of the areal extent of the bottom covered by water with temperatures ≤ 0^{o}C, between 0^{o}C to 1^{o}C, and ≥ 1^{o}C for Div. 3L during the fall period and for the northern Grand Bank region with water depths within 100-m. The time series for Divs. 3NO shown in Fig. 9 are only available since 1990. The percentage area of the bottom covered by subzero ^{o}C water reached a minimum of about 20% in 1982 and a maximum of near 100% in 1994 in water depths less than 100-m. This area decreased significantly during 1995, particularly in water depths less than 100-m to roughly one-half the value during the first half of the 1990s. On the Grand Bank the area covered by water in the 0^{o} to 1^{o}C temperature range varied from a low of 0% in 1983 and 1992 to near 40% in 1995. A corresponding increase in the areal extent of water ≥ 1^{o}C also occurred during 1995. In 3NO (Fig. 9) the recent trend is the same with a significant decrease in the area covered with subzero ^{o}C water and a corresponding increase in the area covered with water above 1^{o}C during 1995. The total area covered by subzero ^{o}C water, however, is smaller than the 3L region. In general, the trends are more pronounced on the Grand Bank in water depths ≤ 100-m.

The average bottom temperature in NAFO Div. 3L during the fall increased from approximately 0.5^{o}C from 1980 to 1994 to about 1.5^{o}C during 1995 to 1998 in water depths less than 100-m and from approximately 1^{o}C to 1.5^{o}C averaged over all water depths (Fig. 8c). In divisions 3NO the average temperature reached a minimum of approximately 1^{o}C in 1993, increased to about 1.7^{o}C in 1995 and have remained relatively constant up to 1998 (Fig. 9c).

3LNO spring

Temperature data from the assessment surveys in NAFO Divs. 3LNO during spring were interpolated at the same resolution as were done for the fall data. Shown in Fig. 10 are time series of the areal extent of the bottom covered by water with temperatures ≤ 0^{o}C, between 0^{o} to 1^{o}C and ≥ 1^{o}C during spring and for the Grand Bank region with water depths within 100-m. From 1975 to 1983 most of the bottom area was covered by water above 0^{o}C with only approximately 20% covered by subzero ^{o}C water. Since about 1984 there was a large increase in the area of subzero ^{o}C water with percentages averaging about 50%. The record high value occurred during 1991 when the percentage area of subzero ^{o}C water on the Grand Bank reached more than 70%. Since 1994 there has been a general decrease in the percentage area of the bottom covered by subzero ^{o}C water and the corresponding increase in the area covered by water ≥ 1^{o}C. The area covered by water in the 0^{o} to 1^{o}C temperature range varied from a high of near 40% in 1978, less than 20% in 1983, 1984 and 1993 to near 25% in 1998 (Fig. 10a). During the spring of 1998 water with temperatures above 1^{o}C covered more than 50% of the bottom area on the Grand Bank, compared to about 10% in 1990. The 1998 value represents the largest area of relatively warm water on the Grand Bank since 1983.

The time series of average bottom temperatures for the 3LNO region (Fig. 10c) shows a downward trend that begin in 1984 superimposed on large interannual variations of about 1°C amplitude. This trend continued until the early 1990s. The highest temperature in the 24-year record occurred in 1983 when the average temperature was 3.2 °C and the lowest temperature of -0.3°C occurred in 1991. Recently, temperatures have increased over the lows of the early 1990s with the average bottom temperature during the spring of 1998 reaching 1.8°C, overall, and to 1.2°C in water depths less than 100-m.

3Pn and 3Ps winter/spring

Oceanographic data from the groundfish assessment surveys in the NAFO Div. 3P were collected since the early 1970s between January and June. These data were assume synoptic for that time period and were interpolated onto a regular grid at a spatial resolution of 97 km^2 or approximately 0.1° latitude by 0.1° longitude. A total of 580 grid points or 56,260 km^2 were used within the boundaries of the region. Except for 1980 (which is not included), the percentage of the total area interpolated ranged from about 85% to 100%. Shown in Fig. 11 are time series of the areal extent of the bottom covered by water with temperature ≤ 0°C, 0°C to 1°C and ≥ 1°C. Note the large increase in the percentage area of the bottom covered by subzero °C water in 1985 that persisted well into the mid-1990s. The percentage area of subzero °C water during the spring of 1998 decreased to pre-1985 levels. The bottom area covered with water between 0°C to 1°C, except for 1979 and 1988, have remained below 20%. The bottom area with temperatures above 1°C before 1985 was approximately 70% to 80% and since 1984 is has been nearly constant between 50% to 70%.

Shown in Fig. 11b are the areal indices for the same temperature ranges but restricted to water depths ≤ 100-m, which includes Burgeo, St. Pierre and Green Banks. The areal extent of subzero °C bottom water increased from values generally less than 30% from 1970 to 1984 to 100% in 1985. Except for 1988 it remained near 80% until 1994, at which time it began to decrease and was less than 10% in 1998. The area in the temperature range of 0°C to 1°C exhibit large fluctuations with relatively high values during the 1970s, 1988 and during 1996. The area of these banks covered by bottom water with temperatures ≥ 1°C was significant prior to 1985, virtually non-existent until 1996 and had increased to about 50% in 1998.

The average bottom temperature of the surveyed area in Div. 3P ranged between 3° to 4°C from 1970 to 1984 and decreased to between 2° to 2.5°C from 1985 to 1998 (Fig. 11c). On the banks, in water depths ≤ 100-m, the average temperature from 1970 to 1985 ranged between approximately 0.5° to 1°C, decreased significantly during 1985 and has slowly recovered to about 1°C by 1998.

Summary

The average near-bottom temperature fields for NAFO Sub-areas 2 and on the Newfoundland Shelf were presented for the spring and fall time periods. Interannual variations in the near-bottom thermal index for NAFO Divs. 2J and 3KLNOP were examined by calculating the areal extent of the bottom covered by water in three different temperature ranges. The areal extent of subzero °C bottom water during the fall in divisions 2J, 3KLNO decreased during 1995 and have remained relatively low up to 1998 with a corresponding increase in bottom water above 1°C. The analysis revealed a significant decrease in the areal extent of subzero °C water and a corresponding increase of about 70% in the extent of water above 1°C during the spring of 1998 compared to 1997 in 3LNO. The 1998 value represents the largest area of relatively warm water on the Grand Bank since 1983.

In NAFO Div. 3P the areal extent of subzero °C bottom water covering the banks shows a dramatic increase since the mid-1980s, very low values in 1996 and 1998, while in 1997 it represented approximately 60% of the total area. The areal extent of bottom water with temperatures above 1°C was about 50% of the total area of the banks in the 3P region during 1998 the first significant amount since 1984. In all divisions considered the trends were more pronounced on the banks and in the near shore regions where the CIL intersects the bottom.

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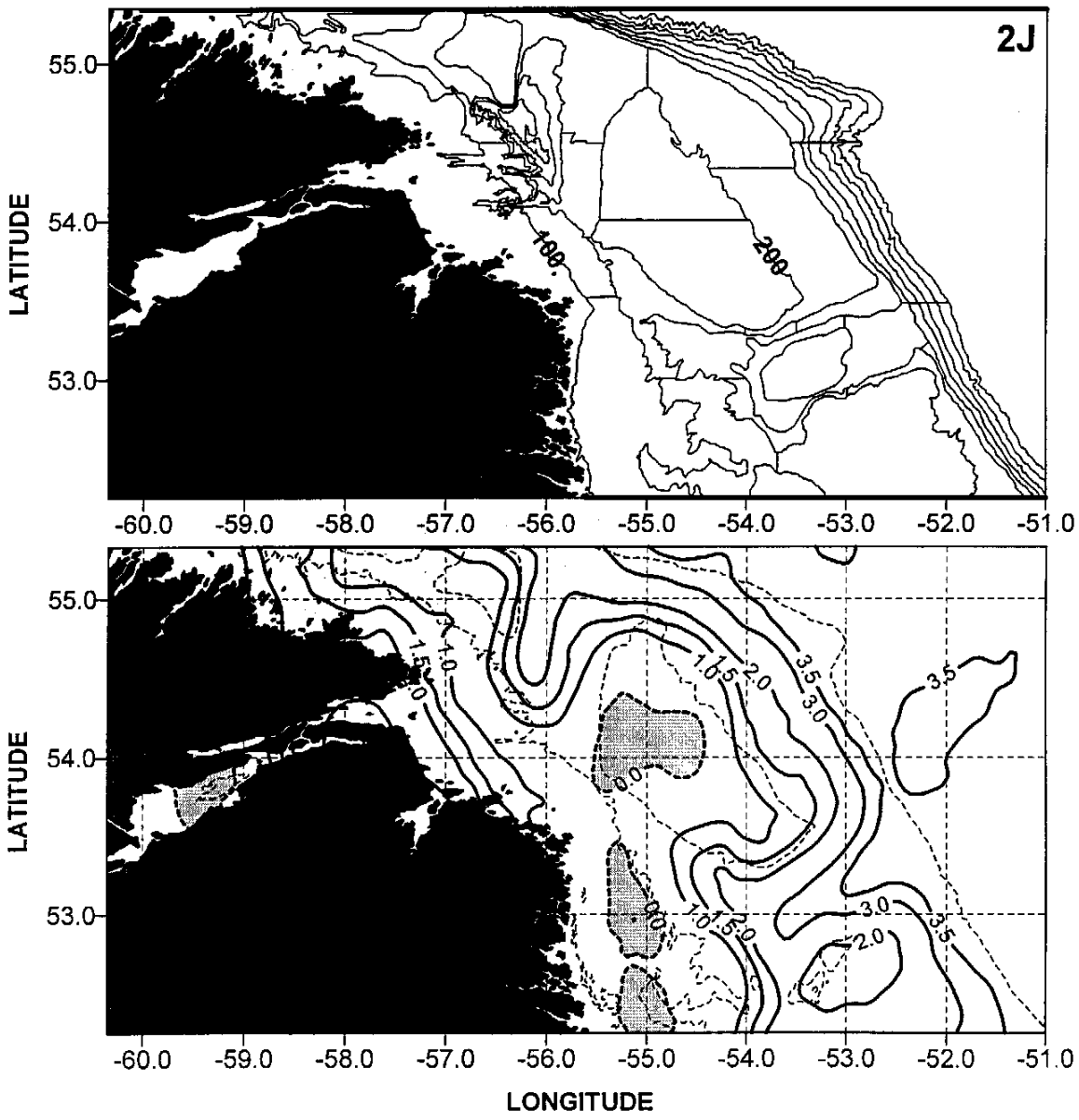

Fig. 1. Location map showing the strata boundaries in NAFO Div. 2J and the average 1961-1990 fall bottom temperature contours (in °C).

