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

C S A S — **S C C S**

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

Research Document 2004/086 — **Document de recherche 2004/086**

Not to be cited without
Permission of the authors *

Ne pas citer sans
autorisation des auteurs *

Physical oceanographic conditions in NAFO Division 3P during 2004 - possible influences on the distribution and abundance of Atlantic cod (*Gadus morhua*)

Conditions océanographiques physiques dans la division 3P de l'OPANO en 2004 – effets possibles sur la répartition et l'abondance de la morue (*Gadus morhua*)

E. B. Colbourne and/et E. F. Murphy

Department of Fisheries and Oceans
P. O. Box 5667
St. John's, Newfoundland
A1C 5X1

* This series documents the scientific basis for the evaluation of fisheries resources in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

This document is available on the Internet at:

* La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au Secrétariat.

Ce document est disponible sur l'Internet à:

http://www.dfo-mpo.gc.ca/csas/

ISSN 1499-3848 (Printed / Imprimé)

Canada

ABSTRACT

Oceanographic data from NAFO Division 3P during the spring of 2004 are examined and compared to the previous year and the long-term (1971-2000) average. Temperature measurements on St. Pierre Bank show anomalous cold periods in the mid-1970s and from the mid-1980s to mid-1990s. Beginning in 1996 however, temperatures started to moderate, decreased again during the spring of 1997 and returned to more normal like values during 1998. During 1999 and 2000 temperatures continued to increase, reaching the highest values observed since the late 1970s in some regions. During 2001-2003 however, temperatures cooled significantly to values observed during the mid-1990s with the average temperature during the spring of 2003 the coldest in about 13 years. Temperatures during the spring of 2004 warmed considerably over 2003 values to 1^{o}C above normal in the surface layers and by almost 0.5^{o}C in the near-bottom depths over St. Pierre Bank. The areal extent of $<0^{o}$C bottom water during 2003 increased to the highest in about 13 years but decreased during 2004 to <10%, the lowest since 1988. The areal extent of bottom water with temperatures $>3^{o}$C has remained relatively constant at about 50% of the 3P area during the past decade. On St. Pierre Bank bottom water with temperatures $<0^{o}$C essentially disappeared during the warm years of 1999 and 2000. It appeared again however during 2001 to 2003 covering about 90% of St. Pierre Bank in 2003. During the spring of 2004 it again disappeared with $<0^{o}$C water restricted to the eastern most regions and the approaches to Placentia Bay. In general, temperatures during the spring of 2004 increased significantly over values observed during 2001-2003. The most evident trend in the numbers of cod caught per set during the multi-species surveys was the high number of zero catches in the $<0^{o}$C water on St. Pierre Bank and regions to the east of the Bank, mainly from 1985 to 1998 but also from 2001 to 2003. During 1999 and 2000 larger catches became more wide spread over St. Pierre Bank as cold ($<0^{o}$C) water disappeared from the area. In general, during most surveys the larger catches occurred in the warmer waters (2^{o}-6^{o}C) along the slopes and areas to the west of St. Pierre Bank. In 2004 there was no observed shift in the distribution of cod over St. Pierre Bank and there were many low or zero catches in the warm deeper waters off the banks compared to most years. Finally, variations in the estimated abundance and biomass of cod from the RV surveys in strata with water depths <92 m are significantly correlated with bottom temperatures for that depth range.

RÉSUMÉ

Nous examinons les données océanographiques obtenues dans la division 3P de l'OPANO au printemps 2004 et les comparons à celles de l'année précédente et aux moyennes à long terme (de 1971 à 2000). Les mesures de température effectuées sur le banc Saint-Pierre montrent des périodes anormalement froides au milieu des années 1970 et du milieu des années 1980 au milieu des années 1990. Les températures se sont légèrement réchauffées en 1996, puis ont diminué au printemps 1997 et sont revenues à la normale en 1998. En 1999 et en 2000, les températures ont continué de se réchauffer, atteignant dans certaines régions les valeurs les plus élevées observées depuis la fin des années 1970. Toutefois, entre 2001 et 2003, les températures se sont considérablement refroidies, atteignant des valeurs observées au milieu des années 1990. La température moyenne dans la division 3P au printemps 2003 était la plus froide depuis environ 13 ans. Les températures au printemps 2004 ont été considérablement plus chaudes que celles en 2003, atteignant 1 ^{o}C au-dessus de la normale dans les couches superficielles et augmentant de près de 0,5 ^{o}C près du fond sur le banc Saint-Pierre. En 2003, la superficie couverte par de l'eau de fond de température inférieure à 0 ^{o}C a augmenté pour atteindre un sommet en environ 13 ans, puis elle est passée sous la barre des 10 % en 2004, la valeur la plus faible depuis 1988. La superficie couverte par de l'eau de fond de température supérieure à 3 ^{o}C est demeurée relativement constante (environ 50 % de la division 3P) au cours de la dernière décennie. Sur le banc Saint-Pierre, l'eau de fond de température inférieure à 0 ^{o}C a ni plus ni moins disparu durant les années chaudes de 1999 et de 2000, est réapparue en 2001 pour couvrir environ 90 % du banc en 2003, puis a disparu à nouveau au printemps 2004, sauf dans les régions les plus à l'est et aux abords de la baie Placentia. De manière générale, les températures enregistrées au printemps 2004 sont considérablement plus chaudes que celles observées entre 2001 et 2003. La tendance la plus évidente sur le plan de la quantité de morues capturées par mouillage d'engin lors des relevés plurispécifiques est le grand nombre de mouillages sans capture dans les eaux de température inférieure à 0 ^{o}C sur le banc Saint-Pierre et dans les régions à l'est du banc, surtout de 1985 à 1998, mais aussi de 2001 à 2003. En 1999 et en 2000, les mouillages capturant de nombreuses prises se sont répandus sur le banc de Saint-Pierre à mesure que l'eau froide (< 0 ^{o}C) disparaissait de la région. Lors de la plupart des relevés, les volumes de prises importants se sont produits dans les eaux chaudes (de 2 à 6 ^{o}C) le long des talus et dans les régions à l'ouest du banc Saint-Pierre. En 2004, aucune variation n'a été observée en ce qui a trait à la répartition de la morue sur le banc Saint-Pierre, et, par rapport à la plupart des autres années, de nombreux mouillages ont capturé peu ou pas de poissons dans les eaux profondes chaudes au large des bancs. Finalement, les variations dans l'abondance et la biomasse estimée de morue dans les strates de moins de 92 m de profondeur, estimées lors des relevés de navire de recherche, sont significativement corrélées avec les températures de fond pour ces profondeurs.

1. Introduction

The general circulation in the 3P region consists of modified Labrador Current Water, the inshore branch of which flows through the Avalon Channel, and around Cape Race. This branch then divides into two parts, one flowing to the west around the north of St. Pierre Bank, and the other flows to the south between Green Bank and Whale Bank. Additionally, part of the offshore branch of the Labrador Current flows around the tail of the Grand Bank, westward along the continental slope (where it may interact with the Gulf Stream and slope waters), to the Laurentian Channel and into the Gulf of St. Lawrence (Fig. 1a).

Since the early 1970s, the ocean environment in the Northwest Atlantic has been dominated by near-decadal oscillations with cold periods in the early 1970s, mid-1980s and early 1990s and a general warming trend towards the mid-to-late 1990s. During the cold periods, colder-than-normal winter air temperatures prevailed over the Northwest Atlantic resulting in increased winter and spring ice cover and a colder and fresher-than-normal water mass overlying most of the continental shelf in Atlantic Canada (Colbourne et al. 1994; Drinkwater 1996). These conditions generally correspond to periods of positive winter North Atlantic Oscillation (NAO) index anomalies. The extent to which events influences the 3P region are documented by several studies (Hutchings and Myers 1994; Moguedet and Mahe 1991; Battaglia and Poulard 1987; Forest and Poulard 1981; Colbourne 1994, 1996, 1999, 2000, 2001, 2002 and 2003).

This report summarises oceanographic conditions in NAFO Division 3P up to the spring of 2004 with comparisons to the previous year and represents the eighth such review of winter/spring oceanographic conditions in support of the annual cod assessments for this region. The base period used to compute anomalies up to 2000 was defined as the 30-year time period from 1961-1990, in accordance with the convention of the World Meteorological Organization and recommendations from the North Atlantic Fisheries Organization's (NAFO) Scientific Council. Beginning in 2001 the base period used for the computation of anomalies has been advanced to 1971-2000. There are however, insufficient salinity data available in this time period to produce meaningful averages. Therefore the base period for salinity anomalies encompassed all available data from the mid-1920s to 2003.

Assessments of the cod stock in this region have indicated a steady decline in biomass (SPA estimates) from the peak in 1985 to a minimum in 1992 followed by an increase during 1993-1997 after the implementation of a fishing moratorium. Recruitment also experienced a general decline since the early 1980s remaining at historical low values during most of the 1990s with a slight increase during 1997-1999 (Brattey et al. 2002). In this report, we present an overview of oceanographic conditions during 2003 and 2004 and provide an update to Colbourne and Murphy (2003), where a review of recent trends in the distribution and abundance of cod in relation to their thermal habitat was presented.

2. Data and Methods

Oceanographic data for NAFO Division 3P are available from archives at the Marine Environmental Data Service (MEDS) in Ottawa and from a working database maintained at the Northwest Atlantic Fisheries Centre (NAFC) in St. John's NL. The bulk of these data are temperatures collected during the Canadian groundfish assessment surveys of February, March and April since 1973. The station positions where oceanographic measurements were available for the 2003 multi-species survey are shown in Fig. 1b. Since the winter of 1990, water temperatures and salinity on these surveys have been measured, for the most part, using a trawl-mounted Seabird 19 CTD. Prior to that, XBTs were the primary instrument. Data from the net-mounted CTDs are not field calibrated, but are checked periodically and factory calibrated when necessary maintaining an accuracy of 0.005^{o}C in temperature and 0.005 in salinity. The XBTs are accurate to within 0.1^{o}C. In addition to these data, all available historical data in the period 1971-2000 were used to establish the long-term means.

Vertical cross-sections of the temperature and salinity fields and their anomalies for April 2003 and 2004 were constructed by projecting the positions of all observations in corridor A (Fig. 1b) along a straight line with their offshore distances calculated from the shoreline in Sub-division 3Pn. The cross-section start near Rose Blanche on the south coast of Newfoundland, then follow a southeasterly direction crossing Burgeo Bank, Hermitage Channel, and St. Pierre Bank, terminating near the edge of the continental shelf on the southwestern Grand Bank.

