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Biological and Chemical Oceanographic conditions on the Newfoundland and Labrador Shelf during 2004

Conditions océanographiques, biologiques et chimiques sur le plateau de Terre-Neuve en 2004

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ABSTRACT

We review the information concerning the seasonal and inter-annual variations in the concentrations of chlorophyll a, major nutrients, as well as the abundance of major taxa of phytoplankton and zooplankton measured from Station 27 and along standard transects of the Atlantic Zone Monitoring Program (AZMP) in 2004. The timing of the spring bloom was earlier than in 2003, reversing a trend of increasing delay in the onset of the bloom that had started in 2000, at least over the central portion of the Newfoundland and Labrador Shelf. Deep nutrient inventories at Station 27 remained below the 2000-01 levels but showed signs of increased variability toward the end of 2004. Surface nutrient inventories were higher than in 2003, possibly due to a less intense spring phytoplankton bloom brought on by a deeper winter mixed layer and an abrupt stratification in the spring. The abundance of the dominant zooplankton taxa at Station 27 and on the Grand Banks reached the lowest levels encountered since the inception of the AZMP. In contrast, zooplankton abundance levels along the Bonavista and Seal Island transects were generally close to the maximum levels encountered. The signal was strongest for *Calanus finmarchicus, C. glacialis* and *C. hyperboreus*, the three species which make up the bulk of the zooplankton biomass in the region. Although other species did show similar trends, these were generally not statistically significant.

RÉSUMÉ

Nous faisons un bilan des variations saisonnières et interannuelles dans les concentrations de chlorophylle *a* et des principaux éléments nutritifs, ainsi que dans l'abondance des principaux taxons de phytoplancton et de zooplancton, mesurés à la station 27 et le long de transects du Programme de monitorage de la zone atlantique (PMZA) en 2004. La prolifération planctonique de printemps s'est produite plus tôt qu'en 2003, renversant la tendance d'un retard à la hausse du début de la prolifération, amorcée en 2000, au moins dans la partie centrale du plateau de Terre-Neuve. Les concentrations d'éléments nutritifs en profondeur à la station 27 se situaient encore au-dessous des niveaux de 2000-2001, mais ont montré des signes de variabilité accrue vers la fin de 2004, alors que les concentrations dans la couche de surface étaient plus élevées qu'en 2003, peut-être à cause d'une prolifération phytoplanctonique de printemps moins intense résultant d'une couche mélangée plus profonde en hiver et d'une stratification abrupte au printemps. Les taxons dominants de zooplancton à la station 27 et sur les Grands Bancs ont connu leurs plus faibles niveaux d'abondance depuis le lancement du PMZA. Par contre, l'abondance du zooplancton le long des transects de la baie de Bonavista et de l'île Seal se rapprochait généralement des niveaux maximums rencontrés. Le signal était le plus fort dans le cas de *Calanus finmarchicus, C. glacialis* et *C. hyperboreus*, les trois espèces qui constituent la majorité de la biomasse zooplanctonique dans la région. Quoique d'autres espèces montraient des tendances semblables, elles n'étaient pas statistiquement significatives.

Introduction

The Altantic Zone Monitoring Program (AZMP) was implemented in 1998 with the aim of increasing DFO's capacity to understand, describe, and forecast the state of the marine ecosystem and to quantify the changes in the ocean physical, chemical and biological properties. A critical element of the AZMP involves an observation program aimed at assessing the variability in nutrients, phytoplankton and zooplankton.

The AZMP derives its information on the state of the marine ecosystem from data collected at a network of sampling locations (fixed point stations, cross-shelf sections, and groundfish surveys) in each region (Quebec, Gulf, Maritimes, Newfoundland) sampled at a frequency of bi-weekly to once annually.

A description of the seasonal patterns in the distribution of phytoplankton (microscopic plants) and zooplankton (microscopic animals) provides important information about organisms that form the base of the marine foodweb. An understanding of the production cycles of plankton, and their interannual variability, is an essential part of an ecosystem approach to fisheries management.

Methods

We review optical, chemical, selected physical indices, and biological oceanographic conditions on the Newfoundland and Labrador Shelf during 2004. More frequent directed sampling from research vessels and Ships of Opportunity at Station 27 and the completion of three surveys on the Newfoundland Shelf during 2004 provided reasonable spatial and temporal series coverage of standard variables which provides a foundation for comparison with previous years. Collections and standard variables are based on sampling protocols outlined by the Steering Committee of the Atlantic Zonal Monitoring Program (AZMP) (Mitchell et al. 2002). A number of non-standard AZMP variables are also presented for additional information. Protocols for additional measures are described in Pepin and Maillet (2001). Observations presented in this document are based on surveys listed in Table 1 and Figure 1.

Analysis

Annual estimates of mean abundance of most zooplankton species at both the fixed site and as an overall average along each of the four standard transects were based on general linear models (GLMs) of the form

$$Ln(Density) = \alpha + \beta_{YEAR} + \delta_{MONTH} + \varepsilon$$

for the fixed station, where *Density* is in unit of m^{-2}, α is the intercept, β and δ are categorical effects for year and month effects, and ε is the error, and

$$Ln(Density) = \alpha + \beta_{YEAR} + \delta_{STATION} + \varepsilon$$

for each of the transects, where δ takes into account the effect of station location. Density is log-transformed to deal with the skewed distribution of the observations.

Fixed Station – Seasonal and inter-annual variability in water column optics and solar radiation

The availability of light for photosynthesis in an aquatic ecosystem is determined by the penetration of the light (Kirk 1994), expressed asthe vertical attenuation coefficient (K_d), which is determined by dissolved and coloured substances and particulate matter in seawater. The vertical attenuation coefficient (K_d) was estimated by:

K_d_chla (m^{-1}) = 0.027m^{-1} + 0.015 m^{-1} + B(z) * 0.04 m^{-1} (Platt *et al.* 1988)

where B(z) is the concentration of chlorophyll *a* in mg m^{-3} (substitute calibrated chlorophyll a from *in-situ* chlorophyll *a* fluorescence when discrete measures were not available) at depth (z) in meters. The additional coefficients in the above equation are related to the components of pure seawater and dissolved substances. The average value of K_d was calculated for the upper water column (5-50m depth). Values of attenuation estimated from *in-situ* downward photosynthetic active radiation (PAR) in the upper 50m compared well with vertical attenuation coefficient determined from the Platt *et al.* 1988 model (data not shown). The time series of K_d at Station 27 in 2004 was consistent with the earlier observations, but was reduced compared to the conditions noted during the spring bloom in 2002 (Figure 2). Attenuance increased rapidly in response to the onset of the spring bloom from initial background levels of ca. 0.1 m^{-1}. The trend in the series shows an increasing K_d during the production cycle (April-September), being related principally to the timing of the spring bloom. The trend in attenuance indicated higher extinction of light (by factor of 2) in the water column in 2002 in comparison to 2004 and earlier years. Periodically, small changes in K_d were observed outside the main production period throughout the time series. Measures of K_d provide estimates of the euphotic depth (depth of the 1 % light level) based on:

Euphotic depth (m) = 4.6 / K_d_PAR

The euphotic depth defines the boundary above which net photosynthesis can occur, and is often used to determine the depth range for integrated primary production estimates. Time series of euphotic depth varied seasonally at Station 27 with minima observed during the spring bloom while deeper values occurred during post-bloom periods (Figure 2). In general, seasonal patterns and magnitudes of optical properties in 2004 at Station 27 were similar to those observed in previous years.

Knowledge of the flux of radiant energy is essential to interpret variability in the water column light field and primary productivity. Time series of incident downward PAR (photosynthetic active radiation) irradiance collected at a ground station in St. John's, Newfoundland (47.52^{o} N, –52.78^{o} W) provide near-continuous measures to supplement limited *in-situ* PAR observations collected during sample occupations at Station 27 (Figure 2). Measurements were initiated in July 2001 with the use of a Li-Cor datalogger (LI-1400) and quantum PAR irradiance sensor (LI-190SA) attached to the roof at the Northwest Atlantic Fisheries Centre in St. John's, NL. Monthly mean incident PAR irradiance levels show a strong seasonal component and high variability throughout the annual cycle. The average monthly values of incident PAR, total PAR and total daily insolation (accounting for differences in day length) indicated that December had the lowest average total daily PAR at 5.14 moles m^{-2} and highest in May at 40.02 mol m^{-2} in 2004 (Table 2).

Given the optical, chemical, and biological time series at Station 27 is limited in duration, we evaluated the seasonal change in these measures by computing seasonal averages and percent change from the current year versus the combined average for earlier years (2000-2003). The mean percent seasonal change in 2004 showed higher levels of attenuance during winter and slightly lower during spring and summer leading to reciprocal changes in the depth of active photosynthesis (Figure 3). Lower levels of solar radiation were observed in 2004 relative to recent years (2000-03). This negative trend was evident throughout the year with the greatest change observed during the winter-spring period (Figure 3).

Fixed Station – Seasonal and inter-annual variability in water column structure

Time series of physical measures estimated at Station 27 in 2004 included the stratification index (SI; difference in sigma-t values between 50m and 5m divided by 45m; see Craig *et al*. 2001, Craig and Colbourne 2002), mixed layer depth (MLD; depth centre of the pycnocline), and integrated temperature (IT; 0-50m integral) (Figure 4). Seasonal development of the SI was more limited in time compared to the earlier time series but, peak levels (~ 0.6 kg m^{-4}) were consistent with previous years. Seasonal development of a deep winter MLD in winter and a late shoaling in the spring of 2004 indicated stronger water column mixing in 2004 compared to 2003 and 2000 but comparable to 2001-02 (Figure 4).

The magnitude and timing of the maximum in the IT time series indicated consistent trends throughout 2000-04, in contrast, to the winter minima which has increased systematically during this period (Figure 4). The significant warming evident in the upper water column early in the seasonal cycle at Station 27 continues the overall trend observed for the NW Atlantic region (Colbourne et al. 2004).

Seasonal variations in the SI, MLD, and IT were apparent at Station 27 compared to earlier years (Figure 5). The percent change in the SI in 2004 varied seasonally with negative anomalies during autumn and winter while positive anomalies were evident for the spring and summer. Overall, the MLD was greater in 2004 compared to previous years, with the exception of the summer. The percent change in the IT time series was very significant in the first half of 2004 with > 400 % increase compared to previous years. Despite this very large positive increase observed during the winter and spring in 2004, thermal conditions during the latter part of the year were comparable to previous years. As well, the change in the IT time series did not appear to influence stratification, as might be expected.

Fixed Station - Seasonal Variability in Phytoplankton, Nutrients, and Productivity

Vertical profiles of chlorophyll *a* at Station 27 continue to vary in terms of the timing and magnitude of the spring bloom. The initiation of the bloom in 2004 began with subsurface chlorophyll *a* concentrations in the upper photic zone increasing to > 1.0 mg m^{-3} from background concentrations of < 1.0 mg m^{-3} in late March (Figure 6). We use the criteria of integrated chlorophyll *a* levels ~ 100 mg m^{-2} in upper 100m to define start and end times of the phytoplankton bloom. The initiation of the spring bloom was detected on 25 March (122.8 mg m^{-2}), peaked at a biomass concentration of 362.0 mg m^{-2} on 17 April, and maintained levels until 10 May (97.5 mg m^{-2}) for a duration of 47 days based on discrete chlorophyll *a* concentrations and *in-situ* chlorophyll *a* fluorescence observations. The bloom duration was nearly identical compared to observations in 2002-03, but differed substantially from 2000 conditions with an earlier bloom and 2-fold increase in duration (Pepin and Maillet 2002). Subsequent to the initiation of the bloom, a deep chlorophyll *a* maxima occurred in early May, presumably senescent diatom cells sinking rapidly to the bottom. Surface chlorophyll *a* distributions across the NW Atlantic detected from SeaWiFS remote sensing data confirmed the approximate timing and duration of the spring bloom in the Avalon Channel region[1]. There was no evidence of accumulations of phytoplankton biomass beyond the spring bloom in 2004, i.e. no autumn bloom, a pattern consistent with observations during earlier years. The chlorophyll *a* anomaly for 2004 indicated a weaker bloom compared to 1993-03 average (Figure 6).

Time series measures of integrated chlorophyll reiterated the importance of spring bloom periods in the seasonal dynamics of phytoplankton abundance at Station 27 (Figure 7). Integration of chlorophyll *a* at the shallow depth strata (0-50m) captured the main trends, but revealed significant amounts of phytoplankton biomass that occur in deeper strata (> 50m), particularly during the spring blooms of earlier years. The magnitude of phytoplankton biomass in 2004, inferred from integrated chlorophyll *a*, was comparable to previous years, except for somewhat higher

[1] http://www.mar.dfo-mpo.gc.ca/science/ocean/ias/seawifs/seawifs_3.html

values observed in 2002 (Figure 7). The time series of integrated *in-situ* (calibrated) chlorophyll *a* fluorescence provided greater depth resolution sampling to describe the dynamics of phytoplankton biomass when discrete sampling was not conducted but gave good agreement when both sources of information were available.

Distributions of the inorganic nutrients (nitrate, silicate, and phosphate) included in the observational program of the AZMP strongly co-vary in time and space (Petrie et al. 1999). For that reason and because the availability of nitrogen is hypothesized to be limiting to the growth of phytoplankton in the NW Atlantic, more emphasis in this report will be placed on variability in nitrate concentrations.

The vertical structure of nitrate (combined nitrate and nitrite, henceforth referred to as nitrate) shows dynamic seasonal changes in the water column at Station 27. Concentrations of nitrate were typically > 2 mmol m^{-3} throughout the water column and approached maxima of 8 mmol m^{-3} near the bottom prior to the spring bloom (Figure 8). Subsequently, concentrations of nitrate were depleted rapidly to values < 0.5 mmol m^{-3} down to 100m, which is somewhat deeper than previously observed at Station 27. Nitrate concentrations remained very low (< 1-2 mmol m^{-3}) throughout the year in the upper water column until very late in the year when nutrient replenishment was observed. Deep water concentrations of nitrate shoaled during August-September, coincident with the annual minima in water column salinity from ice-melt further north. We estimated the seasonal values based on earlier data for nitrate during the 1993-03 period, and computed the respective anomalies for 2004 and for earlier years back to 2000 for comparison. Typically, nitrate anomalies are near zero over much of the water column but, the largest changes tend to be associated with the spring bloom (Figure 8). In 2004, positive anomalies were evident during autumn over much of the water column.

Time series of nutrient inventories at Station 27 showed differences between years (Figure 9). Silicate and nitrate inventories in the upper 50m showed expected seasonal trends with winter and fall maxima, rapid depletion during the spring bloom, and occasional periodic intrusions during the late summer – early autumn (Figure 9). Sources of these periodic nutrient intrusions may be related to shoaling of deep pools below the mixed layer, wind-induced mixing from passage of storms, and advective transport from the inshore branch of the Labrador Current. Both nutrient inventories showed coherence throughout much of the time series. Nutrient inventories in the deep layer for silicate and nitrate in the early part of 2004 continue to show lower values consistent with 2001-03 levels, down by ~10-40% from concentrations observed during 2000 (Figure 9). We also noted that in 2004 silicate concentrations are slightly elevated compared to nitrate, while in deep water, nitrate levels tend to be slightly greater than silicate. The cause for the continued low levels in deep inventories of these major limiting nutrient inventories remains unknown, but may be linked to changes in productivity, water column structure, and influence of volume transport of the inshore branch of the Labrador Current.

The mean percent change in phytoplankton biomass and nutrient inventories were variable throughout 2004 (Figure 10). Comparatively lower phytoplankton biomass was observed during the production cycle in 2004. Higher (>50 %) inventories of silicate and nitrate characterized the spring in the upper water column but, lower levels were evident for both nutrients for the deep strata throughout the year (Figure 10).

In 2004, the phytoplankton collection protocol was changed to collection of discrete samples at 10m depth to limit difficulties of very low cell counts of the major taxa with the earlier protocol using an integrated sample from 5 to 100m. Therefore, change in the collection protocol should be taken into account when comparing densities of the major phytoplankton taxa over the available time series. The cell densities of major taxonomic groups consisting of dinoflagellates and flagellates continued to decline in 2004, consistent with the overall trend observed in previous years, while diatom cell densities reached relatively high levels during the spring bloom (Figure 11). Diatoms reached peak cell densities of > $5x10^5$ cells L^{-1} during the spring bloom in 2004, contributing significantly to the total phytoplankton community at that time, but remained at low densities during the remainder of the year. The concentration of dinoflagellates were typically lower by an order of magnitude compared to diatoms, but continued to remain at low densities as in the previous year (Figure 11). The flagellates were the dominant group numerically reaching peak concentrations near $2x10^5$ cells L^{-1} during the latter part of the time series, but their abundance has also continued too decline along with the other major groups in recent years (Figure 11). The high concentrations of flagellates observed throughout the year in 2000 have not occurred in the latter part of the time series. With the exception of the spring bloom sampling period, flagellates made up typically > 80 % of the total phytoplankton community. Although flagellates dominated the phytoplankton community by numbers, their typical small size (6-8 µm) suggests their contribution to the overall biomass of phytoplankton is limited throughout most of the year (C.H. McKenzie pers. comm.). It is difficult to speculate as to the cause of the apparent decline in cell density of the major phytoplankton groups over this short time period. This decrease in abundance may be in part the result of a change in the sample collection methodology as mentioned above, although we would expect cell densities to be higher in general in the upper mixed layer, and lower concentrations as a result of mixing the upper and lower water column with the integrated sample.

Time series (biweekly-monthly) measures of primary production have been collected at Station 27 using ship's of opportunity since June 2000 (Pepin and Maillet 2001). A total of 67 P-E experiments have been conducted to date at this fixed coastal station. The method employed to evaluate photophysiology of natural phytoplankton assemblages is photosynthesis (P) versus irradiance (E) experiments with the ^{14}C technique (Steemann Nielsen 1952). We estimated daily water-column integrated primary production using the algorithm (numerical integration of spectral model) from the software for calculation of primary production in the oceanic water column as described by Platt and Sathyendranath (2000)[2].

The time series of daily integrated primary production at Station 27 revealed an average rate of carbon fixation of 705.3 mg C m^{-2} d^{-1} with large seasonal changes from the mean, with values ranging from < 150 mg C m^{-2} d^{-1} during winter to values > 3000 mg C m^{-2} d^{-1} during the spring bloom, representing over 20-fold variability (Figure 13). The early time series (2000-01) was characterized by lower rates of carbon fixation compared to 2002-03, while in 2004, carbon fixation rates were similar to the early time series. Higher rates of primary productivity observed in 2002-03 were associated with higher values for photosynthetic parameters. The possible causes of these changes in P-E parameters, related to algal metabolism remain unclear, but have been attributed to changes in the taxonomic composition, light history and physiological condition of cells in previous studies. Seasonal changes in primary production were apparent in the time series with maxima in the spring and summer-early autumn months, while minima generally occurred during the late autumn and winter periods. In general, temporal fluctuations in primary production at Station 27 coincided with transitions in the phytoplankton assemblage, one dominated principally by diatoms and flagellates and substantially higher biomass during the spring bloom (April-May), to one dominated by small-sized flagellates along with a contribution from dinoflagellates and lower biomass at other times.

Oceanographic Sections - Seasonal Variability in Limiting Nutrients and Phytoplankton Biomass

The distribution of nitrate, the primary limiting nutrient influencing phytoplankton growth, have varied seasonally and spatially across the standard AZMP sections since the inception of the program. Depletion of nitrate concentrations in the upper water column (upper 50m) was evident in the Avalon Channel and Shelf along the southeast Grand Banks and Flemish Cap sections during occupations in Spring 2004, in contrast to higher nitrate concentrations for the Bonavista section (Figure 14). Areas of depleted nutrients coincided with biological consumption inferred from the distribution of chlorophyll *a*. The location of the offshore branch of the Labrador Current and slope water regions were characterized by elevated concentrations of nitrate along all sections, presumably being influenced by the North Atlantic Waters rich in inorganic nutrients (Figure 14).

The summer occupations across the northeast Newfoundland and Labrador sections are typically characterized by further depletion of nitrate concentrations to < 0.5 mmol m^{-3} in the upper 50m of the water column from levels observed during the spring occupations (Figure 15). There was evidence of depletion in nitrate concentrations, but this varied in the extent of depth by location of the section. The

[2] http://www.ioccg.org/software/Ocean_Production/index.html

largest vertical extent in biological uptake of nitrate occurred along the Newfoundland Shelf sections (Flemish Cap, Bonavista, and White Bay sections) extending to depths of ca. 50m. The vertical extent of nitrate uptake was lower along the Labrador Shelf section. Shoaling of the nitracline is evident from the inshore to offshore areas over all sections, which is consistent with conditions observed in earlier years. The summer 2004 concentrations of chlorophyll *a* were substantially lower across the Newfoundland and Labrador sections, although evidence of episodic or localized blooms were observed, while surface concentrations were limited to coastal and offshore regions (Figure 15). SeaWiFS colour imagery confirm low surface chlorophyll *a* levels across the Newfoundland and Labrador Shelf. Slope water regions were also characterized by elevated concentrations of nitrate along all sections during this time enhancing the vertical gradient in nutrient concentrations.

Evidence of surface nutrient replenishment was observed during the autumn occupations across the Bonavista section, while upper water-column nitrate levels were still somewhat depleted across the SE Grand Banks and Flemish Cap sections (Figure 16). Despite relatively low concentrations of nitrate, increased biological activity was evident across the sections with chlorophyll a concentrations of 1-3 mg m^{-3}, indicating the occurrence of a limited autumn phytoplankton bloom.

Seasonal and annual mean differences in nitrate inventories in the upper 50m and deeper layers (50-150m) were evident along the oceanographic sections (Figure 17). Seasonal nitrate inventories in the upper 50m have tended to increase from 2000 to 2003, notably along the mid-Newfoundland Shelf sections (Bonavista and Flemish Cap), less so along the southern and northern sections. In 2004, nitrate inventories tended to decrease, again most notably along the mid-Shelf sections during spring and autumn (Figure 17). Minima in nitrate inventories usually occurs during summer, and all sections show lower inter-annual variability in 2004.

Lower seasonal and inter-annual variability in nitrate is apparent in deeper waters compared to the upper water column inventories across the sections (Figure 18). Nitrate inventories in the deep layer (50-150m) in 2004 were comparable to levels observed in previous years. Lower levels of nitrate that characterize the SE Grand Banks is related to the shallower depths compared to the other sections.

In general, chlorophyll *a* levels were higher during spring 2004 compared to recent years, particularly along the mid-Shelf region, however, inventories were comparable with the early time series (Figure 19). Chlorophyll a concentrations during spring occupations of the Bonavista section declined systematically from 300 mg m^{-2} in 2000 to values of 60 mg m^{-2} in 2003 but recovered substantially in 2004 (270 mg m^{-2}). Concentrations during the summer and autumn surveys, in contrast, were typically 5-fold lower, and consistent with observations in previous years.

Oceanographic Sections – Seasonal and inter-annual variability in water column optics and physical structure

Seasonal and spatial variability in optical, physical, and biological structure are apparent on the Newfoundland and Labrador Shelf (Pepin et al. 2003). The percent change in the vertical attenuation coefficient in 2004 indicated consistent positive seasonal trends across all sections compared to earlier years (Figure 20). The euphotic depth tended to shallow in 2004 compared to previous years, while deepening along the SE Grand Banks during spring and autumn occupations. The trend in stratification was lower in 2004 across the Newfoundland Shelf during the spring and summer occupations but, increased substantially (> 150 %) on the SE Grand Banks section during the spring survey (Figure 20). The seasonal trend in MLD tended to decrease across the sections in 2004, with moderate positive trends observed only for the Bonavista section. The trends in water temperatures were generally positive across the Newfoundland and Labrador Shelf, with a sharp increase noted for the Bonavista section during the spring occupation (Figure 20).

The percent change in chlorophyll *a* inventories in 2004 tended to be positive compared to earlier years across the sections, the only exception being the Seal Island section which showed a negative trend (Figure 21). Silicate and nitrate inventories in the upper 50m were generally higher (20-100%) in 2004, except for the SE Grand Banks, Flemish Cap, and Bonavista sections during some of the spring and summer occupations. The deep (50-150m) nutrient inventories in 2004 showed mixed results with relatively small positive trends in nitrate concentrations, while concentrations of silicate tended to decline, with the exception of the SE Grand Banks section (Figure 21). Differences in timing between surveys conducted annually during 2000-04 and changes in the production cycle may contribute to the observed patterns in chlorophyll *a* and nutrient dynamics.

