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Biological and Chemical Oceanographic conditions on the Newfoundland and Labrador Shelf during 2005

Conditions océanographiques, biologiques et chimiques sur le plateau Terre-neuvien au cours de l'année 2005

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ABSTRACT

We review the information concerning the seasonal and inter-annual variations in the concentrations of chlorophyll a, major nutrients, as well as the abundance of major taxa of phytoplankton and zooplankton measured from Station 27 and along standard transects of the Atlantic Zone Monitoring Program (AZMP) in 2005.

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

RÉSUMÉ

Nous passons en revue les données des 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 2005.

La prolifération phytoplanctonique a eu lieu plus tôt en 2003, renversant la tendance d'apparition tardive amorcée en 2000, tout au moins dans la partie centrale du plateau de Terre-Neuve-et-Labrador. Les concentrations d'éléments nutritifs en profondeur à la station 27 sont demeurées inférieures à celles de 2000-2001, mais donnaient des signes de variation accrue vers la fin de 2004. Les concentrations en surface étaient supérieures à celles de 2003, vraisemblablement à cause d'une prolifération phytoplanctonique moins intense au printemps, attribuable à une couche mixte davantage en profondeur pendant l'hiver et à une stratification abrupte au printemps. L'abondance des taxons dominants de zooplancton à la station 27 et sur les Grands bancs a atteint son plus bas niveau depuis le début du PMZA. Par contre, l'abondance du zooplancton le long des transects de Bonavista et de l'île Seal était généralement près du maximum connu. Cette tendance était surtout forte pour *Calanus finmarchicus, C. glacialis* et *C. hyperboreus*, les trois espèces qui composent la plus grande proportion de la biomasse de zooplancton dans la région. Bien que les autres espèces aient semblé suivre la même tendance, celle-ci n'était pas statistiquement significative.

Introduction

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

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

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

Methods

We review optical, chemical, selected physical indices, and biological oceanographic conditions on the Newfoundland and Labrador Shelf during 2005. 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 2005 provided reasonable spatial and temporal series coverage of standard variables which provides a foundation for comparison with previous years. Collections and standard variables are based on sampling protocols outlined by the Steering Committee of the Atlantic Zonal Monitoring Program (AZMP) (Mitchell et al. 2002). Observations presented in this document are based on surveys listed in Table 1.

Analysis

Annual estimates of water column inventories of nutrients, chlorophyll, the mean abundance of key zooplankton species and some physical variables at both the fixed site and as an overall average along each of the four standard transects were based on general linear models (GLMs) of the form

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

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

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

for each of the transects and seasons, where δ takes into account the effect of station location. Density, either in terms of numbers or biomass, is log-transformed to deal with the skewed distribution of the observations. Physical variables, inventories of nutrients and chlorophyll were not transformed. To derive an estimate of the inter-annual variations based on all occupations of the transects, a full model which includes seasonal effect is applied

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

An estimate of the least-squares means is used as the measure of the overall year effect.

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

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

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

where B(z) is the concentration of chlorophyll *a* in mg m^{-3} (substitute calibrated chlorophyll *a* from *in-situ* chlorophyll *a* fluorescence when discrete measures were not available) at depth (z) in meters. The additional coefficients in this 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 seasonality in the attenuation coefficient at Station 27 in 2005 was greatly reduced compared to previous years (Figure 1). The peak in the attenuation coefficient that coincides with the timing of the spring bloom was substantially reduced in 2005. The duration of the peak in attenuance was also reduced but, background levels and the timing of the maximum were consistent with values observed in previous years. One must be cautious in interpreting this pattern in contrast to previous years because of an important gap in the occupation of Station 27 during the spring of 2005 as a result of the unavailability of ships.

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

Time series of physical measures estimated at Station 27 in 2005 included the stratification index (SI; difference in sigma-t values between 50m and 5m divided by 45m; see Craig *et al*. 2001, Craig and Colbourne 2002), mixed layer depth (MLD; depth centre of the pycnocline), and integrated temperature (IT; 0-50m integral) (Figure 2a). Seasonal development of upper water column stratification and the mixed-layer were generally consistent with previous years. Overall, higher background levels in the SI were apparent in 2005 (63 % increase) compared to previous years (2000-04). Mixed-layer depth was deeper (62 % increase) and more prolonged (70 % increase) during winter and spring but, was shallower throughout the summer and autumn periods in 2005 compared to previous years (Figure 2a). Although there were statistically significant inter-annual variations in seasonally-adjusted mean stratification, the overall pattern indicates that there has been limited variation in overall stratification in the last three years (Figure 3).

Seasonal development of the upper water column temperatures indicated consistent trends throughout 2000-05 (Figure 2b). The warming trend evident in the upper water column in previous years at Station 27 continued in 2005.

Fixed Station - Seasonal Variability in Phytoplankton and Nutrients

Vertical profiles of chlorophyll *a* at Station 27 continue to vary in terms of the magnitude and duration of the spring bloom (Figure 4). Near-surface chlorophyll *a* levels were unusually low throughout the spring bloom in 2005 in contrast to previous years (Figure 4a). We use the criteria of integrated chlorophyll *a* levels ~ 100 mg m^{-2} in upper 100m to define start and end times of the phytoplankton bloom. The initiation of the bloom in 2005 was detected in mid-April although we estimated the start of the primary production around early March based on the progression of the bloom in previous years and MODIS Satellite Colour Imagery[1]. The peak inventories of chlorophyll *a* of 300-400 mg m^{-2} and duration of 45-90 days observed in previous years was much less pronounced in 2005 at 174 mg m^{-2} and 19 days respectively (Figure 4b). There was evidence of small accumulations of phytoplankton biomass beyond the spring bloom in 2005 (i.e. short-term summer and autumn blooms), a pattern consistent with observations during earlier years.

The time series of integrated chlorophyll (0-50m and 0-100m) and fluorescence both show similar seasonal trends in overall values. There is an indication that there are significant concentrations of phytoplankton biomass below 50 m, probably as a result of the sinking of the spring phytoplankton bloom.

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

Although there are differences in the timing of the seasonal cycle among years, the GLM estimate of mean chlorophyll (0-100 m) and fluorescence do not show any statistically significant inter-annual variations. For both integrated chlorophyll and fluorescence, there are indications of a decreasing trend in annual means since 2002, with the lowest value of the time series occurring in 2005 (Figure 3).

The vertical distributions of the inorganic nutrients (nitrate, silicate, and phosphate) included in the observational program of the AZMP show strong seasonal covariation (Petrie et al. 1999). For this reason, and because the availability of nitrogen is hypothesized to be limiting to the growth of phytoplankton in the NW Atlantic, more emphasis in this report will be placed on variability in nitrate concentrations.

The vertical structure of nitrate (combined nitrate and nitrite, henceforth referred to as nitrate) shows dynamic seasonal changes in the water column at Station 27. Concentrations of nitrate were typically > 3 mmol m^{-3} throughout the water column and approached maxima of 10 mmol m^{-3} near the bottom prior to the spring bloom (Figure 5a). Subsequently, concentrations of nitrate began to decrease in the upper 50m to < 2 mmol m^{-3} and were depleted rapidly to values < 0.5 mmol m^{-3} in the upper 50m by early June. Nitrate concentrations remained very low (< 1-2 mmol m^{-3}) throughout the year in the upper water column until very late in the year when nutrient replenishment was observed. Deep water concentrations of nitrate shoaled during August-September as observed in previous years, coincident with the annual minima in water column salinity from ice-melt further north.

Time series of nutrient inventories at Station 27 showed differences between years (Figure 5b). Silicate and nitrate inventories in the upper 50m showed expected seasonal trends with winter and fall maxima, rapid depletion during the spring bloom, and occasional periodic intrusions during the late summer – early autumn (Figure 5b). Sources of these periodic nutrient intrusions may be related to shoaling of deep pools below the mixed layer, wind-induced mixing from passage of storms, and advective transport from the inshore branch of the Labrador Current. Both nutrient inventories showed coherence throughout much of the time series. Nutrient inventories in the deep layer for silicate and nitrate continue to show lower values consistent with the decline observed after 2000 (Figure 5b). The cause for the continued low levels in deep inventories of these major limiting nutrient inventories remains unknown, but may be linked to changes in productivity, water column structure, and influence of volume transport of the inshore branch of the Labrador Current. Mean annual nitrate and silicate inventories in the upper (0-50 m) water column showed statistically significant inter-annual variations since 2000 but there was little coherence between the two nutrients (Figure 3). The highest inventory of nitrate occurred in 2001 while the highest inventory of silicate occurred in 2003. Overall, nitrate inventories in the upper water column are generally lower than those of silicate. Mean annual nitrate and silicate inventories in the lower (50-150 m) water column also showed significant inter-annual variations since 2000 but in contrast to the upper water column, both nitrate and silicate show very similar trends. Since 2000, the deep water inventories of both nutrients have been decreasing at Station 27, with the lowest value being recorded in 2005. There has been relatively little change since 2003, but the seasonally-adjusted means show a continuing decrease with time. This may be having an impact on overall phytoplankton production because we have seen a gradual decrease in standing stock since 2002, but the high measurement error in phytoplankton abundance, whether in terms of chlorophyll or fluorescence, may limit our ability to detect inter-annual variations in production.

Oceanographic Sections - Seasonal Variability in Limiting Nutrients and Phytoplankton Biomass

The vertical distribution of nitrate and chlorophyll *a* have varied seasonally and spatially across the standard AZMP sections since the inception of the program. Vertical distributions of nitrate were mainly depleted (< 1 mmol m^{-3}) in the upper 50m along all sections during occupations in spring 2005 (Figure 6). Sub-surface and near-surface chlorophyll *a* concentrations were limited to the outer Shelf / Slope waters along the SE Grand Banks and Flemish Cap sections, in contrast to the near-shore and Shelf regions along the Bonavista section (Figure 6). The location of the offshore branch of the Labrador Current and slope water regions were characterized by elevated concentrations of nitrate along all sections, presumably being influenced by the North Atlantic Waters rich in inorganic nutrients and characterized by enhanced vertical mixing.

The summer occupations across the northeast Newfoundland and Labrador sections are typically characterized by further depletion of nitrate concentrations to < 1.0 mmol m^{-3} in the upper water column from levels observed during the spring occupations (Figure 7). There was evidence of depletion in nitrate concentrations, but this varied in the extent of depth by location of the section. The largest vertical extent in biological uptake of nitrate occurred along the Newfoundland Shelf sections (Flemish Cap, Bonavista, and White Bay sections) extending to depths of ca. 75m. The vertical extent of nitrate uptake was lower along the Labrador Shelf section. Shoaling of the nitracline is evident from the inshore to offshore areas over all sections, which is consistent with conditions observed in earlier years. The summer 2005 concentrations of chlorophyll *a* were comparable across the Newfoundland Grand Banks and Labrador Shelf sections to previous years. Evidence of episodic or localized phytoplankton blooms were observed along the Flemish Cap and Seal Island sections coincident with the location of the nitracline (Figure 7). MODIS satellite colour imagery confirmed low surface chlorophyll *a* levels across the Newfoundland and Labrador Shelf sections. Slope water regions were also characterized by elevated concentrations of nitrate along all sections during this time enhancing the vertical gradient in nutrient concentrations.

Limited enhancement of nitrate distributions were apparent along the SE Grand Banks and Flemish Cap sections, while being more pronounced on the Bonavista section, particularly in the outer Shelf and Slope waters during the autumn occupations (Figure 8). Despite the relatively low concentrations of nitrate in the upper water column, increased biological activity was evident in the outer Shelf along the SE Grand Banks and Flemish Cap sections, indicating the occurrence of a limited autumn phytoplankton bloom in these areas in 2005, similar to observations in previous years.

The generalized linear models generally show that within season, variables that describe the upper water column (stratification, chlorophyll, surface nitrate and silicate inventories) show significant inter-annual variations (Table 2). The only exceptions are the summer chlorophyll and nitrate inventories along the Bonavista Bay and Seal Island transects. Nitrate and silicate inventories in deeper layers (50-150 m) show less inter-annual variability, particularly in the fall, but there are significant inter-annual variations in deep water nutrient inventories in the spring (Table 2). Despite statistical significance, partly because of the overall accuracy of the surveys and consistent spatial patterns in the distribution of water masses, there are no consistent overall trends in either surface or deep water inventories among the four oceanographic transects (Figure 9). One must be particularly careful in the interpretation of inter-annual variations in chlorophyll and nutrient inventories from the spring surveys because differences in the timing of the cruises relative to that of the biological production cycle can lead to aliasing. The rise (2000-2003) and fall (2004-2005) in spring chlorophyll concentrations along the Southeast Grand Banks, Flemish Cap and Bonavista Bay transects (and vice versa for surface inventories of nitrate and silicate) indicate that timing of the spring phytoplankton bloom, relative to the timing of our surveys, moved from an early to a later and back to an earlier date during the six year period. The median date of the surveys varied by 10 days, with 2004 being the earliest (days 107-122) and 2005 being the latest (days 120-129): from 2001-2004 the median date of the survey varied by only three days.