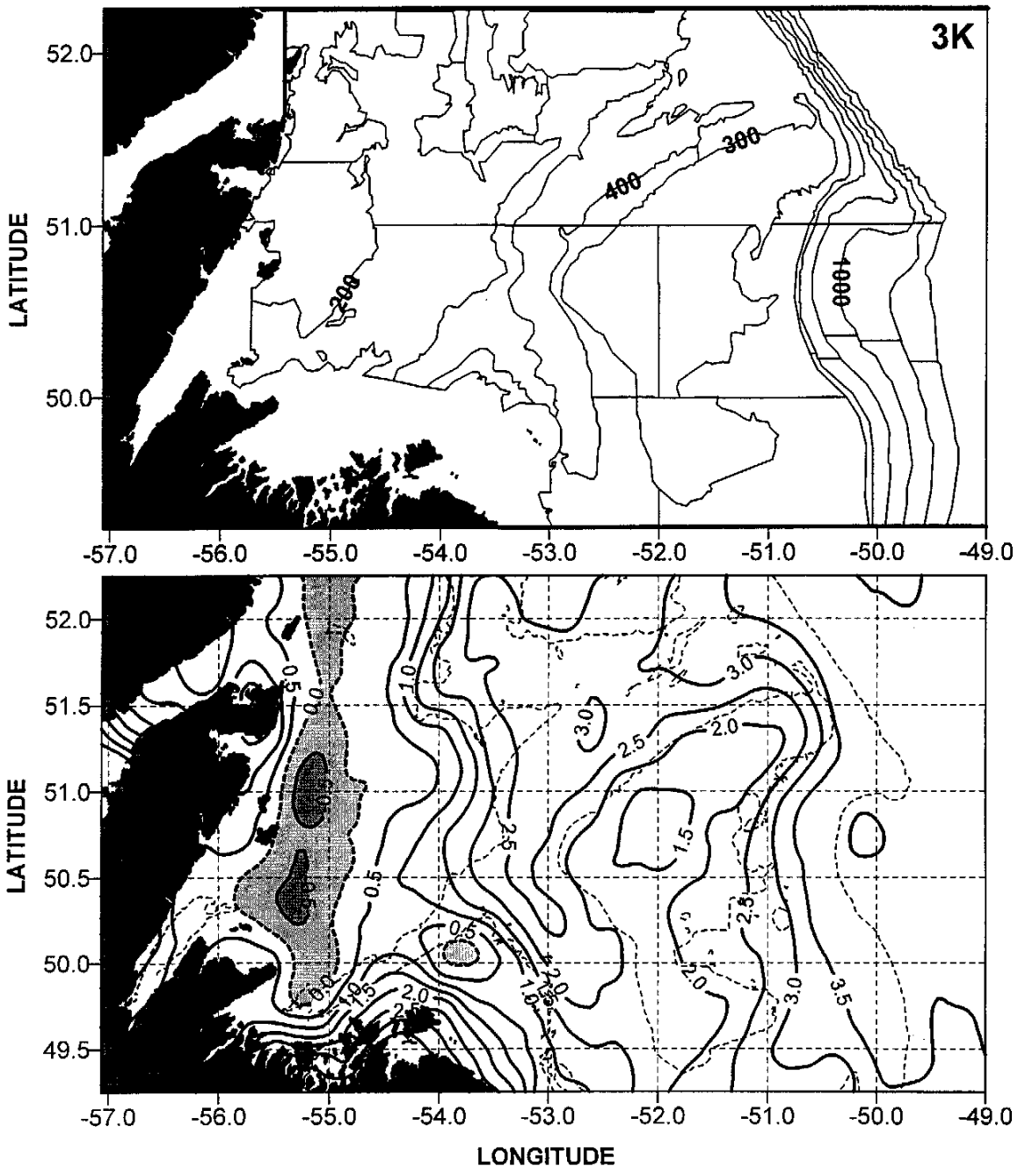

Fig. 2. Location map showing the strata boundaries in NAFO Div. 3K and the average 1961-1990 fall bottom temperature contours (in °C).

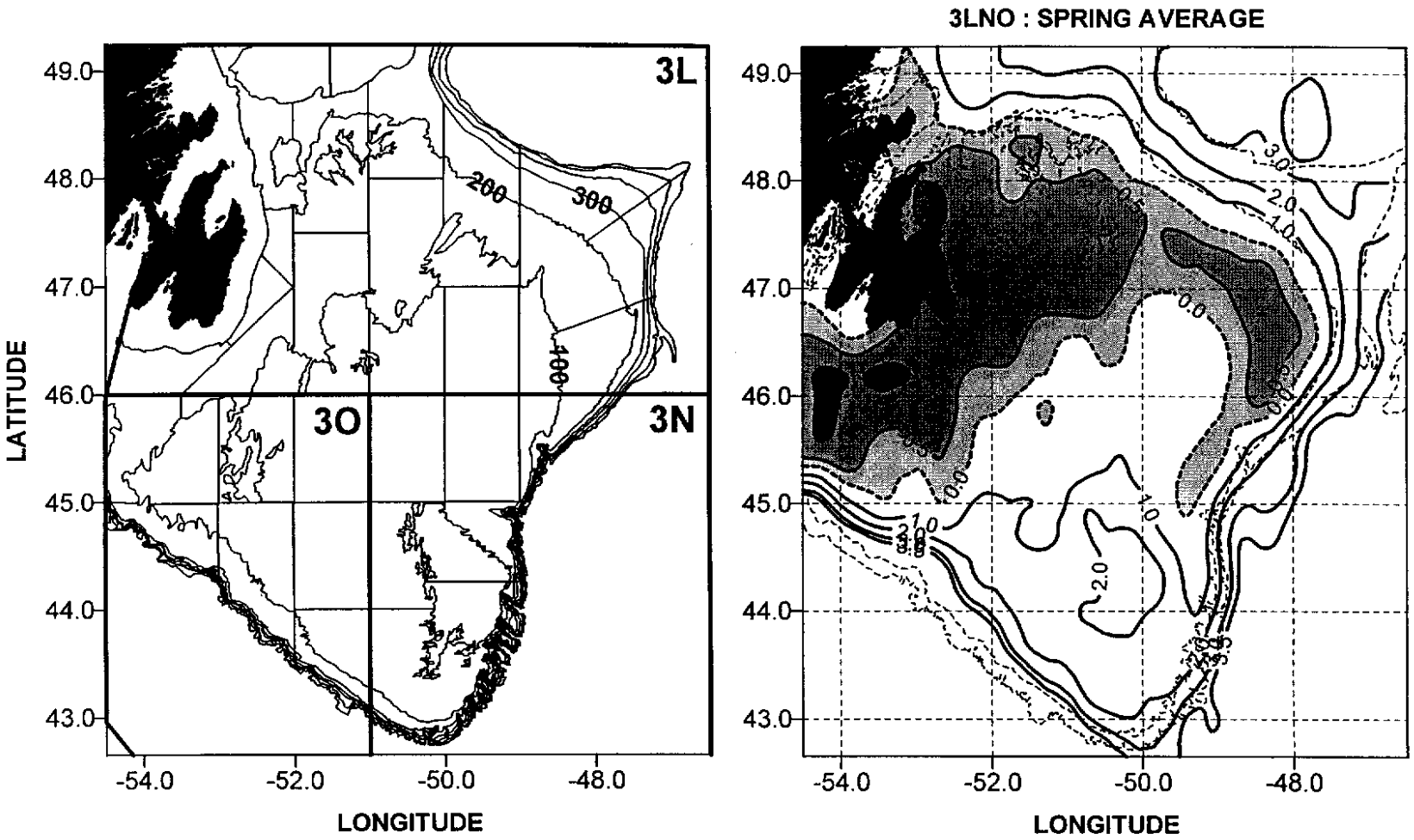

Fig. 3. Location map showing the strata boundaries in NAFO Divs. 3LNO and the average 1961-1990 spring bottom temperature contours (in °C).

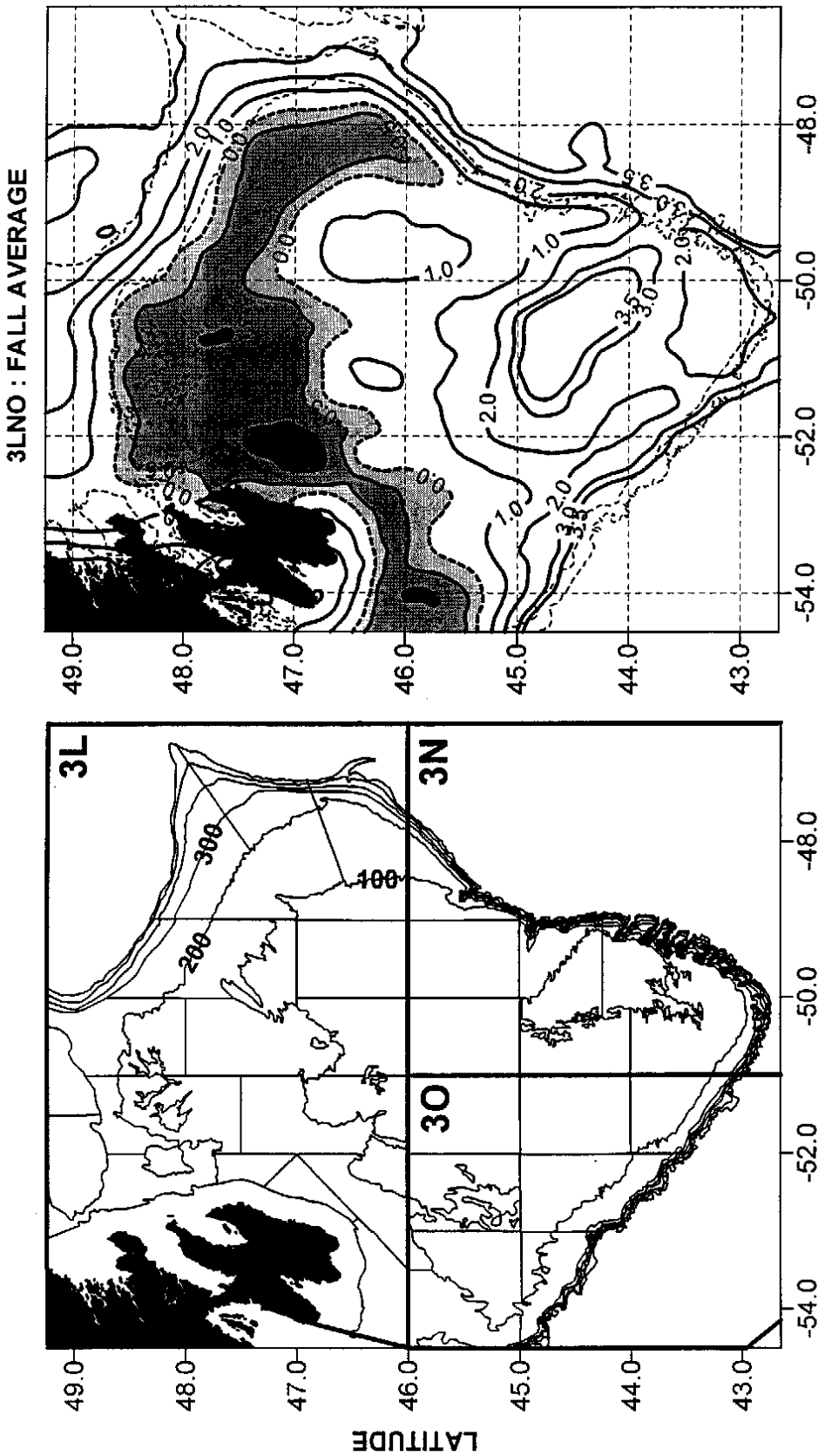

Fig. 4. Location map showing the strata boundaries in NAFO Divs. 3LNO and the average 1961-1990 fall bottom temperature contours (in °C).