Satellite Imagery

We used SeaWiFS (http://seawifs.gsfc.nasa.gov/SEAWIFS.html) satellite imagery from the Bedford Institute of Oceanography (Dartmouth, NS) to obtain sea surface chlorophyll *a* biweekly composite plots across 10 statistical sub-regions on the Newfoundland and Labrador Shelf (Figure 22). Time series of bi-weekly surface chlorophyll *a* concentrations from the Newfoundland and Labrador sub-regions showed a regular seasonal bimodal pattern with a dominant periodicity during the spring and fall across all areas. Time series of surface chlorophyll *a* concentrations for the Newfoundland and Labrador statistical sub-regions provided some insight into the magnitude, duration, and timing of surface blooms across the NW Atlantic (Figure 23). In 2004, large surface blooms were observed predominately through April and May in southern regions (St. Pierre Bank and Southeast Shoal), and along the NE Newfoundland Shelf (Hibernia, Avalon Channel, St. Anthony Basin), in contrast to weaker surface blooms further north on the Labrador Shelf. The timing of surface blooms has varied across the statistical sub-regions during the time series from 1998-2004 (Figure 23). The most striking change in the timing of surface blooms has been in the Flemish Pass. From 1999, surface blooms in this sub-region have shifted progressively later in time by almost two months until 2004, when surface blooms shifted back to the timing observed in the late 90's. Although the delay in timing was not as prominent in the other statistical sub-regions as observed in the Flemish Pass, similar delays in the timing of surface blooms occurred in the southern areas of the Newfoundland and Labrador Shelf (Figure 23). The most northerly sub-regions (Hudson Strait and Northern Labrador) displayed less discrete bloom times and lower chlorophyll *a* concentrations but, more prolonged surface blooms occurring over several months extending into the autumn period compared to southerly sub-regions. Changes in the timing of surface blooms provides important information in regard to interpretation of phytoplankton biomass during the seasonal occupations of sections along the Newfoundland and Labrador Shelf. In all instances there may be subsurface concentrations of chlorophyll *a* that can not be detected from sea surface observation using satellite ocean color sensors. However, the general correspondence between our discrete measurements with the ocean color data suggests that the inter-annual trends in the timing of the production cycle may be well represented by remotely sensed data.

Continuous Plankton Recorder (CPR) – Plankton Trends

The Continuous Plankton Recorder (CPR) Survey provides an assessment of long-term changes in abundance and geographic distribution of planktonic organisms ranging from small phytoplankton cells to larger macrozooplankton. (Warner and Hays 1994). CPR collections in the northwest Atlantic began in 1959 and continued with some interruptions during the latter period through till 1986. Collections were renewed in 1991 and continue to present. The recorder is towed by ships of opportunity along a number of standard routes throughout the North Atlantic. The CPR device collects plankton at a nominal depth of 7m through an aperture and organisms are retained on a moving band of silk material and preserved. Various subsamples are collected for microscopic analysis from a section of silk representing 18.5 km tow distance and ca. $3m^3$ of water filtered[3]. Every second section is analyzed providing a horizontal scale of ca. 37 km. The CPR taxonomic categories varied from species to subspecies, while others are identified at coarser levels such as genus or family.

The methods used to collect and enumerate plankton samples collected as part of the CPR Survey have remained unchanged since the inception of the Program in 1959 to present. This consistency allows analysis and valid comparisons between years. We chose representative categories from the CPR database for phytoplankton, copepods, and macrozooplankton from the Grand Banks region

[3] See SAFHOS web site at (http://192.171.163.165/) for a description of the CPR Program collected for The Sir Alister Hardy Foundation for Ocean Science of Plymouth, England.

including NAFO Divisons 3L and 3Ps. We computed monthly means of relative abundance over the periods; 1961-70, 1971-78, 1991-00, and compared these near-decadal trends with the most recent years 2001-03.

The distribution of monthly means of phytoplankton indicate peak abundance in the spring and smaller magnitude blooms during the autumn (Figure 24). The relative abundance of large diatom cells (*Chaetoceros spp*.) and dinoflagellates (*Ceratium arcticum*) have increased in the 1990's and most recent years from lower levels observed during the 1960-70's (Figure 24). The monthly means of the bulk index of phytoplankton abundance (phytoplankton colour index) has shifted in recent years by about 1 month later in contrast to earlier decades. Although changes in abundance of diatoms and dinoflagellates has increased during the late 90's and recent years compared to earlier decades, these changes have not been reflected in the bulk phytoplankton colour index which has remained relatively unchanged (Figure 24).

The distribution of monthly means of calanoid copepods (*Calanus finmarchicus*; all stages CI-CVI) indicate bi-modal peaks in abundance similar to the patterns observed in phytoplankton, while smaller copepods (*Pseudocalanus / Paracalanus* and *Oithona* spp.) were present throughout the year (Figure 25). While *C. finmarchicus*, a ubiquitous copepod in the NW Atlantic, were generally increasing during the 1990's, the abundant smaller copepods have shown a systematic decline from record high abundances in the early 90's to recent years, particularly in the case of *Pseudocalanus* / *Paracalanus* spp. Recently, *C. finmarchicus* has also declined in abundance in recent years (Figure 25).

The distribution of monthly means of selected macrozooplankton categories (all stages) over the decades have shown some shifts in timing of occurrence (Figure 26). Peak abundance of *Chaetognatha* generally peak during the summer during the 1960-1970's, while during the 1990's and in recent years more limited seasonality in occurrence as well as shifts to both earlier and later occurrence of this predatory planktivore. The abundance of *Chaetognatha* have been highly variable throughout the CPR collections and there appears to have been a general increase from 2001 to 2003. However, the abundance pattern is well within the range of previous observations, albeit at the high extreme of the distribution. The abundance of *Euphausiacea* and *Hyperiidea* has shown a general decrease since the early 1990s, with the abundance of *Euphausiacea* being at the lowest overall levels recorded since the start of the CPR surveys. The decline in the *Hyperiidea* has been much less dramatic and the overall abundance is near the average values recorded during the 1960-1970s period.

Fixed Station - Zooplankton

From 1999 to 2001, the general pattern of seasonality in overall zooplankton abundance at Station 27 has been low numbers of organisms at the start of the year with the highest abundance occurring in late fall but since 2002 there has been relatively little seasonality in the overall abundance of animals at this site (Figure 26). In 2004, the overall abundance of zooplankton was low relative to the long term average. In 8 of the 12 dominant taxa, the overall seasonally adjusted abundance was either the lowest since 1999, or the second lowest. Although the abundance were generally not significantly different from 2003, the abundance of *Metridia* spp. and *Pseudocalanus* spp. was significantly lower than the overall average from the five previous years (ANOVA, $F_{5,61} = 3.22$, $P< 0.05$, $F_{5,61} = 4.97$, $P<0.01$, respectively). Two years ago (Pepin et al. 2003), we noted that the greatest changes in zooplankton community structure since 1999 has been the growing frequency of occurrence and relative abundance of *C. glacialis* and *C. hyperboreus* as well as *Microcalanus* sp. during the late spring and early summer and the gradual decrease in relative occurrence and abundance of *Temora longicornis* (Figure 26). In 2003, overall occurrence of these four species returned to slightly lower values for the two species of *Calanus* and slightly higher abundances for *T. longicornis*, a pattern which persisted into 2004 although the relative abundance of the large calanoids varied during the last year. The overall abundance of *C. finmarchicus* reached its lowest level since the start of the series in 1999 while the abundance of *C. glacialis* was near normal and that of *C. hyperboreus* reached it second highest seasonally adjusted mean abundance. The seasonal pattern in *Oithona* spp. abundance was similar to previous years, but there is a notable biennial pattern in the relative abundance of this species during winter months, when it dominates the zooplankton community even more than during the rest of the year. However, in terms of overall abundance, 2004 was the second lowest year on record since the inception of the AZMP. For *Microcalanus* sp., the average abundance levels were approximately 50% of the peak abundance reached in 2002 at Station 27. In addition, the abundance of large calanoid nauplii decreased by approximately 20% in 2004 relative to the average of 2003, continuing a trend over the last 3 years. The limited number of observations during the first three months of the year is expected to have had limited impact on these patterns of abundance and occurrence as most of the biological activity occurs during the period of April to October. The seasonally adjusted mean abundance of pelagic gastropods was the second highest on record, increasing by ~ 65% over the abundance observed in 2003, whereas the average abundance of larvaceans was 25% lower than in 2003, and approximately 60% lower than in 2000 when abundance peaked. Because of the patchy distribution and strong seasonality in both groups, the changes were not statistically significant but the change in abundance was notable enough to warrant discussion.

The overall abundance of *C. finmarchicus* at Station 27 was generally 20% lower than in the previous three years, and substantially lower than concentrations observed in 1999 and 2000 (Figure 27). In contrast to previous years, there was no strong peak abundance in early summer, with abundance peaking in September. Peak occurrence of CI stages occurred in late May/early June, as in 1999, 2000 and 2002. The overall pattern of abundance showed a much weaker seasonality than in previous years with the peak abundance being ~50% lower than in the previous two years. As in most years, early stage copepodites were present in the zooplankton community throughout the fall. However, there appeared to be a greater relative abundance of early stage copepodites well into the fall, when CIV and CV generally dominate. We have noted the occurrence of a second cohort in previous years, but the relative strength of the second cohort appears to be particularly significant in 2004. As in previous years, there were very few CVI adults at Station 27 after the end of August. The pattern of abundance of *C. finmarchicus* at Station 27, is in contrast with that observed on the shelf, where the overall abundance north of the Grand Banks in the fall and spring appear to be at the highest levels observed since 1999, but generally consistent with the pattern observed along the Flemish Cap and Southeast Grand Banks lines, where the abundance appears to be reaching the lowest levels since the start of AZMP.

The overall abundance of *Pseudocalanus* sp. showed a weak pattern in seasonal succession of stages, as in previous years (Figure 28). There appears to be an early seasonal cohort that occurs sometime in April/May followed by a second pulse in stages CII-CV in August and September. There is also some indication of a third cohort later in the year at the end of November or beginning of December. The relative seasonality in abundance was strong in 2004, similar to 2000, with distinct low abundance levels in winter and late fall, whereas such patterns were not clearly apparent in 2001-03. The seasonally adjusted mean abundance in 2004 was not significantly different from 2003 (*t-test*, P=0.07) but it was significantly lower than in the years prior to that (ANOVA, $F_{5,61} = 4.97$, $P<0.01$).

The seasonal pattern in the relative distribution of copepod biomass among the six dominant species at this site was not strongly different in 2004 from the pattern in previous years (Figure 29). It is notable that the relative contribution of *Oithona* spp. during the winter of 2004 was higher than previously observed. However, throughout most of the year, the copepod biomass at Station 27 was dominated by *C. finmarchicus*. There is a notable peak in biomass, generally in mid summer, associated with the contribution from *C. hyperboreus*.

The patterns of the dominant zooplankton at Station 27 since the inception of the AZMP reveals that overall abundance for most species has generally been decreasing over time, with the exception of *Temora* spp., which has shown an increase following a large decrease from 1999 to 2001, and pelagic gastropods which show no general trend (Figure 30). However, of the 12 species, only *Pseudocalanus* spp., *C. glacialis*, *Metridia* spp. and *Temora* spp. show statistically significant inter-annual variations in abundance. The consistent trend among most species suggests that the general decrease in abundance reflects lower overall secondary production for Station 27 and adjacent areas (i.e. the Grand Banks).

Oceanographic Sections - Zooplankton

The average seasonally adjusted zooplankton abundance in the fall of 2003 was significantly higher than in the previous years on the Southeast Grand Banks, Flemish Cap and Bonavista Bay transects (Figure 31). The largest concentrations occurred in the inshore areas of the Bonavista and on the top of the bank along Flemish Cap transect and over the Southeast Shoals stations of the Southern Grand Banks transect (Figure 32). In general, the higher abundance of zooplankton was due principally to larger overall abundance of *Oithona* sp., and *Pseudocalanus* sp.. *Oithona* sp. was the dominant copepod across all sections, ranging from ~50-85% of all copepods, even in offshore areas (Figure 32). *Pseudocalanus* sp. was present only in the Shelf areas and was generally absent from stations located in slope waters. The overall abundance of *Pseudocalanus* spp. was near the lowest levels recorded since the start of AZMP. *C. finmarchicus* was present across the entire shelf, a notable difference from 2002 (Pepin et al., 2004), and its overall abundance was at or near the peak levels recorded since 1999. Although overall abundances were very low, *C. glacialis* was also at or near the highest levels recorded. As in previous years, *Metridia* spp. was present along all transects, with a greater relative abundance moveing north and offshore. In the fall of 2002, changes in abundance showed considerable spatial heterogeneity. *Calanus finmarchicus* was the most important component of the biomass of the dominant copepod species during the Fall of 2003. (Figure 33). Along the Southern Grand Banks transect, *Pseudocalanus* spp. and *Oithona* spp. were important components of the total biomass over the Southeast Shoals, while *C. hyperboreus* was a key species further North (Figure 33).

During the spring of 2004, the overall abundance of zooplankton was generally the highest on record for most areas (Figure 31). The exception occurred on the Southeast Shoal where overall abundance of *C. finmarchicus, C. hyperboreus, C. Glacialis* and that of large calanoid nauplii were generally lower than previous years. The average abundance of most of the dominant copepod species along the Flemish Cap and Bonavista Bay transects were generally at the highest levels since the inception of the AZMP. The relative species composition and their spatial distribution appeared to be consistent with observations from 2002 and 2003 (Figure 34). A notable difference was the overall high abundance of calanoid nauplii in contrast to the previous year, particularly on the Bonavista Bay transect. Although we had previously noted a general decrease, the overall increase in 2004 more than made up for previous changes. The Southeast Grand Bank transect was dominated by the numerical and biomass of small copepod species (*Oithona* spp., *Pseudocalanus* spp.) (Figure 35). Over the Southeast Shoals, more than 80% of the average biomass consisted of *Pseudocalanus* spp.. Further north, *Oithona* spp. continued to dominate numerically (as is does everywhere on the Newfoundland Shelf), but the biomass was dominated by *C. finmarchicus* and *C. hyperboreus*, with *C. glacialis* and *Metridia* spp. being the third and fourth most important in terms of biomass on the Flemish Cap and Bonavista Bay transects, respectively. Most other species of zooplankton were at near average levels of abundance, with the exception of *Microcalanus* spp. and larvaceans, which were at their highest seasonally adjusted levels since 2000. In the case of *Microcalanus* spp., the overall change in abundance was statistically significant whereas that of larvaceans was not. Although other species have shown fluctuations over time, it appears that our current approach to providing seasonally adjusted estimates of abundance has revealed that many of those changes are not statistically significant.

During the summer 2004 surveys, there appeared to be a split in the long term pattern of abundance of zooplankton when contrasting the Grand Banks, based on the Flemish Cap transect, with the Newfoundland and Labrador Shelf to the north (Figure 31). In general, the overall abundance of many zooplankton species along the Flemish Cap line was at the lowest levels since 2000. This was particularly the case for the three species of *Calanus* as well as for large calanoid naupli. In contrast, the abundance levels of *C. finmarchicus, C. glacialis* and *C. hyperboreus* on the Bonavista Bay and Seal Island transects were at their highest levels since 2000. The abundance of large calanoid nauplii was the exception to this pattern whereby they were near their lowest overall level of abundance along the Bonavista Bay transect and at their highest level off Labrador along the Seal Island transect (Figure 31). There is a general increasing trend in the abundance of *Oithona* spp. along the Bonavista Bay and Seal Island transects since 2000, which is contrast to that along the Flemish Cap transect, where abundance appears to have fluctuated over the last five years, with no discernable trend, or statistically significant change in abundance. Due to the unavailability of *CCGS Teleost,* it was not possible to survey the Makkovik Bank transect in 2004.

The general spatial distribution of the dominant zooplankton species during the summer of 2004 was similar to that of previous years. Numerically, small copepods dominated across the Flemish Cap transect, with the greatest relative abundance occurring over the bank (Figure 36). As one moves further North, *Pseudocalanus* spp. takes on greater relative importance in inshore areas while *C. finmarchicus* is more important in offshore areas. The most variable in terms of year-to-year distribution are the large calanoid nauplii (Figure 31). In terms of biomass, *Oithona* spp. and *Pseudocalanus* spp. are the most important component on the Grand Banks, although the overall biomass is very low (~1 g dry weight m^{-2}) (Figure 37). As one moves offshore or north, the overall biomass increases to levels above 5 g m^{-2}, due in large part to the greater overall abundance of species of large calanoid copepods. *Calanus finmarchicus* generally makes up the bulk of the biomass across most of the Newfoundland Shelf, with the exception of the Flemish Pass and the inshore portions of the Bonavista Bay and Seal Island transects, whereas *C. hyperboreus* is the major component of the summer zooplankton biomass (Figure 37). By contrast, *C. glacialis* and *Metridia* spp. are of lesser importance whereby their combined relative biomass during the spring survey represented 20-40% of the standing stock while it seldom represents more than 20% of the copepod biomass during the summer survey.

During the fall of 2004, the high zooplankton abundance levels that had been noted at the same time during the previous year were generally not apparent. Only in the case of *C. finmarchicus* were abundance levels similar to that found in the previous year, being either the highest (Flemish Cap transects) or second highest in the six year series (Figure 31). In the case of large calanoid nauplii, the overall abundance in the fall of 2004 was generally ranked in the lower half of the observations along any transect, with the lowest levels on record being observed along the Flemish Cap transect. Abundance levels of *Oithona* spp., *Pseudocalanus* spp., *C. glacialis* and *C. hyperboreus* were also ranked in the lower half of observations. In general terms, the spatial distribution of the relative number (Figure 38) and biomass (Figure 39) of the dominant copepod species were similar to that observed in 2003. However, on the Southeast Shoal, the relative contribution of *Oithona* spp. and *Pseudocalanus* spp. to the overall biomass was generally higher than in the previous year, and the overall biomass was also higher (Figure 39). Along the Flemish Cap transect, the relative distribution of biomass among copepod species was remarkably similar to 2003, even though there was a peak in abundance near the coast (Figure 38). The generally higher abundance of *C. finmarchicus* along the Bonavista Bay transect (Figure 39) led to an increase in the relative contribution of this species to the overall biomass, particularly at a loss for *C. glacialis* and the two smaller species of copepods (Figure 31).

Discussion

Overall, the seasonality of chemical and biological variables at Station 27 and along the major AZMP sections in 2004 was similar to previous years (1999-2003). The timing of events on the Newfoundland Shelf (south of Seal Island) was once again similar to conditions observed in the early part of the program but in contrast to 2001 when the onset of the spring phytoplankton bloom was delayed. However, satellite information indicates that the relative delay in the onset of the spring bloom remained as one moved further north.

It is becoming clear that inter-annual variations in the seasonality of vertical mixing and water column structure plays an important role in the seasonal phytoplankton cycle along the Newfoundland Shelf. In 2001, the delay in the onset of the spring bloom was associated with persistent deep mixing of the water column. Although the timing of the spring bloom returned to an average start time, the strength of the mixing during the period January-March, as determined from the depth of the mixed layer, appears to have resulted in a reduction in the overall magnitude of the phytoplankton bloom.

Variations in the physical environment since the inception of the Atlantic Zone Monitoring Program is likely to be contributing to the variability in the magnitude of the spring phytoplankton bloom. Since 2000, there has been a gradual intensification in the overall productivity and standing stock of phytoplankton during the spring until 2003. The gradual rather than abrupt shoaling of the mixed layer may have provided sufficient light and high nutrient availability to permit the development of denser phytoplankton population, mainly composed of diatoms, than in previous years. In 2004, it appears that the spring phytoplankton bloom followed a relatively abrupt shoaling of the mixed layer, that may have resulted in a smaller fraction of the surface nutrient inventory being converted into biomass However, in addition to the factors that regulate the vertical structure of the water column, there is a preliminary indication that inter-annual variations in incident light may also have contributed to the increase in the overall intensity of the spring phytoplankton bloom. Although intercalibration of light observations from the Northwest Atlantic Fisheries Centre with those collected by the Canadian Meteorological Service (CMS) has yet to be completed, the first indications are that incident radiation during the spring and summer months in 2001-03 are at the upper extreme of light levels observed in the past three decades at St. John's Airport. In 2004, light levels were lower than the overall peak in 2001-03 but the value remained elevated relative to those from CMS, further raising the need for intercalibration.

In 2001, the deep nutrient inventories (> 50m) observed at Station 27 showed a 30-50% decrease over conditions in previous years but the change was not observed along any of the standard sections. The conditions at Station 27 persisted in 2004 but there appears to be limited evidence for nutrient depletion over the remainder of the Shelf, in contrast to previous suggestions that the inner part of the Bonavista transect may have shown a decrease in deep nutrient inventories (Pepin *et al*. 2002). There was some evidence of greater variability in the deep nutrient inventory at Station 27, but the pattern was no strong enough to suggest a significant change at this time. The surface nutrient inventories appear to have been higher in 2004 than in the previous year, but the limited intensity of the spring phytoplankton bloom may be partly the cause.

The relationship between silicate and nitrate concentrations in the upper layer (0-50 m) indicates that during much of the year, nitrate appears to have a greater potential to limit phytoplankton production. However, there is also an indication that replenishment of silicate is more extensive than that of nitrate throughout much of the year, and this was particularly evident in 2003 and 2004 at both Station 27 and on the Newfoundland Shelf. However, it is unclear at this time the mechanism through which this occur, because deep water inventories of both nutrients are comparable. One possibility is that the uptake of silicate changes seasonally as a result of changes in phytoplankton community structure.

The overall standing stock of phytoplankton on the NE Newfoundland Shelf was generally comparable for slightly higher than in previous years, as were surface nutrient inventories. There was relatively little change in the deep water nutrient inventories. Although stratification was less intense over much of the Grand Banks, which suggests that nutrient replenishment may have occurred more readily, the integrated temperature was also lower. However, primary production, and dense phytoplankton blooms, are know to occur when temperatures are low, suggesting that the effect of temperature on phytoplankton standing stock may be affected indirectly through the impact of other strophic levels. This trend was reversed for the Labrador sections occupied during the summer. Satellite data suggests that an intense phytoplankton bloom was occurring in the Labrador Sea during our summer surveys, but the overall standing stock on the Shelf was relatively limited. Alternatively, higher grazing pressure from a slight increase in the density of large calanoid copepods may have maintained standing stocks at low levels, which could also be mediated through variations in temperature.

The decline in abundance of major phytoplankton taxa observed in recent years appears to have persisted into 2004. The cell densities of diatoms, dinoflagellates, and flagellates have continued to decrease. Although flagellates do not make up a substantial portion of the overall phytoplankton biomass compared to larger diatom and dinoflagellate cells, the decrease in the abundance of all taxa may suggest a change in the dynamics of the microbial food web dynamics in the area. Further investigation is required.

The overall abundance of zooplankton at both Station 27 was generally in keeping with previous observations. The notable change in the zooplankton community structure at the fixed station has been in the increase in the abundance of cold water species of copepods observed in 2002 did not appear to persist into 2003 and 2004. The abundance of copepodites of *Metridia* sp., *C. glacialis*, *C. hyperboreus* and *Microcalanus* sp. which had become more frequent members of the community although the overall increase in their abundance has been modest returned to levels consistent with conditions at the start of the monitoring program. The warm water species, *T. longicornis*, whose abundance peaks during the fall, has shown an increase in overall abundance and in relative frequency of occurrence at Station 27.

The most notable advance in 2004 was in our ability to provide quantitative analysis of inter-annual differences in the abundance of dominant zooplankton taxa at Station 27 and along the key oceanographic transects. The analytical approach is somewhat simplistic and does not take into consideration of major shifts in the spatial distribution of species (this appears as part of the error). However, the approach has revealed significant inter-annual variations in the abundance of zooplankton on the Shelf. Many taxa, particularly the three *Calanus* species, appear to be at the highest levels encountered North of the Grand Banks, whereas the opposite is true over the Grand Banks, at least since the inception of AZMP. Variations in cross-shelf transport may play a role in this pattern but we have not conducted the analysis required to investigate this possibility.

The approach based on general linear models to determine the inter-annual variations in abundance of taxa from AZMP collections did raise some questions about the programs overall ability to accurately monitor zooplankton abundance and species composition. Data from Station 27 revealed that only 12 taxa were sufficiently abundant and frequent to allow appropriate inter-annual comparison in abundance patterns, which included copepods, gastropods, larvaceans and euphausiids. In contrast, only 7 to 8 species of copepods were sufficiently abundant and frequent on the shelf to allow effective and reliable intercomparison throughout the AZMP implementation period. Other groups, such as bivalves, gastropods, euphausiids and larvaceans were highly patchy in their distribution, making statistical intercomparisons unfeasible at this time. Longer time species of observations may be required before we can detect significant inter-annual variations in abundance based on the AZMP survey design and collection methods. We did investigate the potential to simply contrast seasonal and inter-annual variations in abundance without taking into consideration the spatial distribution of each species. This did allow a greater number of species to be included in the analysis but the complexity of the results requires further investigation at this time before we feel that we can comment on the overall trends.

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Table 1. Listing of AZMP Sampling Missions in the Newfoundland and Labrador Region in 2004. The transects are Southeast Grand Banks (SEGB); Flemish Cap (FC); Smith Sound (SS), Trinity Bay (TB), Bonavista Bay (BB); Funk Island (FI); White Bay (WB); Seal Island (SI), and the fixed station (Station 27). See Figure 1 for station locations along sections and fixed coastal station. Total numbers of hydrographic (CTD and XBT profiles) and biological (nutrients, plant pigments, phytoplankton, zooplankton, and including partial occupations) profiles provided for each seasonal section and fixed station occupations.

Mission ID	**Dates**	**Sections/Fixed**	**# Hydro Stns**	**# Bio Stns**
TEL524	Apr 17-May 2, 2004	SEGB, FC, BB, SS	100	48
WT552	Jul 21-Aug 3, 2004	FC, BB, WB, SI	75	44
Hud586	Nov 19-Dec 5, 2004	SEGB, FC, BB, FI, SS, TB	148	60
Fixed	Jan-Dec 2004	Station 27	55	21
Total			378	173

Table 2. Mean (± SD) daily photosynthetic active radiation (PAR), total monthly radiation and total daily insolation obtained in 2004 from Li-Cor PAR sensor located at the Northwest Atlantic Fisheries Centre (47.52^o N, -52.78^o W), St. John's, NL.

