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**Biological and Chemical
Oceanographic conditions on the
Newfoundland and Labrador Shelf
during 2007**

**Conditions océanographiques,
biologiques et chimiques sur le
plateau Terre-Neuvien au cours de
l'année 2007**

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ABSTRACT

We review seasonal and interannual variations in the concentrations of chlorophyll *a*, major nutrients, as well as the abundance of major taxa of phytoplankton and zooplankton measured from Station 27 and along standard transects of the Atlantic Zone Monitoring Program (AZMP) in 2007. The inventories of nitrate, the principal limiting nutrient, which had remained relatively low throughout most of the time series, appear to have increased somewhat in 2007. Indications of a decrease in phytoplankton abundance at Station 27 since 2002 were reversed in 2006. Phytoplankton abundance remained high in 2007, but the magnitude of the change is not statistically significant nor was it reflected along the oceanographic transects. In 2007, the overall abundance of zooplankton at Station 27 appears to have increased in many taxa, with *Calanus hyperboreus*, *Metridia* spp., and euphausiids reaching their highest levels since the start of monitoring activities. The abundance of *Calanus finmarchicus* at Station 27 remains substantially above its lowest level (2005). On the Grand Banks, many species of small copepods were at their highest levels on record, but the abundance of *Calanus glacialis* and *C. hyperboreus* showed a substantial decrease. Furthermore, the abundances of most meroplankton, larvaceans and ostracods were below the long term average throughout the region. Although near the long term average, many carnivorous taxa have shown a consistent decreasing trend in abundance since either 2004 or 2005.

RÉSUMÉ

La présente étude passe en revue les données sur les variations saisonnières et interannuelles des teneurs en chlorophylle *a* et en éléments nutritifs importants, ainsi que sur l'abondance des principaux taxons du zooplancton et du phytoplancton, récoltées à la station 27 et le long de transects normalisés du Programme de monitoring de la zone atlantique (PMZA) en 2007. Les quantités de nitrate, principal élément nutritif limitatif, qui sont demeurées relativement basses pendant la majeure partie de la série chronologique, semblent avoir augmenté quelque peu en 2007. La tendance à la diminution de l'abondance du phytoplancton notée à la station 27 depuis 2002 a été renversée en 2006. L'abondance du phytoplancton est demeurée élevée en 2007, mais le changement n'est pas significatif du point de vue statistique et n'a pas été observé le long des transects océanographiques. En 2007, l'abondance générale du zooplancton à la station 27 a semblé croître dans de nombreux taxons; le *Calanus hyperboreus*, l'espèce *Metridia* et les euphausiacés ont d'ailleurs atteint leur plus bas niveau depuis le début des activités de surveillance. L'abondance de *Calanus finmarchicus* à la station 27 est demeurée de beaucoup inférieure à son niveau le plus faible (enregistré en 2005). Sur les Grands bancs, de nombreuses espèces de petits copépodes ont atteint leur plus haut niveau jamais enregistré, mais l'abondance de *Calanus glacialis* et de *C. hyperboreus* a affiché une importante diminution. De plus, l'abondance de la plupart des méroplanctons, des larvacés et des ostracodes s'est trouvée inférieure à la moyenne à long terme, partout dans la région. Finalement, l'abondance de nombreux taxons carnivores, bien qu'elle se soit approchée de la moyenne à long terme, a connu une tendance uniforme à la baisse depuis 2004, ou 2005.

INTRODUCTION

The Atlantic Zone Monitoring Program (AZMP) was implemented in 1999 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 2007. 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 2007 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 Logistics 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.

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 derived from in-water light extinction measurements using a CTD-rosette mounted PAR (photosynthetic active radiation) meter. The downward vertical attenuation coefficient of PAR ($K_{d- PAR}$) was estimated from the linear regression of $\ln(E_d(z))$ versus depth z (where $E_d(z)$ is the value of downward PAR irradiance at z m) in the depth interval from near surface to 50 m. When in-water PAR data were not available, the vertical attenuation coefficient was calculated by:

$$K_{d_chl a} (m^{-1}) = 0.027 m^{-1} + 0.015 m^{-1} + B(z) * 0.04 m^{-1} \quad (\text{Platt et al. 1988})$$

where $B(z)$ is the concentration of chlorophyll *a* in $mg\ m^{-3}$ (we substitute calibrated chlorophyll *a* from *in-situ* chlorophyll *a* fluorescence when discrete concentrations were not available) at depth z . 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 using the chlorophyll *a* profile in the upper 50 m.

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

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

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

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

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 normalize the skewed distribution of the observations. In the case of zooplankton, one was added to the *Density* term to include observations where no animals were counted in the sample. Physical variables, inventories of nutrients and chlorophyll were not transformed. To derive an estimate of the interannual variations based on all occupations of the transects, a full model which includes seasonal effect is applied

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

An estimate of the least-squares means based on type III sums of squares is used as the measure of the overall year effect.

The analysis performed on key zooplankton species includes 16 taxa for the fixed station, and 27 taxa for the oceanographic sections. Because of the number of taxa and sections, we present a first attempt to synthesize the information by grouping the taxa as small copepods (*Microcalanus* spp., *Oncaea* spp., *Oithona* spp., *Pseudocalanus* spp., *Temora longicornis*, *Spinocalanus* spp., *Paracalanus parvus*, *Centropages* spp. *Chiridius glacialis* and *Acartia* spp.), large copepods (*Calanus finmarchicus*, *Calanus glacialis*, *Calanus hyperboreus*, *Metridia* spp., and large calanoid nauplii), carnivores/omnivores (*Euchaeta norvigica*, euphausiids, hyperiid amphipods and *Pelagia noctiluca*, *Aglantha digitale*, *Sagitta* spp., and ostracoda), and non-copepod secondary producers (meroplankton (barnacle, bivalve and polychaete larvae), larvaceans, and pelagic gastropods (principally *Limacina* spp.)). The annual seasonally-adjusted estimate of abundance of each taxa was then ranked for the 9 years of the monitoring program for each transect and the data were then grouped geographically as either coming from the Newfoundland/Labrador shelf (Bonavista and Seal Island sections) or the Grand Banks (Flemish Cap and southeast Grand Banks sections). The distribution of the observations for 2007 of the four groups was then assessed to determine if it differed from uniform.

We also calculated the abundance-size spectra for each oceanographic section based on the stage distribution data for *Oithona* spp., *Pseudocalanus* spp., *Temora longicornis*, *Centropages* spp., *Calanus finmarchicus*, *Calanus glacialis*, *Calanus hyperboreus*, and *Metridia* spp. from all stations along the section. Average body weights for each stage of each species were collated from the literature or estimated from preserved samples (unpublished data). Abundance (m⁻²) and body weight were log-transformed and we estimated the first order linear relationship (abundance = *f*(body weight) between these variables for each season using a GLM that included a term for the year-effect. This is a preliminary exploration of the data. Although there were indications of curvature in the data, the addition of second and third order

terms for body weight did not explain a significantly greater proportion of the variation in abundance.

SATELLITE REMOTE-SENSING OF OCEAN COLOUR

Phytoplankton biomass was also estimated from ocean colour data collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) “Aqua” sensor (<http://modis.gsfc.nasa.gov/>). The MODIS data stream began in July, 2002. The composites and statistics from MODIS used in this report are only provisional since they have not yet been intercalibrated with the SeaWiFS imagery. Satellite data do not provide information on the vertical structure of phytoplankton in the water column but do provide highly resolved (~1.5 km) data on their geographical distribution in surface waters at the large scale. Bi-weekly composite images of surface chlorophyll for the entire NW Atlantic (39-62.5 N Lat., 42-71 W Lon.) are routinely produced from SeaWiFS/MODIS data¹. Basic statistics (mean, range, standard deviation, etc.) are extracted from the composites for selected sub-regions. We report on the available time series of mean surface chlorophyll *a* levels at selected sub-regions on the Newfoundland and Labrador Shelf (Fig. 1).

CONTINUOUS PLANKTON RECORDER (CPR) SURVEY

The Continuous Plankton Recorder (CPR) Survey² provides an assessment of long-term changes in abundance and geographic distribution of planktonic organisms ranging from phytoplankton cells to larger macrozooplankton (Warner and Hays 1994, Richardson et al. 2006). CPR collections in the northwest Atlantic began in 1959 and continued with some interruptions until 1986. Collections were resumed in 1991 and continue to present. Data are available approximately one year after collection; therefore we are limited to 2006 data in this report.

The recorder is towed by ships of opportunity along a number of standard routes throughout the North Atlantic. The CPR device collects plankton at a nominal depth of 7 m. Water passes through a small aperture, and organisms are retained on a moving band of silk material and preserved. Sections of silk representing 18.5 km tow distance and ca. 3 m³ of water filtered are analyzed microscopically using standard methods since the inception of the program thereby allowing valid comparisons between years. Every second section is analyzed providing a horizontal scale of ca. 37 km.

The CPR taxonomic categories vary from species to coarser levels such as genus or family. Throughout this report, we use the same level of identification of each taxon as provided in the original microscopic analysis. The CPR sampling distribution was uneven spatially and temporally because of the opportunistic nature of sampling with commercial ships, variations in shipping routes, and CPR funding. The CPR taxa included indices of phytoplankton abundance and the dominant assemblages of phytoplankton such as the Phytoplankton Colour Index [PCI], diatom [*Chaetoceros* spp.] abundance, summed dinoflagellate [*Ceratium arcticum*] and potential harmful algal bloom species [HAB]. The main HAB genera included *Dinophysis* spp., *Nitzschia* and *Pseudo-nitzschia* spp., *Gonyaulax* spp., *Gymnodinium* spp., and *Prorocentrum* spp. The mesozooplankton groups included *Calanus finmarchicus* (CV-CVI stages), other copepods [copepoda], macrozooplankton [combined euphausiacea and hyperiidea taxa], and summed invertebrate larval and post-larval stages of decapoda and echinodermata (see Richardson et

¹ (http://www.mar.dfo.mpo.gc.ca/science/ocean/ias/seawifs/seawifs_1.html)

² See SAFHOS web site at (<http://192.171.163.165/>) for a description of the CPR Program collected for The Sir Alister Hardy Foundation for Ocean Science of Plymouth, England.

al. 2006). We did not differentiate the data based on bathymetry (e.g. shelf versus slope) and included all the data bounded by the NAFO Div. 3L, 3 m, 3N, 3O, and 3Ps (Fig. 1). The data are presented as relative abundance ($\text{Log}_{10} (N+1)$) because the catchability of the different taxa sampled by the CPR is not equal among taxa. Without known correction factors, it would be erroneous to compare the abundance of organisms among taxa. The CPR provides an index of abundance over time for individual taxa assuming a constant catchability.

OBSERVATIONS

Fixed Station – Seasonal and interannual variability in water column optics, solar radiation, and water column structure

The vertical light attenuation at Station 27 reached the highest levels recorded relative to observations from previous years (Fig. 2). The peak in the vertical attenuation coefficient that coincides with the timing of the spring bloom was substantially elevated in 2007 relative to 2005-06. The duration of the peak in light attenuation in 2007 was also higher in contrast to previous years, but background levels and the timing of the maximum were consistent with prior observations. The seasonal cycle in light attenuation in 2007 was generally consistent with previous years with the exception of higher levels observed in April. As a result of higher light attenuation levels observed in spring 2007, euphotic depths were generally shallow (10-30 m) but quickly deepened post-bloom approaching depths in excess of 100 m in early May. We suggest some caution in the overall interpretation of any given time series. Sampling may not capture the full dynamic range of the variables, because the occupations of Station 27 can vary from year to year, particularly during winter and spring.