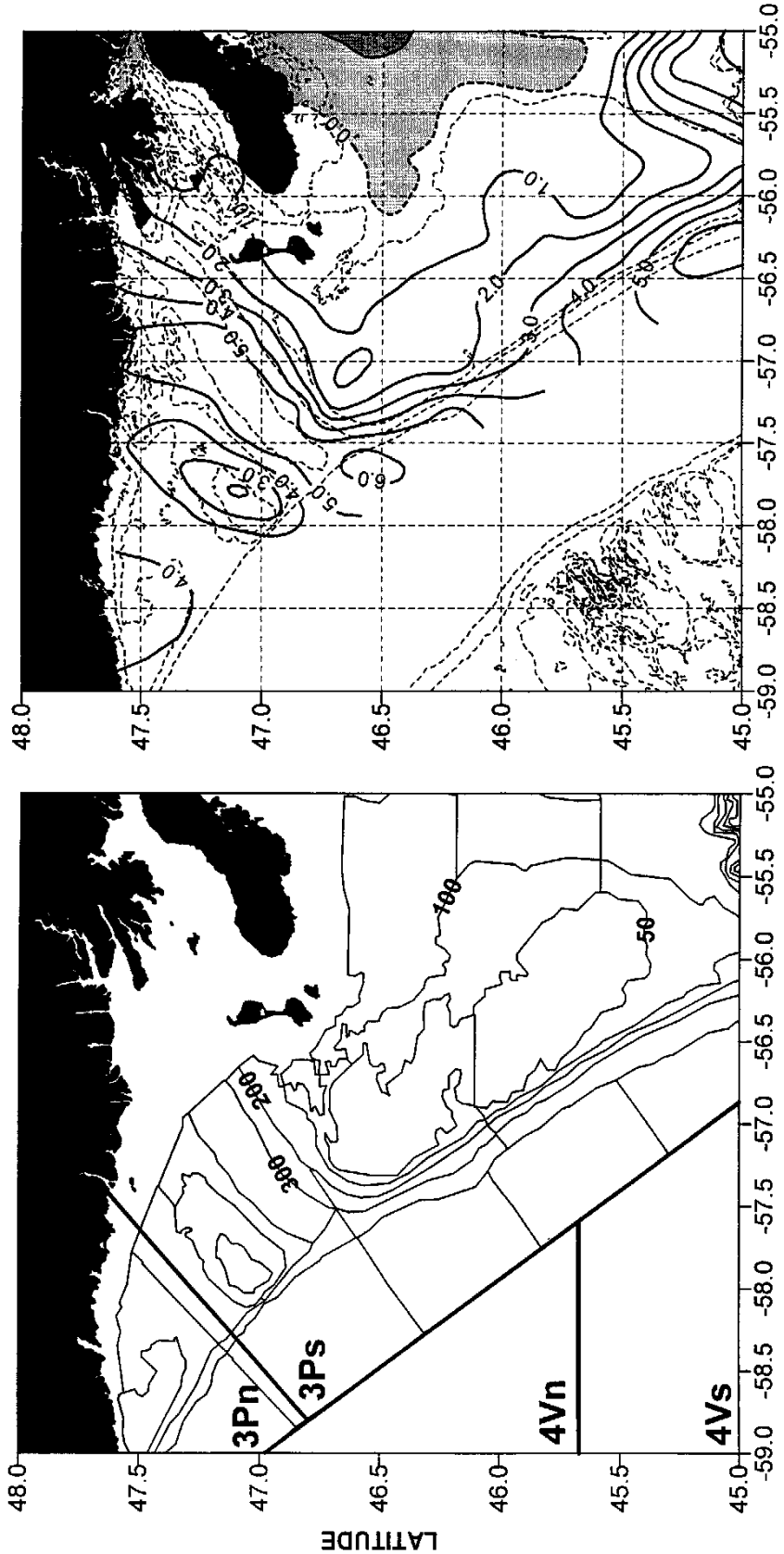

Fig. 5. Location map showing the strata boundaries in NAFO Sub-Divs. 3Pn and 3Ps and the average 1961-1990 spring bottom temperature contours (in °C).

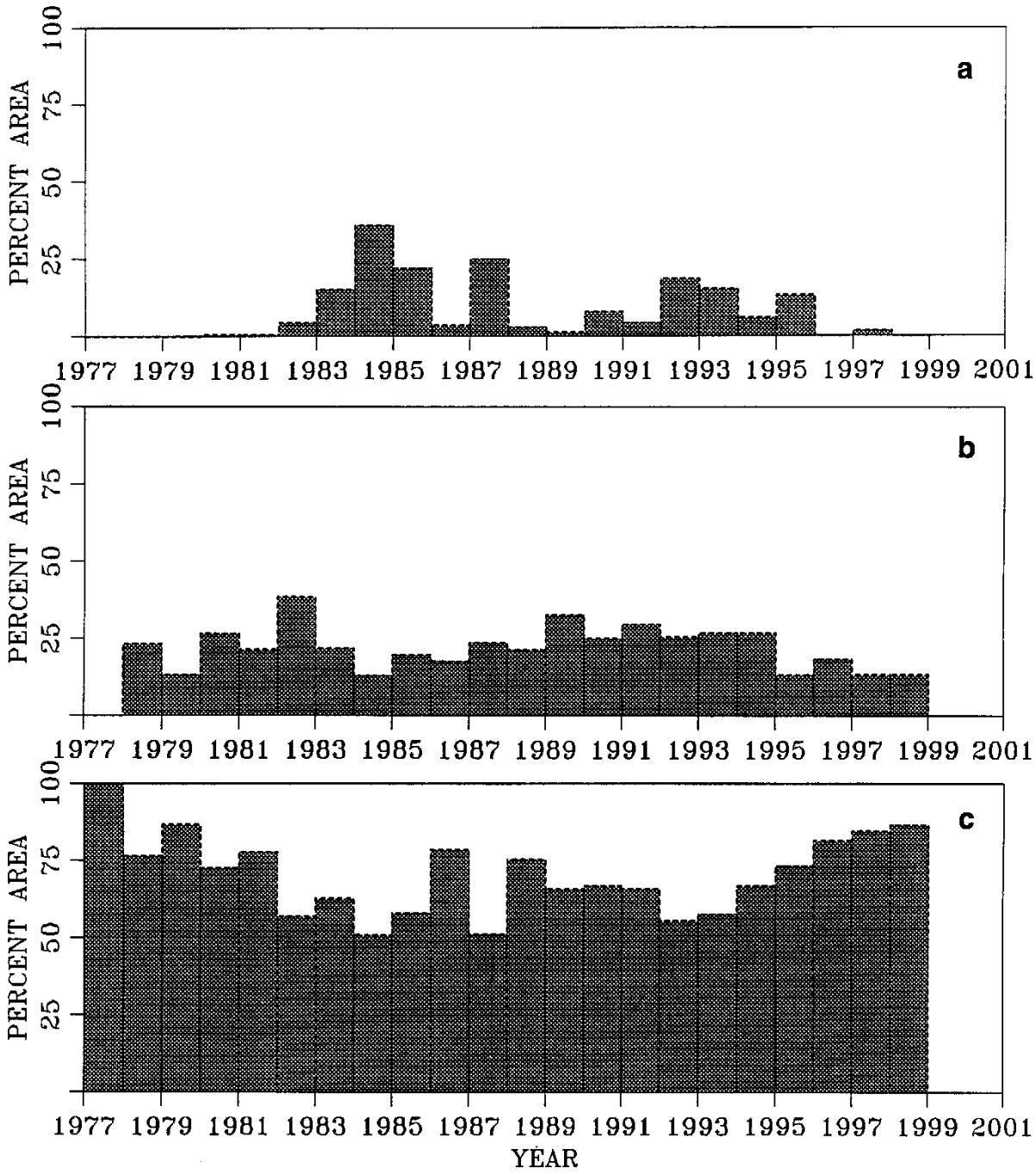

Fig. 6a. Time series of the percentage area of NAFO Div. 2J covered by water with bottom temperatures (a) ≤ 0°C (b) between 0°C to 1°C and (c) ≥ 1°C, during the fall.

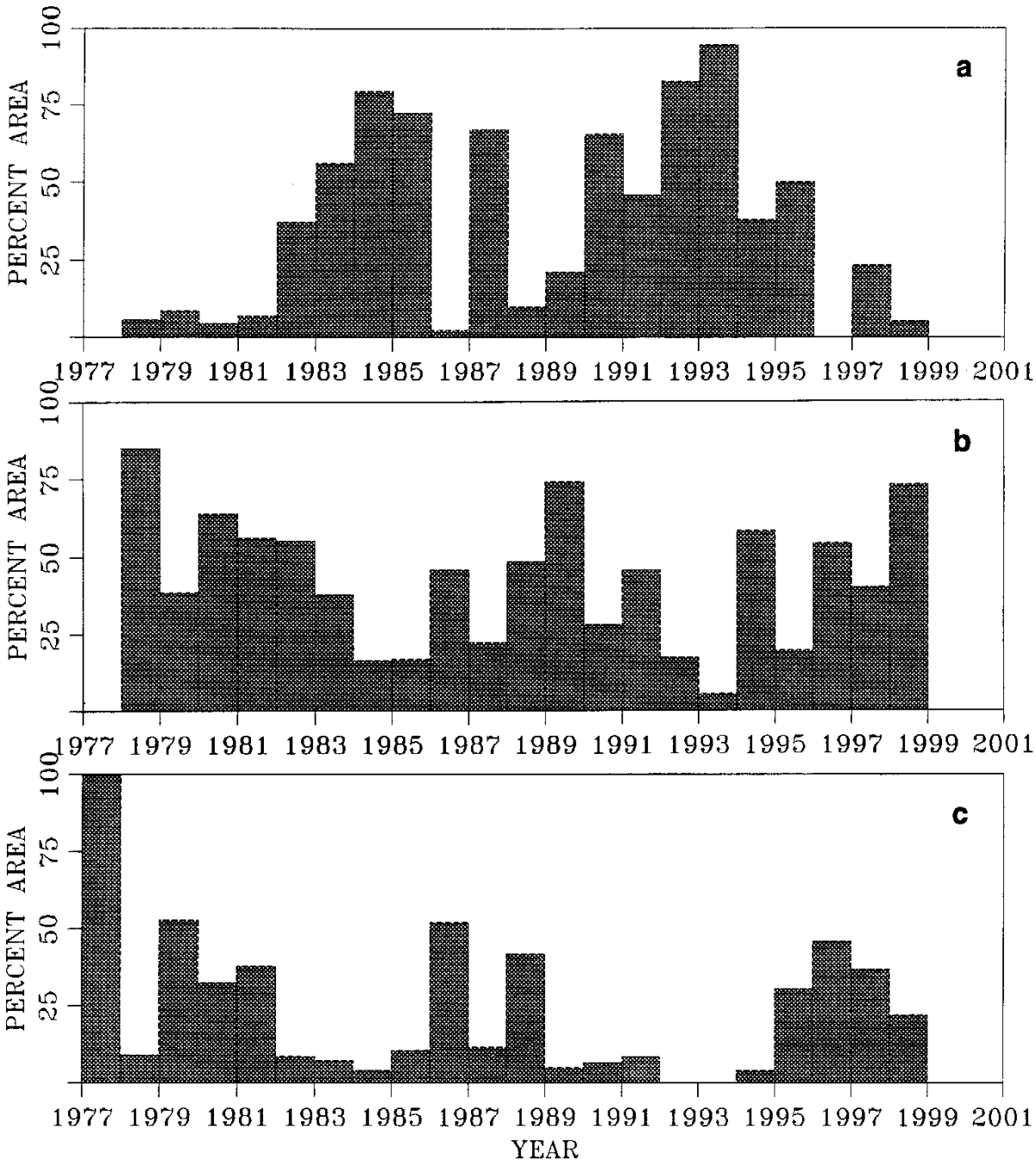

Fig. 6b. Time series of the percentage area of the Hamilton Bank and the near shore region of Div. 2J (with water depths within 200-m) covered by water with bottom temperatures (a) ≤ 0°C, (b) between 0°C and 1°C and (c) ≥ 1°C, during the fall.

