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Biological and Chemical Oceanographic conditions on the Newfoundland Shelf during 2003.

Conditions océanographiques, biologiques et chimiques sur le plateau Terre-Neuvien au cours de l'année 2003.

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ABSTRACT

We review the information concerning the seasonal and interannual 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 in 2003. The vertical attenuation coefficient at Station 27 was consistent with previous observations but was reduced relative to the Spring Bloom in 2002. Water column stability was weaker than in previous pervious, a trend consistent across most of the Newfoundland Shelf. The reduction in the upper and lower water column inventories of the major limiting nutrients at Station 27 observed in earlier years, continued to decline in 2003. This trend was not apparent along the seasonal section occupations. The magnitude and duration of the Spring Bloom at Station 27 in 2003 was comparable with previous years, a pattern confirmed for the Avalon Channel using SeaWiFS remote sensing data. The cell densities of major taxanomic groups of phytoplankton consisting of Diatoms, Dinoflagellates and Flagellates declined in 2003, continuing a trend noted since 2000. This decline may be the result of a change in collection methodology and is currently being evaluated. Overall, phytoplankton biomass on the Newfoundland and Labrador Shelves was lower in 2003 relative to the average of 2000-02.

In 2003, the overall abundance of zooplankton at Station 27 was comparable to previous years. The relative abundance of cold water (*Calanus glacialis*, *C. melgolandicus, Microcalanus* sp.) and warm water species (*Temora longicornis*) appeared to have returned to conditions found in the late 90s after showing a shift toward cold water species in recent years. The most notable changes in zooplankton community during the spring and summer of 2003 involved the lower abundance of large calanoid nauplii throughout the region (~33-50% of average) and the near absence of *Aglantha digitalea* (~10-30% of average). With respect to other changes, the Newfoundland-Labrador shelf boundaries appeared to delineate areas of change. In the southern region, larvaceans were substantially lower than the previous years' average (~50%) whereas abundance in the northern region we slightly above normal. On the Labrador shelf, species of *Oncea*, *Calanus* and *Metridia* were generally 2-3 times more abundant than the average for previous years.

RÉSUMÉ

Nous passons en revue les données de variations saisonnières et interannuelles des concentrations de chlorophylle *a* et des principaux éléments nutritifs ainsi que de l'abondance des principaux taxons de phytoplancton et de zooplancton à la station 27 et le long de transects standard du Programme de monitorage de la zone atlantique en 2003. Le coefficient d'atténuation vertical à la station 27 correspondait aux observations antérieures, mais il était inférieur à ce qu'il était au cours de la prolifération phytoplanctonique printanière de 2002. La stabilité de la colonne d'eau était moindre que les années précédentes, une tendance observée dans la plupart des secteurs du plateau continental de Terre-Neuve. La baisse des concentrations des principaux éléments nutritifs limitants dans les parties supérieure et inférieure de la colonne d'eau observée à la station 27 au cours des années antérieures s'est poursuivie en 2003. Cette tendance n'était pas apparente le long des transects saisonniers. L'ampleur et la durée de la prolifération phytoplanctonique printanière à la station 27 en 2003 étaient semblables à celles observées les années précédentes, une tendance confirmée dans le chenal d'Avalon à l'aide de données de télédétection obtenues grâce à SeaWiFS. Les densités de cellules des principaux groupes taxonomiques de phytoplancton, comprenant les diatomées, les dinoflagellés et les flagellés, ont diminué en 2003, poursuivant ainsi la baisse qui a débuté en 2000. Cette baisse pourrait être le résultat d'une modification de la méthode de prélèvement et est en train d'être évaluée. Dans l'ensemble, la biomasse du phytoplancton sur les plateaux continentaux de Terre-Neuve et du Labrador en 2003 était inférieure à la moyenne des années 2000 à 2002.

En 2003, l'abondance totale du zooplancton à la station 27 était semblable aux valeurs enregistrées les années précédentes. L'abondance relative des espèces d'eaux froides (*Calanus glacialis*, *C. melgolandicus* et *Microcalanus* sp.) et celles des espèces d'eaux chaudes (*Temora longicornis*) semblaient être retournées aux conditions observées vers la fin des années 1990 après une tendance à la hausse de la proportion des espèces d'eaux froides dans les années récentes. Les principaux changements survenus dans la communauté de zooplancton au printemps et à l'été 2003 ont consisté en la faible abondance des nauplii calanoïdes de grande taille dans l'ensemble de la région (environ de 33 à 50 % de la moyenne) et en la quasi-absence de *Aglantha digitalea* (environ de 10 à 30 % de la moyenne). En ce qui a trait aux autres changements, les limites des plateaux continentaux de Terre-Neuve et du Labrador semblaient correspondre aux limites géographiques des changements. L'abondance des appendiculaires dans la région sud était beaucoup inférieure à la moyenne des années précédentes (environ 50 %), tandis que dans la région nord, elle était légèrement supérieure à la normale. Sur le plateau continental du Labrador, l'abondance des espèces des genres *Oncea*, *Calanus* et *Metridia* était en général de 2 à 3 fois supérieure à la moyenne des années précédentes.

Introduction

We review optical, chemical, selected physical indices, and biological oceanographic conditions on the Newfoundland and Labrador Shelf during 2003. 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 2003 provided reasonable spatial and temporal series coverage of standard variables which provides a foundation for comparison with previous years. Collections and standard AZMP variables are based on sampling protocols outlined by the Steering Committee of the Atlantic Zonal Monitoring Program (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.

Fixed Station – Seasonal and interannual 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 field (Kirk 1994) and regulated by the vertical attenuation coefficient (K_d), which is related to 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 metres. 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 2003 was consistent with the earlier observations, but attenuation was reduced compared to the conditions noted during the spring bloom in 2002 (Figure 2). Attenuation 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, being related principally to the observed increase in chlorophyll *a* concentration. The trend in the vertical attenuation coefficient indicated higher extinction of light (by factor of 2) in the water column in 2002 in comparison to 2003 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 to which significant photosynthesis can occur, and is often used to constrain 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. The depth of the euphotic zone was higher in winter 2003, showed a rapid decline with the onset of the Spring Bloom, and showed somewhat higher values during the post-bloom period compared to the earlier series (Figure 2).

Knowledge of the flux of radiant energy is essential to interpret variability in the water column and primary productivity. Time series of incident downward PAR 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. Total daily incident PAR shows a strong seasonal component and high variability throughout the annual cycle. The average monthly values of daily incident PAR and standard deviation, total PAR and total daily insolation (accounting for differences in day length) indicated that December had the lowest average total daily PAR at 5.23 moles m^{-2} and highest in June at 45.7 mol m^{-2} in 2003 (Table 2). Monthly time series of global sky radiation obtained from Environment Canada and converted (Ting and Giacomelli 1987) to PAR from 1964-1998 showed a maximum annual variability of ca. 25 % (Figure 3). The annual climatology for solar radiation suggested that recent PAR measurements collected at NWAFC station during 2001-03, were among the highest recorded during the available time series for the months of April through to October (Figure 3). Comparison of the observed daily PAR irradiance levels in 2002 with the clear-sky model (Bird 1984) predictions reveals the high variability in the light regime at the daily level as a consequence of the variability in cloud cover (Figure 4). Given the influence of extensive cloud cover throughout the year in this region, we would suggest a 25 % reduction in the clear sky model of Bird 1984 to provide a more realistic light field for use in bio-optical and primary productivity models.

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 (2000-2002). The mean percent seasonal change in 2003 showed consistent negative trends in the vertical attenuation coefficient, with the largest change observed during winter, and levels approaching the short-term average by late in the year (Figure 5). Changes in euphotic depth are reciprocal to that of vertical attenuation, and thus showed consistent positive trends in 2003 compared to earlier years (Figure 5).

Fixed Station – Seasonal and interannual variability in water column structure

Time series of physical measures estimated at Station 27 in 2003 included the stratification index (difference in sigma-t values between 50m and 5m divided by 45m; see Craig *et al*. 2001, Craig and Colbourne 2002), mixed layer depth (depth centre of the pynocline), and integrated temperature (upper 50m) (Figure 6). The magnitude, timing, and duration of stratification showed similar trends during the time series although weaker in 2003 compared to earlier years. The stratification index reached maxima in late August-early September and minima in December through March. Although the magnitude of stratification was slightly weaker in 2003, the duration of peak stratification was slightly longer (ca. two weeks) compared to earlier years (Figure 6).

The mld series, taken as the depth centre of the pyncocline, showed maxima in January 2003, several weeks earlier than previously observed at Station 27. This early onset of the maxima in mld, was followed by a abrupt shoaling consistent with the pattern in earlier years but occurring several weeks earlier observed previously (Figure 6). Larger, prolonged maxima in mld were observed in 2001-02 compared to 2000 and 2003. Deepening and prolonged duration in mld is likely related to reduced water column stability due to increased wind stress observed during the Winters of 2001-02 (Pepin *et al*. 2002) and may contribute to observed variation in the timing and magnitude of phytoplankton blooms.

The upper 50m integrated temperature series displayed a strong seasonal cycle with maxima reached in September-October and minima in March-April. The integrated temperature series displayed small interannual variation in the timing, duration, and magnitude at the fixed station (Figure 6). On average thermal conditions in the upper 50m were cooler in 2003 compared to previous years at Station 27.

Seasonal variations in the stratification index, mixed layer depth, and integrated temperature were apparent at Station 27 compared to earlier years (Figure 7). The percent change in both the stratification index and integrated temperature varied seasonally with large negative trends during the first half of the year followed by nominal differences observed during the latter part of the year compared with the early series. The percent seasonal change in mixed layer depth showed an opposite pattern with a positive increase in both winter and summer while decreases were apparent during the spring and fall.

Fixed Station - Seasonal Variability in Nutrients

We examined the 2003 time series of major nutrients including nitrate (combined nitrate and nitrite, henceforth referred to as nitrate), and silicate. Concentrations of silicate and nitrate were typically > 2 mmol m^{-3} throughout the water column and approached maxima of 16 mmol m^{-3} near the bottom prior to the Spring Bloom (Figure 8). Concentrations of both major nutrients were depleted rapidly to values < 0.5 mmol m^{-3} within the upper 50m during the Spring Bloom and remained very low throughout the latter part of the year until a gradual increase in the concentration of both nutrients occurred in the fall. The nutricline shoaled periodically during the latter part of the year. We estimated the seasonal values based on earlier data for both limiting nutrients during the 1993-03 period, and computed the respective anomalies for 2003 versus the 10 year average. The silicate and nitrate anomaly profiles indicated nominal differences prior to the timing of the Spring Bloom, while elevated concentrations were observed for both nutrients in the upper 50m in 2003 compared to the long-term average conditions, suggesting a delayed production cycle (Figure 8). The anomaly plots also revealed extensive reduction in concentrations of both nutrients in deeper waters (> 50m), particularly for silicate where negative anomalies as high as 6 mmol m^{-3} were observed during the summer period (Figure 8).

Time series of nutrient inventories at Station 27 showed differences between years. Silicate and nitrate inventories in the upper mixed layer (< 50m) showed expected seasonal trends with winter and fall maxima, rapid depletion during the Spring bloom, and occasional periodic intrusions during the summer (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. Depletion of upper inventories of nitrate and silicate were more prominent in 2003 during the spring and summer compared to the earlier periods, extending the trend that was observed during the 2001-02 period. Deep inventories for both nutrients also continue to show declining trends (Figure 9). The cause for the continuing decline of these major limiting nutrient inventories remains unknown, but may be linked to changes in productivity and influence of volume transport of the inshore branch of the Labrador Current.

The mean percent change in nutrient inventories were variable throughout 2003. Trends in the upper 50 m silicate inventories were positive across all seasons (maximal in summer), while upper 50m nitrate inventories showed little change during winter-spring, while large negative changes (> 50 %) were observed during summer and fall (Figure 10). The pattern for the deep nutrient inventories for both silicate and nitrate showed consistent negative trends across all seasons compared to earlier years.

Nutrient Depletion - Station 27 and Oceanographic Sections

The relative importance in uptake of silicate and nitrate was investigated seasonally at Station 27 and along the oceanographic sections in 2003. The concentration of silicate versus nitrate at Station 27 in 2003 indicated the uptake of nitrate was the main limiting nutrient to phytoplankton during all seasons compared to silicate (Figure 11). Except for the AZMP survey conducted during spring where both silicate and nitrate appeared limiting (i.e., intercept near zero), nitrate was observed to be the main limiting nutrient being depleted prior to silicate across the northeast Newfoundland and Labrador Shelf sections (Figure 11). Rates of utilization of major nutrients were similar at Station 27 and along oceanographic sections, but slightly higher rates were observed during the summer and fall AZMP surveys compared to Station 27.

Fixed Station - Phytoplankton Abundance and Biomass

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 2003 began with subsurface chlorophyll *a* concentrations in the upper photic zone increasing to > 3.0 mg m^{-3} from background concentrations of < 1.0 mg m^{-3} in early April (Figure 12). We use the criteria of integrated chlorophyll *a* levels $\geq$ 100 mg m^{-2} in upper 100m to define start and end times of the phytoplankton bloom. The Spring Bloom was detected on 9 April (240.2 mg m^{-2}), peaked at a biomass concentration of 481.3 mg m^{-2} on 3 May, and maintained levels > 100 mg m^{-2} until 26 May (105.8 mg m^{-2}) for a duration of 48 days based on discrete chlorophyll *a* concentrations and *in-situ* chlorophyll *a* fluorescence observations. The bloom duration was nearly identical compared to observations in 2001-02, but differed substantially in 2000 with an earlier bloom and 2-fold increase in duration (Pepin and Maillet 2002). 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 is no evidence of accumulations of phytoplankton biomass beyond the Spring Bloom in 2003, a pattern consistent with observations during earlier years.

The cell densities of major taxanomic groups consisting of Diatoms, Dinoflagellates and Flagellates continued to decline in 2003, consistent with trends observed during earlier years. Diatoms reached peaked cell densities of 1.8×10^5 cells L^{-1} during the Spring Bloom in 2003, contributing ca. 70 % of the total phytoplankton, but remained at low densities during the remainder of the year (Figure 13). Densities were substantially greater in 2002, reaching densities of 6×10^5 cells L^{-1} compared to earlier years ($1.3\text{-}2.5 \times 10^5$ cells L^{-1} in 2000-01). The concentration of Dinoflagellates were typically lower by an order of magnitude compared to Diatoms, but continued to show declines in cell densities in 2003. Normally Dinoflagellates represent < 5 % of the total phytoplankton, except during the

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

summer of 2001 when this taxa briefly accounted for > 40 % of the total phytoplankton community due to an unexpected rapid reduction in the concentration of Flagellate cells observed during this time. The Flagellates were the dominant group by numbers reaching concentrations near $5x10^5$ cells L^{-1} early in the time series, but their abundance has also continued too decline along with the other major groups in recent years. 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 from a discrete depth sample in the upper mixed layer used in 2000 and early 2001, to the current method which involves sample integration from 5-100m depths used thereafter.

Time series measures of integrated chlorophyll reiterated the importance of Spring Bloom periods in the seasonal dynamics of phytoplankton abundance at Station 27 (Figure 13). 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 Bloom. The magnitude of phytoplankton biomass in 2003, inferred from integrated chlorophyll *a*, was comparable to previous years, except for somewhat higher values observed in 2002 (Figure 13). 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. The seasonal differences in both chlorophyll *a* inventories based on discrete and *in-situ* sampling indicated negative trends compared to earlier years across all periods (Figure 10).

Oceanographic Sections – Seasonal and interannual variability in water column optics and physical structure

Seasonal and spatial variability in water column optics and physical structure are apparent on the Newfoundland and Labrador Shelf (Pepin et al. 2003). The percent change in the vertical attenuation coefficient in 2003 compared to earlier years showed consistent negative trends across all sections during the spring and summer AZMP surveys (Figure 14). The trend was reversed during the fall occupations, where positive differences were observed across all sections in 2003. In contrast, the percent change in the euphotic zone showed a positive trend in 2003 during the spring and summer occupations, and a negative trend during the fall. The percent change in water column physical structure varied with season and section. The stratification index was consistently lower on the southeast and central Grand Banks during spring and fall occupations, but was higher on sections north of Bonavista during spring and summer occupations in 2003 compared to earlier years (Figure 14). The trend in thermal conditions in the upper 50m water column was negative in 2003 compared to previous years along the southeast Grand Banks up to the Bonavista section during all seasonal occupations, but positive trends were observed for sections further north during the summer occupations.

Oceanographic Sections - Seasonal Variability in Limiting Nutrients and Phytoplankton Biomass

Distribution of silicate and nitrate, the primary limiting nutrients influencing phytoplankton growth, have varied seasonally and spatially across the standard AZMP oceanographic sections since the inception of the program. Depletion of both silicate and nitrate concentrations in the upper water column (< 50m) was evident in the Avalon Channel and Shelf along the southeast Grand Banks and Flemish Cap sections during occupations in Spring 2003, in contrast to more replete conditions throughout the upper water column for the Bonavista Bay section (Figure 15). 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 upwelling and elevated concentrations of silicate and nitrate along all sections (Figure 15). The distribution of major nutrient concentrations observed in 2003 were similar to the pattern in previous years.

The summer occupations across the northeast Newfoundland and Labrador sections are typically characterized by depletion of both silicate and nitrate concentrations in the upper 50m of the water column. In contrast, the depletion of major nutrients in summer 2003 occupations was less evident compared to earlier years, particularly for silicate (Figure 16). Concentrations of silicate were > 1 mmol m^{-3} (< 1 mmol m^{-3} considered limiting) across all summer 2003 sections. There was evidence of depletion in nitrate concentrations, but this varied in the extent of depth by location of the section. The largest vertical removal of nitrate (<1 mmol m^{-3}) occurred along the Flemish Cap section extending to depths of ca. 50m. The vertical extent of nitrate depletion was lower along the Bonavista and Beachy Island sections. Evidence of autumn mixing was evident in fall 2003 with concentrations of silicate and nitrate were > 1 mmol m^{-3} across all sections (Figure 17).

Seasonal and spatial differences in major nutrient inventories in the upper 50m and deeper layers (50-150m) were evident along the oceanographic sections in 2003. Silicate and nitrate inventories in the upper 50m were elevated across all seasonal sections (Figure 18). This may have been the result of lower (from 20 to 70 % reduction) phytoplankton biomass inferred from chlorophyll *a* inventories across the seasonal sections in 2003 compared to previous years. The deep (50-150m) nutrient inventories showed mixed results depending on location and season. The deep inventories of nutrients generally tended to show positive trends during spring and summer occupations, although negative trends were evident for sections north of the southeast Grand Banks (Figure 18). Differences in timing between surveys conducted annually during 2000-03 and changes in the production cycle may contribute to the observed patterns in nutrient dynamics.

Distribution of phytoplankton biomass, inferred from the concentration of chlorophyll *a* and consumption of primary nutrients, showed both wide-spread and smaller discrete patches during the seasonal occupations across the standard sections. The southeast Grand Banks was characterized by high chlorophyll *a* concentrations (mean = 2.08 mg m^{-3}, range = 0.1 to 6.4 mg m^{-3}) during spring 2003 across the entire Shelf out to the Slope waters and extending to depths of 100m (Figure 15). During this time, the chlorophyll *a* distributions along the Flemish Cap and Bonavista sections were more localized, showing near-surface accumulation and patches of elevated concentrations across the Shelf. The summer 2003 concentrations of chlorophyll *a* were substantially lower across the sections, although evidence of episodic or localized blooms were observed along the Flemish Cap section while surface concentrations were evident for the section occupations further north (Figure 16). In contrast to previous years, chlorophyll *a* concentrations were elevated (> 1mg m^{-3}) at localized stations across all sections in fall 2003 (Figure 17). The percent change in chlorophyll *a* inventories in 2003 was largely negative compared to earlier years across all sections (Figure 18). The exception to this pattern occurred during the fall occupation of the southeast Grand Bank and Flemish Cap sections which displayed the only positive trends in 2003.