Fixed Station - Zooplankton

There was relatively limited seasonality in the overall abundance of both *Calanus finmarchicus* and *Pseudocalanus* spp. at Station 27 in 2005, although the seasonal progression of stages was similar to previous years (Figure 10). The seasonal cycle of other copepod species was similar to observations from previous years (Figure 11). Larvaceans appear to show two peaks in abundance, one following the spring phytoplankton bloom, and another in the fall while the pattern of seasonality for pelagic gastropods and euphausiids is less clear (Figure 11). A generalized linear model which included the effects of year and month, as categorical variables, was used to estimate inter-annual variations in the overall abundance of the 12 dominant zooplankton taxa present at Station 27. Analytical results indicated that all species demonstrate a statistically significant seasonal cycle of abundance based on type III sums of squares (i.e the sums of squares obtained by fitting each effect after all the other terms in the model). However, only four of the twelve species showed significant inter-annual variations in overall abundance (*C. glaicialis*, *Metridia* spp., *Pseudocalanus* spp., *Temora longicornis*) (Figure 12). The abundance of all species of *Calanus* (f*inmarchicus, glacialis, hyperboreus*), *Metridia* spp., euphausiids and larvaceans were at or near the lowest value recorded since 1999 while the abundance of large calanoid nauplii was high. These species all showed a decreasing trend in abundance which started in 2003 or earlier. The generalized linear model which included year and month effects explained 37% to 91% of the overall variance in log-transformed abundance of the zooplankton taxa (mean 61%). Over the 1999-2005 observation period, most taxa exhibited approximately a 3-fold variation in abundance in average annual abundance.

The seasonal pattern in the relative distribution of copepod biomass among the eight dominant species at this site was not strongly different in 2005 from the pattern in previous years (Figure 13). It is notable that the relative contribution of *Oithona* spp. and *Pseudocalanus* spp. during the winter of 2005 was higher than previously observed. However, throughout most of the year, the copepod biomass at Station 27 was dominated by *C. finmarchicus* or one of its sister species. There was significant inter-annual variation in total copepod biomass at Station 27 (FIII[17,203] = 2.99, $p < 0.01$), with biomass in 2002 being significantly greater than levels observed in other years (Figure 14)

Oceanographic Sections - Zooplankton

The seasonally-adjusted mean abundance of the dominant copepod species showed important north-to-south differences in the significance of inter-annual variations. Along the southeast Grand Banks transect, which is surveyed only in the spring and fall, only large calanoid nauplii exhibited statistically significant inter-annual variations, with 2000 and 2005 showing high abundances while 2001-04 were generally lower (Figure 15). The remaining six taxa (*C. finmarchicus, C. glacialis, C. hyperboereus, Metridia* spp., *Oithona* spp., and *Pseudocalanus* spp. showed fluctuations in abundance that were not statistically different among years.

The abundance of copepods along the Flemish Cap transect showed a little more variability than on the southeast Grand Banks. *Calanus finmarchicus*, *C. glacialis, Pseudocalanus* spp. and large calanoid nauplii showed significant inter-annual variations in abundance. For these four taxa, the abundance in 2005 was at or near the highest levels recorded since 2000. In the case of large calanoid nauplii, the abundance in 2005 was three times higher than in 2004 while the abundance of *C. finmarchicus* in 2005 was three times higher than in 2000 (Figure 15).

Our observations from the Bonavista Bay transect, which is sampled three times per year, showed that five of the 7 dominant copepod taxa exhibited statistically significant inter-annual variations in abundance based on the GLM (Figure 15). Only in the case *C. glacialis* and large calanoid nauplii were inter-annual variations in abundance not statistically resolvable. However, in all taxa, with the exception of *Metridia* spp., the abundance in 2005 was at (or very near) the highest levels recorded since the inception of the AZMP. The abundance of *Metridia* spp. along the Bonavista transect has been decreasing since 2003.

Copepod abundance along the Seal Island transect, which is sampled only in July, was at (*Metridia* spp.) or near (*C. finmarchicus, C. glacialis, C. hyperboreus,* calanoid nauplii, *Oithona* spp, *Pseudocalanus* spp.) the highest levels recorded since the inception of AZMP (Figure 15). In all taxa, abundances showed statistically significant inter-annual variations. Most species showed a slight decline from abundances recorded in 2004 (or 2003 for *C. hyperboreus*) but in most instances the decrease was not statistically significant. In the case of *C. finmarchicus*, the abundance in 2005 was nearly 19 times higher than the lowest levels recorded in 2000. Most other species showed a 4 to 9-fold variation in overall abundance. Along all other transects, the overall variation in the seasonally-adjusted mean abundance for individual species is of the order of 1.5 to 3-fold between maximum and minimum densities.

We did not detect any substantial variations in the spatial distribution of either abundance or biomass during either the spring (Figure 16) or summer (Figure 17) surveys. Sorting of zooplankton samples from the fall survey was incomplete at the time of the meeting. There were subtle variations, but the general patterns of distribution in 2005 were similar to the average for 2000-2004. In most instances for 2005, the seasonal patterns in abundance along each transect was similar to that observed in previous years (results not shown).

Variations in abundance tended to be more substantial (i.e. significant) than variations in estimated biomass (Table 3). In 4 of the 17 species/transect combinations that showed statistically significant inter-annual variations in abundance, inter-annual variations in biomass were not significant, while the opposite was true in only 1 of 14 cases.

Discussion

Overall, the seasonality of chemical and biological variables at Station 27 and along the major AZMP sections in 2005 was similar to previous years (1999-2004). 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.

There were a few notable trends in the observations from Station 27 and the oceanographic transects. At Station 27, the integrated seasonally-adjusted chlorophyll inventory along with many zooplankton species (*C. finmarchicus, C.*

glacialis, C. hyperboreus, Metridia spp., *Oithona* spp., euphausiids and larvaceans) were are their lowest levels since the start of AZMP. Few of these trends were statistically significant, largely as a result of the considerable sampling variability. Also, the deep (0-150 m) inventories of nitrate and silicate remained low relative to that observed in 2000. However, the trends observed at Station 27 were in marked contrast with those observed along the oceanographic transects. With the exception of the decline in the seasonally-adjusted deep (50-150 m) silicate inventory along the Flemish Cap transect, none of the standard oceanographic variables (integrated chlorophyll, surface and deep nitrate and silicate inventories) showed significant trends during the period 2000-2005. Values in 2005 were generally near the overall mean since the inception of AZMP. In addition, most of the seven major copepod taxa along the Flemish Cap, Bonvasita Bay and Seal Island transects were either at or near their maximum seasonally-adjusted means, in contrast to the patterns at Station 27. Zooplankton abundance along the Southeast Grand Banks showed few clear trends, and none were statistically significant.

Discrepancies between the patterns of seasonally-adjusted means for oceanographic variables and major zooplankton taxa between Station 27 and the oceanographic transects is in marked contrast with the relatively large decorrelation scales found in temperature and salinity (Ouellet et al. 2003). One possible explanation is that the decorrelation scale is relatively small (10s of kms) for chemical and biological variables collected by the AZMP because local coastal processes are highly dynamic in contrast to broad oceanographic bio-physical interactions that govern the patterns of abundance further on the shelf. An analysis of the correlation between observations at Station 27 and transect stations taken during oceanographic surveys shows that the average correlation, based on the seven dominant copepod taxa, is highest for the nearshore stations along the Bonavista Bay and Flemish Cap transects, after which it drops rapidly as one moves offshore (Figure 18). There is no correlation with conditions at the deep water offshore stations, and a nearly inverse relationship with conditions along the Seal Island transect. The high concentration of copepods in offshore waters may therefore have a strong influence on the mean abundance estimated from the GLM analysis.

Aliasing of sampling and the onset of the spring phytoplankton bloom are likely to prevent an estimation of the annual mean phytoplankton standing stock from the oceanographic surveys. Estimates of annual mean phytoplankton standing stock or surface nutrient inventories along oceanographic transects based on GLM analysis are highly influenced by the magnitude of the spring phytoplankton bloom observed during our surveys. However, attempts to derive average annual values were strongly influenced by the stage of the spring phytoplankton bloom, as determined from the relative abundance of nutrients and phytoplankton. In some years (e.g., 2003), phytoplankton standing stock was low during the spring oceanographic surveys whereas the surface nitrate inventory was high, while the opposite was true in 2000. The two-week composite estimates of surface chlorophyll do assist in the interpretation of these patterns but a more temporally-resolved estimate of the seasonal variations in surface chlorophyll throughout the entire Atlantic Zone would assist in determining the degree of inter-annual variation in both the magnitude and duration of the spring phytoplankton bloom. Combining the data from the oceanographic surveys with satellite observations could enable us to obtain a three-dimensional view of the progression of phytoplankton dynamics throughout the Zone and thus provide a more accurate estimate of changes in standing stock.

The most notable advance in 2004 was in our ability to provide quantitative analysis of inter-annual differences in the abundance of dominant zooplankton taxa at Station 27 and along the key oceanographic transects (Pepin et al. 2005). The analytical approach is somewhat simplistic and does not take into consideration of major shifts in the spatial distribution of species (this appears as part of the error). However, the approach has revealed significant inter-annual variations in the abundance of zooplankton on the Shelf. The approach based on general linear models to determine the inter-annual variations in abundance of taxa from AZMP collections did raise some questions about the programs overall ability to accurately monitor zooplankton abundance and species composition. Data from Station 27 revealed that only 12 taxa were sufficiently abundant and frequent to allow appropriate inter-annual comparison in abundance patterns, which included copepods, gastropods, larvaceans and euphausiids. In contrast, only 7 to 8 species of copepods were sufficiently abundant and frequent on the shelf to allow effective and reliable intercomparison throughout the AZMP implementation period. Other groups, such as bivalves, gastropods, euphausiids and larvaceans were highly patchy in their distribution, making statistical intercomparisons unfeasible at this time. Longer time species of observations may be required before we can detect significant inter-annual variations in abundance based on the AZMP survey design and collection methods. We did investigate the potential to simply contrast seasonal and inter-annual variations in abundance without taking into consideration the spatial distribution of each species. This did allow a greater number of species to be included in the analysis but the complexity of the results requires further investigation at this time before we feel that we can comment on the overall trends.

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Table 1. Listing of AZMP Sampling Missions in the Newfoundland and Labrador Region in 2005. The transects are Southeast Grand Banks (SEGB); Flemish Cap (FC); Smith Sound (SS), Trinity Bay (TB), Bonavista Bay (BB); Funk Island (FI); White Bay (WB); Seal Island (SI), and the fixed station (Station 27). 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
TEL601	Apr 30-May 9, 2005	SEGB, FC, BB	78	35
WT624	Jul 17-Aug 3, 2005	FC, BB, WB, SI, TB, SS	165	57
Hud656	Nov 28-Dec 12, 2005	SEGB, FC, BB, TB, SS	122	53
Fixed	Jan-Dec 2005	Station 27	49	20

Table 2. Seasonal significance levels of the year effect for the stratification index, and inventories of chlorophyll (0-100 m), nitrate and silicate (0-50 m and 50-150 m) based on the results of the generalized linear model that included year and station identifier as categorical variables. ns – not significant

Stratification	Spring	Summer	Fall
Southeast Grand Banks	0.001		0.001
Flemish Cap	0.001	0.001	0.001
Bonavista Bay	0.01	0.001	0.01
Seal Island		0.05	

Chlorophyll (0-100 m)			
Southeast Grand Banks	ns		0.001
Flemish Cap	0.05	0.001	0.001
Bonavista Bay	0.001	ns	0.001
Seal Island		ns	

Surface Nitrate (0-50 m)			
Southeast Grand Banks	0.001		ns
Flemish Cap	0.001	0.05	0.05
Bonavista Bay	0.001	ns	0.001
Seal Island		ns	

Deep Nitrate (50-150 m)			
Southeast Grand Banks	0.01		ns
Flemish Cap	0.001	0.001	ns
Bonavista Bay	ns	0.05	ns
Seal Island		ns	

Surface Silicate (0-50 m)			
Southeast Grand Banks	0.001		0.01
Flemish Cap	0.001	0.001	0.001
Bonavista Bay	0.001	0.05	0.001
Seal Island		0.05	

Deep Silicate (50-150 m)			
Southeast Grand Banks	0.01		ns
Flemish Cap	0.01	ns	0.01
Bonavista Bay	0.001	ns	ns
Seal Island		ns	

Table 3. *P*-values of inter-annual variations in abundance and biomass of seven dominant copepod species collected along the four oceanographic transects in the Newfoundland-Labrador region of DFO (SEGB – Southeast Grand Banks; FC – Flemish Cap; BB – Bonavista Bay; SI – Seal Island. P-values are estimated from from the type III sums of squares from a generalized linear model that include year, season, and station identifier as categorical variables.

