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Biological and Chemical Oceanographic conditions on the Newfoundland Shelf during 2001 with comparisons with earlier observations

Conditions Oceanographiques Biologiques et Chimiques sur le Plateau Terre-Neuvien au cours de l'Annee 2001 avec une comparaison avec les observations anterieures

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Abstract

We review the information concerning the seasonal and interannual variations in the concentrations of chlorophyll a, major nutrients, rates of primary production, as well as the abundance of major taxa of phytoplankton and zooplankton measured from Station 27 and standard oceanographic transects on the Newfoundland Shelf. We focus on temporal and spatial series of the different biological, chemical, optical, and physical measures during 2001 but contrast those observations with previous information from earlier periods when data are available. Variations in optical conditions including attenuation and euphotic depth were comparable to the previous year. The magnitude of the spring bloom was comparable between 2001 and 2000, but the timing and duration of the bloom occurred earlier in 2000 and persisted longer by nearly two-fold compared to 2001. Time series of major nutrient pools at Station 27 showed differences between years. Silicate and nitrate pools in the upper mixed layer showed expected seasonal trends during 2000-01. Depletion of nitrate was more prominent in 2000 during the production cycle in contrast to 2001. Integrated deep nutrient pools were nearly two-fold higher in 2000 compared to 2001. The magnitude, timing, and duration of stratification remained similar during 2000 and 2001, although the rate of onset in stratification appears too have been somewhat higher in 2001 compared to 2000. A prolonged maxima in mixed layer depth was observed during late Winter-Spring 2001 and may have contributed to the delay in the formation of the Spring bloom. Major groups of phytoplankton were enumerated seasonally at the fixed station and along standard AZMP transects. The most notable difference observed between recent years was the widespread reduction in Flagellates and Diatoms in coastal and Shelf areas during 2001. The numerical abundance of major zooplankton groups at Station 27 was generally similar to that previously observed in 1999 and 2000, although densities were generally lower in the fall of 2001. The most notable exception was found in the abundance of *Calanus finmarchicus* in the winter of 2001, when a strong cohort of young stages from the previous fall dominated. There was evidence of a delay in the peak production of *Calanus finmarchicus* stage I copepodites by approximately 30 days in contrast to the two previous years. The density of large calanoid nauplii also showed a similar delay and peak concentrations were approximately 50% of that observed in the previous year although overall levels were comparable to those observed in 1999. Overall, the zooplankton community was similar in composition to that observed in 1999 and 2000 although the relative abundance of pelagic gastropods remained high for an extended period in contrast to the two previous years. Overall zooplankton abundance on the Newfoundland Shelf was similar to previously observed densities throughout the spring and summer periods, with the exception of the coastal areas along the Bonavista Bay transect where densities of all major taxa were lower during the summer observation period. In contrast, densities of all major taxa along the coast of Labrador appeared to be elevated during the July Research Vessel survey.

Résumé

Nous passons en revue les données de variations saisonnières et interannuelles des concentrations de chlorophylle *a* et des principaux éléments nutritifs, des taux de production primaire et de l'abondance des principaux taxons de phytoplancton et de zooplancton à la station 27 et sur des transects océanographiques standard, sur la plate-forme de Terre-Neuve. Nous mettons l'accent sur les séries temporelles et spatiales des diverses mesures biologiques, chimiques, optiques et physiques faites en 2001, mais en les comparant avec les données disponibles pour des années antérieures. Les variations des conditions lumineuses, notamment l'atténuation de la lumière et la profondeur de la zone euphotique, étaient semblables à celles de l'année précédente. En 2001, la prolifération printanière du phytoplancton était d'ampleur semblable à celle de 2000, mais elle s'est produite plus tard et a duré presque deux fois moins longtemps qu'en 2000. À la station 27, les concentrations des principaux éléments nutritifs variaient d'une année à l'autre. En 2000-2001, les concentrations de silicate et de nitrate dans la couche mélangée supérieure présentaient les variations saisonnières attendues. L'appauvrissement en nitrate durant le cycle de production était plus important en 2000 qu'en 2001. Les concentrations intégrées des éléments nutritifs en eaux profondes étaient presque deux fois plus élevées en 2000 qu'en 2001. L'ampleur, le moment et la durée de la stratification étaient semblables en 2000 et en 2001, mais celle-ci semble s'être établie un peu plus rapidement en 2001. À la fin de l'hiver et au printemps 2001, on a observé une période prolongée de profondeur maximale de la couche mélangée, ce qui a pu contribuer à retarder la prolifération printanière. Nous avons dénombré les principaux groupes de phytoplancton présents chaque saison à la station fixe et sur les transects standard du PMZA. La réduction généralisée de l'abondance des flagellés et des diatomées en 2001 dans les zones côtières et sur la plate-forme constitue la différence la plus remarquable observée au cours des dernières années. En général, l'abondance des principaux groupes de zooplancton à la station 27 était semblable à celle observée en 1999 et en 2000, quoique les densités étaient généralement plus faibles à l'automne de 2001. L'exception la plus notable était l'abondance de *Calanus finmarchicus* à l'hiver de 2001, lorsqu'une importante cohorte de jeunes stades éclos l'automne précédent dominait la population. Les données indiquent que la production maximale de *Calanus finmarchicus* du premier stade copépodite aurait été retardée d'environ 30 jours par rapport aux deux années précédentes. La densité des nauplii calanoïdes de grande taille a présenté un retard semblable, et leurs densités maximales n'ont atteint qu'environ la moitié de celles observées l'année précédente, quoique les densités globales étaient comparables à celles de 1999. En général, la communauté zooplanctonique présentait une composition semblable à celle observée en 1999 et en 2000, bien que l'abondance relative des gastéropodes pélagiques est restée élevée plus longtemps que lors des deux années précédentes. L'abondance printanière et estivale de l'ensemble du zooplancton sur la plate-forme de Terre-Neuve était semblable aux observations antérieures, exception faite des zones côtières le long du transect de la baie Bonavista où les densités estivales des principaux taxons étaient inférieures. Par contre, le long de la côte du Labrador, les densités des principaux taxons semblaient élevées lors du relevé de navire de recherche effectué en juillet.

Introduction

We review standard optical, chemical, selected physical indices, and biological oceanographic conditions on the Newfoundland and Labrador Shelf during 2001. 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 2001 provided good spatial and temporal series coverage of standard variables. This provides a basis 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 (AZMP)[1]. 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 – Irradiance

The availability of light for photosynthesis in an aquatic ecosystem is determined by the penetration of the light field (Kirk 1994). Time series of the vertical attenuation coefficient (K_d) at Station 27 showed similar trends during 2000-01 (Figure 2). Kd 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 (mg m^{-3}) at depth (z) in metres. The attenuation coefficient is related to dissolved and colored substances and particulate matter within the water. The average value of K_d was calculated for the 0-100m. Attenuation increased rapidly by 3-fold in response to the onset of the spring bloom from initial background levels of ca. 0.1 m^{-1}. After cessation of the Spring bloom, attenuation returned to near background levels in 2000-01 and showed no evidence of late Summer or Fall blooms observed in earlier years. Values of attenuation estimated from in-situ downward PAR irradiance data compared well with vertical attenuation coefficient determined from the Platt *et al.* 1988 model (data not shown). Large variation in the in-situ values of attenuation were always associated with substantial changes in chlorophyll biomass. Measures of vertical attenuation provide estimates of euphotic depth (depth of the 1 % light level) based on:

$$\text{Euphotic depth (m)} = 4.6 / K_{d\_}PAR$$

Time series of euphotic depth varied seasonally at Station 27 with shallow depths of ca. 20m during spring bloom periods while deeper values of ca. 50-80m were observed during Summer through Winter in 2000-01 (Figure 2). We initiated collection of incident downward PAR irradiance at the Northwest Atlantic Fisheries Centre in St. John's, Newfoundland during Summer 2001 to provide near-continuous measures to supplement limited *in-situ* observations collected during sample occupations of Station 27. Total

[1] http://www.meds-sdmm.dfo-mpo.gc.ca/zmp/main_zmp_e.html

incident PAR irradiance collected at the Centre is shown for the later part of 2001 (Figure 2).

Fixed Station – Water column structure

Time series of physical measures including stratification index, mixed layer depth, and integrated temperature in the upper 50m were estimated at Station 27 during 2000-01 (Figure 3). The stratification index, taken as the difference in density between 5 and 50m (see Craig *et al*. 2001 for computation details) showed similar trends during 2000-01 time series. The magnitude, timing, and duration of stratification remained similar during 2000 and 2001. The rate of stratification appears too have been somewhat higher in 2001 compared to 2000. Larger variations between years were apparent in the mixed layer depth (mld) time series, taken as the depth centre of the pynocline. We observed a prolonged maxima in mld during Winter-Spring 2001 which might have contributed to inhibiting phytoplankton aggregations leading to the observed delay in the timing of the Spring bloom (see below). Another possible contributing factor was the thermal regime. The magnitude and duration in integrated temperature at Station 27 were similar between years but the timing was delayed in 2001 compared to 2000.

Fixed Station – Nutrients

We examine the 2001 time series of major nutrients including nitrate (combined nitrate and nitrite, henceforth referred to as nitrate), and silicate and contrast with data obtained in 2000 at Station 27 (Figure 4). Concentrations of silicate and nitrate were typically >2 μM throughout the water column and approached maxima of 10 μM near the bottom prior to the Spring Bloom. Concentrations of both major nutrients were depleted rapidly to values < 0.5 μM to depths > 50m during the bloom and remained very low throughout the latter part of the year until late Fall when nominal increases were observed. The nutricline shoaled periodically during the Summer and Fall. Difference in vertical profiles in concentrations of both major nutrients were apparent between years. Overall, silicate concentrations below the mixed layer tended to be reduced by 2-3 μM during 2001 in contrast to 2000, except during Summer 2001 when concentrations where enhanced by 3-4 μM at intermediate depths. Differences in nitrate concentrations in 2001 relative to 2000 were less pronounced than in silicate, although deep pools were lower by 2 μM during much of the year. Evidence of upwelling of silicate and nitrate observed during the Summer and Fall in 2001 account for the positive differences at intermediate depths.

Time series of major nutrient pools at Station 27 showed differences between years (Figure 5). Silicate and nitrate pools 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 (more pronounced in 2001 due to shoaling of the deep nutrient pools below the mixed layer). Depletion of nitrate was more prominent in 2000 occuring during Spring through the Summer period. Consistent differences in trends for deeper nutrient pools (50-150 m) of silicate and nitrate were apparent between years. In 2000, integrated levels of silicate and nitrate were nearly one and a half to two-fold higher compared to 2001.

Fixed Station – Phytoplankton

Vertical profiles of chlorophyll *a* at Station 27 differed substantially between 2001 and 2000 (Figure 6). Prior to the occurrence of the spring bloom in 2001, a subsurface chlorophyll a maximum was observed at ca. 50m. The main bloom was detected near mid-May and extended from surface to depths of 75m. Chlorophyll *a* concentrations declined to background levels by early June. The spring bloom in 2000 was initiated in early April and declined to background levels by early May. In 2000, a deep chlorophyll a maximum layer was detected at 40m about 20 days after the primary bloom. There is no evidence of Summer or Fall blooms from July through December in either year, when chlorophyll *a* concentrations are generally < 1.0 mg m^{-3} throughout the water column.

Time series measures of integrated chlorophyll *a* during 2000-01 reiterated the importance of spring bloom periods in the seasonal dynamics of phytoplankton abundance at Station 27 (Figure 7). Integration of chlorophyll in surface waters (0-50m) captured the main trends, but there are significant amounts of phytoplankton biomass that occur at deeper strata (> 50m), particularly during the spring bloom. Although the magnitude of the spring bloom was comparable between 2000 and 2001, reaching levels in excess of 400 mg m^{-2}, the timing and the duration of the bloom occurred earlier in 2000 and persisted longer at 92 days (chla > 100 mg m^{-2}) than the 54 days observed in 2001. Initiation of the spring bloom in 2000 occurred on 21 February, peaked on 4 April at 433 mg m^{-2} and persisted until 23 May when thereafter values fell below 100 mg m^{-2}. In contrast, initiation of the spring bloom in 2001 occurred on 10 April, peaked on 16 May at 438 mg m^{-2}, and persisted until 3 June. The time series of integrated (calibrated) fluoresence revealed nearly identical trends to extracted chlorophyll a fluorescence measures during 2000-01 (Figure 7). Examination of phytoplankton cell density from microscope counts showed a close correspondence to integrated chlorophyll *a* and calibrated fluorescence during the first half of 2000, but was not consistent with observations thereafter in 2000 and in 2001 (Figure 7). Reasons for this discrepancy may be related to the dominance of very small flagellate cells representing a small porportion of the total integrated chlorophyll *a* during non-bloom periods. The times of collection for direct phytoplankton cell counts were somewhat more limited compared to chlorophyll *a* measurements and it is possible that peaks in cell abundance may have been missed.

To summarize the chlorophyll *a* profiles collected at Station 27 during 2000-01, the vertical structure of phytoplankton biomass can be characterized using a shifted Gaussian formulation:

$$B(z) = B_o + (h / (\sigma\sqrt{2\pi}) \exp[-(z- z_m)^2/2\sigma^2] \qquad \text{(Platt } et\ al. \text{ 1988)}$$

Where B_o is the background biomass (mg m^{-3}), h is the total biomass above background (mg m^{-2}), σ is the standard deviation of chlorophyll a biomass (m), and z_m is the depth of the chlorophyll maximum. The model was fit to chlorophyll *a* extracted from discrete water samples collected at standard depths at Station 27 (Figure 7). The time series of B_o typically varied from 0-1 mg m^{-3} with higher variability observed during Winter-Spring compared to Summer-Fall periods in 2000-01. Variability in the biomass (h parameter) time series resembled the expected trends with peak values observed during the spring bloom and periodic increases during the Summer and Fall in 2000 which were not apparent during 2001. Thickness of the chlorophyll maximum, given by the σ parameter, was maximal during the Winter and Fall and minimal during Spring and Summer in 2000, compared to maxima observed during Winter-Spring and minima during Summer through the Fall in 2001. The depth of z_m showed maxima during Winter, and abrupt shallowing during the spring bloom, rapid deepening post-bloom, and thereafter periodic shoaling towards the surface layer during Summer and Fall periods.

The cell densities of major taxanomic groups consisting of diatoms, dinoflagellates and flagellates were investigated at near monthly intervals at Station 27 during 2000-01 (Figure 8). Diatoms reached cell densities in excess of $2.5 x 10^5$ cells L^{-1} during the spring bloom in 2000 and $1.3 x 10^5$ cells L^{-1} in 2001, contributing 40 % and 80 % of the total phytoplankton respectively. The larger contribution of diatoms to the spring bloom in 2001 is related to the unexpected rapid reduction in numbers of Flagellate cells observed during this time. A secondary peak in the concentration of Diatoms was observed in Summer 2000, which was not apparent during 2001. The concentration of Dinoflagellates were typically smaller by an order of magnitude compared to Diatoms, but persisted throughout the year. Normally Dinoflagellates represent < 5 % of the total phytoplankton, except during early Summer in 2001 when Dinoflagellates briefly accounted for > 40 % of the total phytoplankton community. The flagellates were the dominant group by numbers reaching concentrations near $5 x 10^5$ cells L^{-1} and more highly variable compared to Diatoms and Dinoflagellates. With the exception of the spring bloom periods during 2000-01, Flagellates made up typically > 80 % of the total phytoplankton community. Although Flagellates dominated the community assembladge by numbers, their typical small size (6-8 µm) indicates their contribution to biomass is limited during the seasonal occurrence of larger Diatoms and Dinoflagellates cells (C.H. McKenzie pers. comm.).

Phytoplankton population composition at Station 27 is dominated seasonally by several key genera (Table 2). The Diatom genera Chaetoceros, Thalassiosira, Skeletonema, and Pseudo-Nitzschia represent important members of the spring bloom and resident members seasonally at Station 27 during 2000-01. The Dinoflagellate genera of Gymnodinium are present throughout the year, although in low concentrations. Other important genera include Procentrum and Scrippsiella that also occur seasonally. Given the inherent difficulties with identification of Flagellate genera, the majority of which are not identified in our collections, represent the numerically dominant members of the phytoplankton taxa at Station 27. Important genera that could be identified during 2000-01 included Dinobyron, Chrysochromulina, Plagioselmis, Pyramimonas, and Hillea.

We measured daily primary production rates at Station 27 from ^{14}C photosynthesis-irradiance (P-E) experiments conducted in the laboratory using seawater collected at 10m (see Pepin and Maillet 2001 for a complete description of methods). A total of 24 P-E experiments were conducted throughout different months of the year during 2000-01. Measures of daily primary production (PP) and estimated integrated daily primary production (IPP) within the euphotic zone, using data on day length, chlorophyll a and PAR irradiance profiles were conducted at Station 27 utilizing data from P-E experiments (Figure 9). Rates of daily primary production showed elevated values in Spring (peak values in May) and Fall (September-October) periods during 2000-01. Observed rates of daily primary production at 10m ranged from 5-96 mg C m^{-2} d^{-1}. Integrated primary production ranged from ca. 70 to 1500 mg C m^{-2} d^{-1} with maximal levels occurring throughout the late Spring (May) to early Fall (September).

Transects – Irradiance

High attenuation coefficients and spatial variability were observed along the southeast Grand Banks, Flemish Cap, and Bonavista Bay transects during Spring, particularly along the inner and mid-Shelf regions, while lower values and less spatial variability was observed along the outer Shelf-Slope region (Figure 10). Consequently, depth of the euphotic zone was more varied (ca. 10-80m) across the different transects in the inner-mid Shelf areas compared to further offshore (ca. 30-60m). The Summer 2001-2000 period was characterized by lower levels of attenuation and spatial variability, typically < 0.1 m^{-1}, except for the Seal Island (Hamilton Bank) transect which revealed slightly higher values. Euphotic depth typically exceeded 60m, except for selected stations where depths were as shallow as 20m. The Fall 2001-2000 period showed the lowest level of spatial variability, with values ranging from 0.05-0.10 along the transects, and ca. 60-80m for euphotic depth.

Transects – Water column structure

The overall magnitude and spatial variability in stratification and temperature in the upper mixed layer (< 50m) was low during Spring in both years (Figure 11). Values for the stratification index were typically < 0.01 Kg m^{-4}. A positive gradient in temperature existed from inshore to offshore regions along transects during this time, with the southeast Grand Bank transect showing a rapid increase in the Slope waters near the influence of the Gulf Stream. Increased stratification was evident during the Summer in 2001 and 2000 with values normally ranging from 0.02-0.06 Kg m^{-4} across all transects. Similar trends were observed in temperature in the upper mixed layer, but the spatial gradient was less apparent compared to the Spring period. Reduced levels of stratification (0.01-0.04 Kg m^{-4}) were observed for all transects during Fall, more so for the Bonavista transect with values < 0.01 Kg m^{-4} along the mid and outer Shelf in both years.

Transects – Nutrients

Spatial and seasonal variability was apparent in the major nutrient pools along the standard AZMP transects (Figure 12). Depletion of both silicate and nitrate was evident along much of the inner and mid Shelf at depths < 50m for southeast Grand Banks and Flemish Cap transects during Spring 2001-2000 in contrast to elevated levels for both nutrients throughout the Bonavista transect. Depletion of nutrients appeared to be more complete in 2000 than in 2001, partly because of the timing of the survey relative to the onset of the spring phytoplankton bloom. On the Grand Banks, the depletion of nutrients extended all the way to the bottom whereas this was not evident on the Flemish Cap transect (Figures 13 & 14). The location of the offshore branch of the Labrador current coincided with increased concentrations of silicate and nitrate along the outer Shelf and Slope water regions comparable with that of the Bonavista transect. Integrated concentrations of silicate and nitrate remained depleted along much the Flemish Cap transect during Summer in both years, while the Bonavista and Seal Island showed more replete conditions for these nutrients in the upper mixed layer (Figure 15 & 16). Evidence of mixing was evident in the Fall period during 2001-2000, with increased concentrations of silicate and nitrate in the upper 50m observed along the standard AZMP transects (Figure 17 & 18).

Similar spatial and seasonal variability was observed for the deep pools of major nutrients along the standard AZMP transects (Figure 19). Depleted levels of both silicate and nitrate concentrations were also observed during Spring in both years along the inner and mid Shelf regions for the Southeast Grand Banks and Flemish Cap transects in deeper (50-150m), waters. Depletion of the deep pools during Spring, is in part attributed to the shallow nature of the Shelf (bottom depth typically < 100m) and timing and duration of the production cycle in these areas (Figures 13 & 14). Higher concentrations of the major deep nutrient pools were again observed along the Bonavista transect and in coastal and outer Shelf-Slope water regions for the southeast Grand Banks and Flemish Cap transects in both years. The Summer period was characterized by slightly elevated silicate and nitrate concentrations along transects compared to Spring. This was particularly apparent along inner and mid Shelf regions of the Flemish Cap transect in 2000. Due to logistic difficulties, the outer Shelf was not sampled in 2001 and thus no comparisons can be made between years for that region of the Flemish Cap transect. The pattern in the deep nutrient pools for the Fall period was similar to that of Spring with somewhat depleted levels, particularly for nitrate in contrast to silicate in both years along the mid Shelf region for the Southeast Grand Banks transect. Increased levels for both silicate and nitrate were generally observed in coastal and the outer Shelf regions along southeast Grand Banks and Flemish Cap transects. The Bonavista transect again showed the highest levels for both major nutrients during the Fall period in both years. Maximum deep nutrient concentrations (~200m) in the Spring, Summer and Fall were generally at similar levels between 2000 and 2001 although somewhat higher than in 1999.

It should be noted that the large differences between 2000 and 2001 in the integrated nutrient pools (0-50m and 50-150m) noted that Station 27 were not readily apparent along the major transects, particularly in the case of the integrated silicate pool.

Transect – Phytoplankton

Spatial series of biological measures investigated along AZMP transects during 2001-2000 included integrated chlorophyll *a* (extracted) and in-situ fluoresence (calibrated against extracted chlorophyll *a*) (Figure 20). In general, the in-situ fluorescence data compared well with the extracted data during the Summer and Fall periods, although the chlorophyll *a* concentrations estimated from fluorescence tended to be greater during Spring than from the estimates based on bottle samples. The Spring bloom was evident along the inner and mid Shelf for the Southeast Grand Banks and Flemish Cap transects in 2001 with integrated chlorophyll a values > 200 mg m^{-2}, while in 2000 values were typically < 200 mg m^{-2}. Substantially lower phytoplankton biomass was evident during Summer and Fall periods in both years except for the Seal Island in which integrated values exceeded 100 mg m^{-2}.

Much of the chlorophyll biomass on the Southeast Grand Banks in the Spring was located at depth indicating that our survey was timed well after the onset of the spring phytoplankton bloom in this region (Figure 21). Further North, phytoplankton biomass was still constrained to surface waters. During the Summer survey, phytoplankton biomass was generally low across most of the Newfoundland Shelf and along the coast of Labrador (Figure 22) although concentrations on the latter were generally higher than on the Shelf. This is in contrast with observations in 2000 when high chlorophyll concentrations were found along most of the Labrador coast. This is also in contrast with information from satellite imagery of the sea surface (see below) which indicates that the timing of our surveys should have noted elevated concentrations of chlorophyll in 2001 in contrast to 2000. During the Fall survey, most chlorophyll *a* profiles indicated concentrations that were similar to values observed in July (Figure 23). However, there were areas with high surface concentrations, particularly along the outer portions of the banks on the Southeast Grand Banks and Flemish Cap transects. This is not inconsistent with information derived from satellite imagery of the sea surface (see below).

Major groups of phytoplankton were enumerated seasonally at selected stations along standard AZMP transects. The most notable difference observed between years was the overall reduction in Flagellates and Diatoms in coastal and Shelf areas during 2001 (Figure 24). Concentrations of phytoplankton were typically below 1×10^6 cells L^{-1} on the southeast Grand Banks transect, with the exception being the occurrence of a large Flagellate population observed during Spring 2001 along the mid-Shelf region reaching near 5×10^6 cells L^{-1}. Along the Flemish Cap and Bonavista transects, near two-fold increased concentrations of Flagellates and Diatoms were observed from coastal to offshore areas in 2000 in contrast to 2001. These trends were less evident in the Seal Island transect. We exercise caution regarding the interpretation of the seasonal variation in major phytoplankton groups due to the timing of the production cycle m

Satellite Imagery

Bi-weekly composite image of sea surface chlorophyll observations along the major oceanographic transects and at Station 27 for the period 1998-2001 were obtained from the research group at the Bedford Institute of Oceanography.

The information for Station 27 revealed a general pattern that was not inconsistent with the data collected during routine occupations of the site. It appears that from 1999 to present, there was been an increasing delay in the onset of the spring phytoplankton bloom (Figure 25). There is considerable variability in the data from satellite imagery, possibly due to the small footprint used to estimate mean conditions at the site. There may be considerable patchiness in the area due to small scale features beyond the 4.5 km × 4.5 km box surrounding the site.