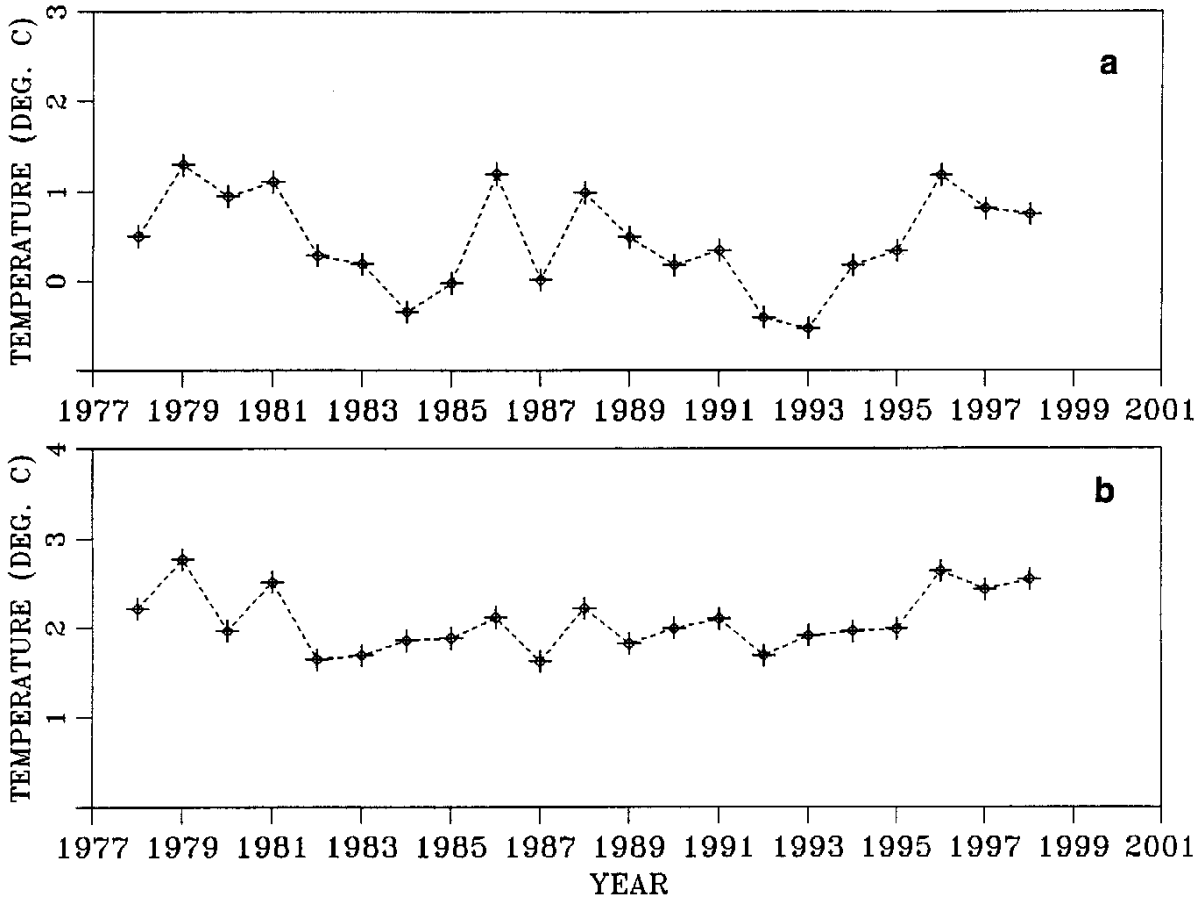

Fig. 6c. Time series of the mean bottom temperature (a) within 200-m depth in Div. 2J and (b) in NAFO Div. 2J, during the fall.

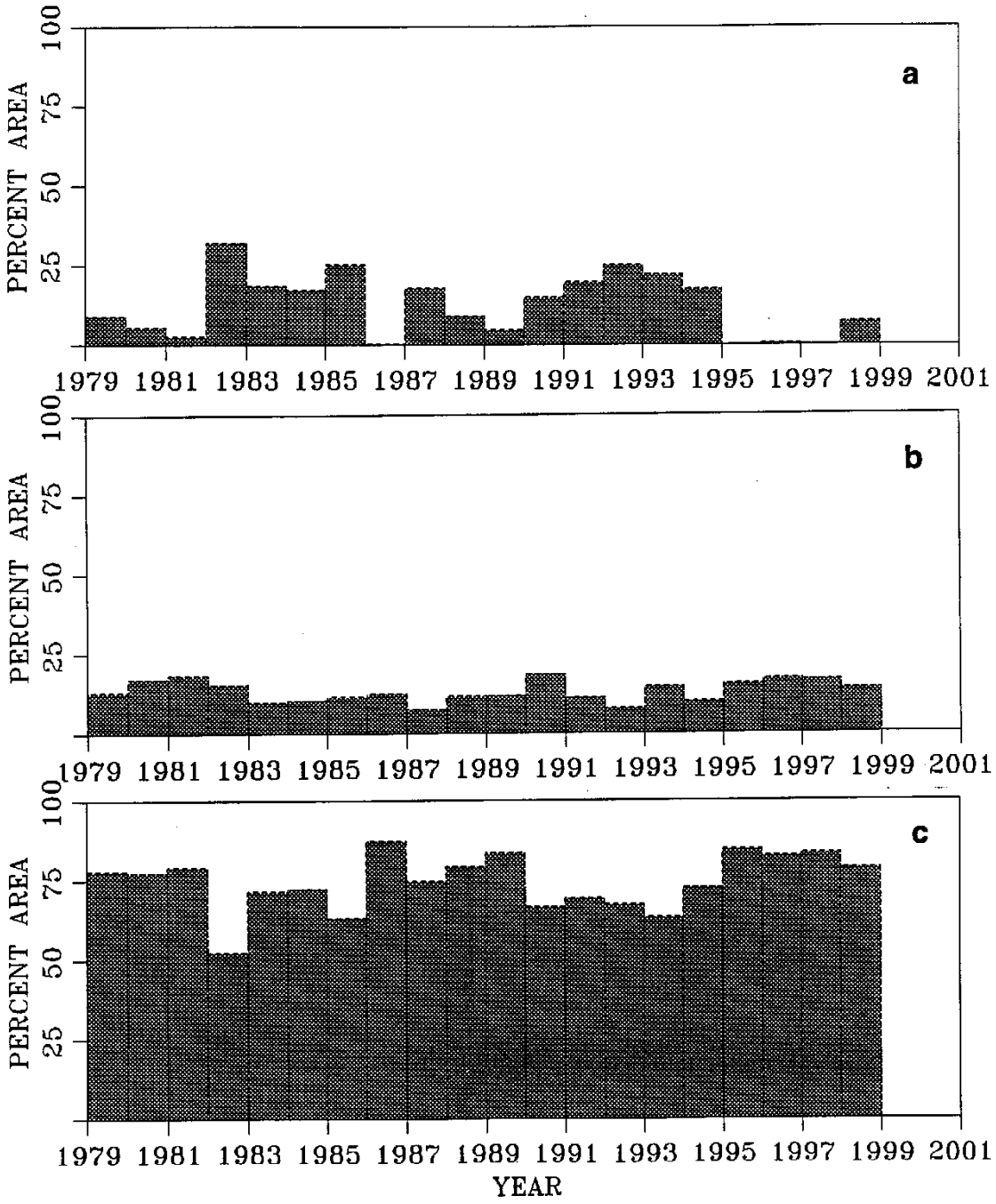

Fig. 7a. Time series of the percentage area of NAFO Div. 3K covered by water with bottom temperatures (a) ≤ 0°C (b) between 0°C to 1°C and (c) ≥ 1°C, during the fall.

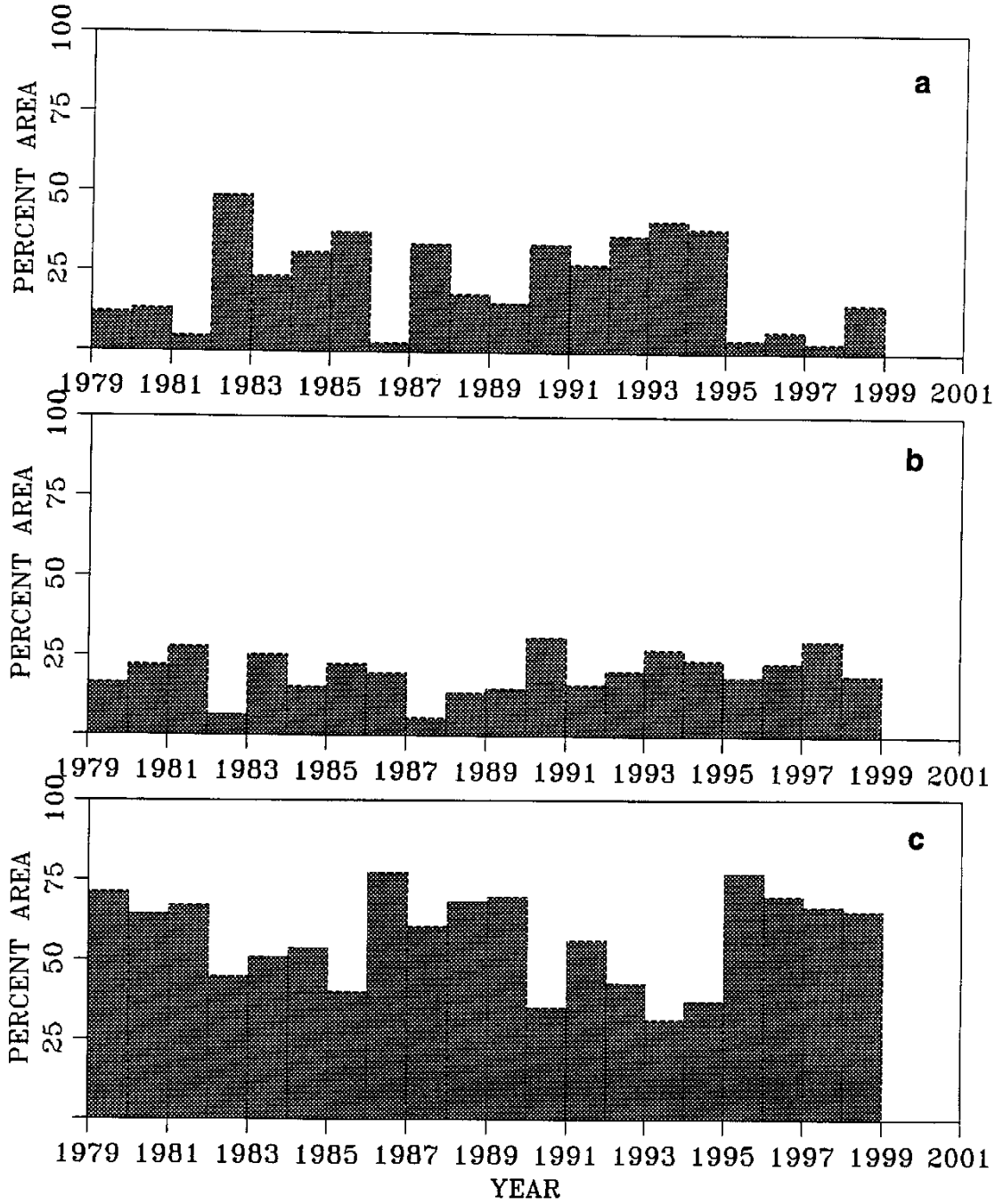

Fig. 7b. Time series of the percentage area of Div. 3K (with water depths within 300-m) covered by water with bottom temperatures (a) ≤ 0°C, (b) between 0°C and 1°C and (c) ≥ 1°C, during the fall.

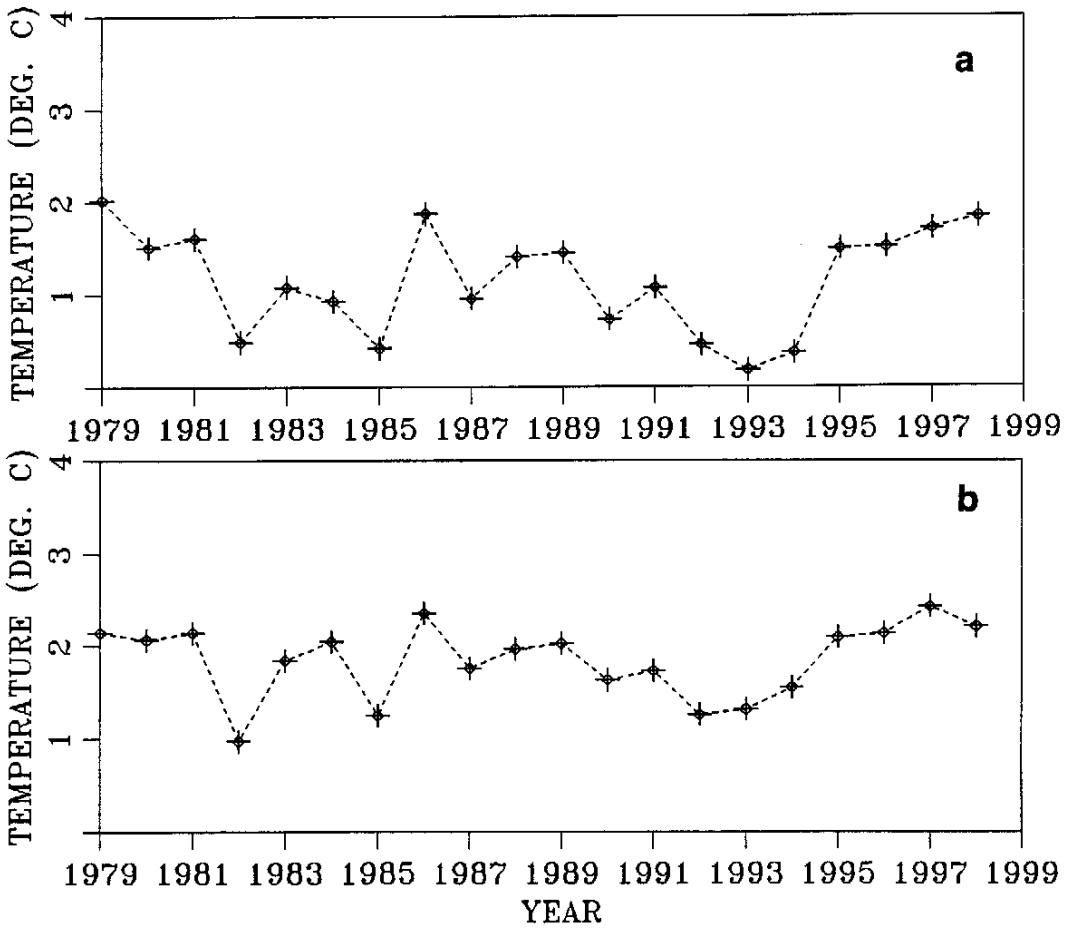

Fig. 7c. Time series of the mean bottom temperature (a) within 300-m depth in Div. 3K and (b) in NAFO Div. 3K, during the fall.