Phytoplankton genera were enumerated during the seasonal occupations of oceanographic sections at selected stations in 2003. Both *Chaetoceros* and *Thalassiosira sp.* dominated the spring Diatom assemblages along the sections, as in previous years. In addition, a localized bloom of the Diatom *Fragilariopsis sp*. was detected inshore along the Funk Island section. The major Dinoflagellate genera consisted of small (< 20 um) cells of *Gymnodinium* and *Prorocentrum sp.* during spring. As in earlier years, a large proportion of the Flagellate genera could not be identified although the cells were enumerated and categorized by size and presence/absence of pigment in the cells. The principal Flagellate genera observed during spring 2003 that could be identified were composed of the coccolithophorid *Emiliana huxleyi*, *Dinobryon*, and *Chrysophyte* cysts on the Flemish Cap section, while a localized bloom of *Phaeocystis sp*., both as colonies and single cells, were detected on the central southeast Grand Banks section. Lower concentrations of Flagellates were observed along the more northerly (Bonavista and Funk Island) sections.

Diatoms were largely absent during the summer occupations on sections, as in previous years. Dinoflagellates consisting of *Gymnodinium*, *Prorocentrum, Gonyaulax, and Heterocapsa sp.* were the dominant phytoplankton genera during the summer occupations across the sections on the Newfoundland Shelf. The fall 2003 survey was characterized by an unusual bloom of *Pseudo-Nitzschia sp*. with cell concentrations increasing from 6.1×10^4 to 3.9×10^5 cells L^{-1} across the transition from the Flemish Pass and Cap region to the Shelf break and Slope waters. Enhanced chlorophyll *a* concentrations were observed along this region from the discrete bottle samples (Figure 17). Lower concentrations of Diatoms were observed during fall, the principal genera being *Chaetoceros* and *Nitzschia sp*. on the southeast Grand Banks and Flemish Cap sections. The common Dinoflagellate genera during this period included *Gonaulax* and *Gymnodinium sp.*, while the principal Flagellates identified included the coccolithophorids *Coccolithus* and *Emiliania sp*.

Satellite Imagery

We used SeaWiFS satellite imagery from the Bedford Institute of Oceanography (Dartmouth, NS) to obtain sea surface chlorophyll *a* and sea surface temperature biweekly composite plots across statistical sub-regions on the Newfoundland and Labrador Shelf (Figure 19). 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 (Figure 20). The annual surface chlorophyll *a* concentrations across the Newfoundland and Labrador sub-regions varied little during the available time series from 1998-2003 (Figure 20). We used sea surface temperature as a proxy for location to evaluate variability in chlorophyll a concentrations across the statistical sub-regions. The relationship between annual integrated surface chlorophyll *a* and sea surface temperature was significant ($P<0.05$), but temperature explained only a small proportion of the total variance (Figure 21). 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 general interannual trends in the timing of the production cycle may be well represented by remotely sensed data.

Fixed Station - Zooplankton

Since 1999, 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 (Figure 22). In 2003, the overall abundance of zooplankton was comparable to levels observed in the previous years but the seasonality was difficult to assess because of the lack of observations during the early part of 2003. The total abundance of zooplankton during the summer of 2003 was somewhat higher than in previous years but the average increase was a modest 20%. The overall abundance patterns of *Oithona* sp. and *Pseudocalanus* sp. copepodites were similar to the average of previous observations at this site although reduced by approximately 5%. In last year's assessment (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* (Figures 22, 23). 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* . However, the overall peak abundance of both *C. glacialis* and *C. hyperboreus* was depressed by approximately 40 and 70% respectively over the average peak abundance of previous years but these levels were comparable to those observed in 2001 and the average overall abundance decreased by 30 and 50% respectively. For *Microcalanus* sp., the overall peak and average abundance levels increased by 20-30% but the occurrence decreased by about 20% at Station 27. In addition, the abundance of large calanoid nauplii decreased in 2003 relative to the average of previous years. Overall abundance decreased by approximately 30% and the peak abundance was lower by approximately 40%. The lack 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 other major zooplankton taxa showed no little change in overall or relative abundance (Figure 23).

The overall abundance of *C. finmarchicus* at Station 27 was comparable to previous years although 15% lower than concentrations observed in 1999 (Figure 24). In a pattern similar to 2001, the seasonal succession of copepodite stages did not show a delay, with the CI stages peaking in numbers in July relative to the May and June in 1999, 2000 and 2002. The overall pattern of abundance showed a more marked seasonality than in previous years with the peak abundance being ~20% higher than in the previous two years but similar to that observed in 1999. The large gap in observations during the winter of 2002/03 prevented any assessment of the pattern of occurrence and development during that period of the year. As in most years, early stage copepodites were effectively present in the zooplankton community throughout the fall. There were very few CVI adults at Station 27 after the end of July. This is in contrast to 1999 and 2001 when adult copepodites occurred frequently at the fixed station but similar to 2000 and 2002 when the development status of this species was dominated by CV copepodites.

The overall abundance of *Pseudocalanus* sp. showed a weak overall pattern in seasonal succession of stages, as in previous years (Figure 25). 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. These is also some indication of a third cohort later in the year at the end of November or beginning of December. The seasonality in stage distributions is not strongly reflected in the overall patterns in abundance, which show variability from one observation to the next but not in a manner similar to the seasonality in abundance of *C. finmarchicus*.

Oceanographic Sections - Zooplankton

Total zooplankton abundance in the fall of 2002 was generally higher than in the previous years (Figure 26). The largest concentrations occurred in the inshore areas of the Bonavista and Flemish Cap and over the Southeast Shoals stations of the Southern Grand Banks transect. 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 27). *Pseudocalanus* sp. was present only in the Shelf areas and was absent from stations located in slope waters. *Pseudocalanus* spp. was approximately 2-3 times more abundant throughout the region while *Aglantha digitalea* was similarly abundant in the northern part of the survey areas but approximately 30% of its normal abundance along the Southern Grand Banks transect. *Calanus finmarchicus* was notably absent from the Southeastern Grand Banks and Bonavista bay transects but was present across the entire Flemish Cap line. Further offshore, along the continental slope, the abundance of *C. finmarchicus* was often enhanced by 2-4 fold over previous years. As in previous years, *Metridia* spp. was present along all transects, with a greater relative abundance as one moves north and offshore. In the fall of 2002, changes in abundance showed considerable spatial heterogeneity. Along the Bonavista Bay and Flemish Cap transects, *Calanus finmarchicus* was approximately twice as abundant as the average from previous years but approximately normal on the Southern Grand Banks transect.

During the spring of 2003, the overall abundance of zooplankton was generally comparable to the densities observed in the previous, although numbers appeared to be generally lower than in 2000 and 2001 (Figure 28). The greatest differences occurred on the Southeast Shoal where overall abundance of calanoid nauplii and *Oithona* spp. were generally lower than observations from the survey in 2001 but the overall abundance of *Pseudocalanus* spp. was substantially higher in this region relative to previous observations (Table 3). Across most of the Flemish Cap section, abundance levels were generally lower by an average of 32%, relative to those densities observed in previous years. In contrast to previous years, where some areas show high patchy densities of one taxa or another, there were no large concentrations of any particular organism which stood out. Zooplankton densities along the Bonavista transect were generally comparable to previous years, although as in 2002 the density of organisms in the offshore areas were low relative to the previous two years. The relative species composition and their spatial distribution appeared to be consistent with observations from 2002. The most notable difference was the overall low abundance of calanoid nauplii in contrast to the previous year. The greatest decreases appeared along the Bonavista and Flemish Cap transects where the relative abundance was approximately one half of levels found in 2002. As in 2002, the abundance of *C. finmarchicus*, *Oithona* sp. and *Pseudocalanus* sp. remained low relative to 2000 and 2001. The lower abundance of these major groups of copepods resulted in an apparent increase in the relative importance of other taxa, such as *C. glacialis* and *C. hyperboreus* as well as *Metridia* sp., which were found at abundance levels comparable to previous years (Figure 48). In offshore areas, *C. finmarchicus* was an important component of the copepod community, making up ~20-50% of the overall number of individuals. Large calanoid nauplii and *Pseudocalanus* sp.were relatively more abundant on the Shelf rather than in offshore areas (Figure 29). In the spring of 2003, changes in average abundance along transects were dominated by overall increases along the Bonavista Bay transect and decreases along the two southernmost lines. Most notable, was the substantial increase in copepods *Eucheta* spp. *Chiridius gracilis* along the Bonavista Bay transect as well as increases in the abundance of *Euphausiacea* and *Thysanoessa longicaudata*. The most notable changes along the Flemish Cap and Southern Grand Banks transects were found in the decrease in large calanoid nauplii, the near absence of *Aglantha digitalea*. Other species appeared also to be less well along their seasonal development during the spring survey, with several species showing lower levels than in the average of previous years.

During the summer 2003 surveys, the overall abundance of zooplankton tended to be comparable or slightly higher than the average from previous years (Figure 30). Overall zooplankton along the Flemish Cap line was generally lower across the entire Grand Banks, relative to levels found in previous years, but densities in the offshore areas were generally comparable to previous years. Zooplankton densities along the Bonavista transect were also comparable to the pattern observed in 2000 and 2002, and higher than in 2001 along the inshore portion of the line but densities were generally comparable to previous years along the outer portions of the shelf. At all but one station along the Seal Island transect, the overall zooplankton density was higher in 2003 than in previous years (Table 3). The overall abundance was about twice the average from the previous three years and the increases were observed across the entire shelf. However, further North along the Makkovik Bank section, zooplankton abundance was similar to that found in previous years. There was a notable (2-3 times) increase in the relative abundance of *Oithona* spp. relative to levels observed in the previous year (Figure 31). The increase in one species will inevitably lead to a decrease in the relative abundance of other species. However, there was a substantial decrease in the overall abundance of large calanoid nauplii across the entire shelf, a pattern which echoed that observed in the spring. Furthermore, the relative abundance of *Metridia* spp. and *Calanus hyperboreus* was higher than 2002 along the Makkovik and Seal Island transects but generally lower along the Bonavista and Flemish Cap transects. The most notable changes in zooplankton community during the summer of 2003 involved the lower abundance of large calanoid nauplii throughout the region (~33% of average) and the near absence of *Aglantha digitalea* (~10% of average). With respect to other changes, the Newfoundland-Labrador shelf boundaries appeared to delineate areas of change. In the southern region, larvaceans were substantially lower than the previous years' average (~50%) whereas abundance in the northern region we slightly above normal. On the Labrador shelf, species of *Oncea*, *Calanus* and *Metridia* were generally 2-3 times more abundant than the average for previous years.

Discussion

Overall, the seasonality of chemical and biological variables at Station 27 and along the major AZMP sections in 2003 was similar to previous years (1999-2002). 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 interannual 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 wind stress remained high in 2002, the overall impact on the water column may have been somewhat lessened by the relative timing and intensity of wind events such that the mixed layer depth shoaled more progressively in 2002, thus allowing an earlier Spring Bloom.

Variations in the physical environment since the inception of the Atlantic Zone Monitoring Program may also be contributing to a gradual increase 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. 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. However, in addition to the factors that regulate the vertical structure of the water column, there is a preliminary indication that interannual variations in incident light may also have contributed to the increase in the overall intensity of the Spring phytoplankton bloom. Although intercalibration of observations from the Northwest Atlantic Fisheries Centre with those collected by the Canadian Meteorological Service 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 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 condition at Station 27 persisted in 2002 but there are some indications that the depletion of the deep nutrient pool may have expanded onto the inshore and mid-Shelf portions of the Bonavista section, where a notable decrease in deep nutrient levels were observed in 2002, but the magnitude is considerably less than has been observed at Station 27 (Pepin *et al*. 2002). Further depletion in the deep nutrient inventories was evident at Station 27 in 2003 throughout the different seasonal periods. This trend was reversed for the shallow silicate inventories where large positive changes occurred and was consistent with observations along all seasonal occupations on sections across the Newfoundland and Labrador Shelf.

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 at both Station 27 and on the Newfoundland Shelf.

The overall standing stock of phytoplankton on the NE Newfoundland Shelf was generally less during the spring and summer, but higher during the fall survey's than in previous years. 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, suggesting that decreases in temperature may play an important role in limiting production on the Shelf. This trend was reversed for the Labrador sections occupied during the summer. Alternatively, higher grazing pressure from a slight increase in the density of large calanoid copepods may have maintained standing stocks at low levels.

The decline in abundance of major phytoplankton taxa observed in recent years appears to have persisted into 2003. 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. 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 somewhat reduced occurrence and abundance of large species of copepods such as *Calanus* and *Metridia* may have lead to an decrease in the relative abundance of large calanoid nauplii on the mid- and outer shelf areas. Small species of copepods, such as *Oithona* sp. and *Pseudocalanus* sp. generally dominate the copepod community across much of the NE Newfoundland Shelf, and their dominance appears to have increased over 2002.

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References

Colbourne, E. 2002. Physical oceanographic conditions on the Newfoundland and Labrador Shelves during 2001. Canadian Science Advisory Secretariat, Research Document 2002/023, 27p.

Craig, J.D.C, E.B. Colbourne, and G.L. Maillet. 2001. Preliminary studies of density stratification and fluorescence on the Newfoundland Shelf. Canadian Science Advisory Secretariat, Research Document 2001/085, 25p.

Harrison, G., D. Sameoto, J. Spry, K. Pauley, H. Maass, and V. Soukhovtsev. 2002. Optical, chemical and biological oceanographic conditions on the Scotian Shelf, in the Gulf of Maine and the Southern Gulf of St. Lawrence in 2001. Canadian Science Advisory Secretariat, Res. Doc. 2002/056, 50p.

Kirk, J.T.O. 1994. Light and photosynthesis in aquatic ecosystems. Cambridge University Press, 509 pp.

Mitchell, M.R., G. Harrison, K. Pauley, A. Gagné, G. Maillet and P. Strain 2002. Atlantic Zone Monitoring Program Sampling Protocol. Canadian Technical Report of Hydrography and Ocean Sciences 223, 23 pp.

Pepin, P. and G.L. Maillet. 2001. Biological and chemical oceanographic conditions on the Newfoundland Shelf during 2000 with comparisons with earlier observations. Canadian Science Advisory Secretariat, Res. Doc. 2001/073, 46p.

Pepin, P. and G.L. Maillet. 2002. Biological and chemical oceanographic conditions on the Newfoundland Shelf during 2001 with comparisons with earlier observations. Canadian Science Advisory Secretariat, Res. Doc. 2002/052, 60p.

Platt, T., S. Sathyendranath, C.M. Caverhill, and M.R. Lewis. 1988. Ocean primary production and available light: further algorithms for remote sensing. Deep-Sea Research, Vol. 35, No. 6, pp. 855-879.

Ting, K.C., G.A. Giacomelli. 1987. Availability of Solar Photosynthetically Active Radiation. Transactions of the ASAE, 30(5):1453-1457.

Table 1. Listing of AZMP Sampling Missions in the Newfoundland Region in 2003. The transects are Southeast Grand Banks (SEGB); Flemish Cap (FC); Station 27 (S27); Smith Sound (SS), Trinity Bay (TB), Bonavista Bay (BB); Funk Island (FI); White Bay (WB); Seal Island (SI); Makkovik Bank (MB); Beachy Island (BI), and the fixed station (Station 27). See Figure 1 for station locations along sections and fixed coastal station. Total numbers of hydrographic (CTD) 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**
TEL462	Apr 19-May 4, 2003	SEGB, FC, BB, FI, SS, TB	161	63
2003	Jul 21-Aug 6, 2003	FC,BB,FI,WB,SI,MB,BI, SS, TB	164	62
2003	Nov 16-Dec 6, 2003	SEGB,FC,BB,S27, SS, TB	147	66
2003	Jan-Dec	Station 27	47	20

Table 2. Average and standard deviation (SD) of daily photosynthetic active radiation (PAR), total monthly radiation in moles and total daily insolation obtained in 2003 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}**	Avg. Daily SD	**Total Moles**	**Total Daily Insolation Moles d^{-1}**
January (1-31)	7.76	3.91	240.71	0.16
February (32-59)	15.90	7.20	445.21	0.37
March (60-90)	26.00	9.52	805.90	0.71
April (91-120)	36.41	12.08	1092.32	1.14
May (121-152)	38.57	16.96	1195.75	1.29
June (153-181)	45.68	17.36	1370.48	1.68
July (182-212)	40.01	14.89	1240.21	1.43
August (213-243)	37.37	12.91	1158.53	1.23
September (244-273)	28.95	9.27	868.56	0.84
October (274-304)	15.16	7.18	470.01	0.38
November (305-334)	8.23	4.67	246.81	0.18
December (335-365)	5.23	2.94	162.26	0.10

Table 3. Average percent change in overall zooplankton abundance along major oceanographic transects surveys during the fall of 2002 and spring and summer of 2003. The change in station specific relative change in abundance is shown in the rightmost column. Figures in brackets indicate the average percent change in abundance when an extreme value of the range (shown in bold) is removed for the calculation of the average.

Survey	Transect	Average percent change in abundance	Range
Fall 2002	SEGB	127	-15 – 457
	FC	55	-86 – 456
	BB	116	-70 – 230
Spring 2003	SEGB	-7 (-37)	-62 – **292**
	FC	-32	-90 – 104
	BB	62 (4)	-61 – **525**
Summer 2003	FC	-12	-86 – 130
	BB	10	-70 – 65
	SI	93	0 – 200
	MK	50 (5)	-50 – **275**

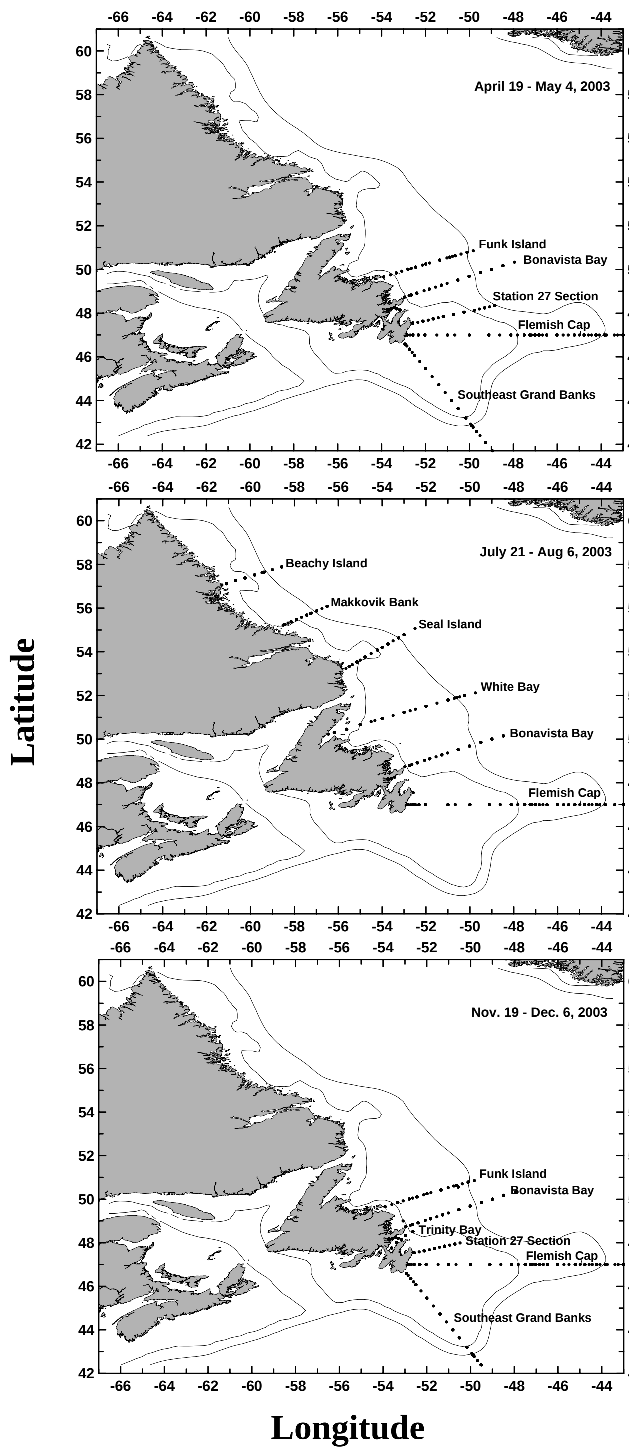

Figure 1. Biological and physical occupations during AZMP seasonal sections on the Newfoundland and Labrador Shelf in 2003. Contour lines are for the 200m and 1000m isobaths.