Abundance				
	SEGB	FC	BB	SI
Calanus finmarchicus	0.5315	0.0016	0.006	0.0001
Calanus glacialis	0.5916	0.04	0.4413	0.002
Calanus hyperboreus	0.7511	0.0563	0.0034	0.051
Calanoid nauplii	0.0001	0.0042	0.4502	0.0004
Metridia spp.	0.4676	0.7832	0.0003	0.0043
Oithona spp.	0.2491	0.1051	0.0003	0.0001
Pseudocalanus spp.	0.5811	0.0001	0.0182	0.0001

Biomass				
	SEGB	FC	BB	SI
Calanus finmarchicus	0.0431	0.028	0.0017	0.0001
Calanus glacialis	0.2049	0.235	0.0981	0.038
Calanus hyperboreus	0.6769	0.1553	0.2667	0.2372
Calanoid nauplii	0.0001	0.0042	0.4502	0.0004
Metridia spp.	0.2447	0.0605	0.0007	0.4658
Oithona spp.	0.2491	0.1051	0.0003	0.0001
Pseudocalanus spp.	0.921	0.0001	0.0015	0.0002

Figure 1. Time series of the attenuation coefficient at Station 27 showing vertical attenuation coefficient K_d_Chl*a*.

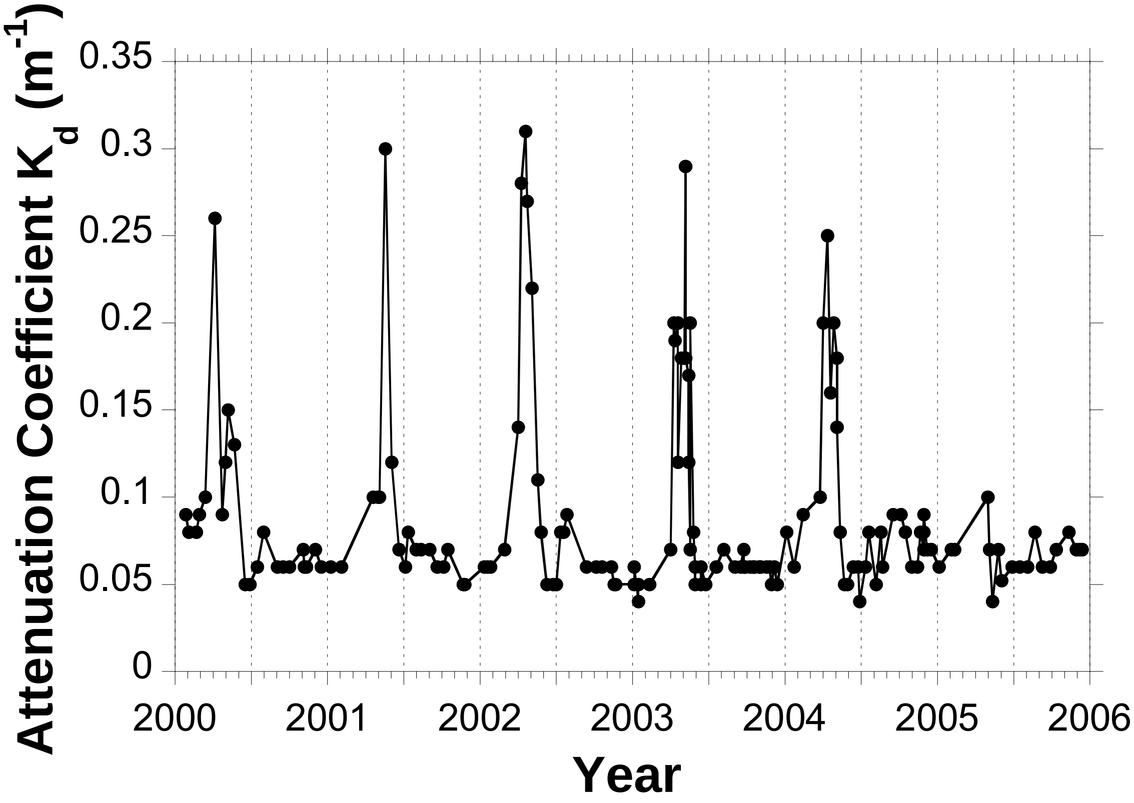


Figure 2. Time series of physical measures at Station 27 during 2000-05 showing stratification index (sigma-t$_{50m}$ – sigma-t$_{5m}$ /45m); mixed layer depth (taken as the depth centre of the pycnocline, upper panel); and integrated temperature in the upper 50m using the trapezoidal method (lower panel).

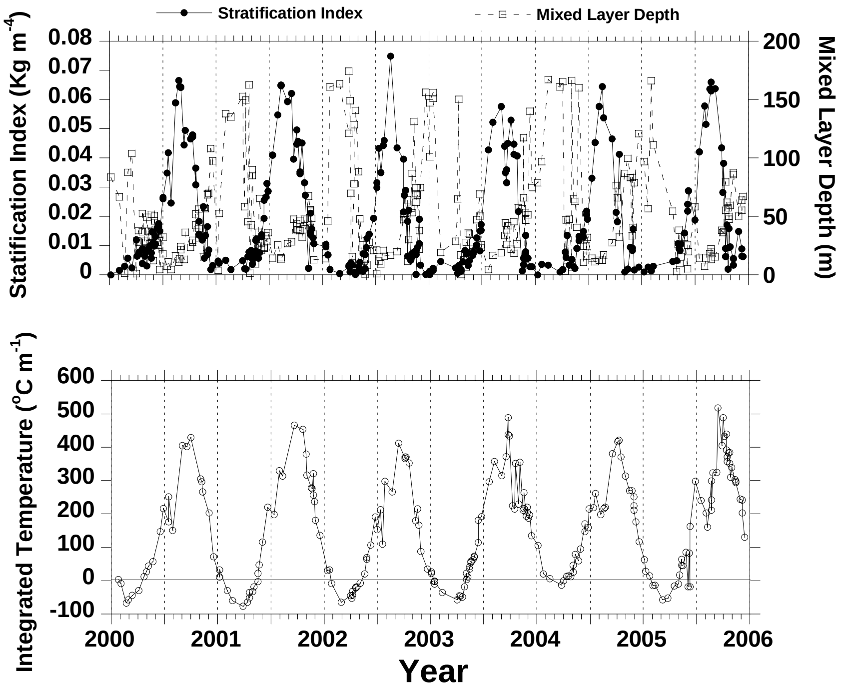


Figure 3. Seasonally-adjusted mean estimates of the attenuation coefficient, integrated temperature (0-50 m), chlorophyll (0-100 m), fluorescence (0-100 m), silicate and nitrate (0-50 m and 50-150 m), and stratification index for Station 27 for the period 2000-2005. Significance levels are in the upper right-hand corner.

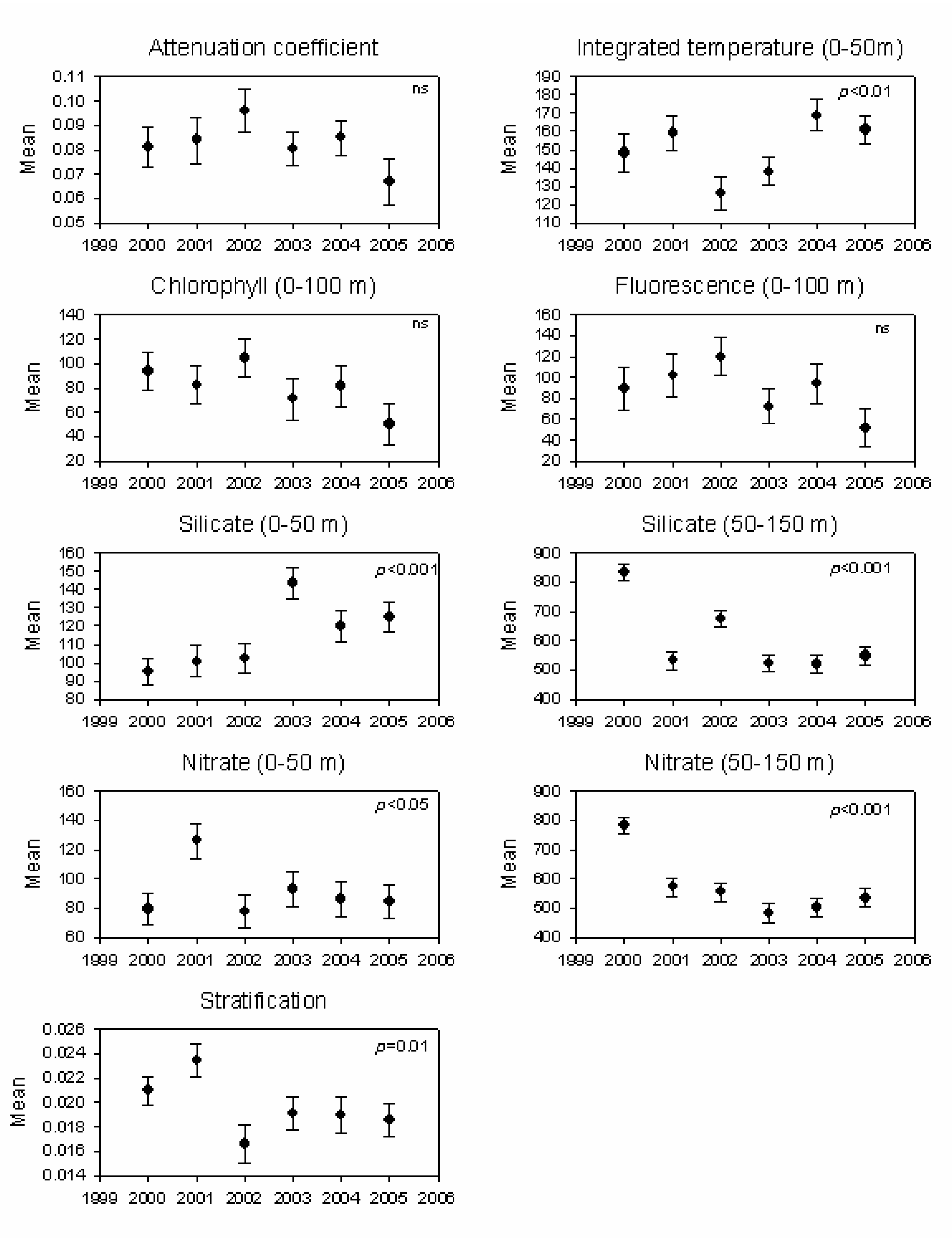


Figure 4. Time series of vertical chlorophyll *a* structure (top panel) and phytoplankton biomass index (0-100m integral of chlorophyll *a*) at Station 27, 2000-05.

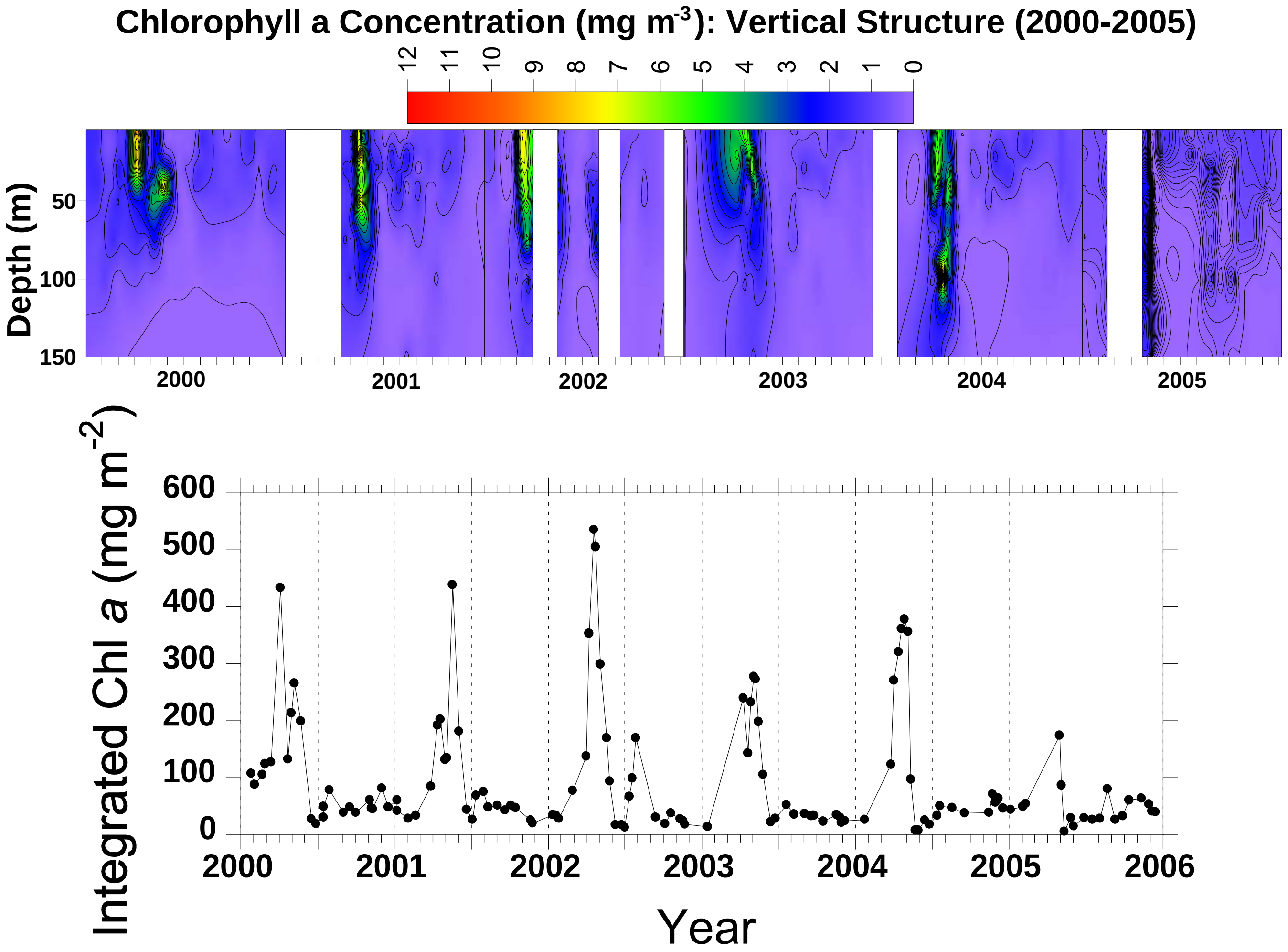


Figure 5. Time series of vertical nitrate (combined nitrate and nitrite) structure (top panel) and nutrient inventories (bottom panels) from upper (0-50m integral) and lower (50-150m integral) at Station 27, 2000-05.