All available oceanographic data were gridded for the winter-spring period of each year at a spatial resolution of approximately 100 km^2 or approximately 0.1^{o} latitude by 0.1^{o} longitude. The mean bottom temperature for each grid element was calculated and combined with the grid area to produce a time series of the spatially averaged bottom temperature and the total bottom area covered by water in selected temperature ranges. Bottom temperature and salinity maps and their anomalies for the spring of 2003 and 2004 were constructed by contouring the near bottom temperature and salinity values, rejecting ones for which the cast depths were not within 10% of the actual water depth. Some temporal biasing may exist in the T/S fields represented by these maps, particularly in shallow regions, given the large area and wide time interval (up to one month) over which the data were collected. A time-series of the gridded mean values were computed from 1970 to 2004 for temperature and from 1990 to 2004 for salinity.

Annual near-surface and near-bottom temperature anomalies were constructed from all available data throughout the year corresponding to area B on St. Pierre Bank (Fig. 1b). The 1971-2000 data set from this area was sorted by month to determine monthly means. The seasonal cycle was then removed from each observation by subtracting the monthly mean to determine anomalies. Unlike the time series of anomalies from fixed points (e.g. Station 27), these anomalies are based on data collected over larger geographical areas and therefore may exhibit variability due to spatial differences in the monthly estimates. In addition, the annual values may be based on only a few monthly estimates for the year. Therefore, caution should be used when interpreting short time scale features of these series. The long-term trends however, generally show real features.

The number of cod of all ages per set is displayed as expanding symbols together with the temperature contours for selected surveys, with an update for 2003 and 2004. The survey catch data from 1983 to the spring of 1995, which were collected using an Engel 145 bottom trawl, were converted to equivalent Campelen trawl units based on the results of comparative fishing studies. Inter-annual variations in the thermal habitat and its effects on cod are then considered by examining the mean temperature fields in relation to the RV estimates of biomass and abundance.

3. Physical Oceanography

3.1 Temperature Section

Vertical cross-sections of the temperature and temperature anomaly fields for April of 2003 and 2004 based on the multi-species survey data within Box A (Fig. 1b) are displayed Fig. 2. No attempts were made to adjust this average for possible temporal or spatial biasing arising from variations either in the number of observations within the time interval or within the area. The average upper layer temperature for April from near shore at Rose Blanche on the south coast of Newfoundland over Burgeo Bank and Hermitage Channel is about 1^{o}C. Over St. Pierre Bank temperatures range from 1^{o}C near the bottom to 2^{o}C near the surface and from 1^{o}-2^{o}C beyond the shelf edge in the upper 100-m of the water column. In the deeper water of Burgeo and Hermitage Channels and on the continental slope temperatures are highly variable and generally range from 2^{o}C at approximately 125-150 m depth to 5^{o} - 7^{o}C in the deepest water. At the edge of the continental shelf on southeastern St. Pierre Bank, the temperature field is marked by a strong gradient separating the warmer slope water from the Newfoundland Shelf water that is advected into the region by the inshore branch of the Labrador Current. In this region water temperatures increases from about 1^{o}C at about 100-m depth, to between 5^{o} to 6^{o}C at about 175-m depth, an average vertical temperature gradient of 1^{o}C per 15-m depth change (Colbourne 2000).

During April of 2003, upper layer (0-125 m) temperatures were <0^{o}C over the entire area except for the southeastern regions (Fig. 2). These values were below normal, by up to 2.0^{o}C over most of the upper water column. During April 2004, upper layer temperatures increased significantly compared to 2003 values by over 2^{o}C over most areas. During the spring of 2004 temperatures were above 0^{o}C in all areas along the corridor shown in Fig. 1a with anomalies ranging from 0.25^{o}C to 1^{o}C above normal. In the deeper waters (>180 m) of Burgeo and Hermitage Channels temperatures were similar to 2003 values but along the southeastern slopes temperatures decreased from 6^{o}C to 5^{o}C during 2004 which were below normal. In general however, spring temperatures along this section over most of the water column during 2004 were above normal, reversing the cold conditions observed during 2003.

3.2 Bottom Temperatures

The average bottom temperature for April ranges from 5^{o}C in the Laurentian, Burgeo and Hermitage Channels to about 3^{o} to 4^{o}C on Rose Blanche and Burgeo Banks. On St. Pierre Bank bottom temperatures range from 0^{o}C on the eastern side to 2^{o} to 3^{o}C on the western side. In general, bottom isotherms follow the bathymetry along the Laurentian Channel and the southwestern Grand Bank, decreasing from 2^{o}C at 200-m depth to about 5^{o}C below approximately 300-m depth (Colbourne 2000).

During the spring of 2003, bottom temperatures over St. Pierre Bank decreased significantly over 2002 values with <0^{o}C water covering most of the Bank and regions to the east (Fig. 3). Consequently, below normal temperatures were more widespread during 2003 compared to 2002, covering most of the bottom areas in the 3P region with values as low as 1^{o}C below normal (Fig. 3). During April 2004, bottom temperatures increased significantly compared to 2003 values over Burgeo and St. Pierre Banks with <0^{o}C water restricted to the approaches to the Placentia Bay area. As a result bottom temperatures in these areas were up to 1^{o}C above normal. In general, the area of the bottom covered by below normal temperatures decreased significantly during the spring of 2004, compared to 2003.

Annual values of the areal extent of the bottom covered with water in the temperature ranges of <0^{o}C, 0^o-1^{o}C 1^o-2^{o}C 2^o-3^{o}C and >3^{o}C are displayed in Fig. 4. Note the large increase in the percentage area of the bottom covered by <0^{o}C water in 1985 that persisted well into the mid-1990s, with the exception of 1988. The percentage area covered by <0^{o}C water during the spring of 1998 decreased to pre-1985 levels and to less than 10% during 2000, but increased to over 25% during 2001 and 2002 and to near 40% in 2003. This area decreased to <10% in 2004. The bottom area covered with water between 0^o-1^{o}C, except for 1979, 1988 and 2004, has remained below 20%. The bottom area with temperatures >1^{o}C before 1985 was approximately 70-80% and from 1984 to 1995 it varied between 50-70%. Since 1995, except for 1997 this area has been increasing and approached pre-1985 values during 1999 and 2000. During the spring of 2001-2004, this area has decreased to between 50-65%, with a slight increase observed in 2004. The area of the bottom covered with water >3^{o}C has remained relatively constant between 40-50% since the late 1980s.

The spatially averaged bottom temperature of the surveyed area in Division 3P ranged between 2^o - 4^{o}C from 1970 to 1984 and decreased to between 2^o - 2.5^{o}C from 1985 to 1997. During 1999 and 2000 the average near-bottom temperature increased to over 3^{o}C, decreased to near 2.0^{o}C from 2001-2003 but increased again in 2004 to 2.5^{o}C (Fig. 4, bottom panel). On the banks, in water depths generally <100-m, the average temperature from 1970 to 1985 ranged between approximately 0.5^o to 1^{o}C. It then decreased significantly during 1985 and has slowly recovered to about 1^{o}C by 1998, 1.6^{o}C during 1999 and to 1.7^{o}C during 2000. During 2001 to 2003, the spatially averaged bottom temperature on the banks decreased to -0.7^{o}C the lowest since 1985, but increased to 0.7^{o}C during the spring of 2004.

3.3 Long-Term Trends

Annual near-surface and 75-m depth temperature anomalies from 1950 to 2004 on St. Pierre Bank bounded by Area B in Fig. 1b are displayed in Fig. 5. The time series is characterised by large inter-annual variations with amplitudes ranging from ±1.5^{o}C from normal. The long-term trend shows amplitudes generally less than ±1^{o}C with periods between 5 to 10 years. The cold periods of the mid-1970s and the mid-1980s in the upper water column are coincident with severe meteorological and sea-ice conditions in the Northwest Atlantic and generally colder and fresher than normal waters over most of the Canadian Continental Shelf. During the cold period beginning around 1984 temperatures decreased significantly by over 1^{o}C in some years. This below normal trend continued until the mid-1990s, since then however temperatures began to warm and from 1997 to 2000, they were above normal. During 2001 temperatures decreased significantly over 2000 values at both the surface and at 75-m depth, reaching values typical of the early 1990s. During

2002 and 2003 temperatures remained cold, reaching 0.7°C below normal at 75 m depth. During 2004 however temperatures rebounded to 1°C above normal at the surface and to 0.5°C above normal at 75 m depth.

3.4 Salinity Section

Vertical cross-sections of salinity and salinity anomalies for April of 2003 and 2004 are shown in Fig. 6. In order to obtain enough data to construct realistic anomaly fields the complete data set dating back to the mid-1920s was used. No attempts were made to adjust the average for possible temporal or spatial biasing arising from variations either in the number of observations within the time interval or within the area. An examination of the data indicates that the observations are well distributed geographically across the complete section, however temporally most of the data have been collected since the early 1990s after the implementation of the trawl-mounted CTD system.

The average upper layer salinity for April from near-shore at Rose Blanche on the south coast of Newfoundland and over Burgeo Bank and Hermitage Channel ranges from about 32 to 32.2. Over St. Pierre Bank, salinities generally range from 32.5 near bottom, to a low of 32.1 near the surface. Along the shelf edge, in the upper 100-m of the water column, there is a strong density front separating the warmer slope water from the Labrador Current shelf water over St. Pierre Bank, in this region salinities generally increase from 32.3 to over 34. In the deeper waters of Burgeo and Hermitage Channels and on the continental slope regions salinities normally increase from 33 at approximately 130-m to 34.5 near bottom (Colbourne 2000).

During April of 2003 (Fig. 6 upper panels) near-surface salinities ranged from <32 near the coast and over Burgeo Channel and Bank and from 32.5-33 over St. Pierre Bank, these values were generally near-normal to saltier than normal over St. Pierre Bank. Salinities below 150-m depth ranged from 33 to >34.5, which for the most part, were near-normal except on the slopes of St. Pierre Bank where they were generally fresher than normal in the depth range of 100-200 m. Salinities along the section during April 2004 were very similar to 2003 values however there was a general increase along the slopes of the banks towards average conditions.