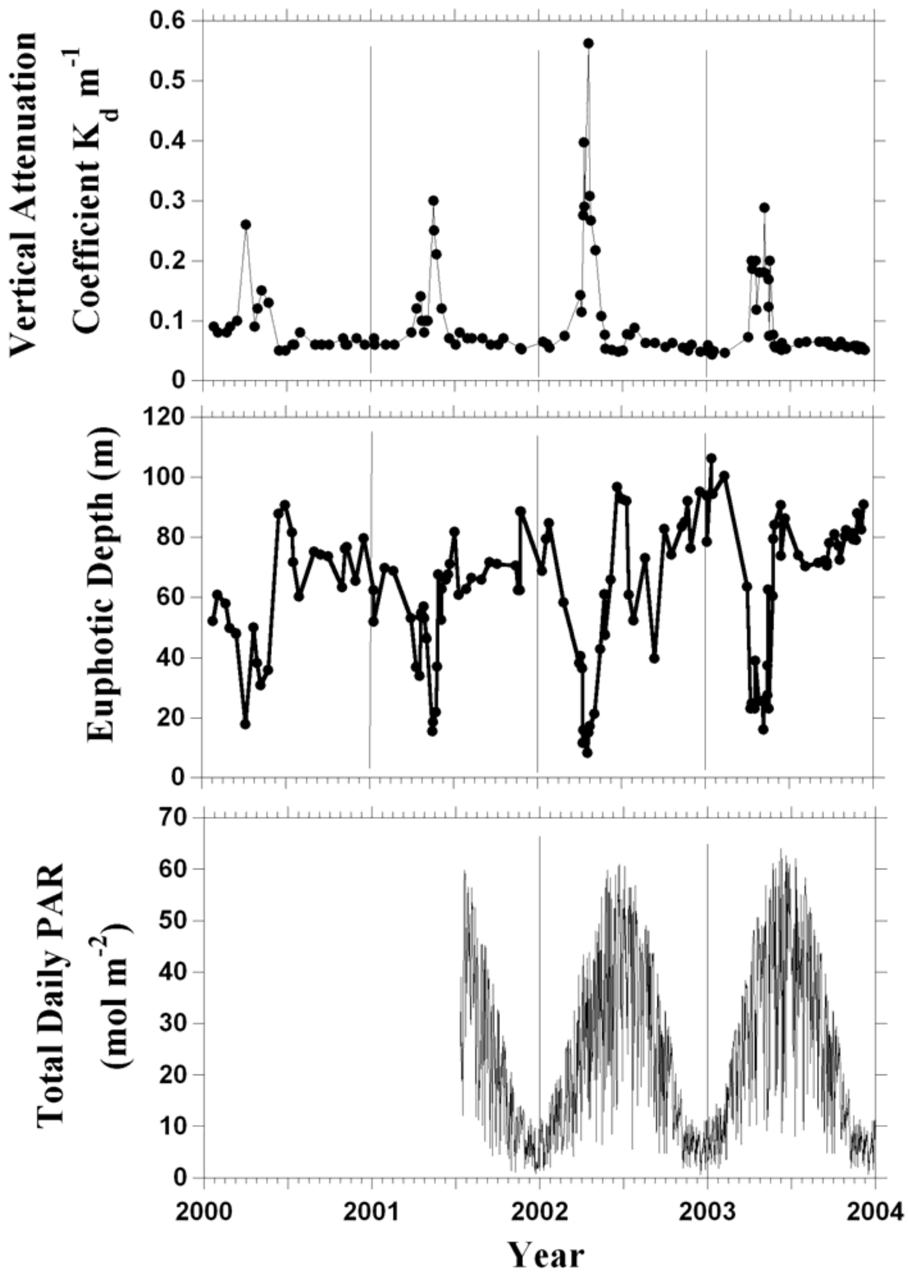

Figure 2. Biweekly time series of optical measures at Station 27 showing vertical attenuation coefficient K_dPAR, euphotic depth, and total average daily photosynthetic active radiation (PAR irradiance sensor located at NWAFC, St, John's, NL).

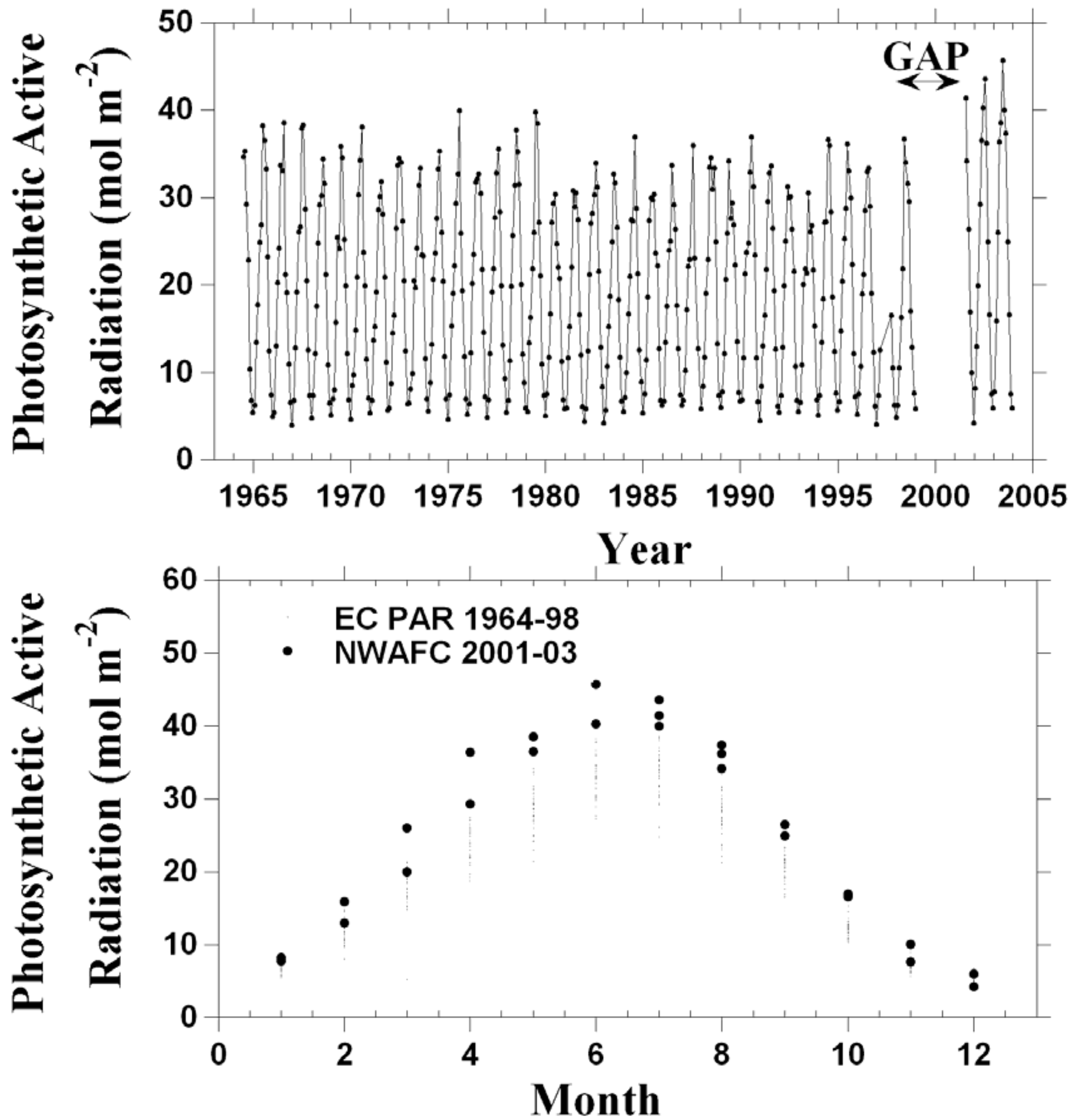

Figure 3. Time series of average monthly values of photosynthetic active radiation (PAR) in St. John's, NL obtained from Environment Canada during 1964-98, and locally collected PAR at the NWAFC during 2001-03 (upper panel). Two gaps exist in the time series; April through August 1997, and January 1999 to June 2001. Monthly climatology of PAR showing recent measurements were among the highest recorded during the available time series for the months of April through to October (lower panel).

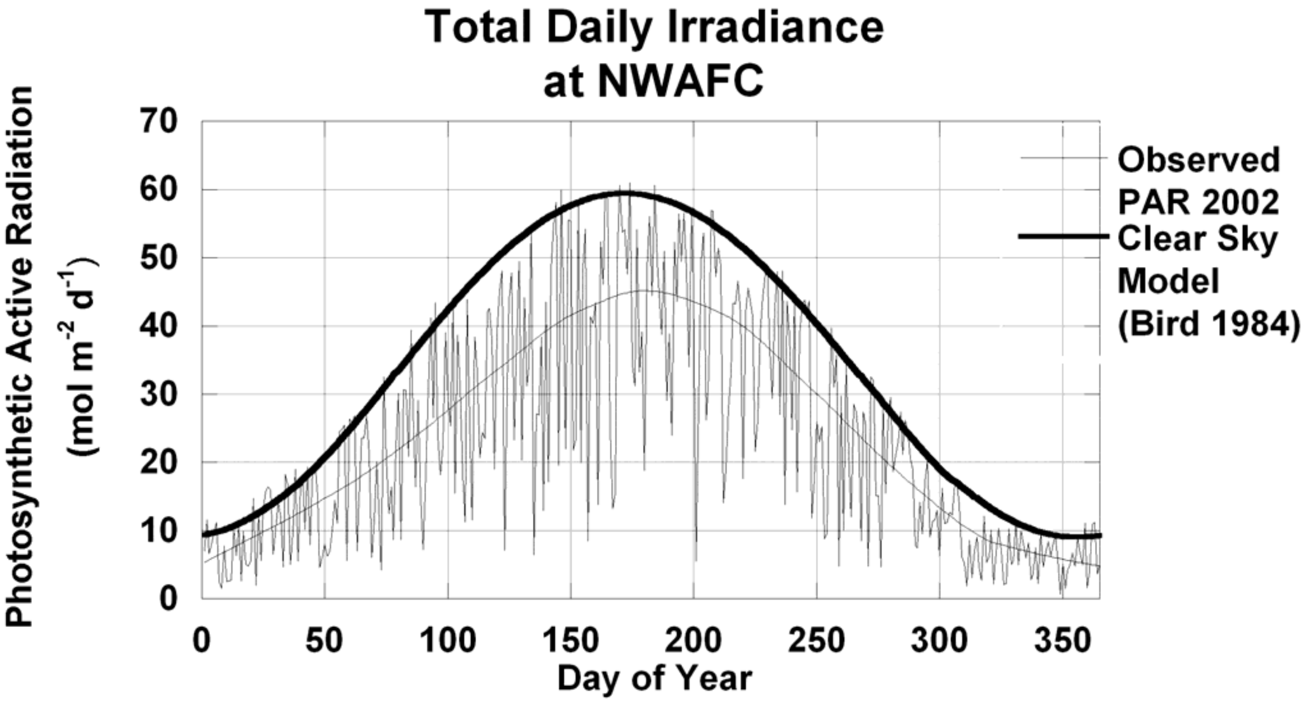

Figure 4. Comparison of clear sky model output from Bird (1984) versus actual total daily irradiance observed at the Northwest Atlantic Fisheries Centre in St. John's, NL during 2002.

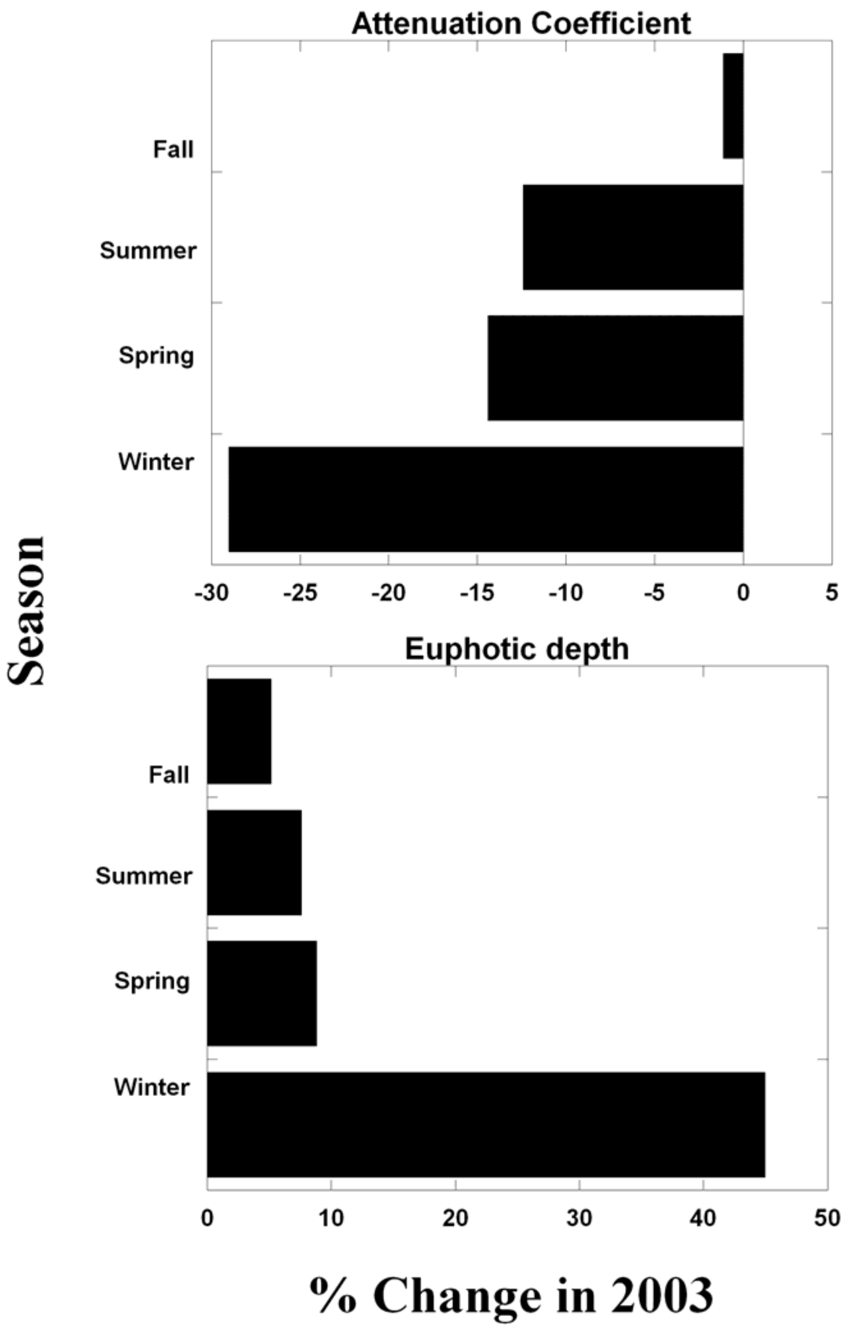

Figure 5. The mean percent change in optical indices (vertical attenuation coefficient and euphotic depth) in 2003 compared to earlier years (2000-02) at Station 27 during different seasons (winter; Dec-Feb, spring; Mar-May, summer; Jun-Aug, fall; Sep-Nov).

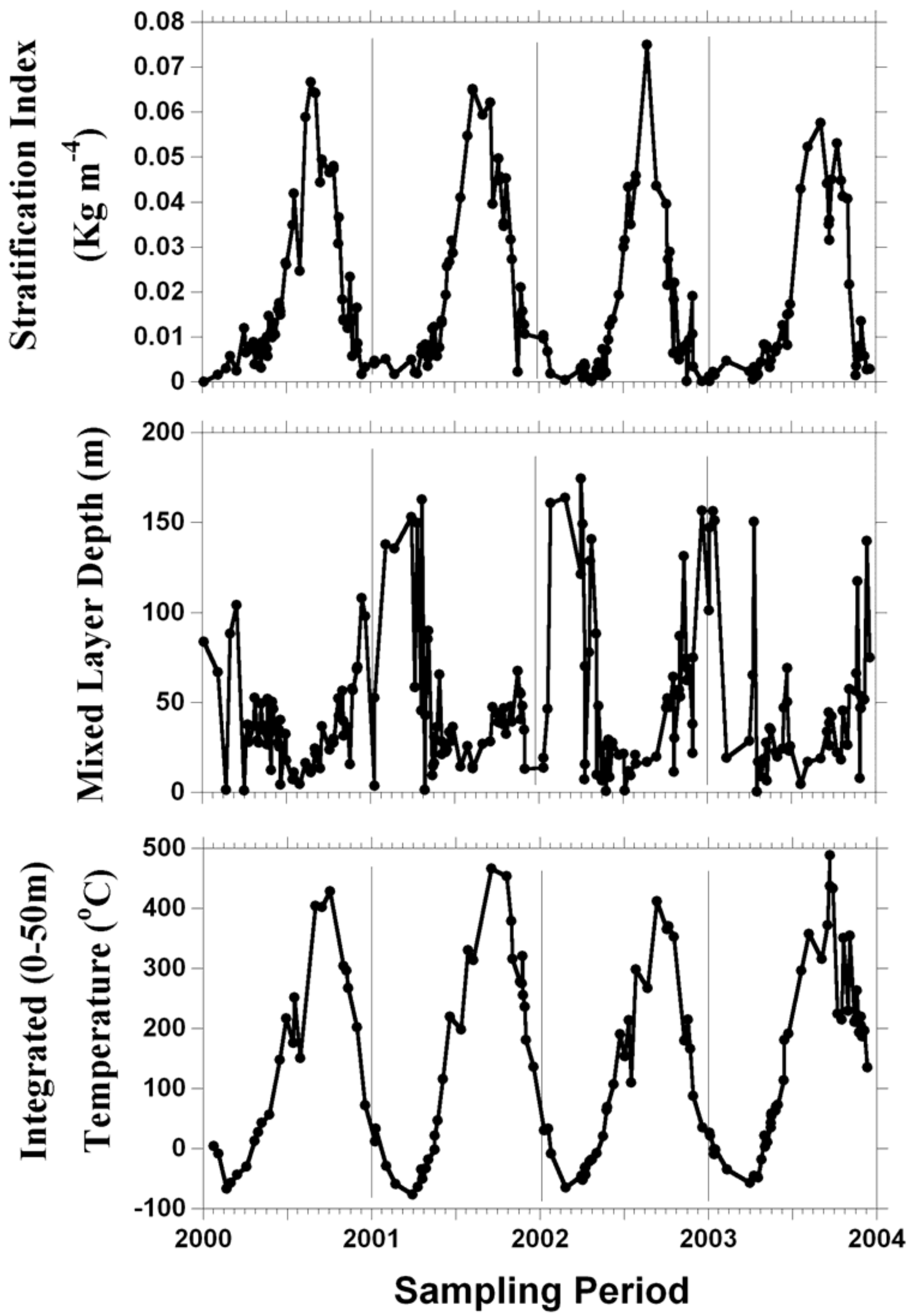

Figure 6. Time series of physical measures at Station 27 during 2000-03 showing stratification index (sigma-t_{50m} – sigma-t_{5m} /45m); mixed layer depth (taken as the depth centre of the pycnocline); and integrated temperature in the upper 50m using the trapezoidal method.