The imagery from four of the major oceanographic transects (Southeast Grand Banks, Flemish Cap, Bonavista Bay and Seal Island) show important trends in sea surface chlorophyll concentrations. In all instances, the images indicate that the onset of the spring phytoplankton bloom was delayed in 2001 relative to 1999 and 2000. The extent of the delay appears to increase with latitude (Figure 26). There is also some indication of an onshore offshore gradient in the timing of the spring bloom but this may also partly reflect the latitudinal gradient along the axis of each transect. The maximum concentration of the spring bloom appeared comparable in 1998 and 1999 relative to the more recent 2000-01. There is also some indication that the duration of high concentrations may have been less protracted in 2001 along the Flemish Cap and Bonavista Bay transects than in previous years. Limited surface chlorophyll a concentrations were apparent for the Summer across all transects with the exception of coastal blooms observed along the Seal Island transect in all years. There is some evidence of a spatially limited fall bloom along all transects although the intensity and duration was substantially less than the spring phytoplankton bloom. As with the spring bloom, the fall event appeared to be somewhat later in the season than in previous years, with the exception of the Seal Island transect where the timing appeared to be similar to observations in 1998-2000.

In all instances there may be subsurface activity in phytoplankton production which is not measured from sea surface observations. However, the good correspondence between our general observations at Station 27 with those of the satellite imagery suggests that the general inter-annual trends in the timing of the spring bloom may be well represented by satellite imagery.

Nutrient Depletion – Station 27 & Transects

The relative importance in uptake of silicate and nitrate was investigated seasonally at Station 27 and along the transect occupations (Figure 27). The concentration of nitrate versus silicate at Station 27 during 2001 indicated the uptake of both silicate and nitrate may be limiting to phytoplankton growth, consistent with observations in recent years (Pepin and Maillet 2001). In contrast, phytoplankton growth along transects appears to be limited largely by nitrate based on the positive intercept values. Rates of utilization of major nutrients were somewhat higher for Station 27 compared to the transects, although based on limited data for the fixed station.

Zooplankton – Station 27

The number of zooplankters at Station 27 showed limited seasonality in 2001, as in previous years (Figure 28). Overall, the total abundance of organisms in 2001 was lower than in 2000 but similar to densities encountered in 1999. The major differences with the previous year were in the overall abundance of plankters in January-March and after August. This pattern was reflected in the overall patterns of abundance of most of the dominant zooplankton species groups (Figure 29). *Oithona* sp., *Pseudocalanus* sp., *Microcalanus* sp. and *Oikopleura* sp. were generally less abundant during the early and later parts of 2001 relative to the previous year but densities were similar to previous years during the period April-July. The only exception to this was found in the abundance of *Calanus finmarchicus* which occurred in higher densities during the early part of the year, after which concentrations were similar to conditions observed in previous years, although densities were near the lower margin by November.

Species composition in 2001 showed a few notable differences from previous years. *Oithona* sp. and *Pseudocalanus* sp. remained the most numerically dominant species found at Station 27. The high concentrations of *Calanus finmarchicus* early and late in the year lead this species to make up a notably higher numerical proportion of the overall zooplankton community than in previous years (Figure 30). Pelagic gastropods (primarily *Lamicina* sp.) made up a substantial proportion of the community during the winter and early spring whereas they are normally a small fraction of the overall community. *Temora longicornis*, *Metridia longa* and *Microcalanus* sp. contributed to the overall zooplankton community in similar proportions as in previous years. *Calanus glacialis* was a substantially smaller proportion of the zooplankton community than in previous years as were calanoid nauplii. In both these groups, the normal seasonality in contribution to the plankton community (in April-June and June-September, respectively) was not apparent in 2001.

The seasonal progression of copepodite stages of *Calanus finmarchicus* in 2001 differed somewhat from that observed in previous years (Figure 31). There was a strong cohort of young (CI-CV) copepodites present at the start of 2001 which made up most (> 95%) of the copepodite population at Station 27. In contrast, approximately 50% of the *Calanus finmarchicus* copepodites in 2000 were reproductive CVI. Furthermore, the peak contribution of CI copepodites was later in 2001 (day 170-210) than in either 1999 or 2000 (day 120-170) , by approximately 30-40 days. Similar patterns were noted for copepodite stages II-IV whereas the high densities of stage V copepodites appeared to be delayed in 2000 relative to 2001 (Figure 32). Densities of reproductive adults (CVI) were similar in 2000 and 2001 throughout most of the year although there was some evidence of high densities during the winter of 2000, which were not apparent in the limited number of samples obtained during this period in 2001. The peak abundance of large calanoid nauplii (stage II+ *C. finmarchicus* and stage I+ *C. glacialis* > 200 µm) was also delayed by approximately 30 days in 2001 relative to 2000, and the highest concentration in 2001 was approximately half of that observed in 2000 but similar to concentrations observed in 1999 (Figure 33). The overall seasonal cycle in abundance of calanoid nauplii appeared more restricted in duration in 2001 than in 2000. Densities were similar during the summer period but higher levels were observed in the spring and autumn of 2000 relative to 2001.

Zooplankton – Transects

Changes in zooplankton abundance from the fall 1999 and spring/summer 2000 to similar periods one year later were variable in both space and time. In general, zooplankton abundance levels were generally higher in the fall of 2000 than in 1999 along the Bonavista, Flemish Cap and Southeast Grand Bank transects (Figure 34). The only major exception was found in the abundance of larvaceans, which occurred in comparable densities to the previous year. The increased abundance in the fall of 2000 did not necessary translate into higher densities in the following spring of 2001 where only pelagic gastropods were substantially more abundant than in the previous year. All other major groups of zooplankton were at similar or lower densities than in 2000 when averaged over entire transects. The overall abundance of all copepodite stages for all species were similar in the spring of 2000 and 2001 along the Bonavista and Flemish Cap transects but densities were substantially lower over the southern Grand Banks (Figure 35). The combined abundance of all other major zooplankton taxa showed a similar pattern to that of copepodite stages with the exception of the Bonavista transect where densities away from the coastal regions were substantially higher in the spring of 2001 relative to 2000 (Figure 36). In the summer of 2001, densities of all major zooplankton groups (copepodites and others) were generally to levels observed in the previous year (Figure 37). The only exception to this seemed to occur on the Bonavista transect where densities over most of the shelf were substantially lower in 2001 relative to the previous year.

The pattern of abundance of *Calanus finmarchicus* along the transects showed strong differences in the cross shelf density differences between the spring of 2000 and 2001. Generally, densities across most of the shelf in the spring of 2001 were similar to those observed in 2000. However, densities were generally lower along the continental slope and the Southeast Shoal (Figure 38) only to be higher in the offshore branch of the Labrador current and over the Flemish Cap. In contrast, densities of large calanoid nauplii were generally low over most of the shelf during the spring of 2001 relative to 2000, and were only at comparable or slightly higher densities in offshore areas. In the spring of 2001, adult females appeared to make up a greater fraction of the overall *Calanus finmarchicus* population than in the previous year, except in regions near the coast, where the stage distribution appeared to reflect a more advanced cohort structure in 2001 than in the previous year (Figure 39). Furthermore, the developmental state of *Calanus finmarchicus* appeared to be more advanced on the tops of the Grand Banks and Flemish Cap than on the inner Shelf or near the continental Slope. Densities of *Calanus finmarchicus* observed during the summer survey were generally higher in 2001 than in 2000 (Figure 40). Densities were consistently and substantially higher along the Labrador shelf and over most of the White Bay and Flemish Cap transects. The only area of lower abundance in 2001 was found across the inshore shelf area along the Bonavista Transect as well as along the outer edge of the White Bay Transect. It is difficult to identify any major departures in the stage structure of *Calanus finmarchicus* during the summer surveys (Figure 41). There was some indication of a greater proportion of CI copepodites stages on the Labrador shelf when 2001 and 2000 are contrasted. However, it is not possible to judge at this time whether this reflects a substantial departure from one year to the next. The contrast in densities was also similar in the distribution of large calanoid nauplii, whereby abundance levels were substantially higher on the Labrador shelf in 2001 when compared with abundance levels observed in 2000 (Figure 42). Densities along the Newfoundland shelf and northern Grand Banks in 2001 were similar to those observed in 2000, with the exception of the inshore region of the Bonavista Bay transect where densities of nauplii were substantially lower in 2001 than in 2000.

Discussion

The seasonality of chemical and biological conditions at Station 27 and along the major transects was similar to previous years (1999 and 2000) but the timing of fluctuations in phytoplankton and some zooplankton species were notably different than in previous years.

The vertical structure of the water column density at Station 27 indicate that more mixing was taking place over an extended winter period when conditions observed in 2001 were contrasted with those in 2000. In addition, the shoaling of the mixed layer in the spring appeared to be more abrupt than in the previous year but the timing was delayed by approximately one month. This was also apparent in the seasonal cycle of surface warming and cooling at this site.

The cycle of nutrient depletion in the upper 50 m of the water column followed a normal seasonal course but as with the vertical density structure of water column, the onset of the depletion was delayed relative to the previous year. The depletion of nutrients in the surface mixed layer appeared to be more substantial in 2001 than in the previous year, with silicate concentration approximately 2-3 µM lower in 2001. However, the deeper mixed layer in 2000 lead to an overall greater decrease in the total nutrient pool in that year relative to 2001. A potentially more important difference between the two years occurred in the deep nutrient pool (50-150m) where overall levels in 2001 were 1.5-2 times lower than in 2000. However, this pattern was not apparent in the three oceanographic surveys conducted in the spring, summer and fall of 2001. Along each of the major transects, deep nutrient pools appeared to be at comparable levels to those observed in previous years.

The onset of the spring phytoplankton bloom was also delayed by approximately 30 days and the duration of the period of high phytoplankton biomass in the upper 50 m of the water column was also reduced by approximately 50% relative to the previous year. Overall integrated peak concentrations were comparable to previous years but the vertical structure and progression of the spring phytoplankton bloom was different. Satellite observations of surface chlorophyll concentrations showed a general pattern that was consistent with the observations at Station 27 and suggest that the delay in the onset of the spring phytoplankton bloom was a shelf wide phenomenon extending from the southern Grand Banks to the coast of Labrador. Throughout the region, there was little indication of a bloom occurring during the fall. Chlorophyll concentrations did not substantially increase and high concentrations were only noted on the top of the Banks along the major transects sampled during the fall survey. Satellite observations of surface chlorophyll concentrations were consistent with the observations at Station 27 and along the oceanographic sections.

A notable point about the composition of phytoplankton throughout the region deals with the significant two-fold decrease in the density of small flagellates. Although these organisms do not make up a substantial portion of the total biomass of phytoplankton, in which diatoms are more important, flagellates play an important role in the microbial food web. Their decrease may be indicative of changes in this portion of the pelagic ecosystem during 2001.

It is noteworthy that both nitrate and silicate appear to be limiting phytoplankton growth at the fixed station (Station 27) whereas nitrate was a more limiting factor along the major oceanographic transects.

Overall zooplankton densities at Station 27 in 2001 were lower than in the previous year but similar to observations in 1999. The most notable differences appeared to occur at the start and end of the year, when the numerically dominant small copepods (*Oithona* sp. and *Pseudocalanus* sp.) were less abundant than in previous years. The relative importance of *Calanus finmarchicus* was greater in 2001 than in the two previous years, largely as a result of the influx of a cohort of young copepodite stages (CI-CV) from the fall of 2000 into the winter of 2001. The seasonal appearance of the summer peak in abundance of stage I (and subsequent stages) copepodites was delayed by approximately 30 days in contrast to 1999 and 2000. The peak in concentration of large calanoid nauplii was also delayed by a similar period of time and the magnitude of the peak concentration was approximately 50% of the level observed in 2000 but similar to that observed in 1999. Densities during the summer months were comparable to previous levels but the density of these young copepod stages was lower in the fall. Some important questions arise from these observations: Was the delay on the occurrence of peak concentrations of early stage copepodites the result of the delay in the onset of the spring phytoplankton bloom? Was this delay due to a difference in the timing of reproduction or did it relate more to differences in survival of nauplii? Were there differences in the condition of reproductive females between years? Did the large second cohort of copepodites found in 2000 contribute substantially to the dynamics of this species?

Densities of *Calanus finmarchicus* on the Newfoundland Shelf during the spring survey were similar to observations in previous years but there were substantially fewer copepodites found on the southern Grand Banks during this period. The apparent discrepancy with observations at Station 27 may have been due to the timing of the spring survey, which occurred after the appearance of the winter cohort of young copepodites. During summer survey, densities of *Calanus finmarchicus* were substantially higher on the Labrador Shelf than in 2000, while concentrations in the Newfoundland Shelf and Grand Banks were generally similar to observations in 2000.

Most other major zooplankton taxa were slightly less abundant on the Newfoundland and Labrador Shelves than in the previous year. Once again, we must question whether differences in the onset of the spring phytoplankton bloom had a significant impact on the patterns of reproductive success of the major zooplankton taxa in the region? This is an important research question for which there is currently insufficient information to allow us to reach any substantive conclusions.

Acknowledgements

We thank Dan Lane and Sandy Fraser for their steadfast work on this project. The assistance of Wade Bailey, Charlie Fitzpatrick, Greg Redmond, and Paul Stead with work at sea is greatly appreciated. We also wish to thank Eugene Murphy, Dave Downton, Harry Hicks, Randy Bury, Bill Brodie, Len Mansfield, Dan Porter, Don Stansbury, Geoff Perry, and the Technician aboard the ships of opportunity who assisted in the collection of information at Station 27. Glen Harrison and Trevor Platt provided the bi-weekly composite information of surface chlorophyll and temperature derived from satellite collections. The expertise of Gerhard Pohle, Cynthia McKenzie and Mary Greenlaw was crucial to the completion of this work.

References

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.

Kirk, J.T.O. 1994. Light and photosynthesis in aquatic ecosystems. Cambridge University Press, 509 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, Research Document 2001/073, 46p.

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.

Table 1. Listing of surveys, dates and transects for 2001. The transects are: southern Grand Banks (SEGB); Flemish Cap (FC); Station 27 line (S27), Bonavista Bay (BB); Funk Island (FI); White Bay (WB); Seal Island (SI); Makkovik Bank (MB); and Beachy Island (BI) (See Figure 1.).

Year	Day	Transects
2001	111-123 (spring)	SEGB, FC, BB, FI
2001	194-209 (summer)	FC, BB, FI, WB, SI, MB, BI
2001	318-329 (fall)	SEGB, FC, S27, BB

Table 2. Comparison of seasonal variation in major phytoplankton groups in the proportion (%) of total genera contributing at least 5 % of total cell density at station 27 during 2000-01.

Phytoplankton genera	Winter (Jan-Mar)	Spring (Apr-Jun)	Summer (Jul-Sep)	Fall (Oct-Dec)
Diatoms				
Chaetoceros	19.0	38.5	27.3	X
Coscinodiscus	15.8	X	X	X
Dentonula	X	5.5	X	X
Fragilariopsis	X	9.7	X	X
Leptocylindrus	X	X	61.4	X
Navicula	X	6.7	X	X
Planktoniella	6.3	X	X	X
Pseudo-Nitzschia	X	X	5.5	19.3
Skeletonema	22.8	X	X	17.6
Thalassiosira	13.3	21.0	X	X
Thalassionema	7.6	X	X	X
Licomorpha	X	X	X	6.7
Dinoflagellates				
Gymnodinium	54.5	87.8	86.0	92.1
Prorocentrum	26.9	X	X	5.4
Scrippsiella	12.5	X	9.9	X
Flagellates				
Chrysochromulina	8.4	X	X	X
Dinobryon	X	21.7	X	X
Hillea	X	X	X	5.1
Plagioselmis	X	X	X	7.6
Pyramimonas	X	X	6.4	X
Unidentified. small wo/pigment	28.7	16.4	25.2	19.4
Unidentified small w/pigment	34.2	7.4	34.1	31.1
Unidentifed medium w/pigment	17.1	X	11.0	16.2

Figure 1. Station locations during spring (a), summer (b), and fall (c) 2001 surveys on the Newfoundland and Labrador Shelf.

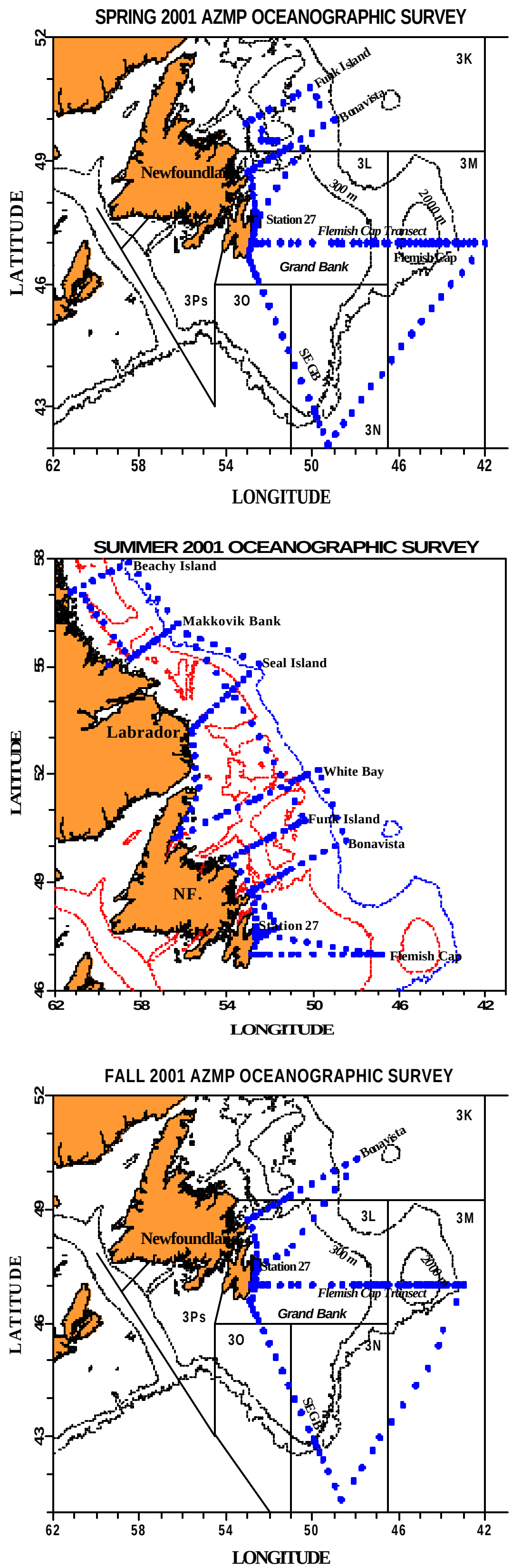

Figure 2. Time series of optical measures at Station 27 during 2000-01 showing vertical attenuation coefficient (K_d_PAR, photosynthetic active radiation 400-700nm), euphotic depth (1 % PAR level) computed from K_d_PAR and chla biomass, and total PAR / 1000 obtained from PAR sensor located at NWAFC, St. John's, NF.

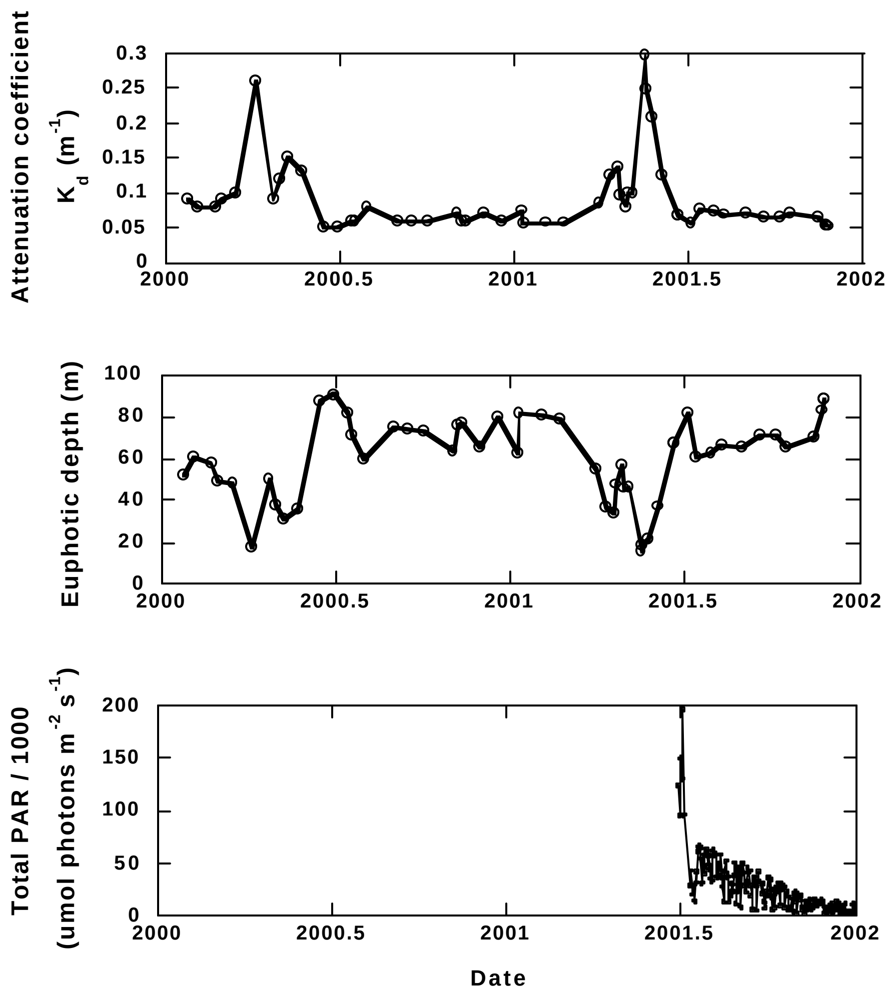

Figure 3. Time series of physical measures at Station 27 during 2000-01 showing stratification index ((sigma-t 5m–sigma-t 50m)/50m), mixed layer depth (depth centre of pycnocline), and integrated temperature in upper 50m using trapezoidal method.

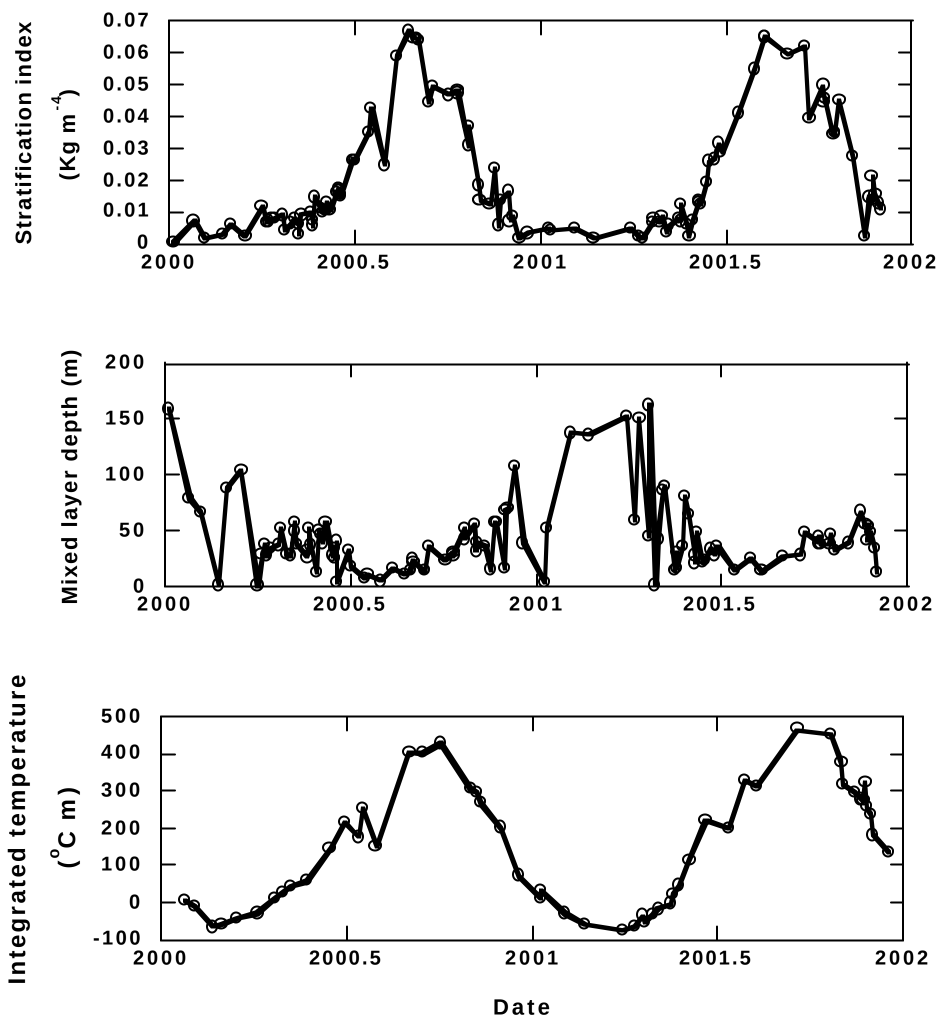

Figure 4. Vertical profiles of silicate and nitrate (combined nitrate and nitrite) concentrations versus day of year at Station 27 during 2001 and difference (2001-2000) plots.