3.5 Bottom Salinity

Average bottom salinities for the winter-spring period ranges from 34 to 34.5 in the Laurentian, Burgeo and Hermitage Channels, about 33 to 33.5 on Burgeo Bank and from about 32.25 to 33 on most of St. Pierre Bank. On the slopes of St. Pierre Bank (100-300 m), salinities generally range from 33 to 34.5 (Colbourne 2000). During April of 2003 bottom salinities were near-normal over most areas except for the slopes of the banks. During the spring of 2004 near bottom salinities over St. Pierre Bank decreased slightly over the top of the bank but otherwise remained similar to 2003 between 32.5 and 33. Along the slopes of the Laurentian Channel, salinities were lower than normal in 2004 similar to 2003 (Fig.7 right panels).

Areal indices based on selected salinity ranges were computed using the same method as was used for temperature, these are displayed in Fig 8 for the ranges of ≤32.25, 32.25-32.5, 32.5-32.75 and >32.75. The areal index was only calculated for the banks with water depths ≤100-m, below that there does not appear to be any significant trend in the salinity data. The analysis is based on salinity data collected during the multi-species surveys from trawl-mounted CTD for the years 1990-2004.

The areal extent of bottom water with salinities ≤32.5 was near constant from 1990-1997 at about 80-90%. During 1998 it decreased to about 35% and increased to over 90% during 2000 but decreased to near 0% in 2001 when conditions were much saltier-than-normal. During April of 2002 it increased again to near 80% but decreased to 50-70 % in 2003 and 2004. The areal extent of bottom water on the banks with salinities >32.5 ranged <10-25% from 1990 to 1997 but increased to about 65% in 1998, which decreased to <10% during the spring of 2000. During the spring of 2001 almost all of St Pierre Bank was covered by water with salinities >32.5 (Fig. 8 top panel), while 2002 and 2004 the areal coverage ranged from 15-50%.

The spatially averaged bottom salinity of the surveyed area in Division 3P (Fig. 8, bottom panel) ranged from 33.3 to 33.45 from 1990 to 1996. From 1997 to 1999 the average salinity increased to 33.56, but decreased again in 2000 to 33.38. During 2001 average salinities were similar to 1999 values but decreased slightly in 2002 and remained about the same in 2003 and 2004. On the banks in water depths <100-m the average bottom salinity was near constant at about 32.35 from 1990 to 1997 but then increased to 32.6 in 1998, which decreased to 32.48 in 1999. During the spring of 2000, salinities on the banks decreased to 32.14 the lowest in the 13 record. During April of 2001 however, salinities increased significantly over 2000 and were similar to values observed during 1998. During 2003 and 2004 salinities increased slightly over 2002 values to around 32.5. In general, since 1998 average salinities in water depths <100 m have been highly variable compared to pre-1998 levels.

4. Atlantic Cod and the physical environment

The near-bottom habitat in the 3P region consists of two distinct oceanographic regimes. The one influenced by cold and relatively fresh water advected from the eastern Newfoundland Shelf by the inshore branch of the Labrador Current includes much of St. Pierre Bank and regions to the east. In this area temperatures generally range from 0^{o}-2^{o}C but are often <0^{o}C in many years. The other regime includes the deeper portions of the Laurentian and Hermitage Channels and areas to the west of St. Pierre Bank. This area appears to be influenced mostly by warmer slope water from the south. Consequently, this region experiences high variability with temperatures ranging from 3^{o}-6^{o}C. A change in the thermal habitat influenced by the Labrador Current took place during the mid-1980s with a significant increase in the area of the bottom covered with <0^{o}C water. Beginning in 1996 the area of <0^{o}C water on the banks decreased significantly, reaching very low values in 1998 and essentially disappearance during the warm years of 1999 and 2000 and again in 2004.

Spring bottom temperature maps together with the number of fish caught per set for Division 3P are shown in Fig. 9 for 1993 a cold year, 2000 a warm year and for 2003 and 2004. The most evident pattern in the number of cod caught per set (displayed as expanding symbols on the temperature fields) is the high number of sets with zero catches for the cold years of 1993 and 2003. This pattern persisted during most years from 1985 to 1998 when most of St. Pierre Bank and regions east of the Bank were covered by bottom water with temperatures <0^{o}C. During 1999 and 2000 larger catches became more wide spread over St. Pierre Bank and surrounding area as cold

(<0^{o}C) water disappeared from the area (Colbourne and Murphy 2002). During 2001 to 2003 however, cold water returned to the area and the number of fishing sets with zero catches also increased. During all surveys most of the larger catches occurred in the warmer (2^{o}-3^{o}C) waters along the slopes of the banks and in the deep channels to the west of St. Pierre Bank. In 2004 bottom temperatures were comparable to the warm conditions observed in 1999 and 2000 however there was no shift in the distribution of cod over St. Pierre Bank as observed previously during most warm years. In fact during 2004 there were many low or zero catches in the warm deeper waters off the banks compared to most years.

To investigate possible temperature preferences by cod in this region, cumulative distributions of temperature and catch weighted (in terms of numbers and weight) cumulative distribution of temperature for various periods are displayed in Fig. 10. The temperature distributions have been weighted annually by sampling intensity within each stratum and by strata area. The cumulative frequency distribution of temperature shows the temperature available to cod historically during the spring period in Division 3P. The cod number and weight temperature distributions show the distribution of catches in relation to the ambient temperature. The results indicate that on average (1972-2001) cod are associated with the warmer portion of the available temperature range with a slightly warmer preference based on weight than numbers. This may imply a greater degree of habitat selection by larger cod. Approximately 20% of the cod by number are associated with <0°C water, while approximately 50% are associated with water >3°C and up to 25% associated with temperatures >5^{o}C. The temperature distribution indicate that about 40% of the surveyed habitat is normally (1972-2001) covered by water with temperatures <0^{o}C. During the warm periods of 1974-1984 and 1998-2000 the distribution of catches nearly coincide with the distribution of available temperature, but during the cold period of 1985-1995, the distributions indicate that the fish may avoid the colder portions of the habitat. The distributions during the cold period of 2001 to 2003 are very similar to those of the previous cold period from 1985-1995 (Fig. 10). During 2004 one set in 0.7^{o}C bottom water contained 30% of the total number of fish caught on the survey and over 60% of the total weight and as a result the distributions were skewed towards colder temperatures.

Inter-annual variations in the spatially averaged bottom temperature of the surveyed area in Division 3P are plotted in Fig. 11 and 12 together with the RV estimates of abundance and biomass for the years 1983 to 2004. Apart from the general decrease in both abundance and bottom temperature from the mid-1980s to the early 1990s and for the most recent years, there is no significant correlation between bottom temperatures and the abundance and biomass of cod (Fig. 11). On the banks however, and in water depths <100 m, the average bottom temperature is significantly correlated with the RV abundance ($r=0.59$, $p<0.05$) and biomass ($r=0.63$, $p<0.05$) corresponding to strata with water depths <92 m (Fig. 12). In general, the cold bottom temperatures experienced during the winter and spring from the mid-1980s to the mid-1990s and during 2001 to 2003 correspond to low RV estimates of abundance and biomass.

The results presented suggest that cod tend to avoid the colder portions of the thermal habitat in this region and consequently change their spring distribution from one year to the next, depending on ocean climate conditions. This result is not without exception however (e.g. 1983, 1987 and 2004) and there may be other reasons for the observed changes in distribution. For example, the extreme variations in the catch rates on St. Pierre Bank, in particular, may be the result of a temperature dependent increase in catchability. It could also be related to other biological or environmental factors, such as increase in prey species or a shift to a more suitable environment for prey species. Variations in the catch rates in the warmer water of the most western regions of Subdivision 3Pn may be influenced by environmental conditions in the Gulf of St. Lawrence, either for cod or their prey, or both. Although the numbers of fish from the 1983-1995 surveys have been converted to equivalent Campelen trawl units there may be some residual effects remaining in the series, which may have contributed to some of the increase in the catches of smaller fish during 1996-2004. Variations in water temperature in the area, particularly on St. Pierre Bank and the eastern areas of 3P may also influence spawning success and possibly improved survival and growth rates of cod.

5. Summary

Time series of temperature anomalies from NAFO Division 3P (particularly on St. Pierre Bank) show anomalous cold periods in the mid-1970s and from the mid-1980s to late 1990s. These conditions were similar to those observed along the east coast of Newfoundland and Labrador, except the latter cold period lasted longer on St. Pierre Bank than it did on the eastern Newfoundland Shelf. During the most recent cold period, which started around 1985, temperatures were up to 1°C below average over all depths and up to 2°C below the warmer temperatures of the late 1970s and early 1980s in the surface layers. Temperatures in deeper water off the banks during all years show significant variations, but remained relatively warm with values in the 3°-6°C range, compared to much colder values (often <0°C) on St. Pierre Bank. Beginning around 1996 temperatures on St. Pierre Bank started to moderate, decreased again during the spring of 1997, but returned to normal values during 1998. During 1999 and 2000 temperatures continued to increase reaching the highest values since the late 1970s in the surface layers. During the spring of 2001 to 2003 however, temperatures cooled significantly over the previous two years to values observed during the mid-1980s by the spring of 2003. Temperatures during the spring of 2004 warmed considerably over 2003 values to 1°C above normal in the surface layers and by almost 0.5°C in the near-bottom depths over St. Pierre Bank.

The areal extent of bottom water with temperatures <0°C increased significantly from the mid-1980s to the mid-1990s. During 1998-2000 this area decreased to very low values but increased again in 2001-2003, returning to values observed during the mid-1990s and to the highest in about 13 years during 2003. During 2004 this area decreased to <10%, the lowest since 1988. The areal extent of bottom water with temperatures >3°C has remained relatively constant at about 50% of the 3P area during the past decade. On St. Pierre Bank bottom water with temperatures <0°C essentially disappeared during the warm years of 1999 and 2000. It appeared again however during 2001 to 2003 reaching about 90% of the area of the Bank in 2003. During the spring of 2004 it again disappeared with <0°C water restricted to the eastern most regions and the Placentia Bay area.

The analysis presented here show significant variations in the water mass characteristics particularly on St. Pierre Bank during the past several years. From the mid-1980s up to 1997, a cold near constant salinity water mass influenced most of the upper 100-m of the water column. A change to much warmer and saltier conditions occurred during 1998 and 1999 and to fresher but still warm conditions during 2000. During 2001 salinities increased to above normal values, while

temperatures generally decreased to below normal values as cold water returned to the region. Observations during the spring of 2003 indicate a continuation of the decreasing trend in temperatures that began in 2001. This trend however was reversed during the spring of 2004 when temperatures increased significantly over the previous year.