Month (Julian Day)	**Avg. Daily Moles m^{-2} ± SD**	**Total Moles Moles m^{-2}**	**Total Daily Insolation Moles d^{-1}**
Jan (1-31)	7.98 ± 3.60	239.49	0.16
Feb (32-59)	12.91 ± 5.71	142.04	0.30
Mar (60-90)	22.26 ± 11.87	690.20	0.60
Apr (91-120)	28.04 ± 11.88	841.32	0.88
May (121-152)	40.02 ± 14.39	1240.52	1.39
Jun (153-181)	35.48 ± 15.17	1064.54	1.30
Jul (182-212)	35.14 ± 15.00	1089.27	1.26
Aug (213-243)	31.08 ± 13.22	963.36	1.02
Sep (244-273)	22.61 ± 9.92	678.38	0.65
Oct (274-304)	13.10 ± 8.76	248.94	0.33
Nov (305-334)	7.02 ± 4.42	210.61	0.15
Dec (335-365)	5.14 ± 3.39	77.15	0.10

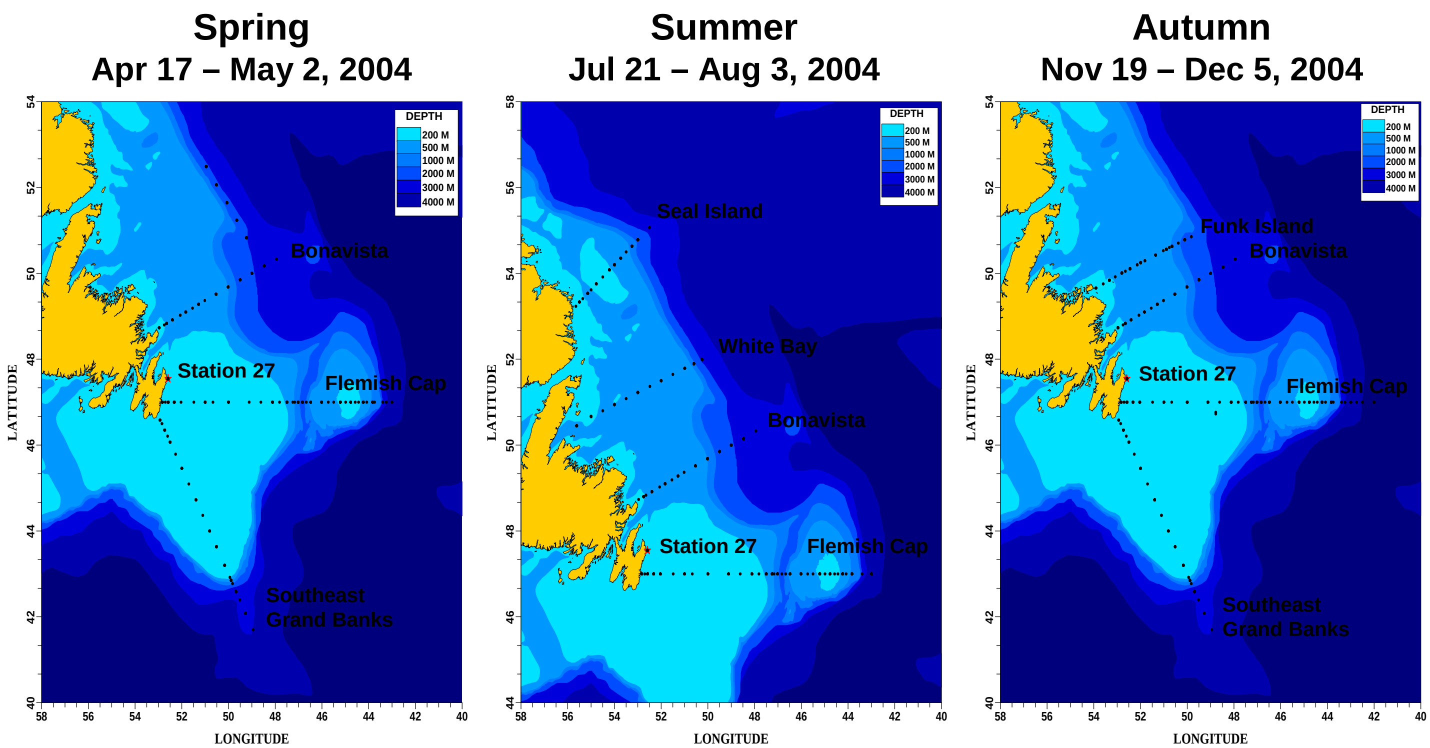


Figure 1. Biological and physical occupations during AZMP seasonal sections and fixed station on the Newfoundland and Labrador Shelf in 2004.

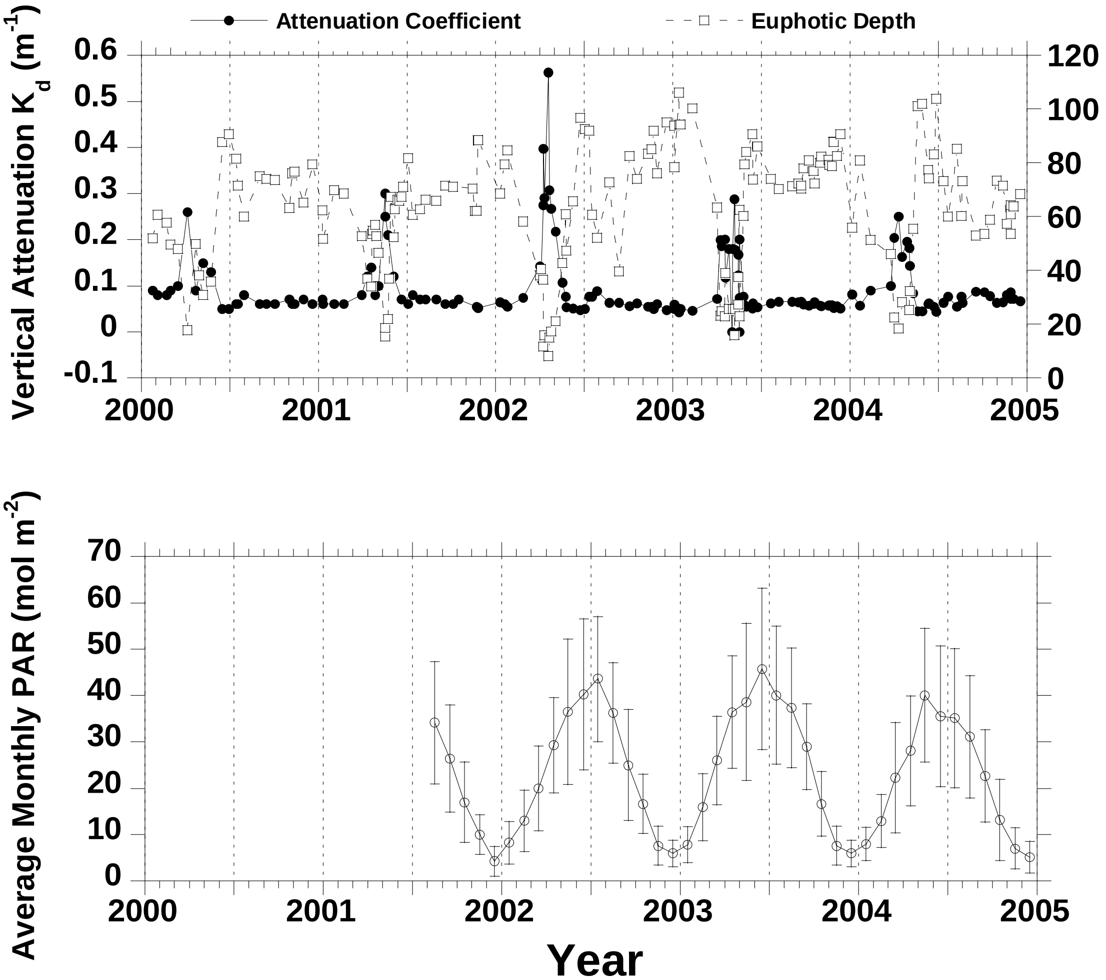


Figure 2. Time series of optical properties at Station 27 showing vertical attenuation coefficient K_dPAR, euphotic depth, and average monthly photosynthetic active radiation (± SD; PAR irradiance sensor located at NWAFC, St, John’s, NL).

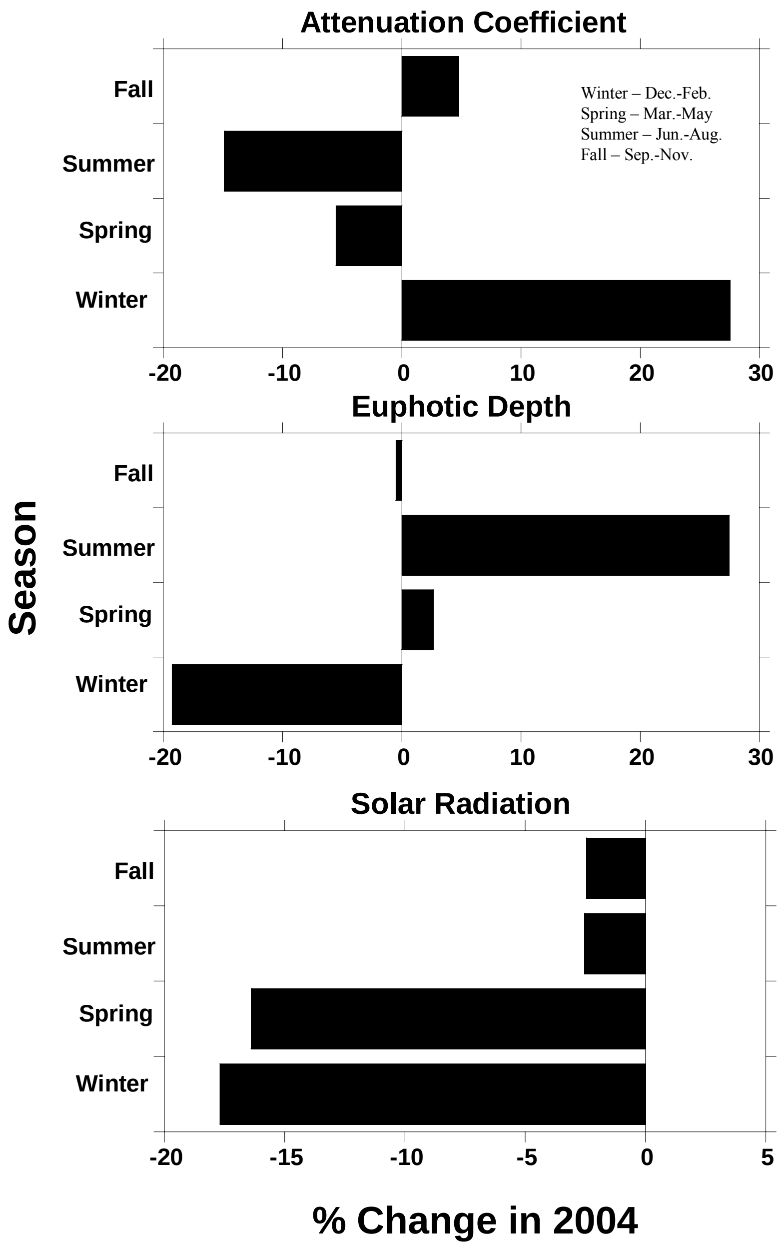


Figure 3. The mean percent change in optical indices (vertical attenuation coefficient and euphotic depth) in 2004 compared to earlier years (2000-03) at Station 27 during different seasons.

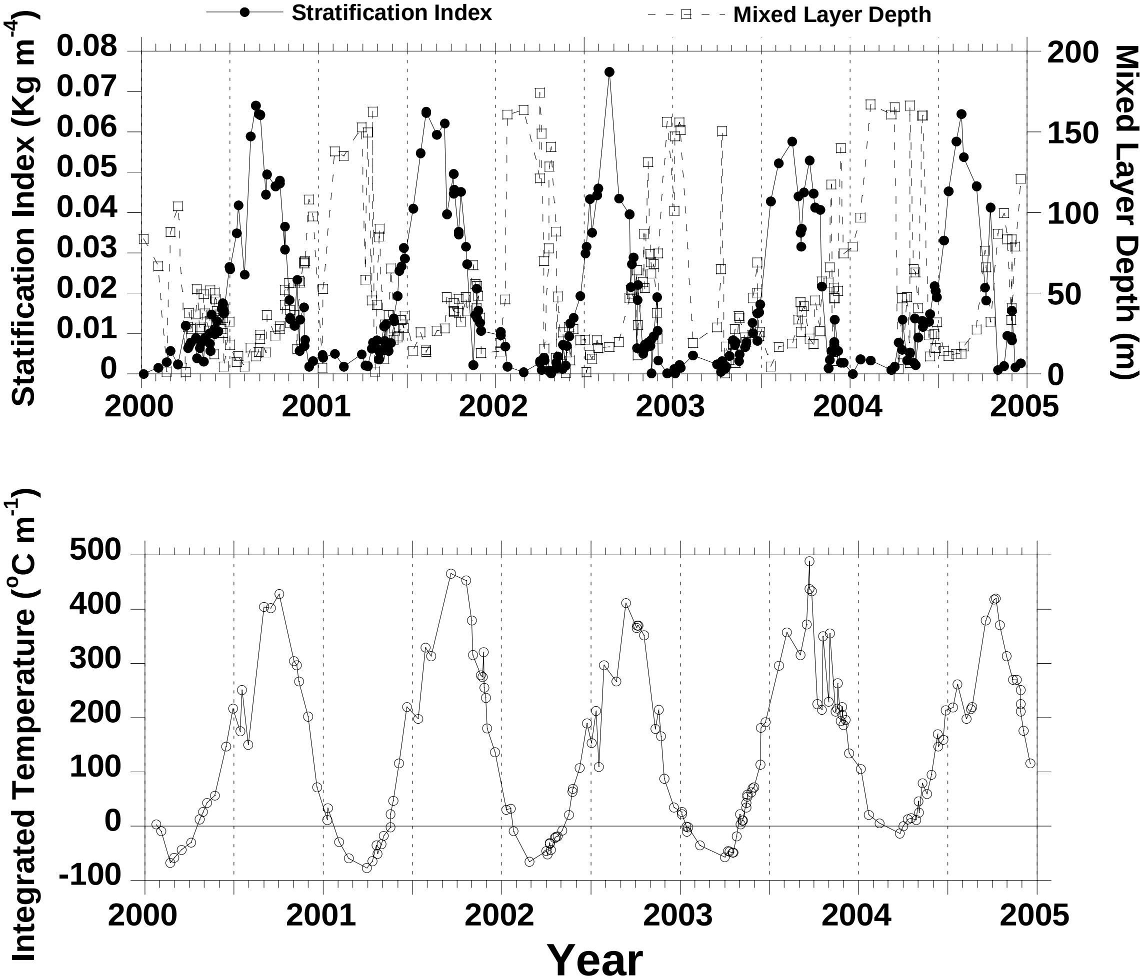


Figure 4. Time series of physical measures at Station 27 during 2000-04 showing stratification index (sigma-t_{50m} – sigma-t_{5m} /45m); mixed layer depth (taken as the depth centre of the pycnocline); and integrated temperature in the upper 50m using the trapezoidal method.

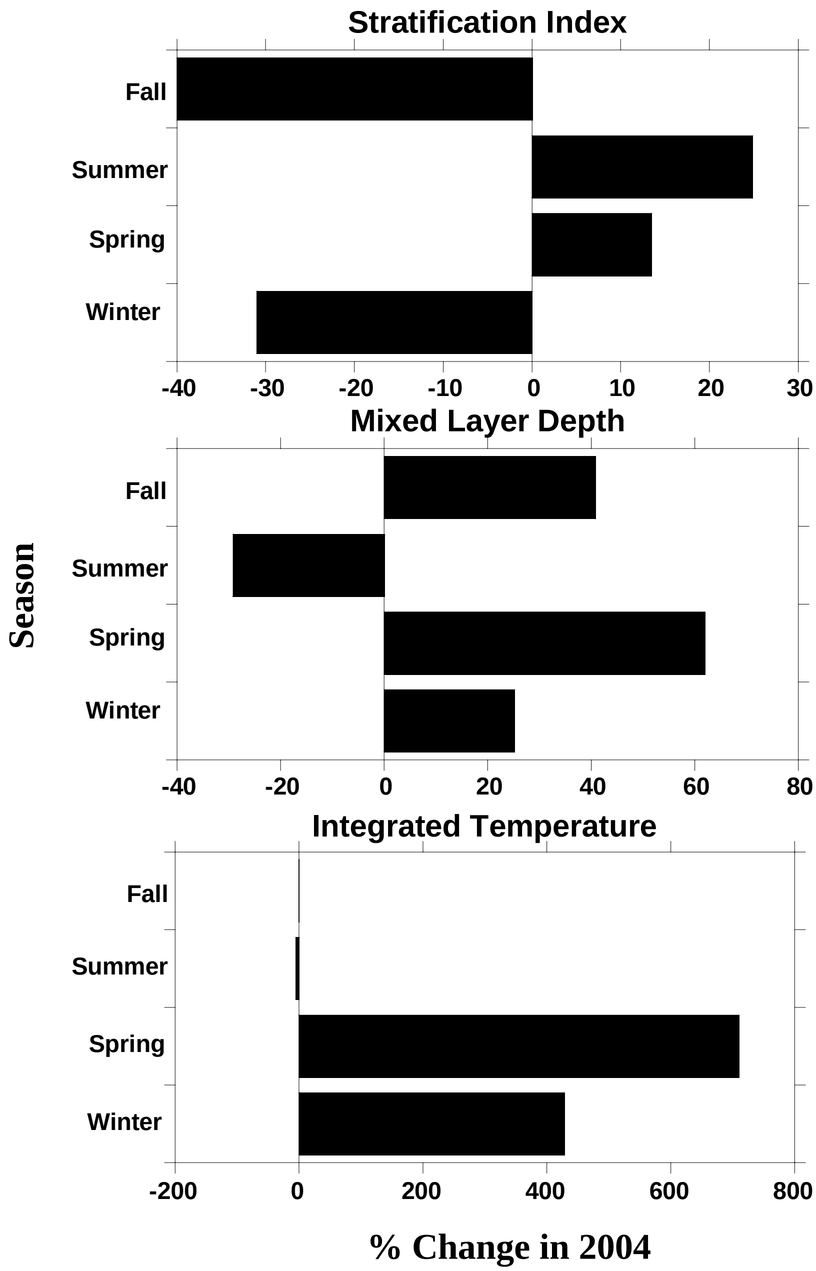


Figure 5. The mean percent change in physical indices (stratification index, mixed layer depth, and integrated temperature) in 2004 compared to earlier years (2000-03) at Station 27 during different seasons.

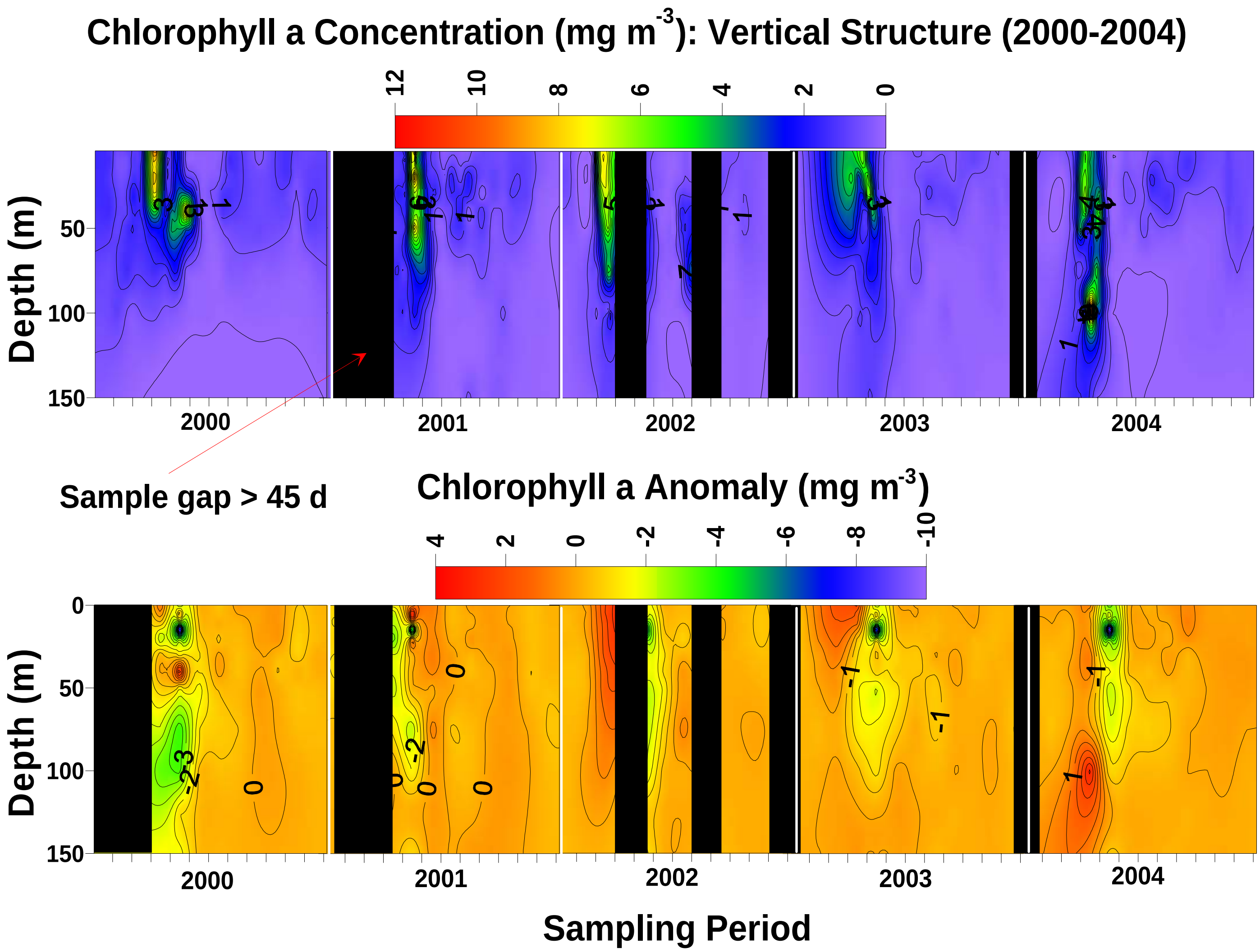


Figure 6. Time series of vertical chlorophyll *a* structure at Station 27, 2000-04. Bottom panel: chlorophyll a anomaly (annual values minus long-term mean; base period starts in 1993).

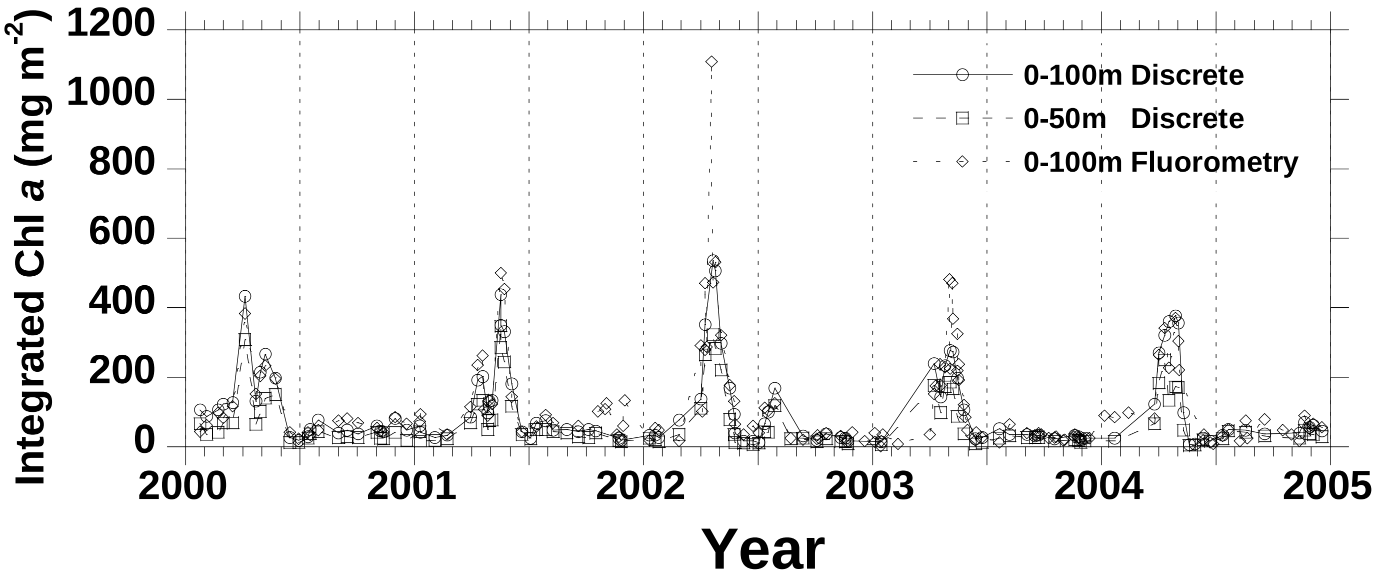


Figure 7. Time series of phytoplankton biomass index at Station 27 during 2000-04 showing integrated chlorophyll *a* and chlorophyll *a* fluoresence at different depth strata from discrete measures and *in-situ* values.