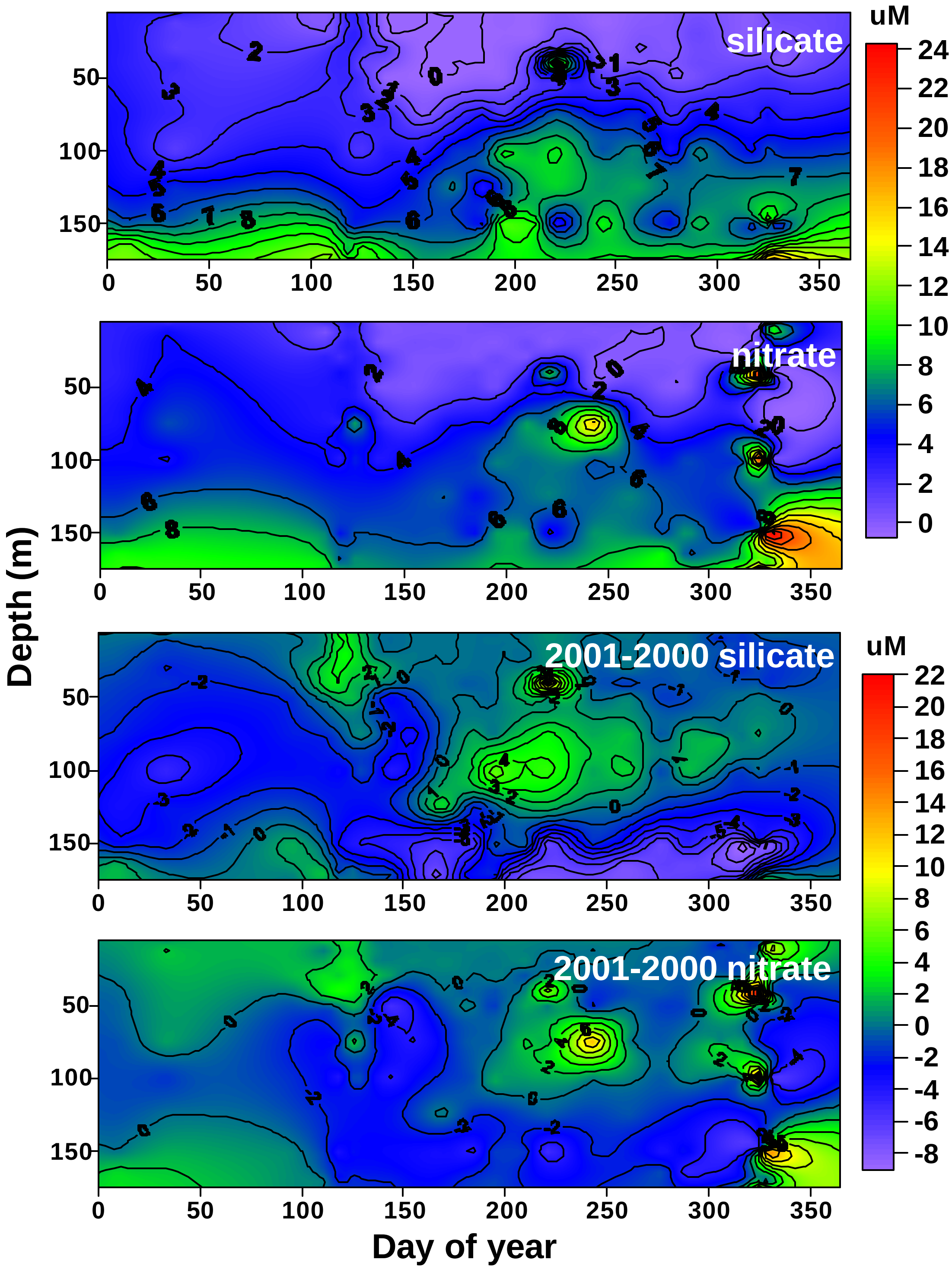

Figure 5. Time series of major nutrient pools at Station 27 during 2000-01 showing integrated silicate and nitrate (combined nitrate and nitrite) at two depth strata. Integrated data estimated using trapezoidal method.

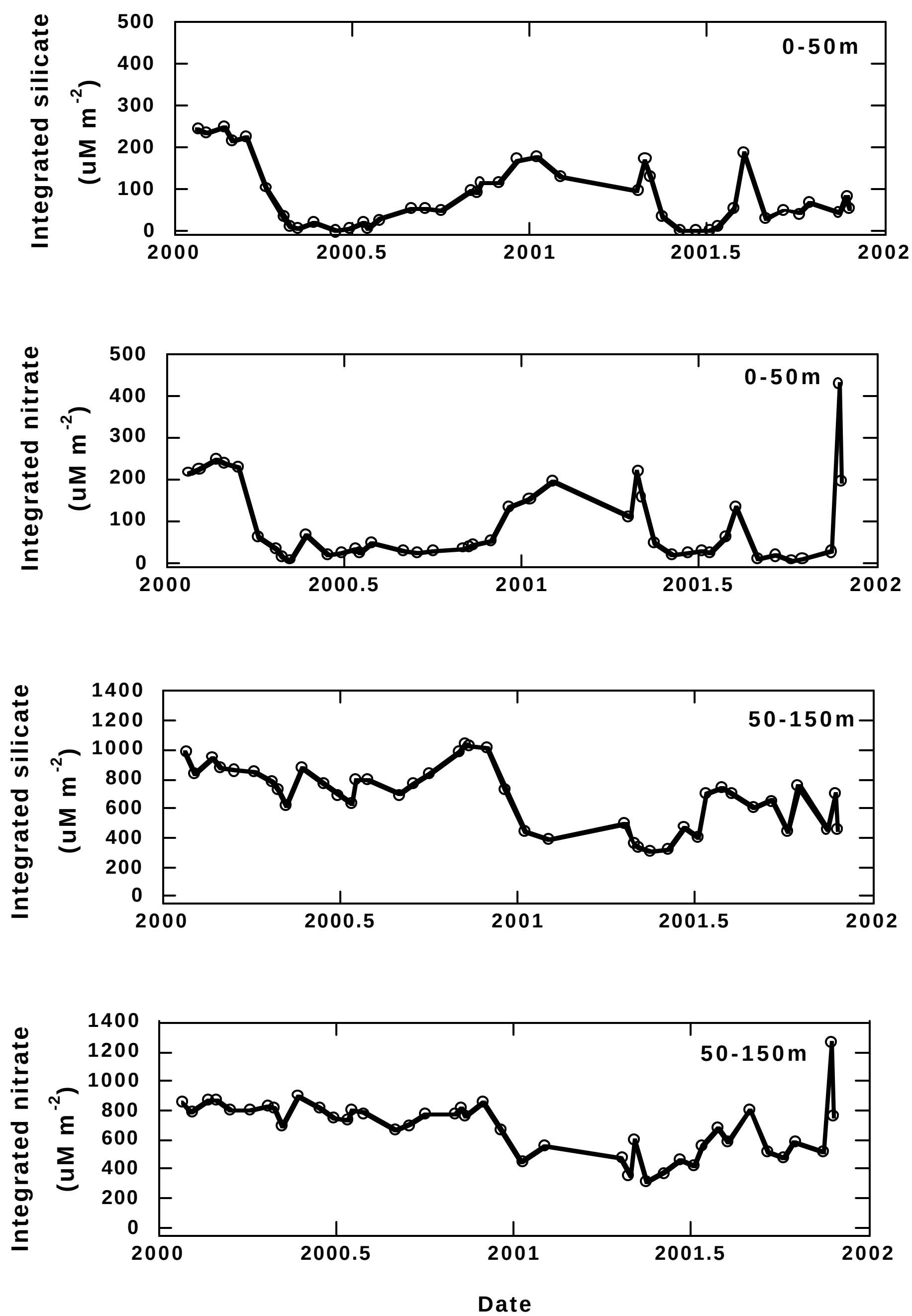

Figure 6. Vertical profiles of chlorophyll a concentrations versus day of year at Station 27 during 2000-01. Sample locations are shown as small open circles.

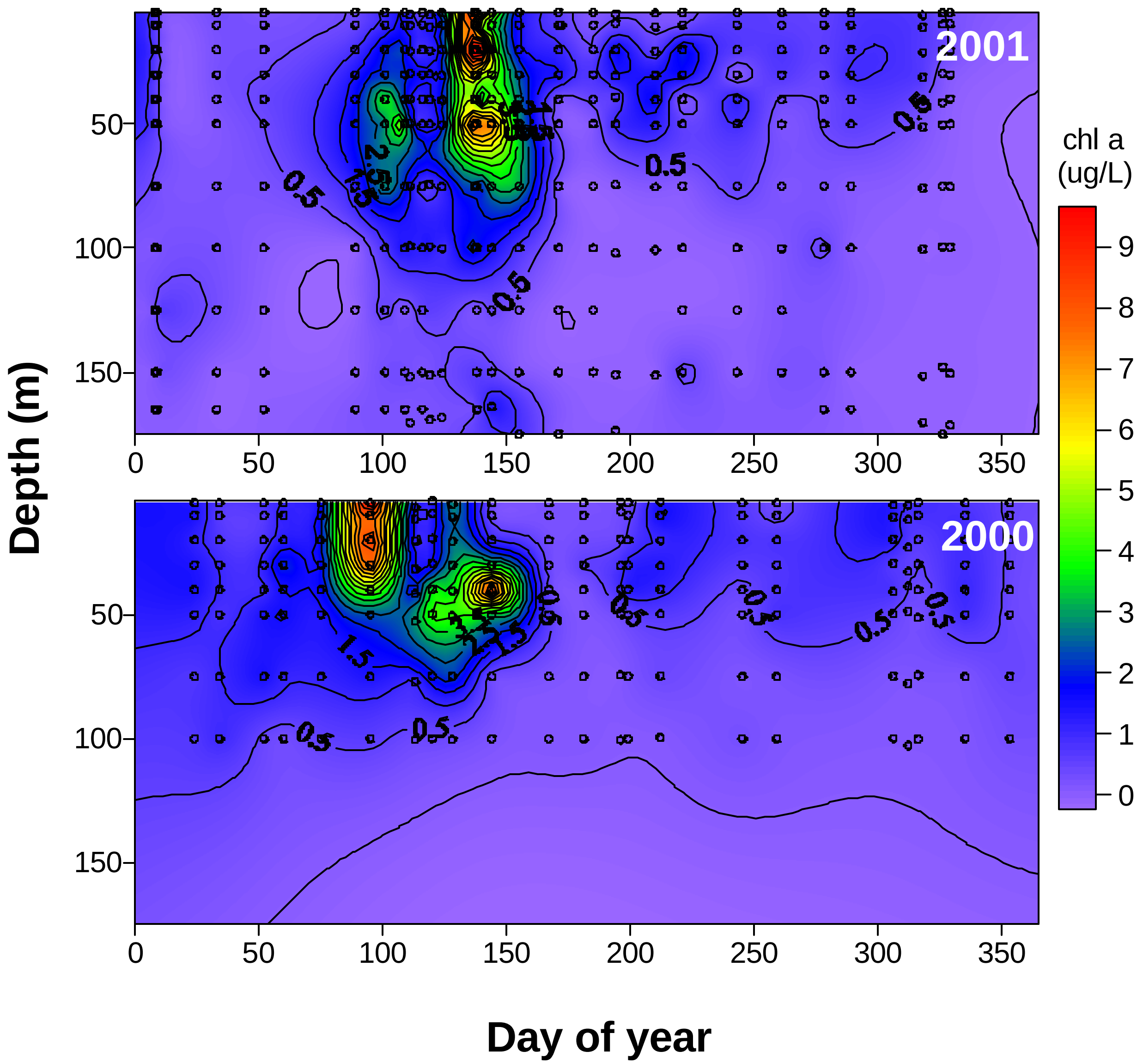

Figure 7. Time series of biological meaures at Station 27 during 2000-01 showing integrated chlorophyll a at two depth strata, integrated *in-situ* fluorescence (calibrated against extracted chlorophyll a), phytoplankton cell density (combined cell counts from all major groups), and estimated parameters derived from Gaussian model fit to extracted chlorophyll a.

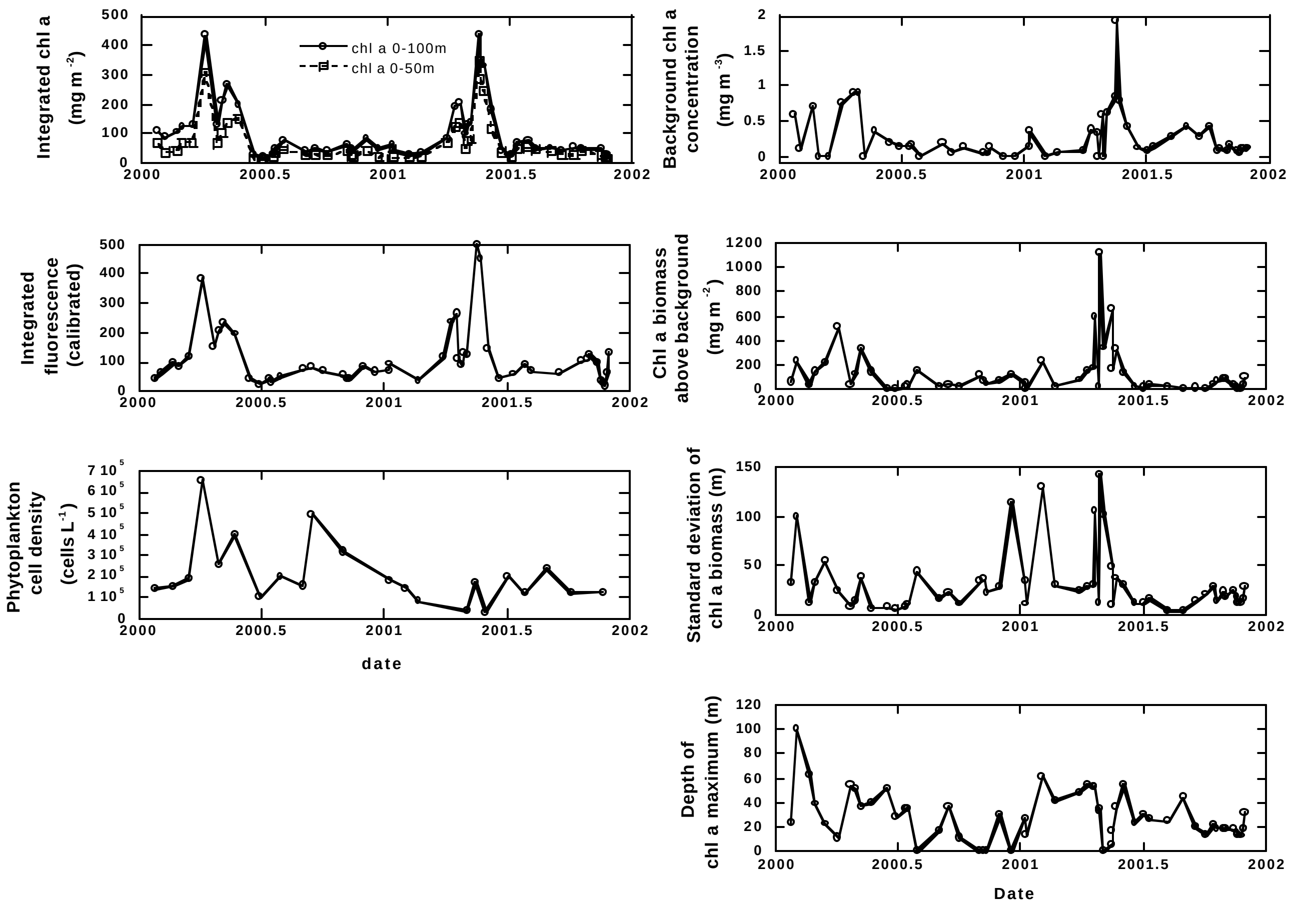

Figure 8. Variation in cell density and relative abundance of major phytoplankton taxa observed at Station 27 during 2000-01 including Diatoms, Dinoflagellates, Flagellates, and major phytoplankton group ratios.

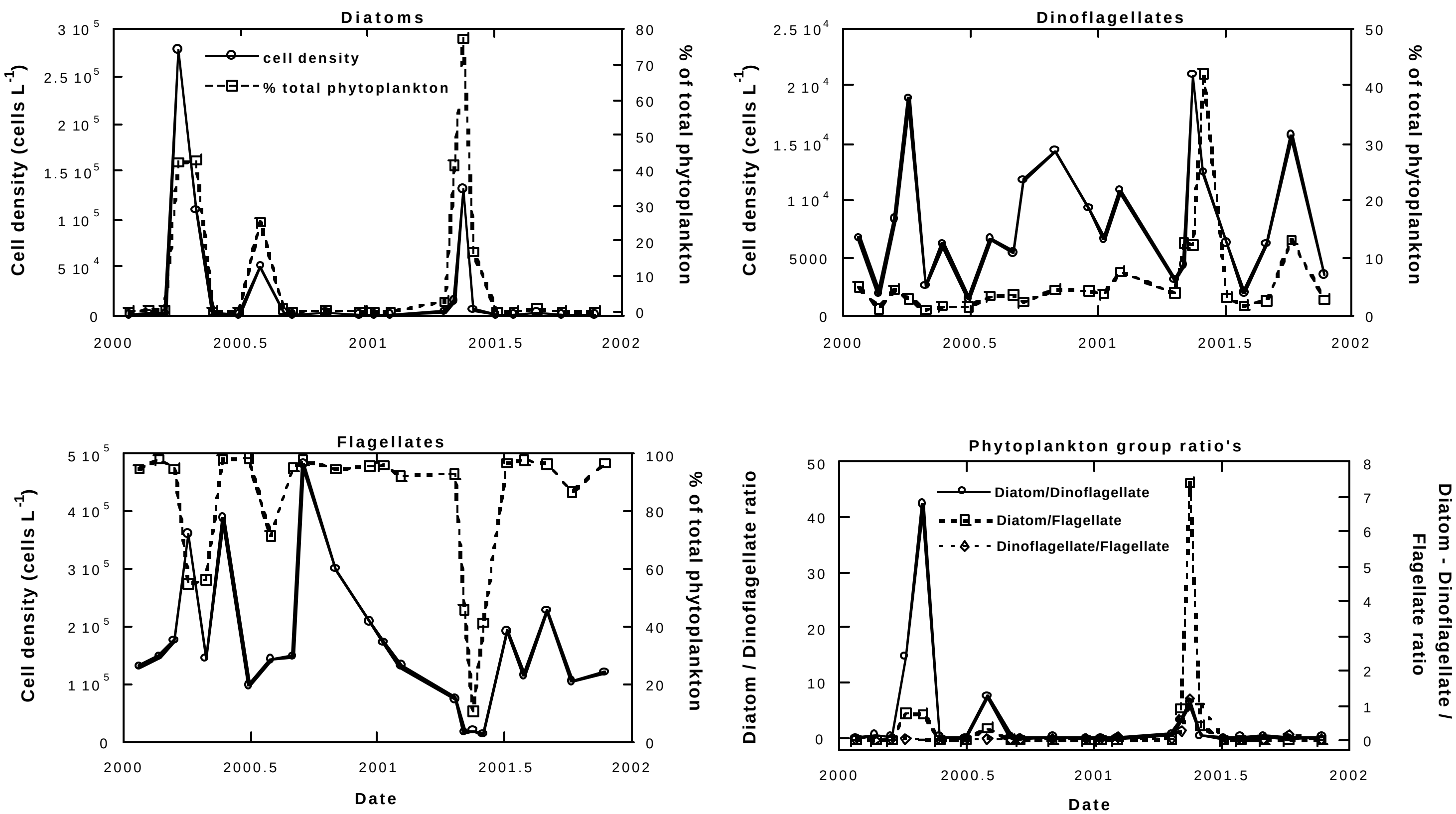

Figure 9. Measured daily primary production (PP) at 10m depth and estimated integrated daily primary production (IPP) over the euphotic (1%) zone at Station 27 during 2000-2001. Primary production measures based on P-E (photosynthesis–irradiance) curves derived from laboratory incubations using a photosynthetron. Smooth curves fitted to PP (solid line) and IPP (broken line) shown for both years.

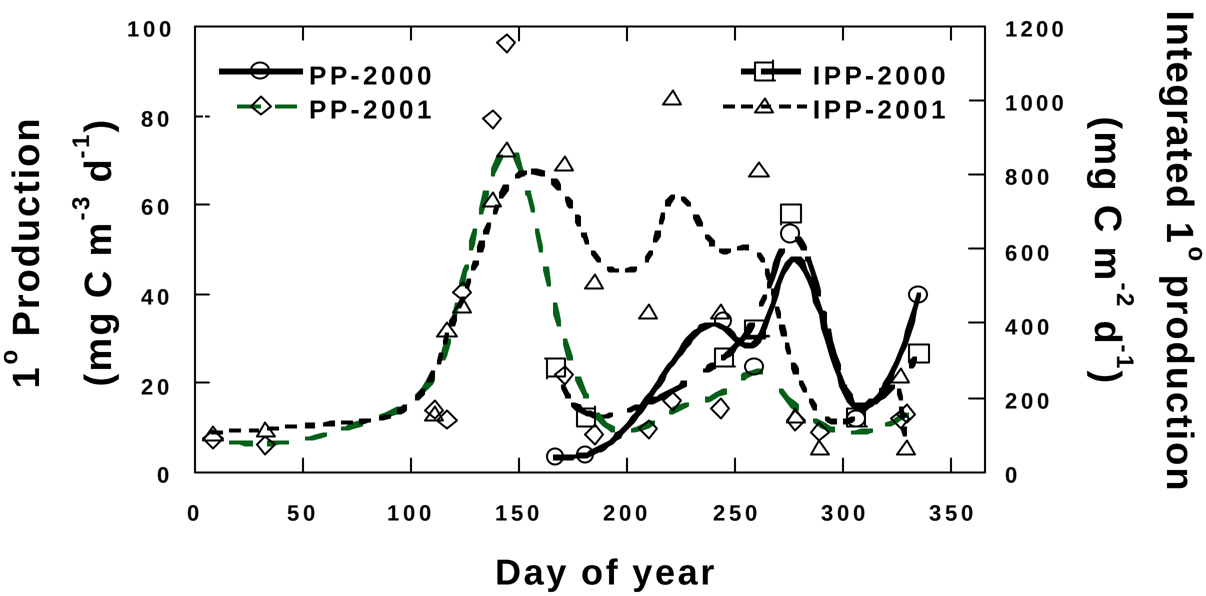

Figure 10. Spatial series of optical measures along transect lines showing vertical attenuation coefficient K_d-PAR, and euphotic depth (1% light level) for Spring (April-May), Summer (July), and Fall (October-November) 2000-01 surveys. Transect lines include southeast Grand Banks (SEGB), Flemish Cap (FC), Bonavista Bay (BB), and Seal Island (SI).