The dominant oceanographic signal potentially influencing cod habitat in this region is the volume of <0^{o}C water advected into the region from the eastern Newfoundland Shelf by the inshore branch of the Labrador Current. The spatial extent and temperature of this water mass that eventually makes its way onto St. Pierre Bank is governed by advection rates, vertical mixing by storms during the winter and spring and surface heat flux. The most evident trend in the numbers of cod caught per set is the high number of zero catches in the cold (<0^{o}C) waters on St. Pierre Bank and regions to the east f St. Pierre Bank mainly from 1985 to 1998 and from 2001 to 2003. During 1999 and 2000 larger catches became more wide spread over the St. Pierre Bank region as the cold (<0^{o}C) water disappeared from the area. In general, during most surveys large catches of cod occurred in the warmer waters (2^{o}-6^{o}C) along the slopes and areas to the west of St. Pierre Bank. In 2004 there was no observed shift in the distribution of cod over St. Pierre Bank and there were many low or zero catches in the warm deeper waters off the banks compared to most years. In general however, variations in the estimated abundance and biomass of cod in strata with water depths <92 m are significantly correlated with bottom temperatures for that depth range. However, there is no significant correlation between bottom temperatures and the abundance of cod for strata with water depths >100 m. Nevertheless, it appears that cod tend to avoid the colder portions of the thermal habitat in most years and consequently change their spring distribution from one year to the next, depending on ocean climate conditions.

Acknowledgements

We thank C. Fitzpatrick, D. Senciall, J. Craig, W. Bailey and P. Stead of the oceanography section at NAFC for data processing and computer software support. We also thank the many scientists and technicians at NAFC for collecting and providing the oceanographic data from the multi-species surveys in NAFO Division 3P and the Marine Environmental Data Service in Ottawa for providing the historical data.

References

Battaglia A. and J. C. Poulard. 1987. Year to year variations in water temperature in NAFO Subdivision 3Ps. NAFO SCR Doc. 87/26, Serial No., N1310, 16p.

Brattey, J., N. G. Cadigan, B. P. Healey, G. R. Lilly, E. F. Murphy, P. A. Shelton, D. E. Stansbury and J.-C. Mahé. An assessment of the cod (*Gadus morhua*) stock in NAFO Subdiv. 3Ps in October 2002. DFO CSAS RES DOC. 2002/96. 102 p.

Colbourne, E. B. and E. F. Murphy. 2002. Recent trends in bottom temperatures and distribution and abundance of cod (*Gadus morhua*) in NAFO Subdivisions 3Pn and 3Ps from the winter/spring multi-species surveys. DFO CSAS RES DOC. 2002/001. 18p

Colbourne, E. 1994. Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps, with Comparisons to the long-term average. DFO Atlantic Fisheries Research Document 94/26.

Colbourne, E. B. 1996. Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 1995 and 1996 with comparisons to the long-term (1961-1990) average. DFO RES DOC. 96/94 14p.

Colbourne, E. B. 1999. Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 1997 and 1998 with comparisons to the long-term (1961-1990) average. DFO RES DOC. No. 39 18p.

Colbourne, E. B. 2000. Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 1999 with comparisons to the long-term (1961-1990) average. DFO RES DOC. 2000/049 20p.

Colbourne, E. B. 2001. Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 2000 with comparisons to the long-term (1961-1990) Average. DFO RES DOC. No. 5 18p.

Colbourne, E. B. 2002. Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 2001 with comparisons to the long-term (1971-2000) average. DFO RES DOC. 2002/024 19p.

Colbourne, E. B. 2003. Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 2002 with comparisons to the long-term (1971-2000) average. DFO CSAS RES DOC. 2003/001 17p.

Colbourne, E. B., S. Narayanan and S. Prinsenberg. 1994. Climate change and environmental conditions in the Northwest Atlantic during the period 1970-1993. ICES mar. Sci. Symp., 198:311-322.

Drinkwater, K. F. 1996. Atmospheric and oceanic variability in the northwest Atlantic during the 1980s and early 1990s. J. Northw. Atl. Fish. Sci. 18: 77-97.

Forest, A. and J. C. Poulard. 1981. Water temperature distributions on NAFO Subdivision 3Ps in autumn 1980 and late winter 1981. NAFO SCR Doc. 81/VI/45, Serial No., N327, 9p.

Hutchings, J. A. and R. A. Myers. The timing of cod reproduction: Interannual variability and the influence of temperature. 1994, Mar. Ecol. Prog. Ser. 108: 21-31.

Moguedet Ph. and J. C. Mahe. 1991. Yearly variations in water temperature in NAFO Subdivision 3Ps from 1978 to 1990. NAFO SCR Doc. 91/24, Serial No., N1904, 9p.

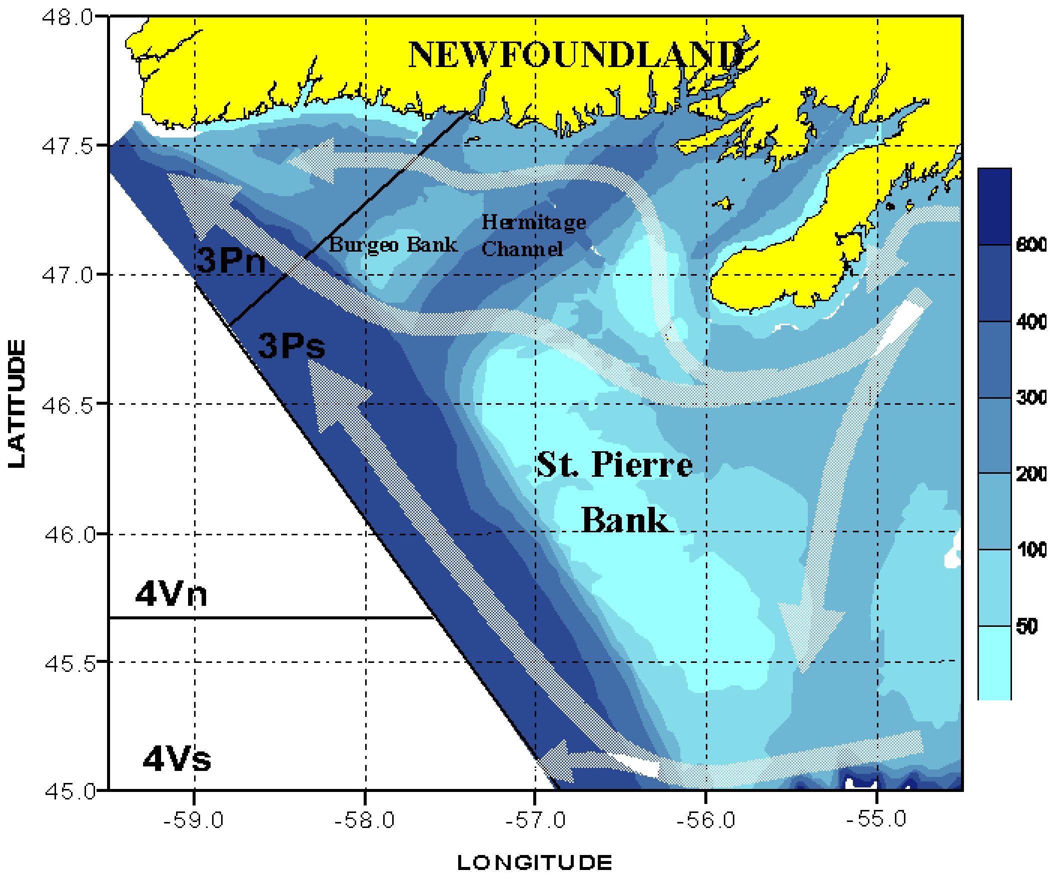


Fig. 1a. Location map showing the bathymetric features (in metres) and the general ocean circulation in NAFO Division 3P.

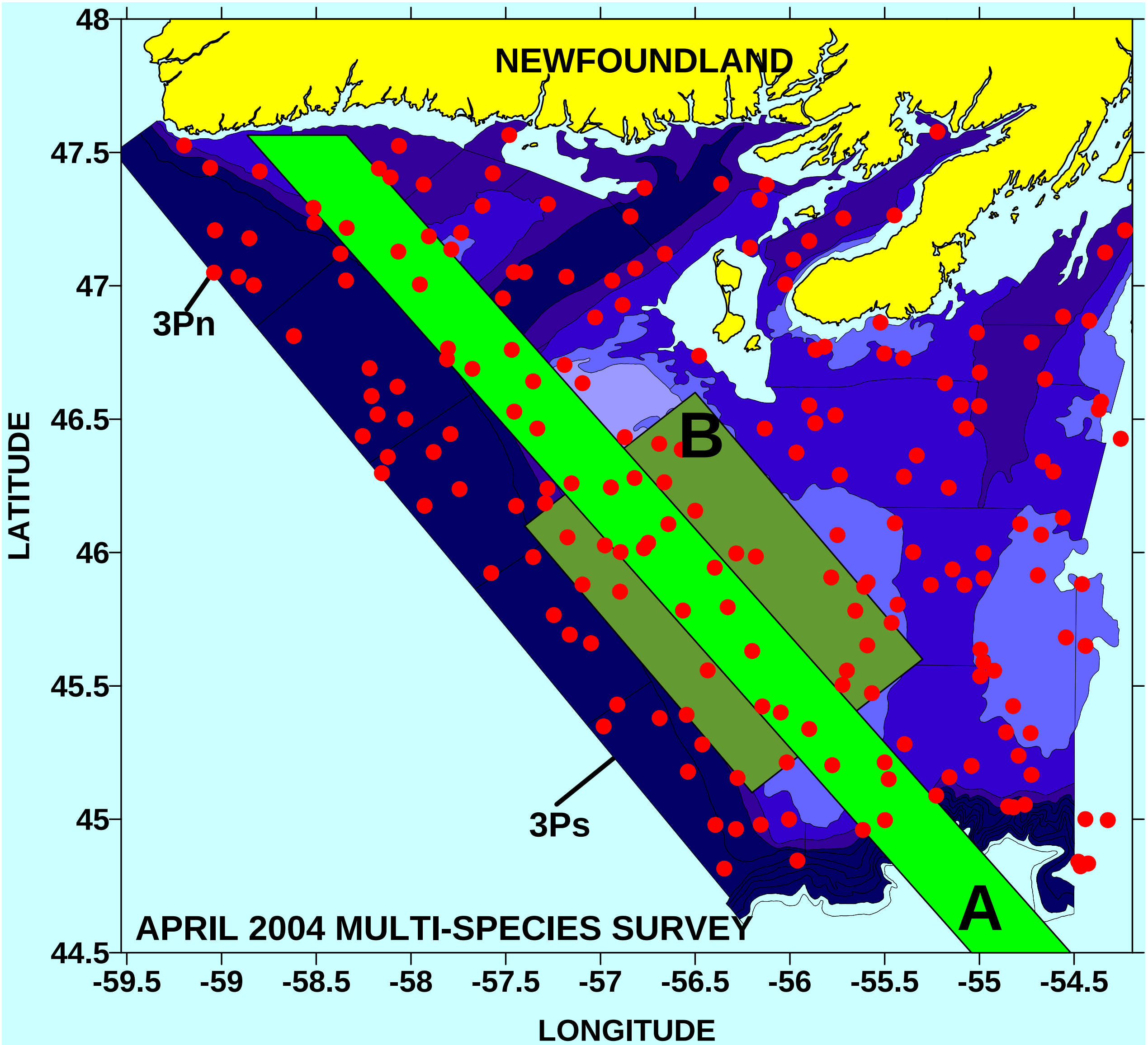


Fig. 1b. Location map showing NAFO Subdivisions 3Pn and 3Ps and the areas A and B from which cross-sections and time series of temperature and salinity were constructed. The set positions where oceanographic measurements were available for the 2004 spring multi-species survey are also shown as well as the strata boundaries.