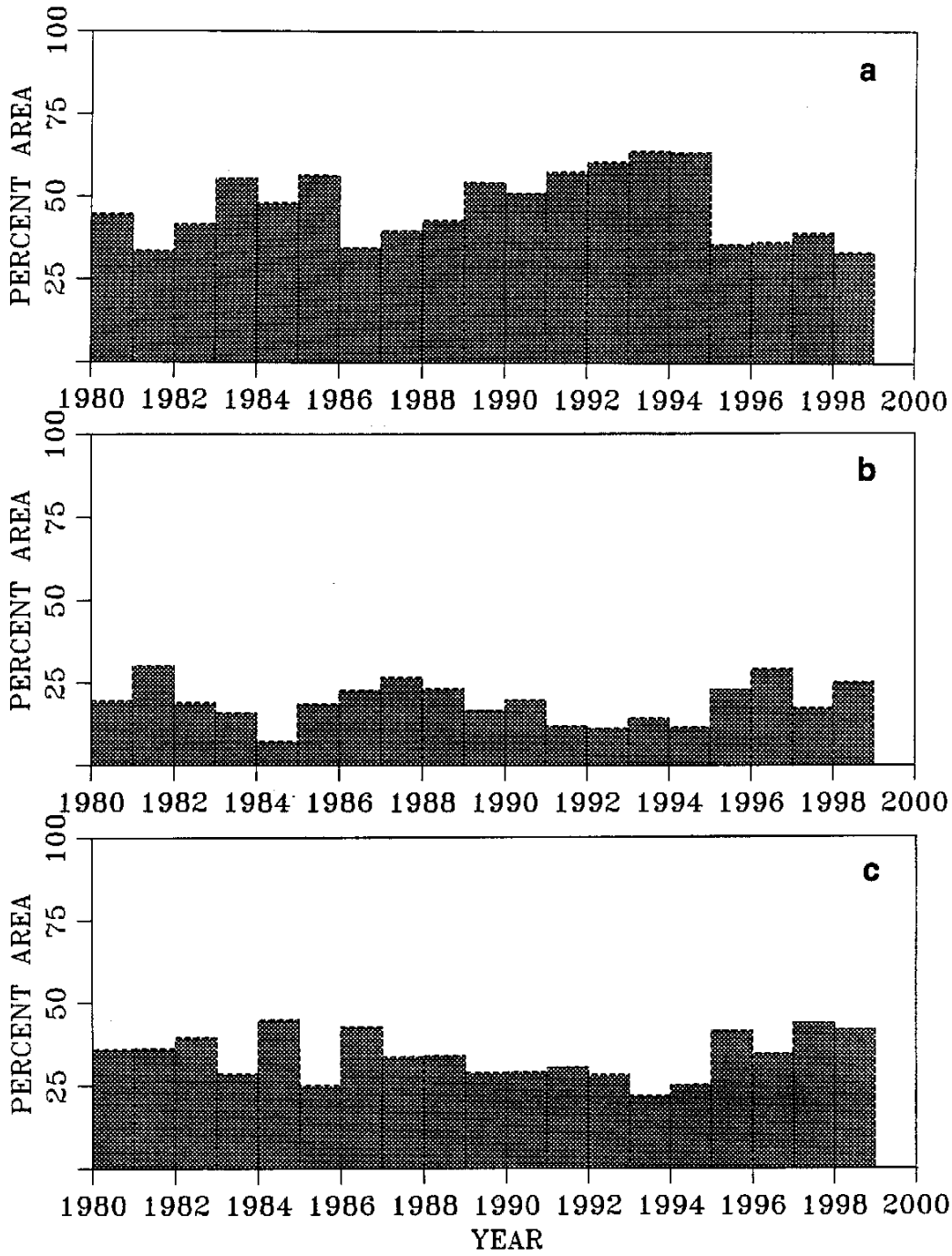

Fig. 8a. Time series of the percentage area of NAFO Div. 3L covered by water with bottom temperatures (a) ≤ 0°C (b) between 0°C to 1°C and (c) ≥ 1°C, during the fall.

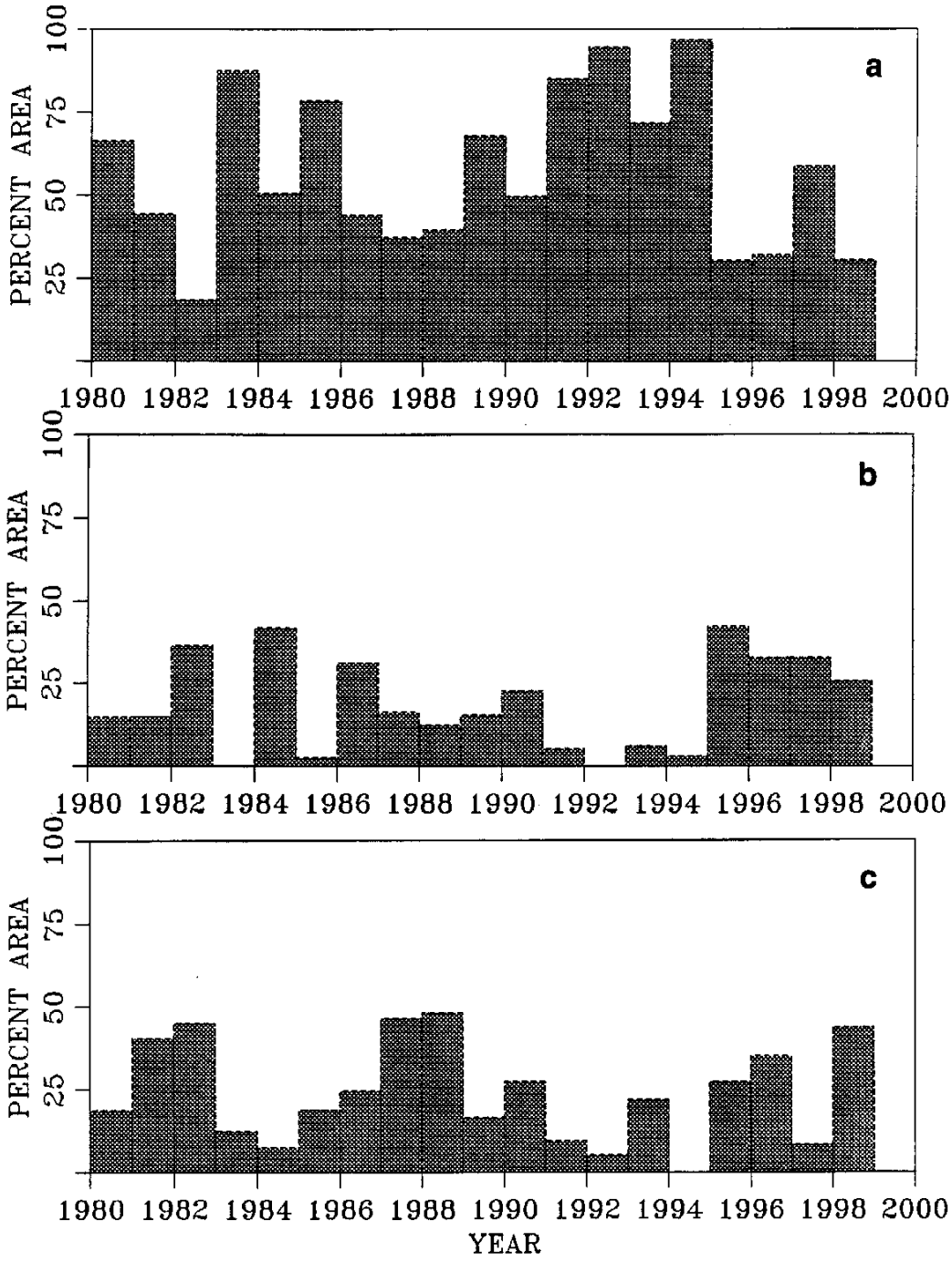

Fig. 8b. Time series of the percentage area of the Grand Bank in Div 3L (with water depths within 100-m) covered by water with bottom temperatures (a) $\leq$ 0°C, (b) between 0°C and 1°C and (c) $\geq$ 1°C, during the fall.

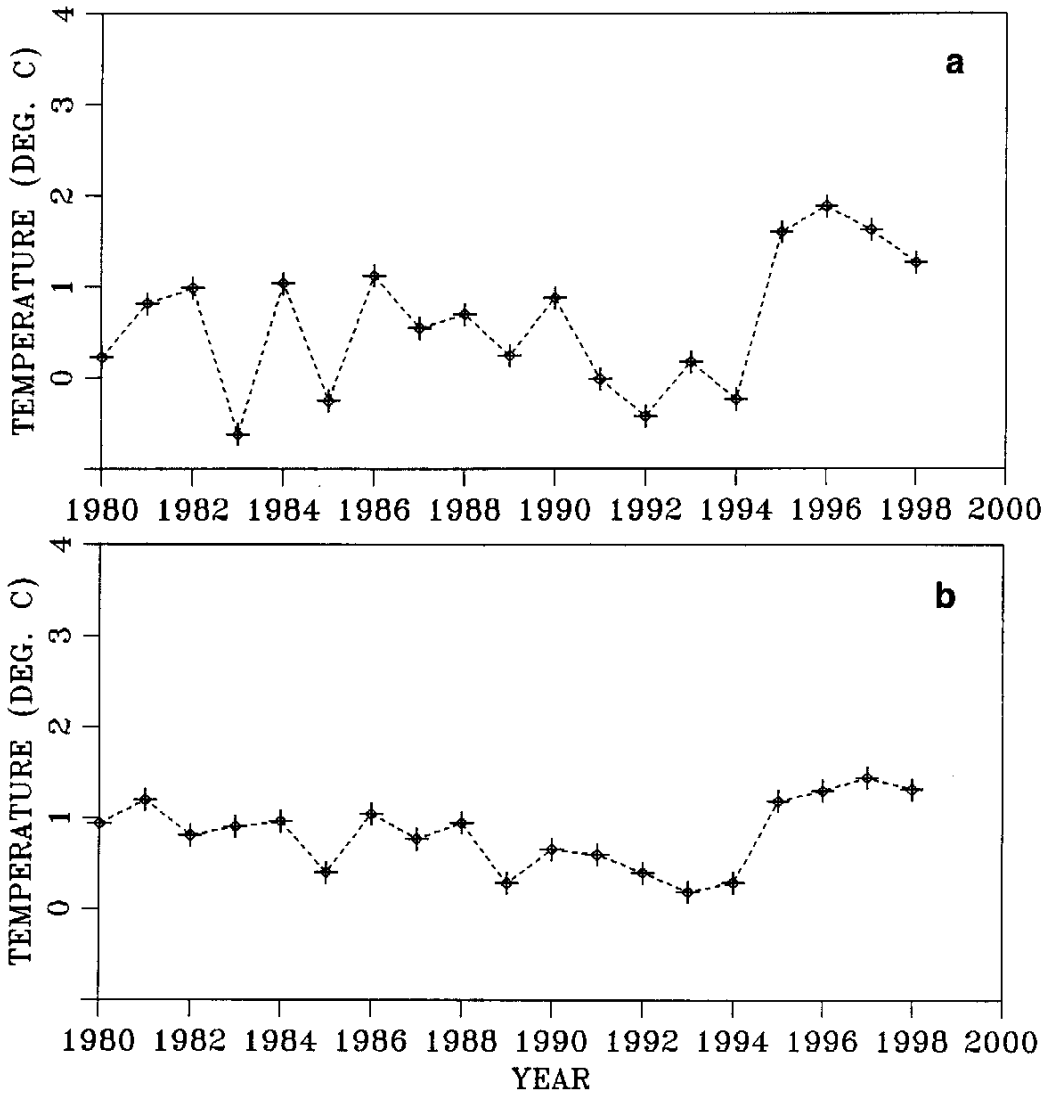

Fig. 8c. Time series of the mean bottom temperature (a) on the Grand Bank within 100-m depth in Div. 3L and (b) in NAFO Div. 3L, during the fall.