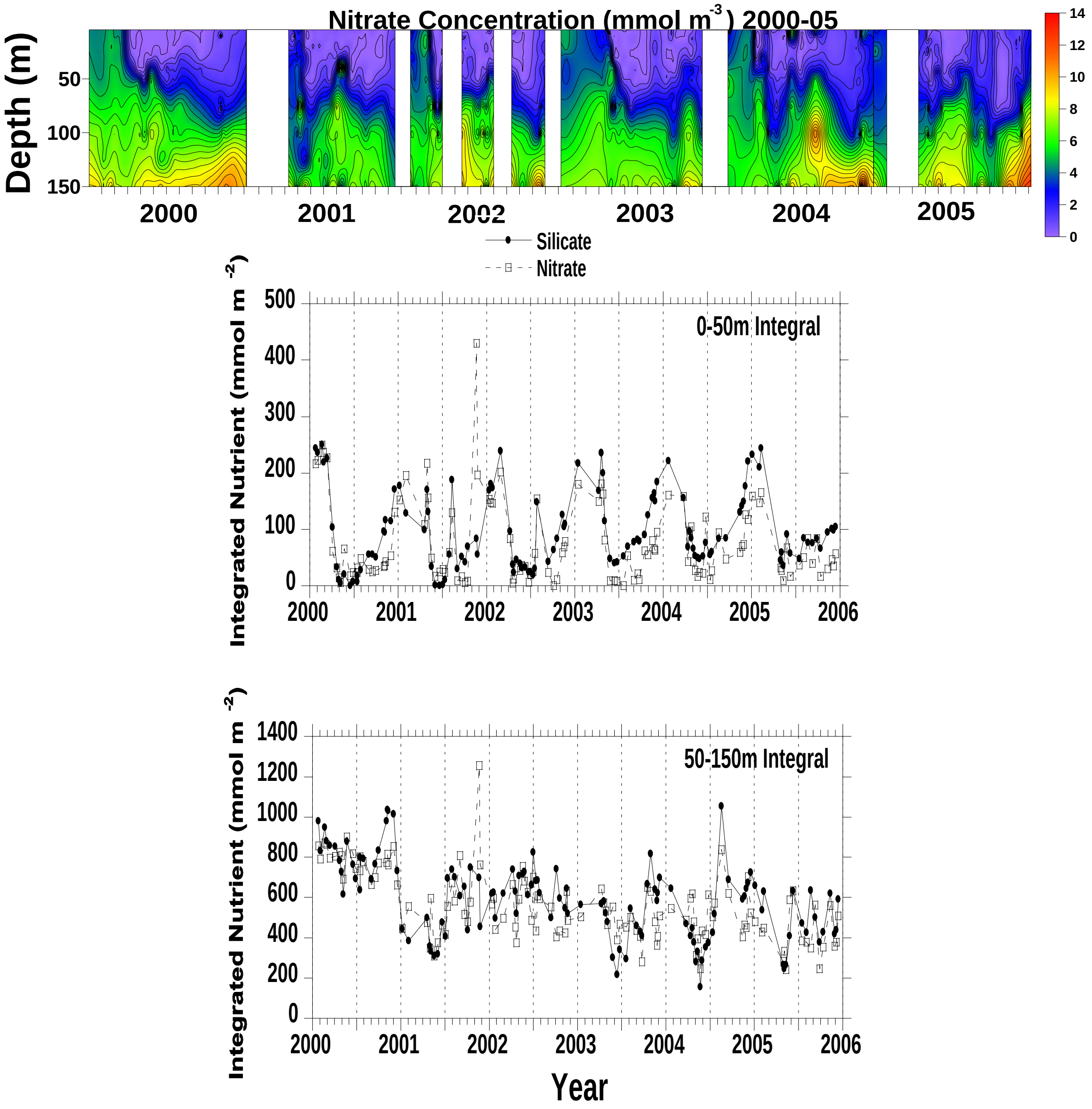


Figure 6. Vertical nitrate and chlorophyll *a* structure along the Newfoundland Shelf sections during the spring survey in 2005.

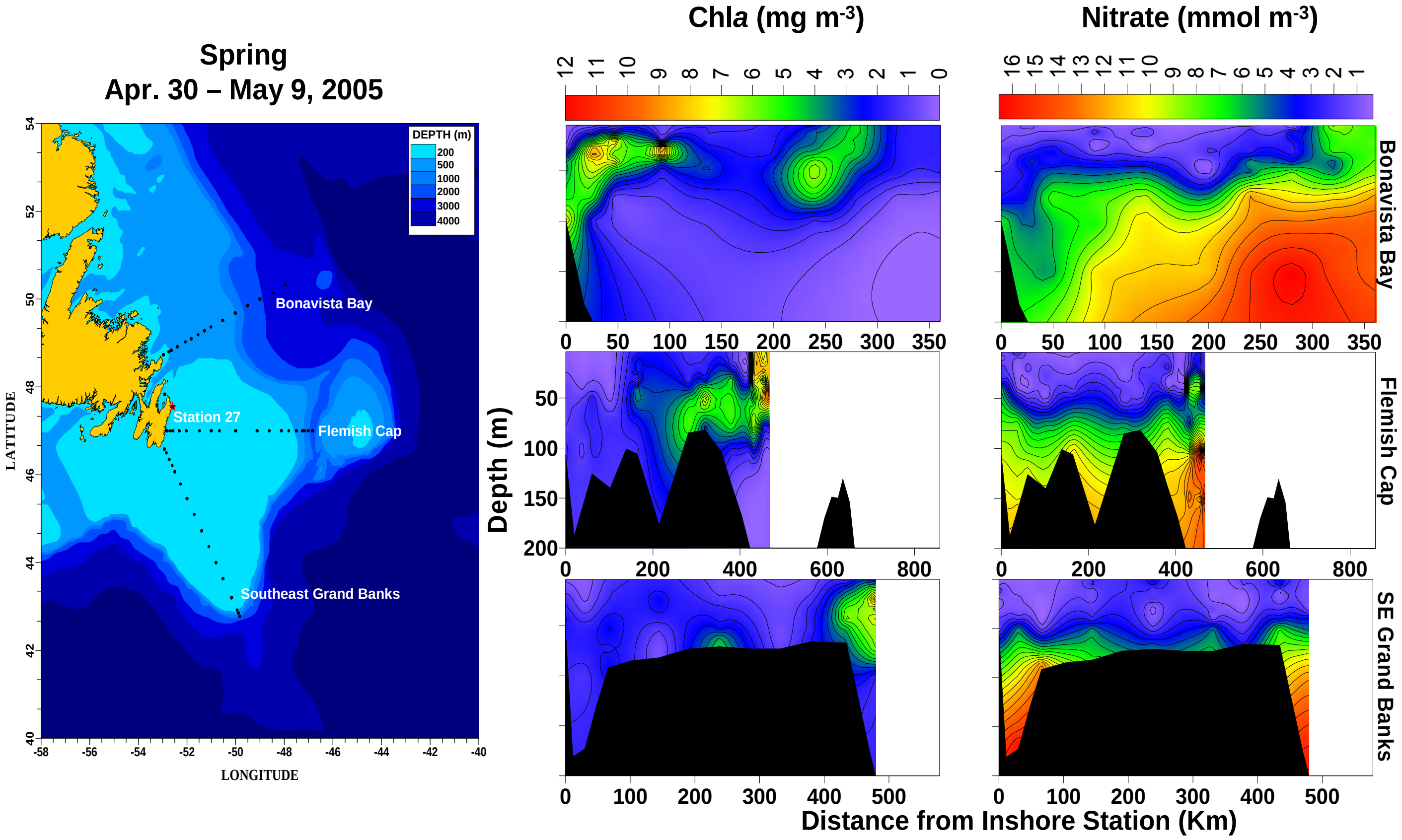


Figure 7. Vertical nitrate and chlorophyll a structure along the Newfoundland and Labrador Shelf sections during the summer survey in 2005.

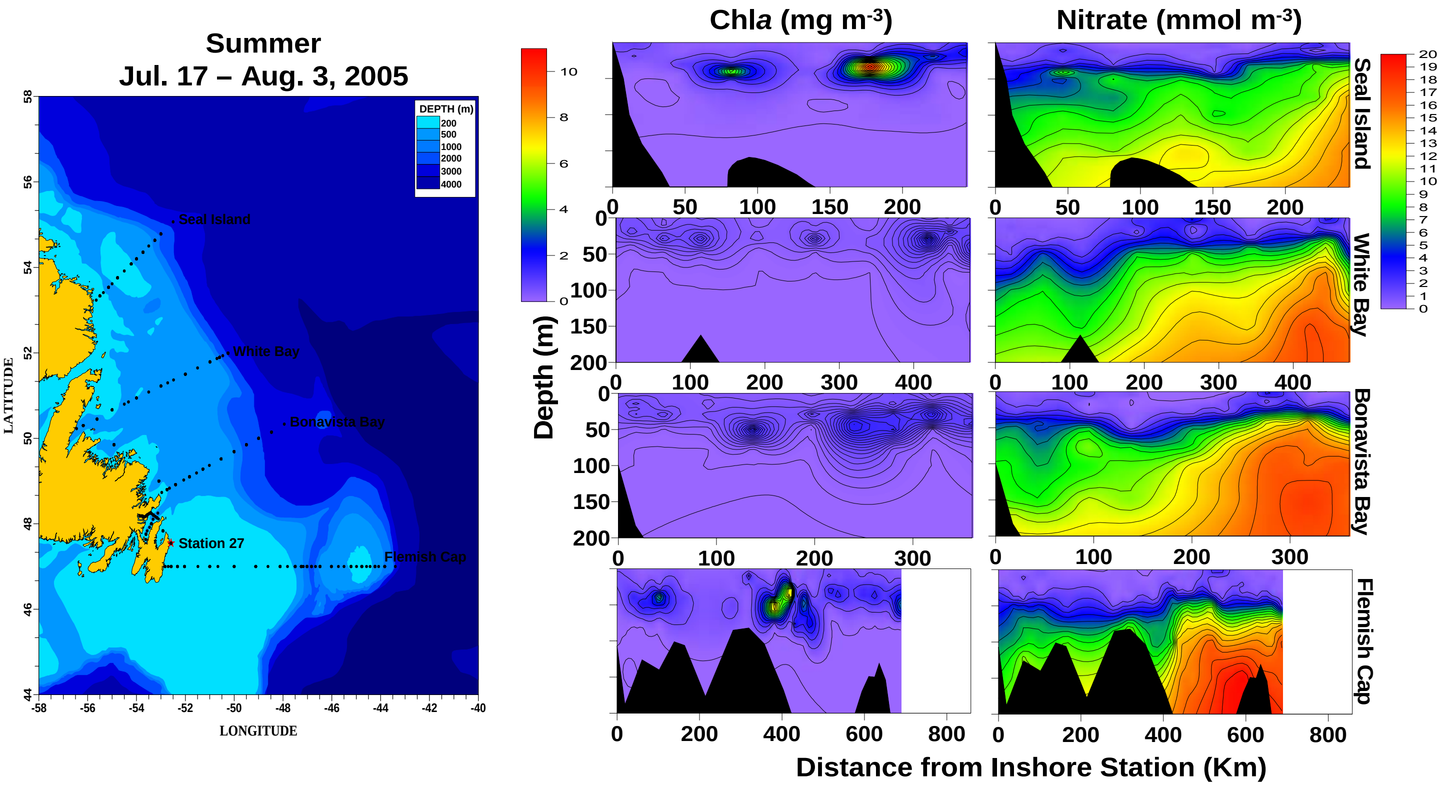


Figure 8. Vertical nitrate and chlorophyll *a* structure along the Newfoundland Shelf sections during the autumn survey in 2005.