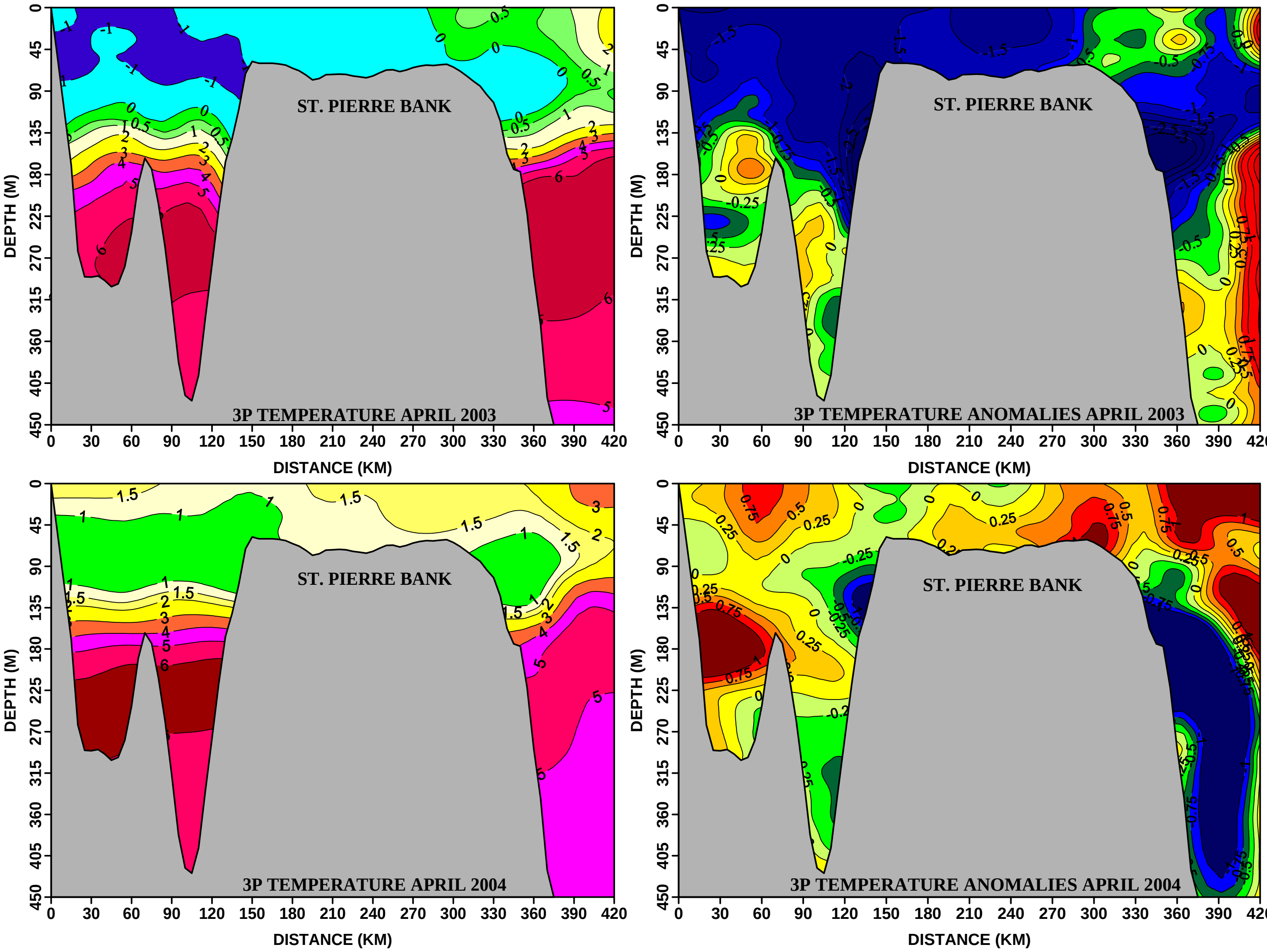


Fig. 2. The April 2003 and 2004 temperature and anomalies (in °C) along the section constructed from the data in Box A of Fig. 1b for NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1971-2000 average.

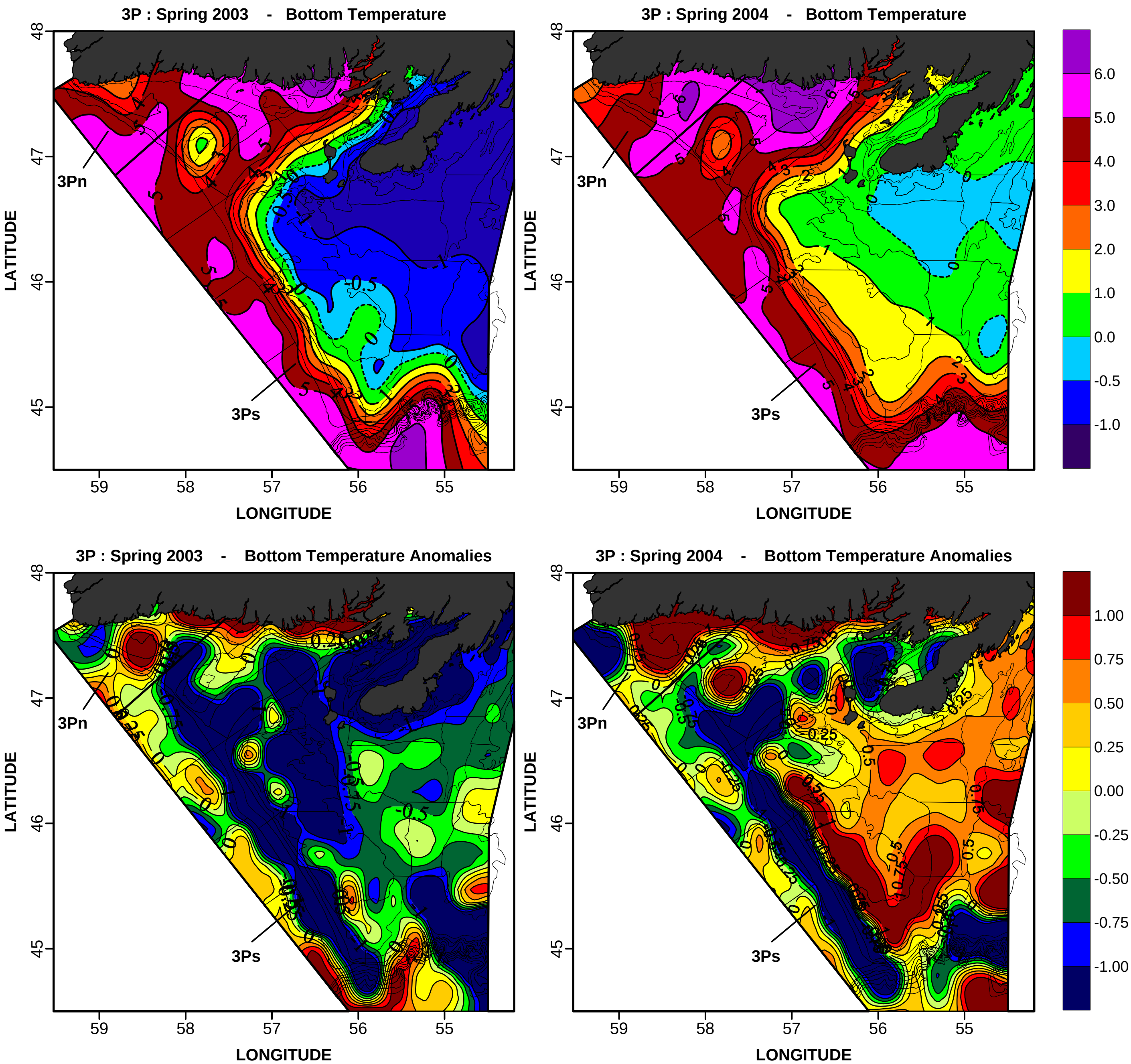
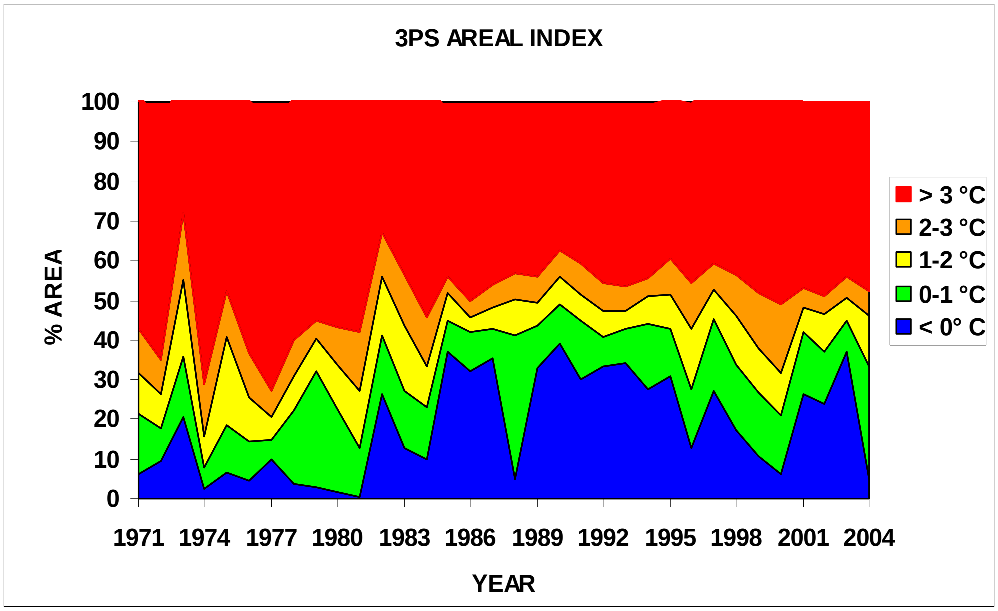


Fig. 3. The April 2003 and 2004 bottom temperature and anomalies (in °C) in NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1971-2000 average.