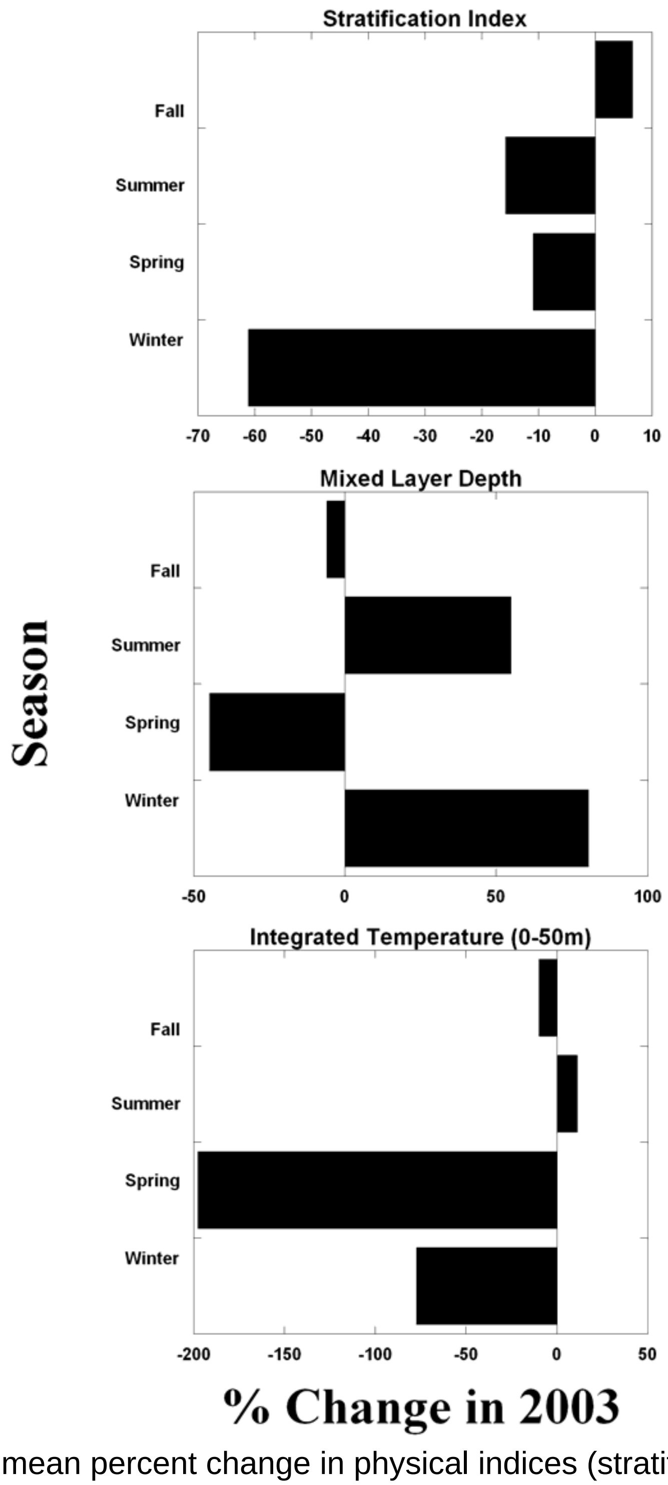

Figure 7. The mean percent change in physical indices (stratification index, mixed layer depth, and integrated temperature) in 2003 compared to earlier years (2000-02) at Station 27 during different seasons (winter; Dec-Feb, spring; Mar-May, summer; Jun-Aug, fall; Sep-Nov).

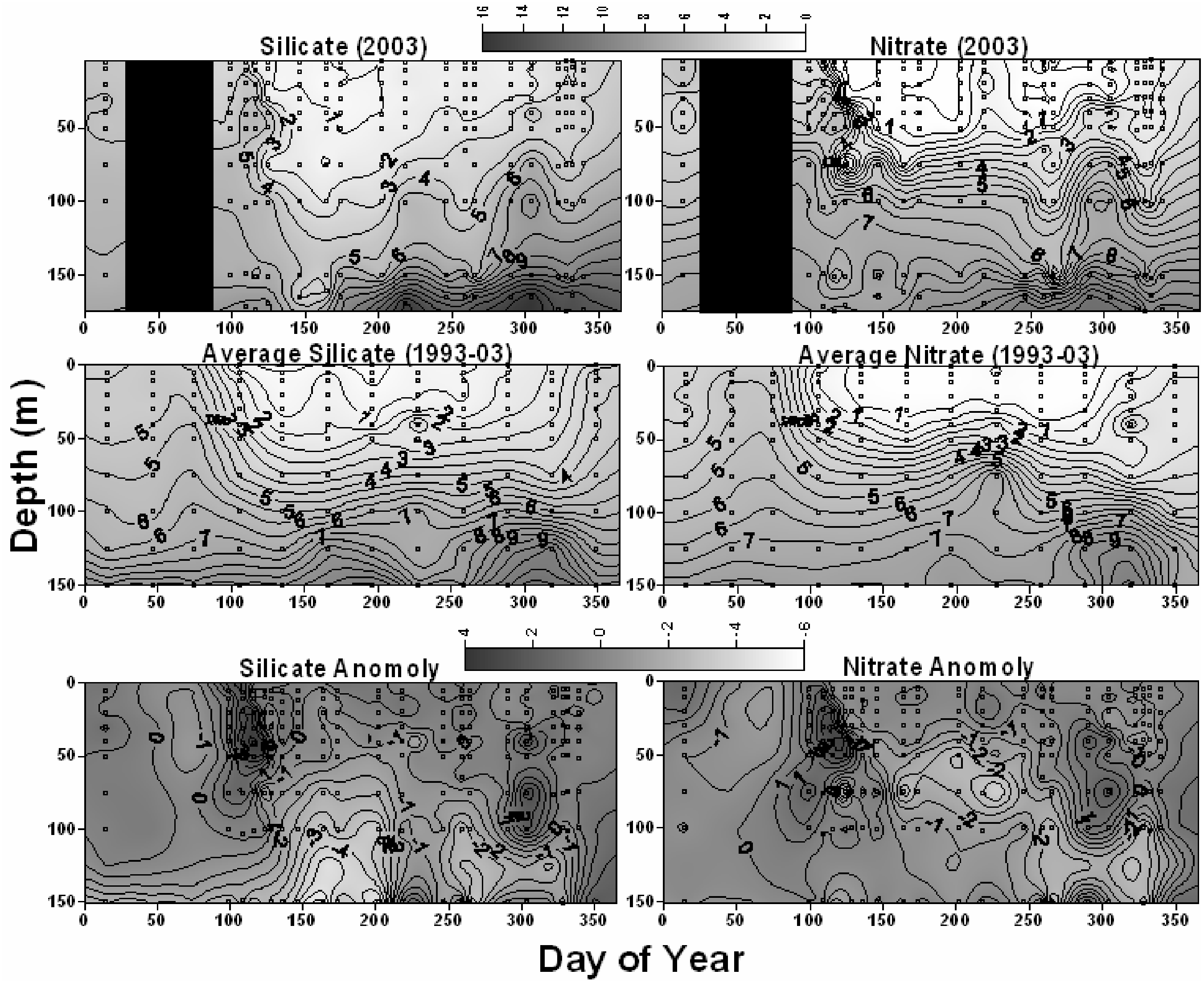

Figure 8. Seasonal variation in vertical structure of silicate and nitrate (combined nitrite and nitrate) concentrations (mmol m^{-3}) at Station 27 in 2003 and average conditions during 1993-03 and respective anomolies. See figure 12 for associated T/S and density properties at Station 27.

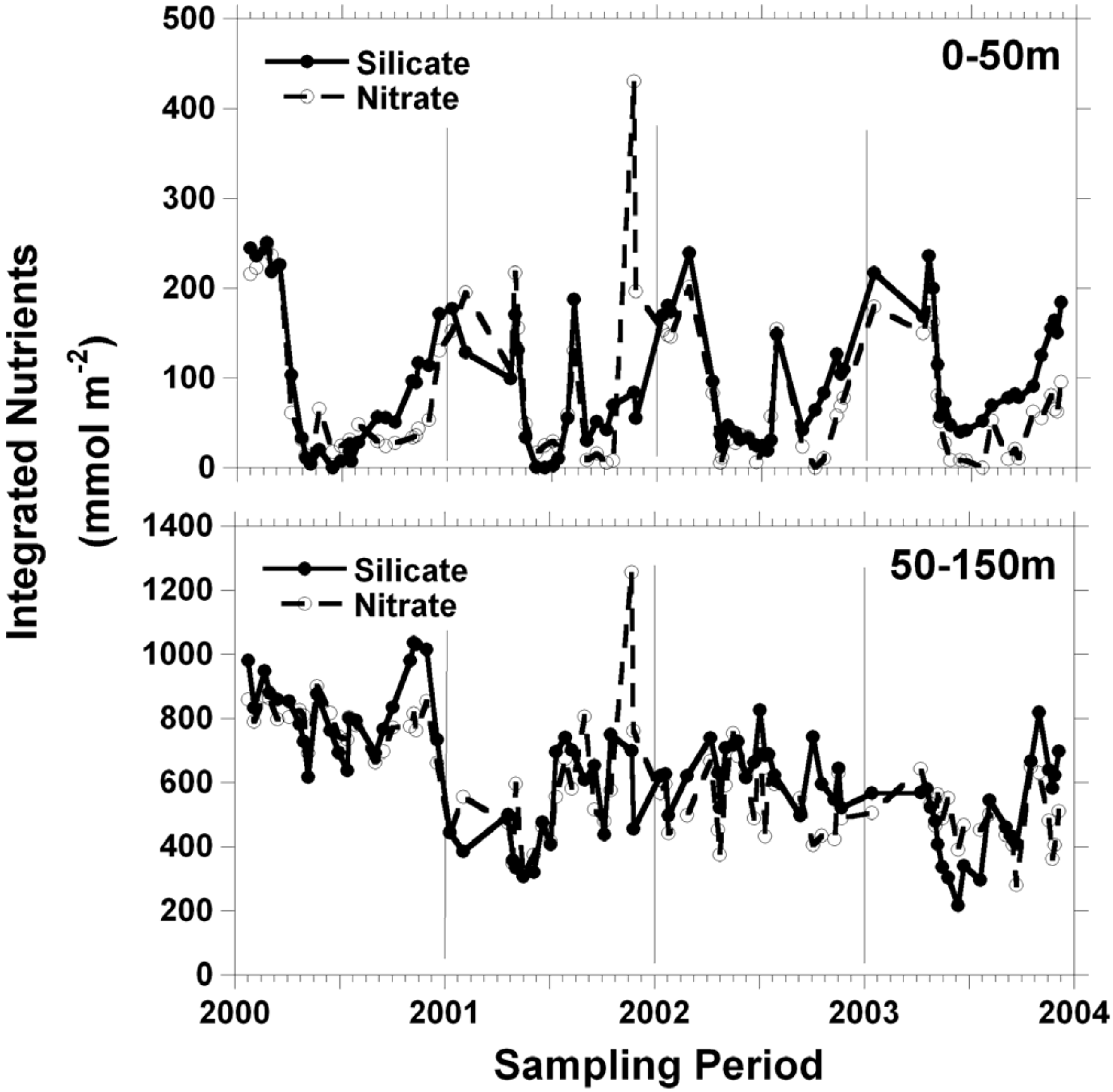

Figure 9. Time series of major nutrient inventories at Station 27 during 2000-03 showing integrated silicate and nitrate (combined nitrate and nitrite) at two depth strata.

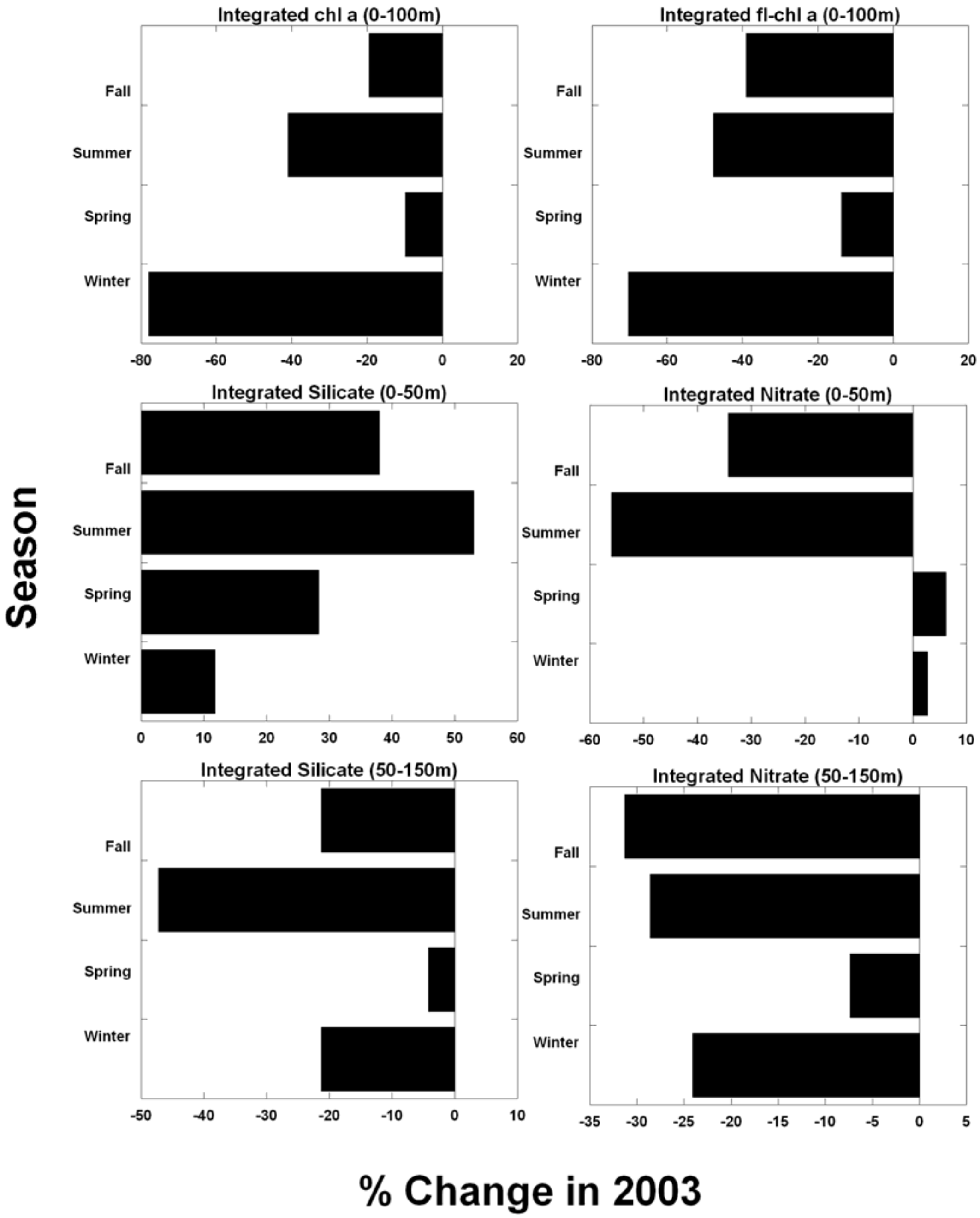

Figure 10. The mean percent change in integrated chlorophyll a and *in-situ* chlorophyll a fluorescence (calibrated) and silicate and nitrate inventories in two depth strata in 2003 compared to earlier years (2000-02) at Station 27 during different seasons (winter; Dec-Feb, spring; Mar-May, summer; Jun-Aug, fall; Sep-Nov).

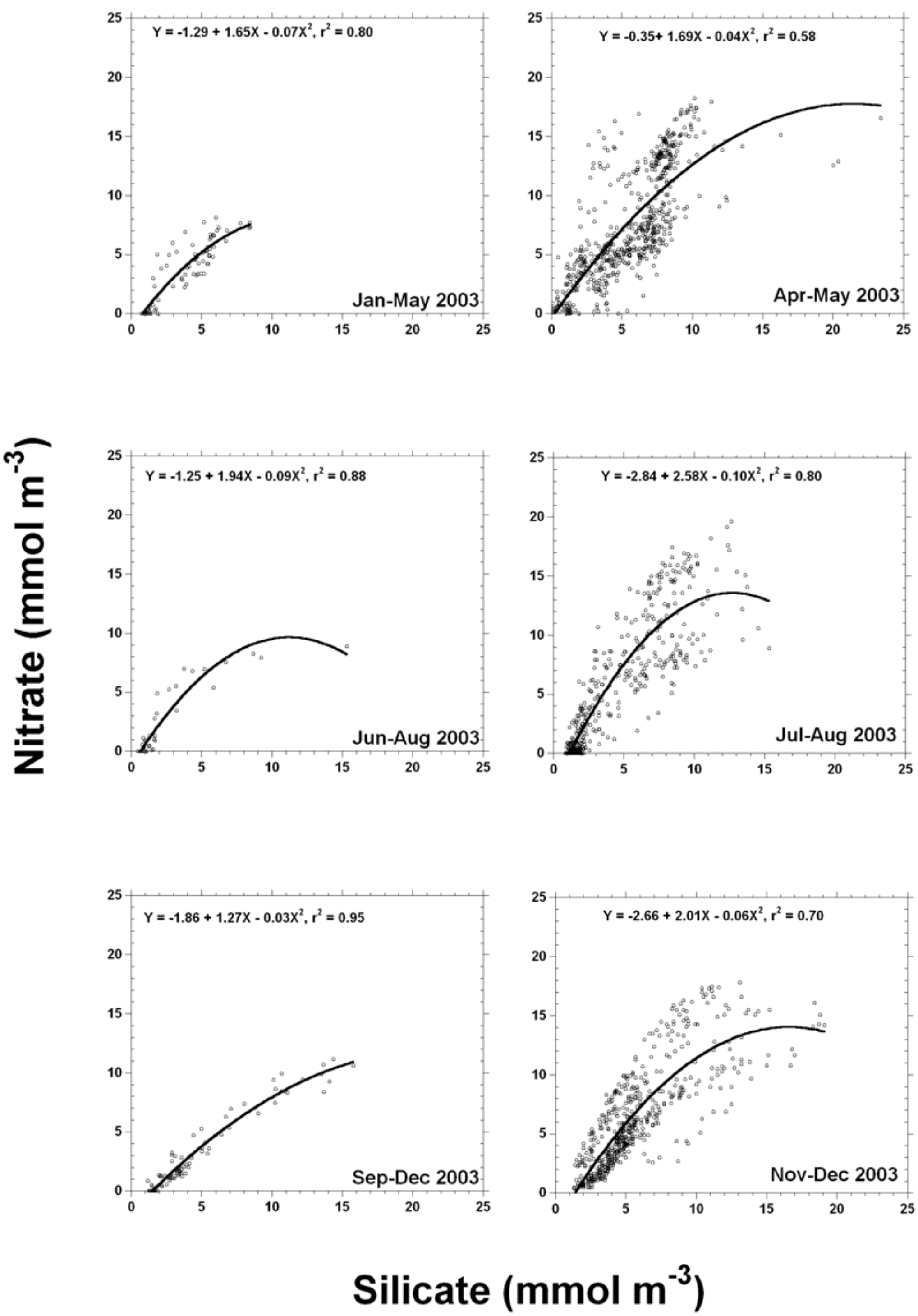

Figure 11. Relationship between nutrient concentrations of silicate versus nitrate at Station 27 (left panels) and AZMP section occupations (all sections pooled).