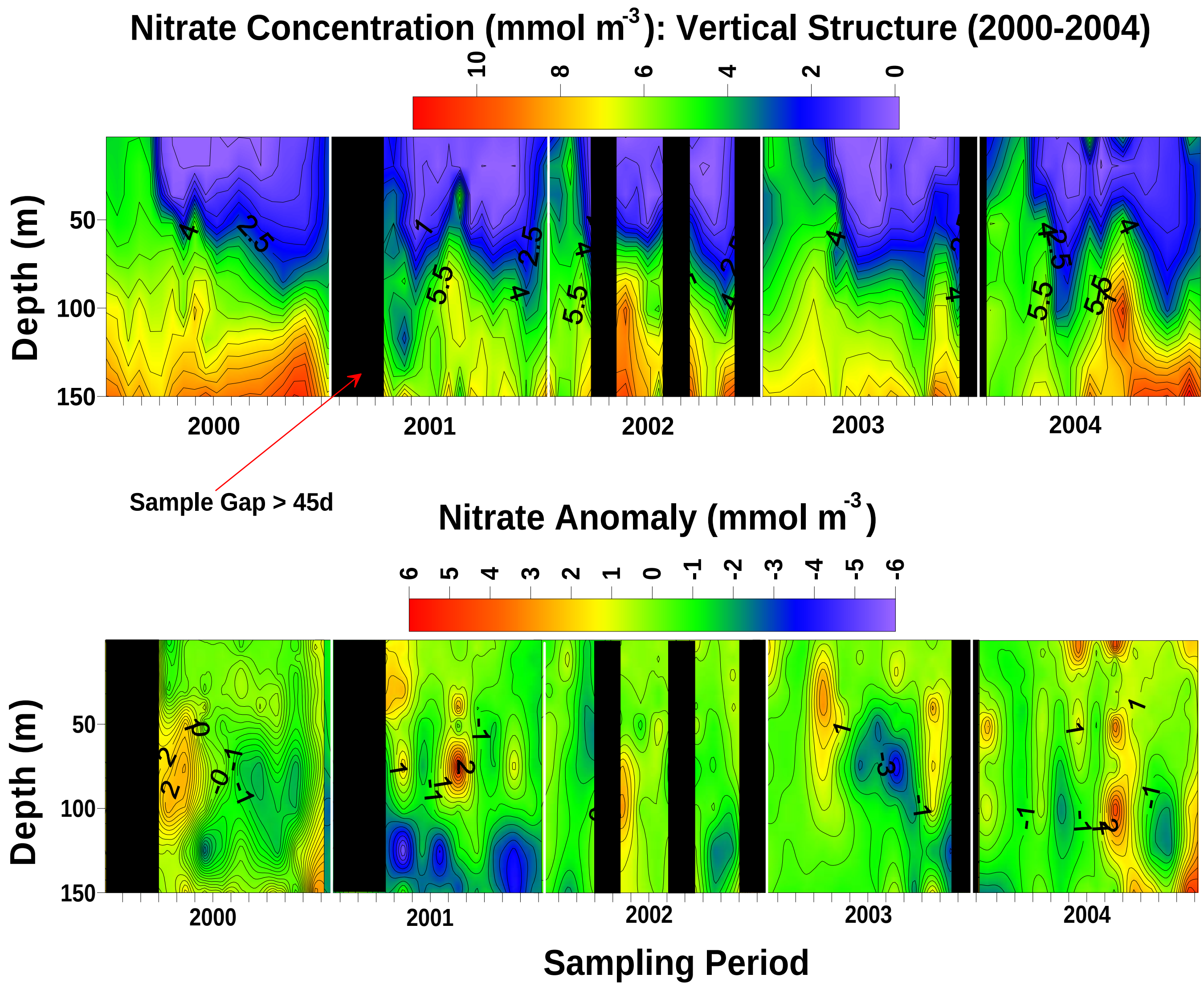


Figure 8. Time series of vertical nitrate structure at Station 27, 2000-04. Bottom panel: nitrate anomaly (annual values minus long-term mean; base period starts in 1993).

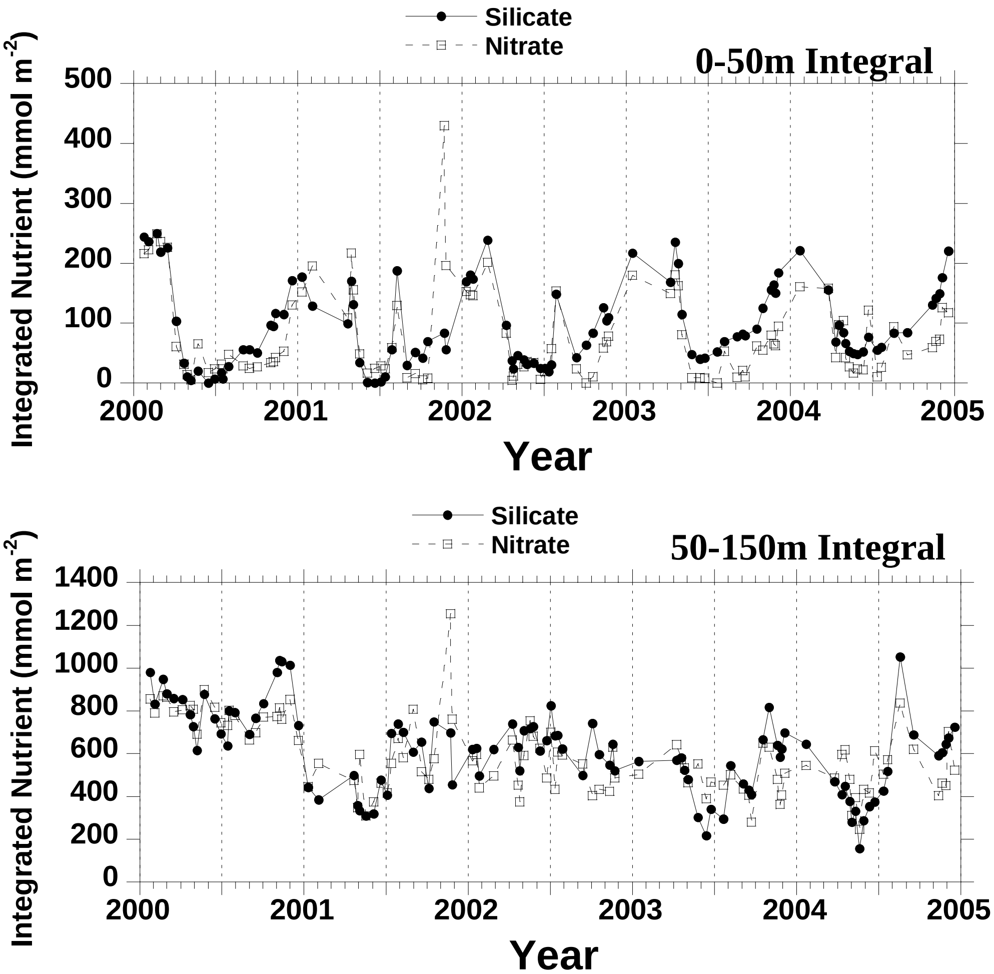


Figure 9. Time series of nutrient inventories of silicate and nitrate (combined nitrate and nitrite) at Station 27 during 2000-04 from upper (0-50m integral) and lower (50-150m integral) depth strata.

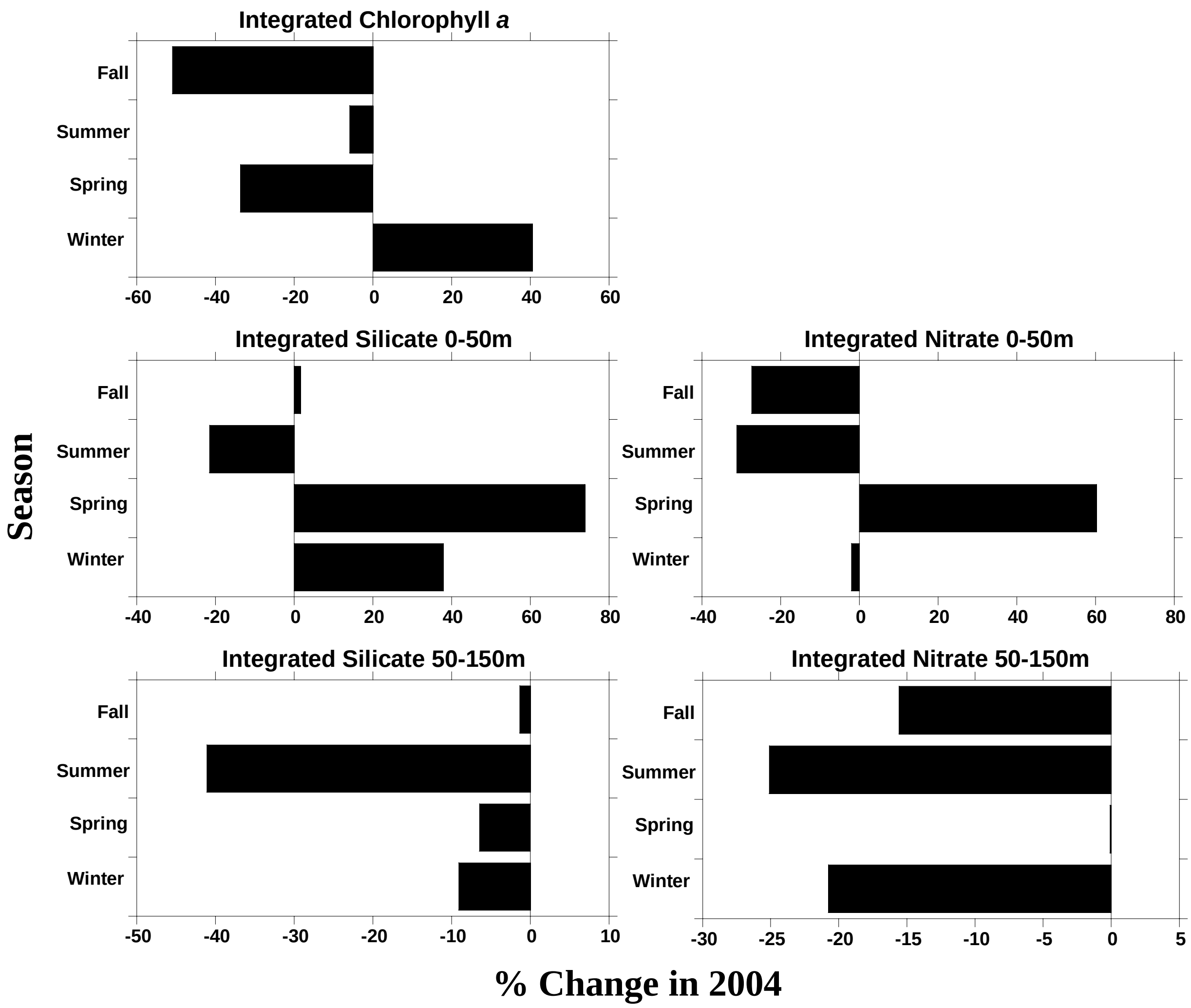


Figure 10. The mean percent change in biochemical indices (chlorophyll *a* and integrated nutrient inventories at different depth strata) in 2004 compared to earlier years (2000-03) at Station 27 during different seasons.

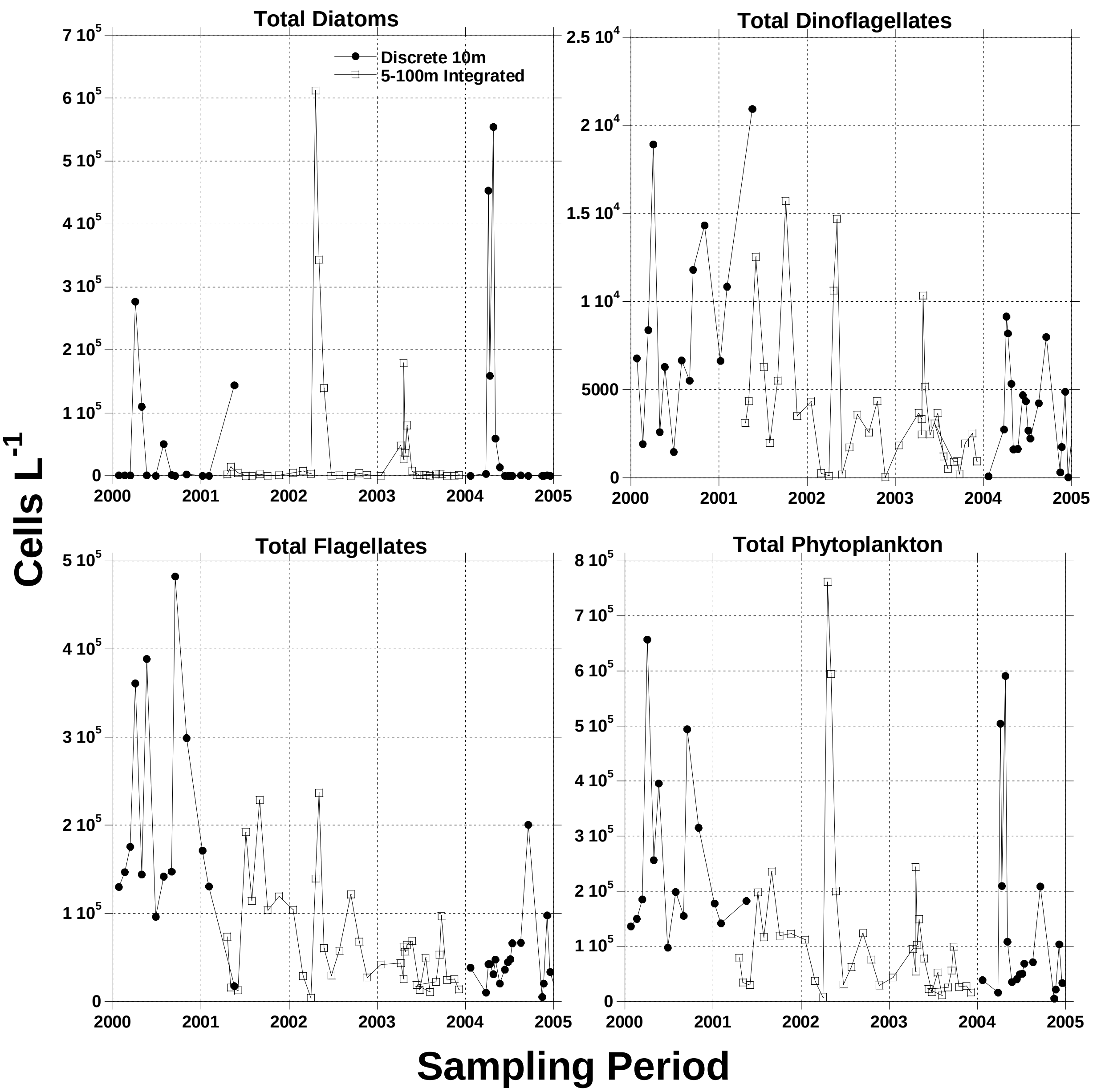
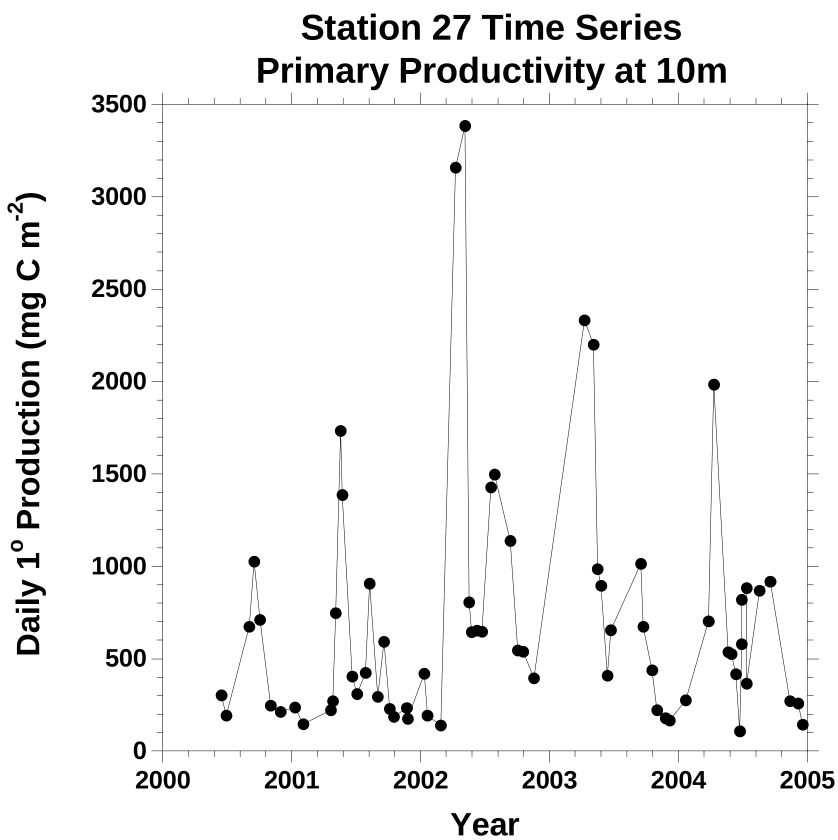


Figure 11. Time series of phytoplankton cell density of major taxa observed at Station 27 from both discrete 10m (prior to 2001 and after 2003) and depth-integrated (5-100m; 2001-03) sampling including Diatoms, Dinoflagellates, and Flagellates.



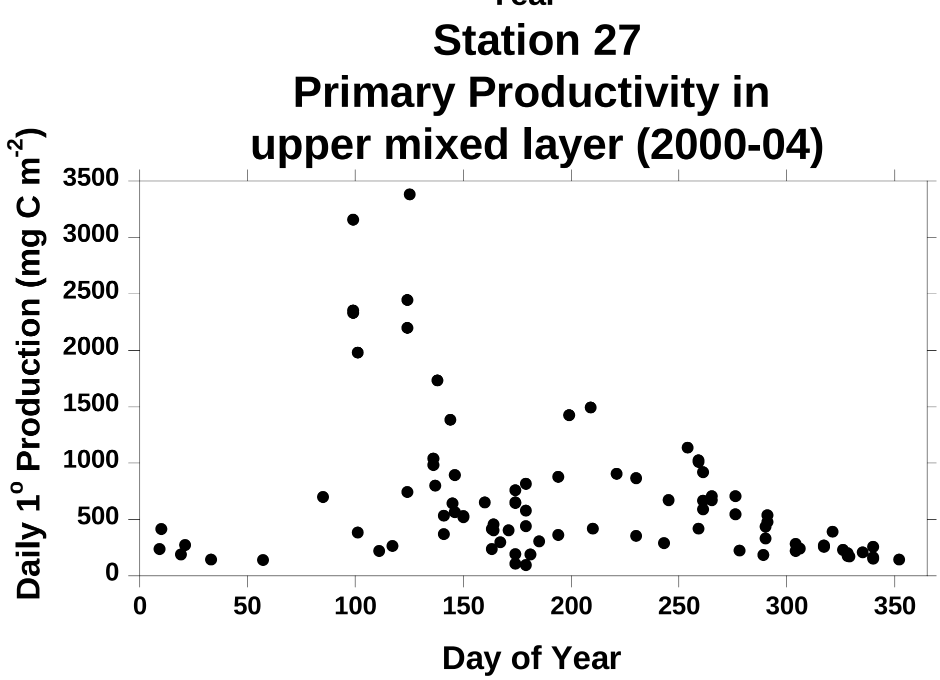


Figure 12. Time series of daily primary production in the upper mixed layer depth and climatology at Station 27 during 2000-04.

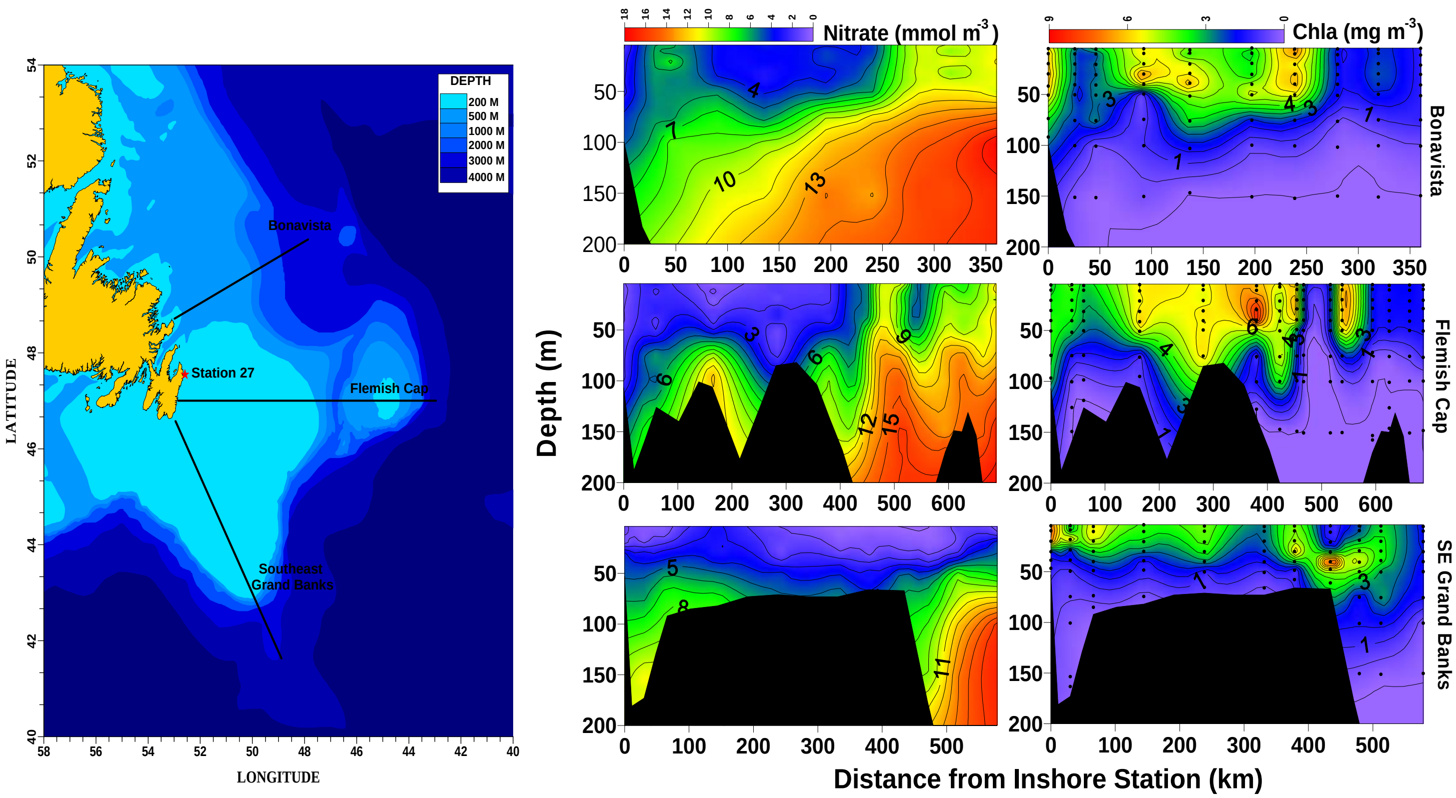


Figure 13. Vertical nitrate and chlorophyll a structure along the Newfoundland Shelf sections during the spring survey in 2004.