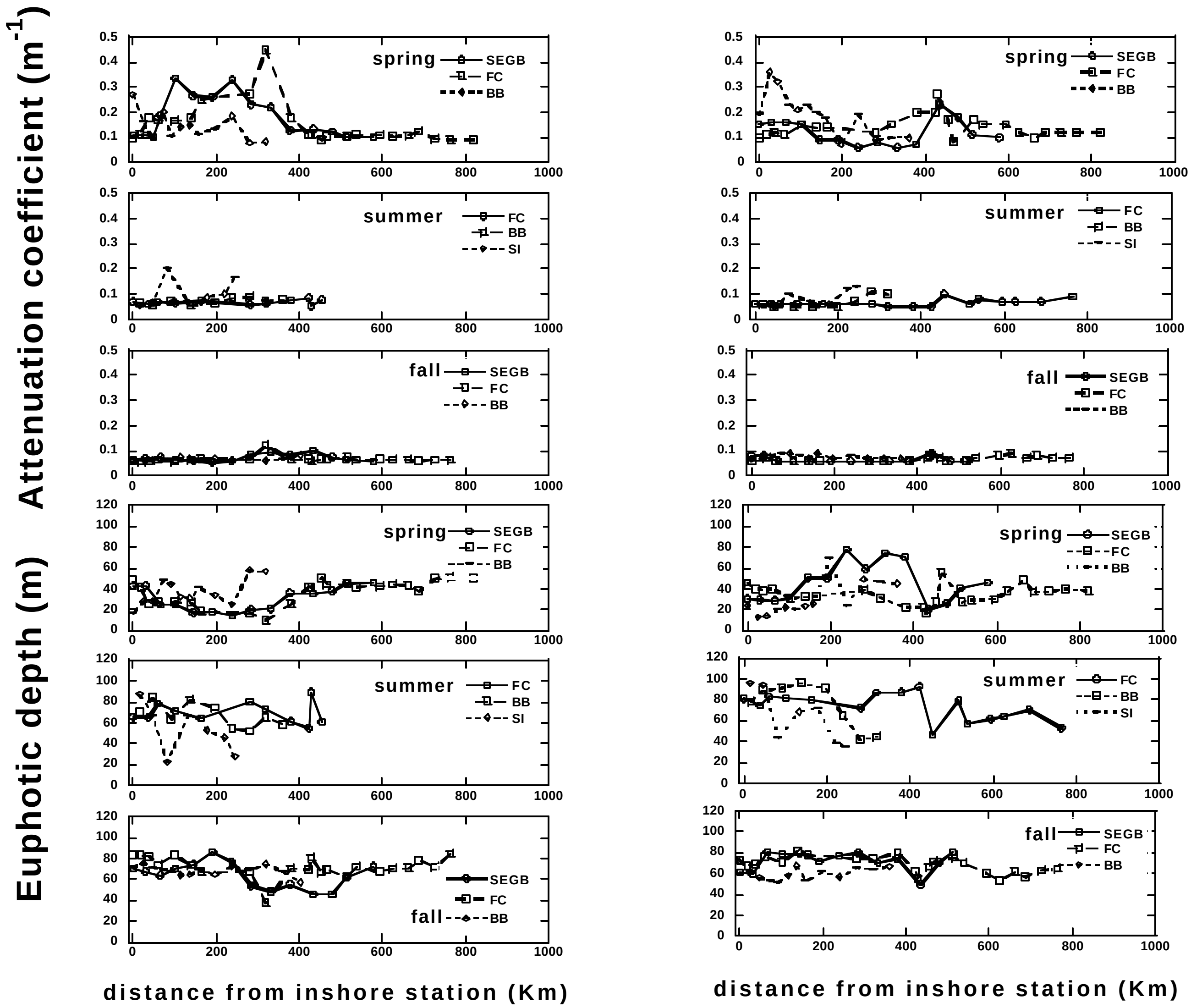

Figure 11. Spatial series of physical measures along transect lines showing stratification index (sigma-t 50m – sigma-t 5m / 45m) and integrated temperature (0-50m) during Spring (April-May), Summer (July), and Fall (November) 2000-01 surveys. Transect lines include southeast Grand Banks (SEGB), Flemish Cap (FC), Bonavista Bay (BB), Seal Island (SI).

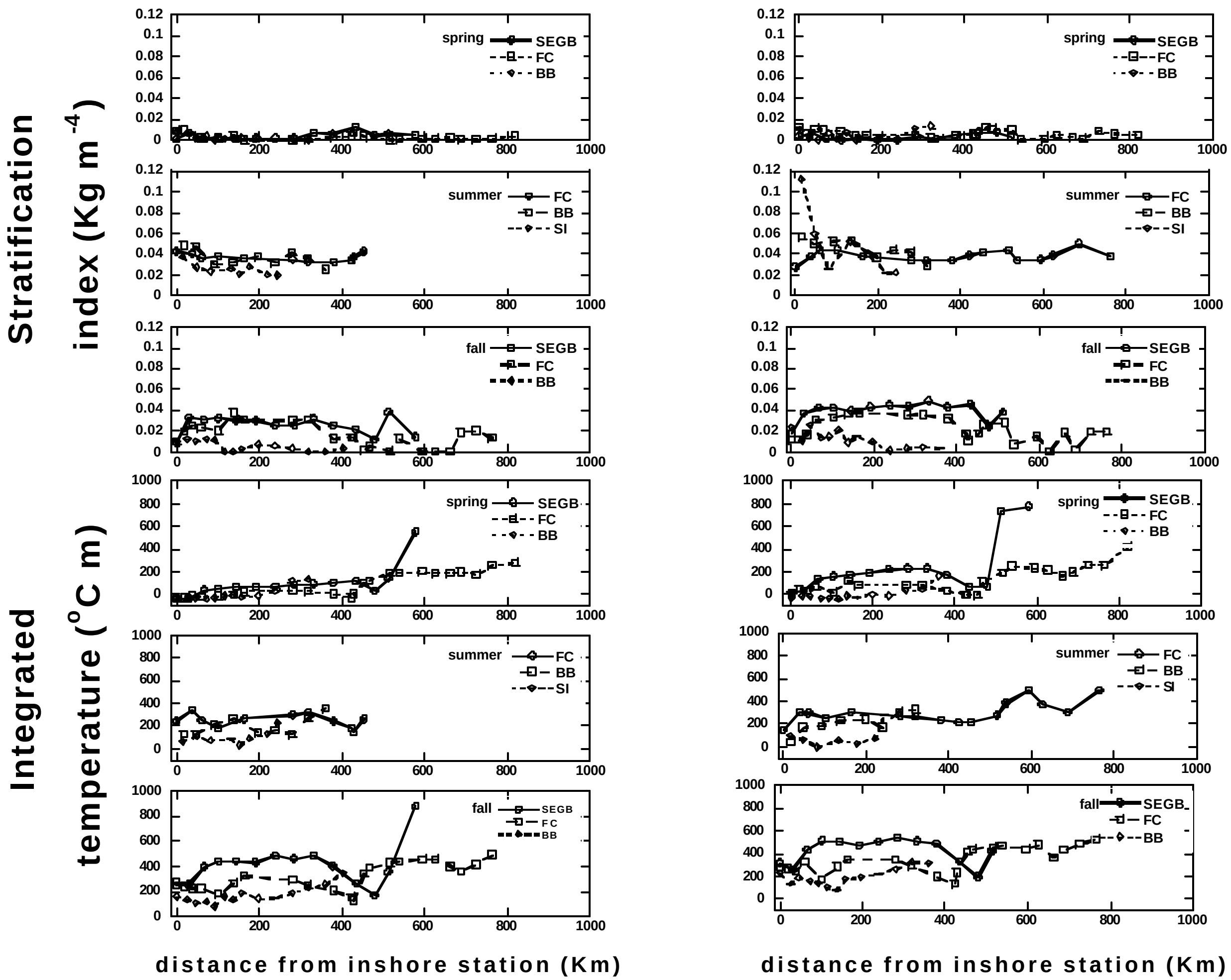

Figure 12. Spatial series of major nutrient pools along transect lines showing integrated silicate (0-50m) and nitrate (0-50m, combined nitrate and nitrite) during Spring (April-May), Summer (July), and Fall (October-November) 2000-01 surveys. Transect lines include southeast Grand Banks (SEGB), Flemish Cap (FC), Bonavista Bay (BB), and Seal Island (SI).

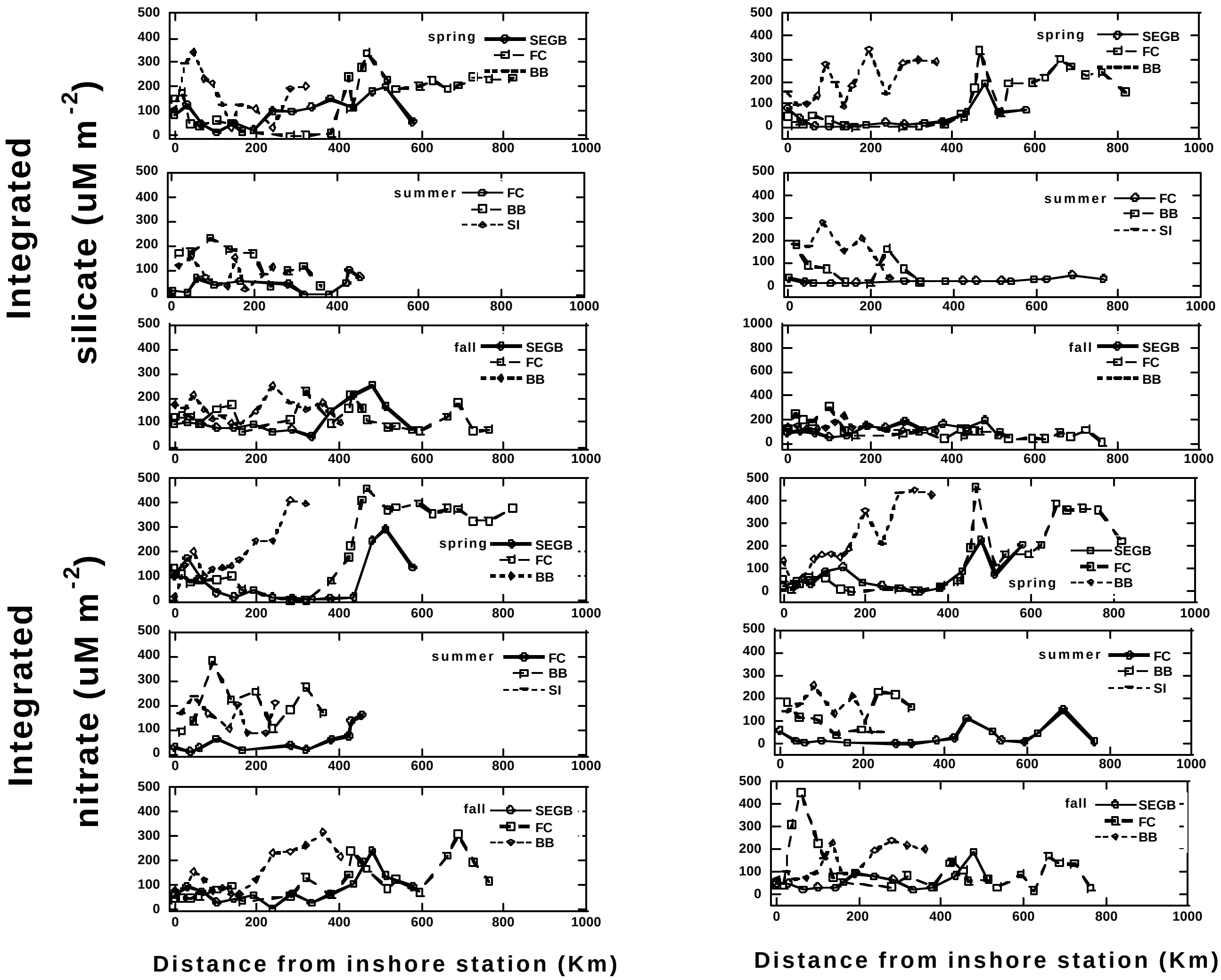

Figure 13. The Spring 2001 concentrations of silicate versus depth along AZMP standard transects. Bottom bathymetry shown in solid black. See Figure 21 for sample locations.

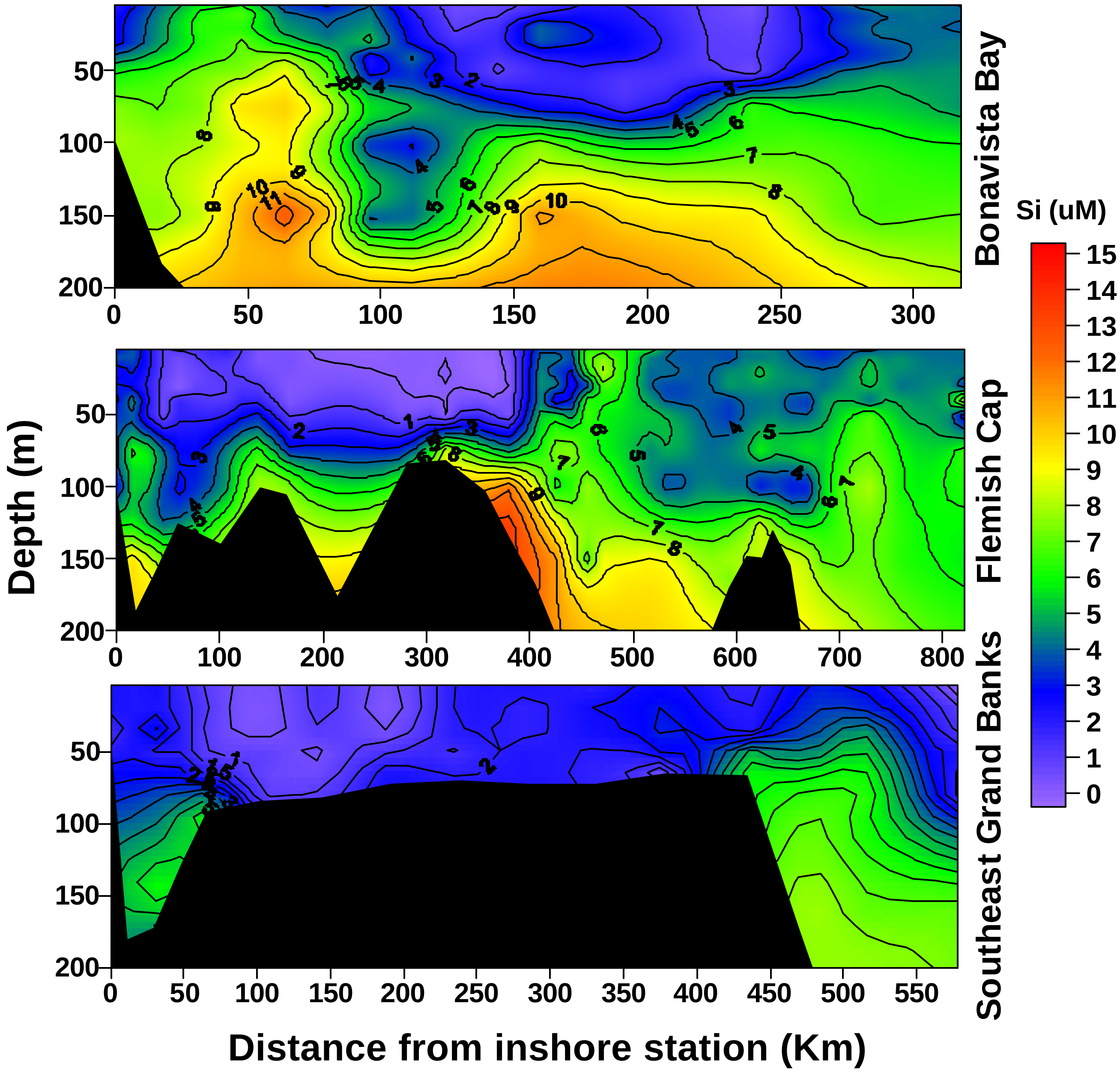

Figure 14. The Spring 2001 concentrations of nitrate (combined nitrate+nitrite) versus depth along AZMP standard transects. Bottom bathymetry shown in solid black. See Figure 21 for sample locations.

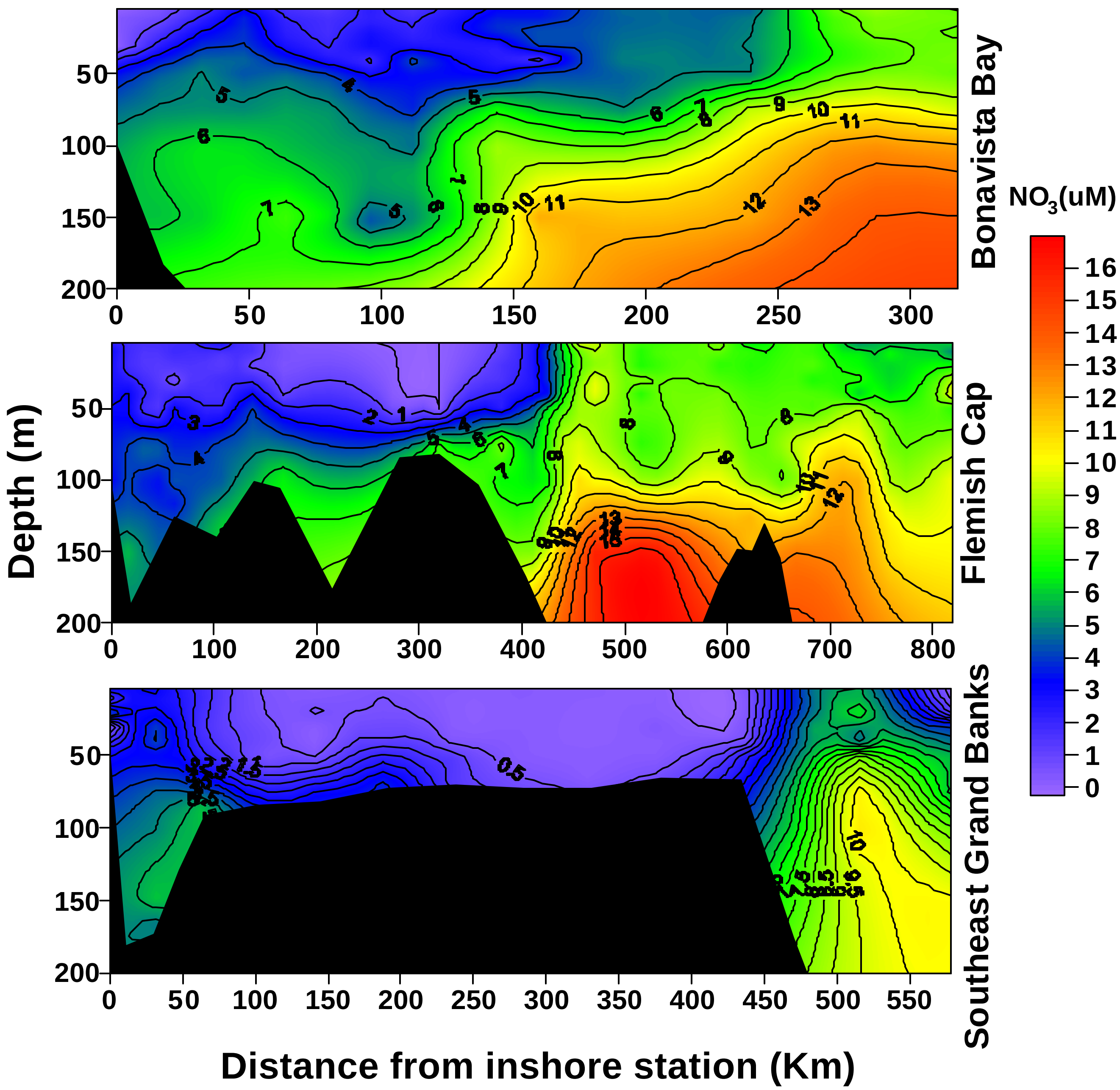

Figure 15. The Summer 2001 concentrations of silicate versus depth along AZMP standard transects. Bottom bathymetry shown in solid black. See Figure 22 for sample locations.

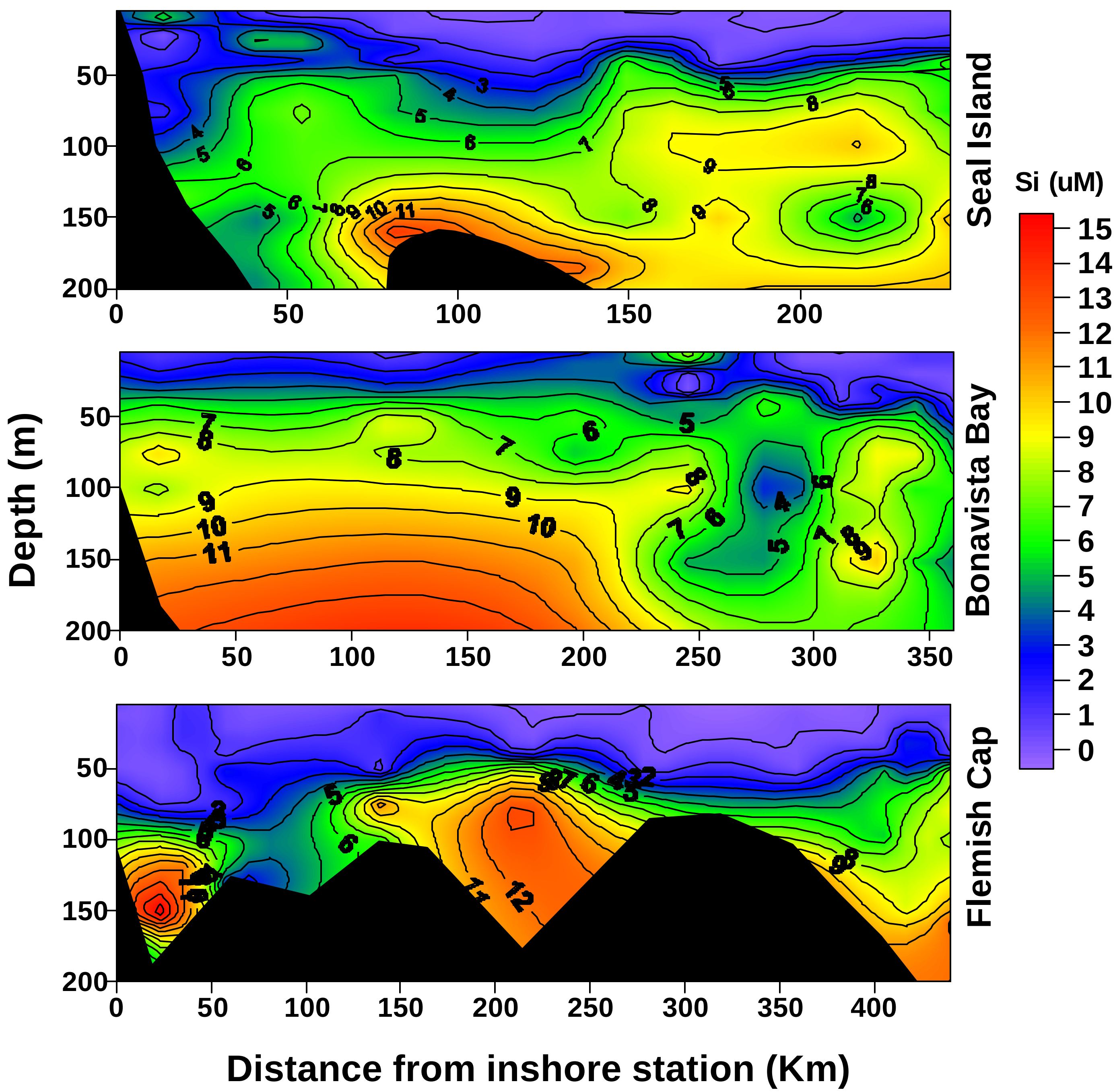

Figure 16. The Summer 2001 concentrations of nitrate (combined nitrate+nitrite) versus depth along AZMP standard transects. Bottom bathymetry shown in solid black. See Figure 22 for sample locations.

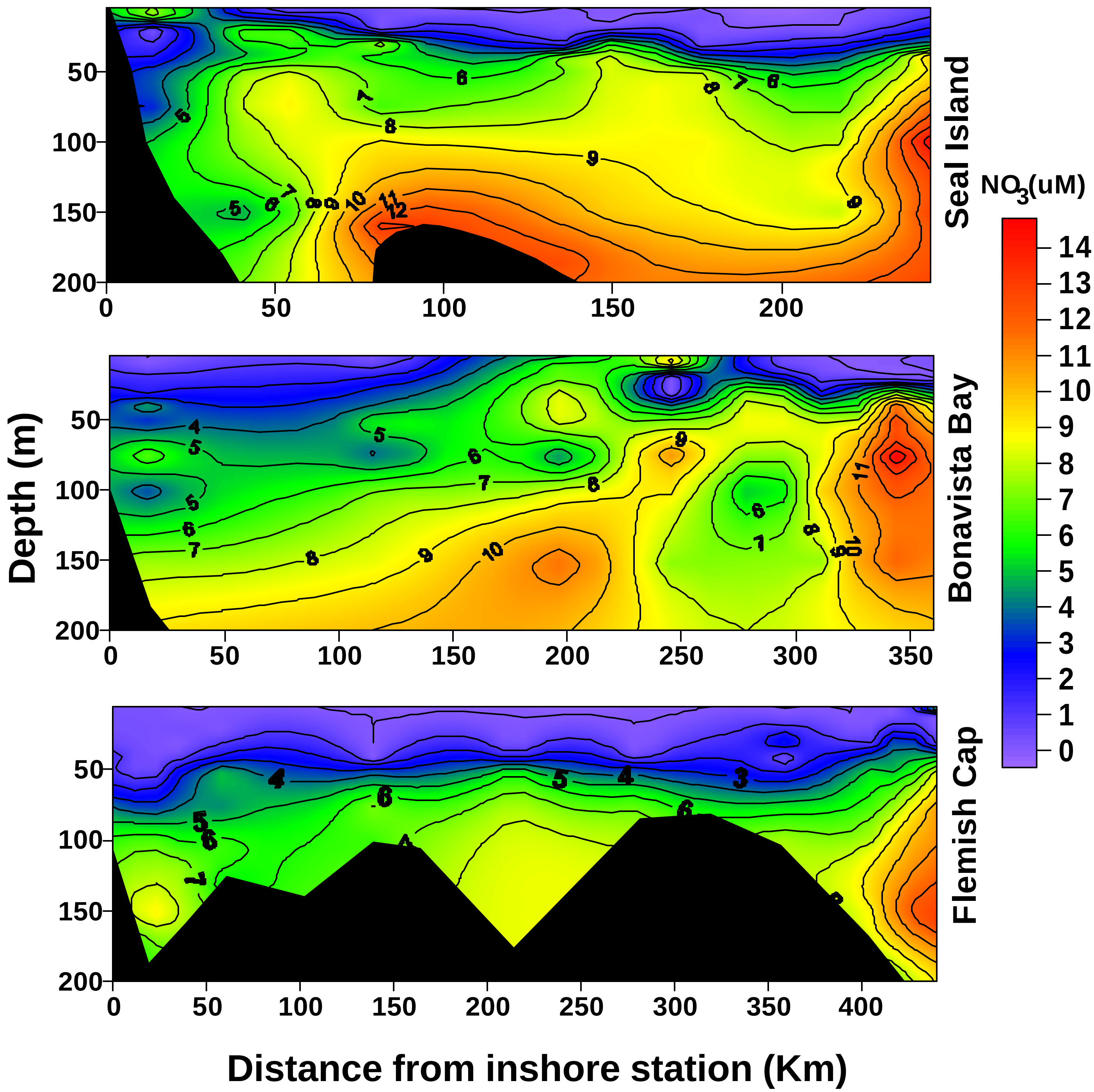

Figure 17. The Fall 2001 concentrations of silicate versus depth along AZMP standard transects. Bottom bathymetry shown in solid black. See Figure 23 for sample locations.