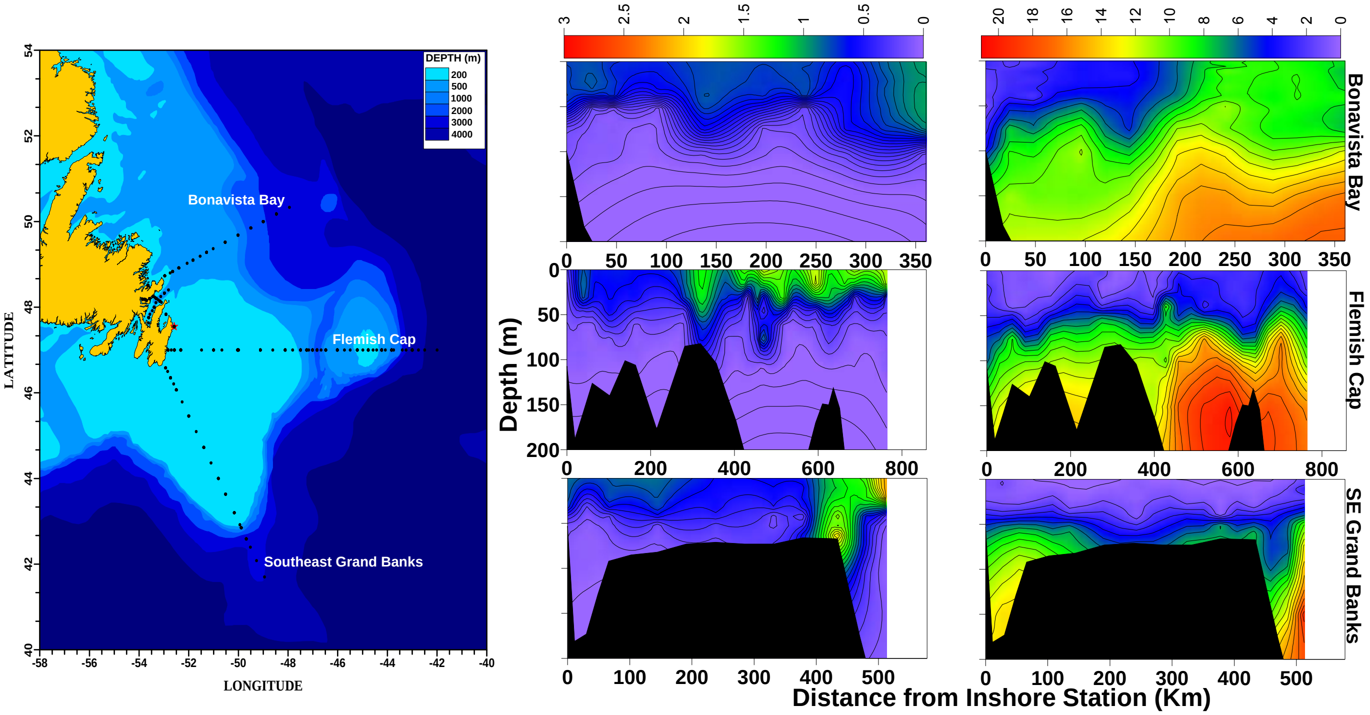


Figure 9. Seasonal mean stratification index, and integrated chlorophyll (0-100 m) and nitrate and silicate (0-50 m and 50-150 m) for the four oceanographic transects. Seasonal transect means are based on the results of a generalized linear model that includes year and station identifier as categorical variables. Note that the Southern Grand Banks transect is only surveyed in the spring and fall and the Seal Island transect is only surveyed during the summer. Flemish Cap and Bonavista Bay transects are surveyed in the spring, summer and fall.

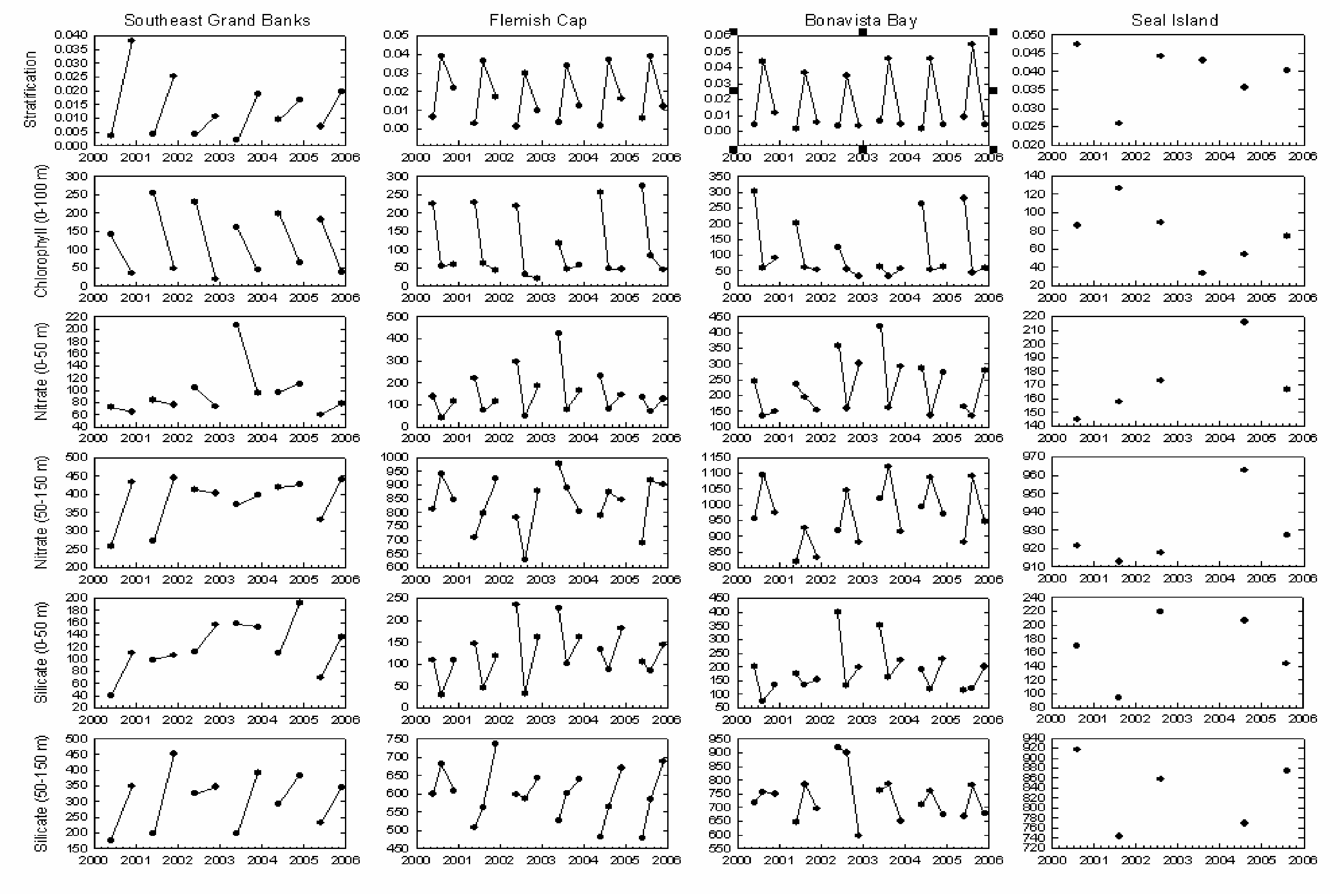


Figure 10. Seasonal cycle of abundance and stage distribution of *Calanus finmarchicus* and *Pseudocalanus* spp. at Station 27 for the period 1999-2005. (Stage CI (blue), CII (teal), CIII (green), CIV (yellow), CV (orange), CVI (brown)).

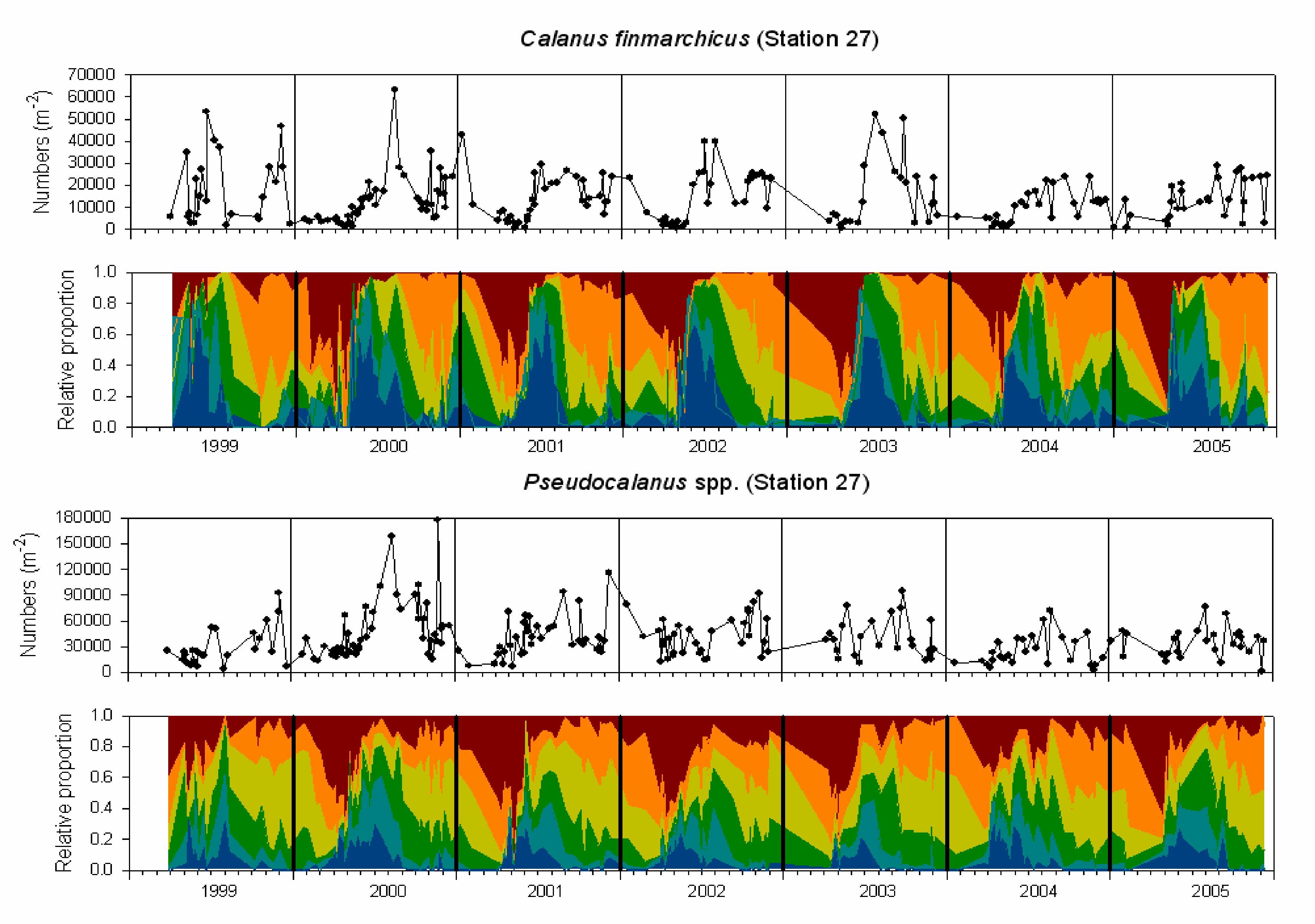


Figure 11. Seasonal cycle of abundance of ten dominant zooplankton taxa from Station 27 for the period 1999-2005.