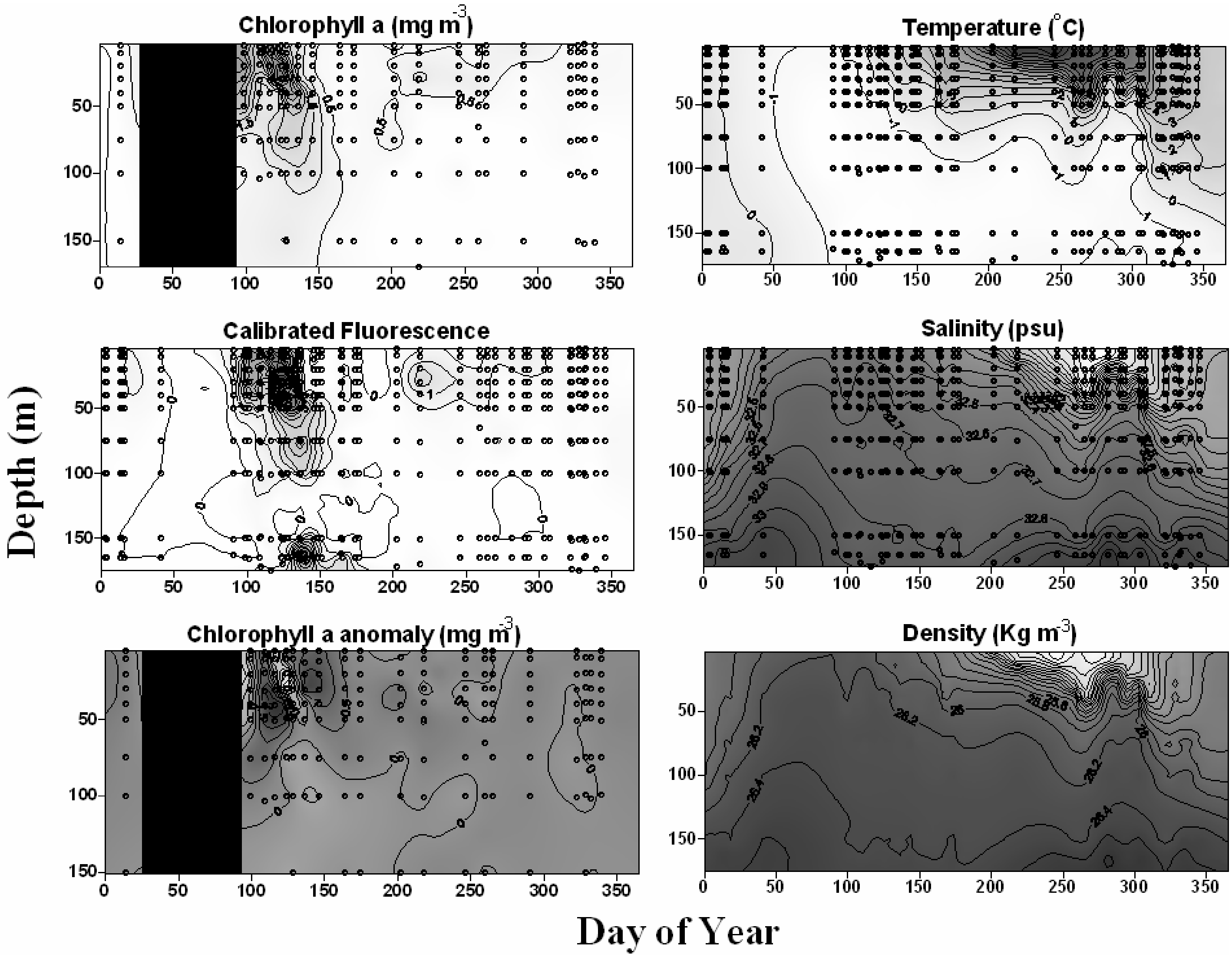

Figure 12. Seasonal variation in vertical structure of phytoplankton biomass inferred from chlorophyll *a* concentration, calibrated *in-situ* chlorophyll *a* fluorescence, and chlorophyll *a* anomaly; year 2003 – average of 2000-02 (left panels), and variability in T/S and density properties at Station 27 in 2003. Filled circles show time and depth of discrete water samples.

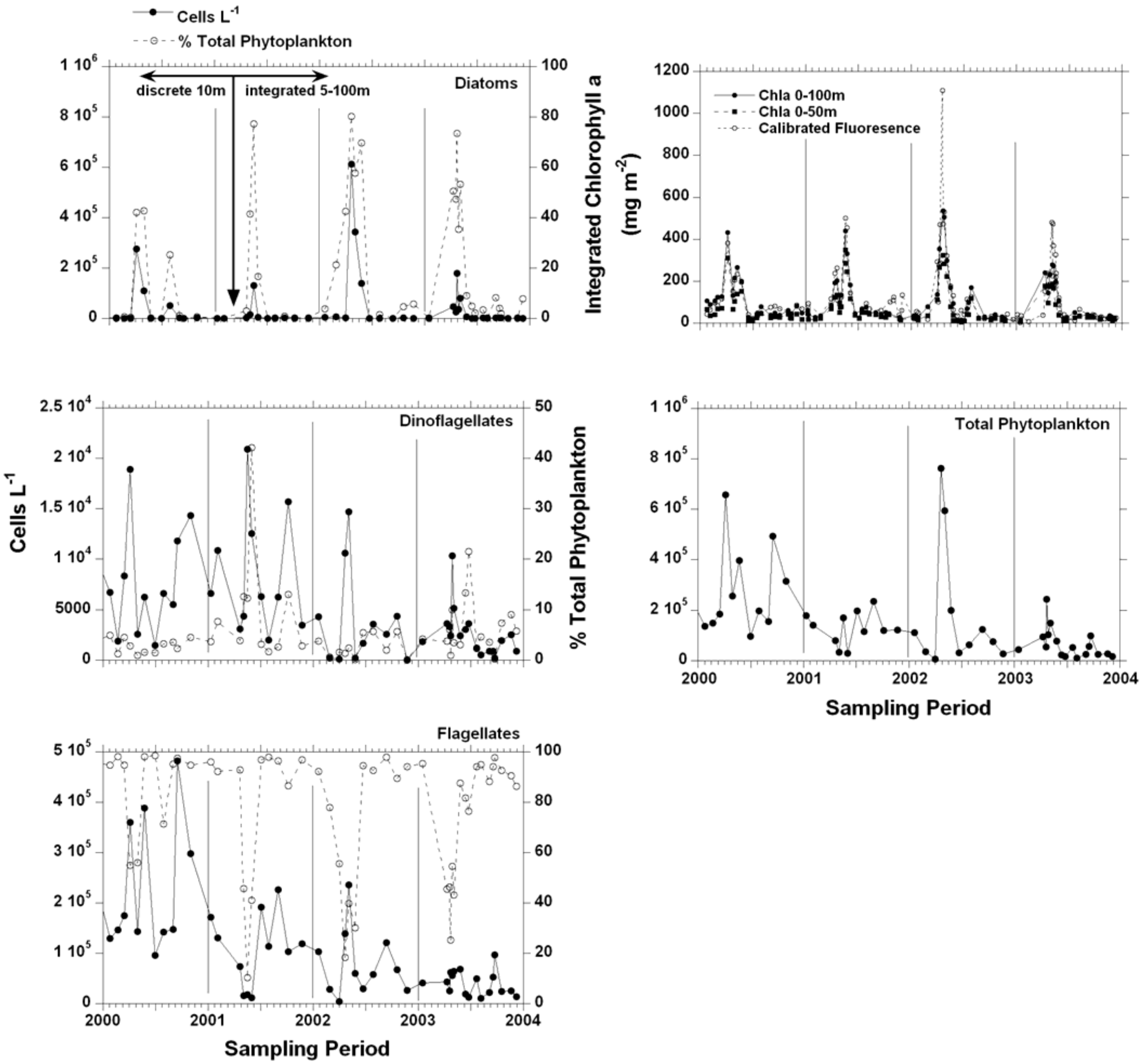

Figure 13. Time series of phytoplankton cell density and relative abundance of major taxa and group totals observed at Station 27 from both discrete 10m (prior to 2001) and depth-integrated (5-100m) sampling including Diatoms, Dinoflagellates, and Flagellates, and inventories of chlorophyll *a*, *in-situ* chlorophyll *a* fluorescence (calibrated against extracted chlorophyll *a*).

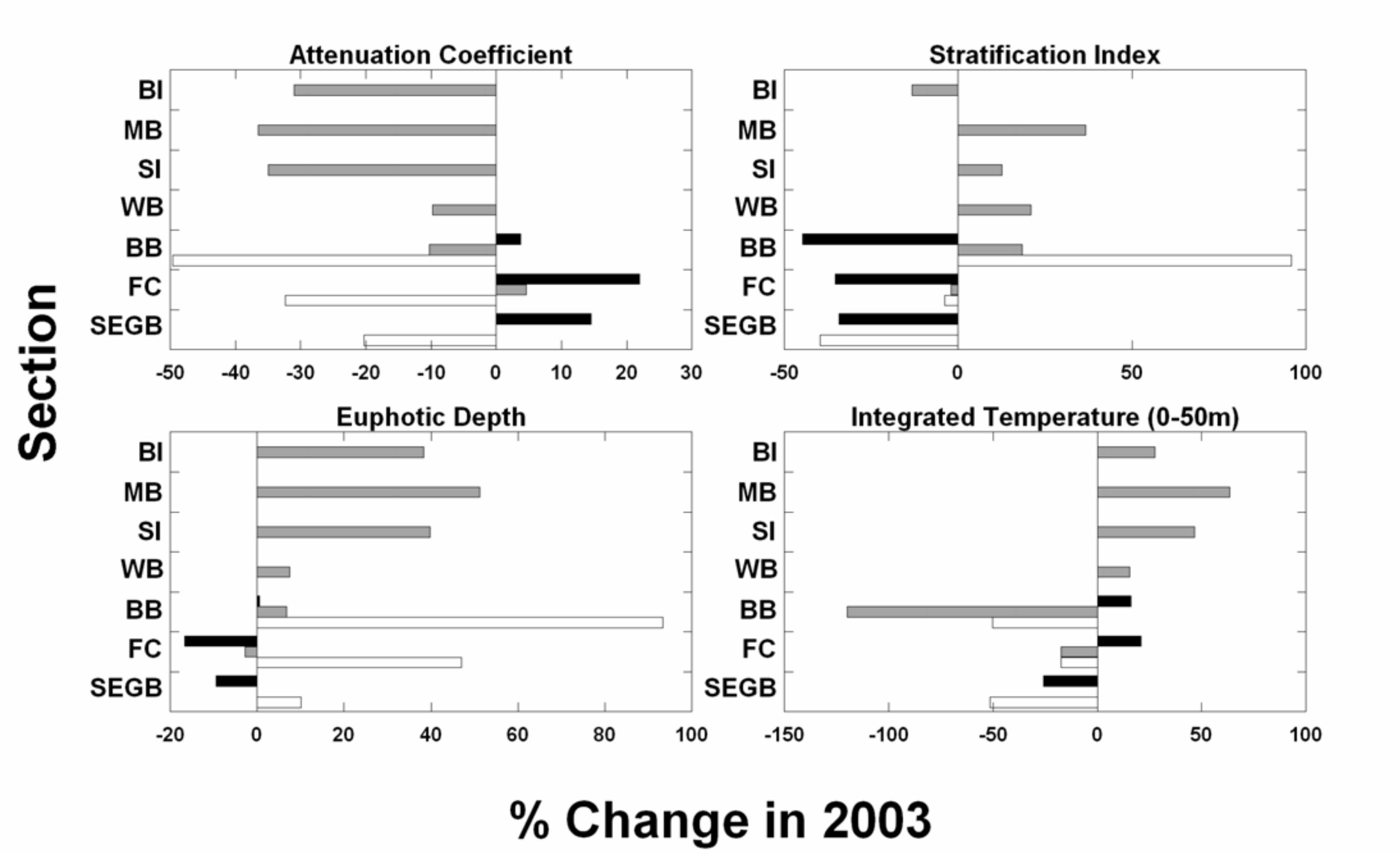

Figure 14. The percent change in optical and physical variables in 2003 compared to earlier years (2000-02) along sections (mean of section) during seasonal occupations. Sections include the southeast Grand Banks (SEGB); Flemish Cap (FC); Bonavista Bay (BB); White Bay (WB); Seal Island (SI), Makkovik Bank (MB); and Beachy Island (BI) and ordered by latitude. See Figure 1 for detailed station locations.

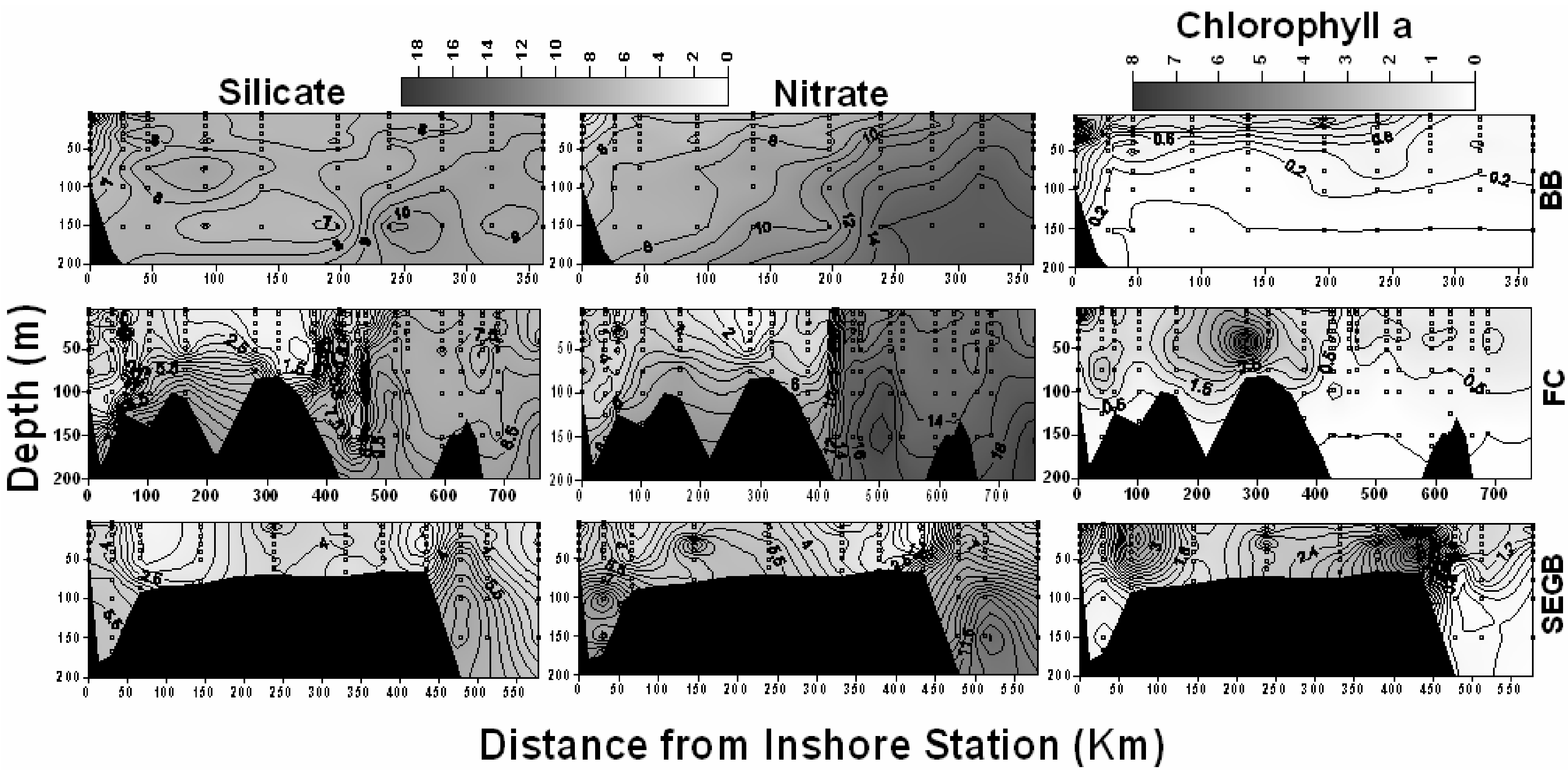

Figure 15. The spring 2003 concentrations (mmol m^{-3}) of silicate, nitrate, and chlorophyll *a* (mg m^{-3}) versus depth along standard AZMP sections including Bonavista Bay (BB); Flemish Cap (FC); and southeast Grand Banks (SEGB). See Figure 1 for detailed sample locations.

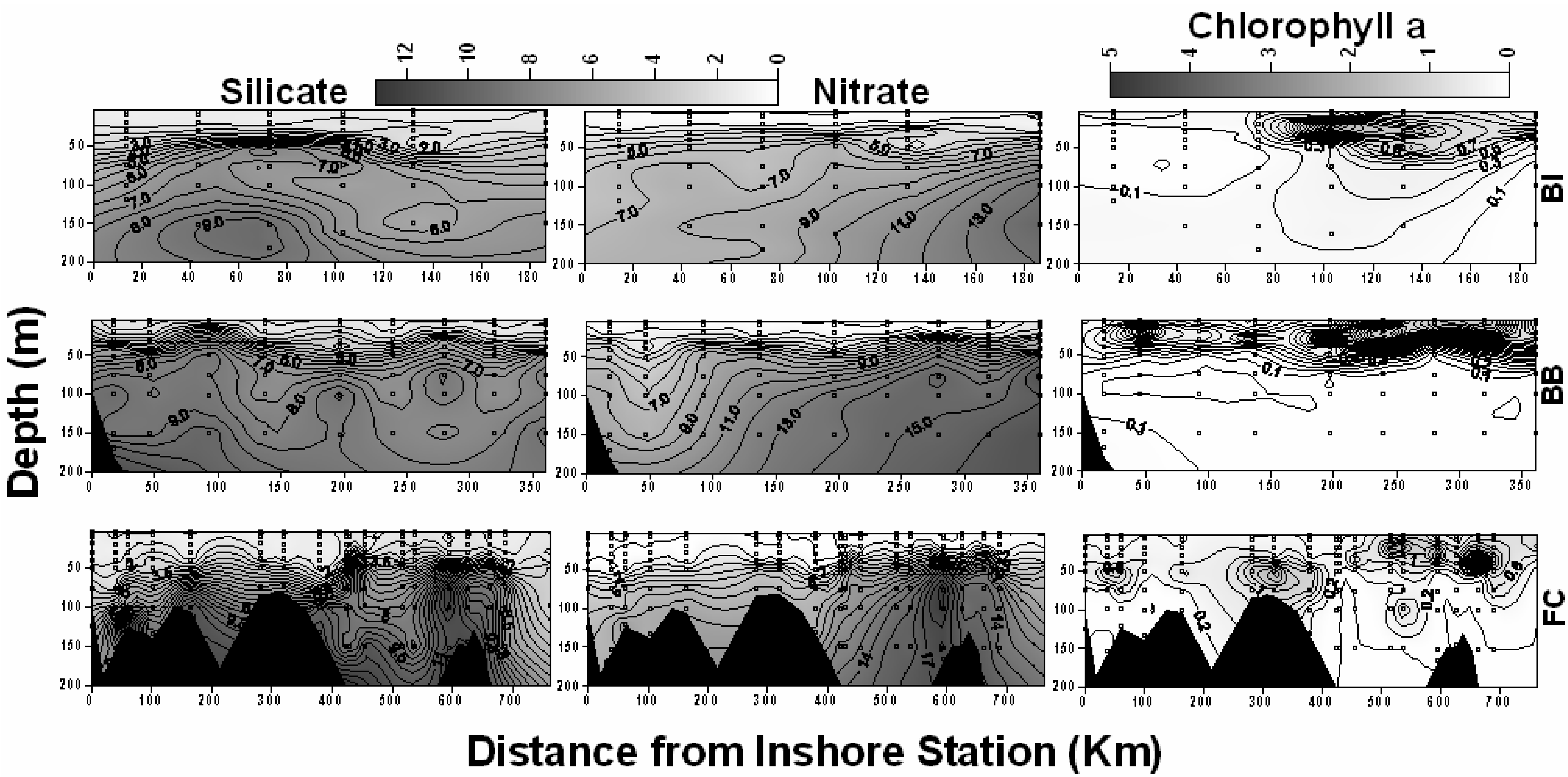

Figure 16. The summer 2003 concentrations (mmol m^{-3}) of silicate, nitrate, and chlorophyll *a* (mg m^{-3}) versus depth along standard AZMP sections including Bonavista Bay (BB); Flemish Cap (FC); and Beachy Island (BI). See Figure 1 for detailed sample locations.