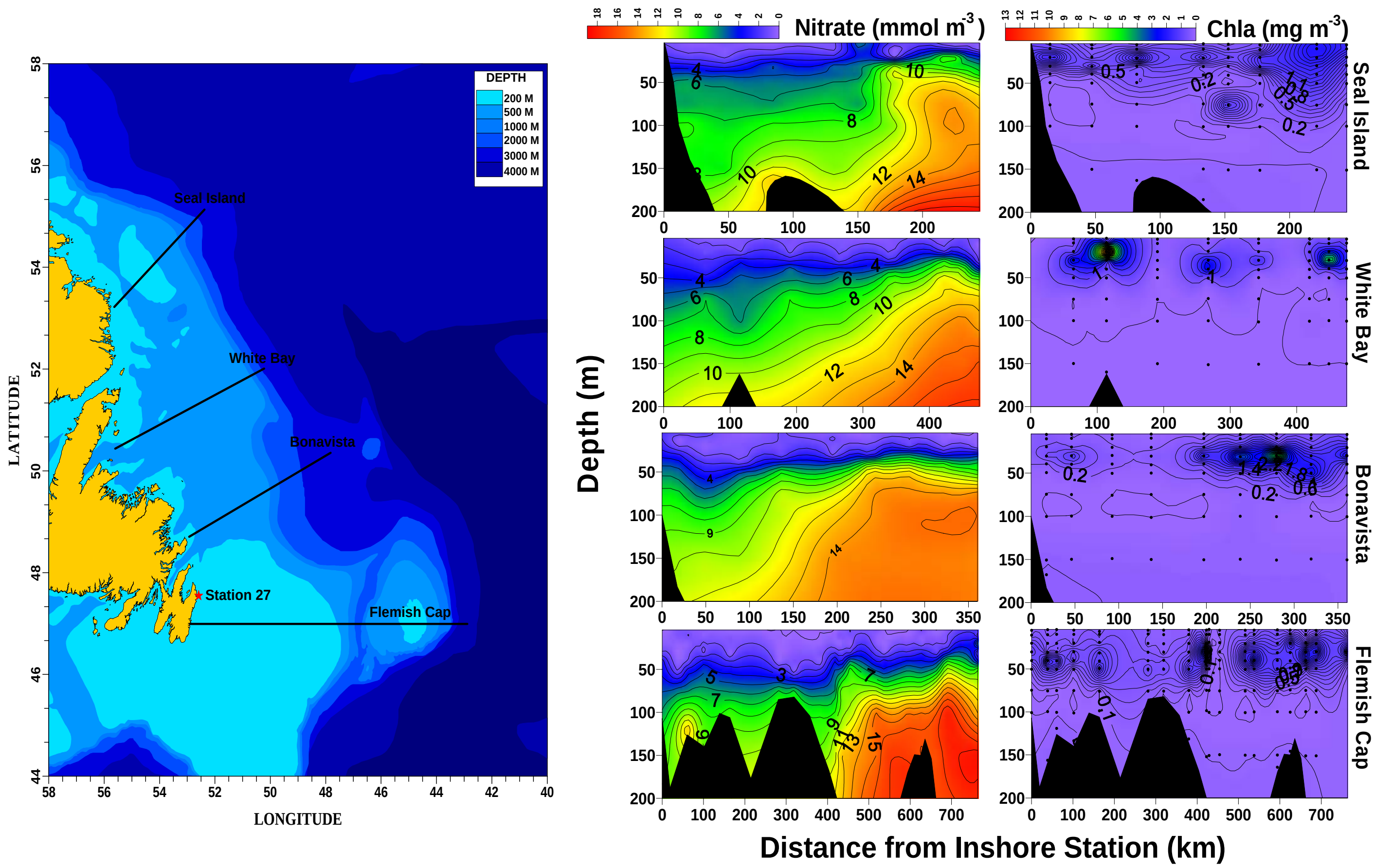


Figure 14. Vertical nitrate and chlorophyll a structure along the Newfoundland and Labrador Shelf sections during the summer survey in 2004.

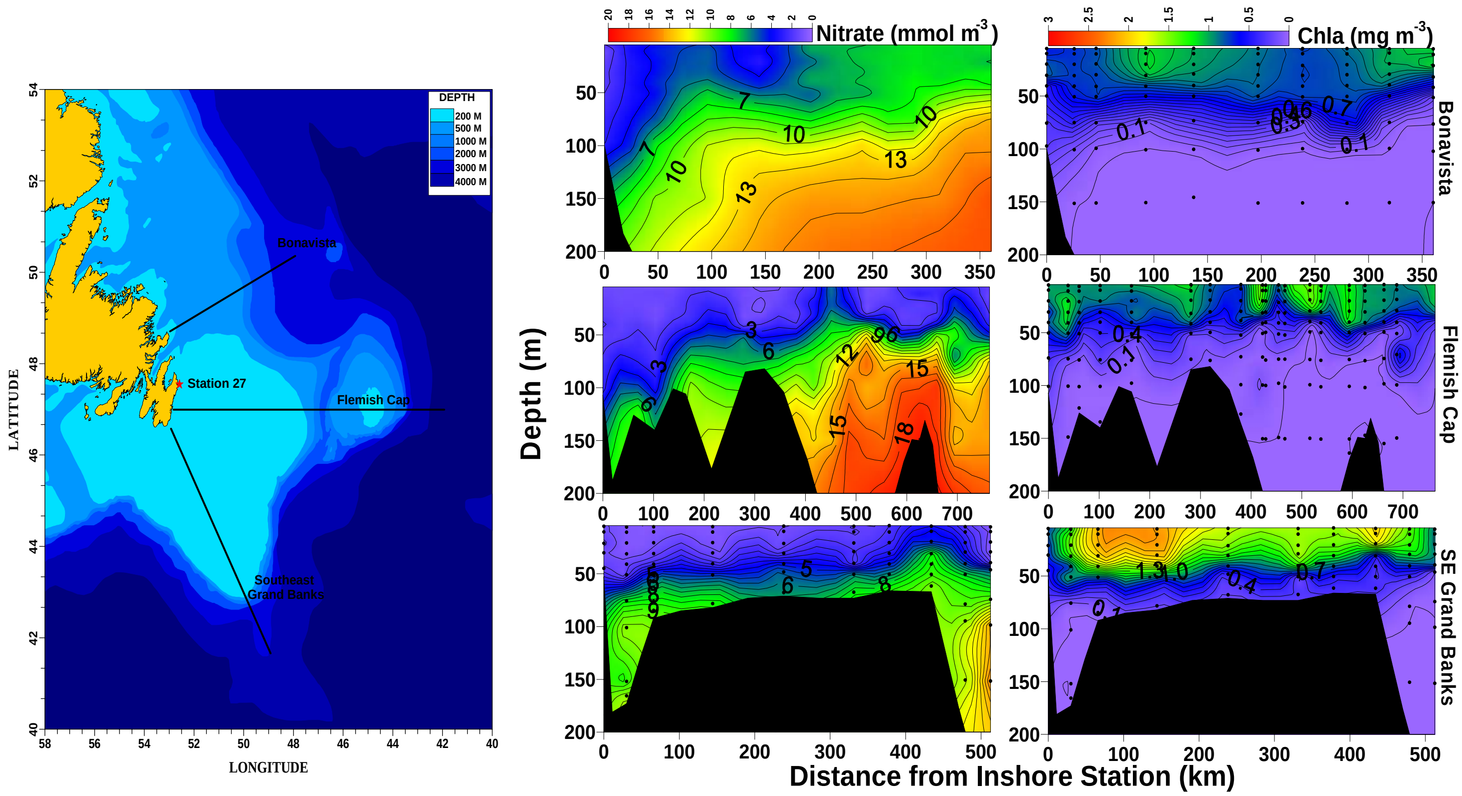


Figure 15. Vertical nitrate and chlorophyll a structure along the Newfoundland Shelf sections during the autumn survey in 2004.

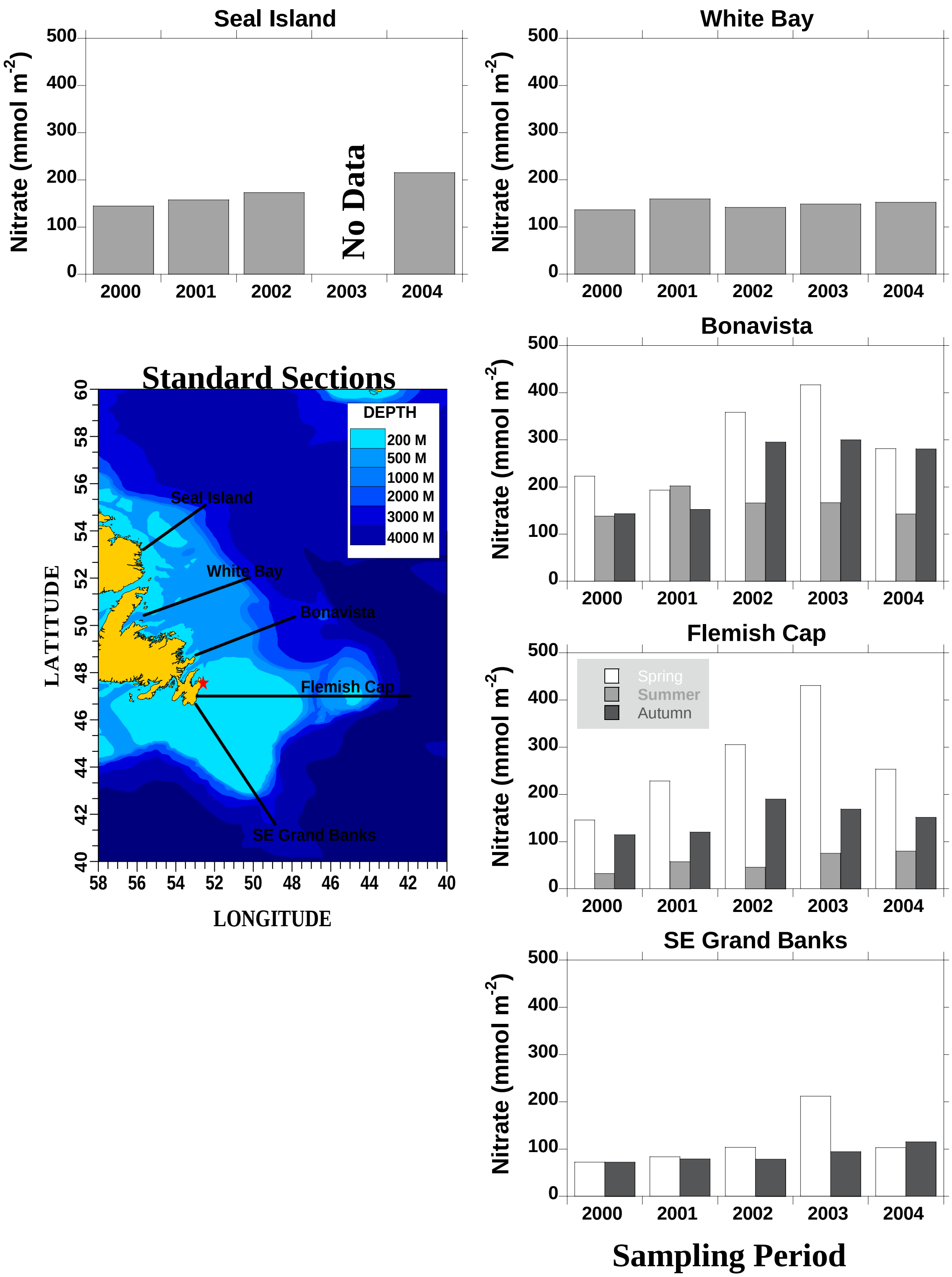


Figure 16. Mean nitrate concentrations (surface-50m integrals) along the Newfoundland and Labrador Shelf sections during the seasonal surveys, 2000-04.

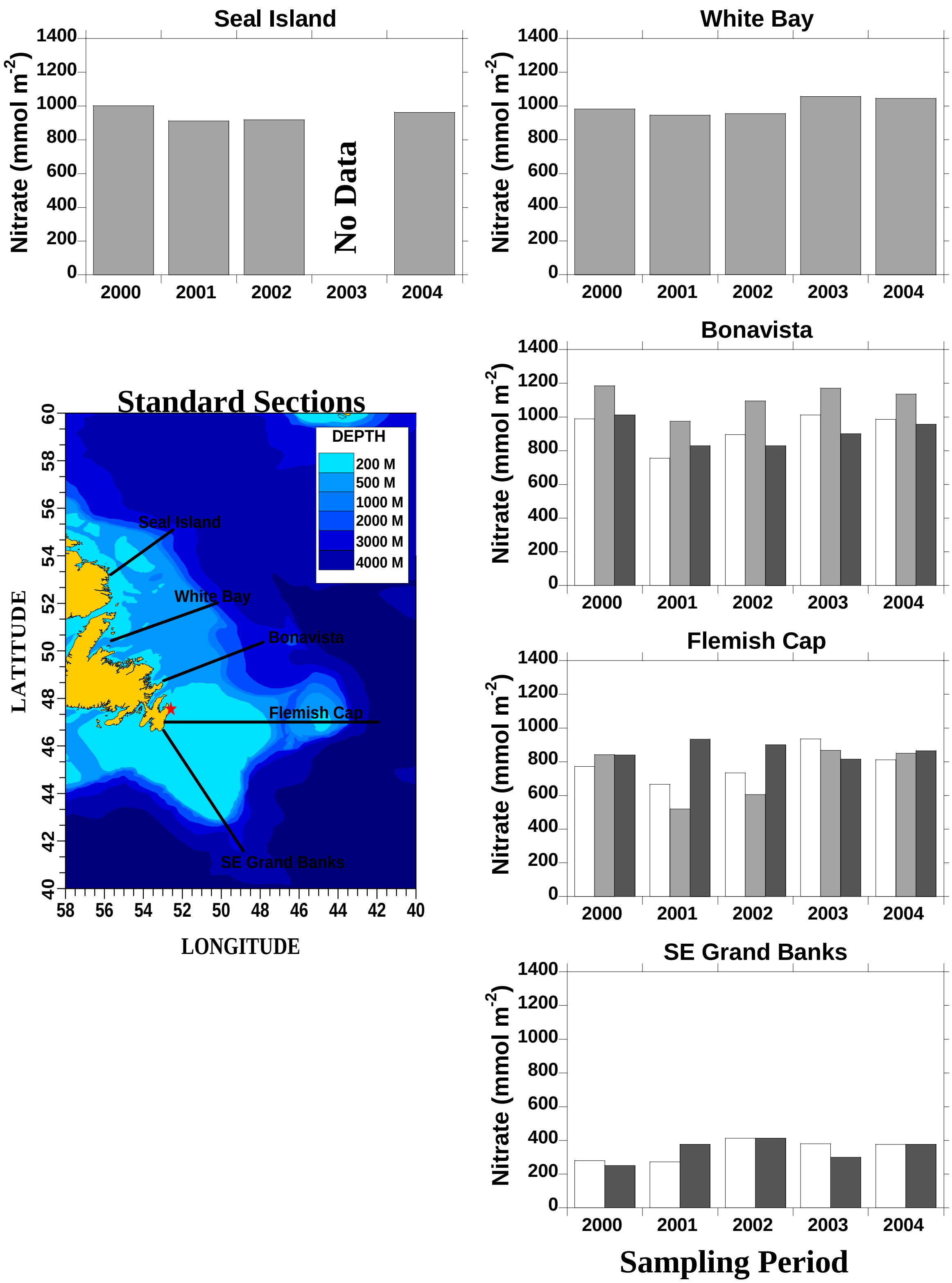


Figure 17. Mean nitrate concentrations (50-150m integrals) along the Newfoundland and Labrador Shelf sections during the seasonal surveys, 2000-04.

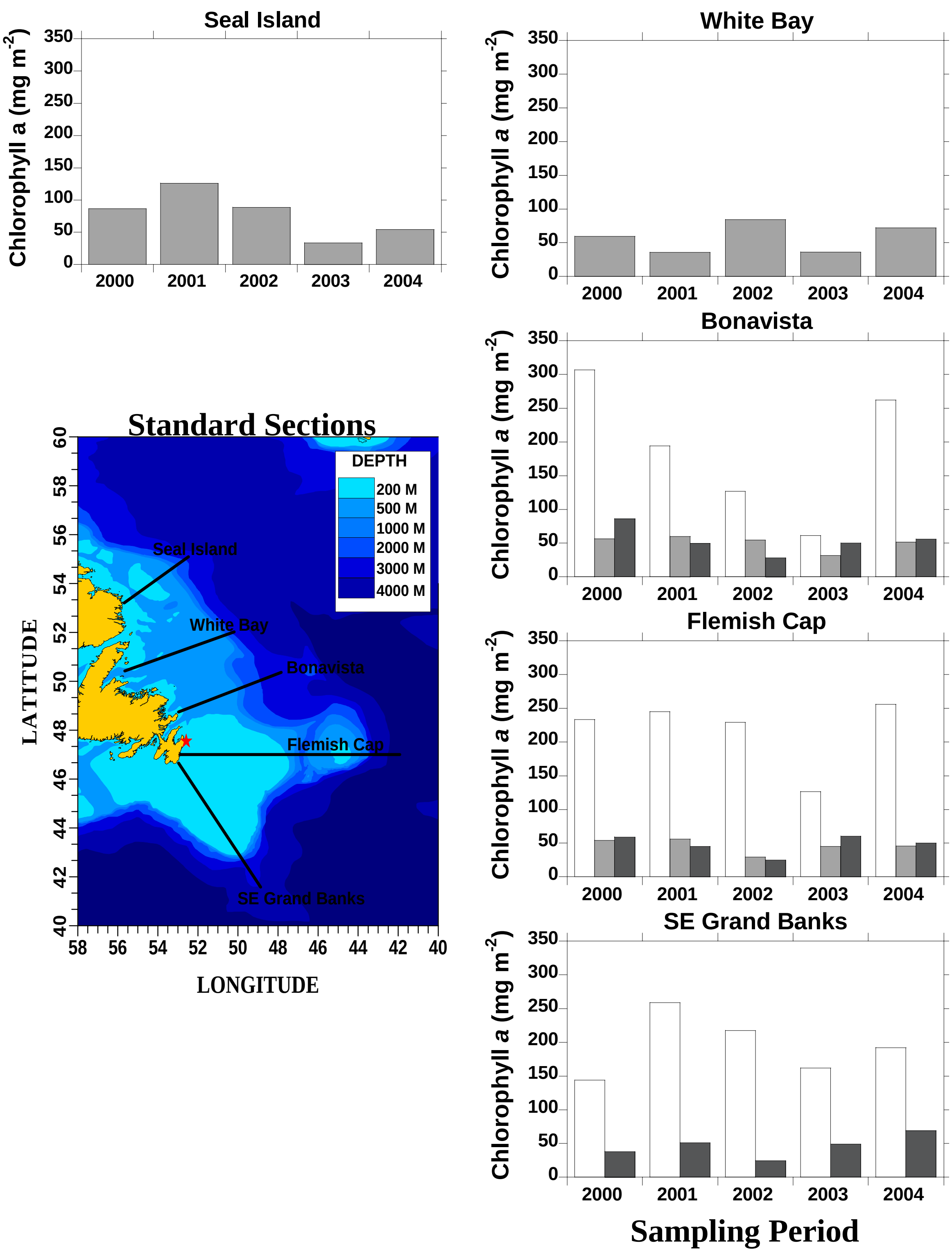


Figure 18. Mean chlorophyll *a* concentrations (0-100m integrals) along the Newfoundland and Labrador Shelf sections during the seasonal surveys, 2000-04.

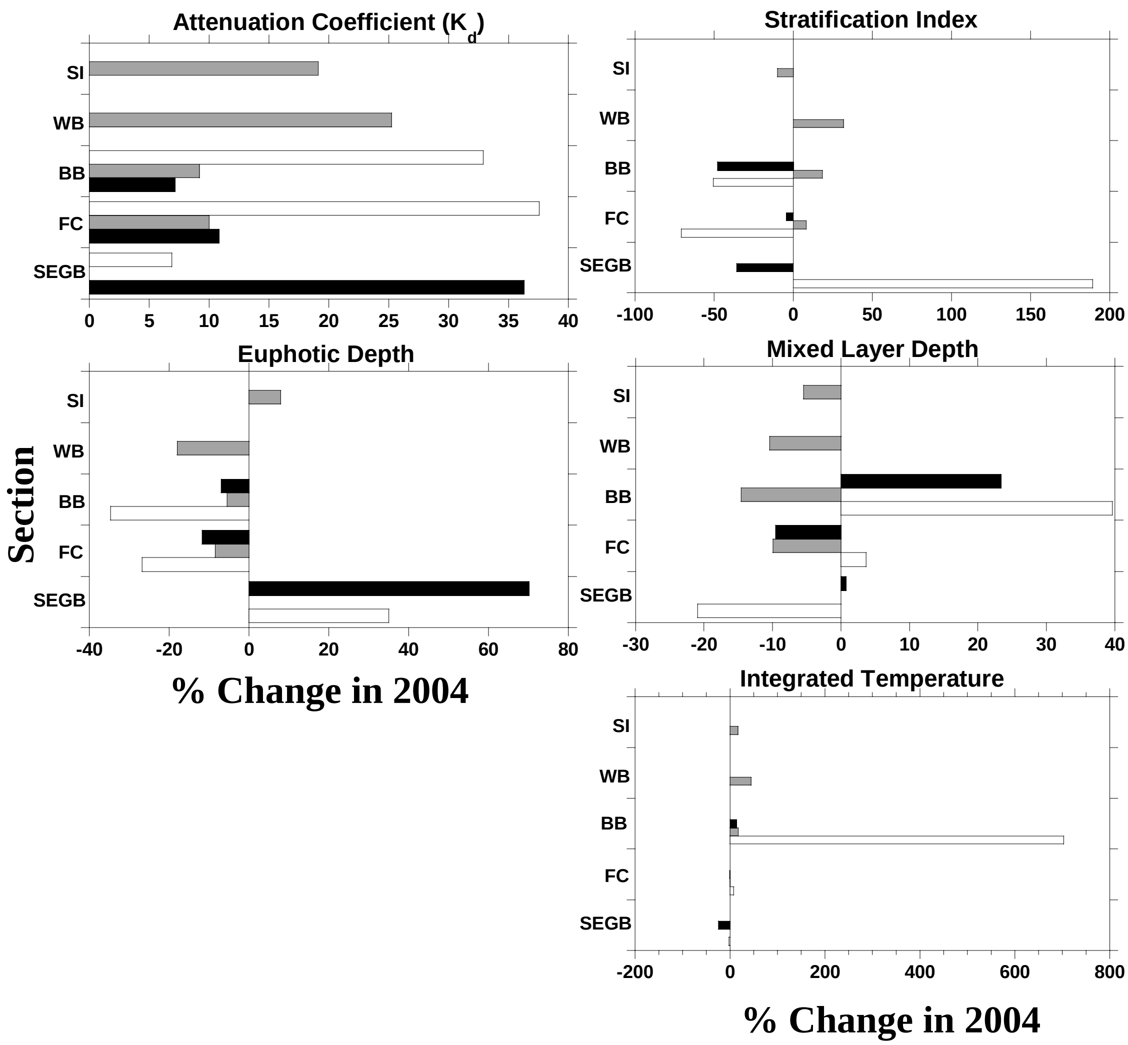


Figure 19. The percent change in optical and physical variables in 2004 compared to earlier years (2000-03) along sections (mean of section) during seasonal occupations. Sections include the southeast Grand Banks (SEGB); Flemish Cap (FC); Bonavista Bay (BB); White Bay (WB); and Seal Island (SI) and ordered by latitude. See Figure 1 for detailed station locations.

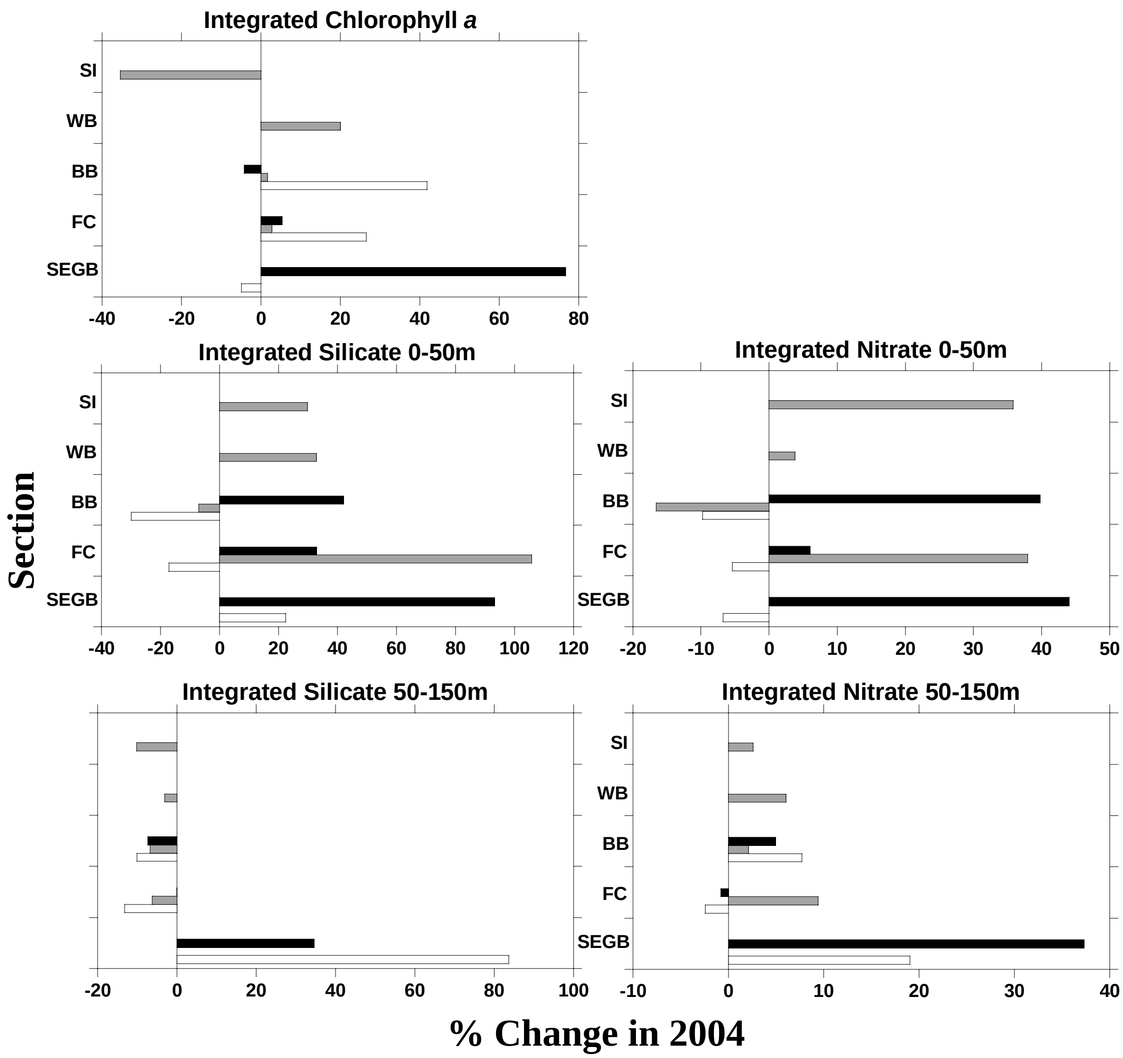


Figure 20. The percent change in chlorophyll *a* and nutrient inventories in 2004 compared to earlier years (2000-03) along sections (mean of section) during seasonal occupations. Sections include the southeast Grand Banks (SEGB); Flemish Cap (FC); Bonavista Bay (BB); White Bay (WB); and Seal Island (SI) and ordered by latitude. See Figure 1 for detailed station locations.