Although there are differences in the timing of the seasonal cycle among years, the GLM estimate of annual mean attenuation of light (K_d) and euphotic depth (Z_{eu}) do not show any statistically significant interannual variations. For both optical measures, there are indications of a decreasing trend in annual means of K_d from 2000 to 2005 (corresponding upward trend in Z_{eu} because attenuation and photic depths are inversely related), with an upward trend observed in recent years (Fig. 6).

Fixed Station – Seasonal and interannual 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 (Fig. 3). In 2007, the integrated chlorophyll *a* levels were the highest observed in the short time series. The initiation of the bloom³ in 2007 was detected by mid-March with integrated concentrations in excess of 100 mg m^{-2} and was confirmed with MODIS Satellite Colour Imagery⁴ (Fig. 12). Peak concentrations in excess of 600 mg m^{-2} (in-vivo chlorophyll *a* fluorescence) were detected in late April 2007. Concentrations remained above 100 mg m^{-2} until 19 May and thereafter dropped off rapidly in late May consistent with satellite imagery. The duration of the bloom in 2007 was 68 days (~10 weeks), the second-longest observed in the time series (in year 2000 the bloom duration was 92 days) compared to 2-6 weeks observed in recent years. There are indications of a relatively stable phytoplankton biomass at Station 27 varying between ca. $50\text{--}100 \text{ mg m}^{-2}$ throughout the year. As in previous years, there was evidence of small accumulations of phytoplankton biomass after the spring bloom again in 2007 (i.e. short-term summer and autumn blooms). There is an indication of

³ We use the criteria of integrated chlorophyll *a* levels $\sim 100 \text{ mg m}^{-2}$ in upper 100 m to define start and end times of the phytoplankton bloom.

significant concentrations of phytoplankton biomass below 100 m depth in 2007, possibly as a result of the sinking of larger diatom cells, the main phytoplankton community of the spring bloom.

Although there are differences in the timing of the seasonal cycle among years, the GLM estimate of mean chlorophyll inventories (0-100 m integral) do not show any statistically significant interannual variations, although the lowest value of the time series occurring in 2005 (Fig. 6).

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). Because the availability of nitrogen and silicate is considered to be limiting to the growth of phytoplankton in the NW Atlantic, more emphasis in this report will be placed on variability in nitrate and silicate concentrations.

The vertical structure of nitrate (combined nitrate and nitrite, hereafter referred to as nitrate) and silicate show dynamic seasonal changes in the water column at Station 27 (figures 4 and 5). Concentrations of nitrate were typically $>3 \text{ mmol m}^{-3}$ throughout the water column and approached maxima of 10 mmol m^{-3} near the bottom prior to the spring bloom (Fig. 4). Subsequently, concentrations of nitrate were depleted in the upper 50 m to $<1.0 \text{ mmol m}^{-3}$ by mid-April and remained relatively low throughout the summer. During the summer and early fall, periodic intrusions of deep waters with high nitrate concentrations into the mixed layer, which have been observed previously, were also apparent in 2007 although weaker than in 2006. Nitrate concentrations in surface waters remained very low ($\leq 1 \text{ mmol m}^{-3}$) until very late in the year (early November) when the breakdown of stratification occurred. 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 nitrate inventories at Station 27 showed differences between years (Fig. 4). Nitrate inventories in the upper 50 m followed the expected seasonal trends with winter and fall maxima, rapid depletion during the spring bloom, and occasional periodic intrusions during the late summer – early autumn (Fig. 4). 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. The nitrate maximum that occurred during the winter-early spring period at Station 27 in 2007 was higher compared to earlier years. During the spring bloom nitrate levels in the upper water column were substantially reduced approaching near complete depletion compared to $20\text{-}40 \text{ mmol m}^{-2}$ observed in previous years. The deep water (50-150 m) inventories of nitrate have remained relatively stable throughout the time series although there appears to be a general strengthening of the seasonality in 2007 compared to earlier observations. The seasonal cycle of deep nitrate inventories which is normally relatively stable throughout the year showed some differences during 2007 compared to earlier years (Fig. 4). Nitrate inventories in the deep layer fell below the long-term mean during the spring bloom, consistent with the dynamics in the upper layer, while summer and autumn levels were above the long-term levels. Nitrate inventories in the upper and lower layers increased in 2007, reversing a negative trend observed since the start of the AZMP (Fig. 6). The cause for the decline in nitrate inventories observed in earlier years 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. Although we have observed changes in nitrate inventories in the shallow and deep layer since the start of the monitoring program in 2000, the seasonally-adjusted GLM mean annual estimates were not significant ($p>0.05$) (Fig. 6).

Concentrations of silicate were typically $>2 \text{ mmol m}^{-3}$ throughout the water column and approached maxima of 10 mmol m^{-3} near the bottom prior to the spring bloom (Fig. 5). Subsequently, concentrations of silicate were depleted in the upper 50 m to $<2.0 \text{ mmol m}^{-3}$ by

mid-April and approached near depletion down to 100 m by mid-May 2007. In the upper water column, silicate concentrations were more variable in contrast with nitrate, and fluctuated from 0-5 mmol m⁻² during late spring and summer. Periodic intrusions of silicate from depth, which have been observed during previous years, were also apparent in 2007 although their occurrence was more gradual and somewhat later in the year compared to previous years (Fig. 5). Silicate concentrations in the upper water column were replenished in the autumn to levels in excess of 3 mmol m⁻², consistent with the observations for nitrate.

The inventories of silicate in the upper 50 m 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 (Fig. 5). Overall, silicate inventories in the upper layer were consistent with levels in 2006 but lower compared to previous years. The cause for the decline in shallow inventories of silicate in 2007 may be related to biological consumption of nutrients as a result of the most intense spring bloom observed in the time series.

The silicate maximum in the upper layer that occurs during winter-early spring period at Station 27 reached comparable levels in 2006-07 but was lower compared to earlier years (Fig. 5). Rapid depletion of silicate inventories occurred during the spring bloom as with nitrate. The deep water (50-150 m) inventories of silicate in 2007 were generally above levels observed earlier in the time series. The seasonal cycle of deep inventories which is normal relatively stable throughout the year showed some differences during 2007 compared to earlier years (Fig. 5). Silicate inventories in the deep layer fell below the long-term mean during the spring bloom and early summer, while late summer and autumn levels were above the long-term mean, consistent with the dynamics in the upper layer. The changes observed in both the upper and lower layers in silicate inventories were consistent with the changes observed in nitrate levels. We have observed changes in silicate inventories in the shallow and deep layer since the start of the monitoring program in 2000 (Fig. 6), although the seasonally-adjusted GLM mean annual estimates were not significantly different ($p > 0.05$) in the shallow layer, while interannual variations in the deep layer were significantly different ($p = 0.001$) largely as a result of substantial reduction in inventories that occurred in 2006.

Oceanographic Sections - Seasonal Variability in Limiting Nutrients and Phytoplankton Biomass

Sub-surface and near-surface chlorophyll *a* concentrations during the spring 2007 survey were elevated compared to previous years over much of the Grand Banks and Newfoundland Shelf. High chlorophyll *a* concentrations up to 14 mg m⁻³ were observed in the upper water column along all sections, although high levels were also observed at depths down to 100 m depth along the Flemish Cap and southeast Grand Banks sections (Fig. 7). Nitrate concentrations were depleted (<1 mmol m⁻³) in the upper 50 m along the southeast Grand Banks and Flemish Cap sections during spring 2007, and prominent shoaling of the nutricline in the offshore was evident. 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 North Atlantic waters rich in inorganic nutrients and enhanced vertical mixing. Based upon the depletion of nitrate in the water column, the spring bloom is initiated along the southern sections and then progresses further north along the Newfoundland Shelf, consistent with past observations and satellite imagery. The extent of nutrient depletion can provide some information as to the relative stage of the spring bloom (e.g. early versus late stage development).

The summer occupations across the northeast Newfoundland and Labrador sections are typically characterized by depletion of nitrate to <1.0 mmol m⁻³ in the upper water column (Fig. 8). There was evidence of depletion in nitrate concentrations in surface waters along all

sections, but the depth of the nutricline varied by location along each section. The largest vertical extent in biological uptake of nitrate occurred along the Flemish Cap, and to a more limited extent along the inner Shelf of the Bonavista Bay and White Bay sections, extending to depths of ca. 40 m. Shoaling of the nutricline from inshore to offshore areas was also evident along all sections, which is consistent with conditions observed in previous years. The summer 2007 concentrations of chlorophyll *a* were comparable to previous years across the Newfoundland Grand Banks and Labrador Shelf sections. Evidence of episodic or localized sub-surface phytoplankton blooms were observed along all sections. MODIS satellite colour imagery confirmed low surface chlorophyll *a* levels across the Grand Banks, Newfoundland and Labrador Shelf sections.

Autumn phytoplankton blooms were observed along the entire extent of the Grand Banks and Newfoundland Shelf sections in 2007 (Fig. 9). Enhancement of nitrate concentrations were apparent along the northern Bonavista section, while being less pronounced across the southeast Grand Banks and Flemish Cap sections during the autumn occupations. Despite the depletion of nitrate in the upper water column, increased biological activity was evident along all sections from near-surface to depths in excess of 50 m. Nitrate depletion was somewhat more latitudinally extensive than in previous years.

The generalized linear models generally show that within season, variables that describe the biological and chemical conditions in the upper water column (inventories of chlorophyll, silicate and nitrate) show significant interannual variations along the main sections except for the fixed station (Table 2; Fig. 10). The exceptions along the sections tend to be associated with the summer survey, particularly along the Bonavista Bay and Flemish Cap. The exception at the fixed station was associated with the deep silicate inventories. Silicate and nitrate inventories in the shallow (0-50 m) and deeper layers (50-150 m) show less interannual variability, particularly in the summer and fall, but there are significant interannual variations in shallow and deep water nutrient inventories in the spring across all of the sections with the exception of the northeast Newfoundland Shelf during spring (Table 2; Fig. 10). The GLM model indicated significant seasonal and interannual variability in optical (vertical attenuation and euphotic depth) and chlorophyll *a*, particularly during the spring and fall and less so for the summer period. One must be particularly careful in the interpretation of seasonal and interannual variations in variables of interest because differences in the timing of the surveys, relative to that of the biological production cycle, can lead to aliasing.

Near surface nutrient scatter plots on the Grand Banks, Newfoundland and Labrador Shelf in 2007 indicate nitrate is the primary limiting nutrient (Fig. 11). In general, the utilization of nutrients follows the "Redfield Ratio" during winter through summer on the Grand Banks, Newfoundland and Labrador Shelf in 2007. Higher utilization above the Redfield Ratio occurred during autumn on the Newfoundland Shelf. Large deviations in the nutrient scatter plots were observed between 2007 and the combined data for 1999-2006 (Fig. 11). In some cases, we observed a dramatic shift in the utilization of nutrients during 2007 and the mean trend in previous years (1999-2006). The silicate to nitrate ratio in the earlier period was lower than the Redfield during all seasons compared to 2007. The cause of the dramatic shift in the utilization of near surface nutrients is unknown but may be the result of changes in the phytoplankton community, water masses and mixing.