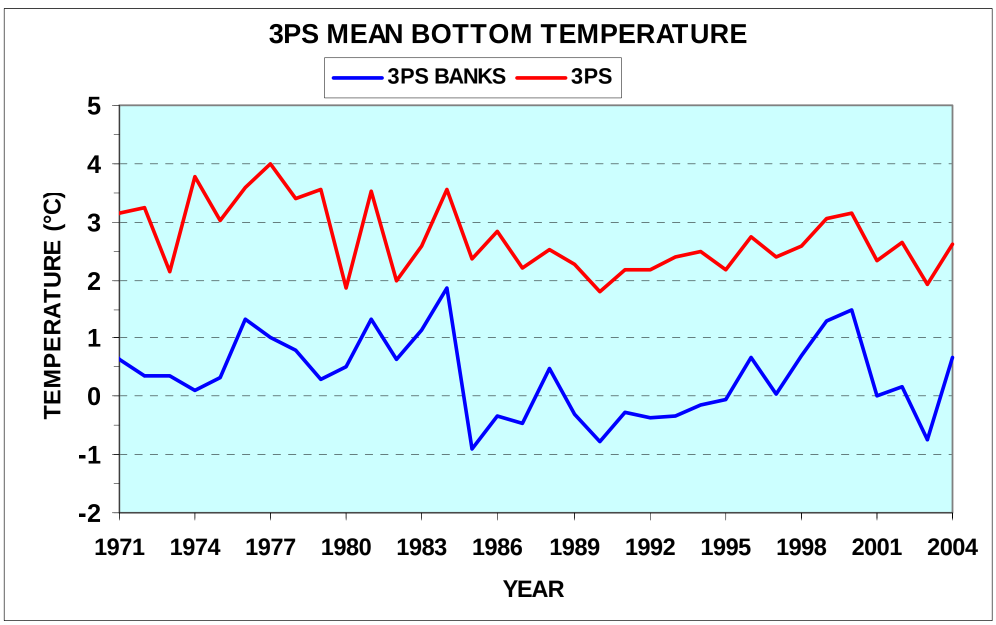
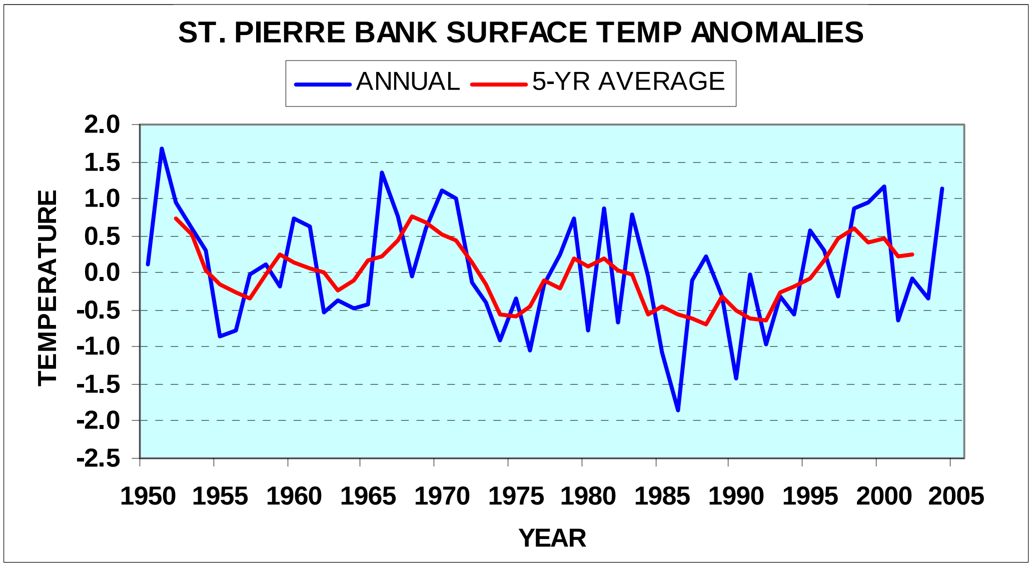


Fig.4. Time series of the percentage area of the bottom in NAFO Division 3P during the winter/spring covered by water with temperatures ≤0°C, 0°-1°C, 1°-2°C 2°-3°C and ≥3°C (top panel) and the mean bottom temperature (in °C) for all strata and for strata with water depths <100 m (bottom panel).



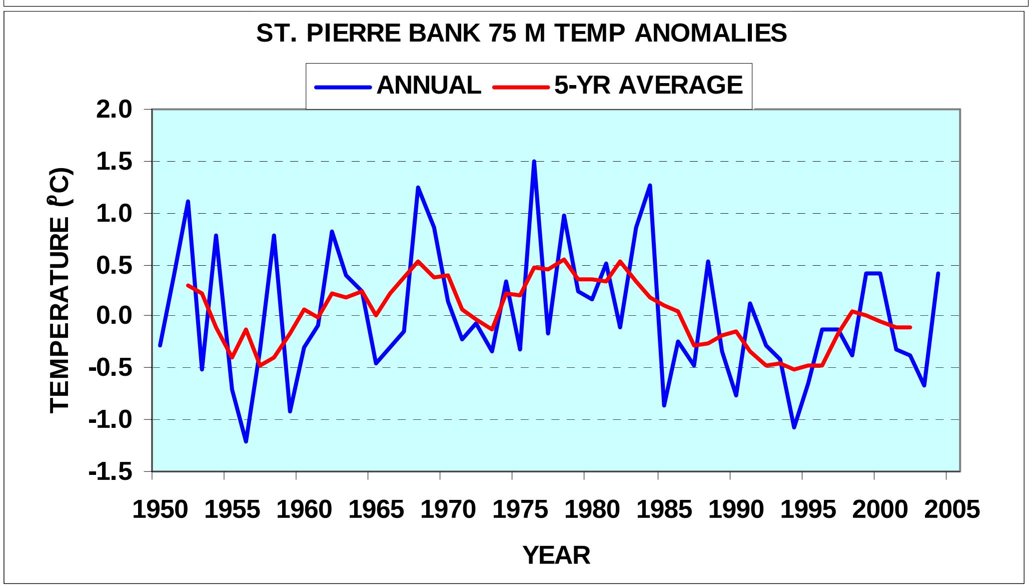


Fig. 5. Annual temperature anomaly time series (in °C) for the near-surface (5 m) and near-bottom (75 m) constructed from all historical data in Box B of Fig. 1b. The heavy solid line represents the 5-year running mean.

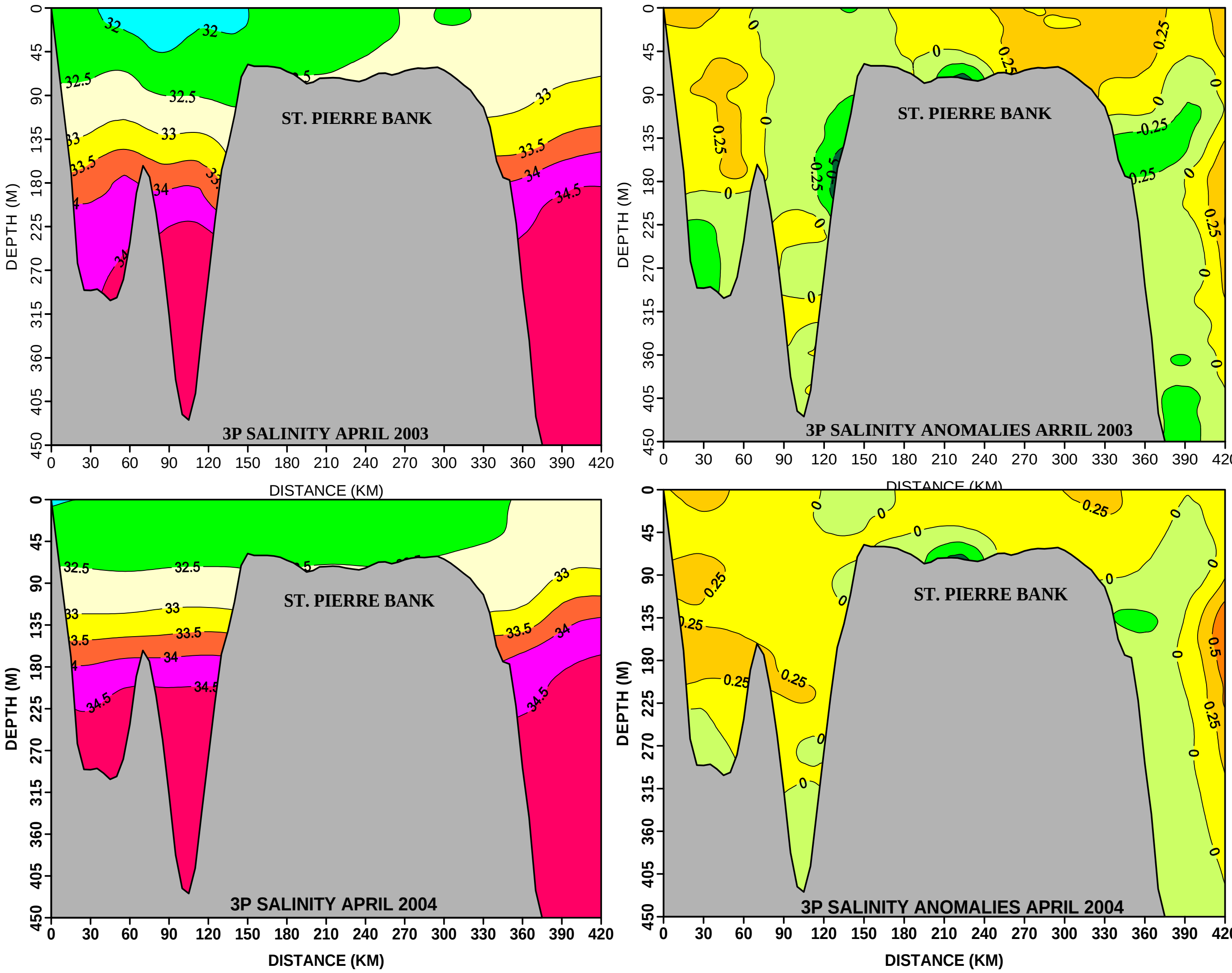


Fig. 6. The April 2003 and 2004 salinity and salinity anomalies along the section constructed from the data in Box A of Fig. 1b for NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1925 to 2000 average.