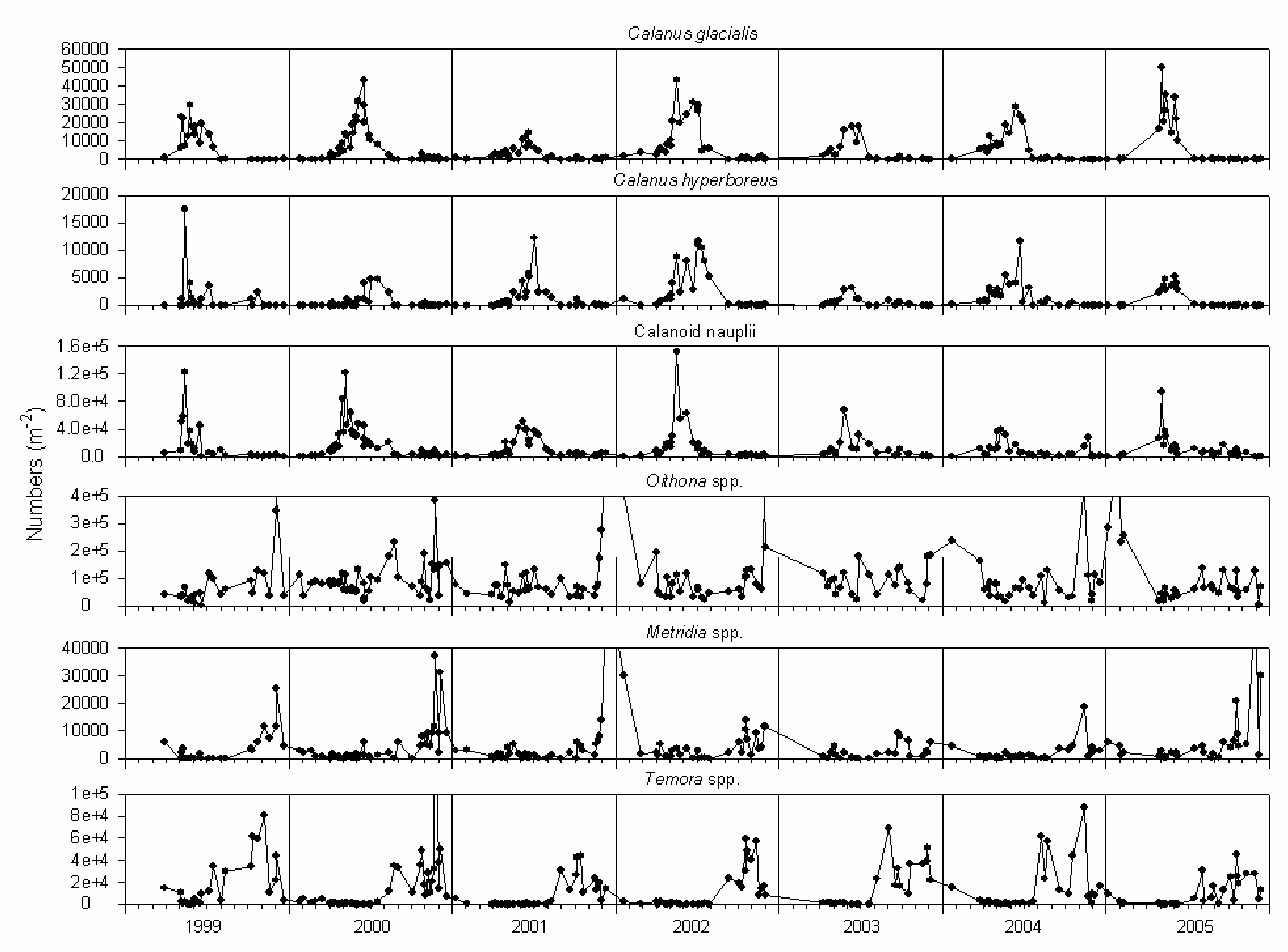


Figure 11. Continued.

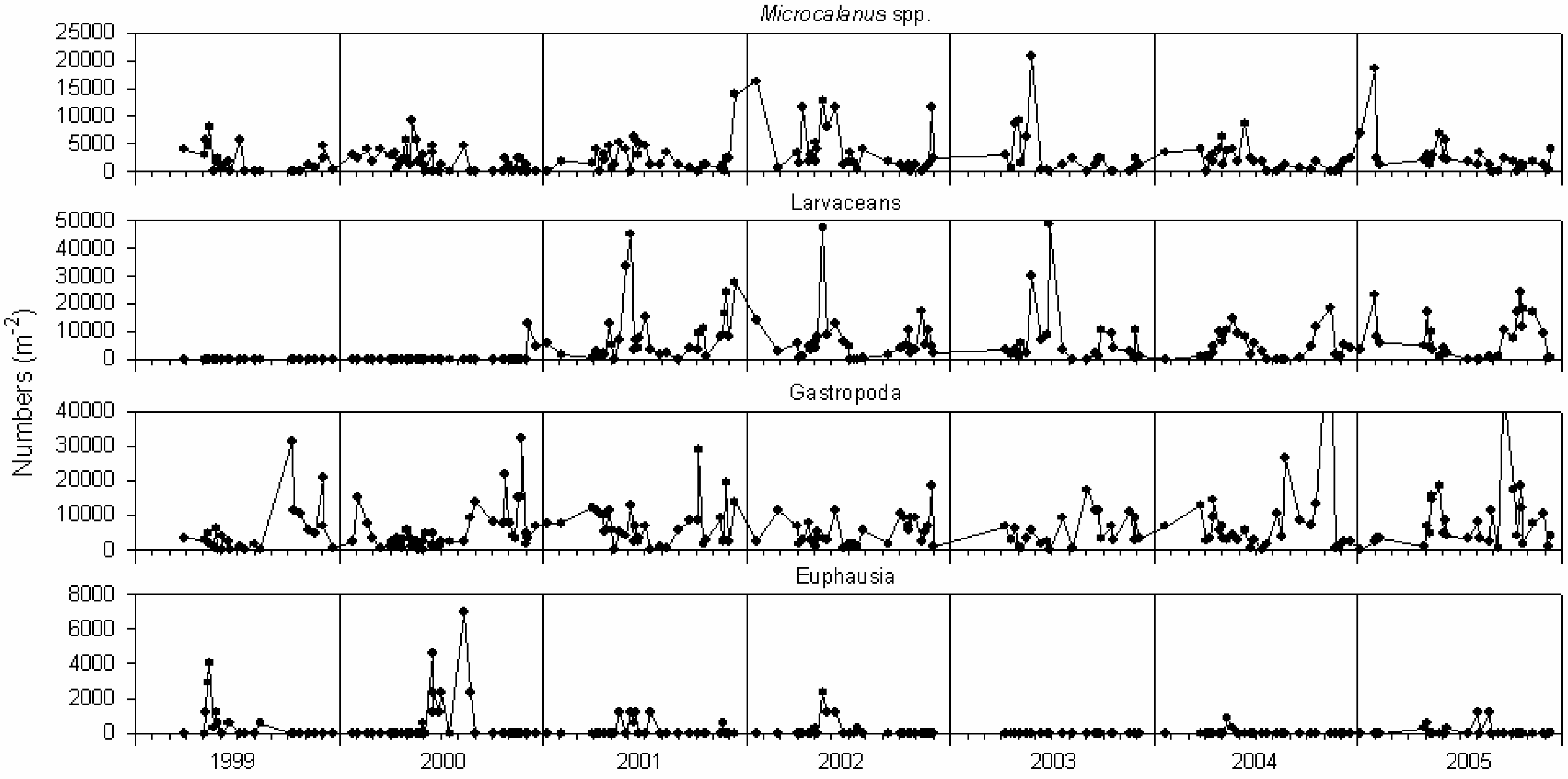


Figure 12. Seasonally-adjusted estimate of the mean abundance of twelve dominant zooplankton taxa from Station 27 for the period 1999-2005. The error bars represent standard errors. The *p*-value in the upper right hand corner indicates the probability of significant inter-annual variations in abundance based on type III sums of squares. The maximum-to-minimum ratio in the lower left hand corner indicates the magnitude of the variation in abundance during the six year period.

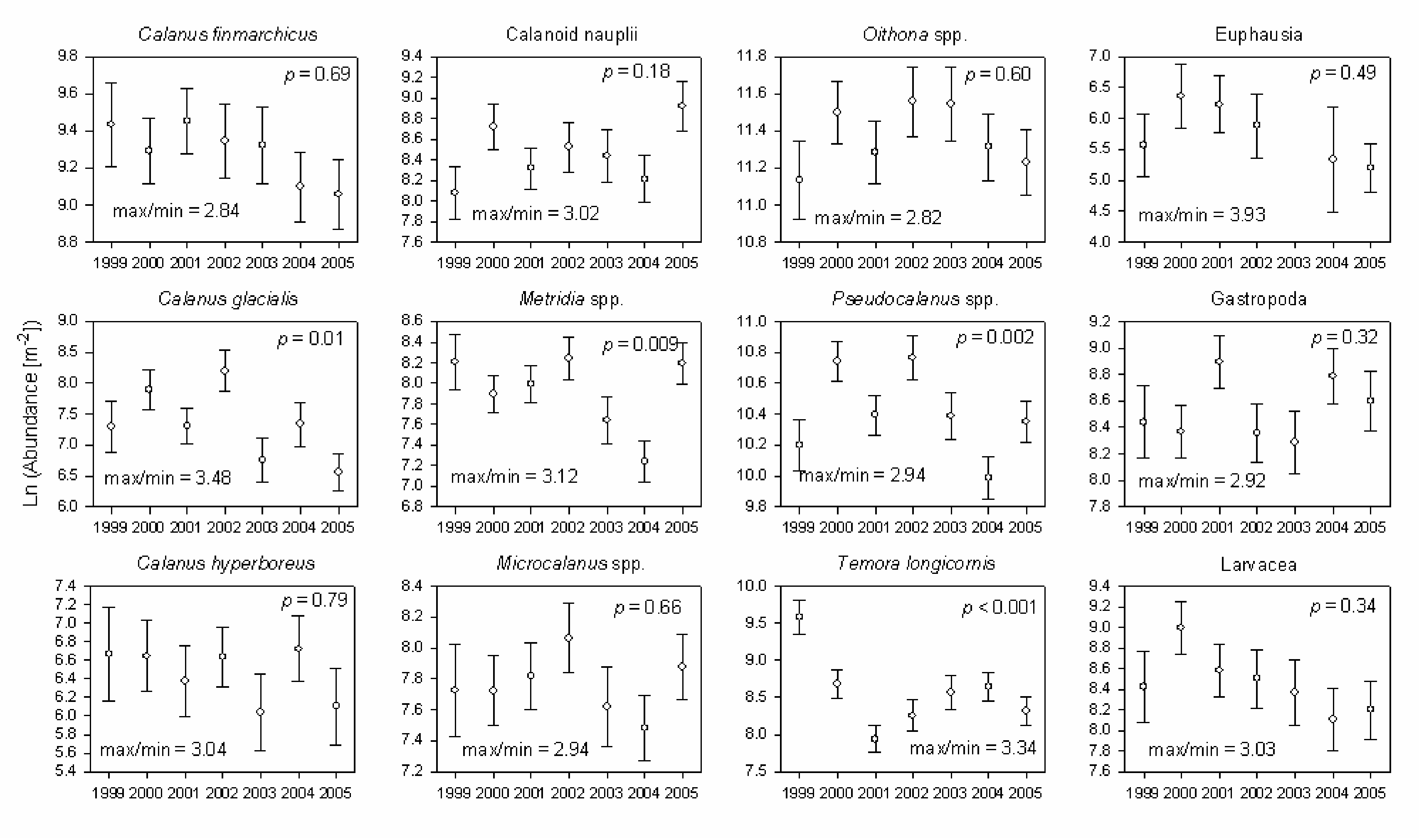


Figure 13. Seasonal cycle of total biomass and species distribution of the dominant copepods at Station 27 for the period 1999-2005.