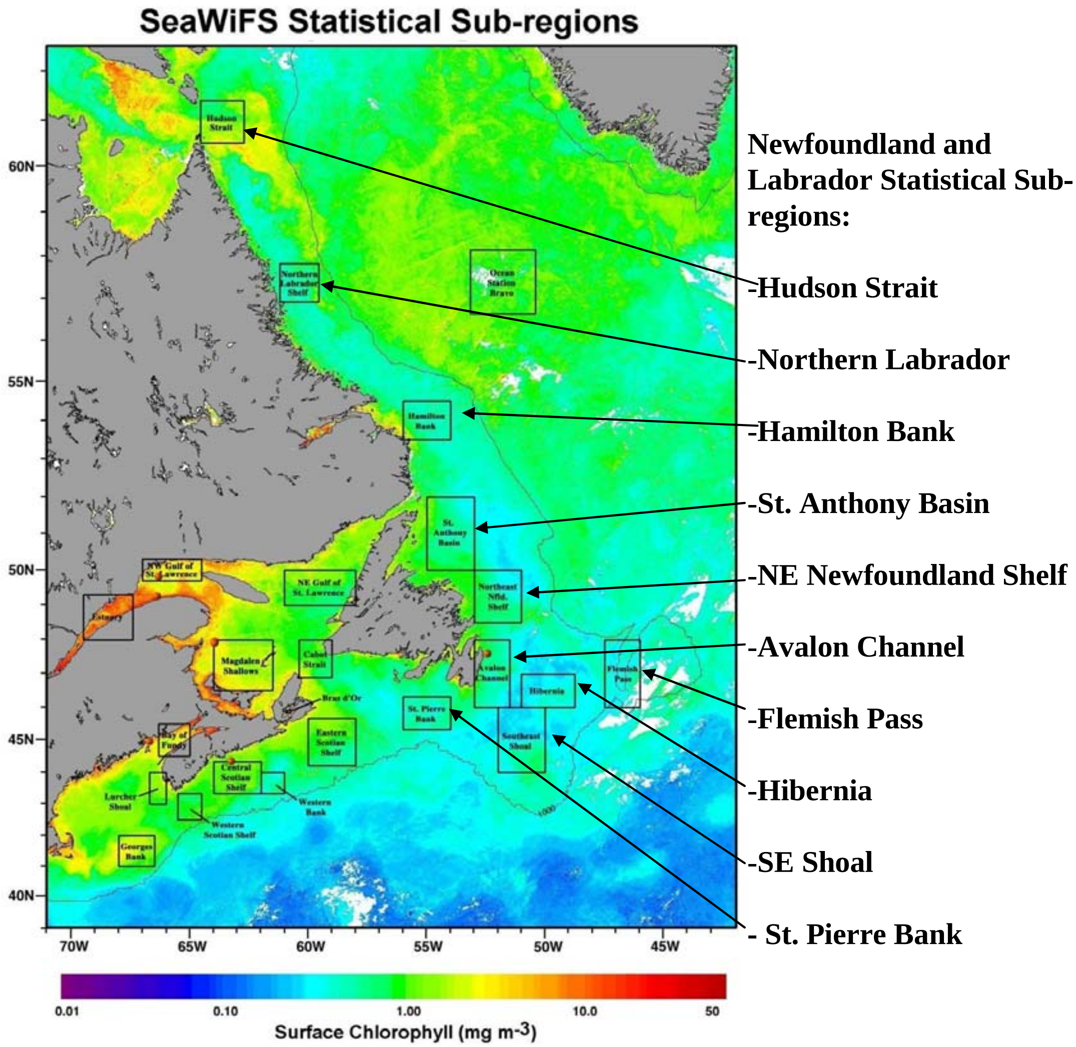


Figure 21. SeaWiFS statistical sub-regions identifed for spatial-temporal analysis of ocean colour data in the Newfoundland and Labrador region.

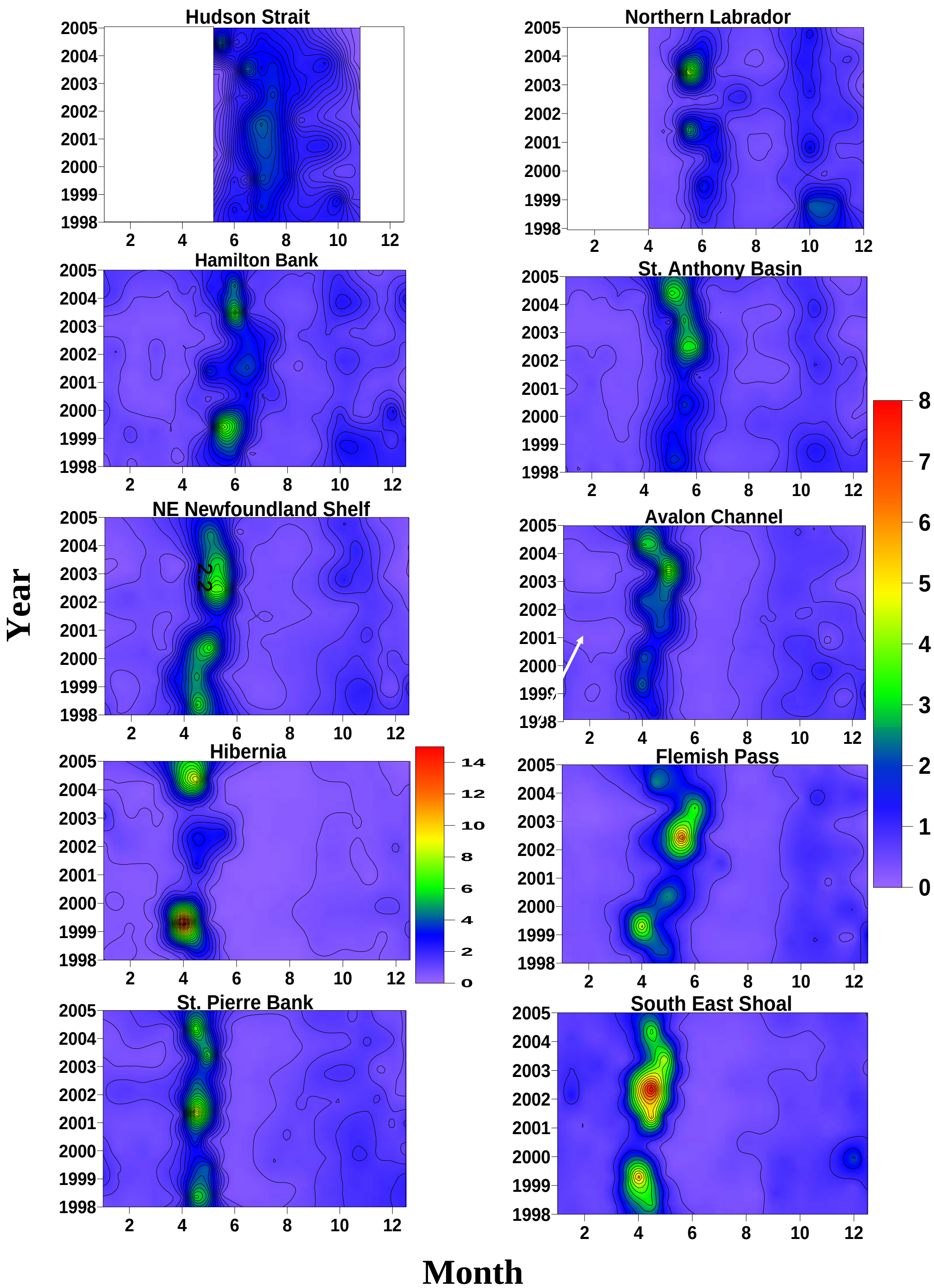


Figure 22. Time series of surface chlorophyll *a* concentrations (mg m^{-3}) from SeaWiFS bi-weekly ocean colour composites, along the Newfoundland and Labrador Statistical Sub-regions from 1998-2004.

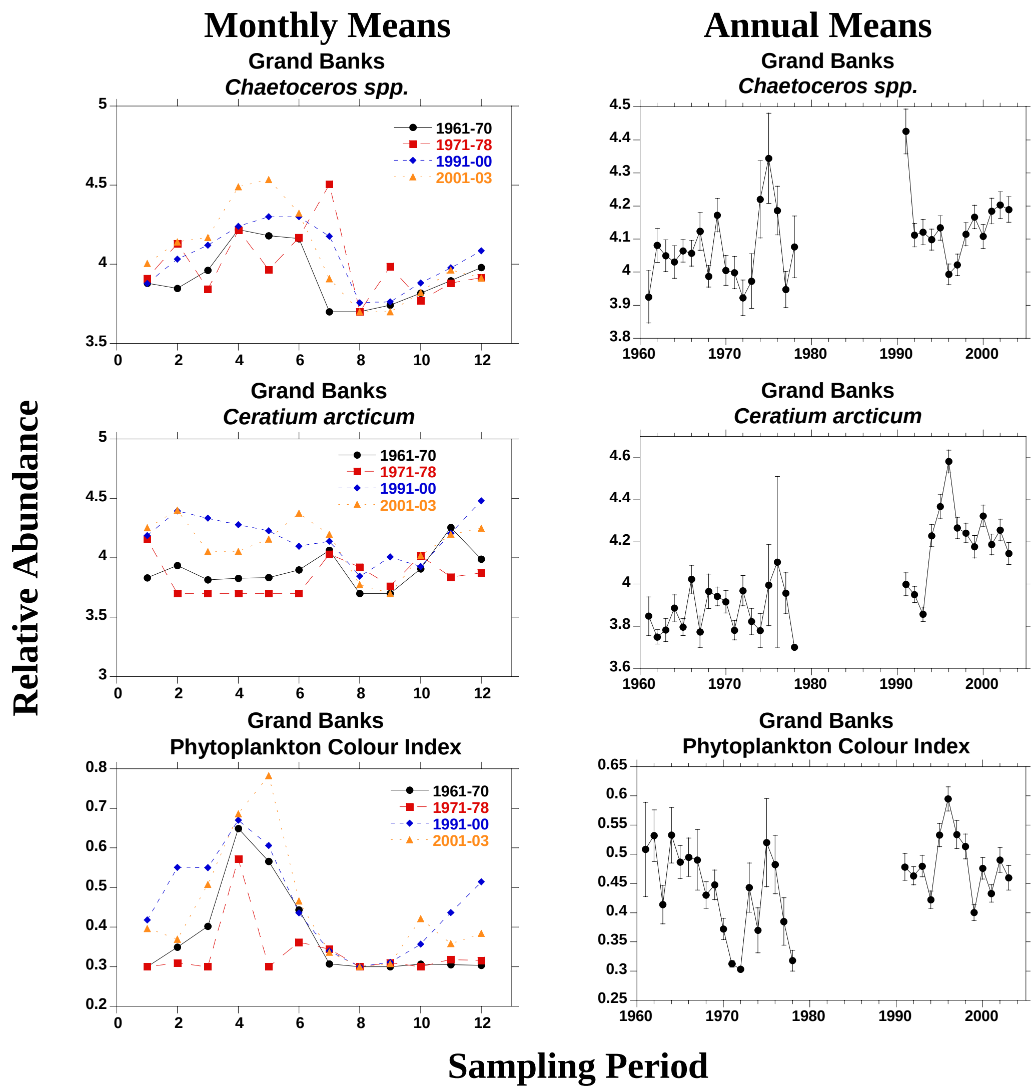


Figure 23. Time series of relative abundance (monthly and annual means) of selected phytoplankton categories from the Grand Banks (NAFO Divisions 3L and 3Ps) from the CPR Surveys 1961-2003. Vertical bars are standard errors.

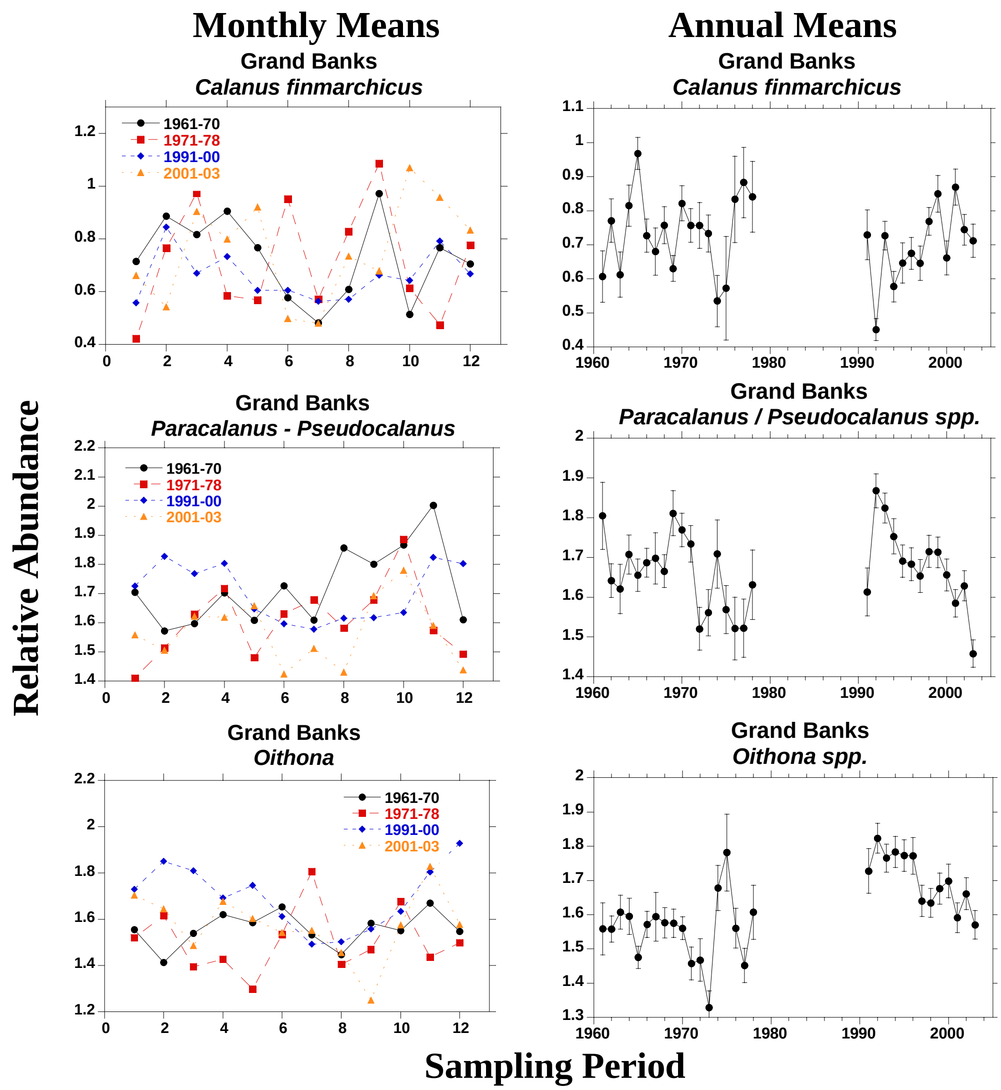


Figure 24. Time series of relative abundance (monthly and annual means) of selected copepods (all stages) from the Grand Banks (NAFO Divisions 3L and 3Ps) from the CPR Surveys 1961-2003. Vertical bars are standard errors.

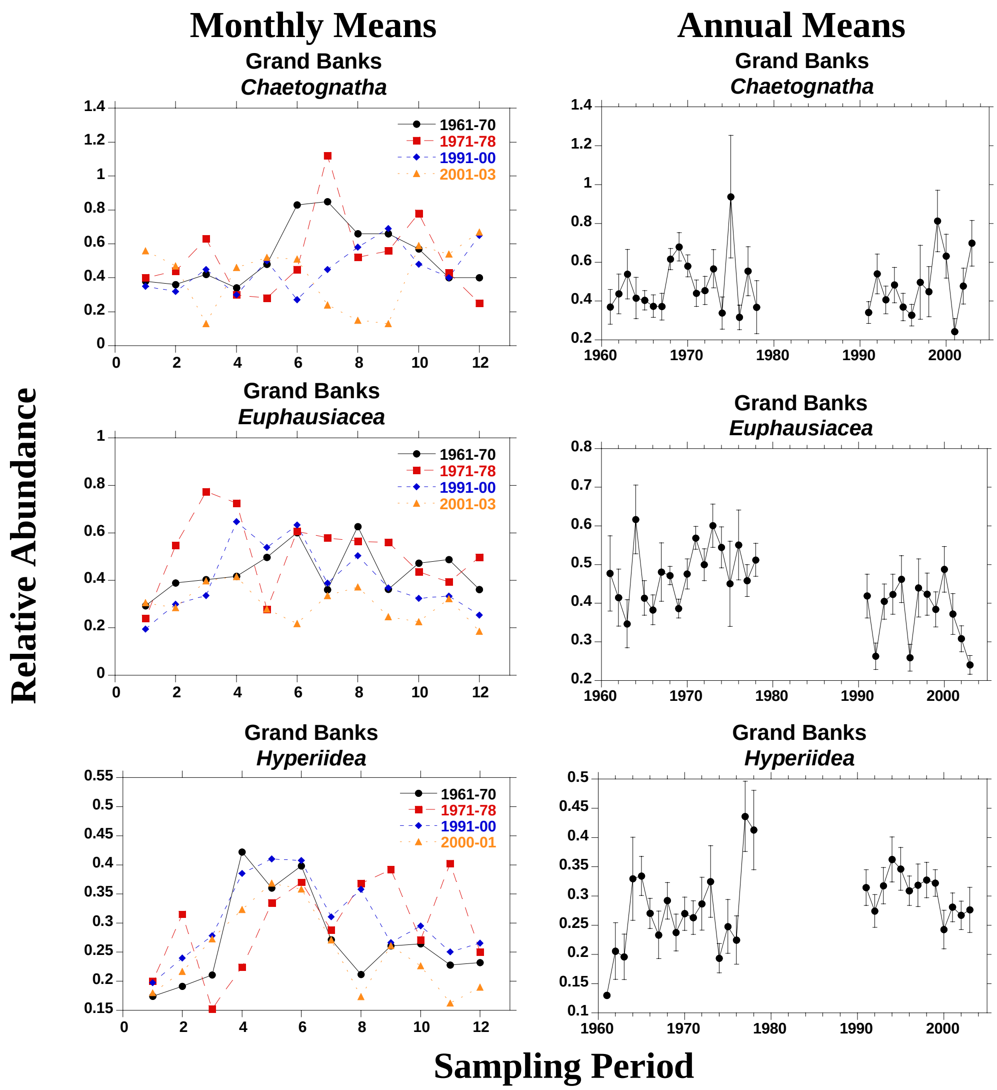


Figure 25. Time series of relative abundance (monthly and annual means) of selected macrozooplankton (all stages) from the Grand Banks (NAFO Divisions 3L and 3Ps) from the CPR Surveys 1961-2003. Vertical bars are standard errors.

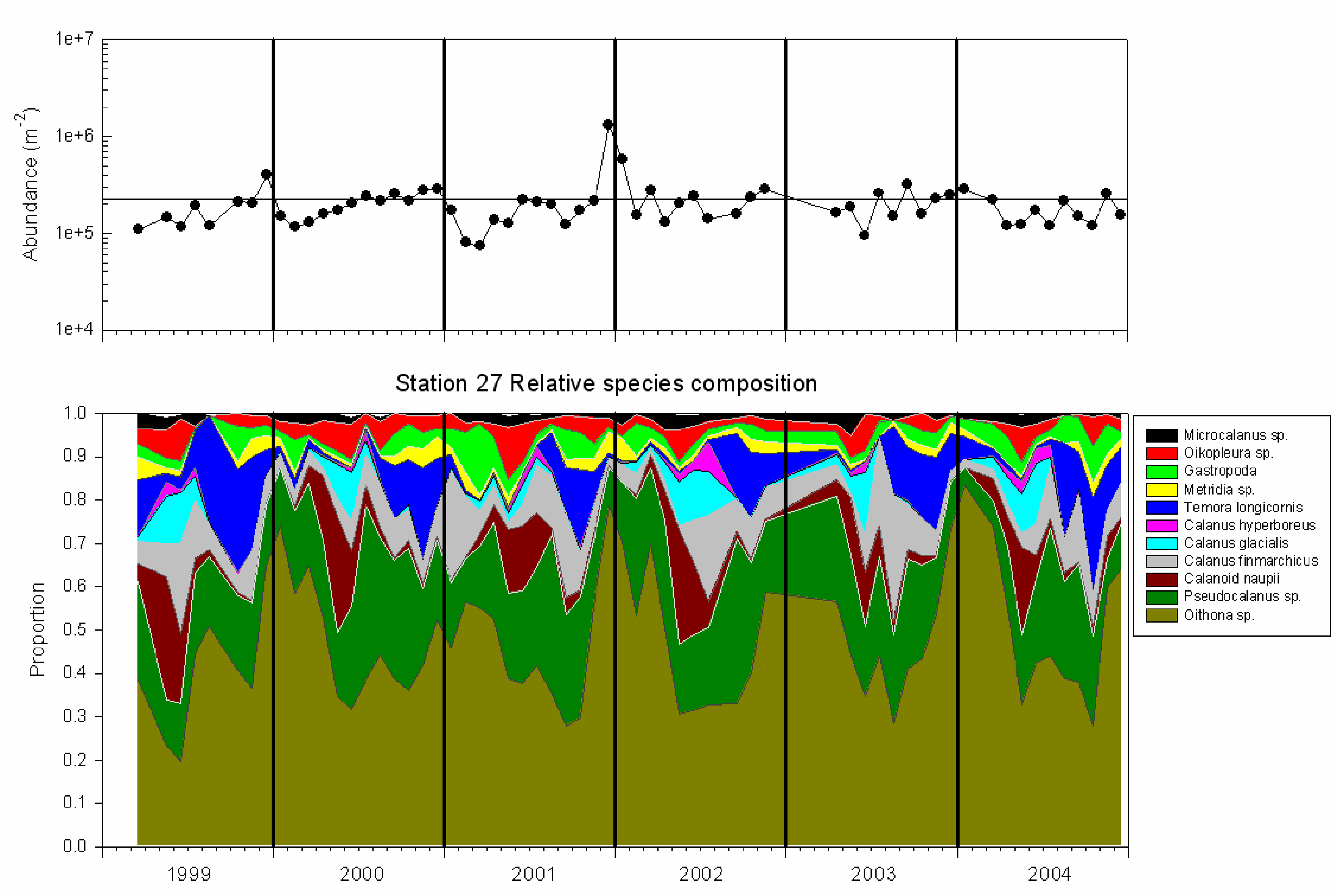


Figure 26. Time series of total zooplankton abundance (upper panel) and relative species composition (Lower panel) from vertical net collections performed at Station 27 since the inception of the AZMP.

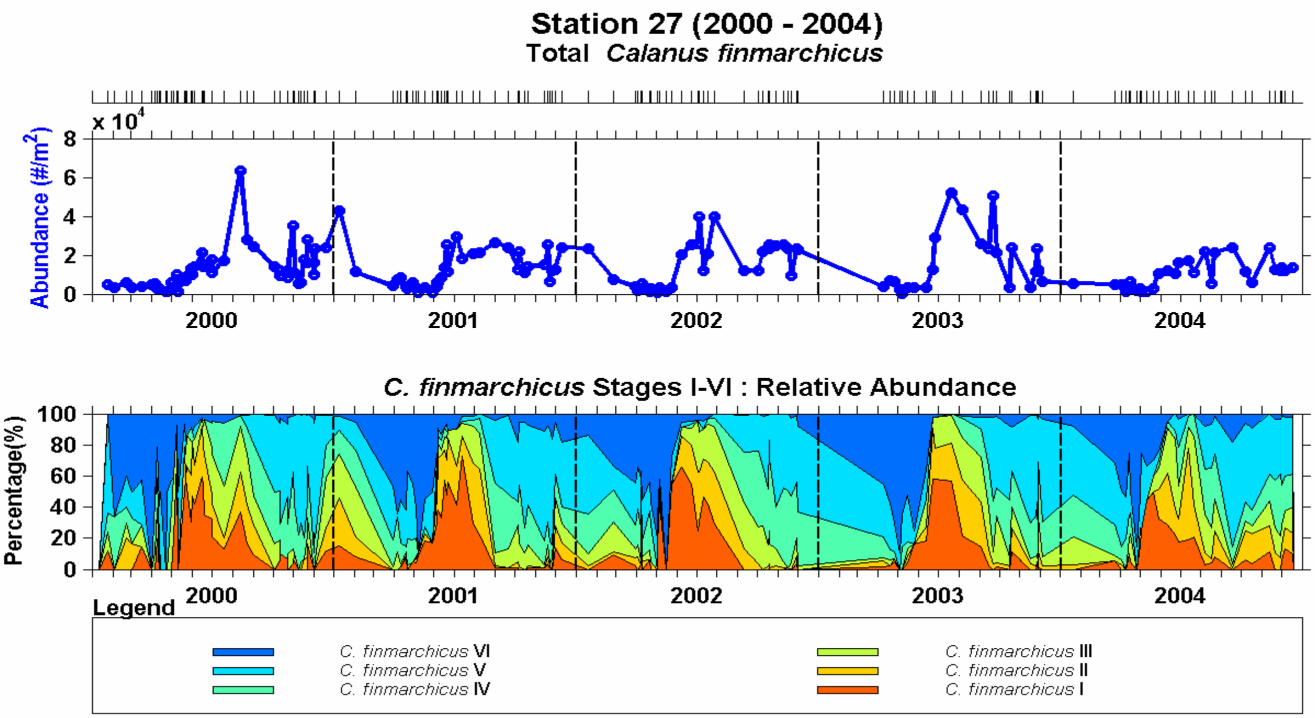


Figure 27. Time series of abundance and copepodite relative stage composition of *Calanus finmarchicus* at Station 27. The tick marks at the top of the figure indicates the collection times of samples.