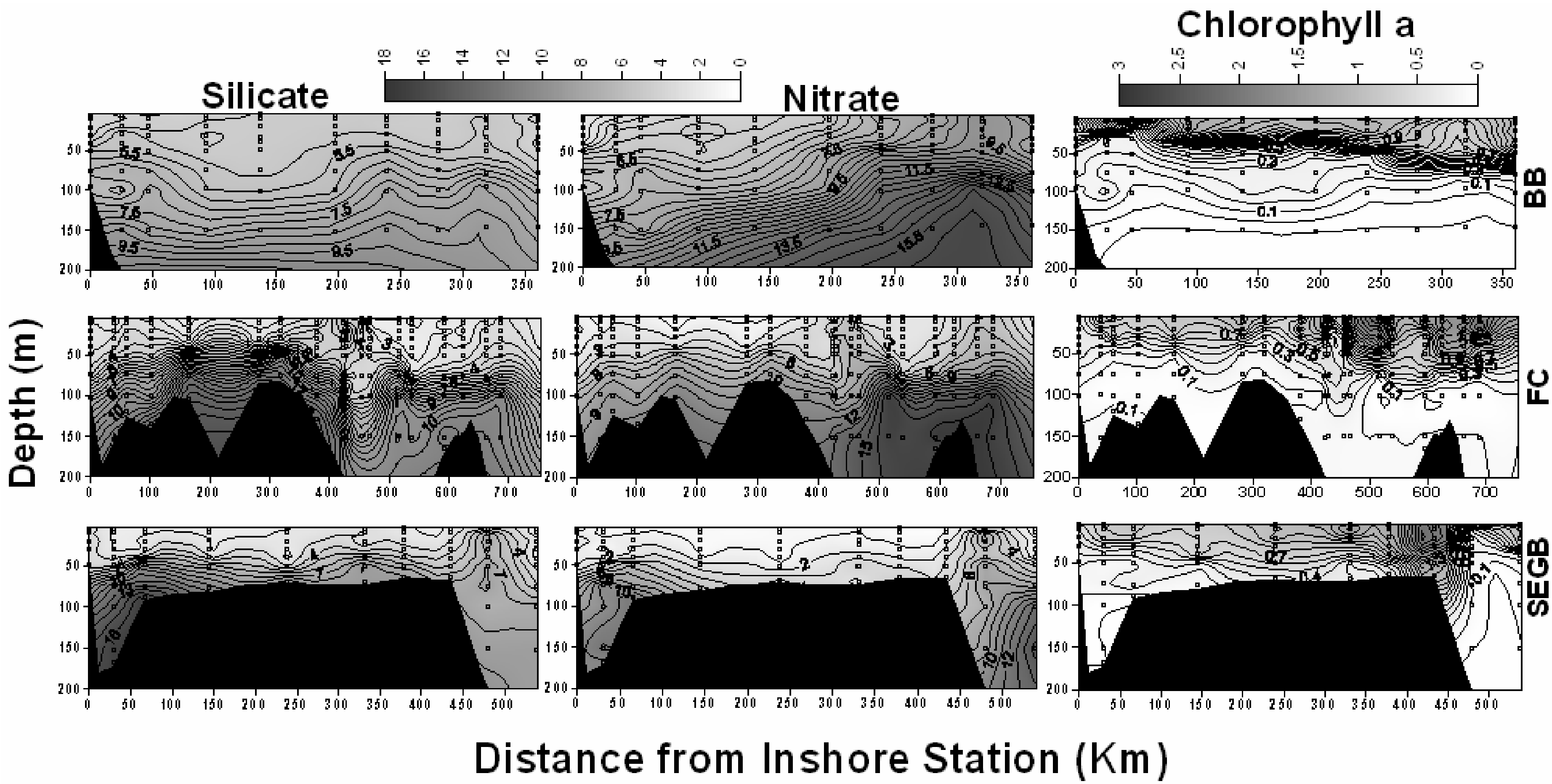

Figure 17. The fall 2003 concentrations (mmol m^{-3}) of silicate, nitrate, and chlorophyll *a* (mg m^{-3}) versus depth along standard AZMP sections including Bonavista Bay (BB); Flemish Cap (FC); and southeast Grand Banks (SEGB). See Figure 1 for detailed sample locations.

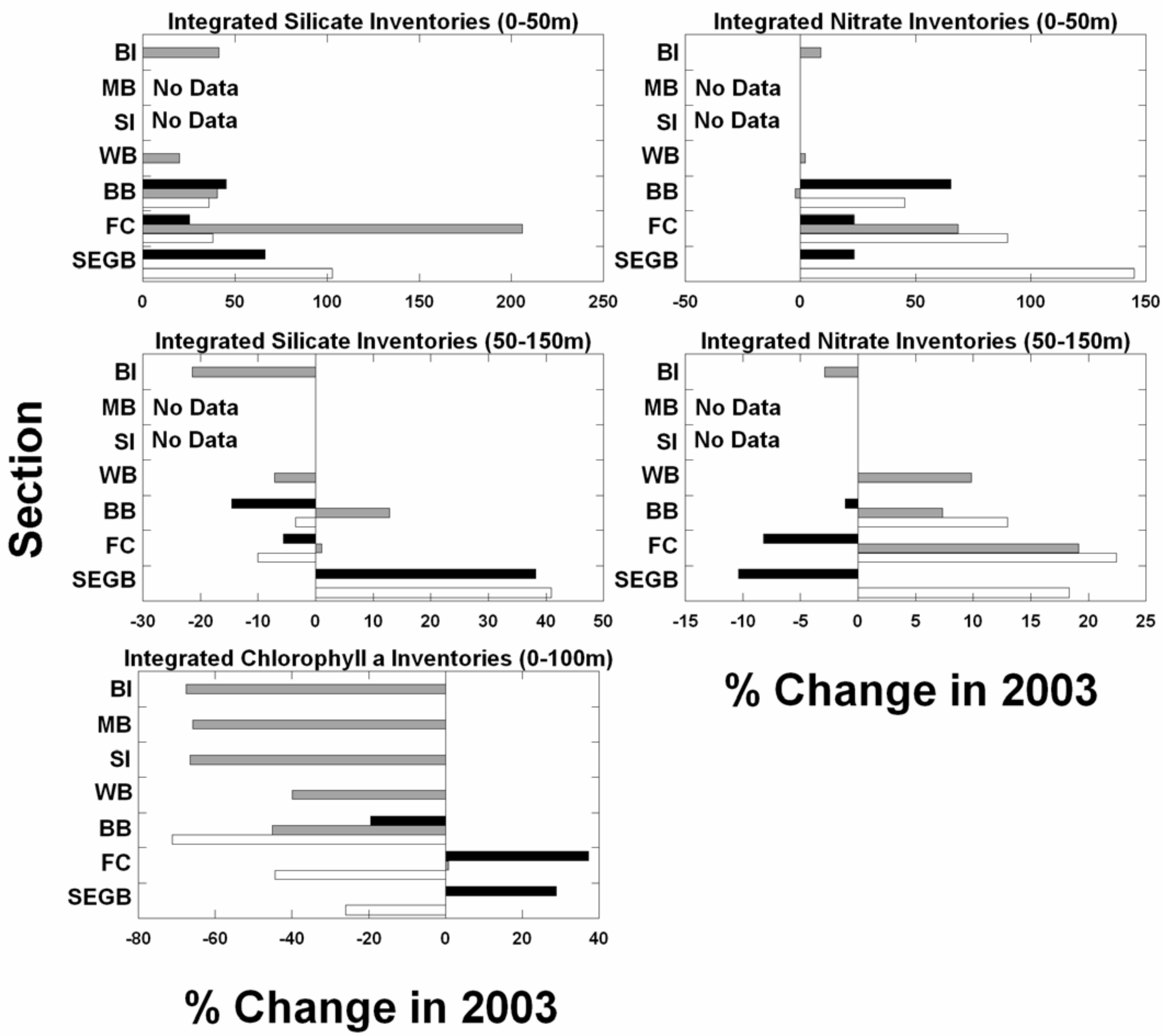

Figure 18. The percent change in chlorophyll *a* and nutrient inventories in 2003 compared to earlier years (2000-02) along sections (mean of section) during seasonal occupations. Sections include the southeast Grand Banks (SEGB); Flemish Cap (FC); Bonavista Bay (BB); White Bay (WB); Seal Island (SI), Makkovik Bank (MB); and Beachy Island (BI) and ordered by latitude. See Figure 1 for detailed station locations.

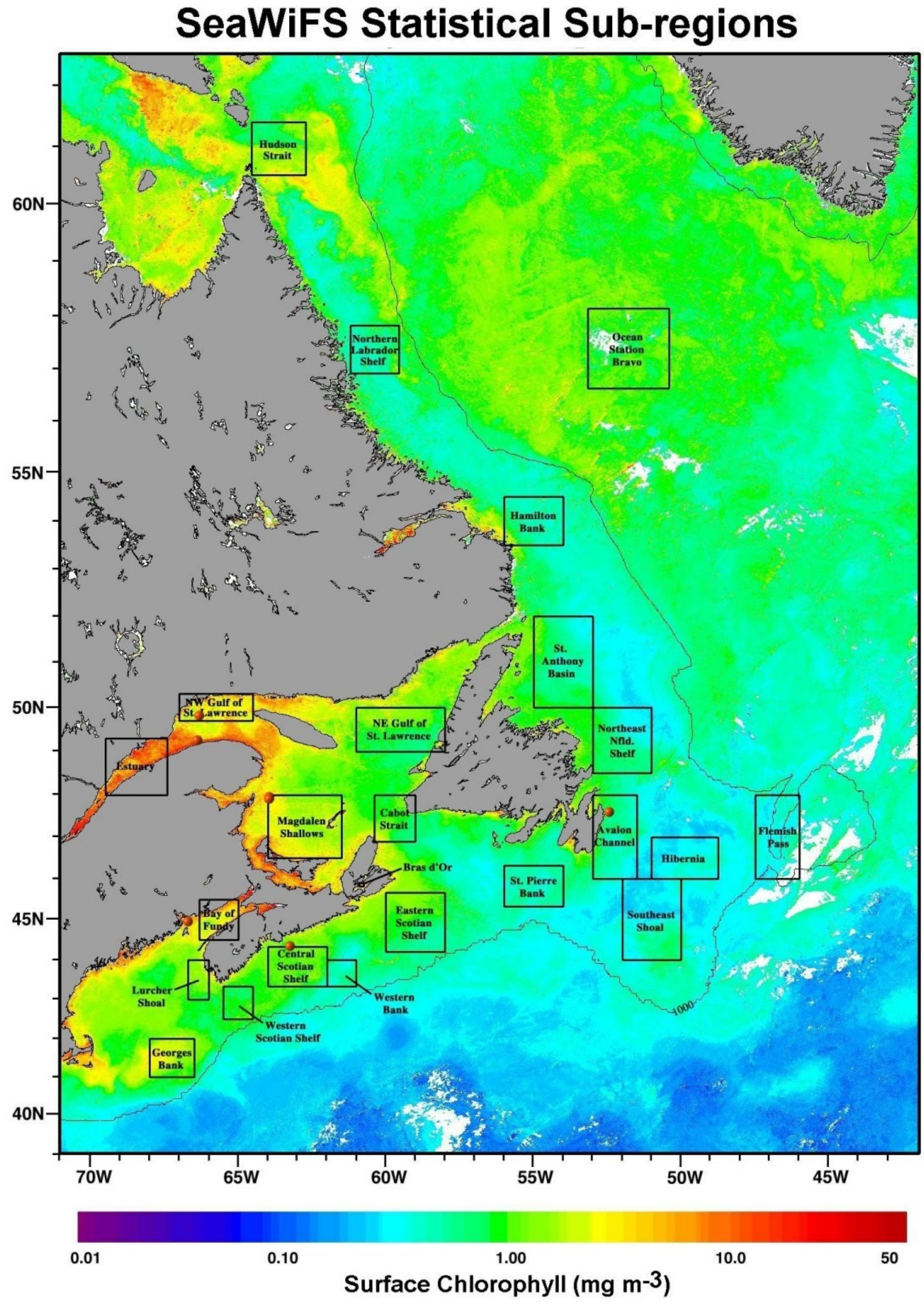

Figure 19. SeaWiFS statistical sub-regions used in production of sea surface chlorophyll *a* and sea surface temperature bi-weekly composite plots.

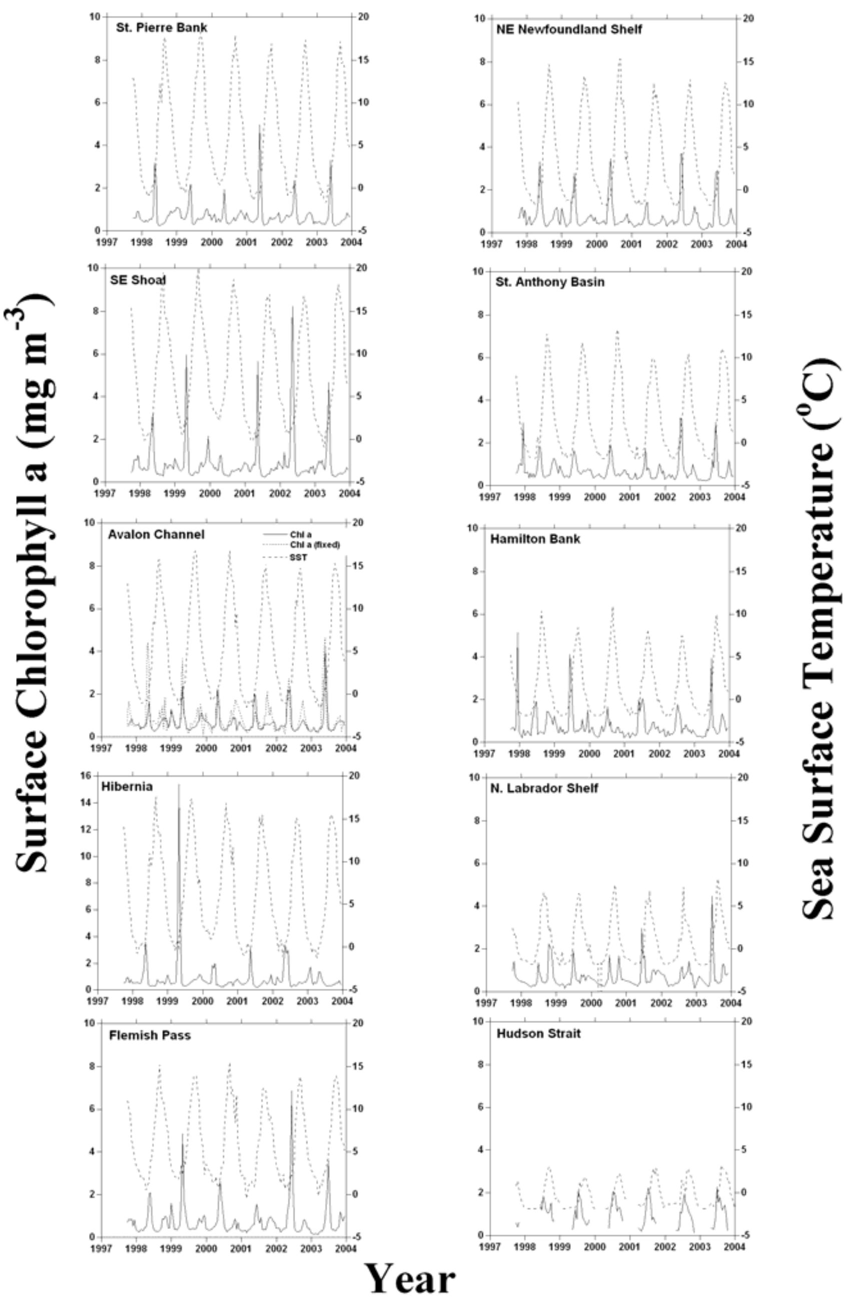

Figure 20. Sea surface chlorophyll *a* and sea surface temperature obtained from SeaWiFS bi-weekly ocean colour and SST composites for selected sub-regions along the Newfoundland and Labrador Shelf during 1998-2003. Notice scale change for Hibernia plot. The Avalon Channel plot also shows chlorophyll *a* for the fixed station. The sub-regions are plotted from west to east and south to north (see Figure 14 for locations of all statistical sub-regions).

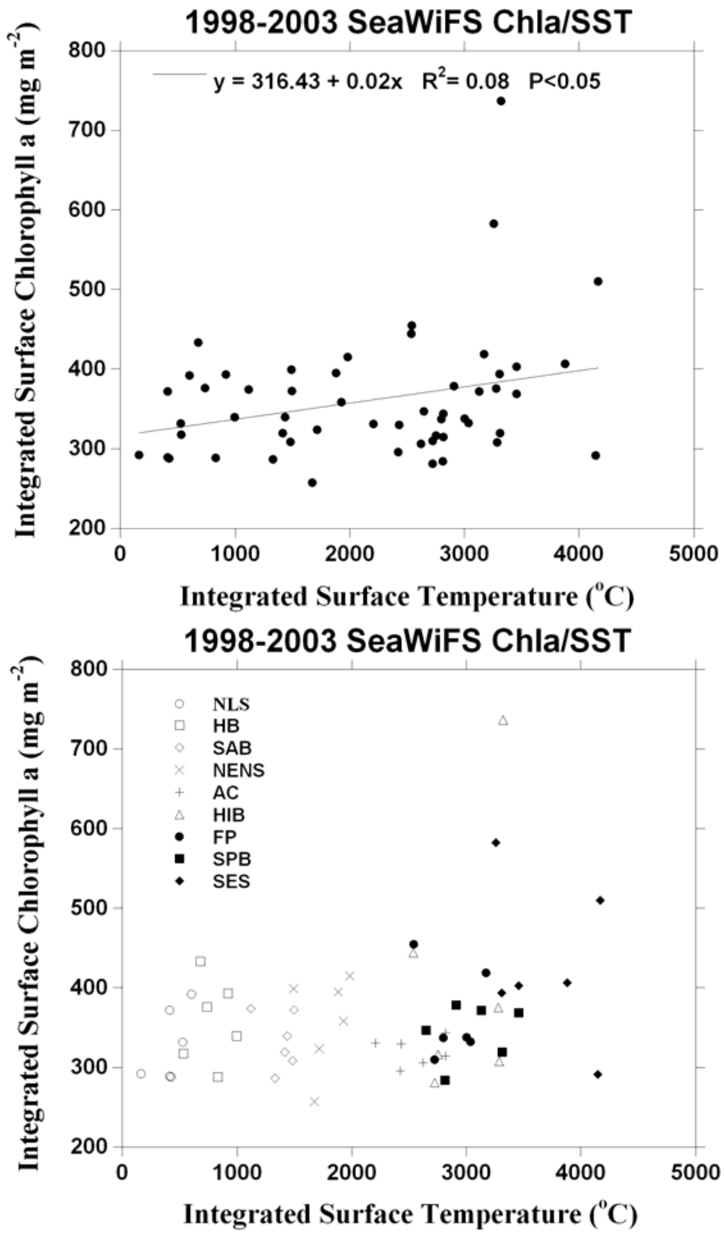

Figure 21. Annual integrated (upper 20m) surface chlorophyll *a* and sea surface temperature obtained from SeaWiFS bi-weekly ocean colour and SST composites for selected sub-regions along the Newfoundland and Labrador Shelf during 1998-2003. Combined data for all sub-regions for surface phytoplankton biomass by sub-region (lower panel). Hudson Strait data was not included due to large number of missing data.