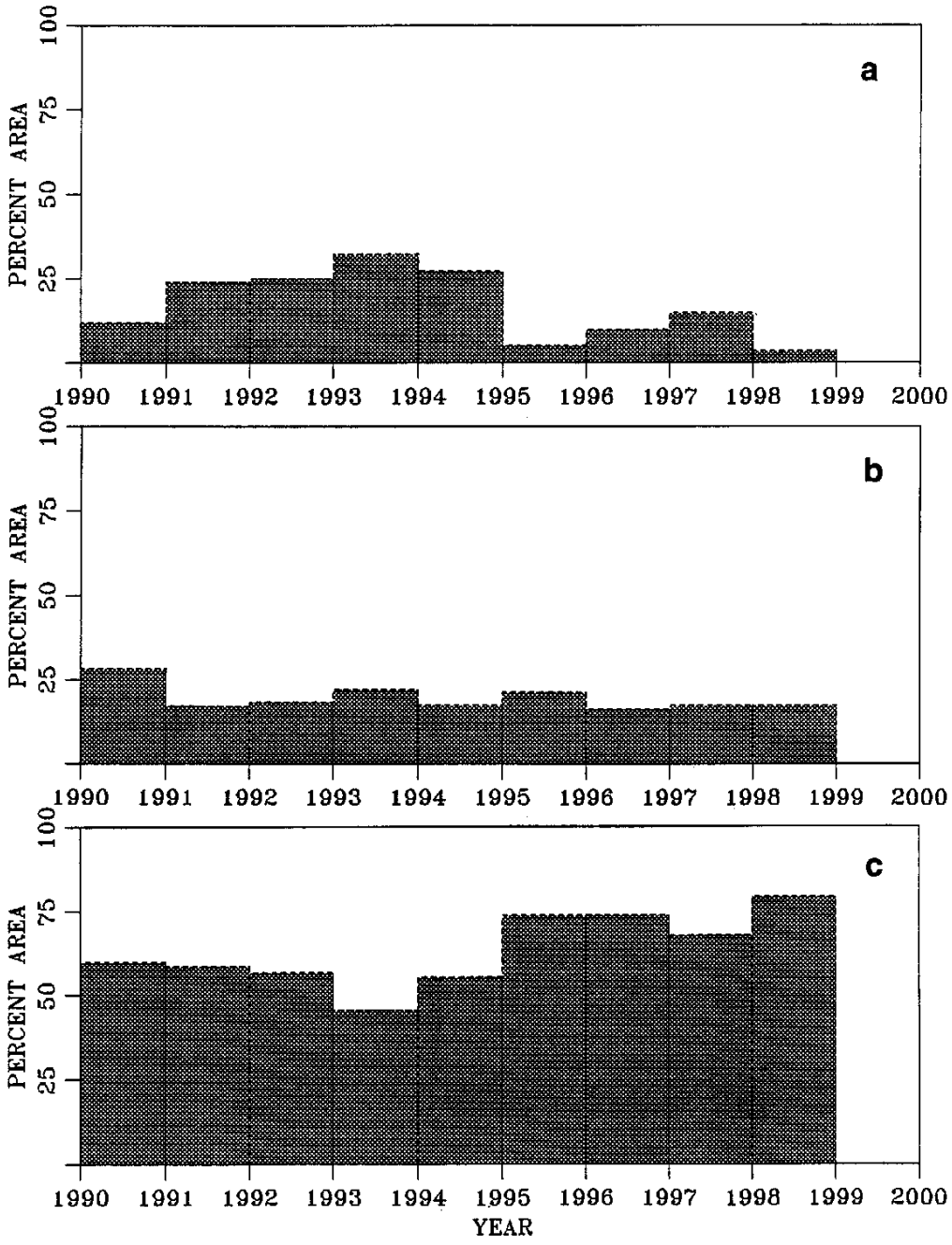

Fig. 9a. Time series of the percentage area of NAFO Divs. 3NO covered by water with bottom temperatures (a) ≤ 0°C (b) between 0°C to 1°C and (c) ≥ 1°C, during the fall.

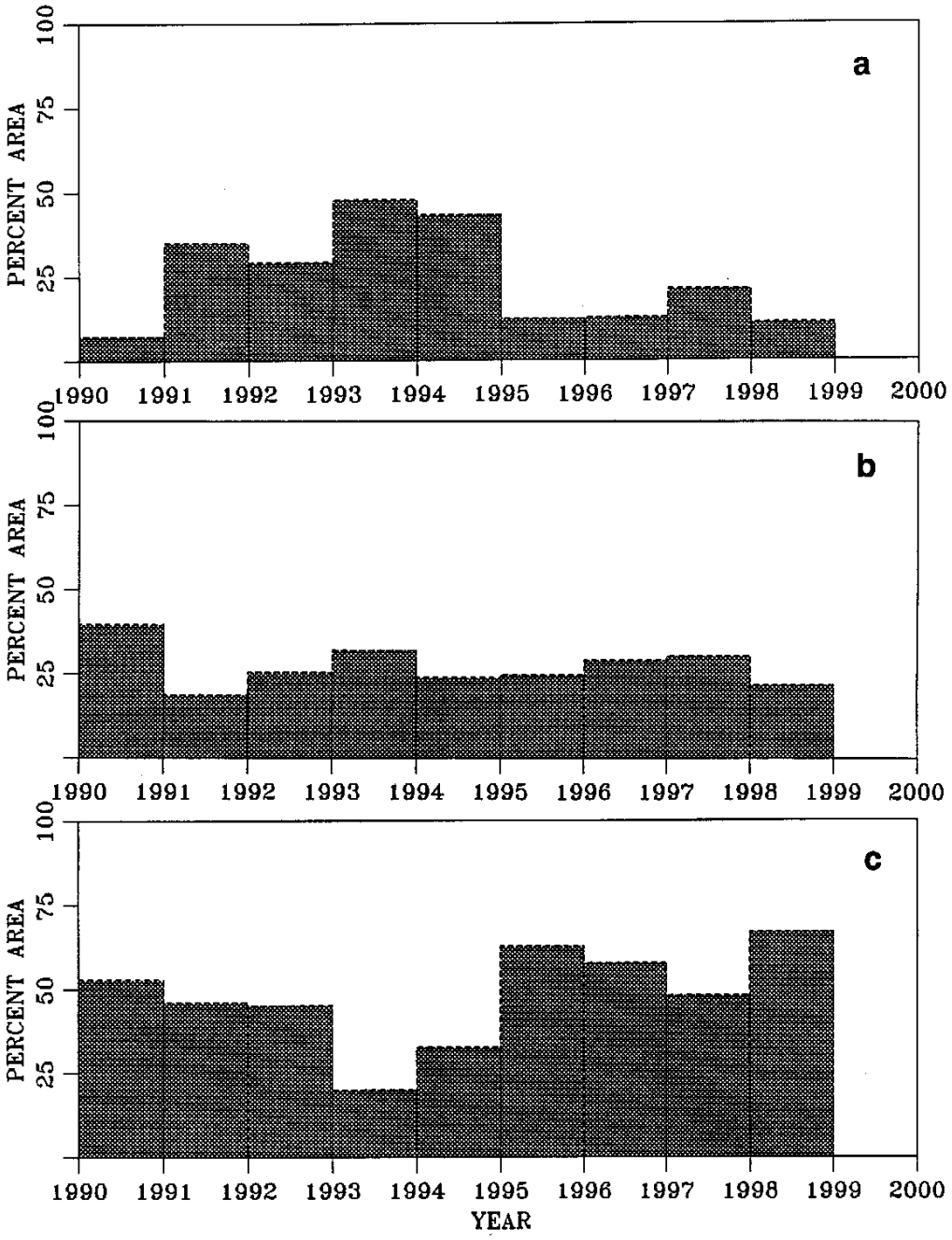

Fig. 9b. Time series of the percentage area of the Grand Bank in Divs. 3NO (with water depths within 100-m) covered by water with bottom temperatures (a) $\leq$ 0°C, (b) between 0°C and 1°C and (c) $\geq$ 1°C, during the fall.

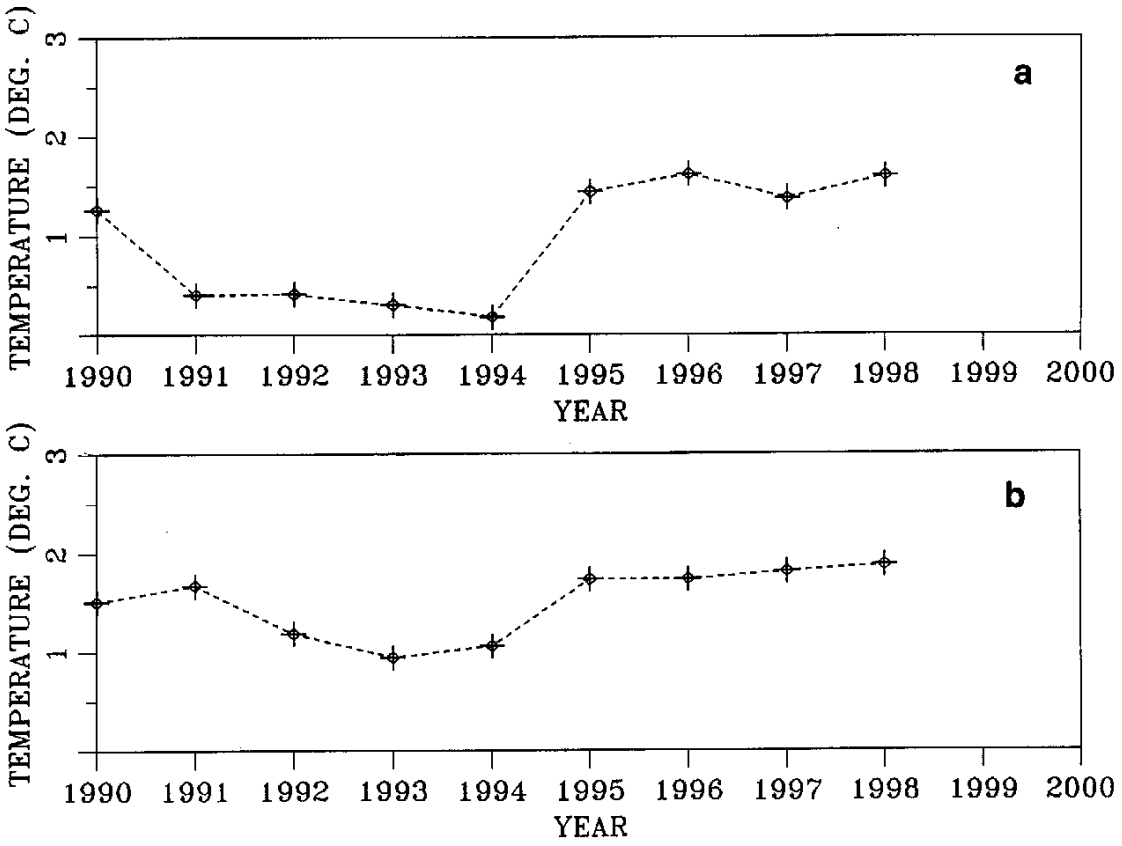

Fig. 9c. Time series of the mean bottom temperature (a) on the Grand Bank within 100-m depth in Divs. 3NO and (b) in NAFO Div. 3NO, during the fall.