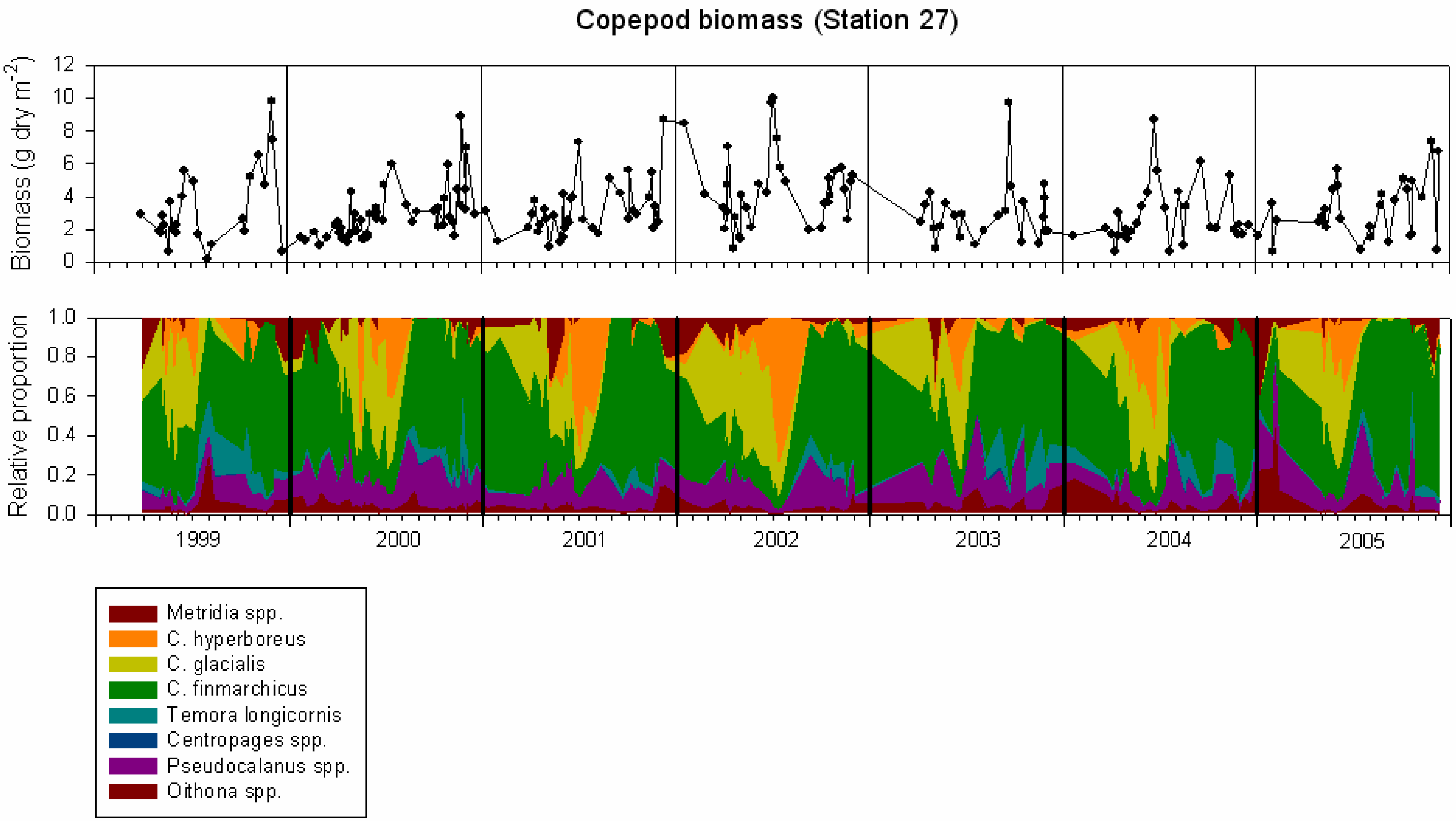


Figure 14. Seasonally-adjusted estimates of the mean biomass of 8 dominant copepod species from Station 27 for the period 1999-2005. The error bars represent standard errors.

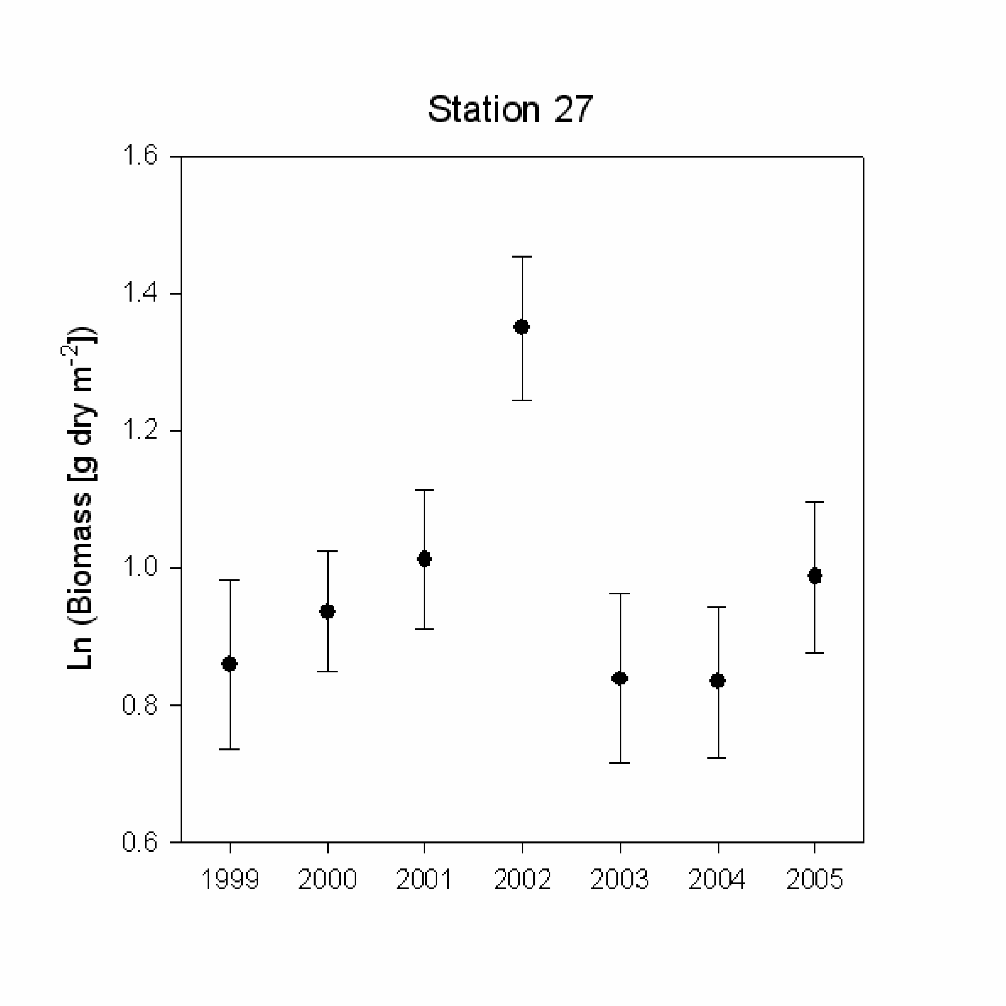


Figure 15. Seasonally-adjusted estimate of the mean abundance of seven dominant copepod taxa from the oceanographic transects for the period 2000-2005. The error bars represent standard errors. Values from the Southeast Grand Banks are based on two occupations per year (spring, fall); values from the Flemish Cap and Bonavista transects are based on three occupations per year (spring, summer, fall); values from the Seal Island transect are based on one occupation per year (summer).

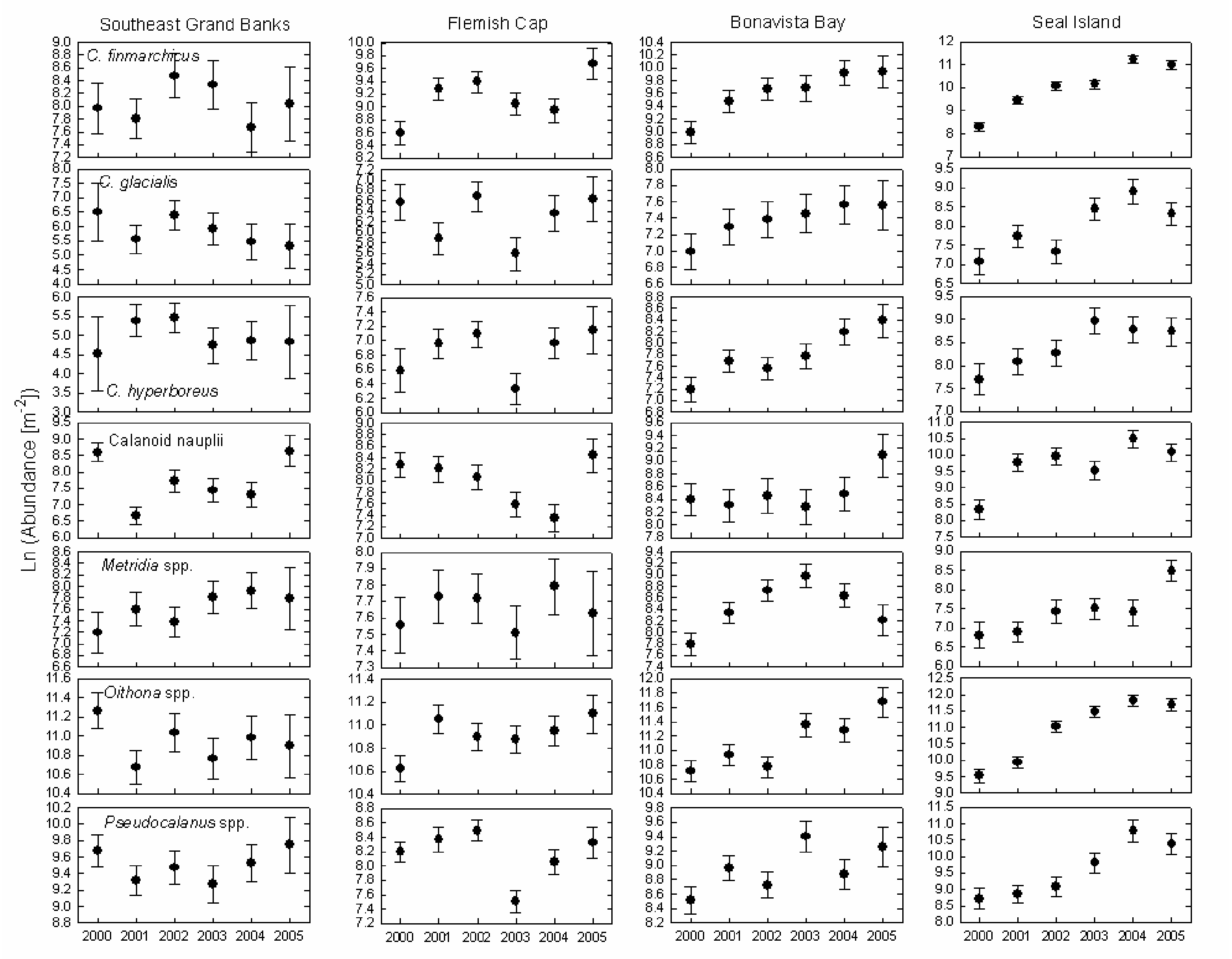
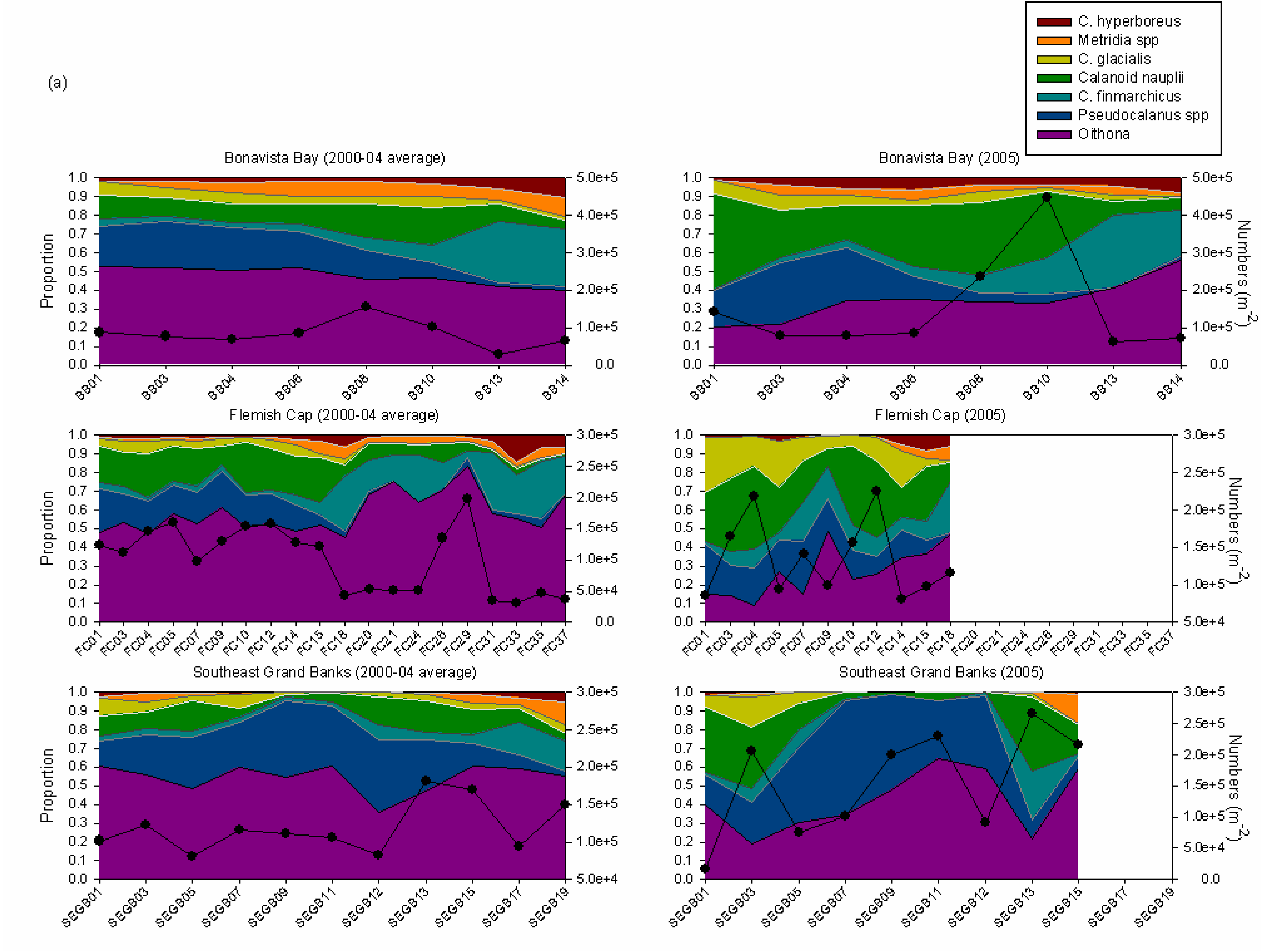


Figure 16. Spatial distribution in (a) abundance, (b) biomass, and species composition for the seven dominant copepod taxa collected along oceanographic transects sampled in the spring surveys. The left-hand panels show the average distribution for 2000-2004 while the right-hand panels shows the observations for 2005.