Remote Sensing of Ocean Colour

Satellite ocean colour (SeaWiFS and MODIS) data can provide large-scale images of surface phytoplankton biomass (chlorophyll *a*) over the whole of the NW Atlantic and in specific sub-regions of interest to enhance temporal and spatial coverage not possible based upon conventional sampling with vessels. Using a two-week MODIS composite image of the Newfoundland and Labrador regions supplements our ship-based observations and provides seasonal coverage and a large-scale context with which to interpret our limited survey data (Fig. 12). The MODIS ocean colour imagery provides information about the timing and spatial extent of the spring bloom which can vary from year to year across the Grand Banks and northeast Newfoundland Shelf.

The early development of surface blooms was observed on the tail of the Grand Banks by the second half of March 2007 (Fig. 12). Patchy surface blooms were observed over the Grand Banks and Newfoundland Shelf during early April. The most intense surface blooms over the whole of the Grand Banks and the Newfoundland Shelf were detected during the later part of April and consistent with our *in-situ* observations. Similarly, the patchy distribution of near-surface chlorophyll *a* concentrations across the sections and higher surface concentrations restricted to the northern sections (Bonavista, White Bay and Seal Island) during the summer 2007 survey was also supported by MODIS composite imagery. The summer 2007 colour imagery also indicated extensive surface phytoplankton blooms across the central Labrador Sea, as observed in previous years. Limited cloud cover in the autumn of 2007 provided capacity to detect surface blooms, confined mainly to the inshore Shelf and outer Slope waters of the Grand Banks and northeast Newfoundland Shelf (Fig. 12).

At larger scales, the statistical sub-regions off Newfoundland and Labrador indicate that the magnitude of surface phytoplankton blooms detected by SeaWiFS (weekly and 4 km resolution) was generally higher in 2007 compared to previous years, particularly in the southern and central sub-regions (Fig. 13). In general, the surface blooms were more intense and longer in duration compared to previous years. Limited activity was apparent on the northern Labrador Shelf and a significant delay in the production cycle was observed at Hamilton Bank (Fig. 13). The occurrence of autumn blooms which is sometimes not captured by conventional sampling, is supported by the high-resolution SeaWiFS imagery across the Grand Banks, and Newfoundland and Labrador Shelves. The satellite data also indicate that the highest surface chlorophyll *a* concentrations of $>2\text{-}3\text{ mg m}^{-3}$ are confined to the southern and eastern portion of the Grand Banks (e.g. southeast Shoal and Flemish Pass sub-regions) compared to lower levels (typically $<2\text{ mg m}^{-3}$) observed further north (Fig. 14). The temporal trends since 1998 indicate that surface blooms have intensified in recent years (Fig. 13) along with changes in the timing of the production cycle (Fig. 13).

Continuous Plankton Recorder (CPR)

The CPR survey provides a long time series of observations since 1961 of the distribution, seasonality, and annual relative abundance of plankton in the NW Atlantic to complement the time series performed by AZMP since 1999. Analysis of CPR data are completed approximately 18 months after collection; therefore only CPR data up to 2006 are currently available.

The phytoplankton colour index (PCI) and the abundance of dinoflagellates have increased during the available time series (Fig. 15). Diatoms, which typically dominate the spring phytoplankton bloom in the Newfoundland and Labrador region, have remained relatively stable. The relative abundance of CPR phytoplankton taxa has remained relatively stable in recent years.

The magnitude and seasonal cycle of phytoplankton abundance has generally remained stable. During 2006, the PCI and diatom abundance were elevated significantly in April (Fig. 15). The seasonal cycle in dinoflagellate abundance during the period 1991-2006 is significantly different from the pattern observed in the 1960-70s. Dinoflagellates are now most abundant during the first half of the year whereas the opposite occurred in the earlier period.

Time series of selected (considered dominant based on recent AZMP results) CPR zooplankton indicated the dominant calanoid (*Calanus* spp.) copepods are currently less abundant than in the 1960-70s (Fig. 16). Copepod nauplii abundance, which was in decline since 2002, has increased somewhat in 2006, particularly during May-June, but their abundance remains below the long-term mean. The relative abundance of the different copepodite and adult stages of *Calanus* spp. has remained largely unchanged in recent years. The changes in relative abundance for these life stages in 2006 were also reflected in a less pronounced seasonal cycle for both CI-CIV copepodites and CV-CVI adults.

Some of the abundant smaller copepods also show significant long term trends. The relative abundance of the warm-water copepod *Temora* spp. has increased steadily since 2002 and the timing of occurrence in 2006 has shifted to winter-early spring compared to past decades (Fig. 17). The relative abundance of the small cyclopoid copepod *Oithona* spp. on the Grand Banks is in steady decline since 1992, similar to the pattern observed for *Parapseudocalanus* spp., although the relative abundance of this small copepod has increased somewhat in recent years.

Similarly, the larger macrozooplankton, such as the Euphausiacea and Hyperiidea, have also been declining in abundance throughout the NW Atlantic during the 1990-2000s, but the overall mean for this period remains higher relative to the 1960-70s (Fig. 18).

Fixed Station - Zooplankton

There was strong seasonality in the abundance of many zooplankton species included in the analysis of Station 27 (Fig. 19). Most species show a single peak in abundance during late spring or early summer (e.g. *Calanus glacialis*, *Calanus hyperboreus*), although in some instances the peak is relatively protracted in duration (e.g. *Calanus finmarchicus* and *Pseudocalanus* spp.). Larvaceans appear to show two small peaks in abundance, one following the spring phytoplankton bloom, and another in the fall (data were missing for fall 2006). Still others peak in late fall and early winter (e.g. *Oithona* spp., *Metridia* spp.). The pattern of seasonality for pelagic gastropods and euphausiids (not shown) generally shows a gradual increase, often peaking in mid to late summer. There was no strong evidence of significant departures from the normal seasonal cycle in any of the species included in the analysis. Note that although some species occur regularly at Station 27, their abundance or frequency of occurrence is too low to obtain accurate estimates of seasonal variability.

A generalized linear model which included the effects of year and month as categorical variables was used to estimate interannual variations in the overall abundance of the 16 dominant zooplankton taxa present at Station 27 (four taxa not included in previous reports were added: *Acartia* spp., *Centropages* spp., *Oncaea* spp. and *Sagitta* spp.) Analytical results indicated that most (11/16) 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 six of the sixteen species showed significant interannual variations in overall abundance (*C. glacialis*, *Metridia* spp., *Pseudocalanus* spp., *Temora longicornis*, calanoid nauplii and larvaceans) (Fig. 20). The abundance of *Calanus glacialis*, *Centropages* spp. and *Temora longicornis* were at or near the lowest value recorded since 1999. In contrast, the abundance of *Calanus hyperboreus*, *Acartia* spp., *Metridia* spp., *Microcalanus* spp., *Oithona* spp., *Pseudocalanus* spp., *Sagitta* spp.,

larvaceans, gastropods and euphausiids were all at high levels in 2007. The generalized linear model which included year and month effects explained 37-91% of the overall variance in log-transformed abundance of the zooplankton taxa (mean 58%). Over the 1999-2007 observation period, most taxa exhibited approximately a 3-fold variation in abundance in average annual abundance.

The seasonal variation in the relative proportions of biomass contributed to the copepod community by the eight dominant species at this site was not strongly different in 2007 from the pattern in previous years (Fig. 21). It is notable that the relative contribution of *C. hyperboreus* during the spring of 2007 was generally greater than previously observed, although the relative abundance was comparable to values seen in 2001 and 2002. Throughout most of the year, the copepod biomass at Station 27 was dominated by *C. finmarchicus* or one of its congeners (either *C. glacialis* or *C. hyperboreus*). There was significant interannual variation in total copepod biomass at Station 27 ($F_{III}[8,247] = 2.12, p = 0.03$), and the high abundance of both *C. hyperboreus* and *Metridia* spp. contributing to an overall biomass 40% higher in 2007 than in 2006 (Fig. 22), and second only to 2002 by 20%.

There was relatively strong seasonality in the overall abundance of both *C. finmarchicus* and *Pseudocalanus* spp. at Station 27 in 2006 and 2007 in contrast to the previous two years, marked by a strong peak in late spring/early summer (Fig. 23). Using the criteria outlined by Johnson et al. (2008), we estimated the days of emergence and entry into dormancy of *C. finmarchicus* from Station 27 for the period 2000-07. The timing of emergence varies from early December to mid February (~68 days) whereas entry into diapause varies from mid-August to late September (~50 days) (Fig. 24). There is a significant inverse correlation ($r = -0.78, p < 0.05$) between the day of emergence and the timing of entry to diapause, suggesting that early emergence may result in late dormancy. Lagging the entry into dormancy forward by one year, to evaluate how entry in diapause might affect the timing of emergence, indicated no relationship at all ($r = -0.13$).

Oceanographic Sections - Zooplankton

Gaps in survey coverage from the autumn of 2006 to the summer of 2007 lead to increased uncertainty in estimates of abundance and biomass throughout the region. However, in many instances the changes in 2007 relative to previous years are sufficiently large that reasonable confidence in the interpretation could be achieved.

Among the small copepods, a number of species were at or near their maximum seasonally-adjusted abundance over much of the Newfoundland Shelf (Fig. 25). *Microcalanus* spp., *Oncaea* spp., *Oithona* spp., *Pseudocalanus* spp., *Temora longicornis* and *Spinocalanus* spp. were highly abundant on most transects, with the exceptions of one transect each (SI, SI, SI, FC, BB, SE, respectively). Species such as *Paracalanus parvus*, *Centropages* spp. *Chiridius gracilis* and *Acartia* spp. were generally lower in abundance than in previous years, or near their long term average abundance level, with the exception of *Centropages* spp. along the FC transect. Relatively few of the small copepods showed statistically significant interannual differences in abundance (*Oncaea* spp., *Oithona* spp., *Paracalanus parvus*, and *Chiridius gracilis*).

The abundance of *Calanus finmarchicus* was slightly lower in 2007 than in previous years along all four oceanographic transects, but the decrease was less than 3-fold in most areas (Fig. 26). *Calanus glacialis* showed a mixed pattern, reaching its lowest levels along the Southeast Grand Banks and Flemish Cap transects, while maintaining near peak abundance along the Bonavista Bay and Seal Island transects. The pattern was echoed for *Calanus hyperboreus* although the negative trend along the two southern transects was not as dramatic as for *C. glacialis*. In contrast *Metridia* spp. reached its highest level on all transects, with the

exception of Seal Island where its abundance was near the long term average. The abundance of large calanoid nauplii has been highly variable in both space and time and shows no consistent trend, although abundance in 2007 has decreased from 2006 in all areas. Most large copepods showed statistically significant interannual variations in abundance throughout much of the area surveyed, although only *C. finmarchicus* and large calanoid nauplii showed significant differences along the Seal Island section.

The abundance of most carnivorous zooplankton in 2007 has generally shown a decrease from 2006 in all taxa and areas (Fig. 27). Species such as *Euchaeta norvigica*, euphausiids, hyperiid amphipods and *Pelagia noctiluca* show more of a long term trend starting in 2003–05 than *Aglantha digitale* and *Sagitta* spp., but abundance in all taxa from this group is highly variable and their overall abundance is generally low. Only hyperiid amphipods and *Pelagia noctiluca* showed statistically significant interannual variations through much of the region. Euphausiids showed significant variations along the Southeast Grand Banks section and *Euchaeta* spp. was significantly variable off Bonavista. Ostracods were less abundant in 2007 than in previous years with most regions showing a general decrease starting the mid 2000s (Fig. 28).