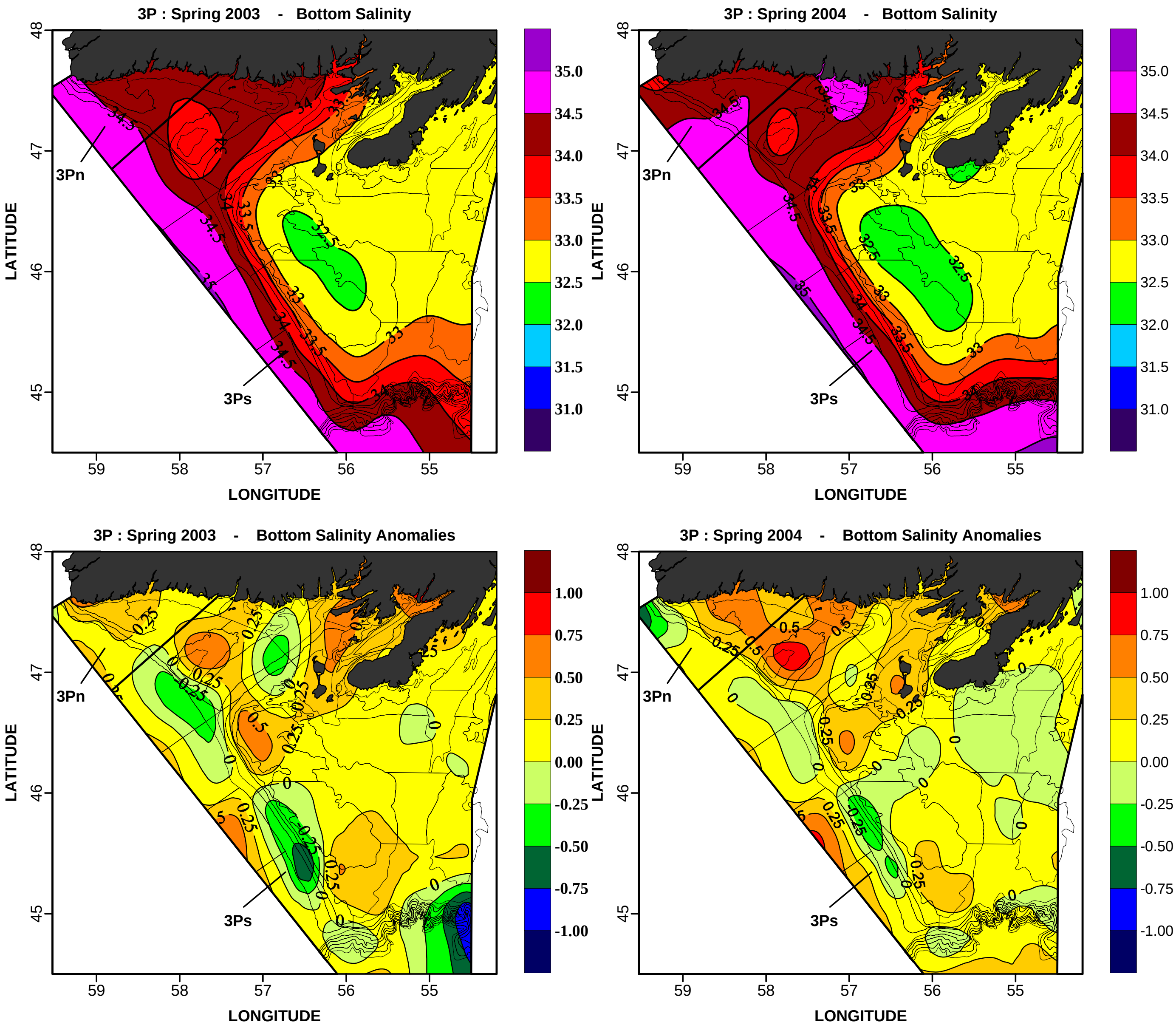


Fig. 7. The April 2003 and 2004 bottom salinity and salinity anomalies in NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the winter/spring 1925-2000 average.

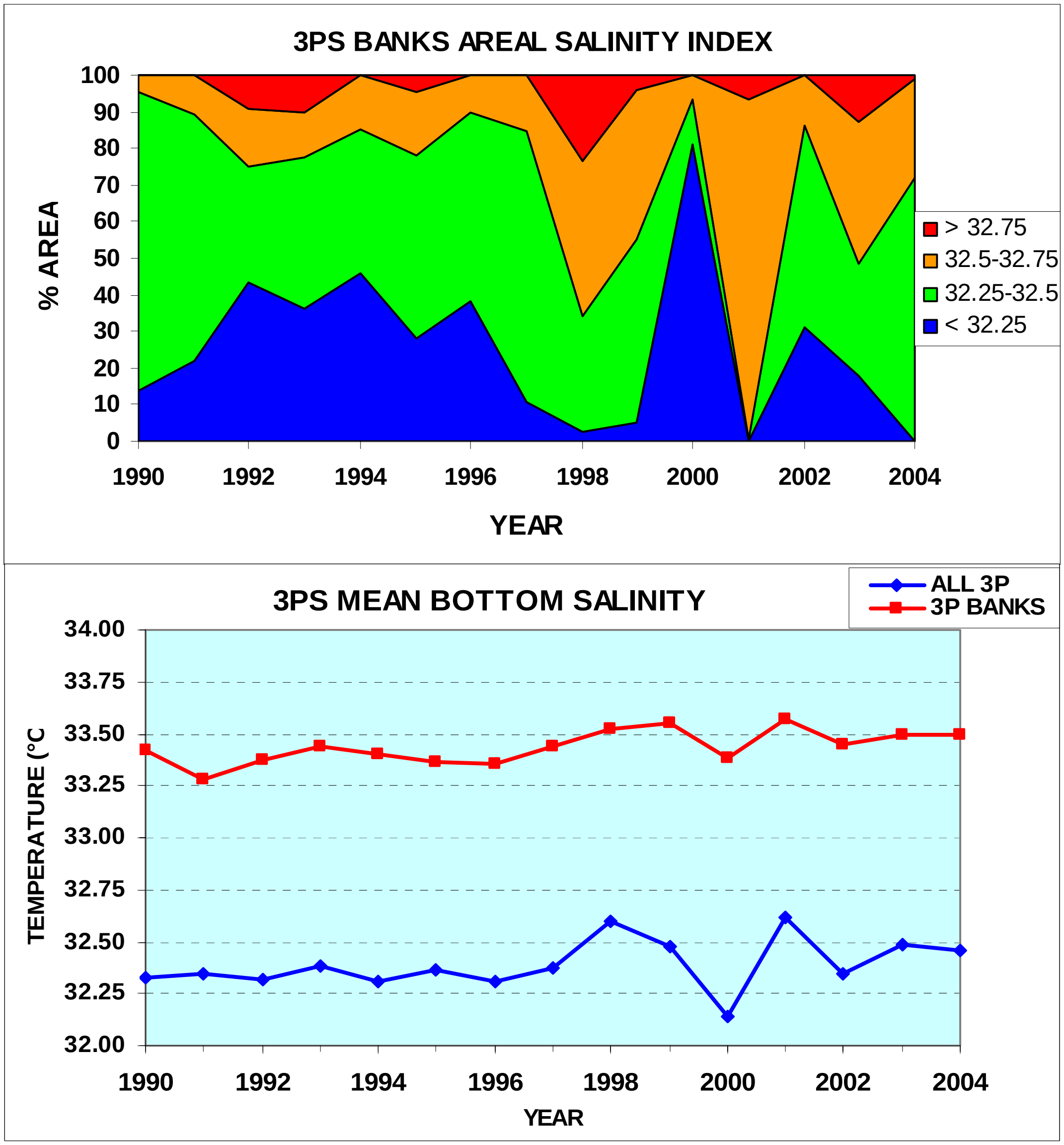


Fig.8. Time series of the percentage area of the bottom in NAFO Division 3P during the winter/spring covered by water in various salinity ranges (top panel) and the mean bottom salinity for all strata and for strata with water depths <100 m (bottom panel).