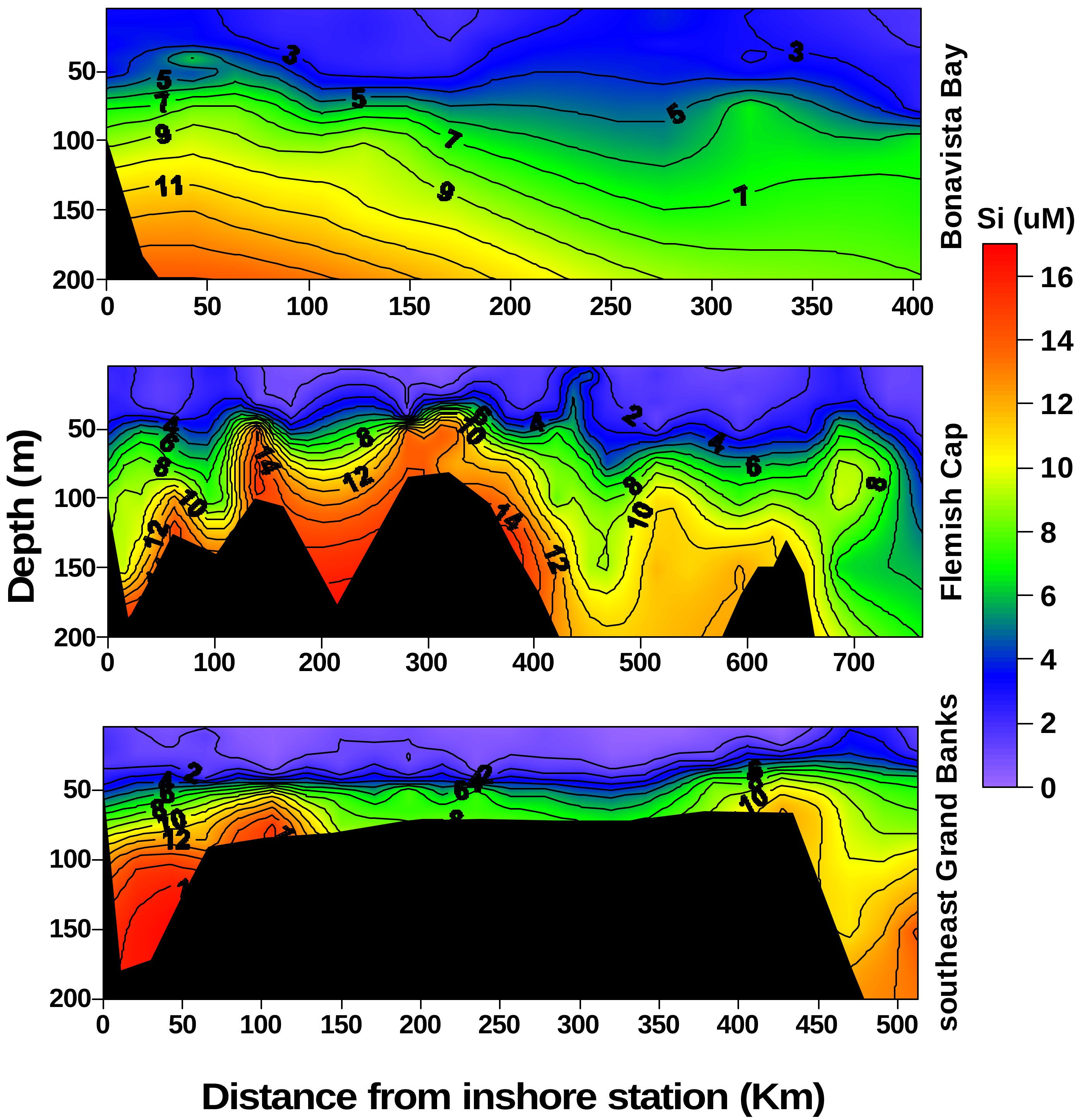

Figure 18. The Fall 2001 concentrations of nitrate (combined nitrate and nitrite) versus depth along AZMP standard transects. Bottom bathymetry shown in solid black. See Figure 23 for sample locations.

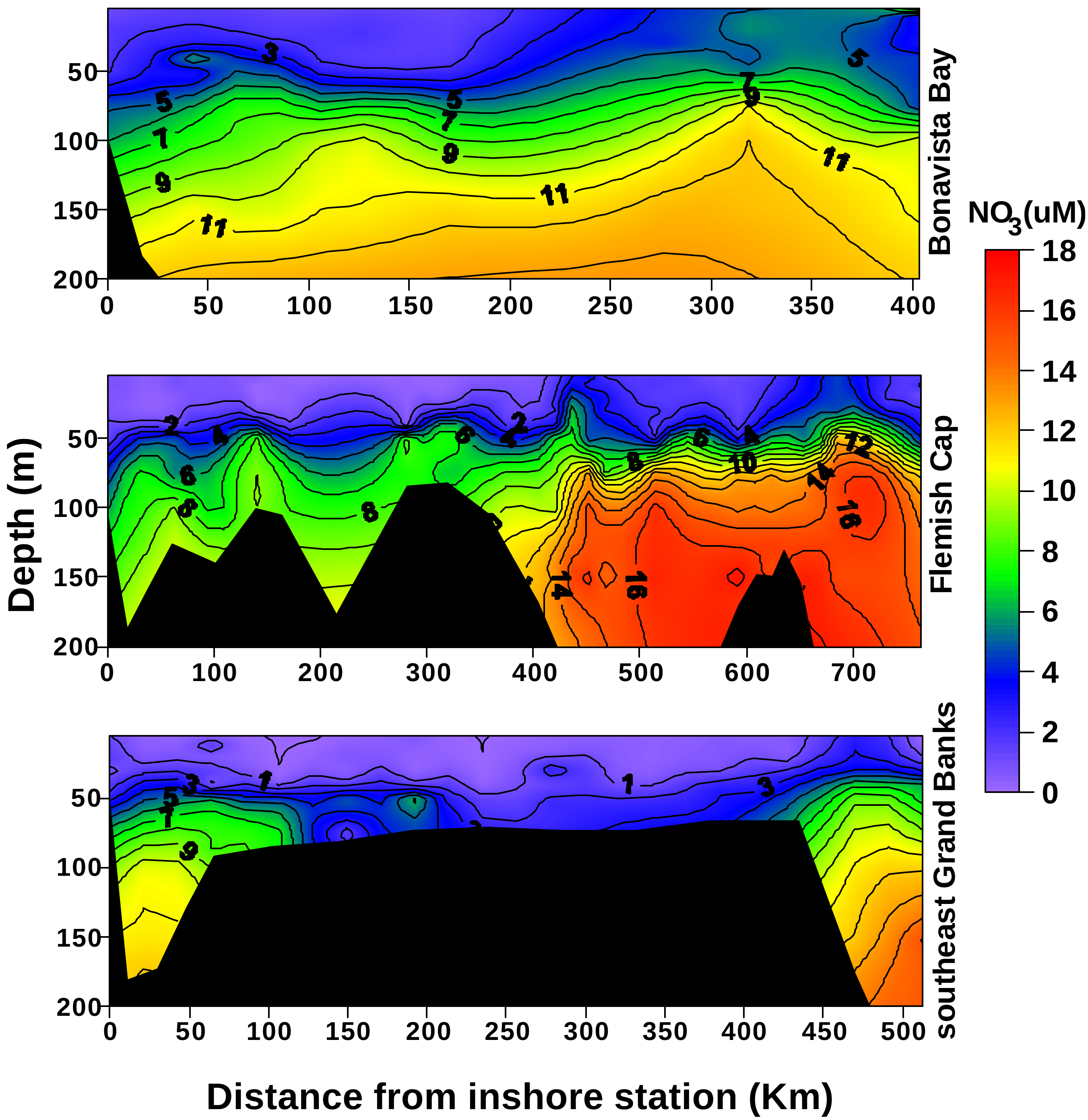

Figure 19. Spatial series of major deep nutrient pools along transect lines showing integrated silicate (50-150m) and nitrate (50-150m, combined nitrate and nitrite) during Spring (April-May), Summer (July), and Fall (October-November) 2000-01 surveys. Transect lines include southeast Grand Banks (SEGB), Flemish Cap (FC), Bonavista Bay (BB), and Seal Island (SI).

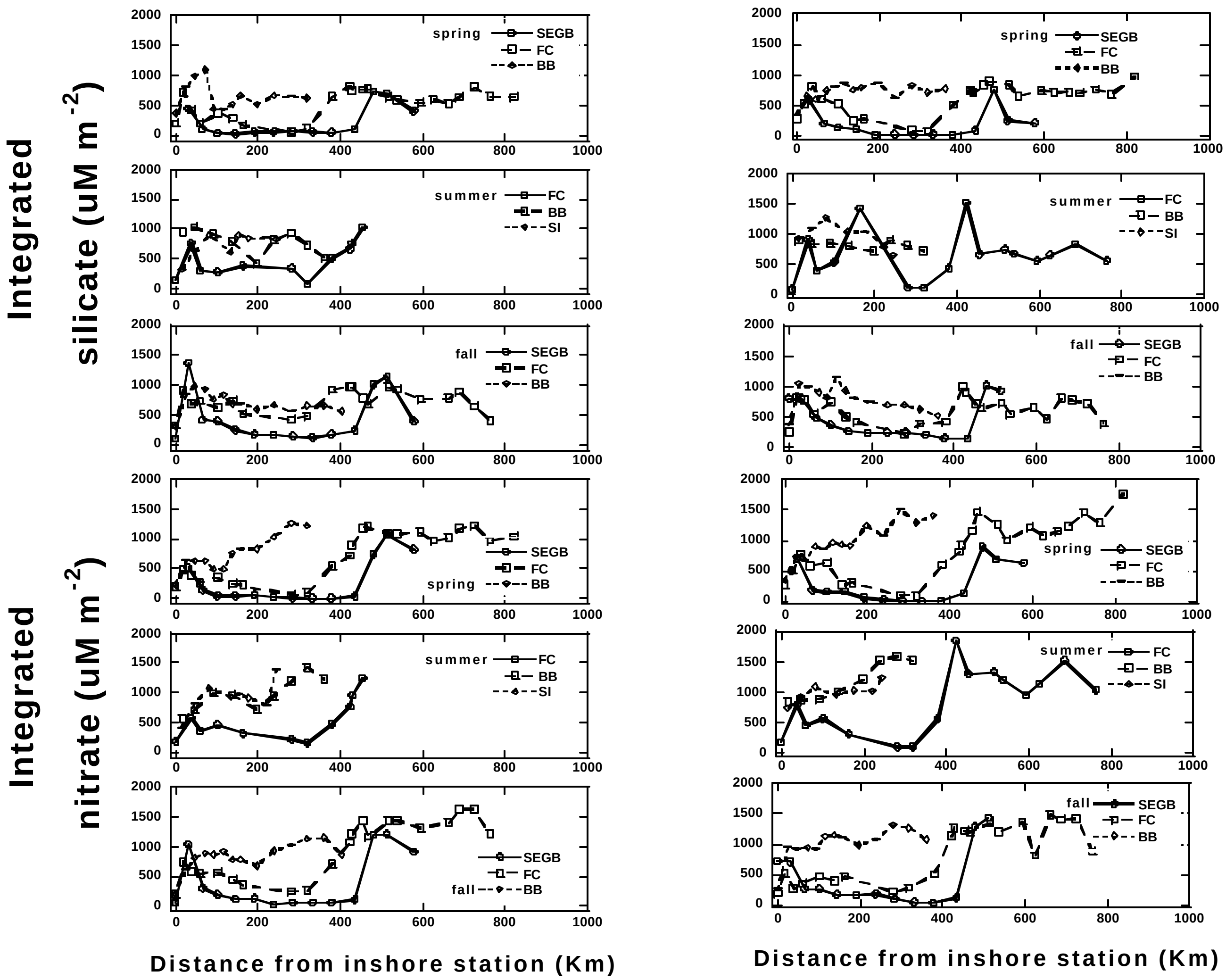

Figure 20. Spatial series of biological measures along transect lines showing integrated chlorophyll a (0-100m), and integrated *in-situ* fluorescence (calibrated against extracted chlorophyll a, 0-100m) during Spring (April-May), Summer (July), and Fall (October-November) 2000-01 surveys. Transect lines include southeast Grand Banks (SEGB), Flemish Cap (FC), Bonavista Bay (BB), and Seal Island (SI).

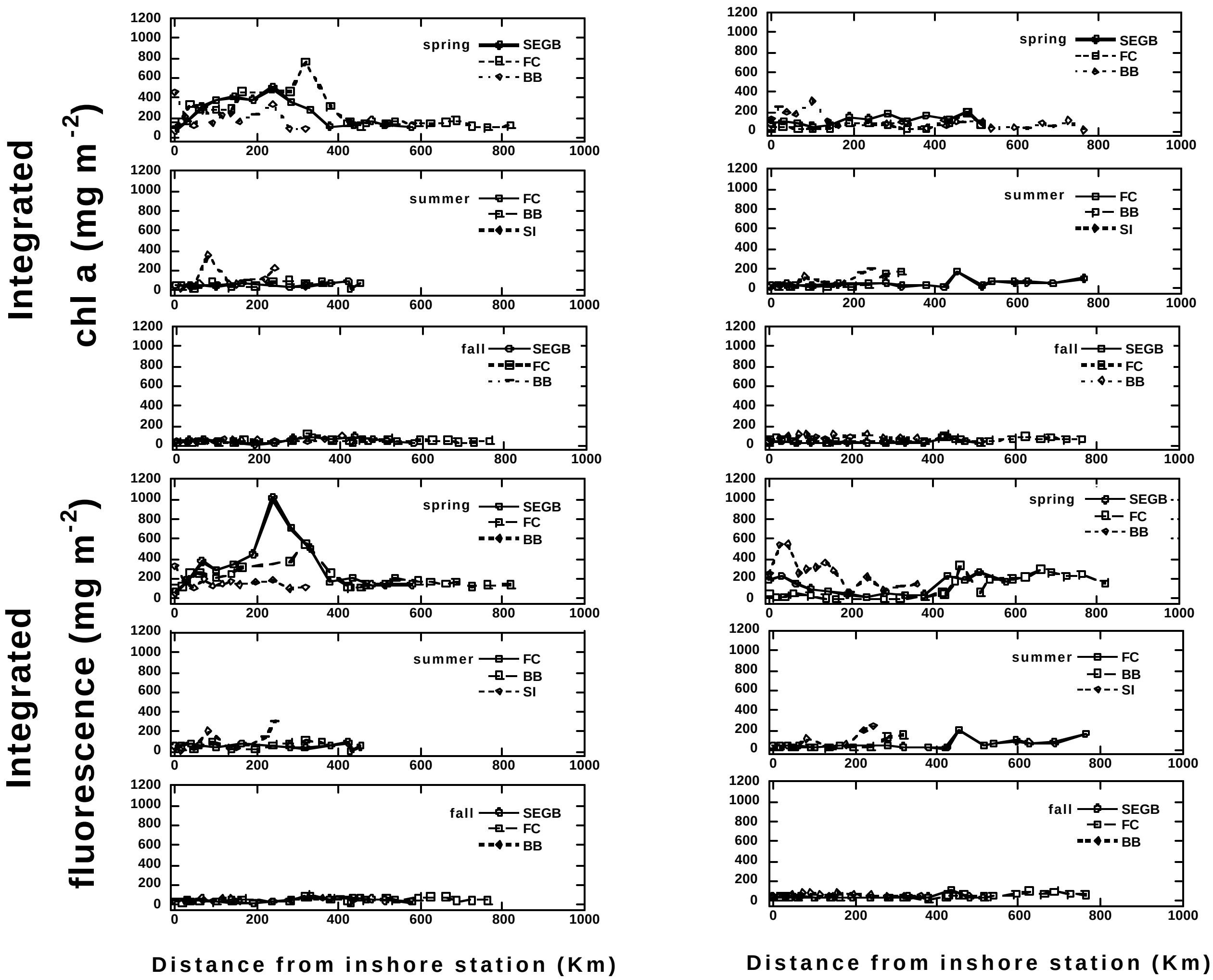

Figure 21. Vertical profiles of chlorophyll a versus distance from inshore station during Spring 2001 oceanographic surveys across standard AZMP transects. Bottom bathymetry shown in solid black. Sample locations shown by small open circles.

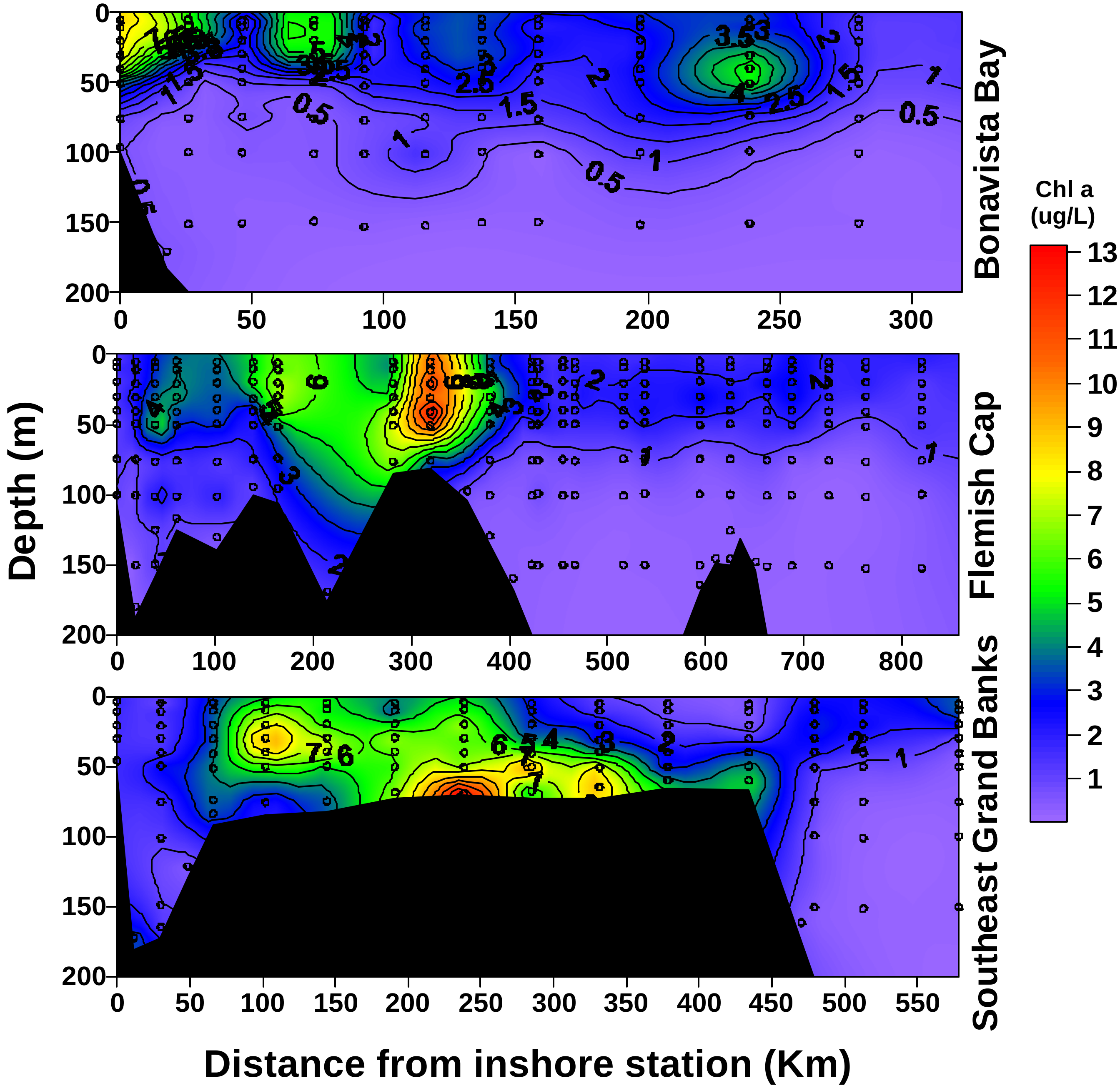

Figure 22. Vertical profiles of chlorophyll a versus distance from inshore station during Summer 2001 oceanographic surveys across standard AZMP transects. Bottom bathymetry shown in solid black. Sample locations shown by small open circles.

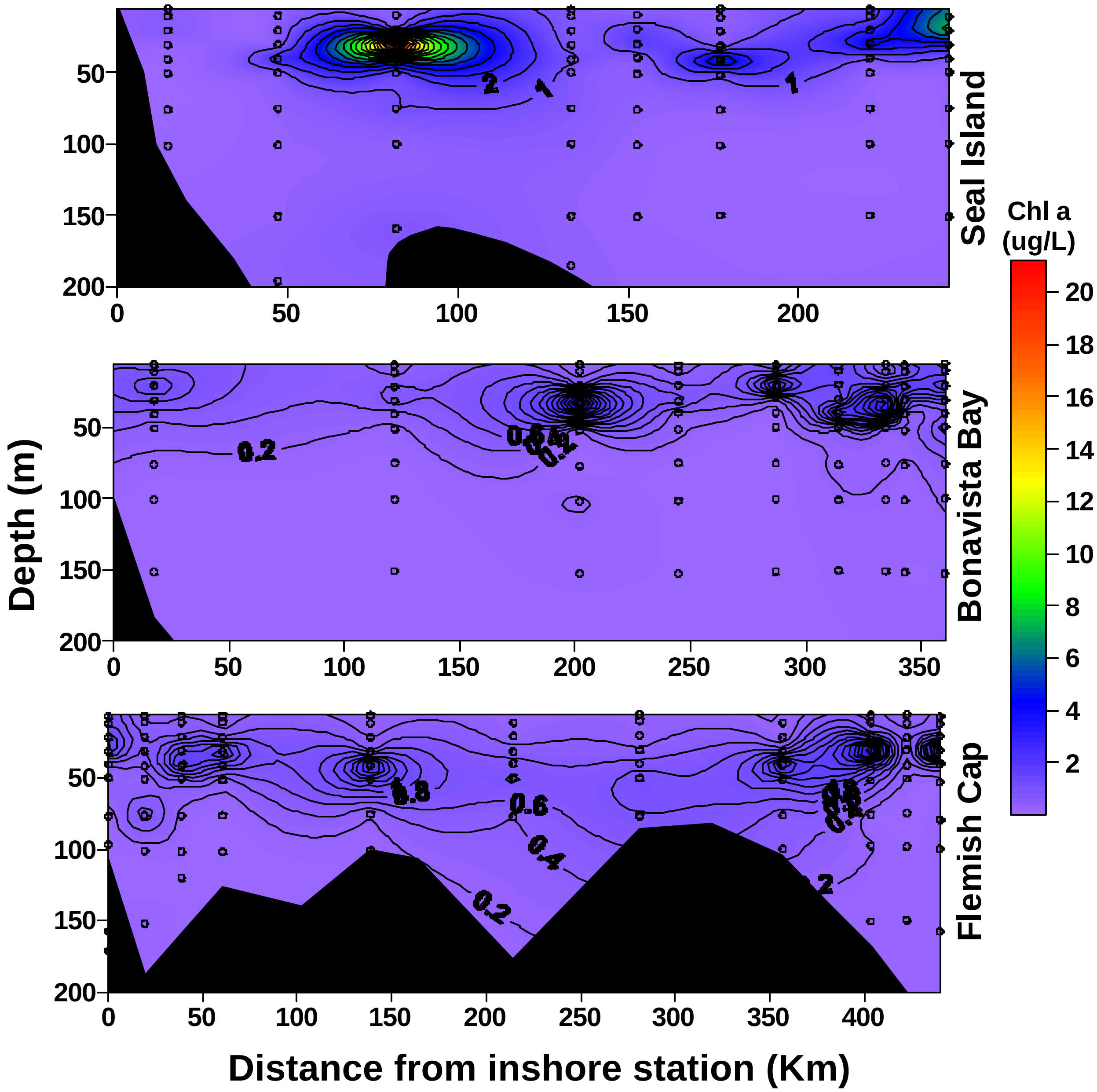

Figure 23. Vertical profiles of chlorophyll a versus distance from inshore station during Fall 2001 oceanographic survey across standard AZMP transects. Bottom bathymetry shown in solid black. Sample locations shown by small open circles.