Over the last three years, the abundance of barnacle larvae has shown a decreasing trend along all transects, although the trend has been longer term along the Southeast Grand Banks and Bonavista Bay transects (Fig. 28). Bivalve larvae have also shown a general decrease in abundance on the Grand Banks, but the abundance has been generally stable off Bonavista Bay. Larvaceans were at or near their lowest level in all areas, although the general long term trends differ substantially among transects. Polychaete larvae were also less abundant in 2007, with the exception of the Southeast Grand Banks where they are near peak levels. The pattern of abundance of pelagic gastropods is highly variable, with average abundance levels in the southern portion of the region and near peak abundance off Labrador. Bivalves and larvaceans showed significant variations throughout the region but interannual variations in most other non-copepod secondary producers, and pelagic gastropods were not statistically significant.

The overall rank of abundance estimates in 2007 on the Grand Banks (Southeast Grand Banks and Flemish Cap transects) and Newfoundland Shelf (Bonavista Bay and Seal Island transects) was close to average on the former and slightly below average on the latter (averages ranks 4.7 and 3.8 respectively; Fig. 29). Non-copepod secondary producers were generally less abundant than normal throughout the region. On the Grand Banks, a greater than expected number of small copepods were at peak levels while large copepods and carnivorous zooplankton tended to be near the median rank or slightly below.

The distribution of biomass among the seven dominant copepod taxa was generally consistent with the 2000–05 average (Fig. 30–32). The biomass of *Oithona* spp. was somewhat more important along the Southeast Grand Banks in the autumn of 2006 than in previous year, doubling at most stations where it is often predominates. Throughout much of the region, the relative biomass of *Calanus finmarchicus* and *Metridia* spp. was generally greater than the long term average, at the expense of *Calanus glacialis* and *hyperboreus*. This pattern persisted from the autumn of 2006 into the summer of 2007. Numerically, small copepods (*Oithona* spp. and *Pseudocalanus* spp.), along with calanoid nauplii, appeared to be more abundant than larger species, relative to the long term mean (2000–05), from the autumn of 2006 to the summer of 2007 in all areas.

Oceanographic section – Seasonal cycle in abundance

The average seasonal cycle of abundance among zooplankton taxa collected on the Flemish Cap and Bonavista Bay transects can be qualitatively classified into four broad classes

(Fig. 33). Taxa that change little in abundance from spring to summer to autumn, often with a summer minimum, include several small copepods (*Acartia* spp., *Centropages* spp., *Pseudocalanus* spp., *Chiridius gracilis*, *Spinocalanus* spp.) along with ostracods, *Pelagia noctiluca*, and pelagic gastropods on the Flemish Cap transect. A number of species peak in abundance in the spring (*Calanus glacialis*, *Calanus hyperboreus*, *Euchaeta norvegica*, euphausiids, *Microcalanus* spp.) as well as calanoid nauplii, *Balanus* and polychaete larvae, and chaetognaths (*Sagitta* spp.). Calanoid nauplii persist during the first half of the year and show their greatest decrease from summer to autumn. Both *Oithona* spp. and *Calanus finmarchicus*, two of the dominant species, show a peak in abundance during the summer, which is followed either by no change from summer to autumn or a moderate decrease in abundance. Some tertiary producers (*Aglantha digitale*, hyderiid amphipods) along with larvaceans, *Oncaea* spp. and pelagic gastropods on the Bonavista Bay transect also follow this pattern in abundance. Finally, a small group of taxa shows a peak in abundance in the fall (*Paracalanus parvus*, *Temora longicornis*, *Metridia* spp. and bivalve larvae).

Oceanographic surveys – Abundance spectrum

In estimating the abundance spectrum along each transect, each station was given equal weighting, irrespective of separation from surrounding ones. There are some indications that there may be systematic deviations from a linear model, but the addition of second and term order body weight terms did not yield consistent results. Because of the large number of stations and weight classes, which results in a large number of error degrees of freedom, the confidence intervals around estimates of the year effect may be overly conservative. This should be considered in the overall interpretation.

The slope of the abundance spectrum, an indication of how rapidly numbers change with increasing body weight, shows an inverse relationship with latitude, being steeper on the SE Grand Banks than on the Newfoundland Shelf (Bonavista Bay, Seal Island transects), with the slope on the Flemish Cap transect being intermediate to these extremes (Fig. 34). The change in slope is not an indication of greater abundance of small organisms on the Grand Banks but rather fewer larger animals overall. On both Grand Banks transects, the height of the abundance spectrum (an index of overall numbers) increases from spring to autumn whereas peak abundance on the Bonavista Bay transect is lowest in the spring, peaks during the summer to settle at intermediate levels in the autumn. On the SE Grand Banks and Flemish Cap transects, the slope of the abundance spectrum was steeper in the spring than later in the year, whereas on the Newfoundland Shelf, the spectrum was steepest in summer.

Interannual variations in the height of the abundance spectrum, which is an index of changes in overall numbers from year-to-year, explain only a modest proportion of the overall variance (~ 4–8%) in abundance (Table 3; Fig. 35), with the exception of the Seal Island transect, where interannual variations account for ~16% of the overall variance. In three instances, the interaction term, indicating a change in community structure, was statistically significant, although the variance explained was ~ 1% or less, suggesting limited value in this approach to detecting short term changes in community structure. There was little regional coherence in the pattern of interannual variations in the height of the abundance spectrum within seasons. In the spring, fluctuations on the Flemish Cap and Bonavista Bay transect show some similarities. They also show some similarities in the autumn but with a greater magnitude of variation on the Bonavista Bay than on the Flemish Cap transect. The general increase in abundance on the Bonavista Bay transect was mirrored somewhat on the spectrum from the Seal Island line, but the association was weak and not statistically significant.

DISCUSSION

Overall, the seasonality of chemical and biological variables at Station 27 and along the major AZMP sections in 2007 was similar to previous years (1999-2006). The timing of events on the Newfoundland Shelf (south of Seal Island) was generally similar to conditions observed in the early part of the program although the spring phytoplankton bloom was slightly earlier than in 2006 and considerably longer than in recent years. Satellite information indicates the onset of the spring bloom, at least since 2002, has become gradually earlier throughout the region of the Newfoundland Shelf and Labrador Sea. However, in 2007 there appeared to be a delay in the onset of the bloom in offshore as well as in the northern portions of the region.

There were a few notable trends in the observations from Station 27 and the oceanographic transects. At Station 27, the inventories of both nitrate and silicate showed a rebound from relatively low levels but overall phytoplankton abundance was near average, with the exception of the spring bloom. The reversal of the trend in deep (50-150 m) nutrient inventories is a marked event because levels recorded in 2006 were the lowest recorded since the inception of AZMP. Nitrate continues to be the primary limiting nutrient on the Grand Banks, and the Newfoundland and Labrador Shelf. The relationship between near surface concentrations of silicate and nitrate showed large changes in the rates of utilization of these nutrients during 2007 and previous years (1999-2006). The reasons for changes in nutrient utilization between 2007 and earlier years are unknown but may be associated with differences in phytoplankton community structure, water masses and mixing. Several of the major zooplankton taxa showed a general increase over the previous year, with *C. hyperboreus*, *Metridia* spp. and euphausiids being at their most abundant levels in the time series. Because these are large species, the overall estimated biomass of zooplankton at Station 27 was the second highest on record.

Because of the increasing information available from AZMP, we are now able to provide model-based (GLM) estimates of abundance for a broader range of taxa for Station 27 (16 versus 12) and oceanographic sections (27 versus 7). There were no outstanding events in 2007 relative to the remainder of the time series, other than an overall high abundance of small copepods on the Grand Banks and a generally low abundance of meroplankton, larvaceans and ostracods. There has been a general decrease in the abundance of *C. glacialis* and *C. hyperboreus* on the Grand Banks, but *Metridia* spp. was at its highest level recorded in 2007. Most carnivorous zooplankton were less abundant in 2007 than in 2006. In many species this reflects a longer term pattern since 2004-2005.

The variation in abundance of dominant taxa at Station 27 appears to reflect a mixture of the patterns on the Grand Banks and the Newfoundland Shelf. For example, the trend in the abundance of *C. glacialis* at Station 27 was consistent with the patterns on the Grand Banks whereas that of *C. finmarchicus* and *C. hyperboreus* were more consistent with the trends observed on the Newfoundland Shelf. 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 (Pepin et al. 2007). 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 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 influenced by the magnitude of the spring phytoplankton bloom observed during our surveys. However, attempts to derive average annual values are 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 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 interannual variation in both the magnitude and duration of the spring phytoplankton bloom. Integration of data from the oceanographic surveys, continuous sampling at fixed stations, and satellite observations would allow 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.

A notable advance in 2004 was in our ability to provide model-based quantitative analysis of interannual 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, which appear as part of the error. However, the approach has revealed substantial interannual variations in the abundance of zooplankton on the Shelf. The approach based on general linear models to determine the interannual variations in abundance of taxa from AZMP collections raised questions about the program's overall ability to accurately monitor zooplankton abundance and species composition. With the longer time series, it is now possible to expand the number of taxa for which model-based estimates of abundance can be obtained. In many instances, the confidence intervals remain large, limiting our ability to evaluate the degree of change over time with any certainty. Most notable is the lack of any statistically significant interannual variations in 16 of 25 taxa collected off Labrador (Seal Island section). This could be the result of having a single observation per year (summer) in that portion of the region, which yields wide confidence intervals in model-based estimates of abundance. On the transects sampled two to three times per year, the number of taxa showing statistically significant variations during the 9 year series ranges from 13 to 17 of 27 taxa for which model-based estimates are available. Trend analysis may be a useful tool which in the future can be used to assess changes in the pelagic ecosystem.

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Table 1. Listing of AZMP Sampling Missions in the Newfoundland and Labrador Region in 2007. The transects are Southeast Grand Banks (SEGB); Flemish Cap (FC); Trinity Bay (TB), Smith Sound (SS), Bonavista Bay (BB); Funk Island (FI); White Bay (WB); Seal Island (SI), Avalon Channel (S27), and the fixed station (Station 27). See Fig. 1 for station locations along sections and fixed coastal station. Total numbers of hydrographic (CTD) and biological (nutrients, plant pigments, phytoplankton, zooplankton, and including partial occupations) profiles provided for each seasonal section and fixed station occupations.

Mission ID	Dates	Sections/Fixed	# Hydro Stns	# Bio Stns
TEL741	Apr 11-Apr 27, 2007	SEGB, FC, BB, FI, TB, SS, S27	120	70
WT766	Aug 2-Aug 15, 2007	FC, BB, WB, SI, FI	81	46
Hud754	Nov 22-Dec 5, 2007	SEGB, FC, BB, TB	66	46
Fixed	Jan-Dec 2007	Station 27	48	21

Table 2. Seasonal and interannual significance levels for inventories of chlorophyll a (0-100 m integral), near-surface and deep inventories of silicate and nitrate (0-50 m and 50-150 m integrals), vertical light attenuation and euphotic depth based on the results of the generalized linear model that included year and station identifier as categorical variables during 2000-07. NS = not significant.