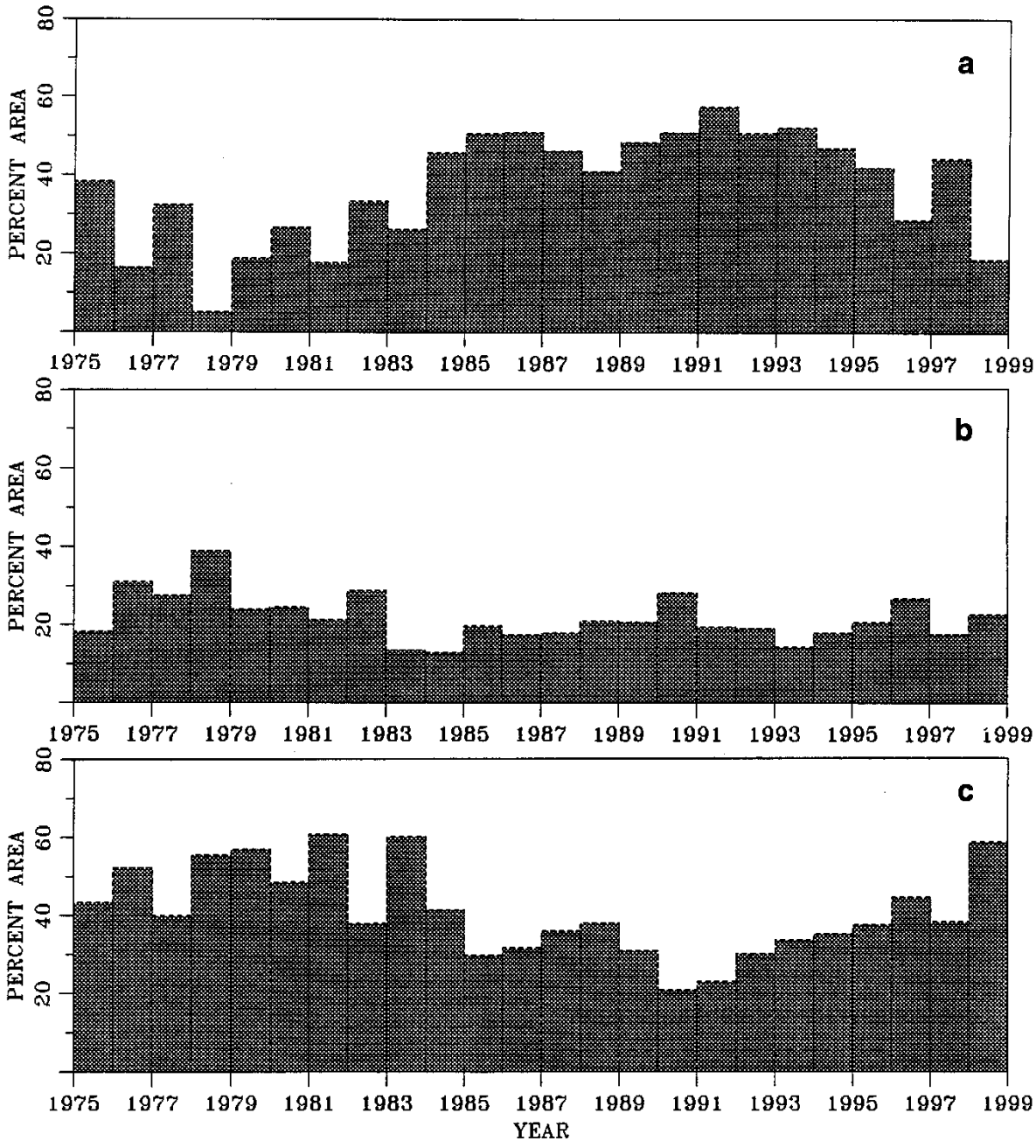

Fig. 10a. Time series of the percentage area of NAFO Divs. 3LNO covered by water with bottom temperatures (a) ≤ 0°C (b) between 0°C to 1°C and (c) ≥ 1°C, during spring.

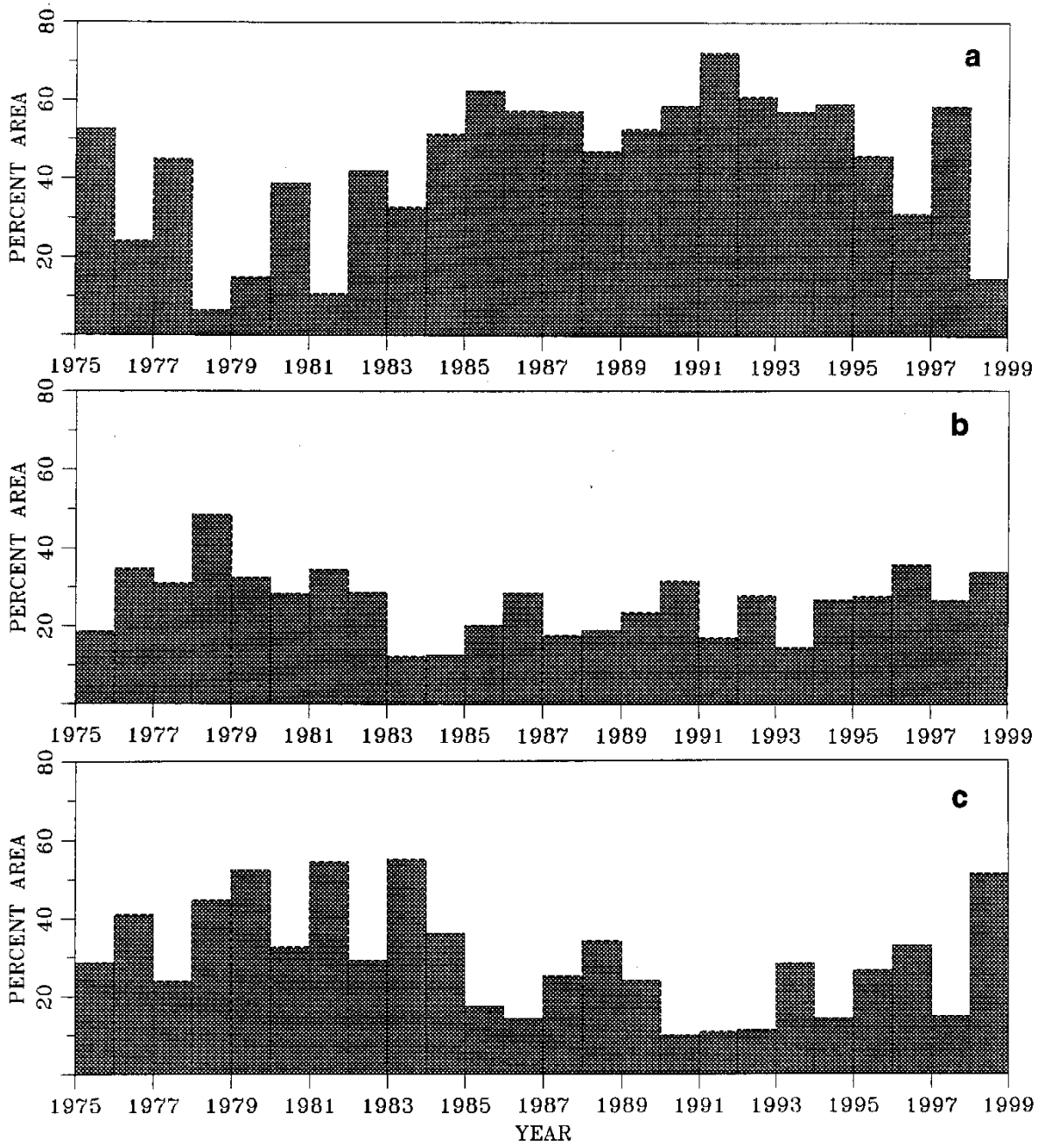

Fig. 10b. Time series of the percentage area of the Grand Bank (with water depths within 100-m) covered by water with bottom temperatures (a) $\leq$ 0°C, (b) between 0°C and 1°C and (c) $\geq$ 1°C, during spring.

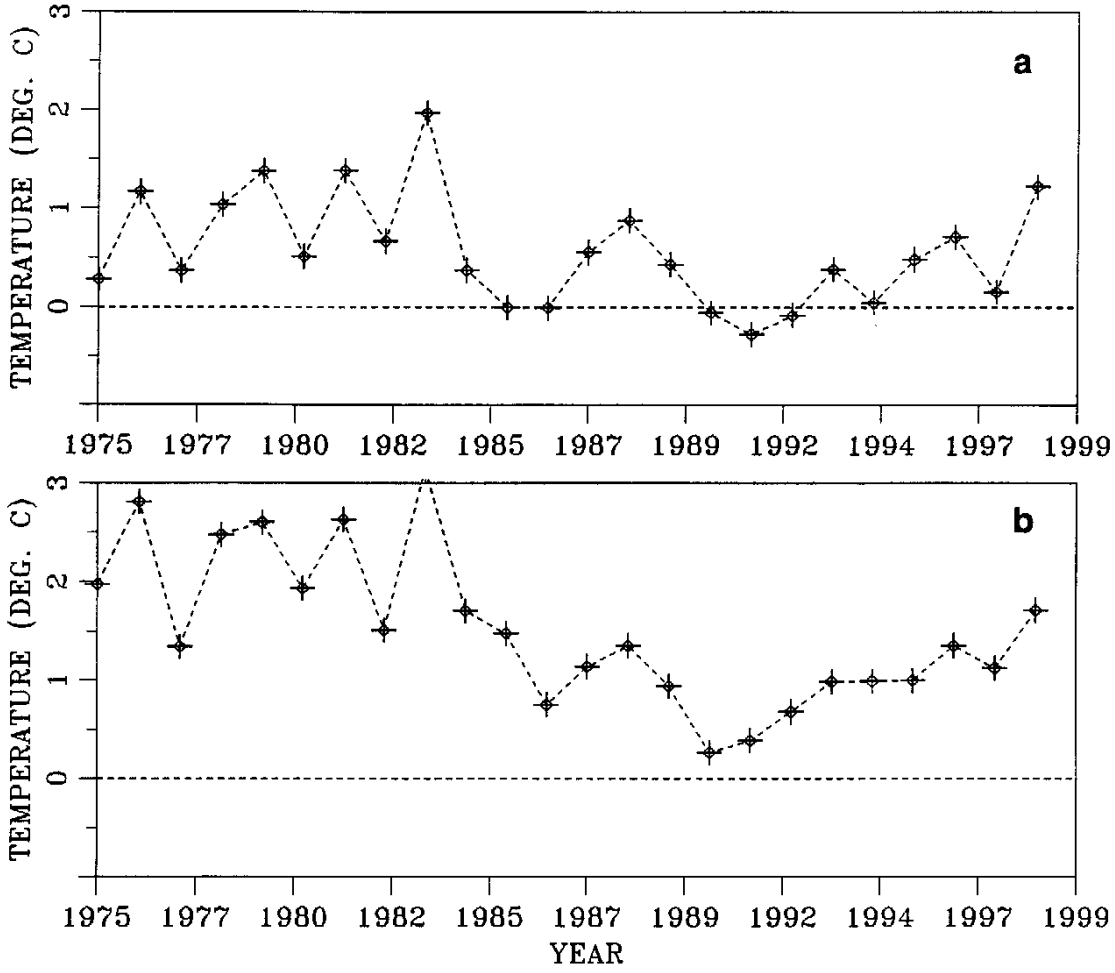

Fig. 10c. Time series of the mean bottom temperature (a) on the Grand Bank within 100-m depth in Divs. 3LNO, and (b) in NAFO Divs. 3LNO, during spring.