Bonavista Bay (2000-04 average)

Bonavista Bay (2005)

Flemish Cap (2000-04 average)

Flemish Cap (2005)

Southeast Grand Banks (2000-04 average)

Southeast Grand Banks (2005)

Figure 16. Continued.

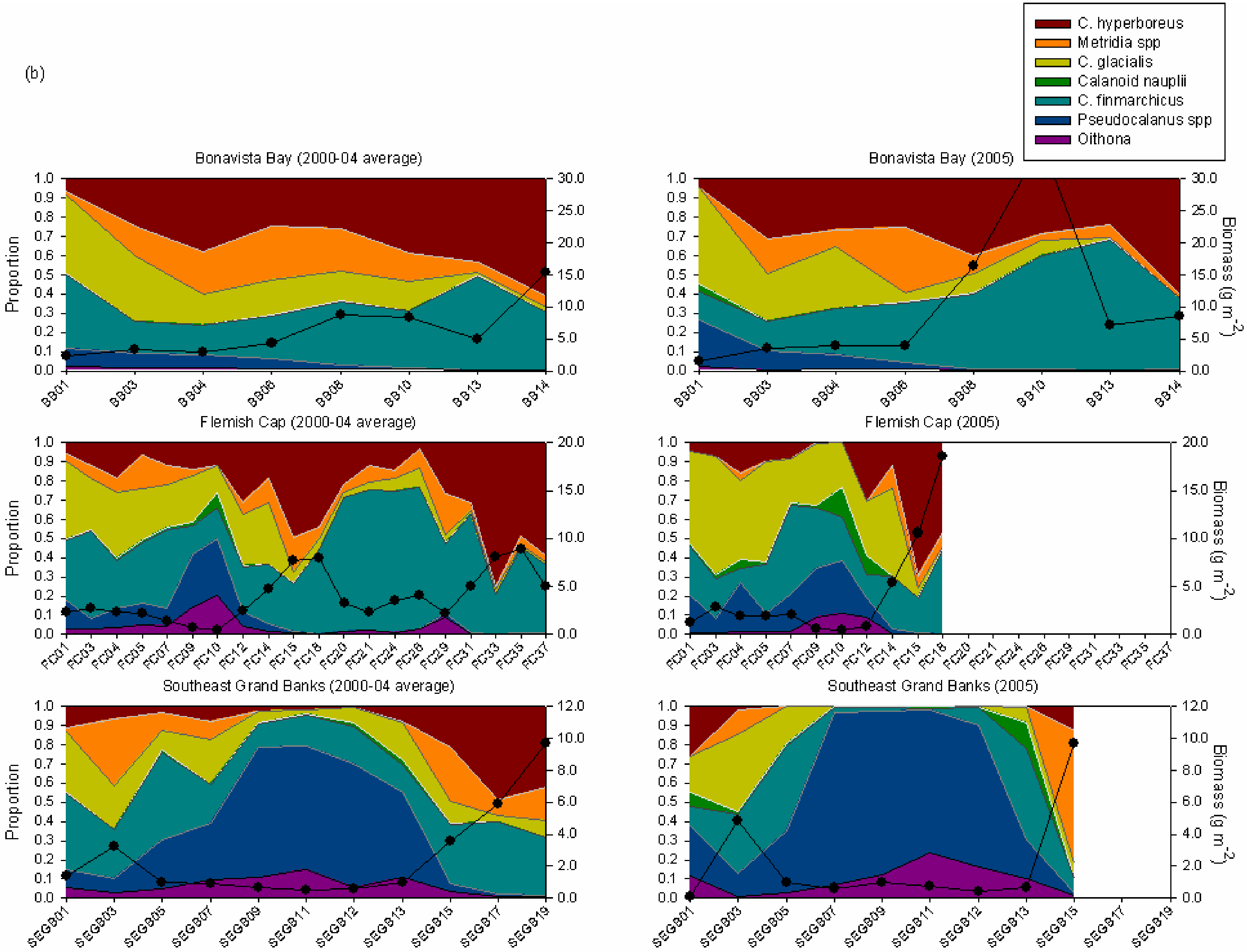


Figure 17. Spatial distribution in (a) abundance, (b) biomass, and species composition for the seven dominant copepod taxa collected along oceanographic transects sampled in the summer surveys. The left-hand panels show the average distribution for 2000-2004 while the right-hand panels shows the observations for 2005.

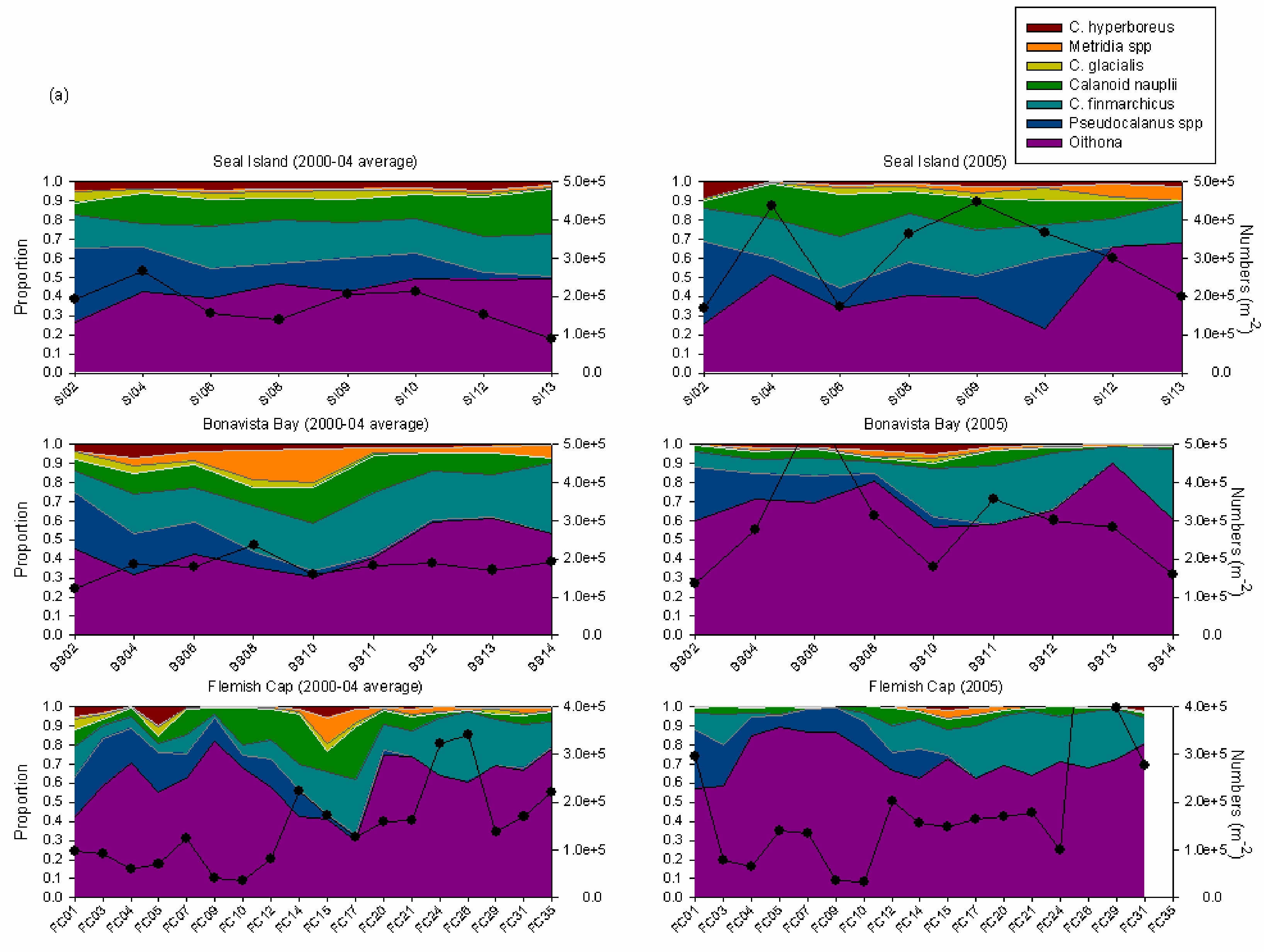


Figure 17. Continued.

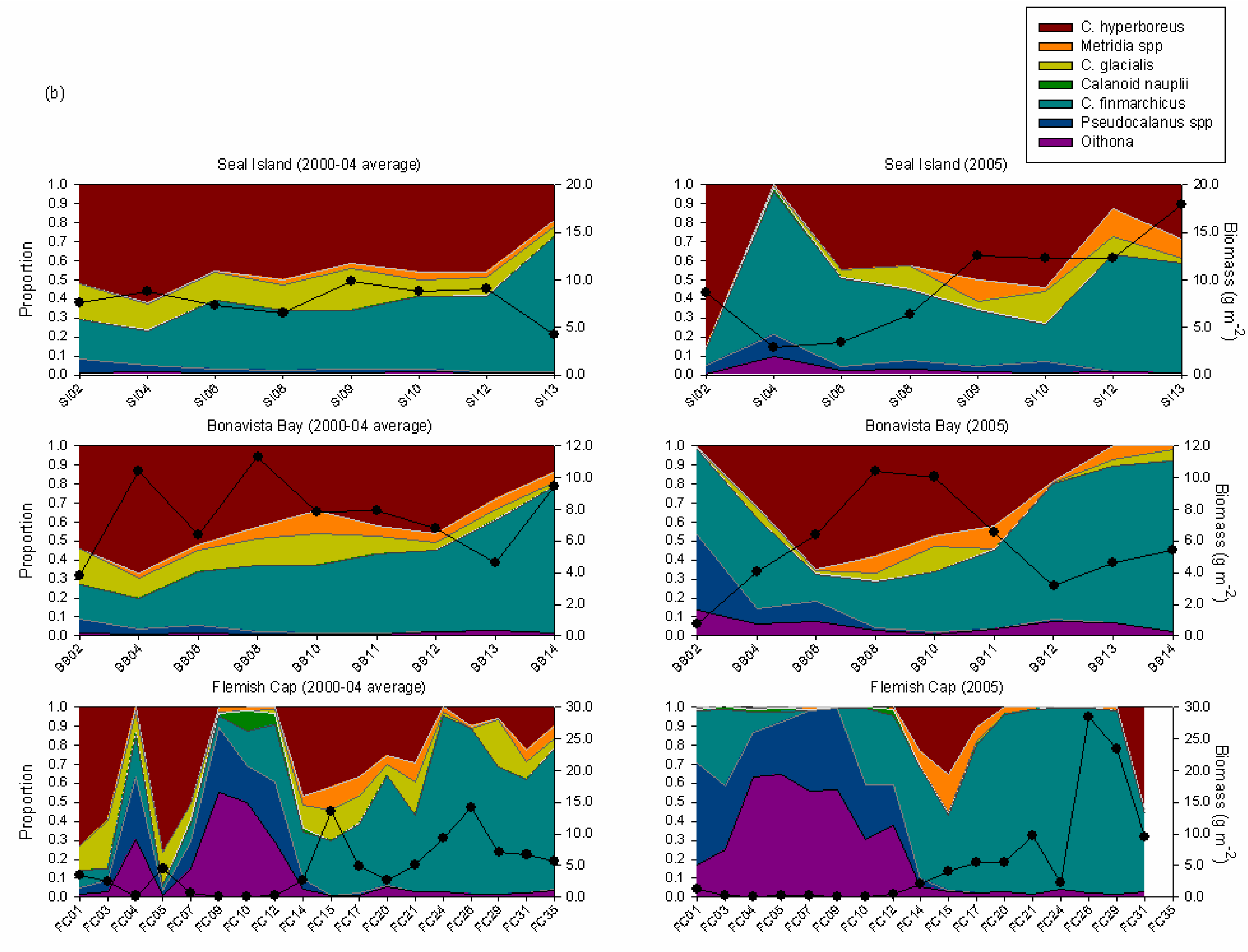


Figure 18. Average correlation of deseasonalized log-transformed zooplankton abundance from each station along the four oceanographic transects. Errors bars represent one standard deviation. The deseasonalized estimates were obtained by subtracting the observation for each station and survey from station-specific seasonal mean (2000-2005). The averages are based on data from the seven dominant copepod taxa for the region.