Chlorophyll (0-100 m)	Annual
Southeast Grand Banks	<0.05
Flemish Cap	<0.05
Bonavista Bay	<0.001
Seal Island	<0.05
Fixed Station	NS
Surface Nitrate (0-50 m)	
Southeast Grand Banks	<0.001
Flemish Cap	<0.001
Bonavista Bay	<0.001
Seal Island	<0.05
Fixed Station	NS
Deep Nitrate (50-150 m)	
Southeast Grand Banks	NS
Flemish Cap	<0.001
Bonavista Bay	<0.001
Seal Island	NS
Fixed Station	NS

Table 3. Type I sum of squares of weight-dependent log-transformed abundance spectra for each transect. Analyses included a year (categorical effect), log-transformed weight, and an interaction term. Black bold-faced values are significant ($p < 0.05$), grey bold-faced values are marginally significant ($0.1 > p > 0.05$).

	SE Grand Banks	Flemish Cap	Bonavista Bay	Seal Island
<i>Spring</i>				
Year	71.6	76.5	54.2	
Ln (W)	316.7	333.8	113.7	
Interaction		4.13	2.67	
Error	1090.4	1119.8	718.7	
<i>Summer</i>				
Year		59.1	18.2	93.4
Ln (W)		149.5	123.8	119.6
Interaction		9.49	2.56	6.50
Error		1053.8	405.6	347.9
<i>Autumn</i>				
Year	28.3	11.3	50.0	
Ln (W)	155.9	166.5	90.0	
Interaction	8.38	4.03	7.54	
Error	756.3	948.8	737.8	

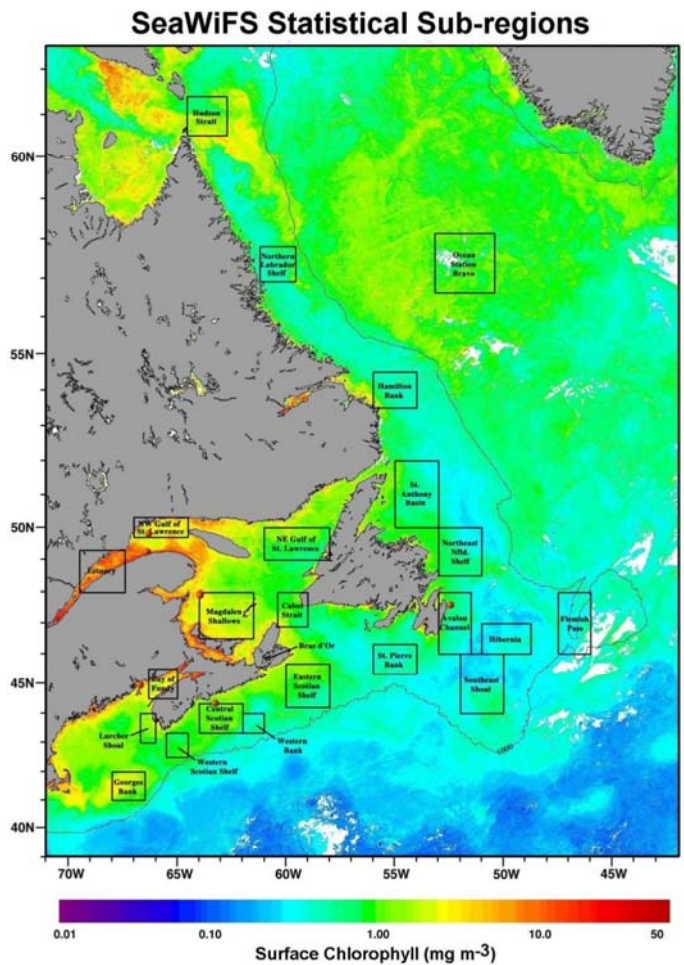
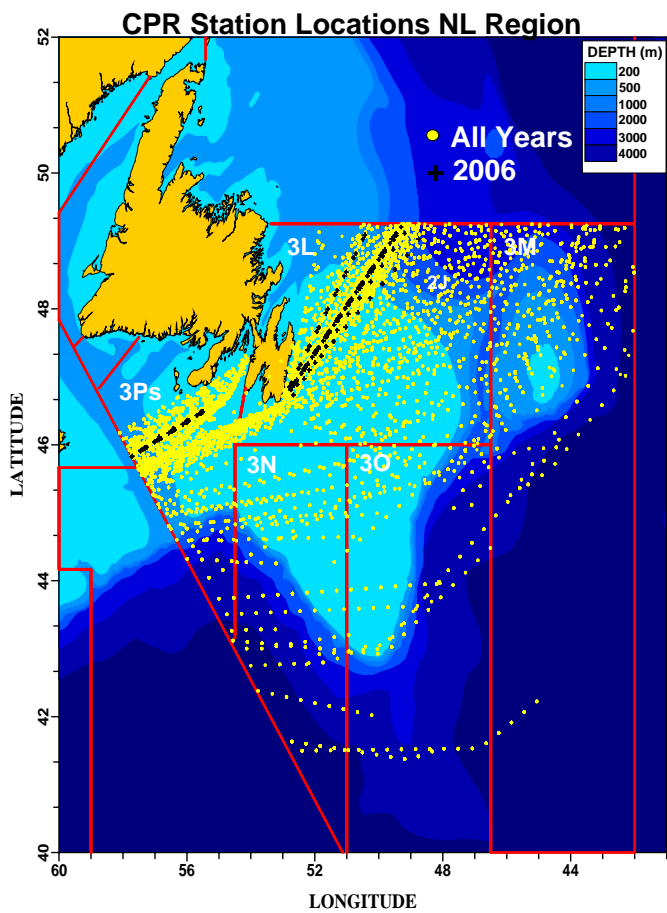


Figure 1. Station location for the continuous plankton recorder (CPR) during 1961-2006, and statistical sub-regions in the Northwest Atlantic for analysis of surface chlorophyll *a* from SeaWiFS ocean colour imagery.

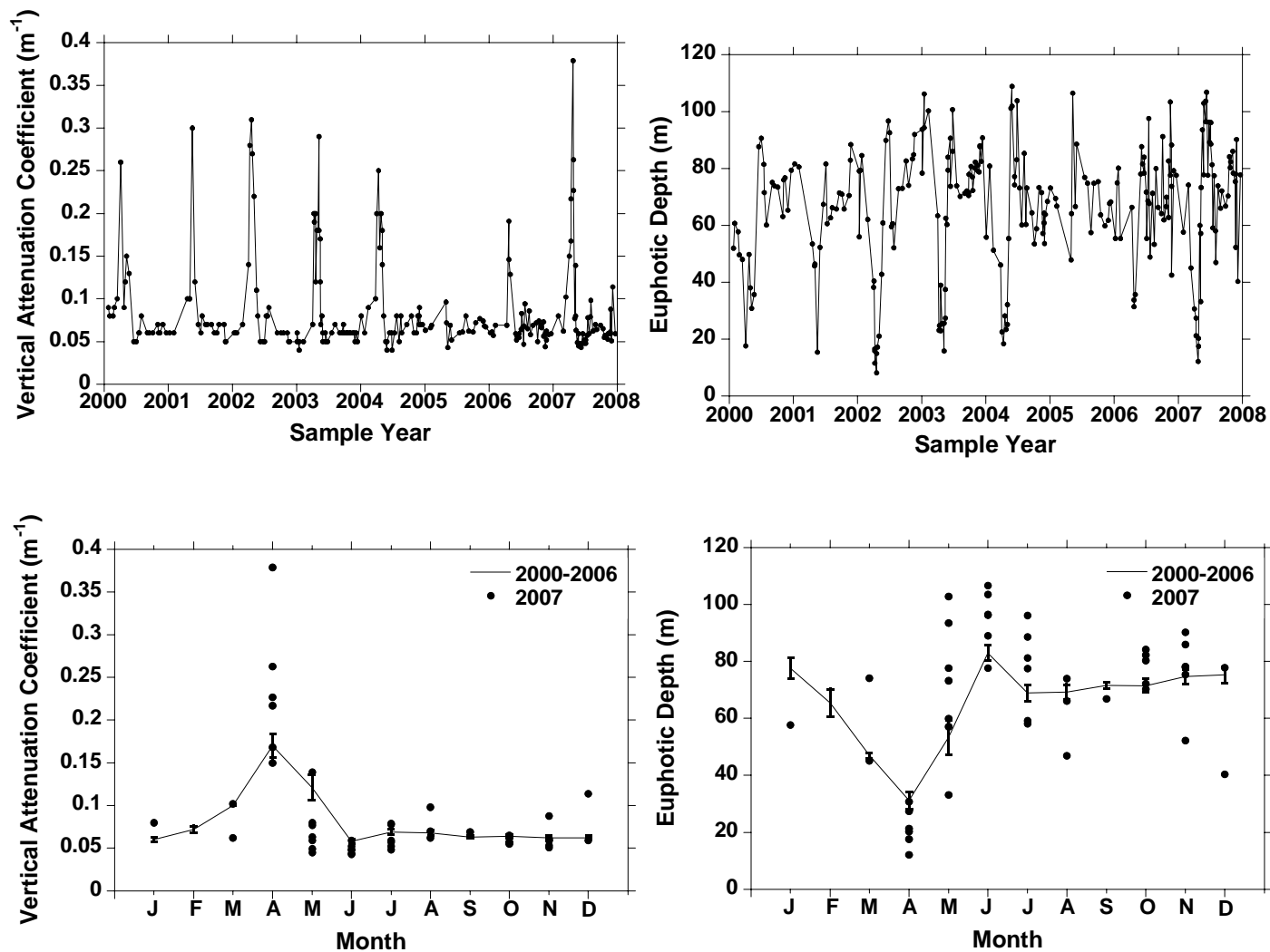


Figure 2. Time series of the vertical attenuation coefficient and euphotic depth (depth of 1 % light) at Station 27 (upper panels), compared with the seasonal cycle from 2000 to 2007 data (lower panels).