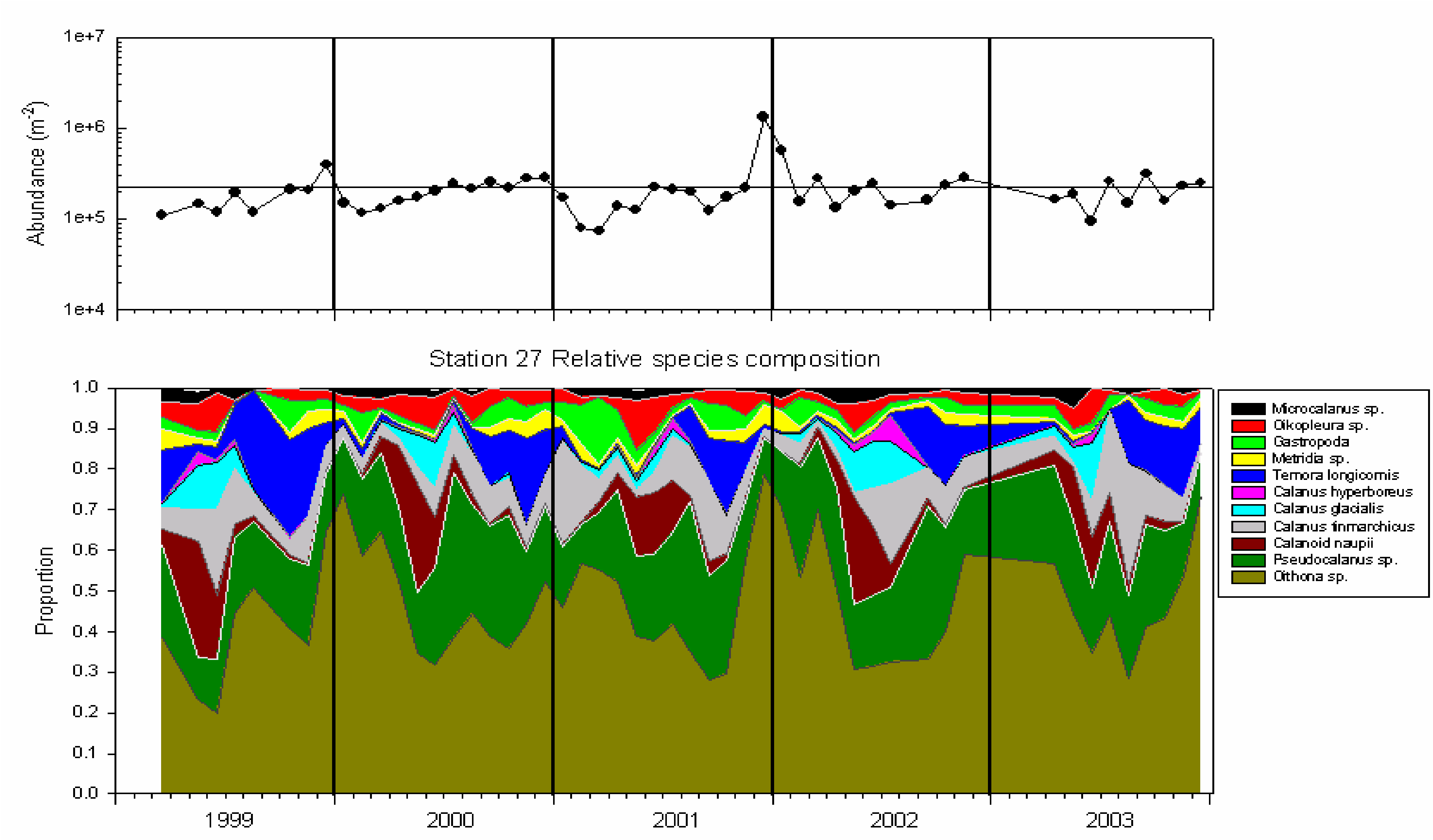

Figure 22. Time series of total zooplankton abundance (upper panel) and relative species composition (Lower panel) from vertical net collections performed at Station 27 since the inception of the AZMP.

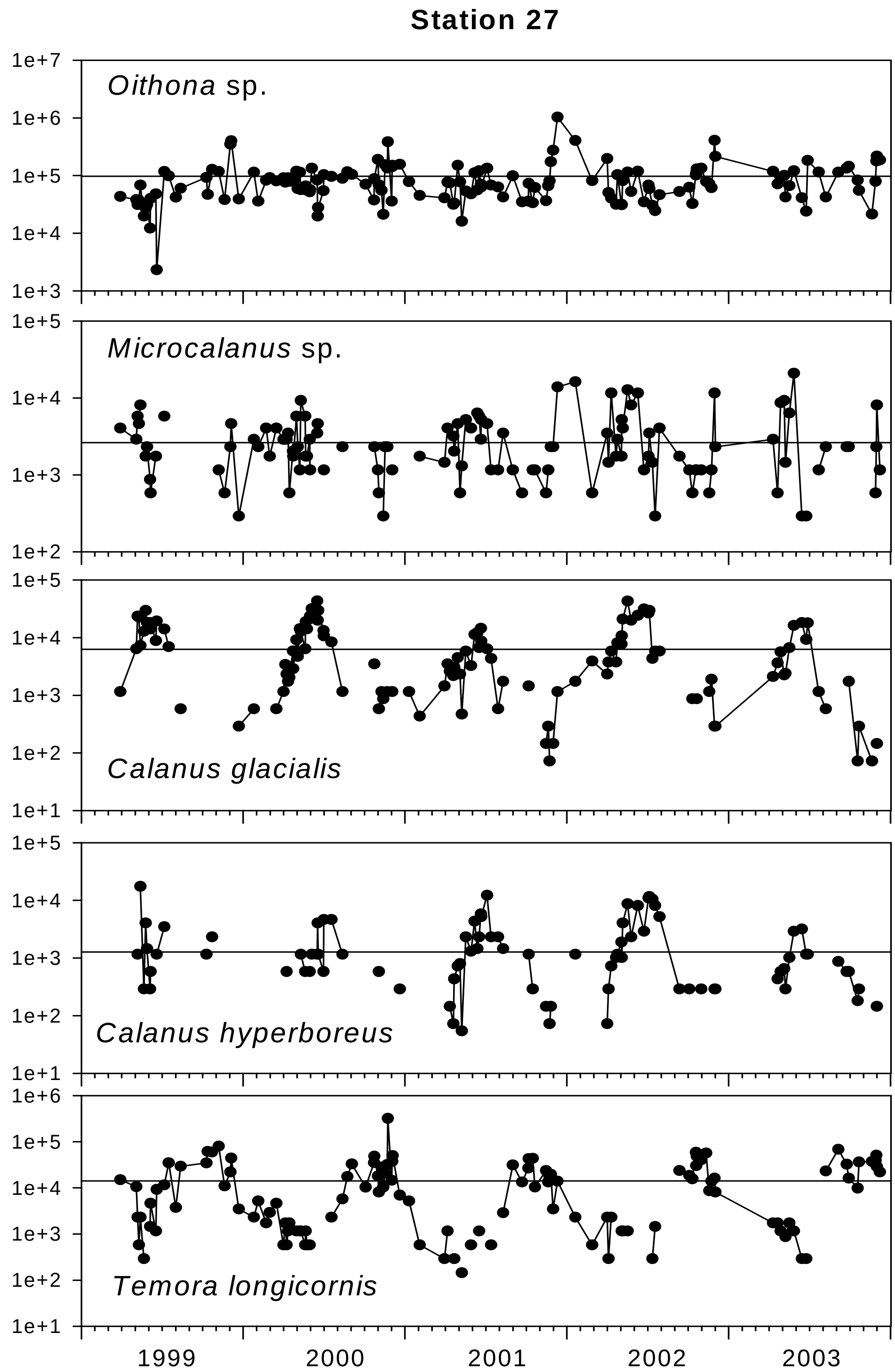

Figure 23. Time series of abundance (m-2) for selected zooplankton taxa from Station 27 since the inception of AZMP. The solid horizontal line represents the overall mean abundance (which includes zero values) from the time series for each taxa and serves only as a reference point.

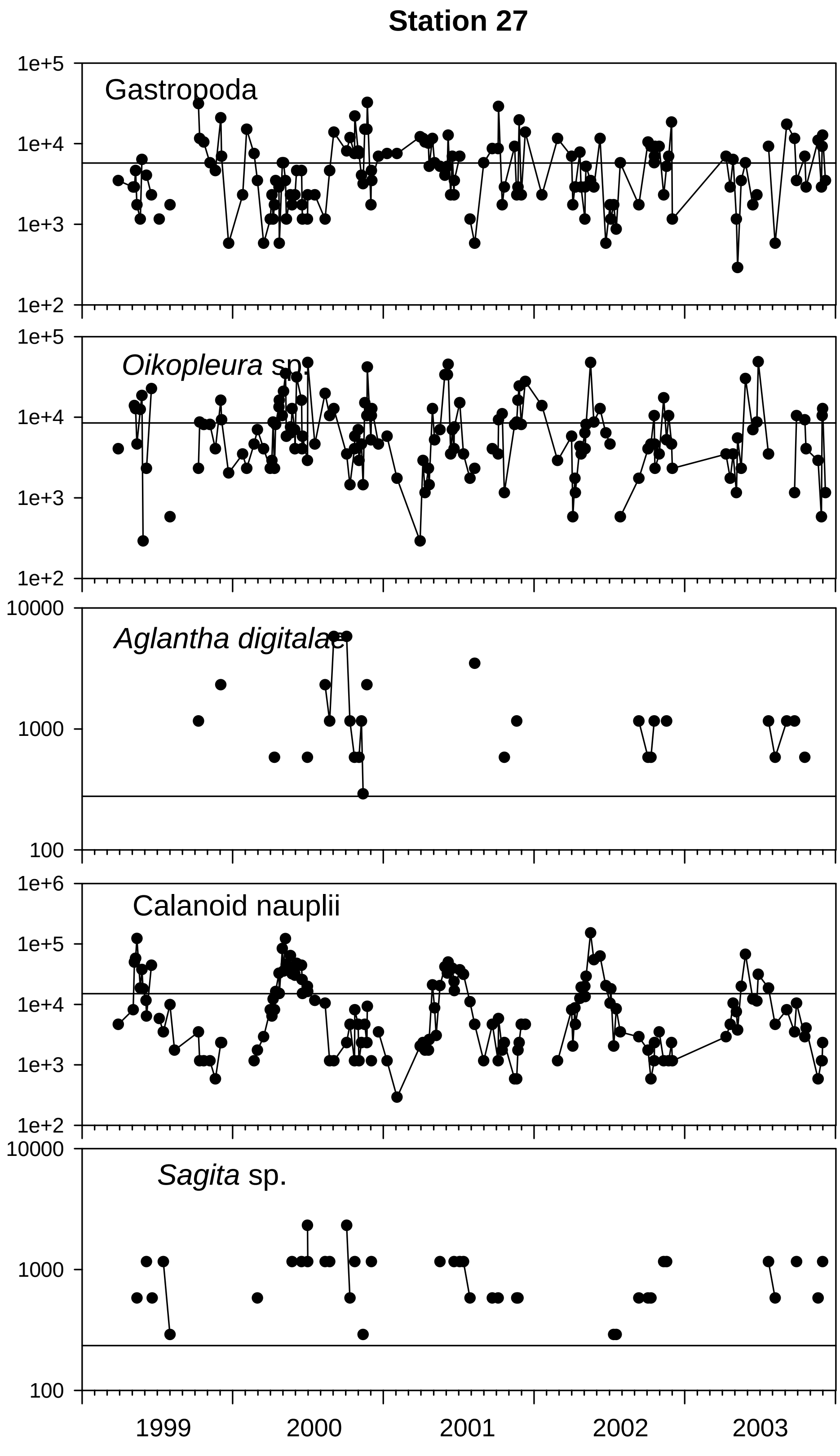

Figure 23 continued.

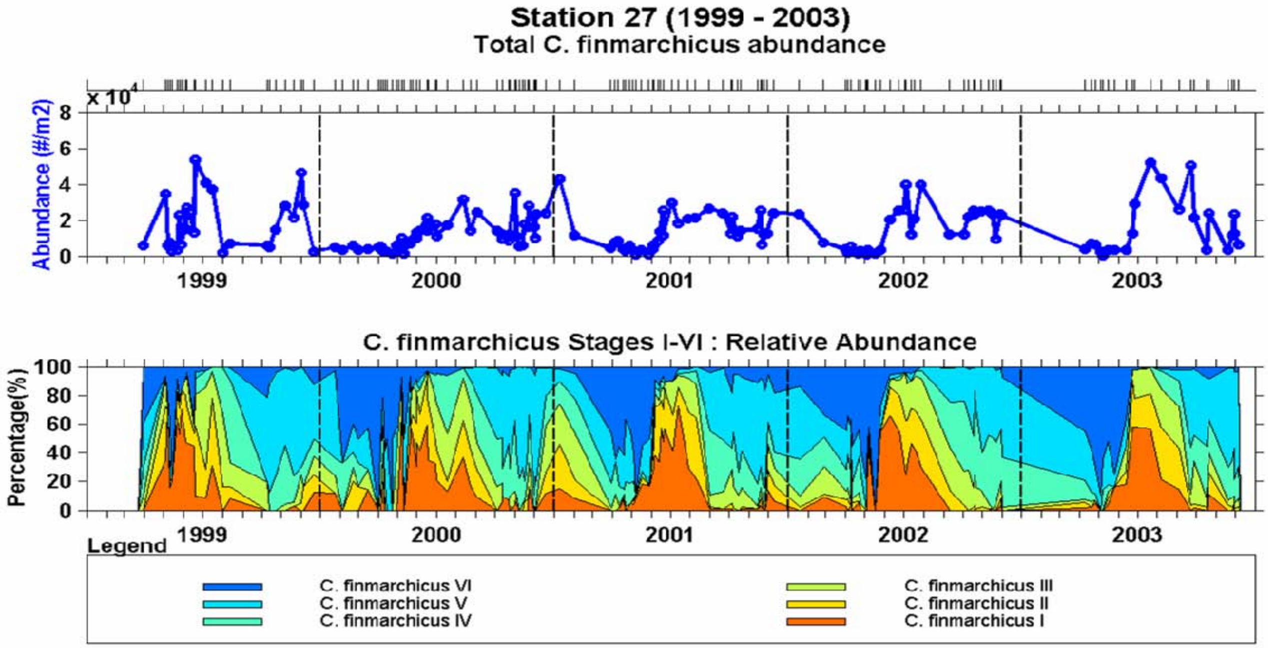

Figure 24. Time series of abundance and copepodite relative stage composition of *Calanus finmarchicus* at Station 27. The tick marks at the top of the figure indicates the collection times of samples.

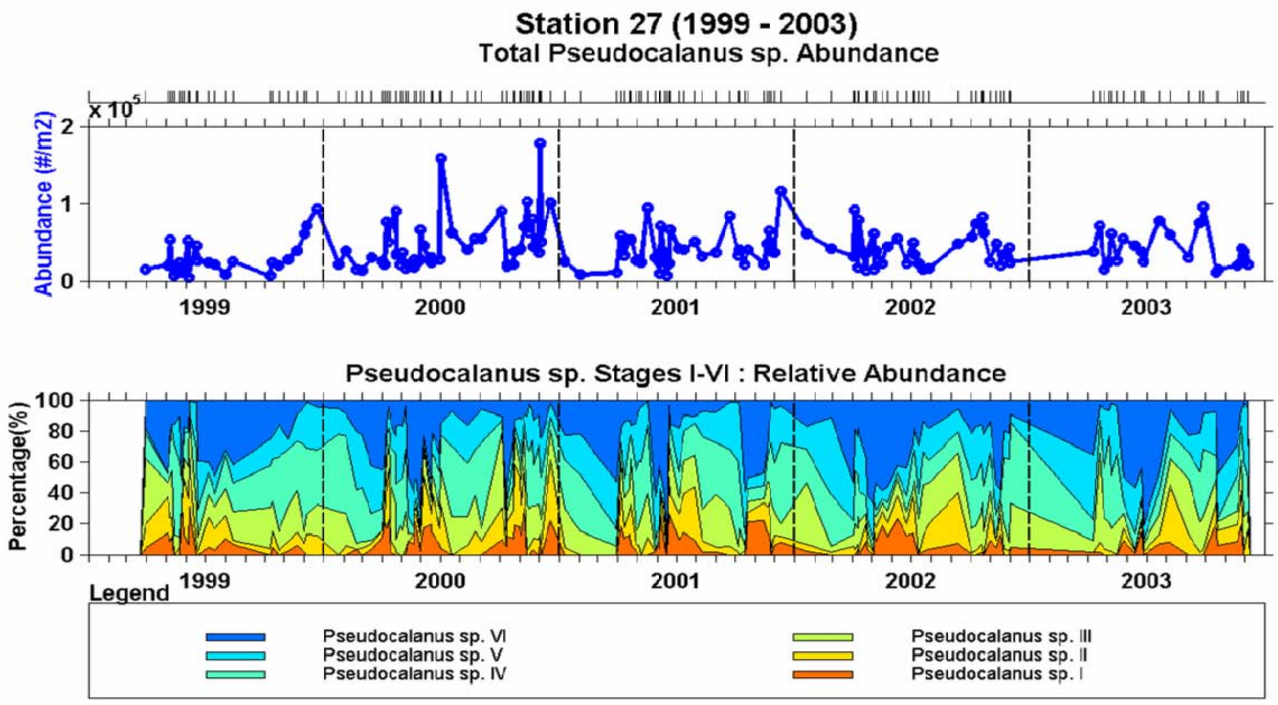

Figure 25. Time series of abundance and copepodite relative stage composition of *Pseudocalanus* sp. at Station 27. The tick marks at the top of the figure indicates the collection times of samples.

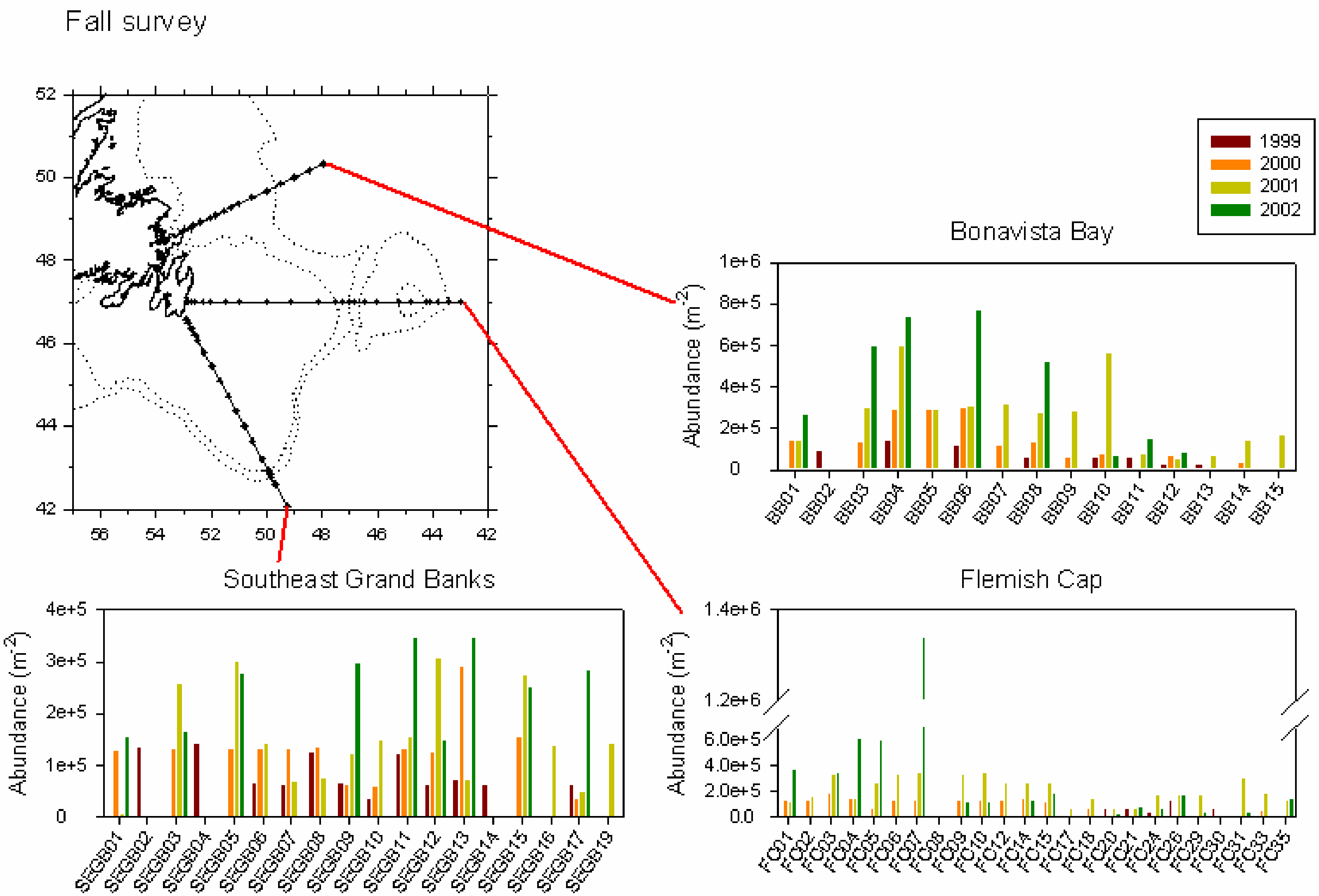

Figure 26. Total zooplankton abundance during fall surveys of the Newfoundland Shelf for the period 1999-2002. Station locations are indicated on the corresponding map. Missing bars indicate that a station was not sampled in a given year and do not indicate the absence of zooplankton at that site.