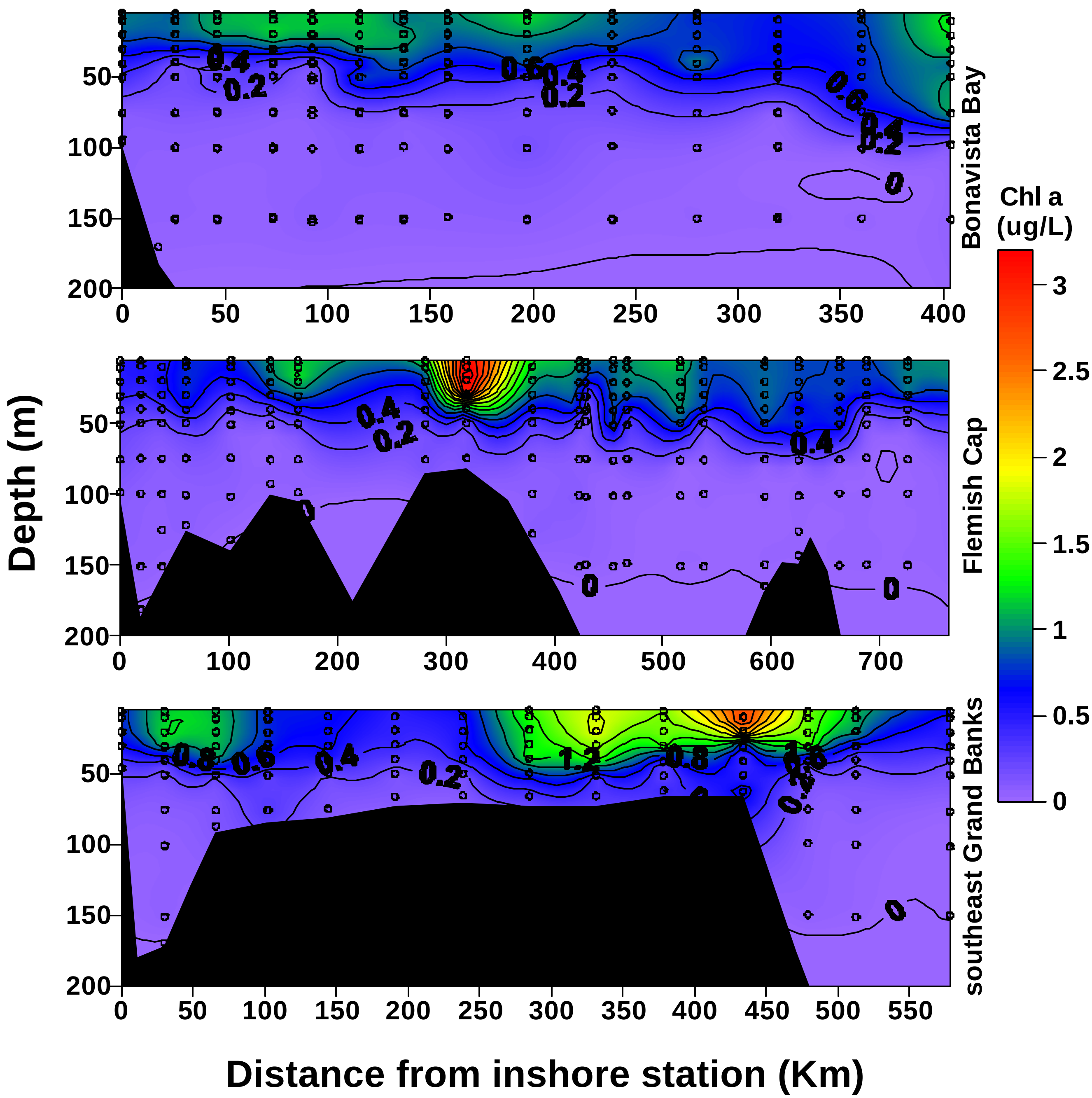

Figure 24. Seasonal variation in major phytoplankton groups at selected stations along standard AZMP transect lines during 2000-01. Notice scale change for southeast Grand Banks data.

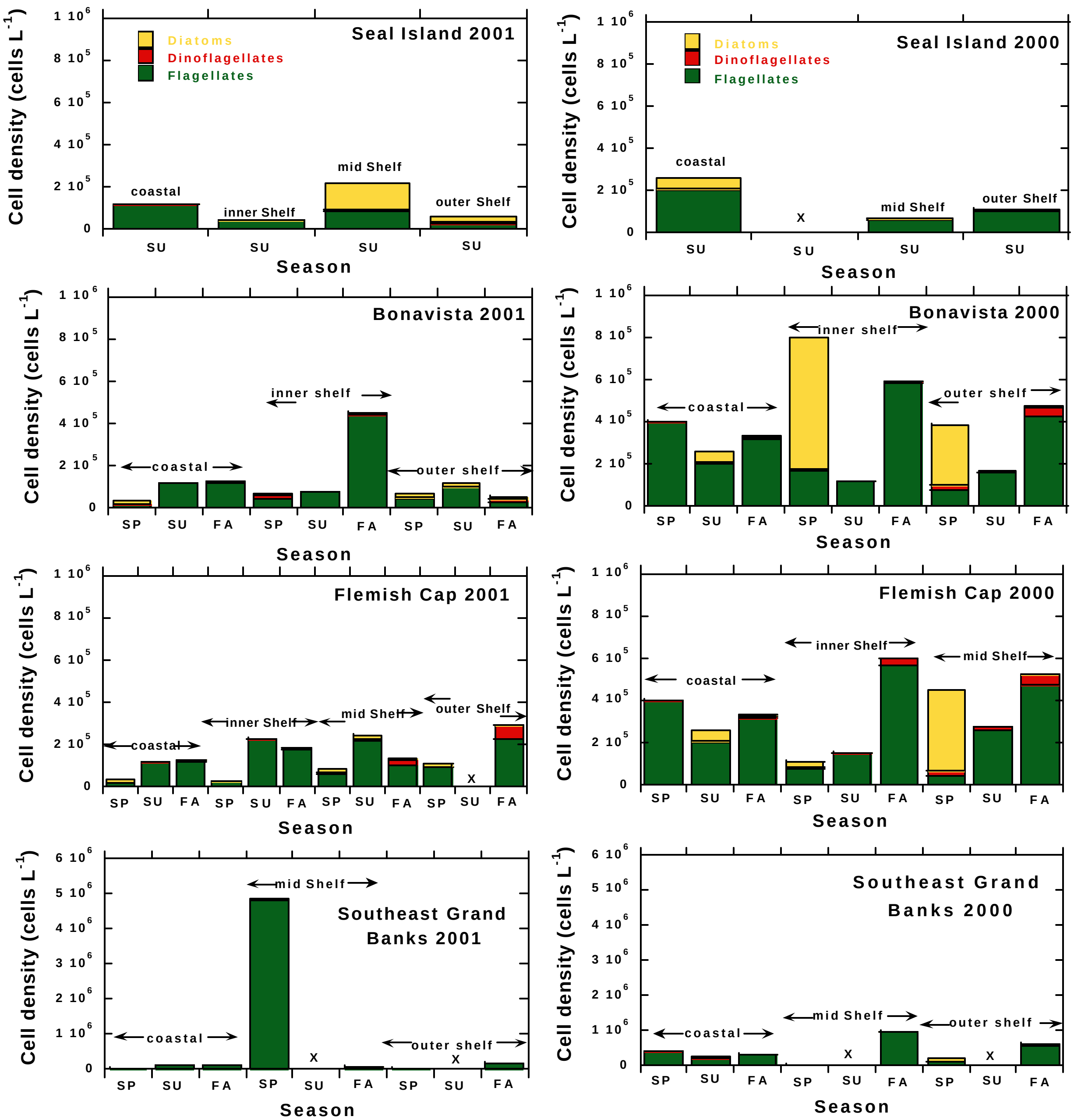

Figure 25. Bi-weekly composite estimates of mean sea surface chlorophyll concentration at Station 27 from the SeaWiFs sensor.

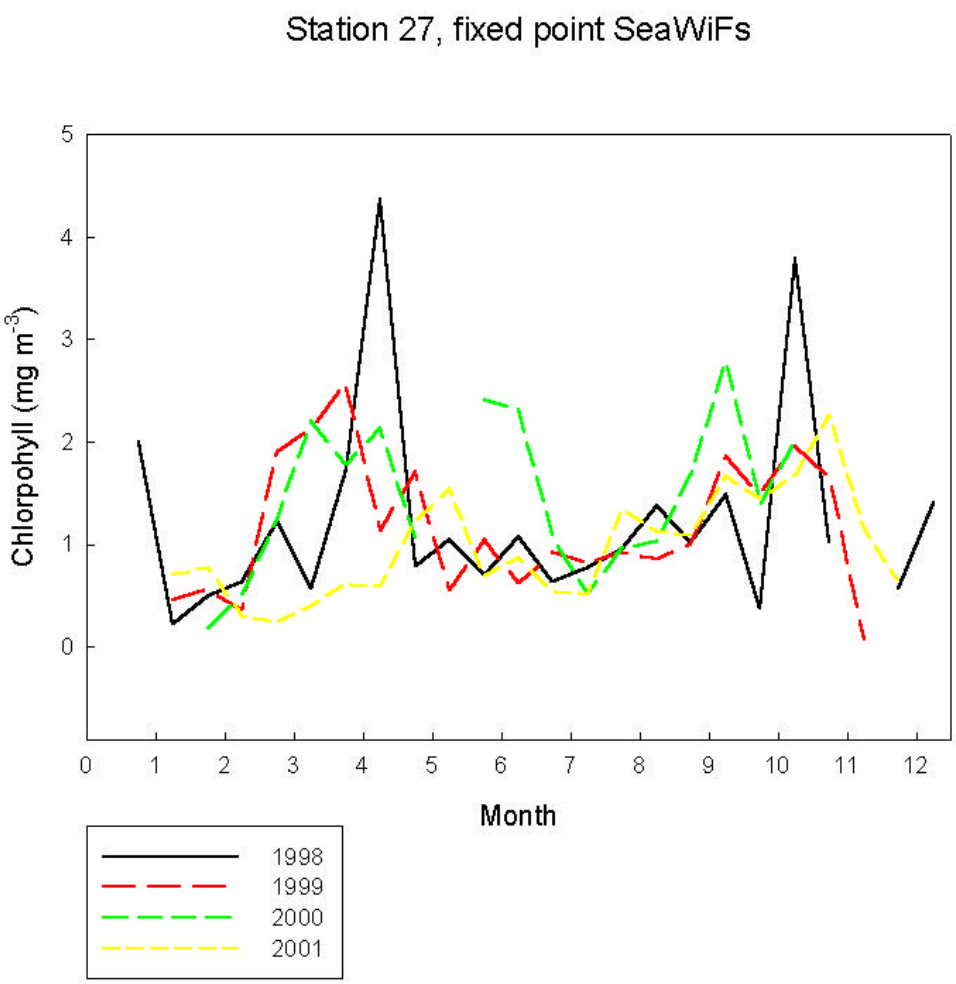

Figure 26. Bi-weekly composite images of satellite derived sea surface concentrations of chlorophyll along the Seal Island, Bonavista Bay, Flemish Cap and Southeast Grand Banks transects.

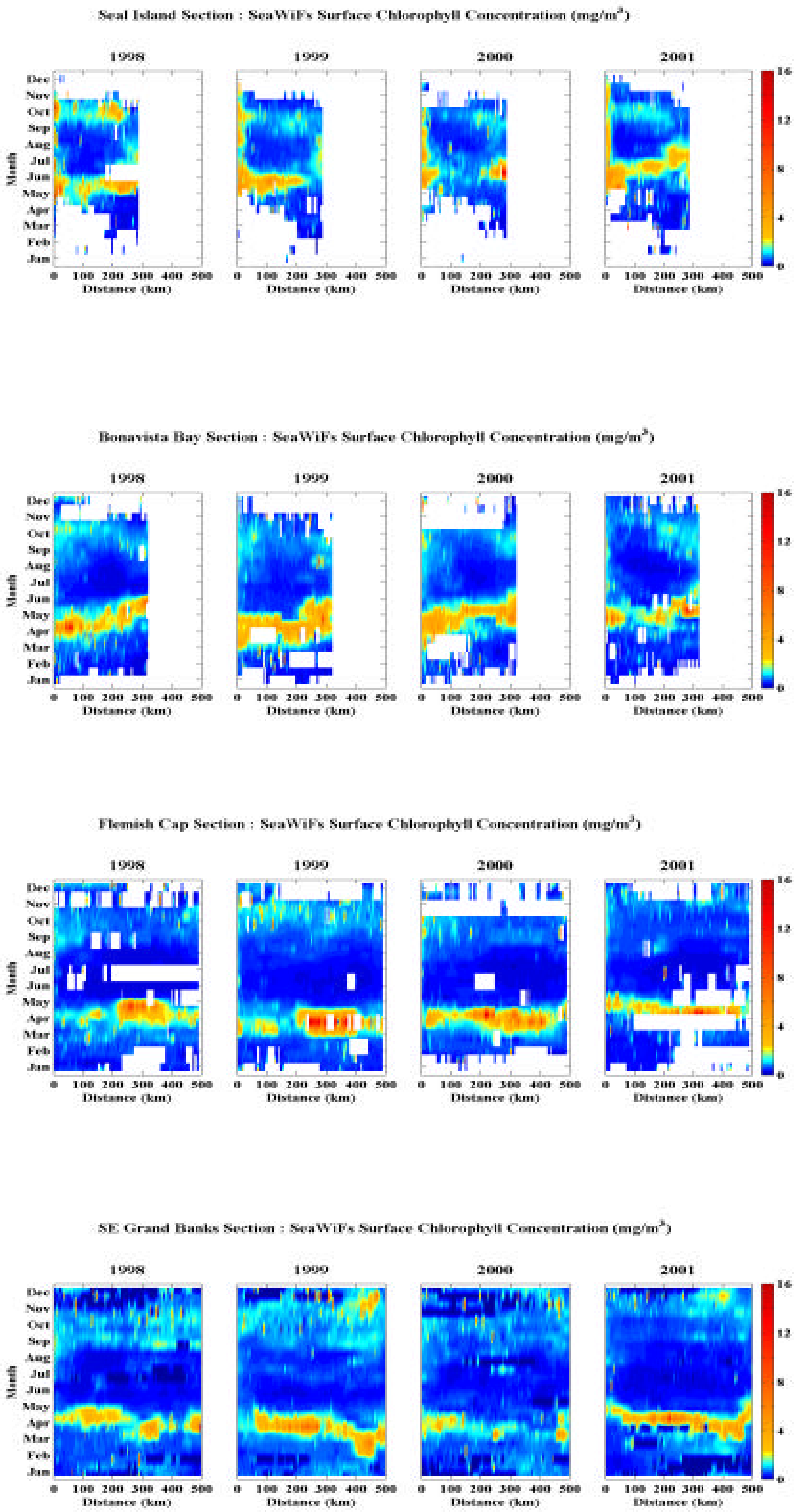

Figure 27. Relationship between silicate and nitrate (combined nitrate and nitrite) for transect occupations and Station 27 during 2001. Linear regression parameters provided for transect and fixed station.

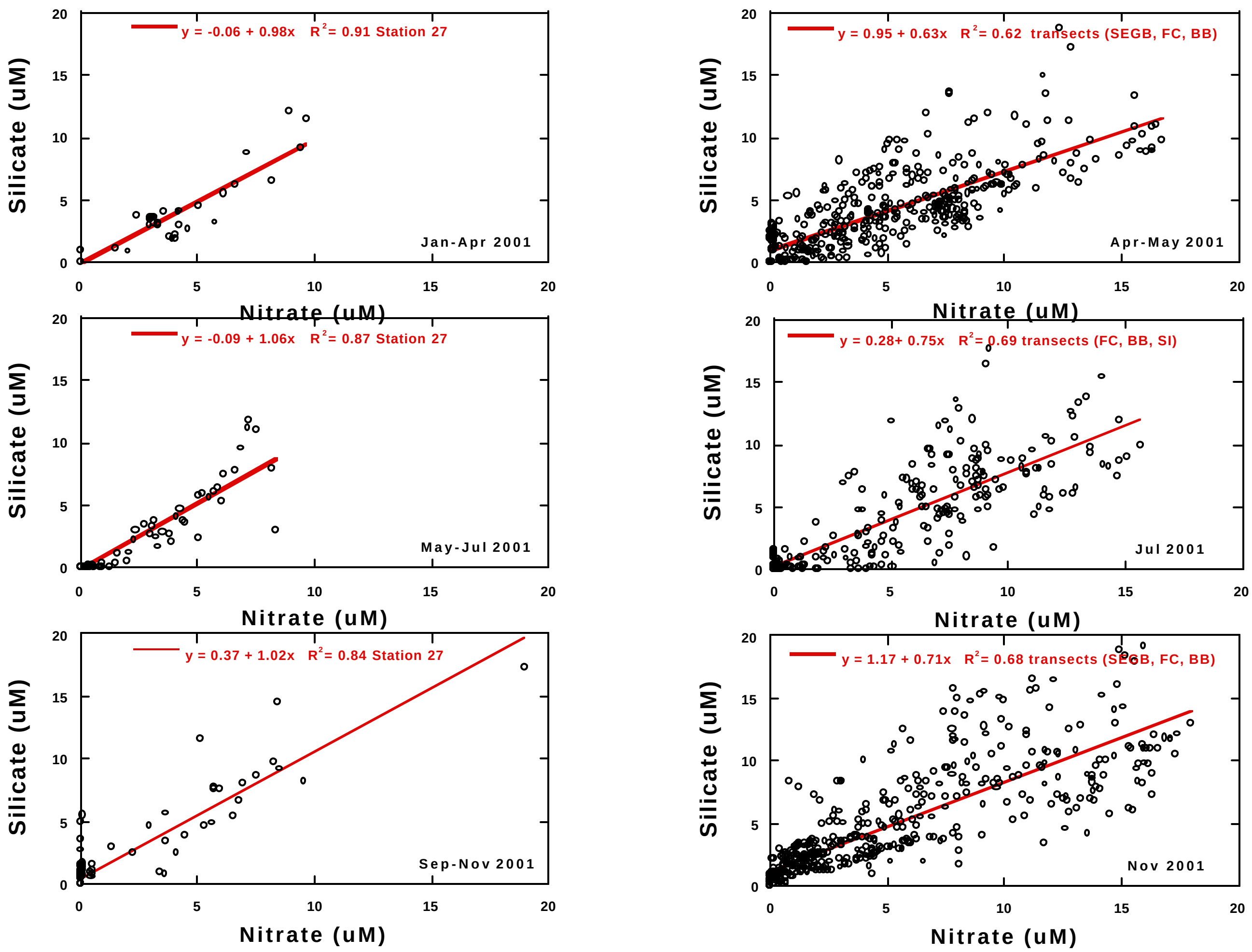

Figure 28. Seasonal combined abundance of all major zooplankton groups at Station 27.

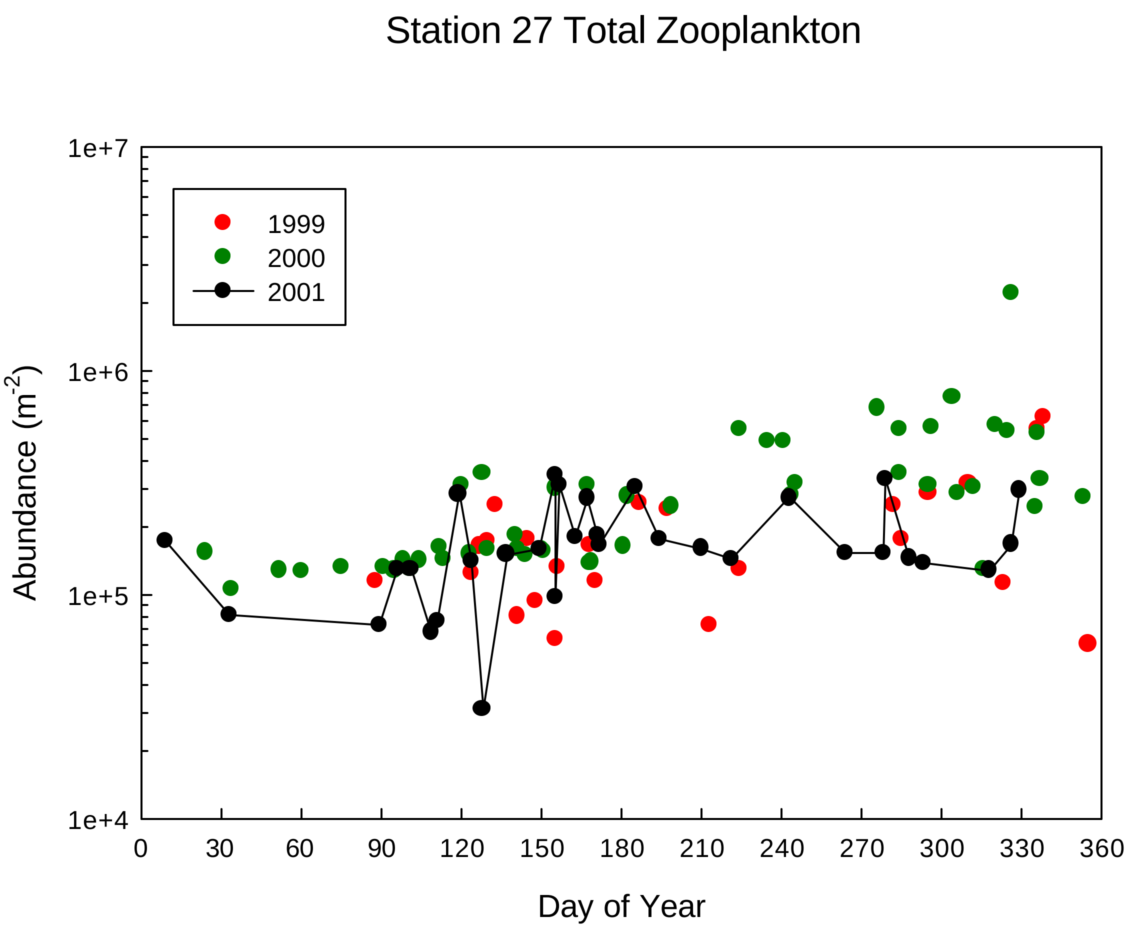

Figure 29. Seasonal pattern in the abundance of 5 dominant taxa at Station 27. Observations for 2001 (black symbols) are contrasted with observations from the previous two years. The exclusion of observations prior to 1999 is due to a change in the sampling depth over which tows are performed at that site.