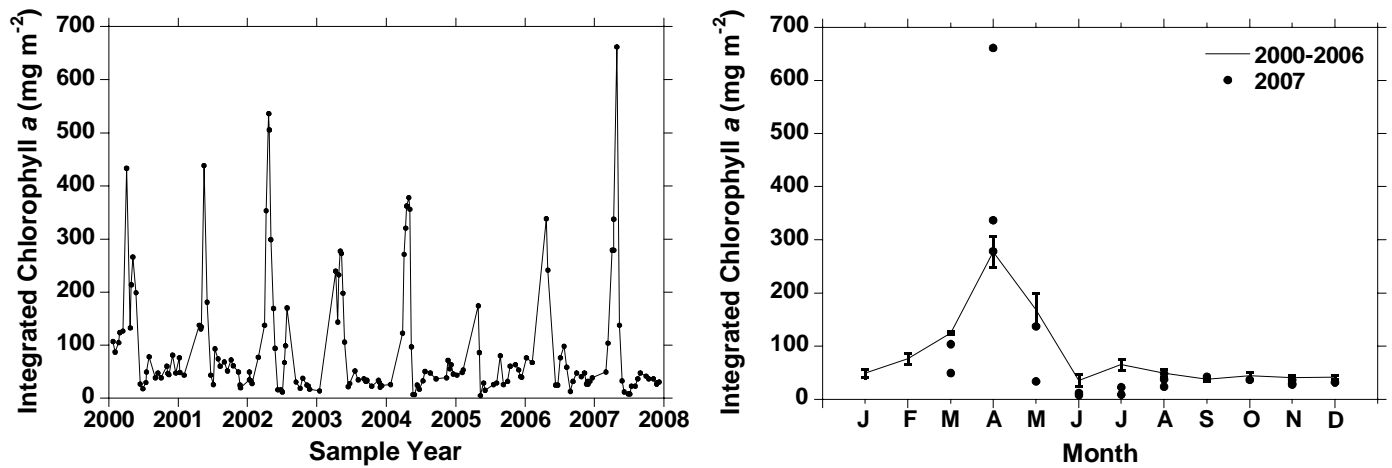
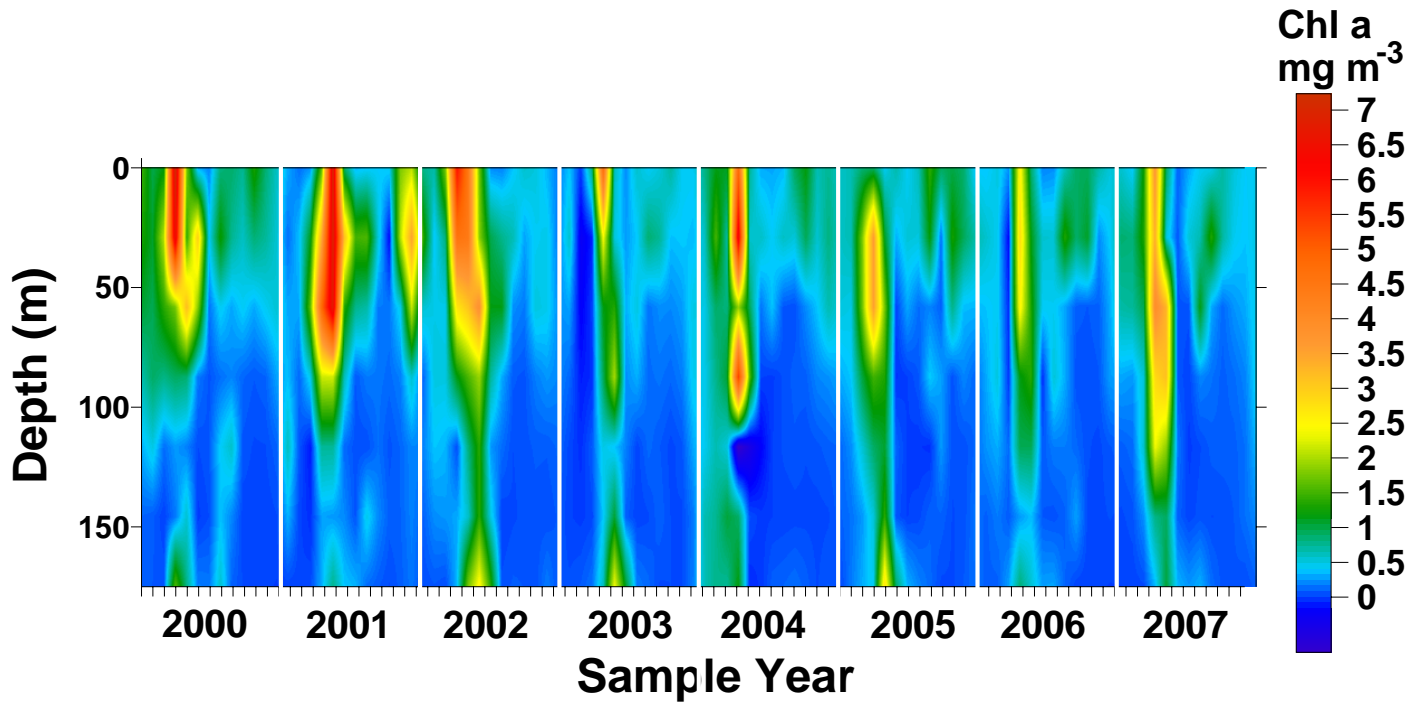


Figure 3. Time series of vertical chlorophyll *a* structure (upper panel), inventories (surface–100 m integrals; lower left panel), and seasonal cycle (lower right panel) from 2000 to 2007 data at Station 27.

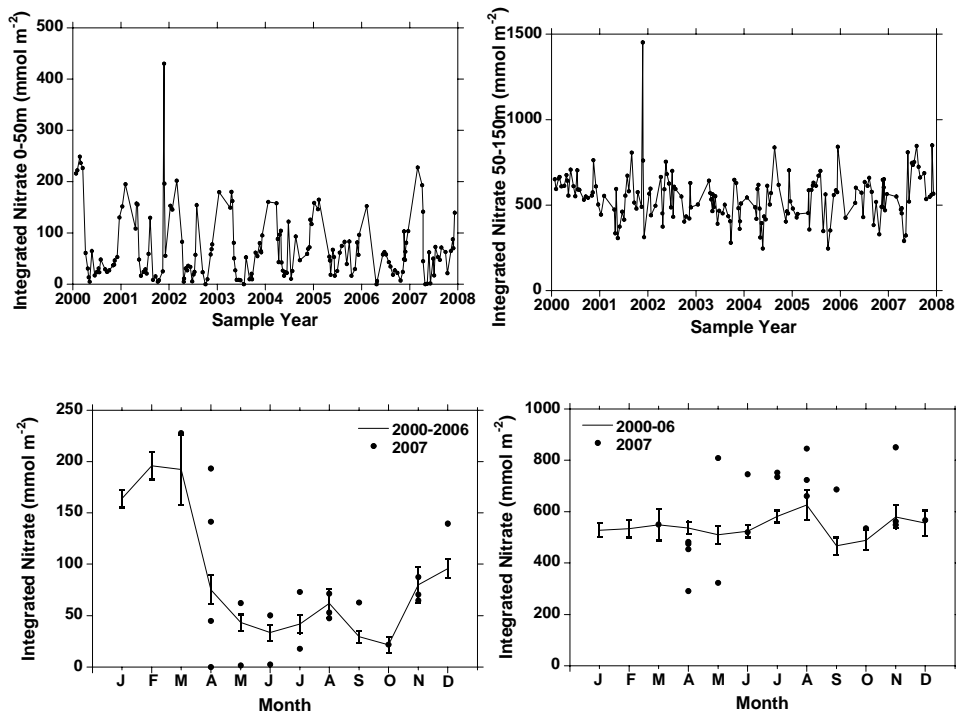
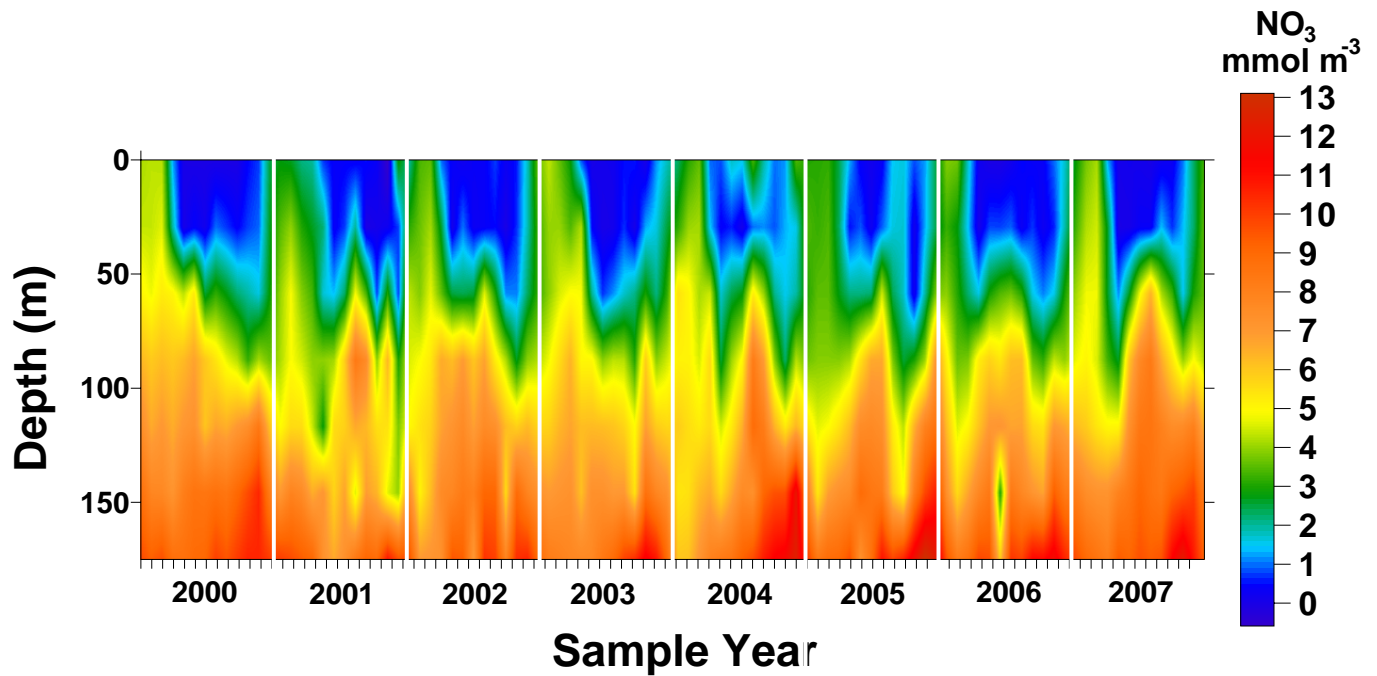


Figure 4. Time series of vertical nitrate structure (upper panel), shallow and deep nitrate inventories (surface–50 m and 50–150 m integrals; middle panels), and corresponding seasonal cycles (lower panels) from 2000 to 2007 data at Station 27.