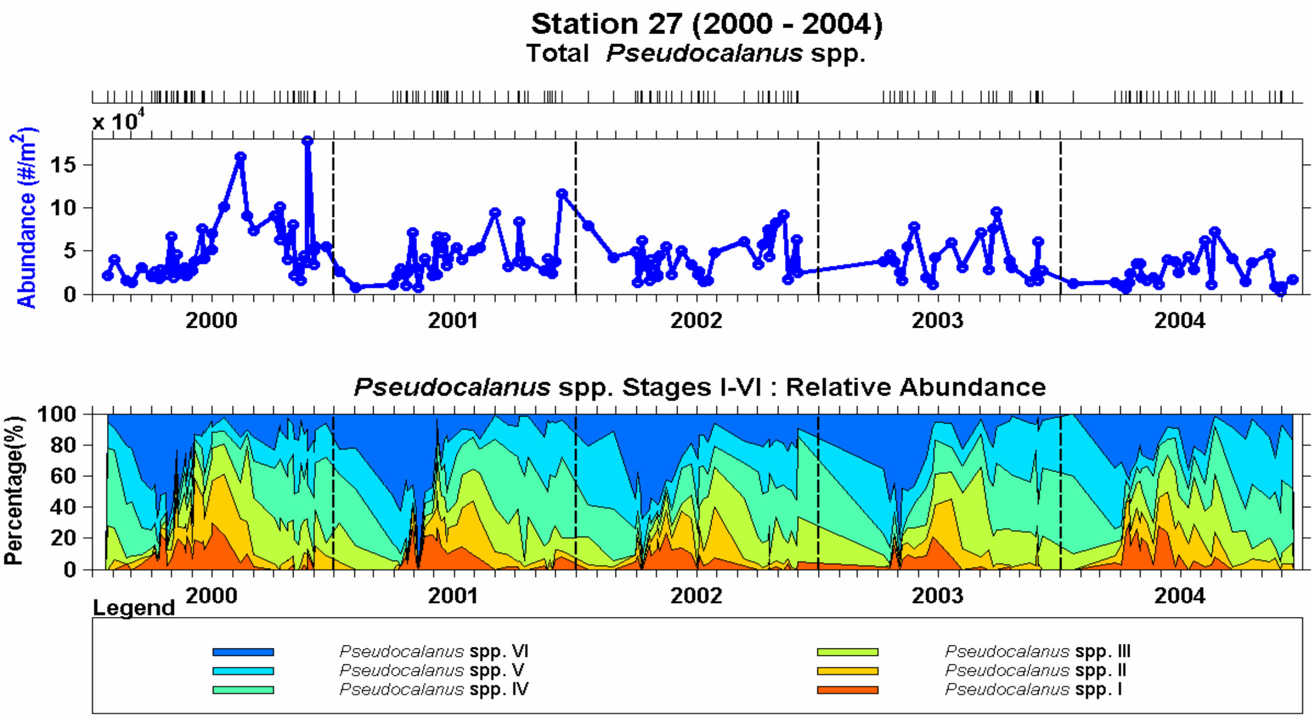


Figure 28. Time series of abundance and copepodite relative stage composition of *Pseudocalanus* sp. at Station 27. The tick marks at the top of the figure indicates the collection times of samples.

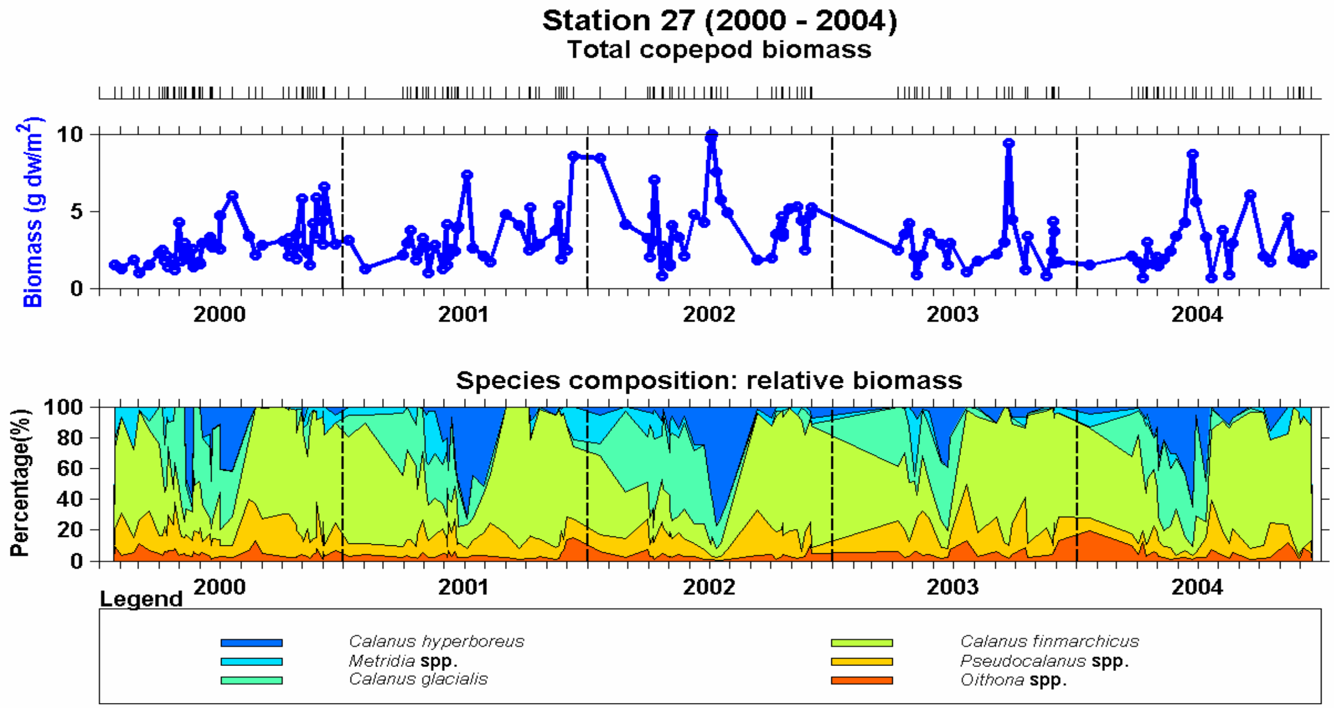


Figure 29. Time series of total biomass and copepodite relative biomass composition of the six dominant species found at Station 27. The tick marks at the top of the figure indicates the collection times of samples.

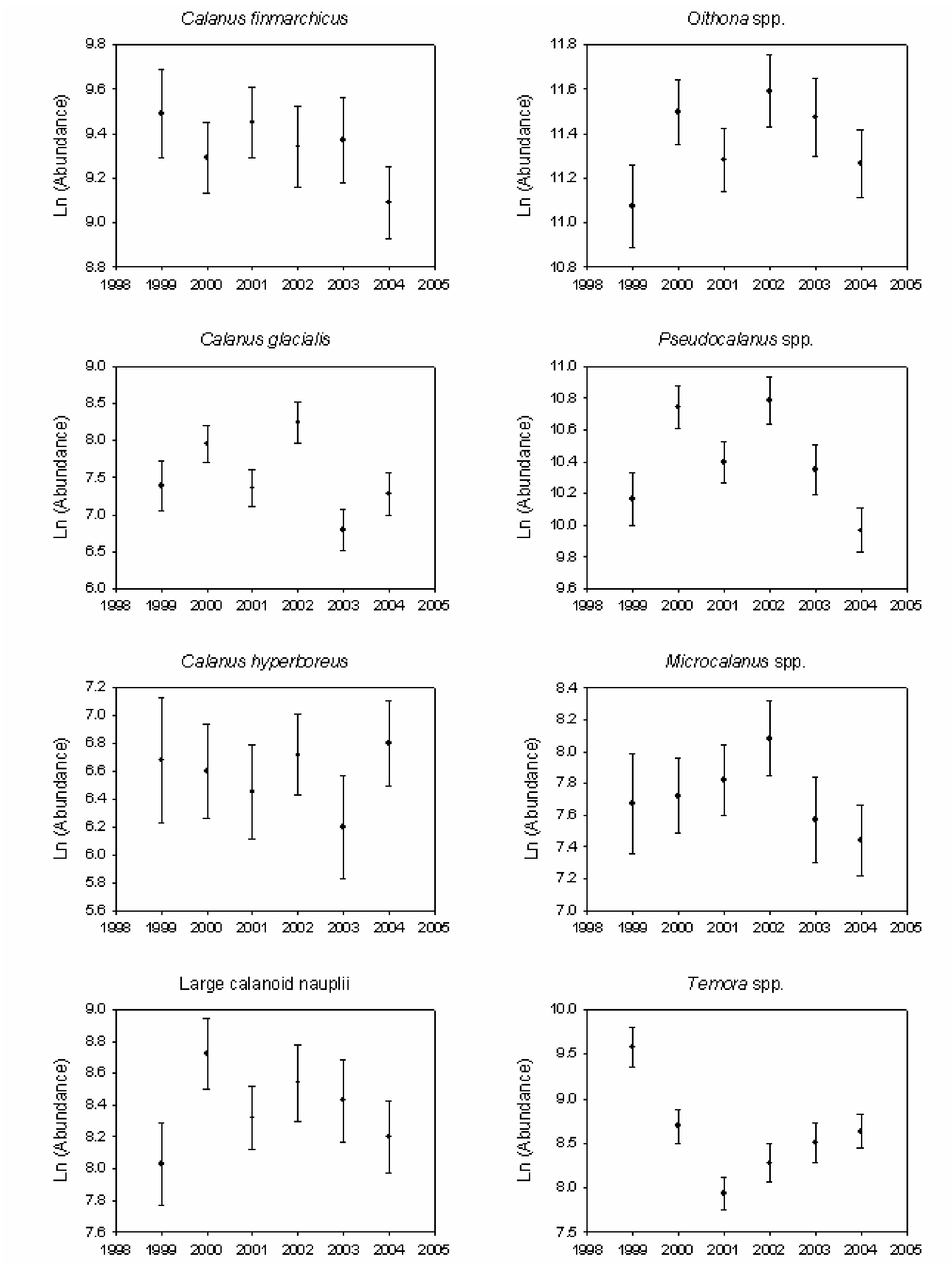


Figure 30. Least-squares seasonally adjusted mean abundance of the dominant zooplankton taxa at Station 27. Estimates are derived from an analysis of variance for each transect with year and station identifier as categorical variables. Error bars represent ± 1 standard error.

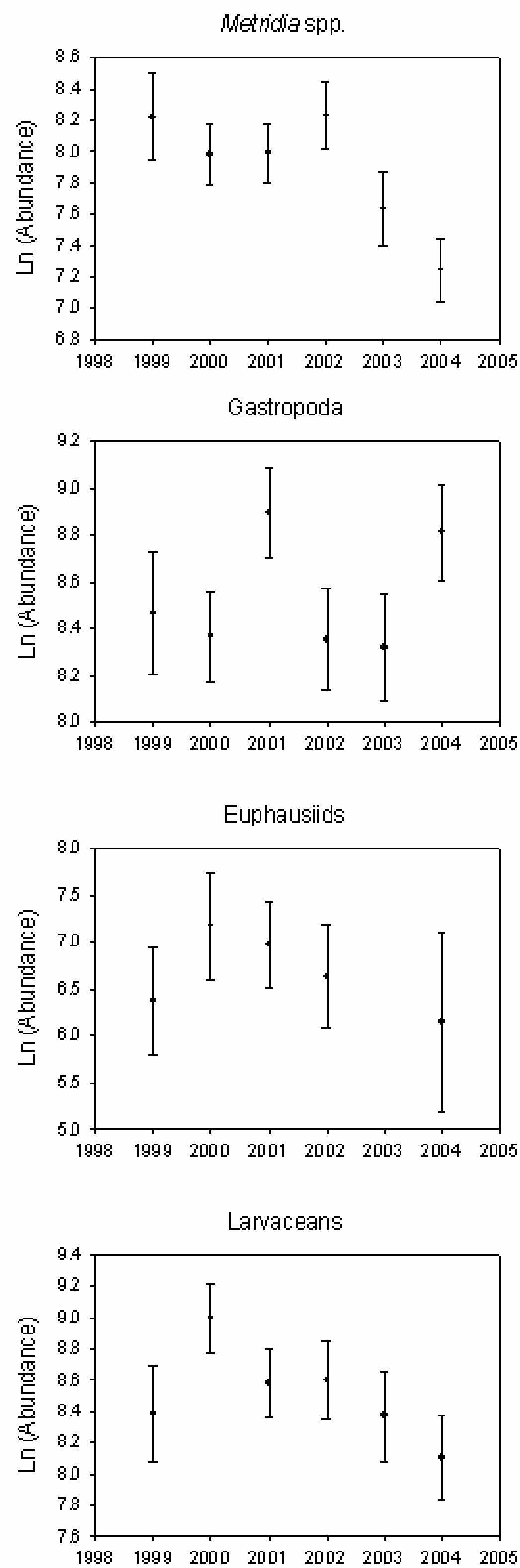


Figure 30. Continued

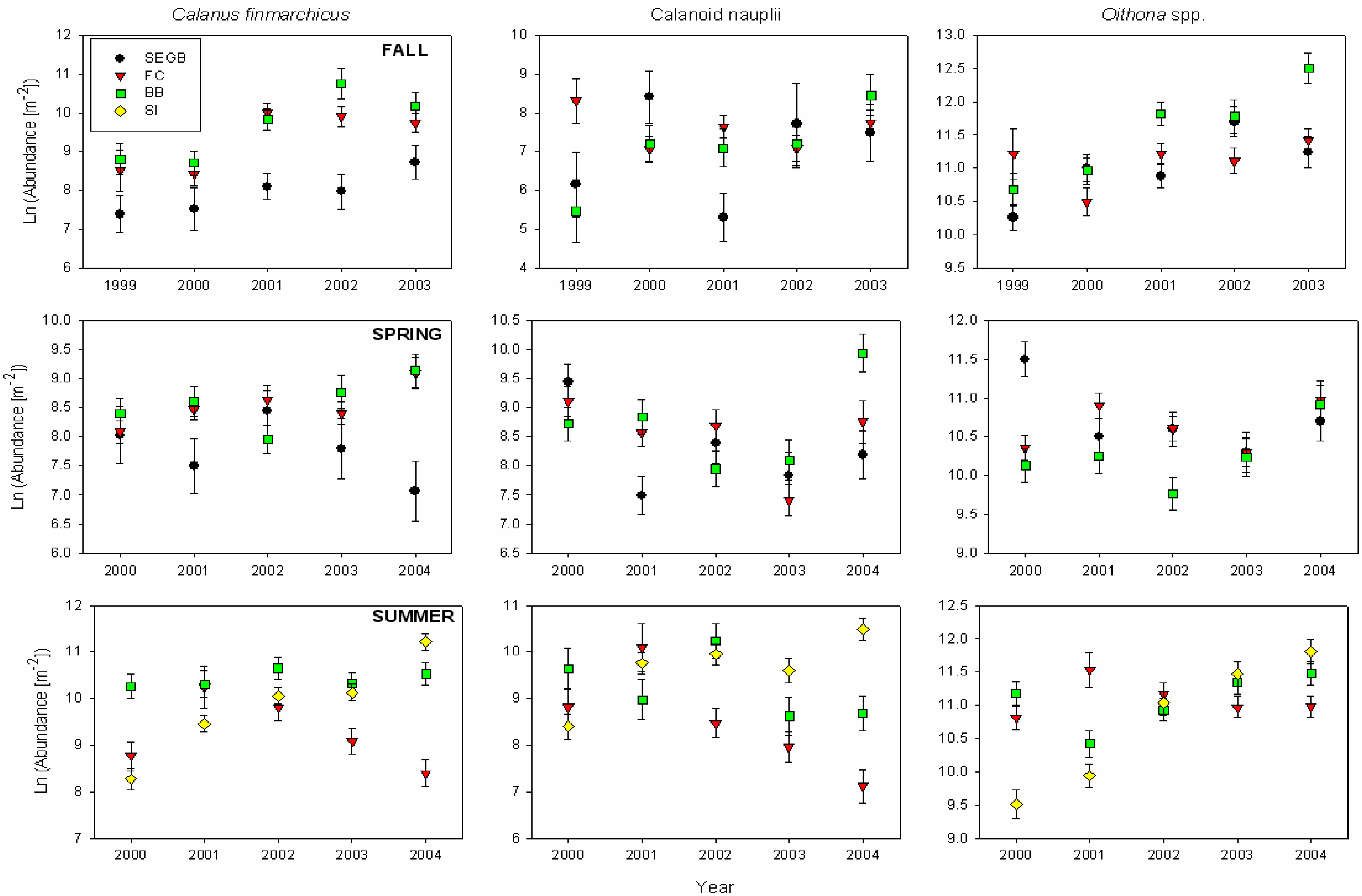


Figure 31. Least-squares mean adjusted abundance of *Calanus finmarchicus*, large calanoid nauplii and *Oithona* spp. for the fall, sping and summer oceanographic surveys conducted along the Southeast Grand Banks (SEGB), Flemish Cap (FC), Bonavista Bay (BB) and Seal Island (SI) transects. Estimates are derived from an analysis of variance for each transect with year and station identifier as categorical variables. Error bars represent ± 1 standard error.

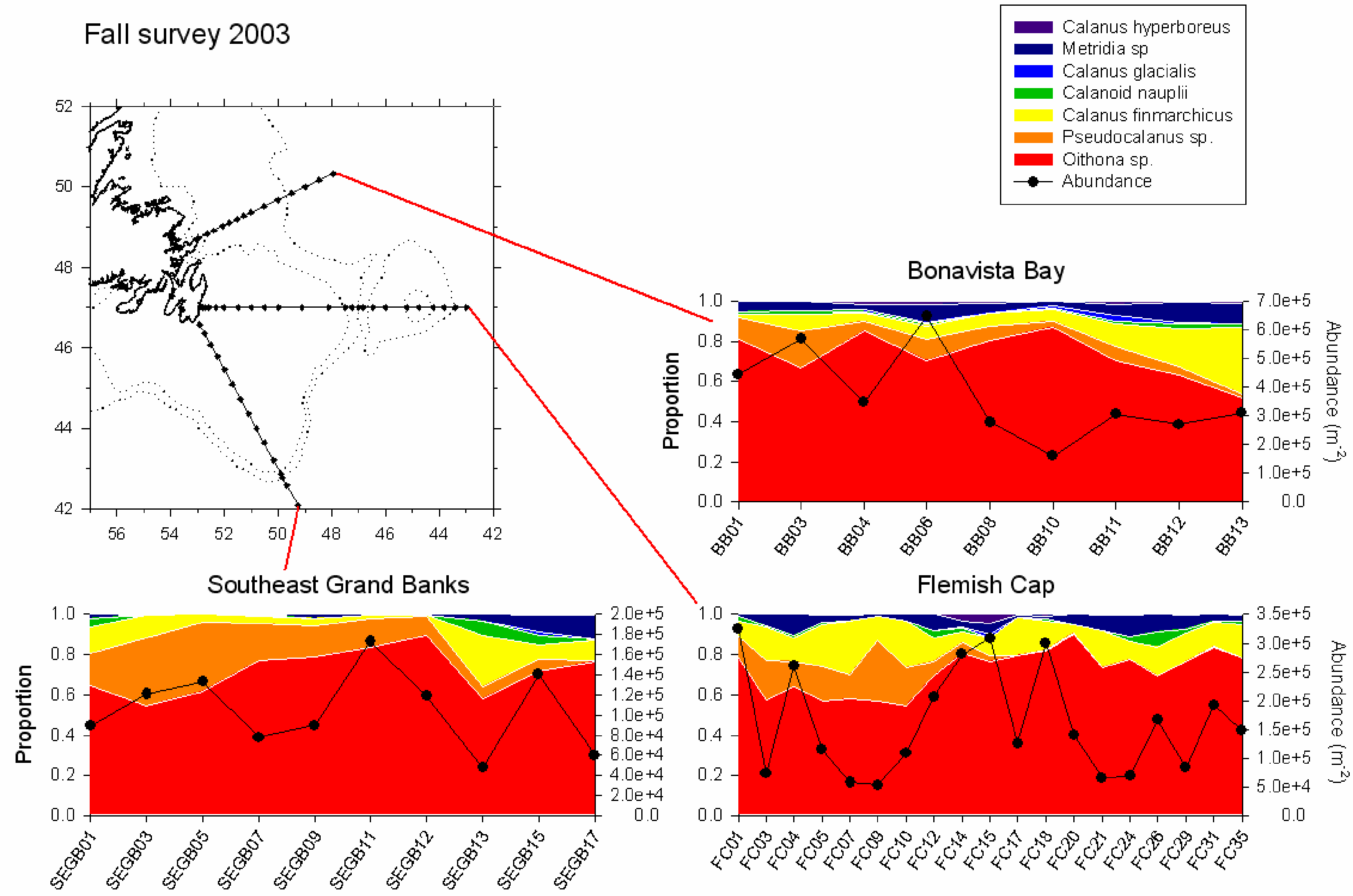


Figure 32. Relative composition of the dominant copepod species during November/December of 2003. The solid line indicates the total abundance of copepod stages at each site. With the exception of calanoid nauplii, all information presented is based on the abundance of copepodite stages. Station locations are indicated on the corresponding map.

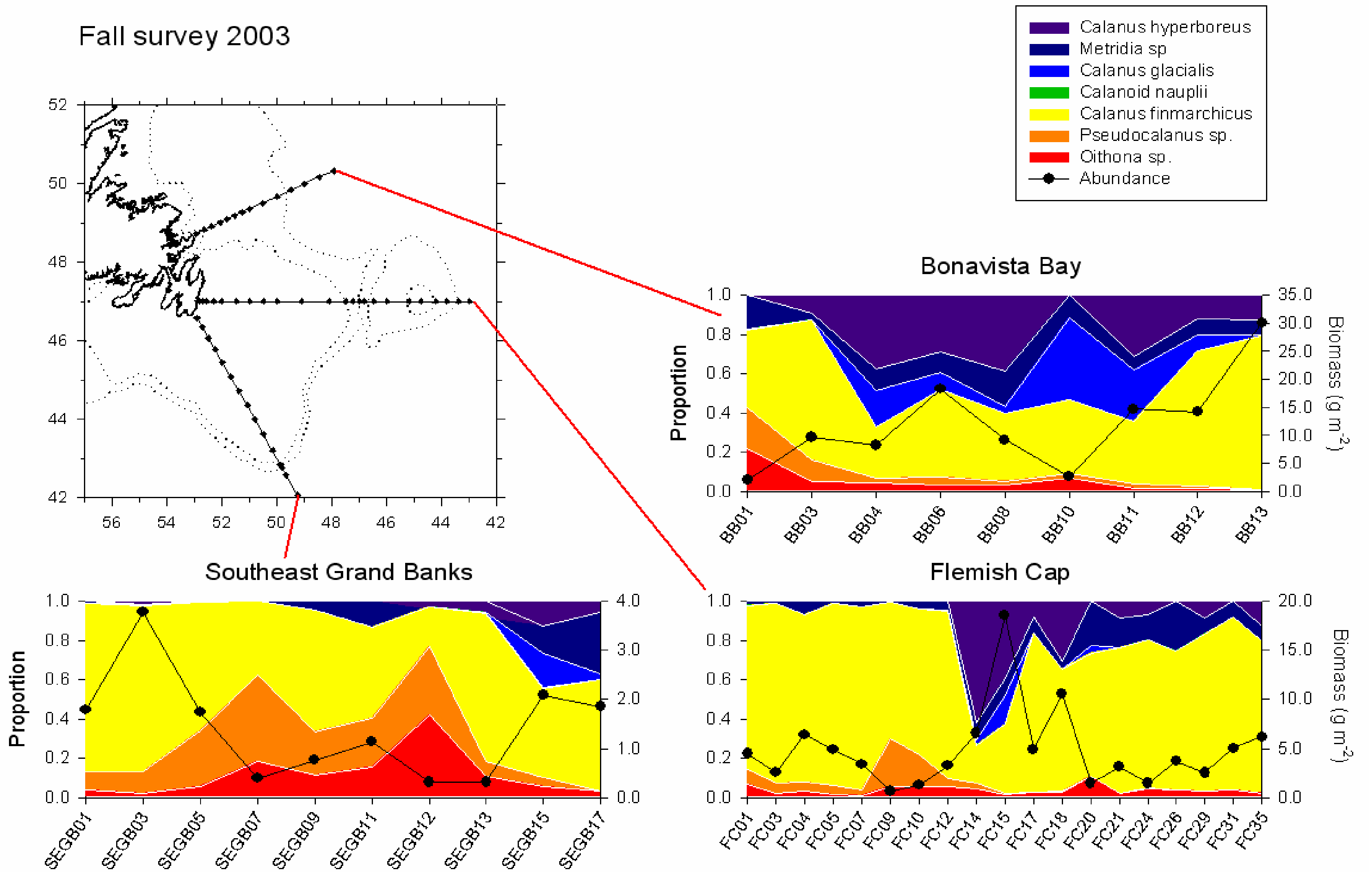


Figure 33. Relative biomass composition of the dominant copepod species during November/December of 2003. The solid line indicates the total biomass of copepod stages at each site. With the exception of calanoid nauplii, all information presented is based on the abundance of copepodite stages. Station locations are indicated on the corresponding map.