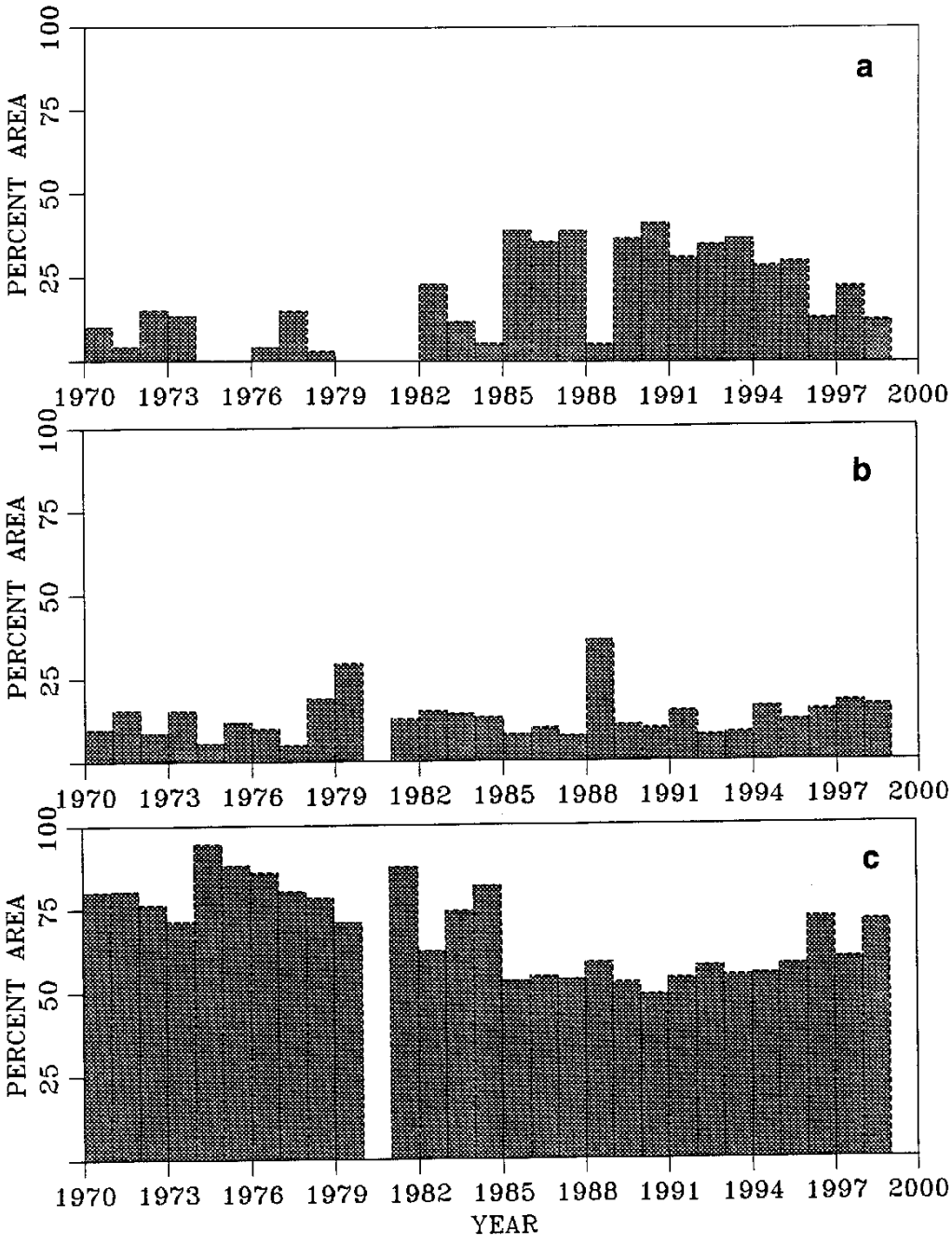

Fig. 11a. Time series of the percentage area of NAFO Sub-Divs. 3Pn and 3Ps covered by water with bottom temperatures (a) ≤ 0°C (b) between 0°C to 1°C and (c) ≥ 1°C, during the winter/spring time period.

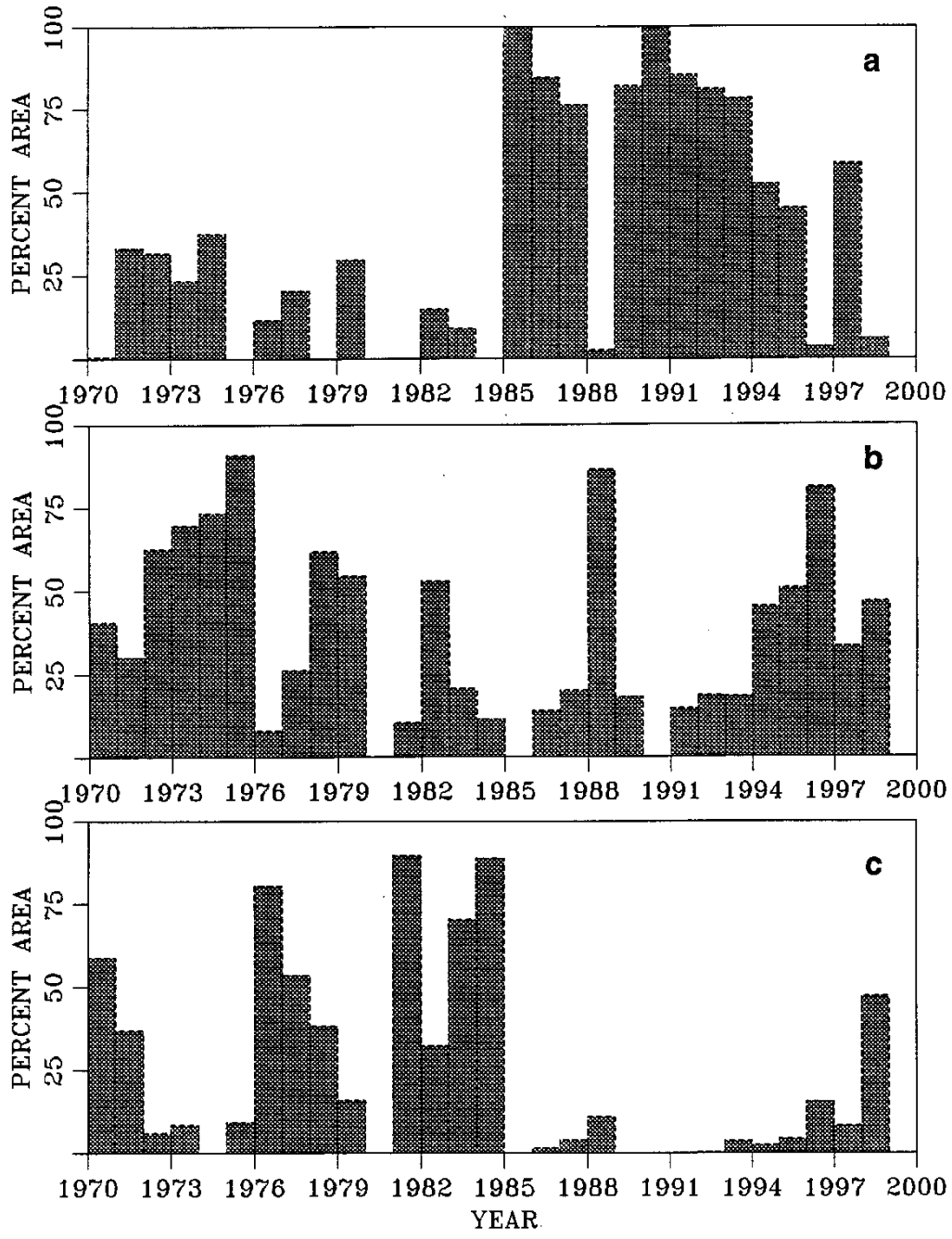

Fig. 11b. Time series of the percentage area of the Burgeo, St. Pierre and Green Banks, located in Sub-Divs. 3Pn and 3Ps (with water depths within 100-m) covered by water with bottom temperatures (a) $\leq$ 0°C, (b) between 0°C and 1°C and (c) $\geq$ 1°C, during the winter/spring time period.

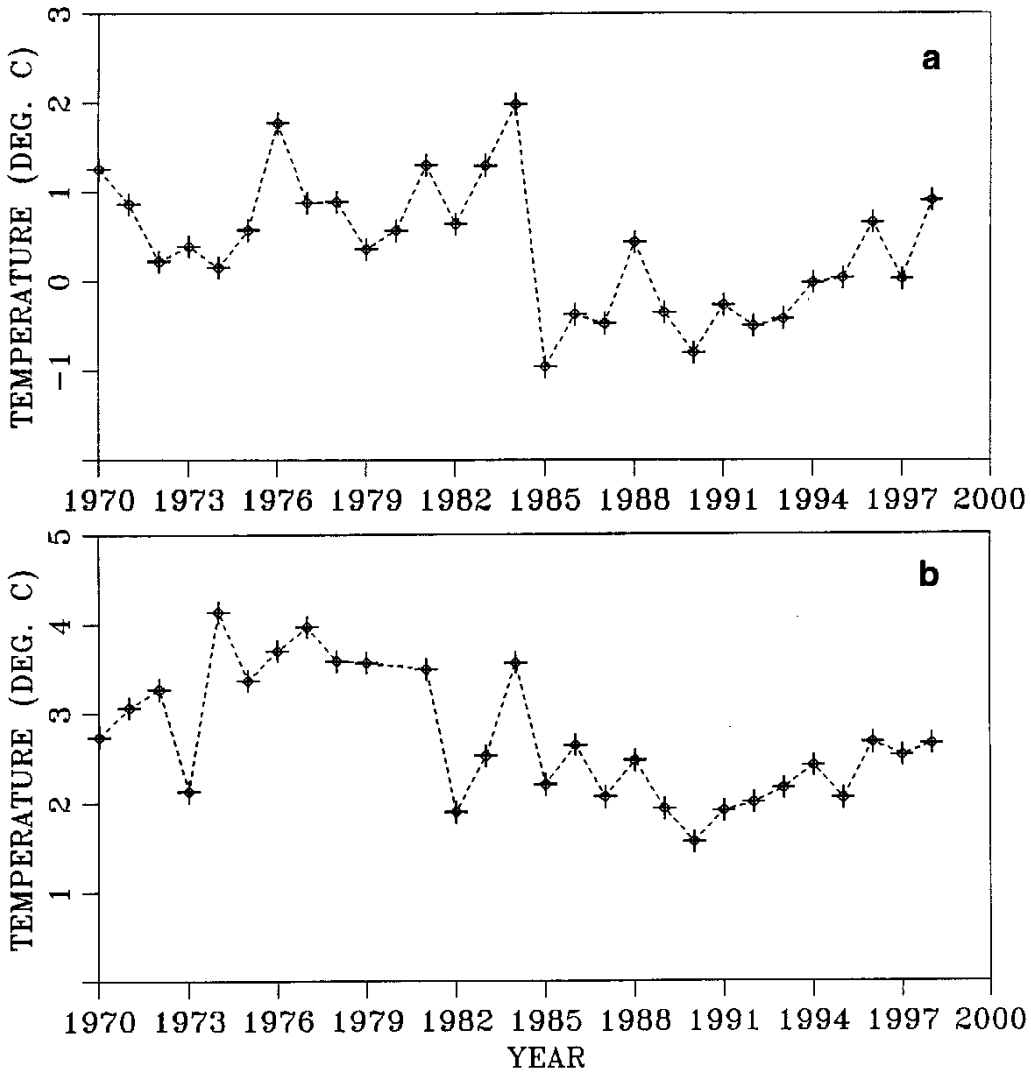

Fig. 11c. Time series of the mean bottom temperature (a) within 100-m depth in Sub-Divs. 3Pn and 3Ps and (b) in NAFO Sub-Divs. 3Pn and 3Ps, during the winter/spring time period.