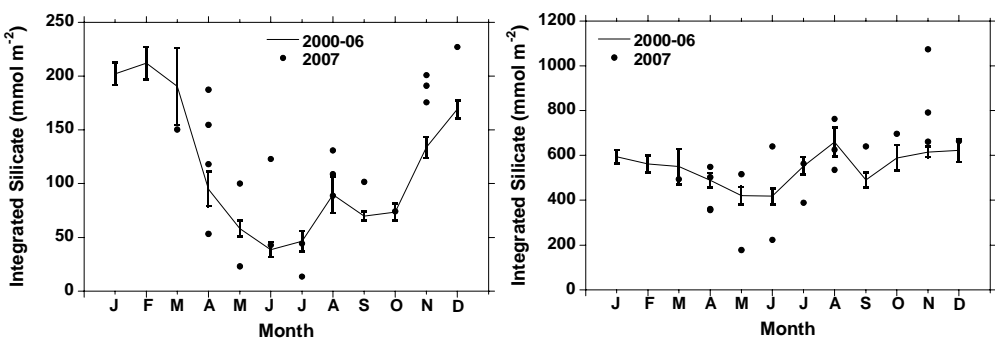
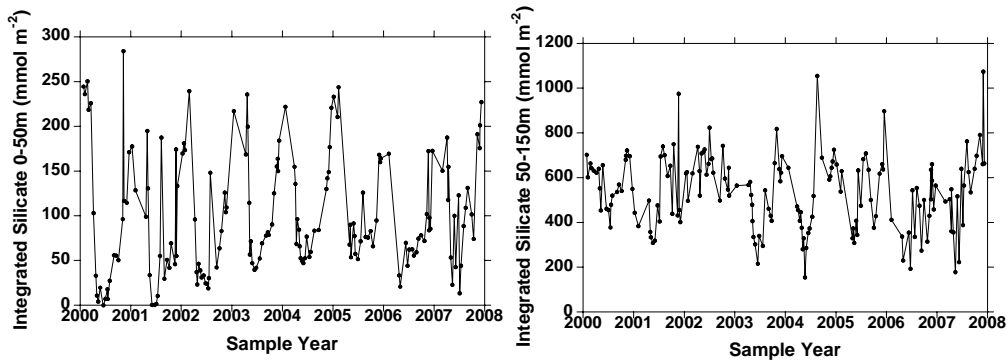
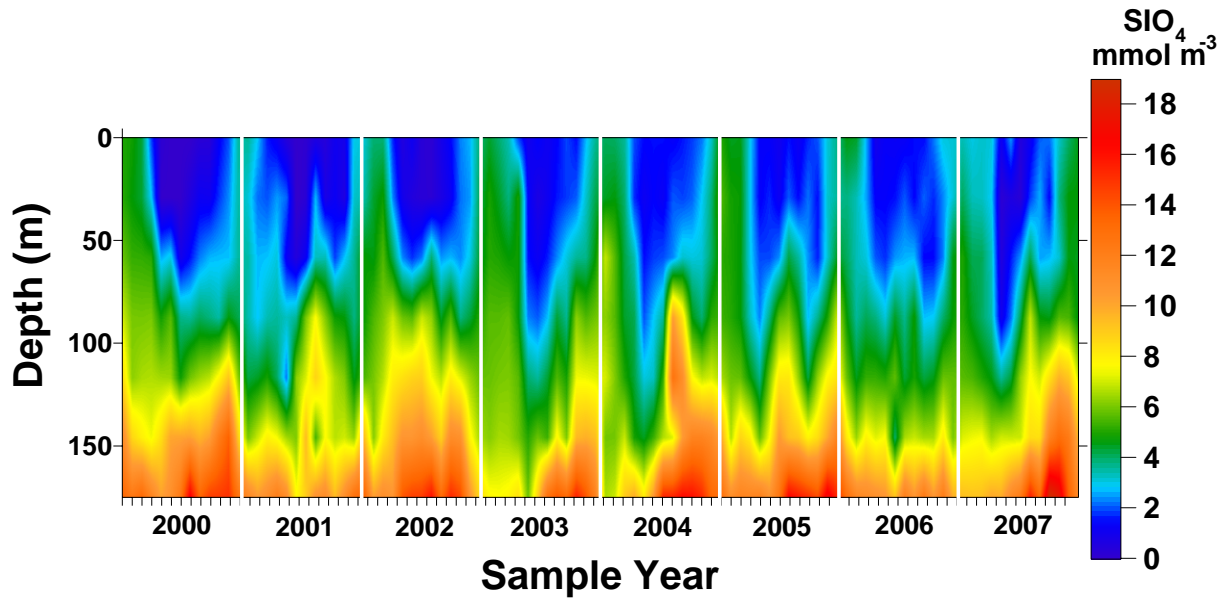


Figure 5. Time series of vertical silicate structure (upper panel), shallow and deep silicate inventories (surface–50 m and 50-150 m integrals; middle panels), and corresponding seasonal cycles (lower panels) from 2000 to 2007 data at Station 27.

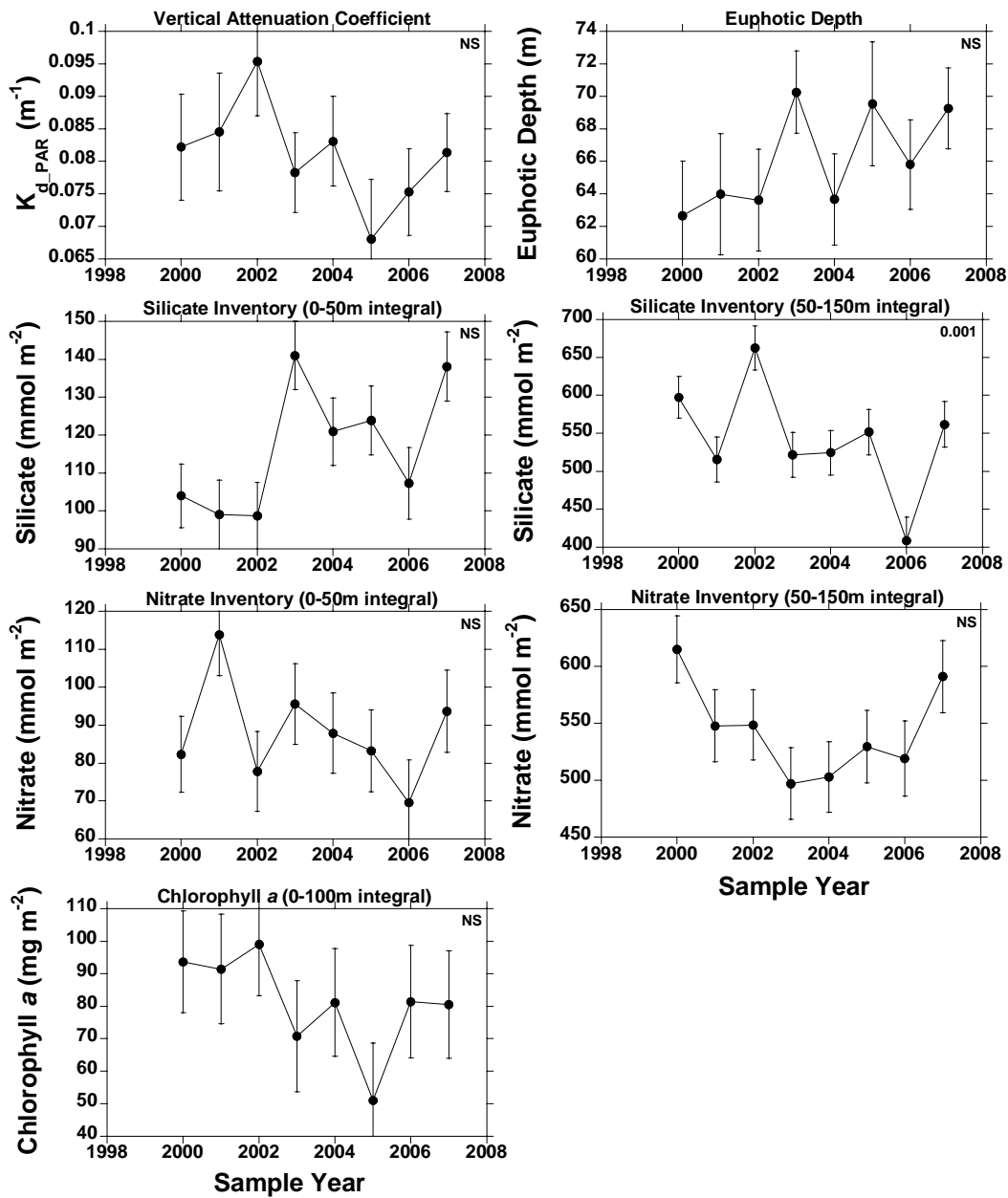


Figure 6. Seasonally-adjusted annual mean estimates (\pm standard error) of optical, chemical, and biological properties for Station 27 during 2000-07. Significance levels of the overall year effect are in the upper right-hand corner.

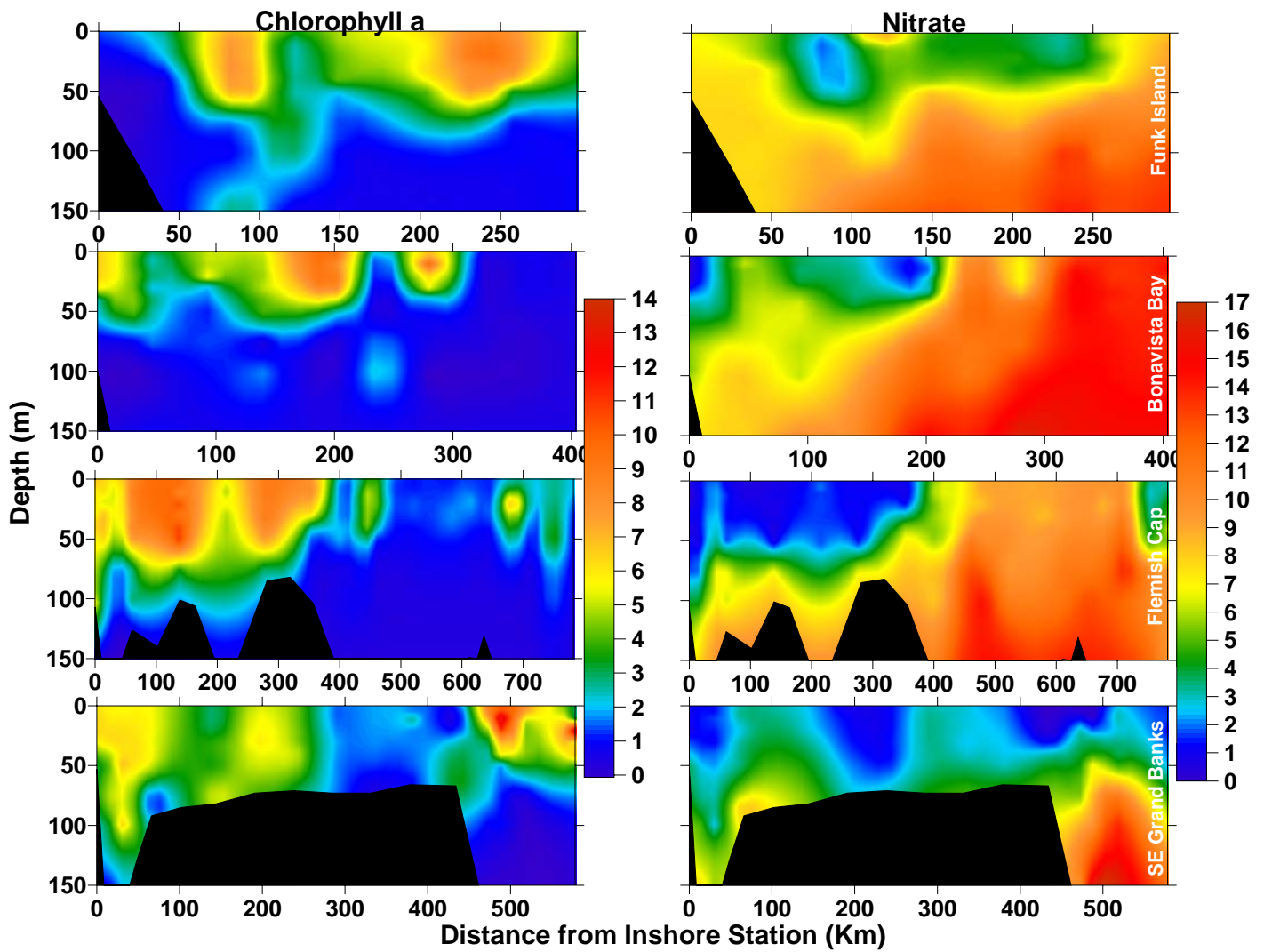


Figure 7. Vertical chlorophyll *a* (mg m^{-3}) and nitrate (mmol m^{-3}) structure along the Newfoundland Shelf sections during the spring Teleost survey in 2007.