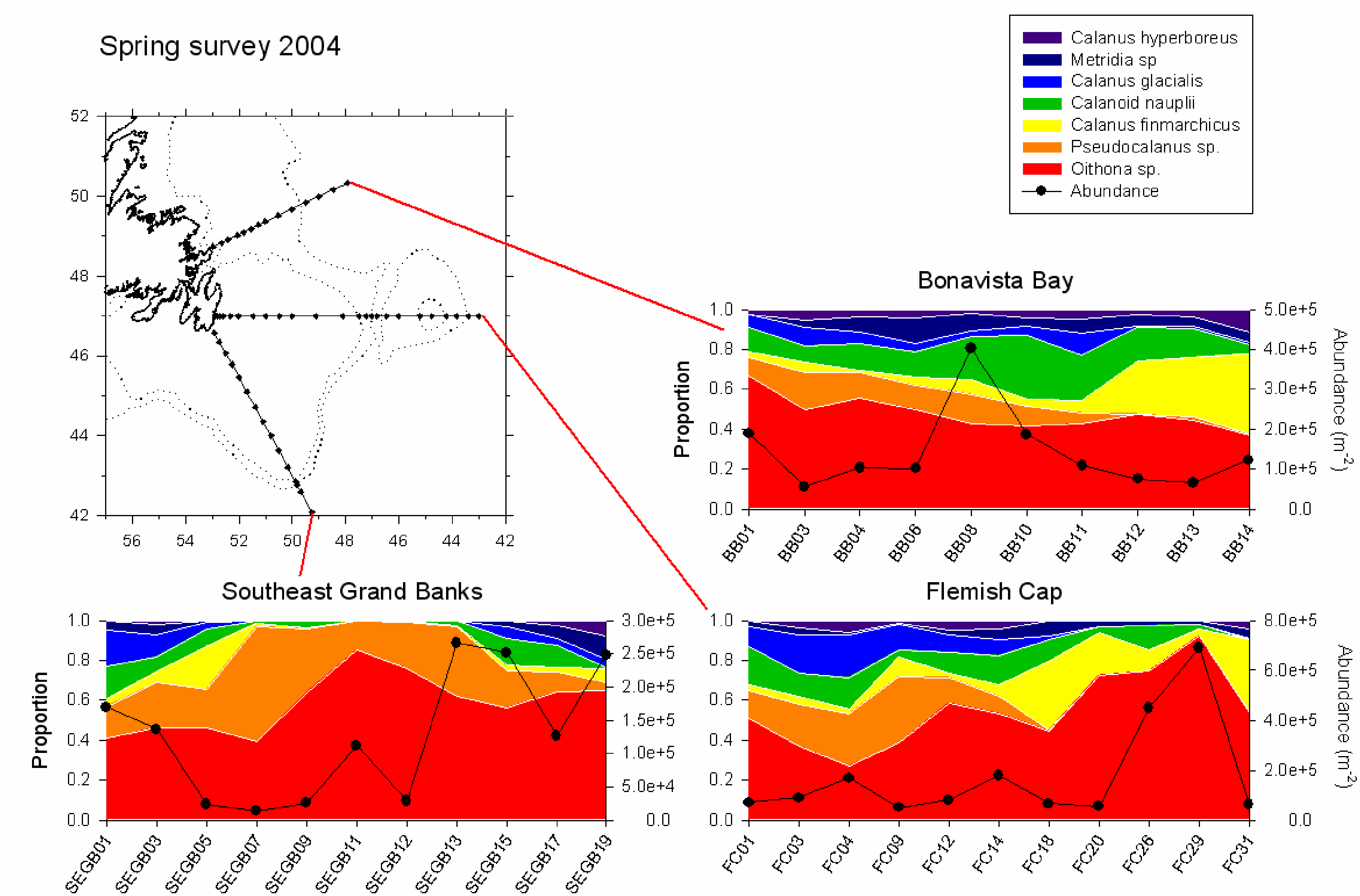


Figure 34. Relative composition of the dominant copepod species during April/May of 2004. The solid line indicates the total abundance of copepod stages at each site. With the exception of calanoid nauplii, all information presented is based on the abundance of copepodite stages. Station locations are indicated on the corresponding map.

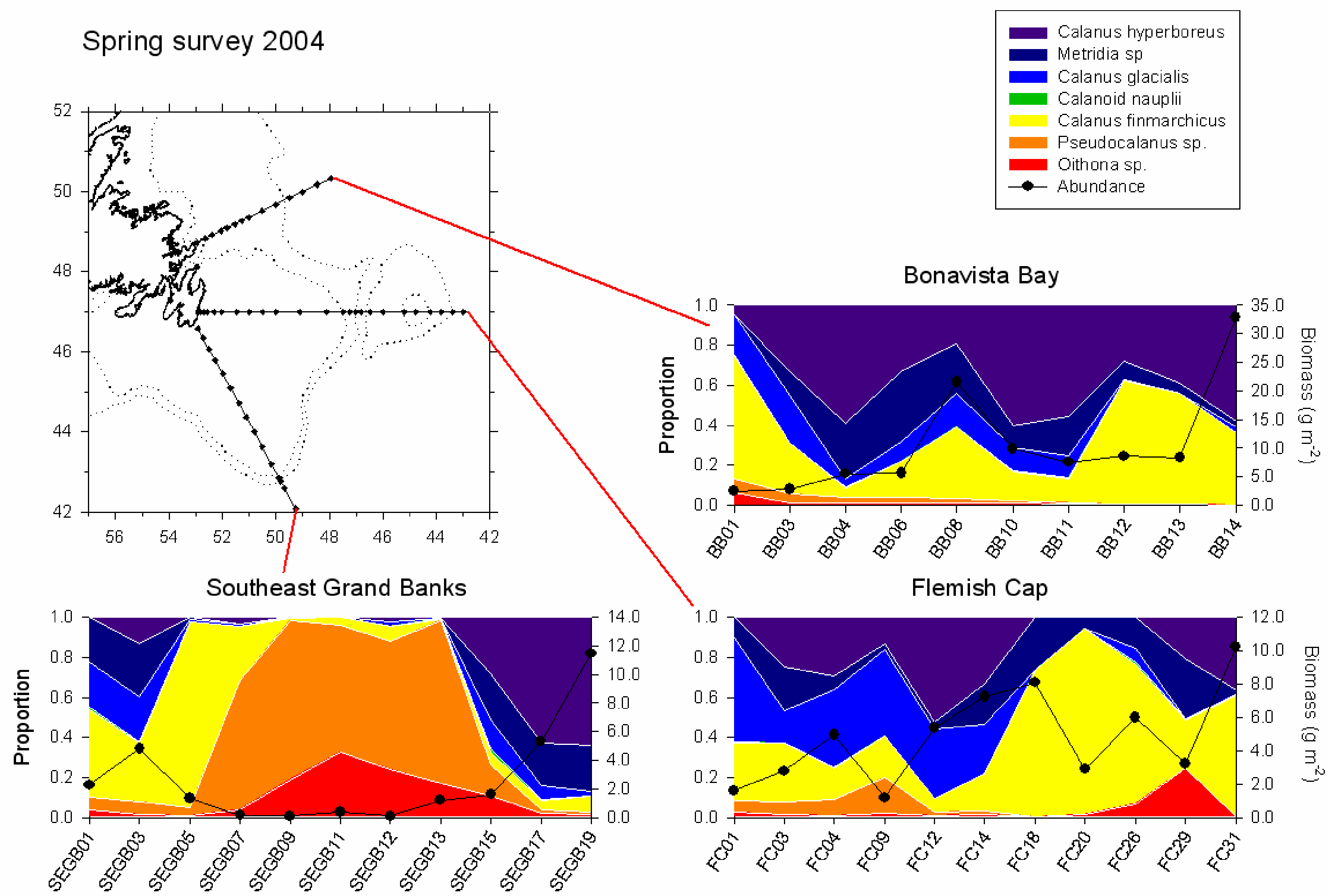


Figure 35. Relative biomass composition of the dominant copepod species during April/May of 2004. The solid line indicates the total biomass of copepod stages at each site. With the exception of calanoid nauplii, all information presented is based on the abundance of copepodite stages. Station locations are indicated on the corresponding map.

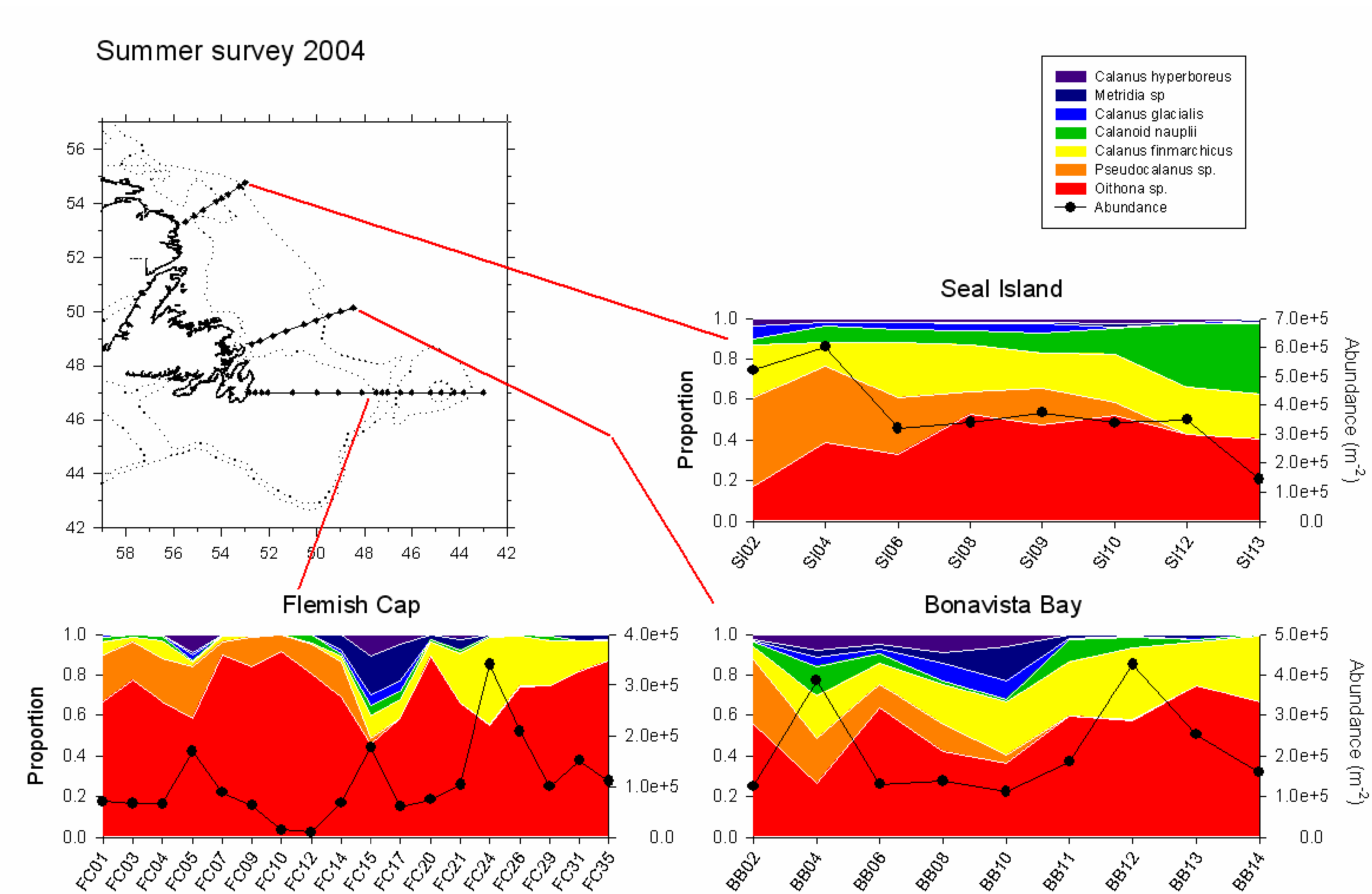


Figure 36. Relative composition of the dominant copepod species during July of 2004. The solid line indicates the total abundance of copepod stages at each site. With the exception of calanoid nauplii, all information presented is based on the abundance of copepodite stages. Station locations are indicated on the corresponding map.

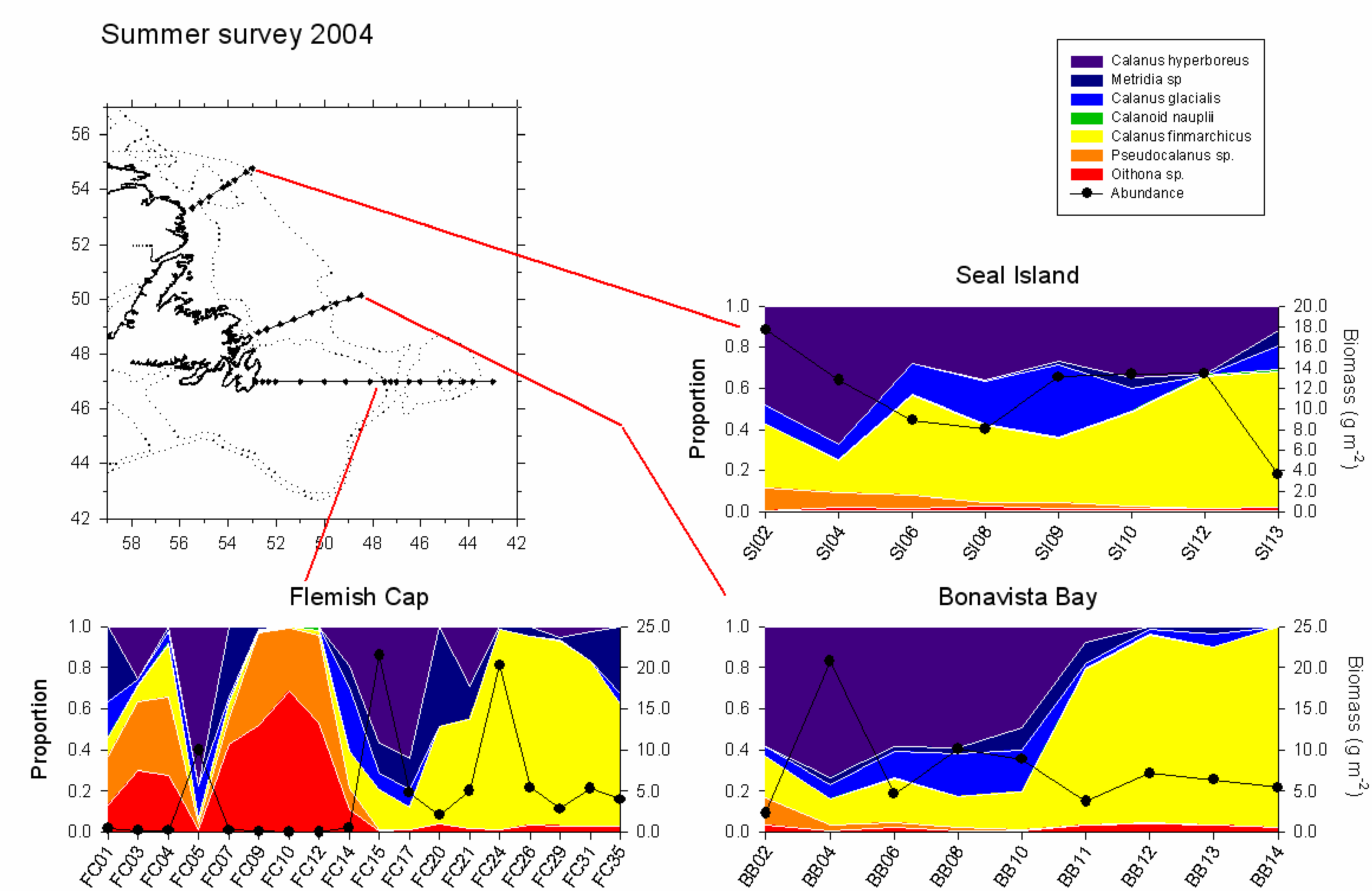


Figure 37. Relative biomass composition of the dominant copepod species during July of 2004. The solid line indicates the total biomass of copepod stages at each site. With the exception of calanoid nauplii, all information presented is based on the abundance of copepodite stages. Station locations are indicated on the corresponding map.

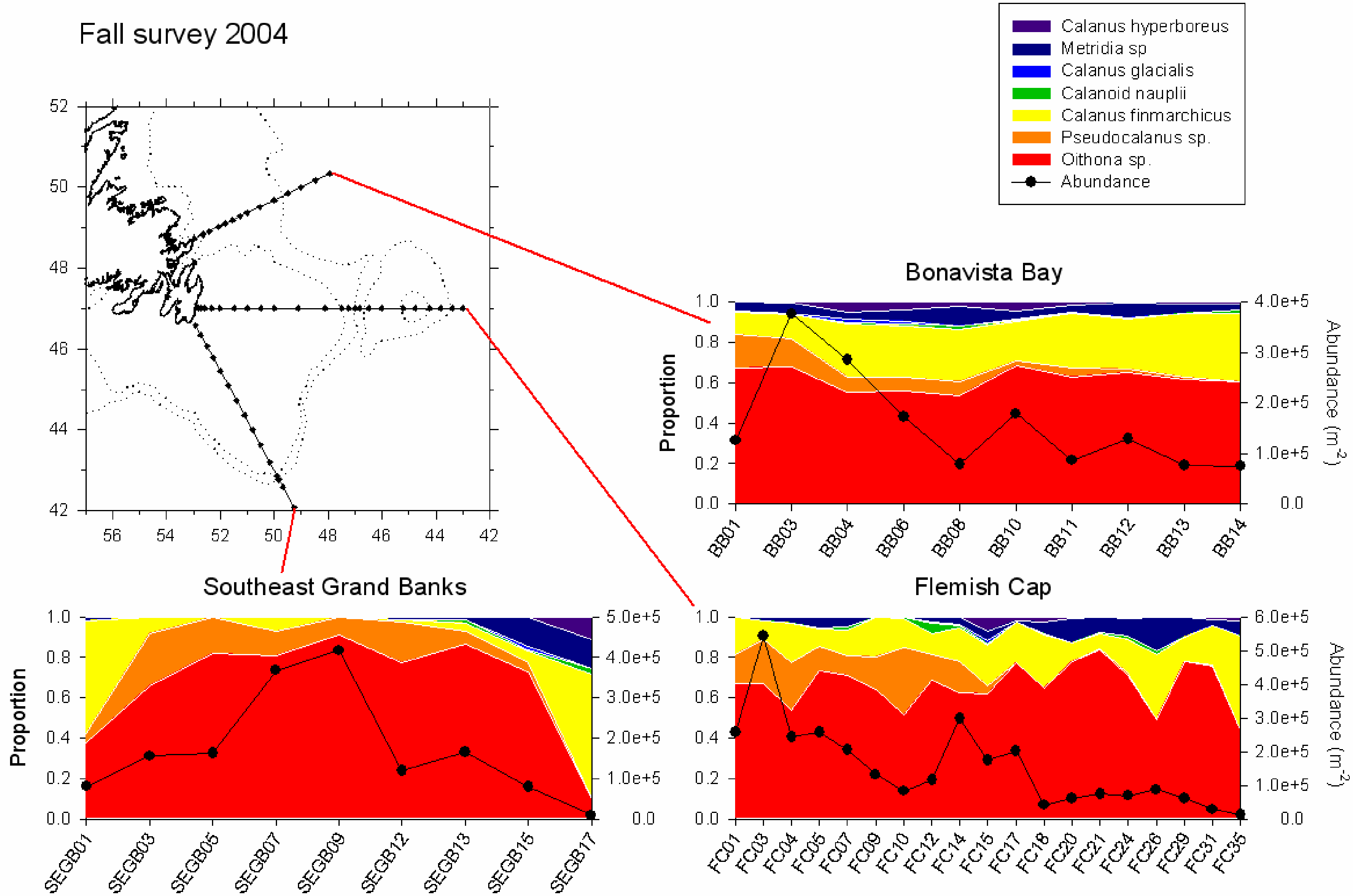


Figure 38. Relative composition of the dominant copepod species during November/December of 2004. The solid line indicates the total abundance of copepod stages at each site. With the exception of calanoid nauplii, all information presented is based on the abundance of copepodite stages. Station locations are indicated on the corresponding map.

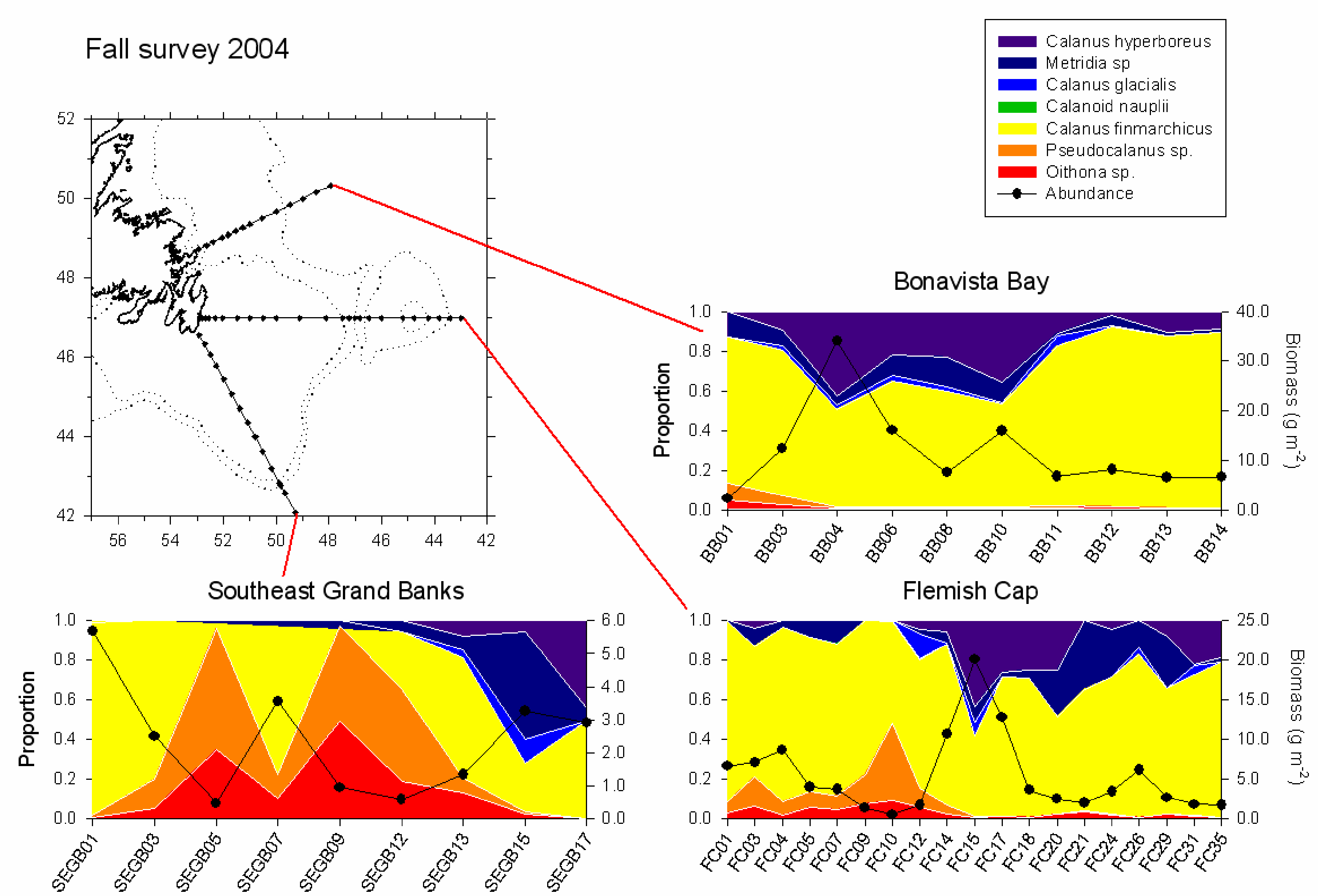


Figure 39. Relative biomass composition of the dominant copepod species during November/December of 2004. The solid line indicates the total biomass of copepod stages at each site. With the exception of calanoid nauplii, all information presented is based on the abundance of copepodite stages. Station locations are indicated on the corresponding map.