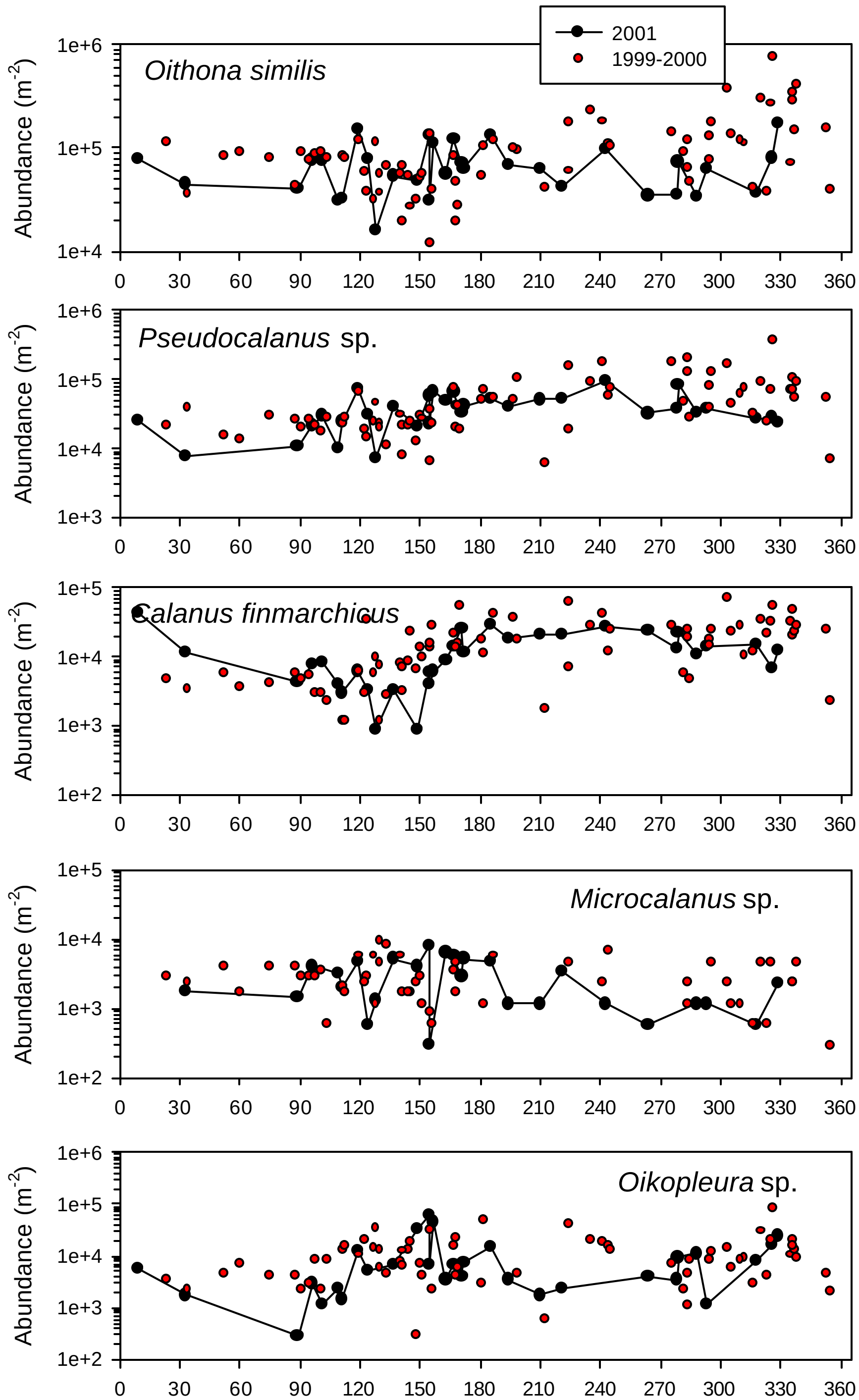

Figure 30. Relative composition of the major zooplankton taxa from collections at Station 27.

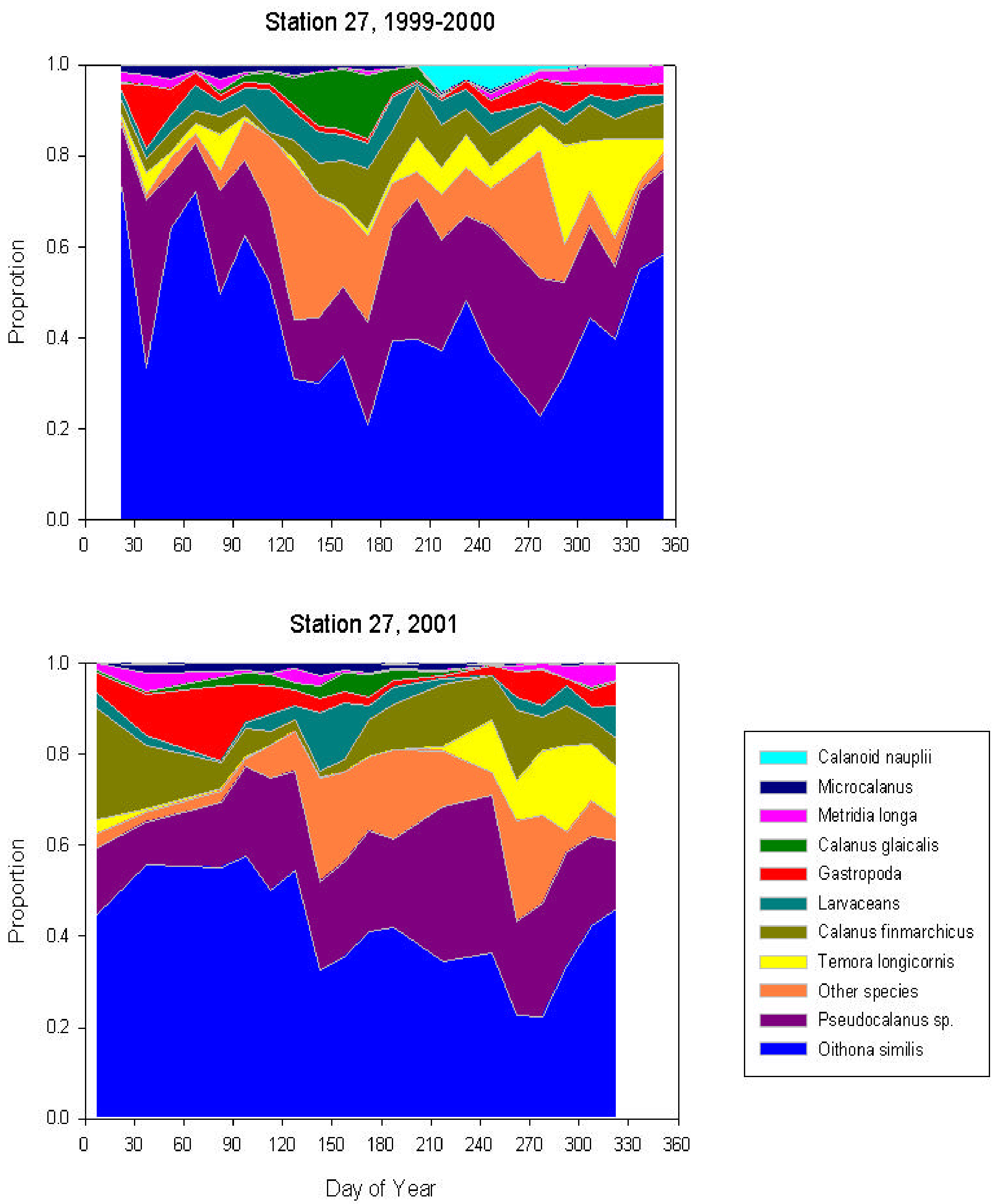

Figure 31. Seasonal cycle in the relative stage composition of *Calanus finmarchicus* at Station 27 for the period 1999-2001.

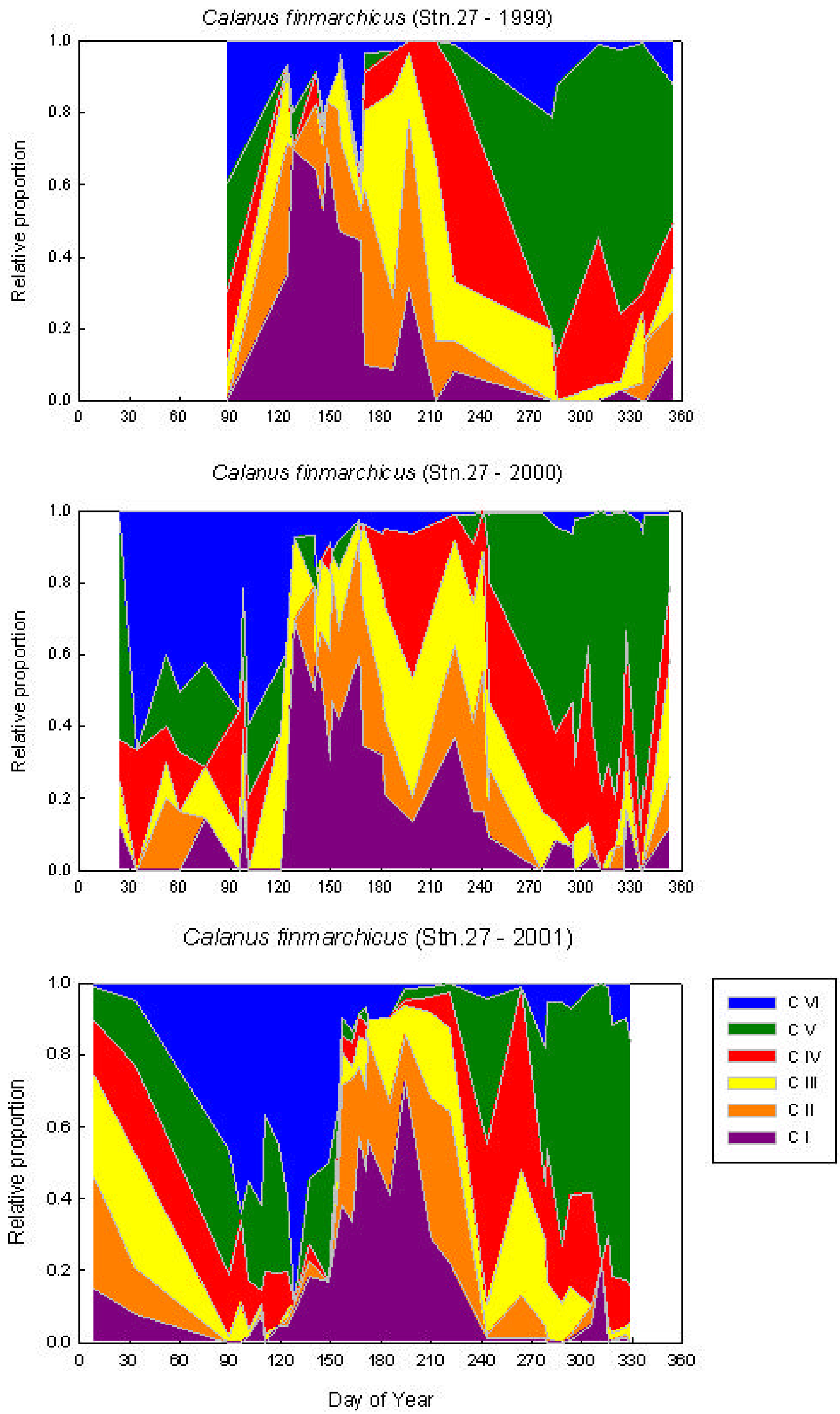

Figure 32. Seasonal stage specific abundance patterns of *Calanus finmarchicus* copepodites at Station 27 contrasting 2000 and 2001.

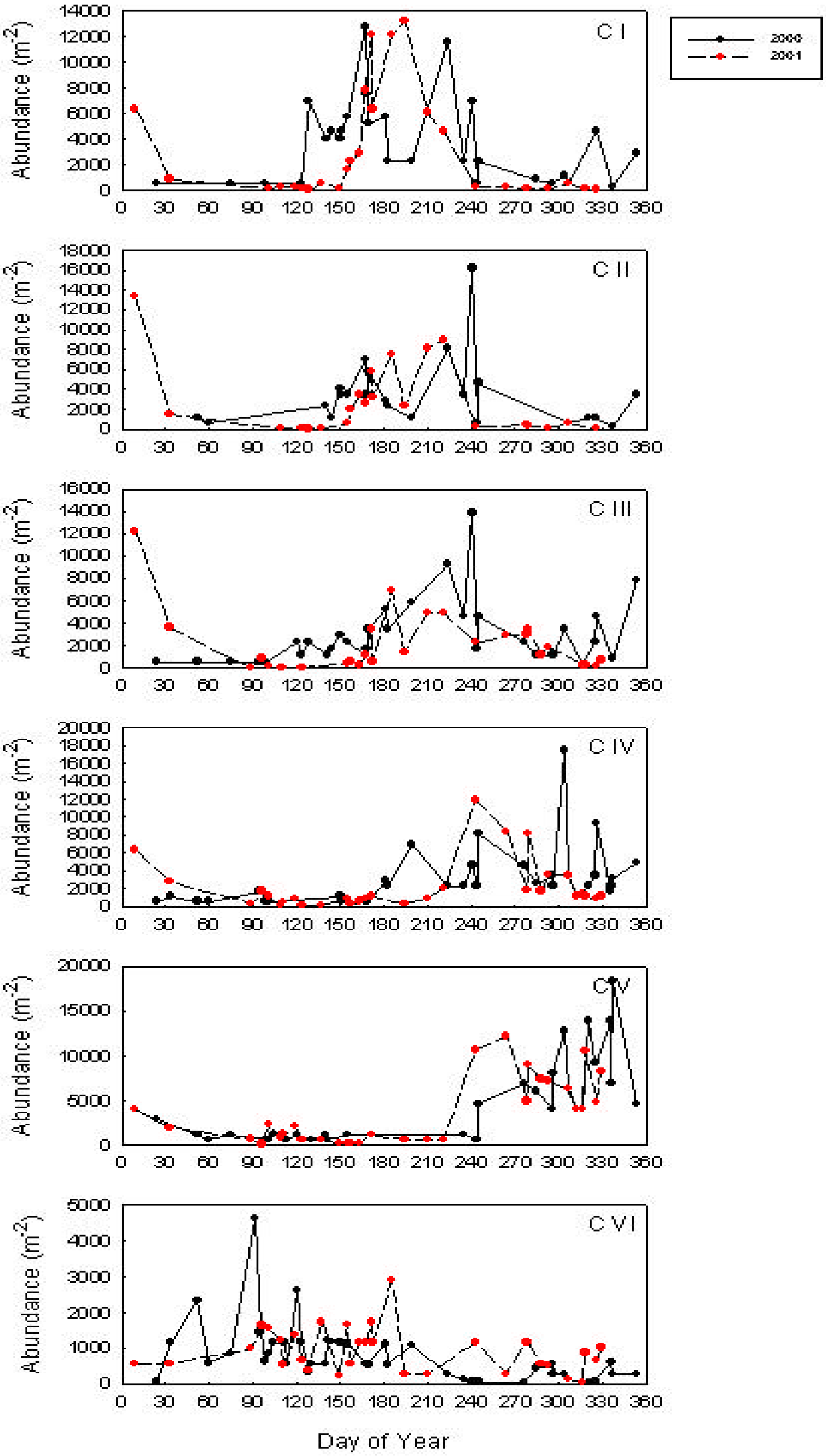

Figure 33. Seasonal abundance pattern of large (> 200 µm) calanoid nauplii at Station 27 in 2000 and 2001.

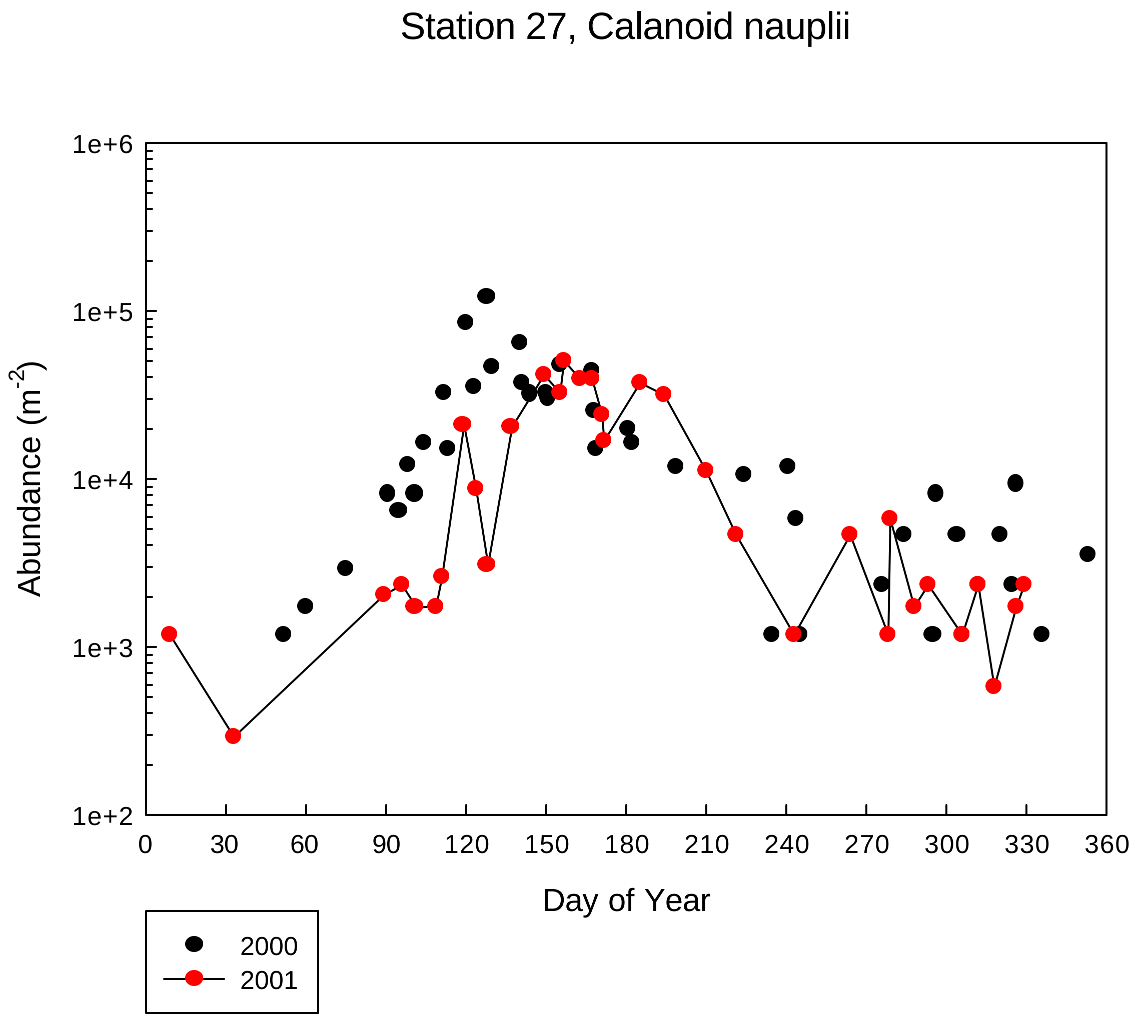

Figure 34. Average abundance patterns of five major taxonomic groups along oceanographic transects sampled as part of research vessel surveys conducted in the fall of 1999 and 2000, and in the spring and summer of 2000 and 2001. Transects are Bonavista Bay (BB), Flemish Cap (FC), Southeast Grand Banks (SE), Beachy Island (BI), Makkovik Bank (MB), Seal Island (SI) and White Bay (WB). The bars indicate average densities for all stations with non zero catches along each transect. Error bars are the standard deviations.

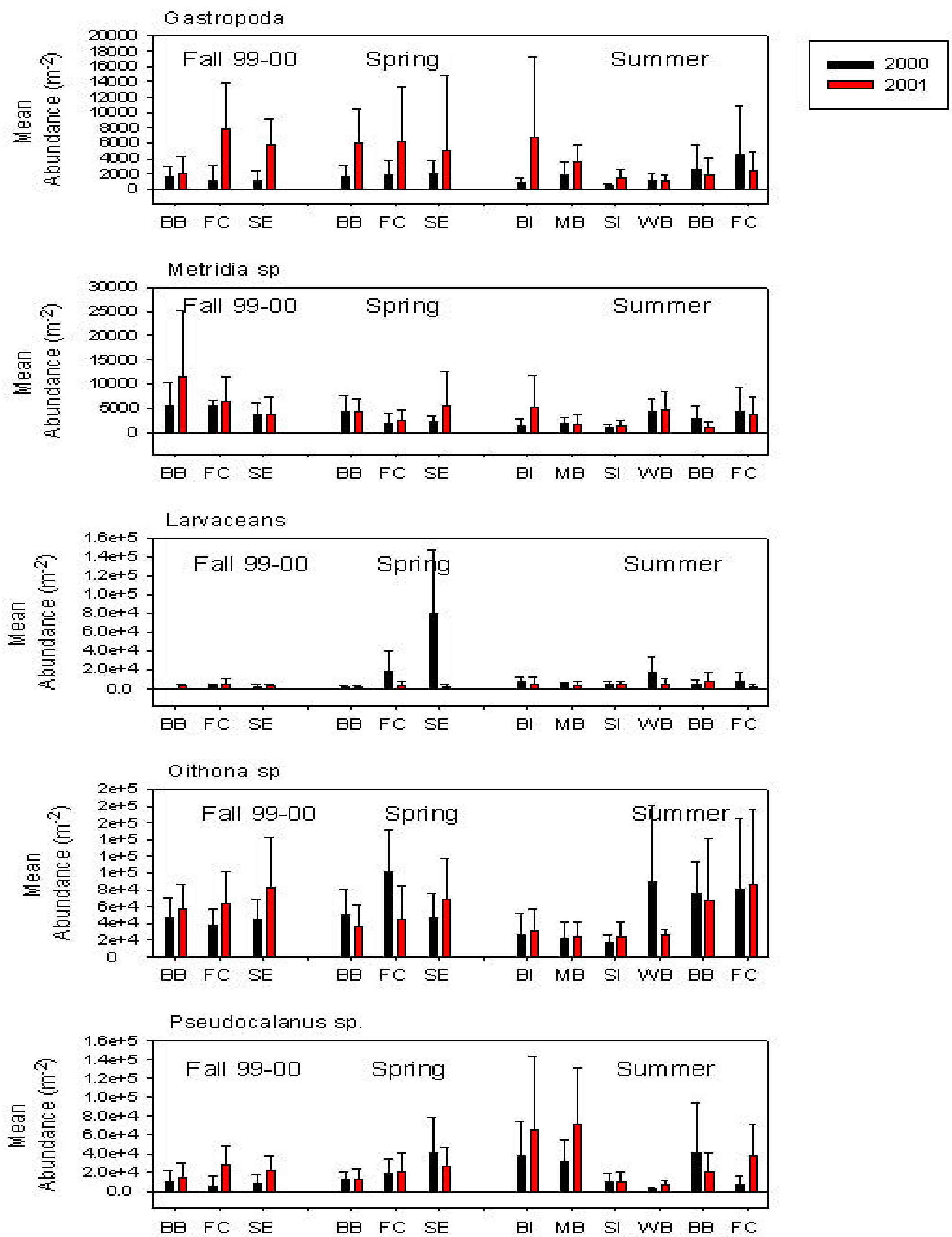

Figure 35. Combined abundance of all copepodite stages sampled along the three transects occupied during the spring surveys of 2000 and 2001.

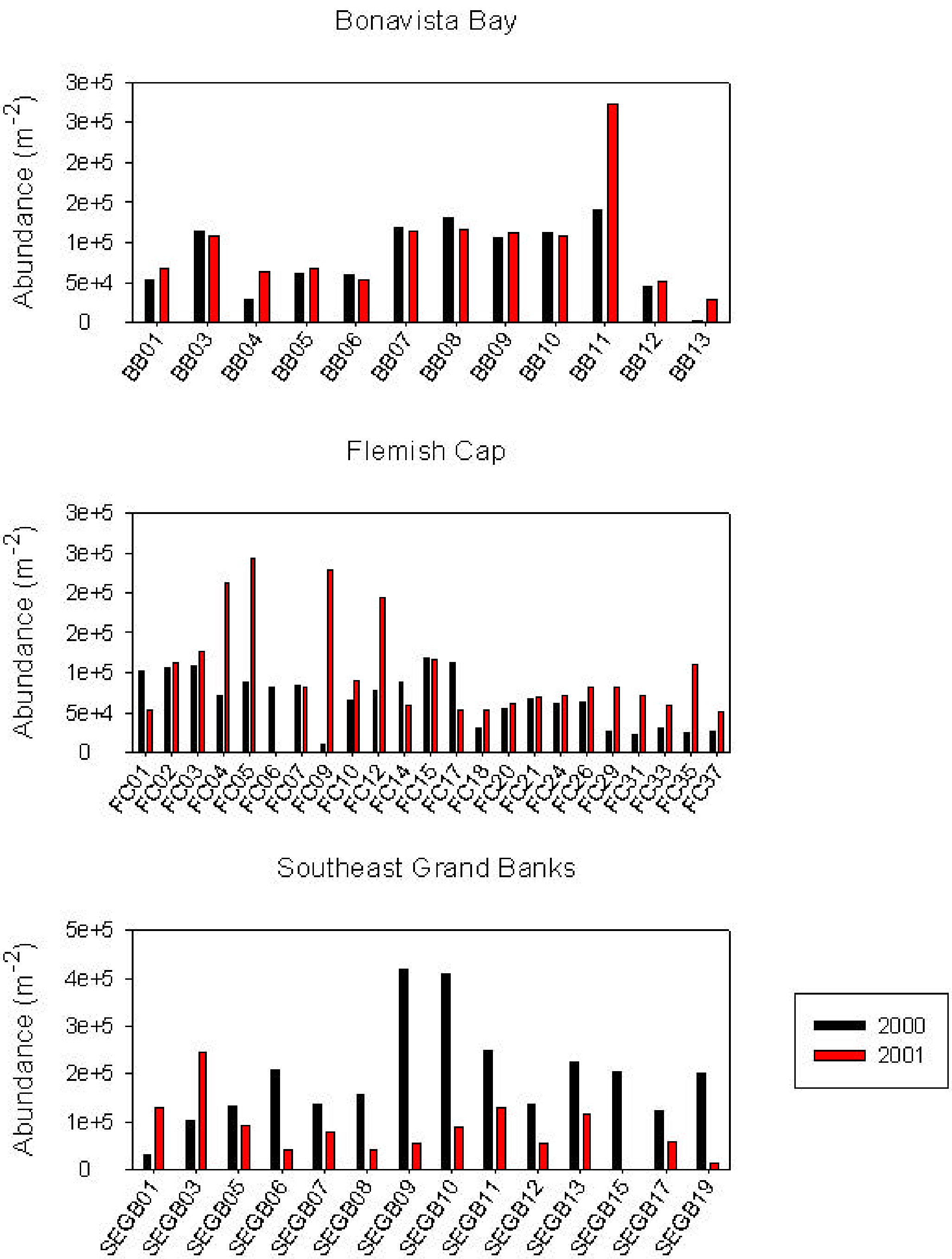

Figure 36. Combined abundance of all major zooplankton, excluding copepodite stages, sampled along the three transects occupied during the spring surveys of 2000 and 2001.