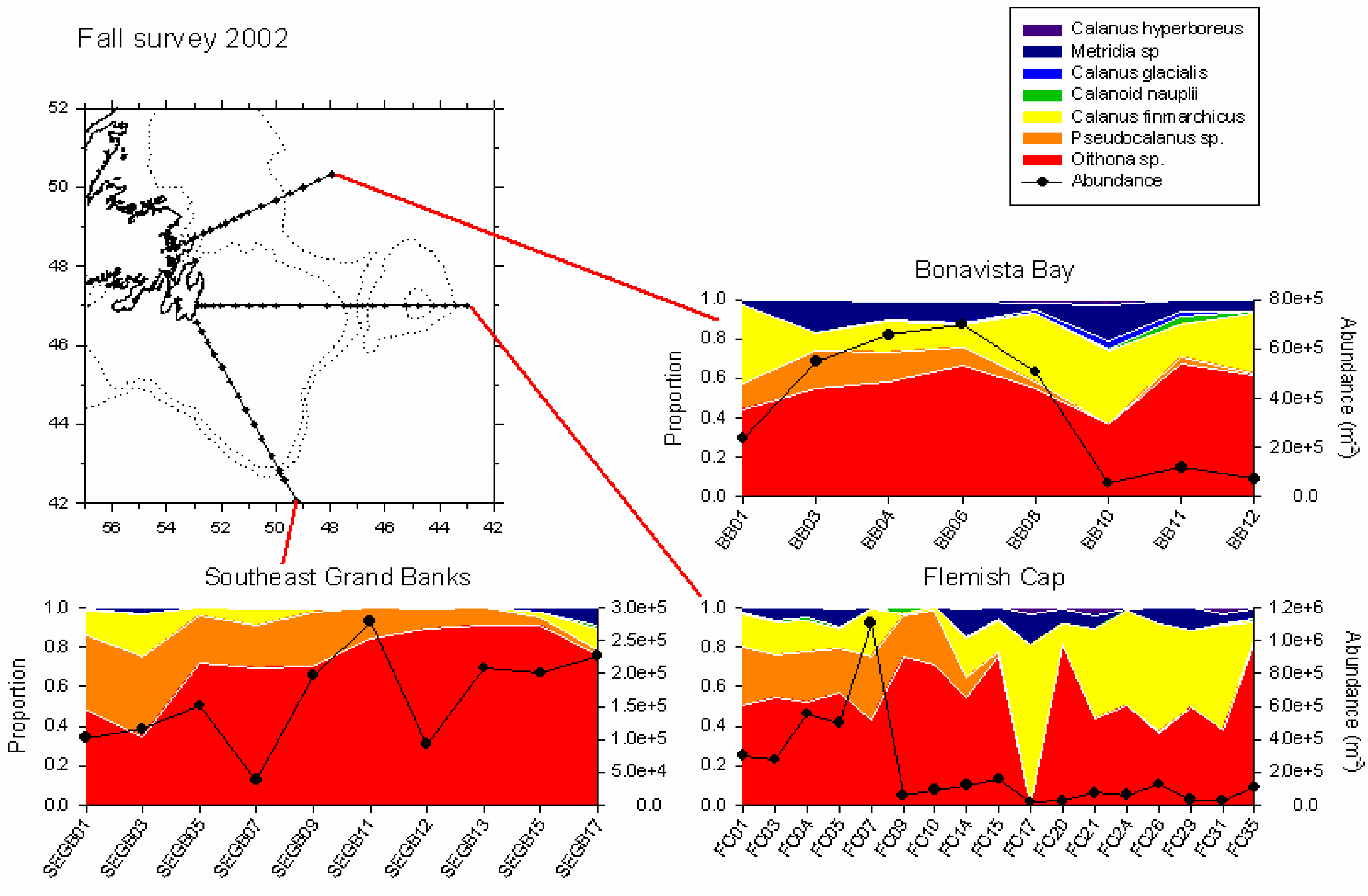

Figure 27. Relative composition of the dominant copepod species during November/December of 2002. The solid line indicates the total abundance of copepod stages at each site. With the exception of calanoid nauplii, all information presented is based on the abundance of copepodite stages. Station locations are indicated on the corresponding map.

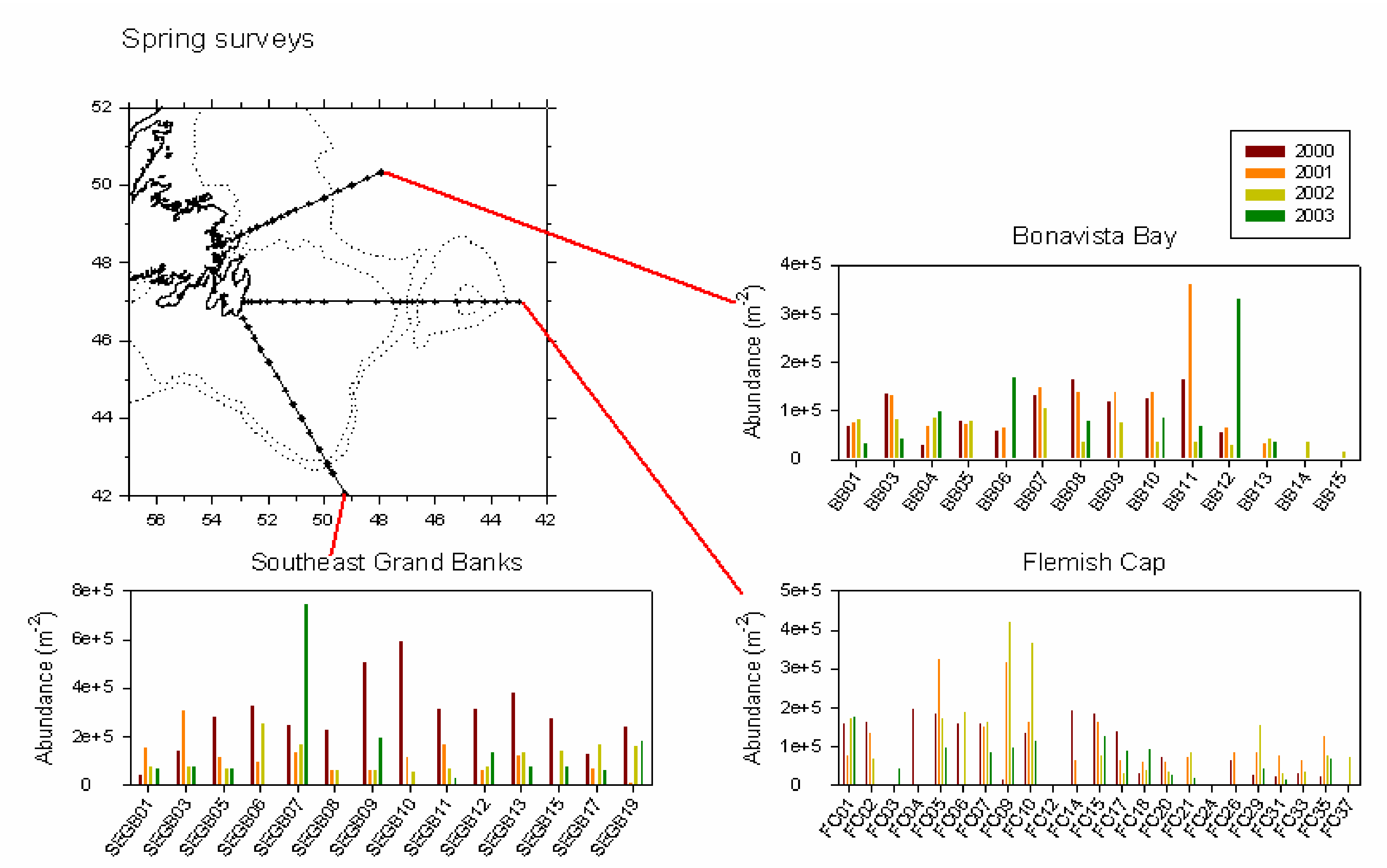

Figure 28. Total zooplankton abundance during spring surveys of the Newfoundland Shelf for the period 2000-2003. Station locations are indicated on the corresponding map. Missing bars indicate that a station was not sampled in a given year and do not indicate the absence of zooplankton at that site.

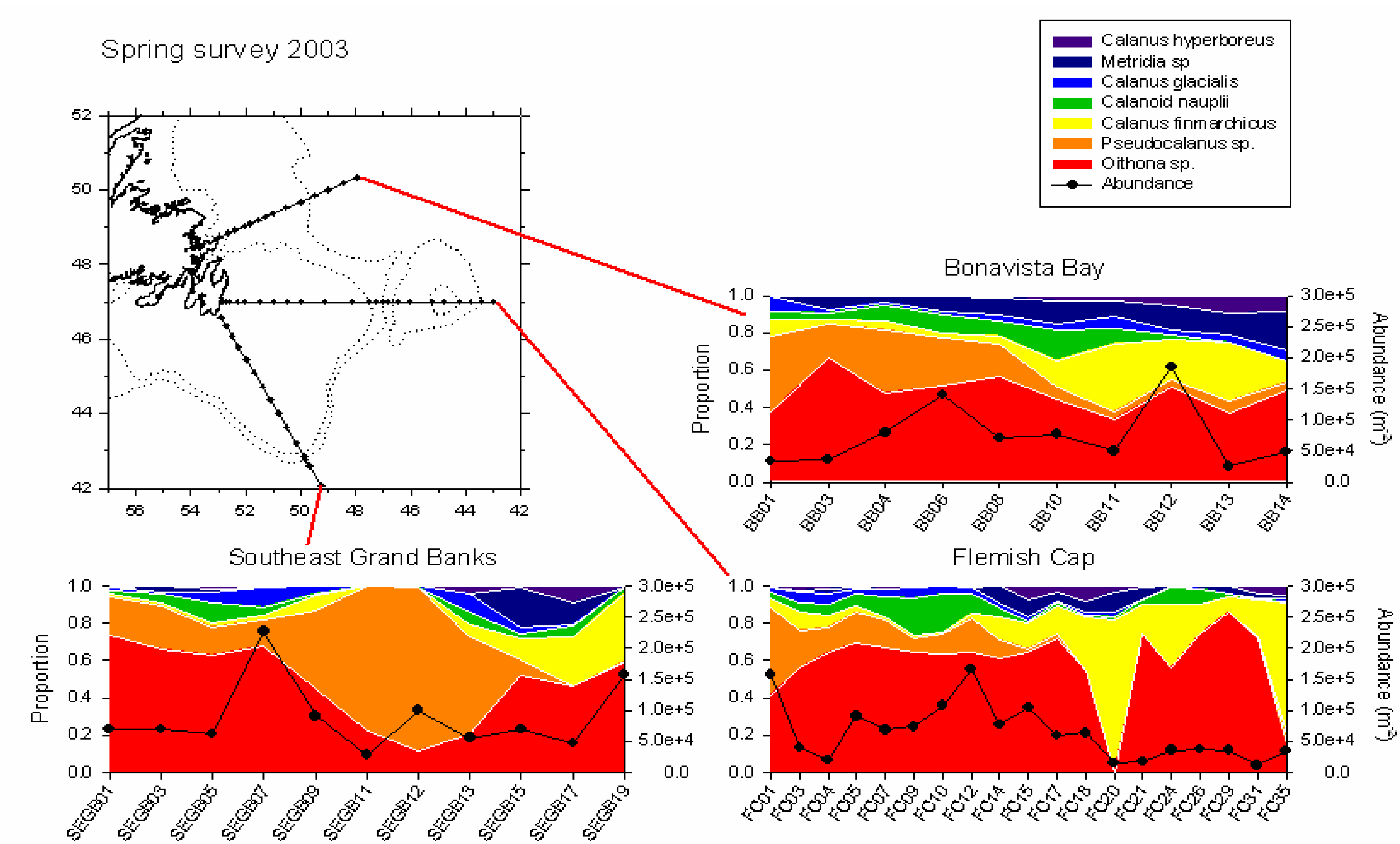

Figure 29. Relative composition of the dominant copepod species during April/May of 2003. The solid line indicates the total abundance of copepod stages at each site. With the exception of calanoid nauplii, all information presented is based on the abundance of copepodite stages. Station locations are indicated on the corresponding map.

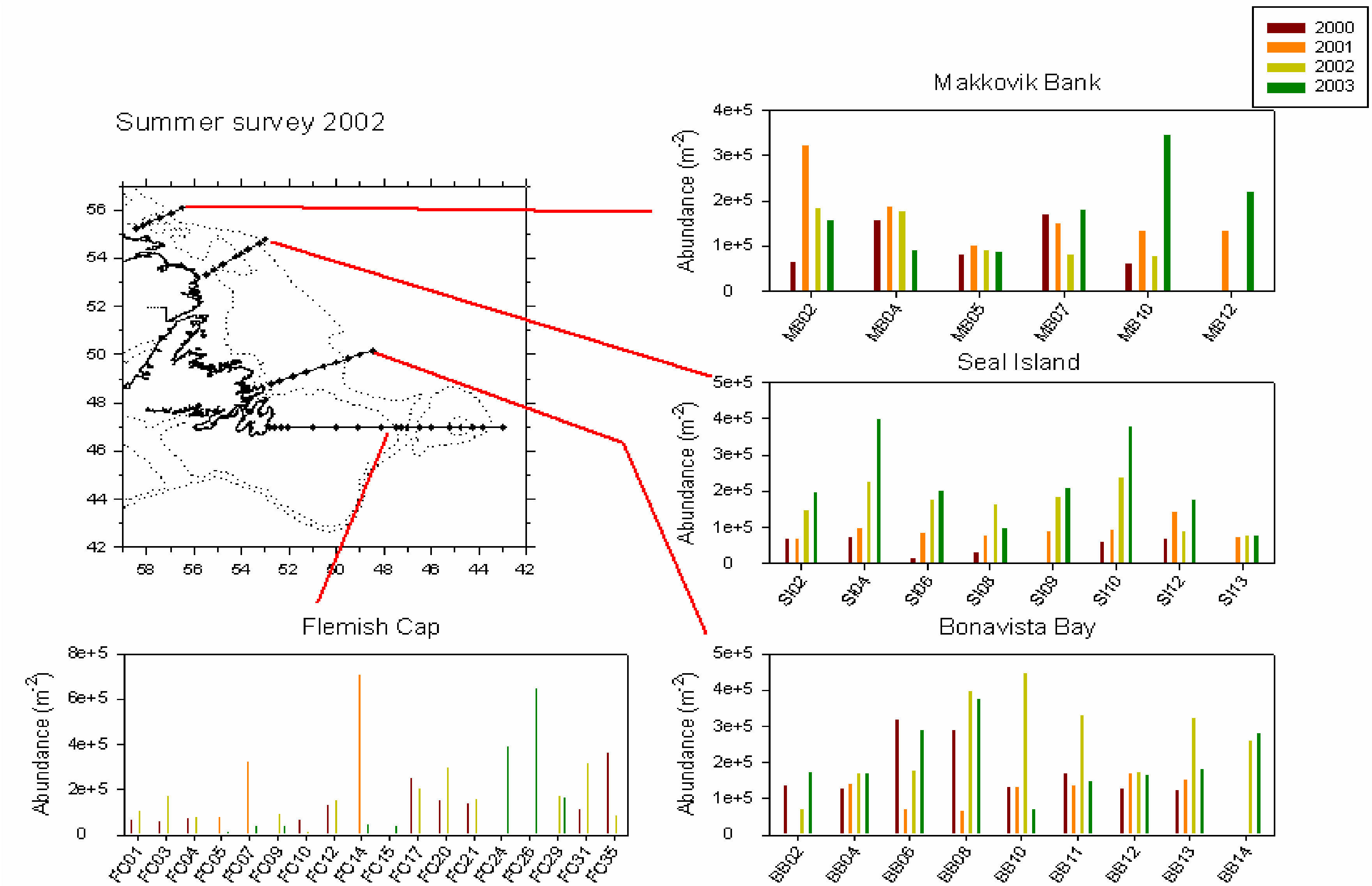

Figure 30. Total zooplankton abundance during summer surveys of the Newfoundland Shelf for the period 1999-2003. Station locations are indicated on the corresponding map. Missing bars indicate that a station was not sampled in a given year and do not indicate the absence of zooplankton at that site.

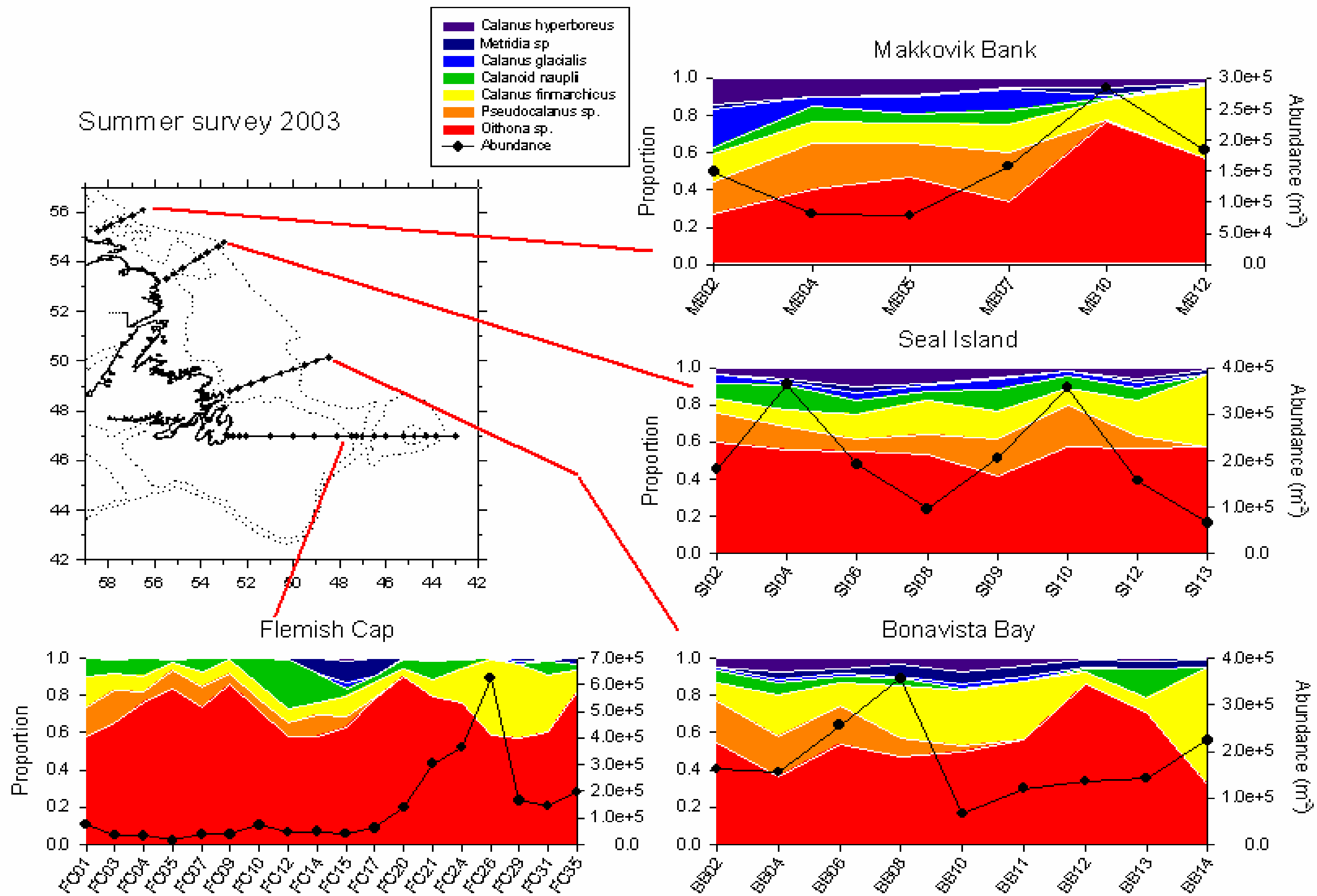

Figure 31. Relative composition of the dominant copepod species during July of 2002. The solid line indicates the total abundance of copepod stages at each site. With the exception of calanoid nauplii, all information presented is based on the abundance of copepodite stages. Station locations are indicated on the corresponding map.