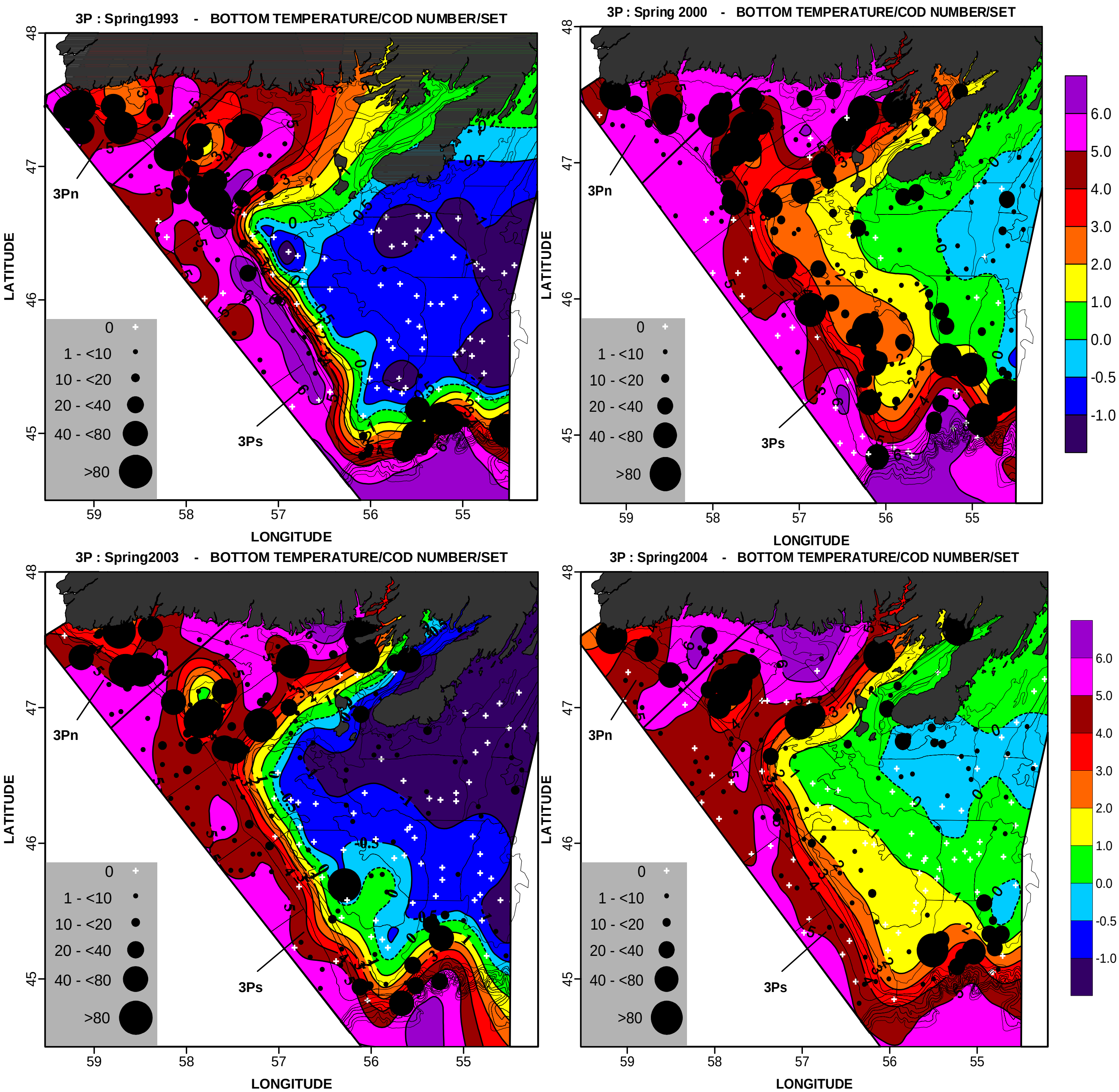


Fig. 9. Bottom temperature contour maps (in °C) for 1993, 2000, 2003 and 2004 based on data collected during the spring multi-species survey of division 3P. The numbers of cod in each fishing set are shown as solid expanding circles. The white crosses represent zero catches.

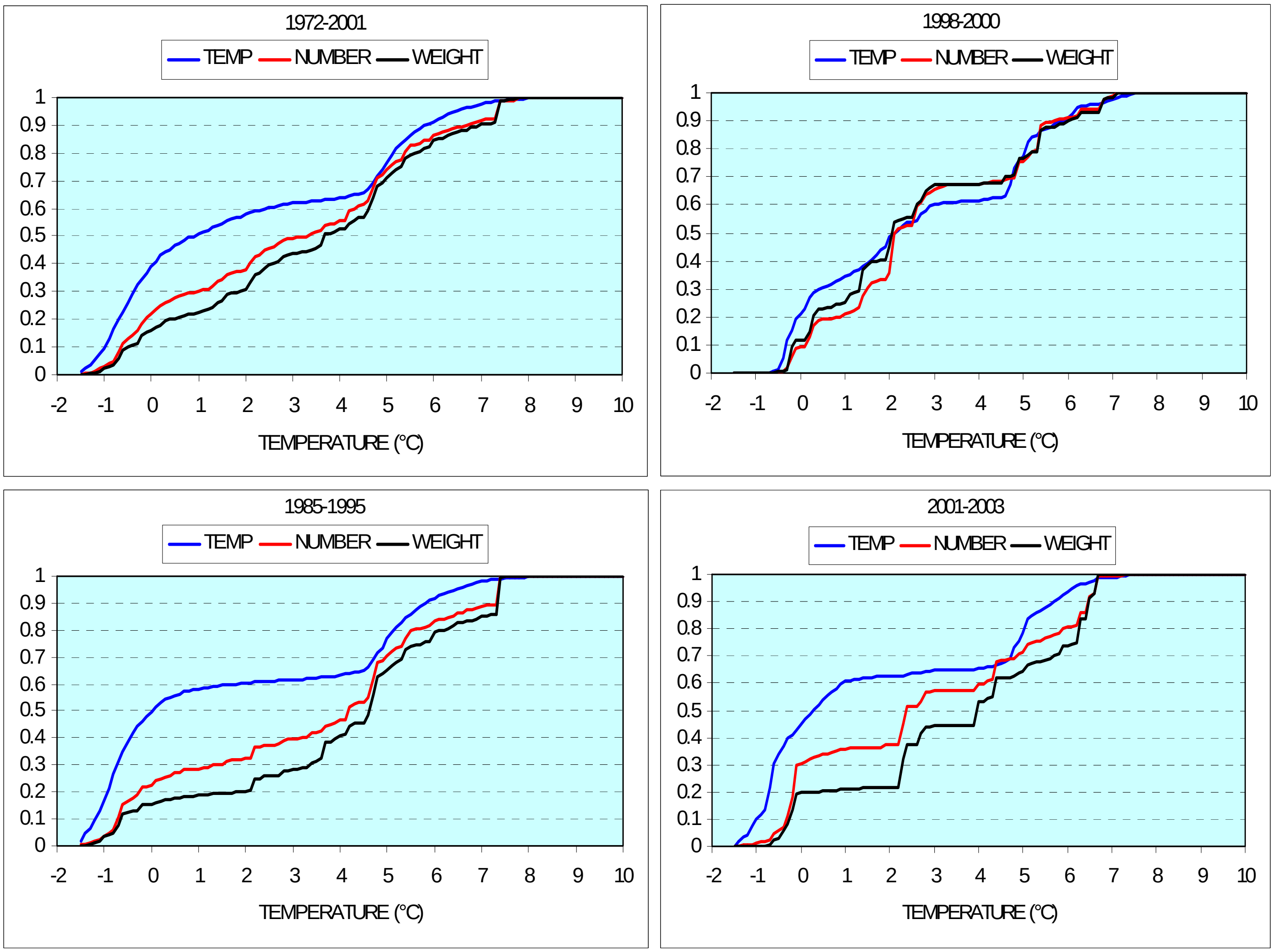


Fig. 10 The stratified cumulative frequency distribution of temperature available to cod and the cod number and catch weighted temperature distributions in NAFO Division 3P for 1971-2001, 1985-1995 a cold period, 1998-2000 a warm period and for 2001-2003.

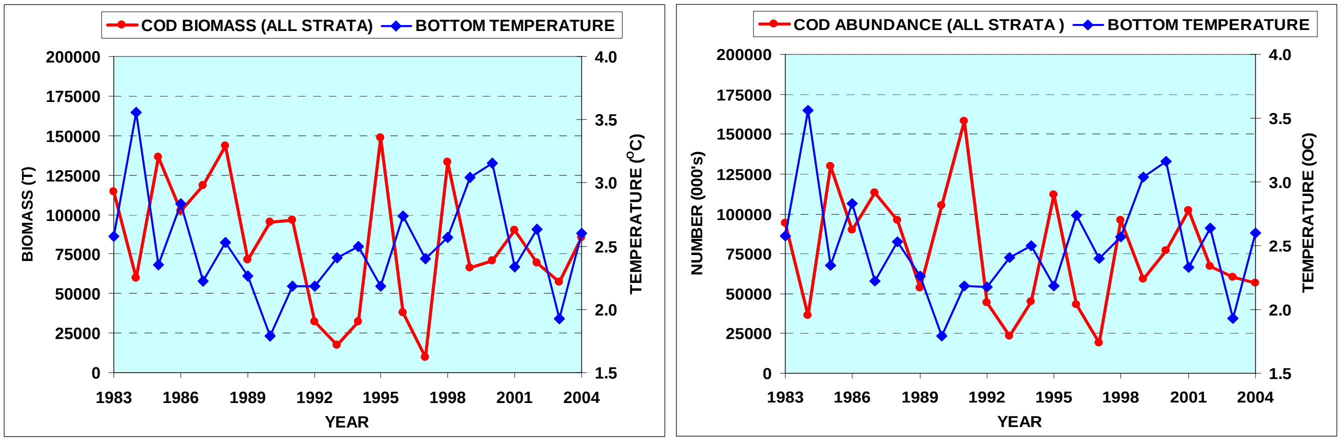


Fig. 11. Time series of the mean bottom temperature and the RV abundance and biomass of Atlantic cod for the surveyed area in NAFO Division 3P.

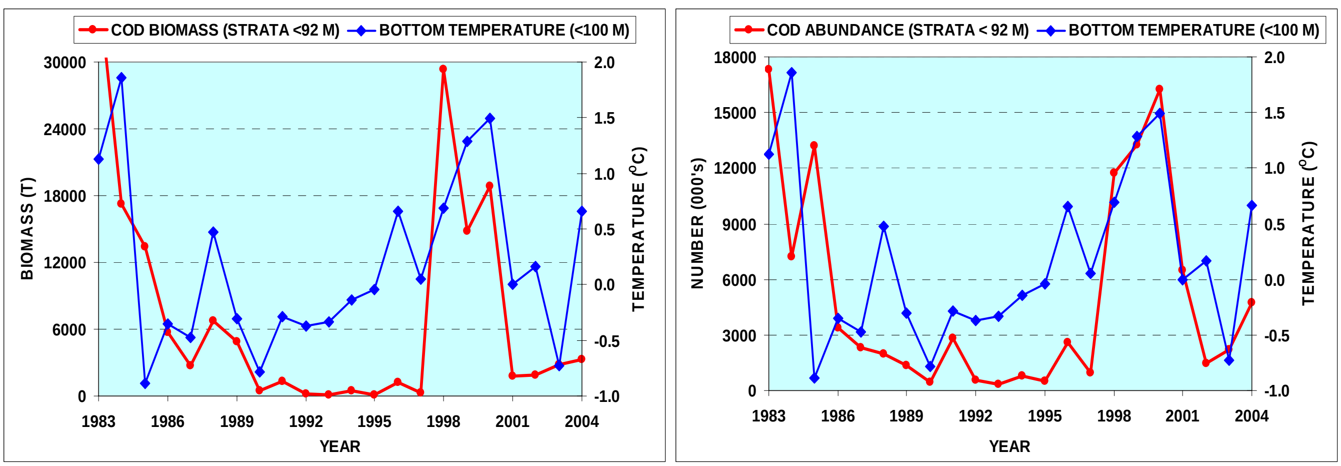


Fig. 12. Time series of the mean bottom temperature for water depths <100 m and the RV abundance and biomass of Atlantic cod for the surveyed area in NAFO Division 3P for strata with water depths <92 m.