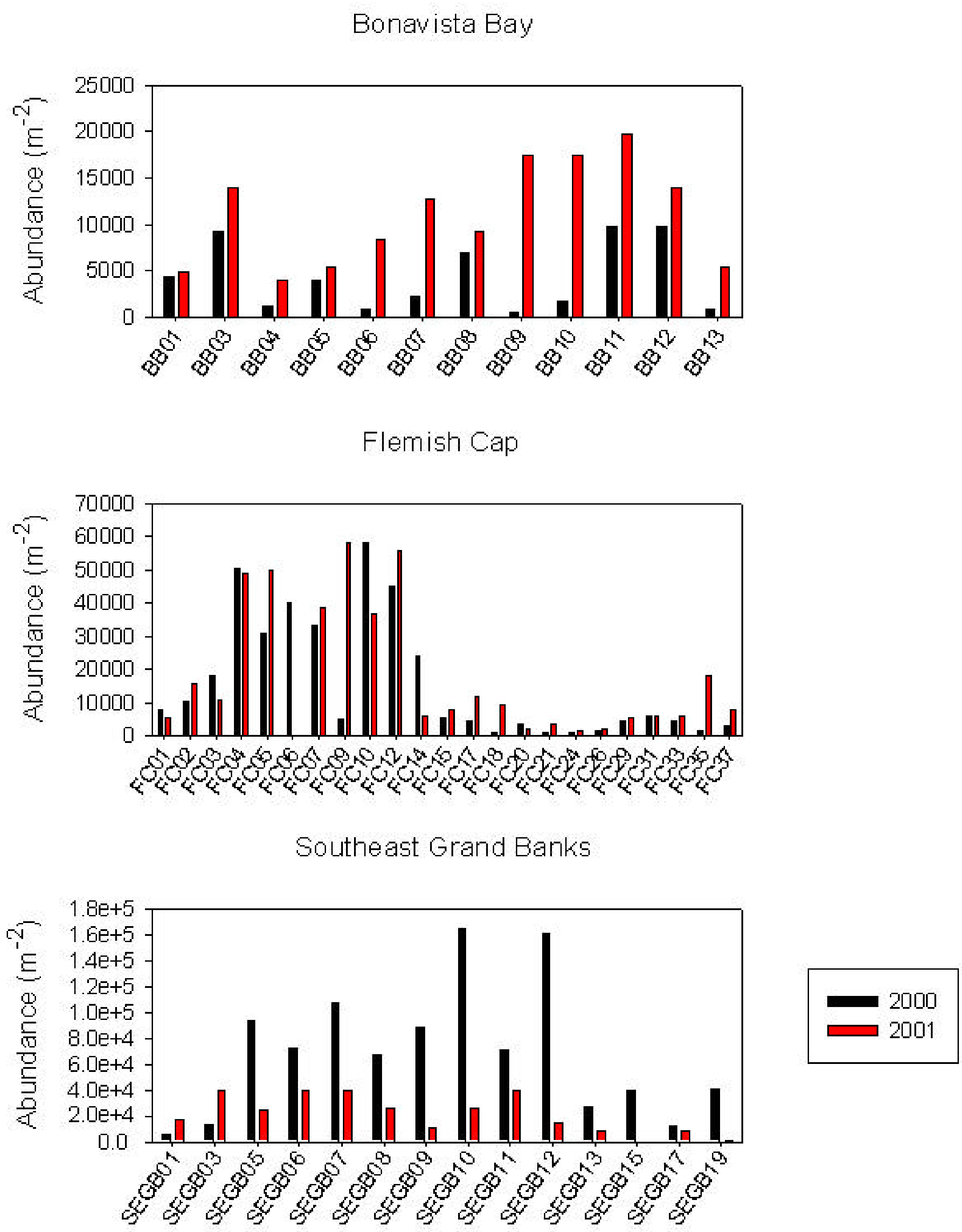

Figure 37. Combined abundance of copepodites and all other major zooplankton sampled along the six transects occupied during the summer surveys of 2000 and 2001.

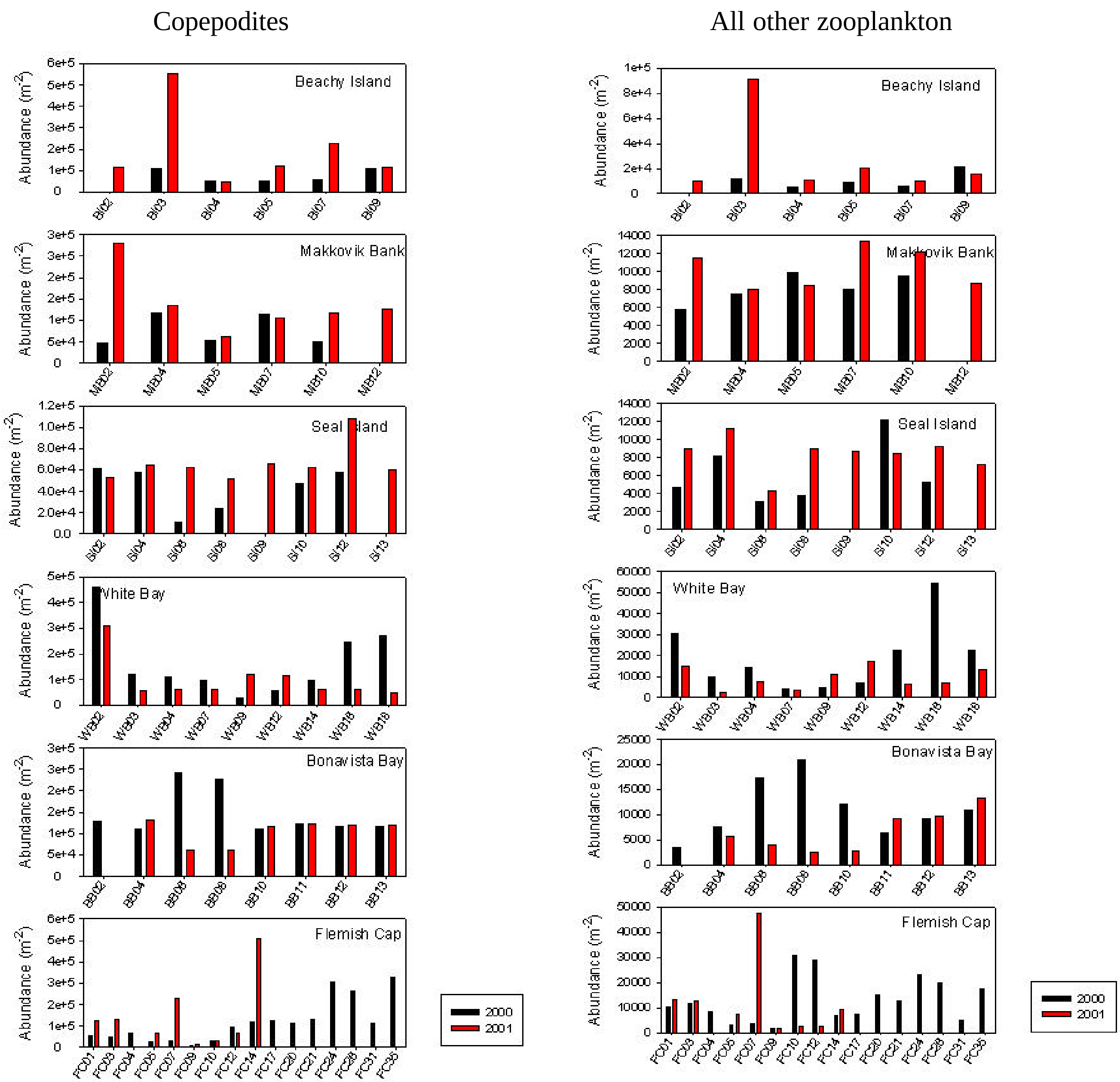

Figure 38. Combined abundance of all stages of *Calanus finmarchicus* copepodite observed along the three transects sampled during the research vessel surveys conducted in the spring of 2000 and 2001.

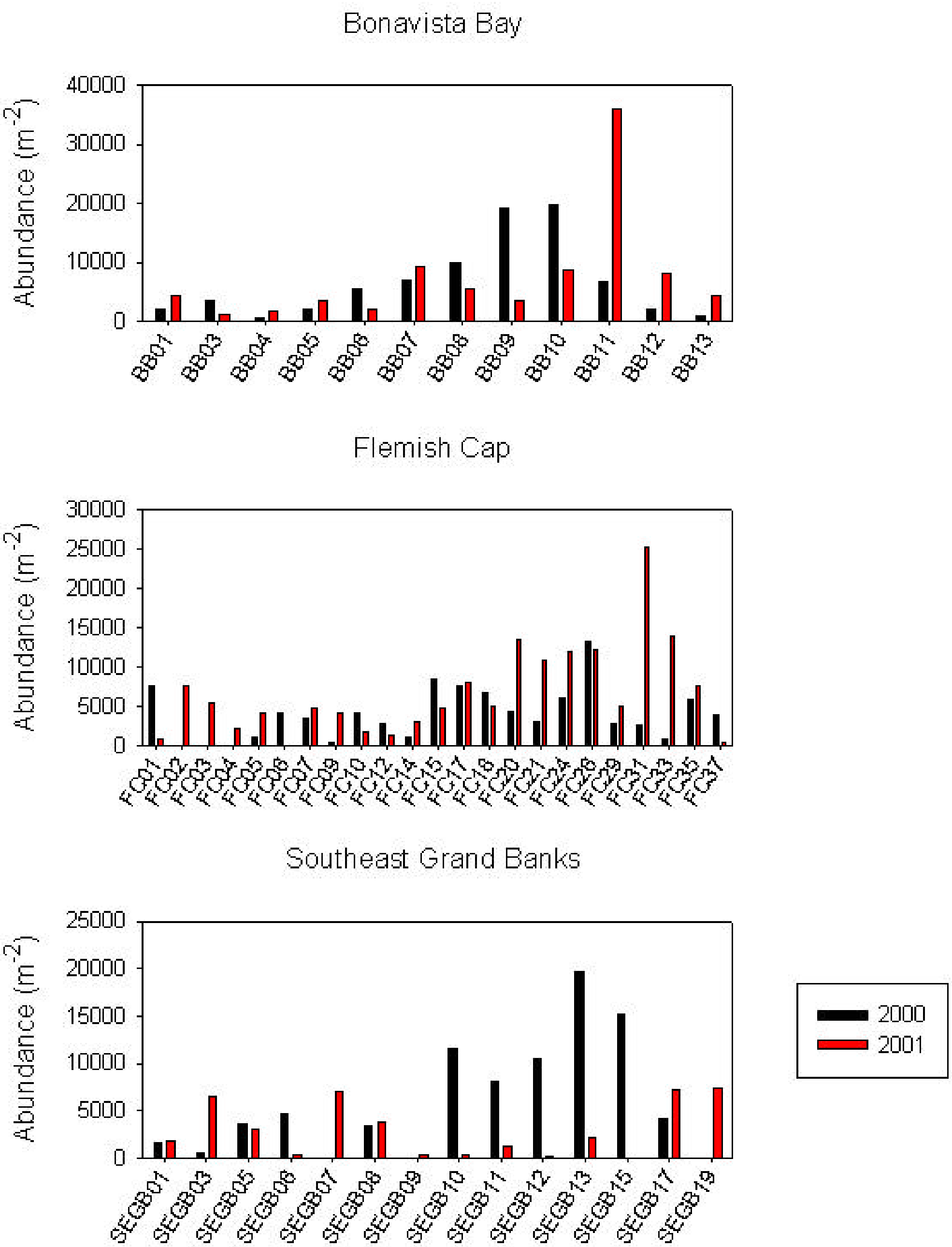

Figure 39. Relative stage composition of *Calanus finmarchicus* copepodites observed along the three transects sampled during the research vessel surveys conducted in the spring of 2000 and 2001.

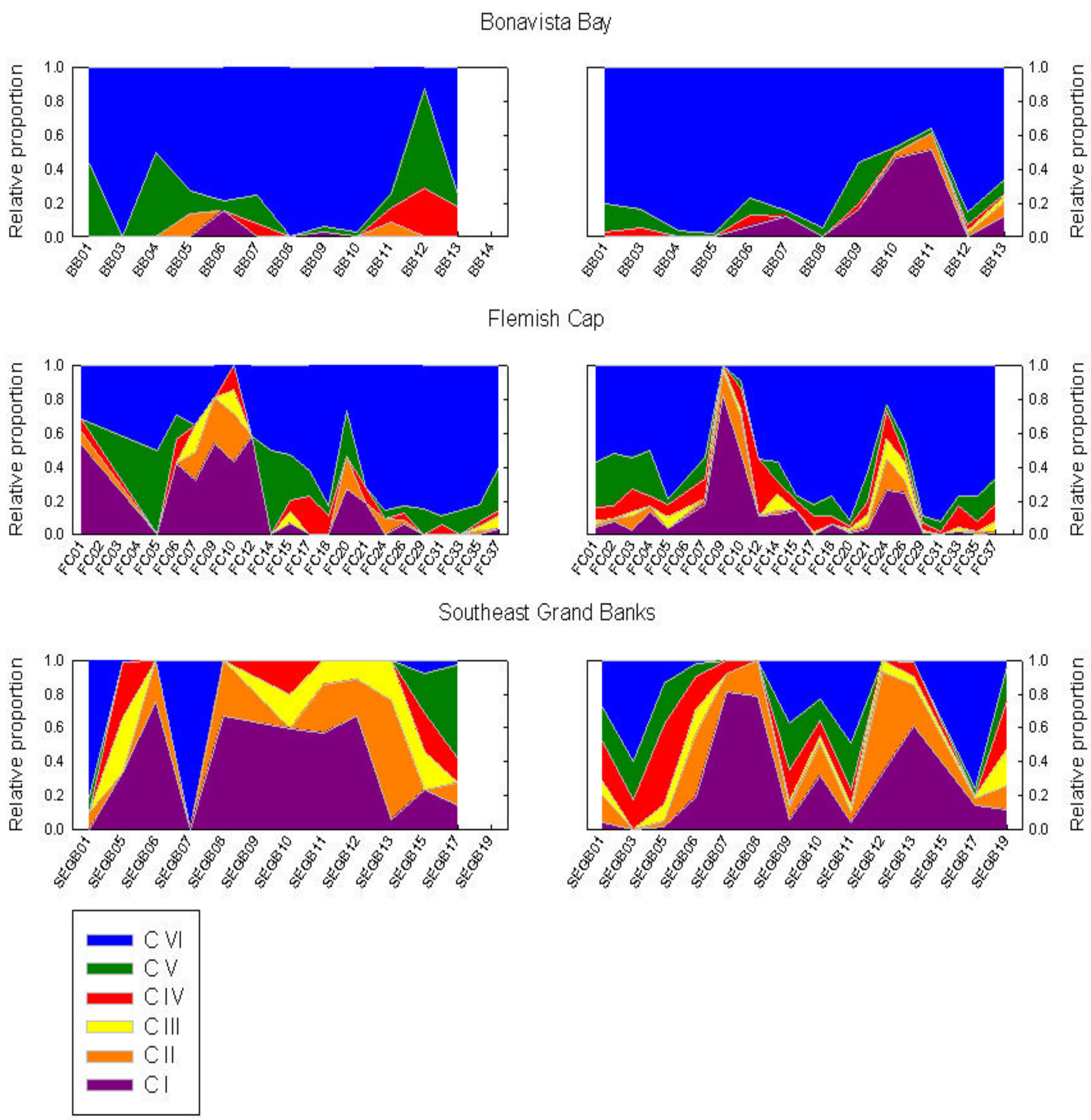

Figure 40. Combined abundance of all stages of *Calanus finmarchicus* copepodite observed along the six transects sampled during the research vessel surveys conducted in the summer of 2000 and 2001.

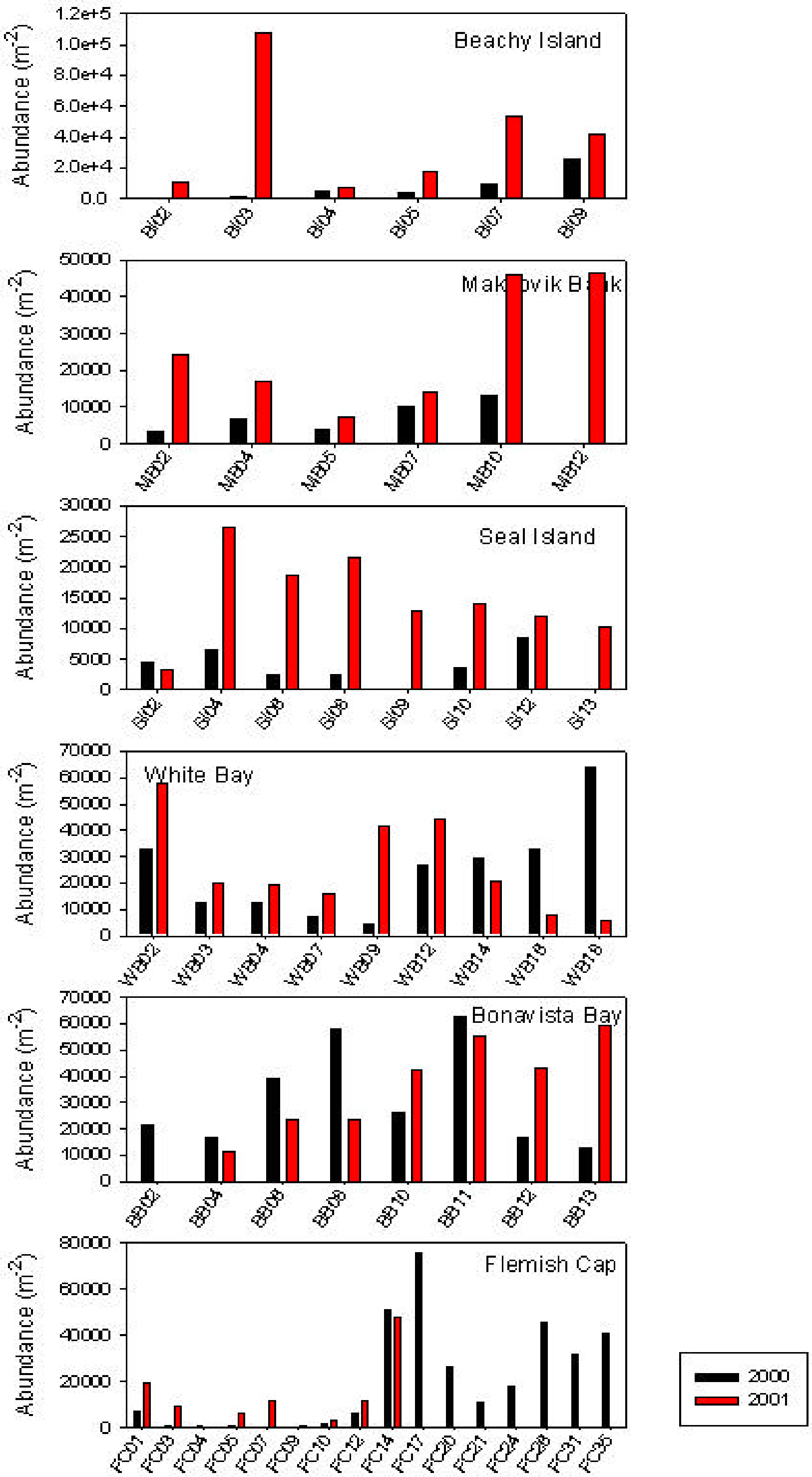

Figure 41. Relative stage composition of *Calanus finmarchicus* copepodites observed along the six transects sampled during the research vessel surveys conducted in the summer of 2000 and 2001. Stage legend as in Figure X12.

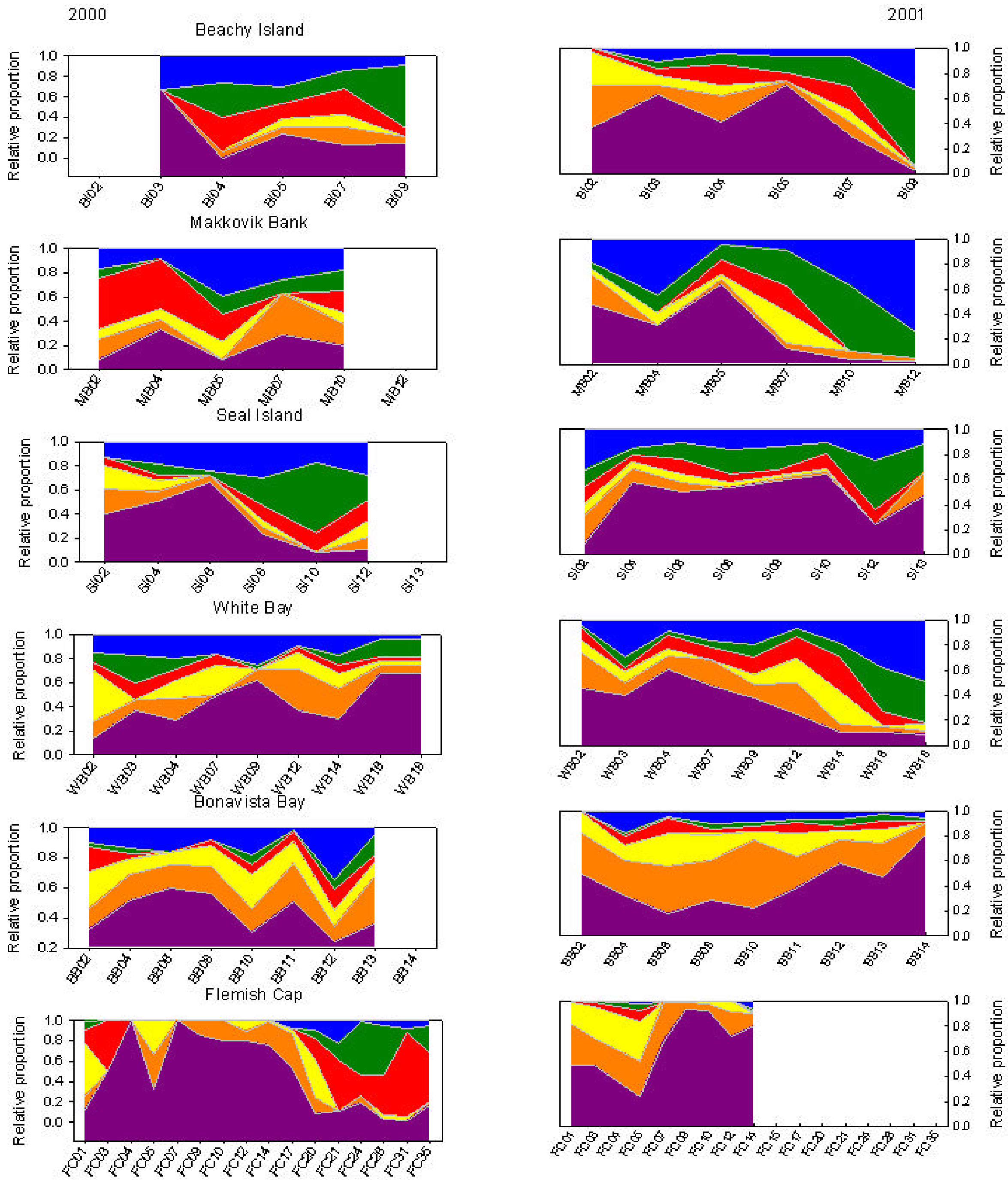

Figure 42. Combined abundance of large calanoid nauplii observed along the six transects sampled during the research vessel surveys conducted in the summer of 2000 and 2001.