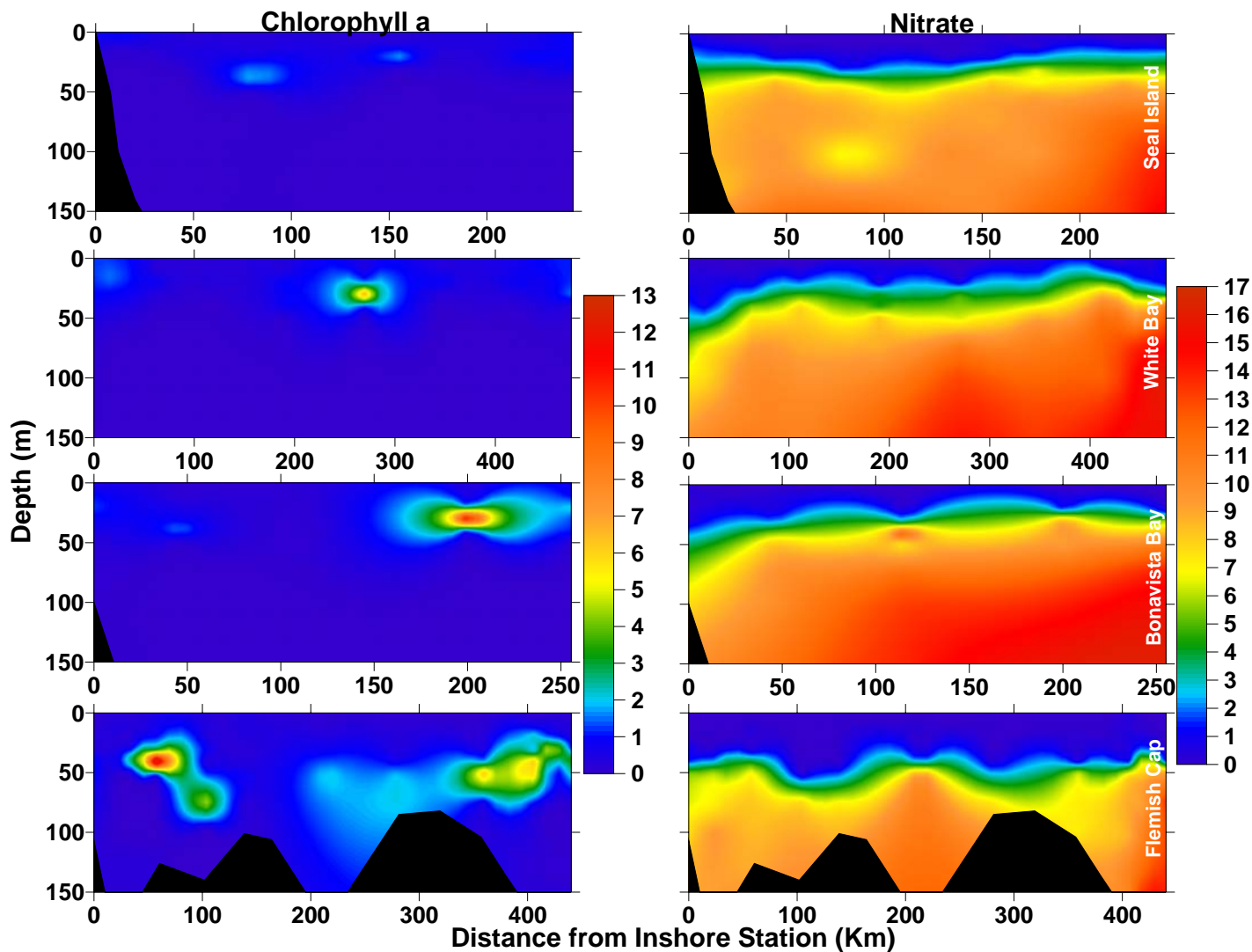


Figure 8. Vertical chlorophyll a (mg m^{-3}) and nitrate (mmol m^{-3}) structure along the Newfoundland and Labrador Shelf sections during the summer *R.V. W. Templeman* survey in 2007.

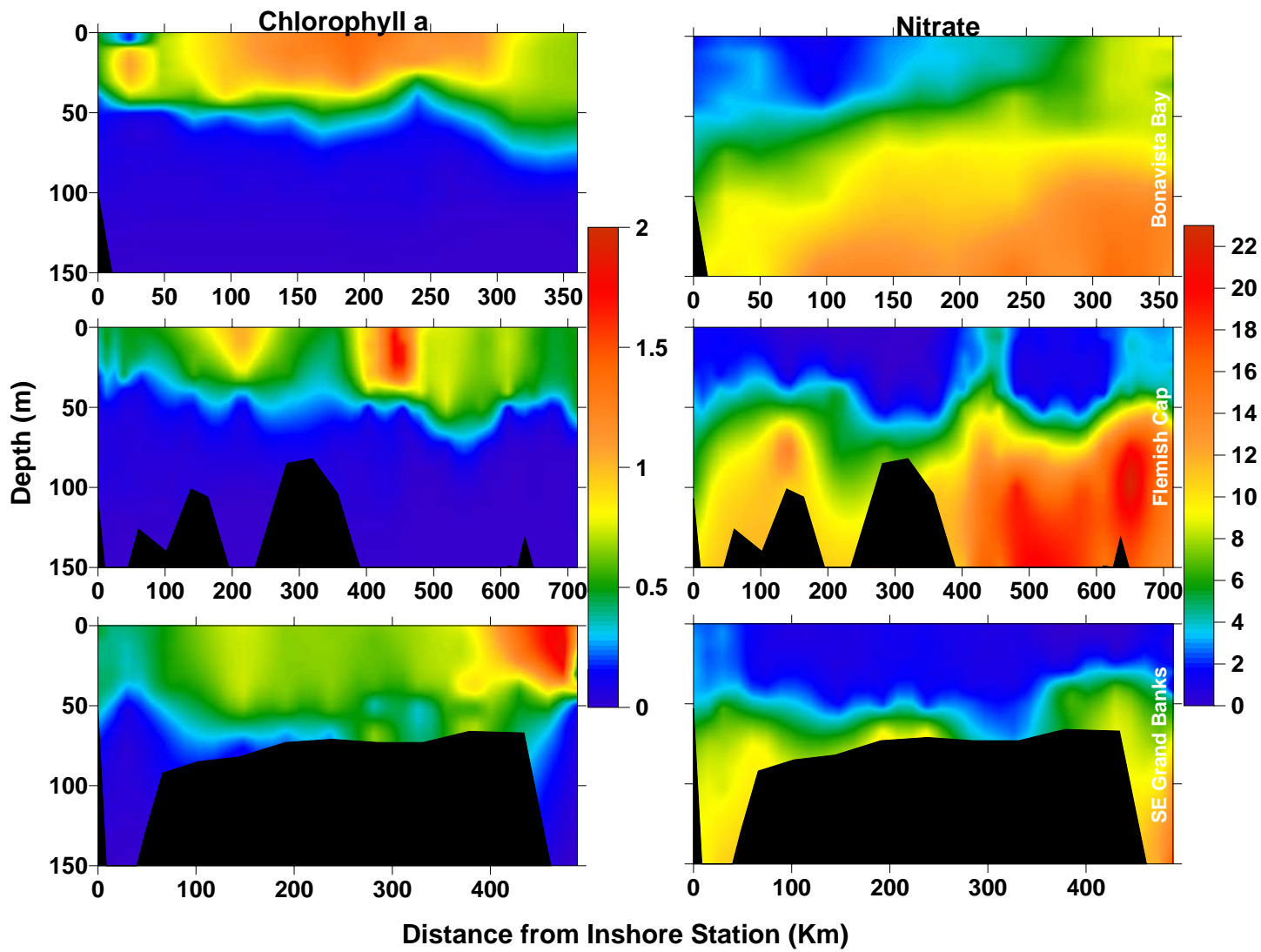


Figure 9. Vertical chlorophyll a (mg m^{-3}) and nitrate (mmol m^{-3}) structure along the Newfoundland Shelf sections during the autumn *R.V. Hudson* survey in 2007.

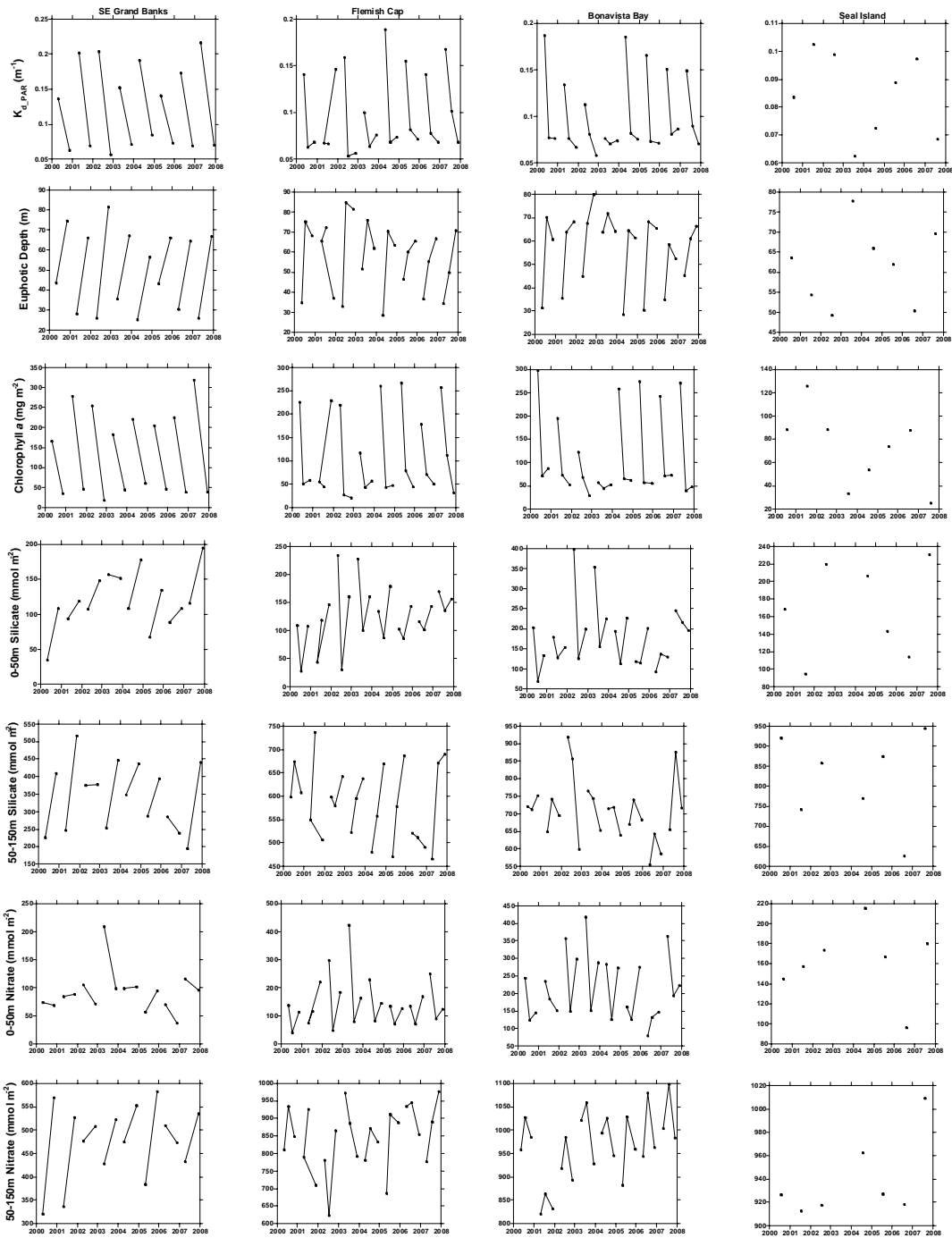


Figure 10. Seasonal mean vertical attenuation coefficient (K_{d_PAR}), euphotic depth (Z_{eu}), integrated chlorophyll (0-100 m), silicate and nitrate inventories (0-50 m and 50-150 m integrals) for the four oceanographic transects. Seasonal transect means are based on the results of a generalized linear 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.

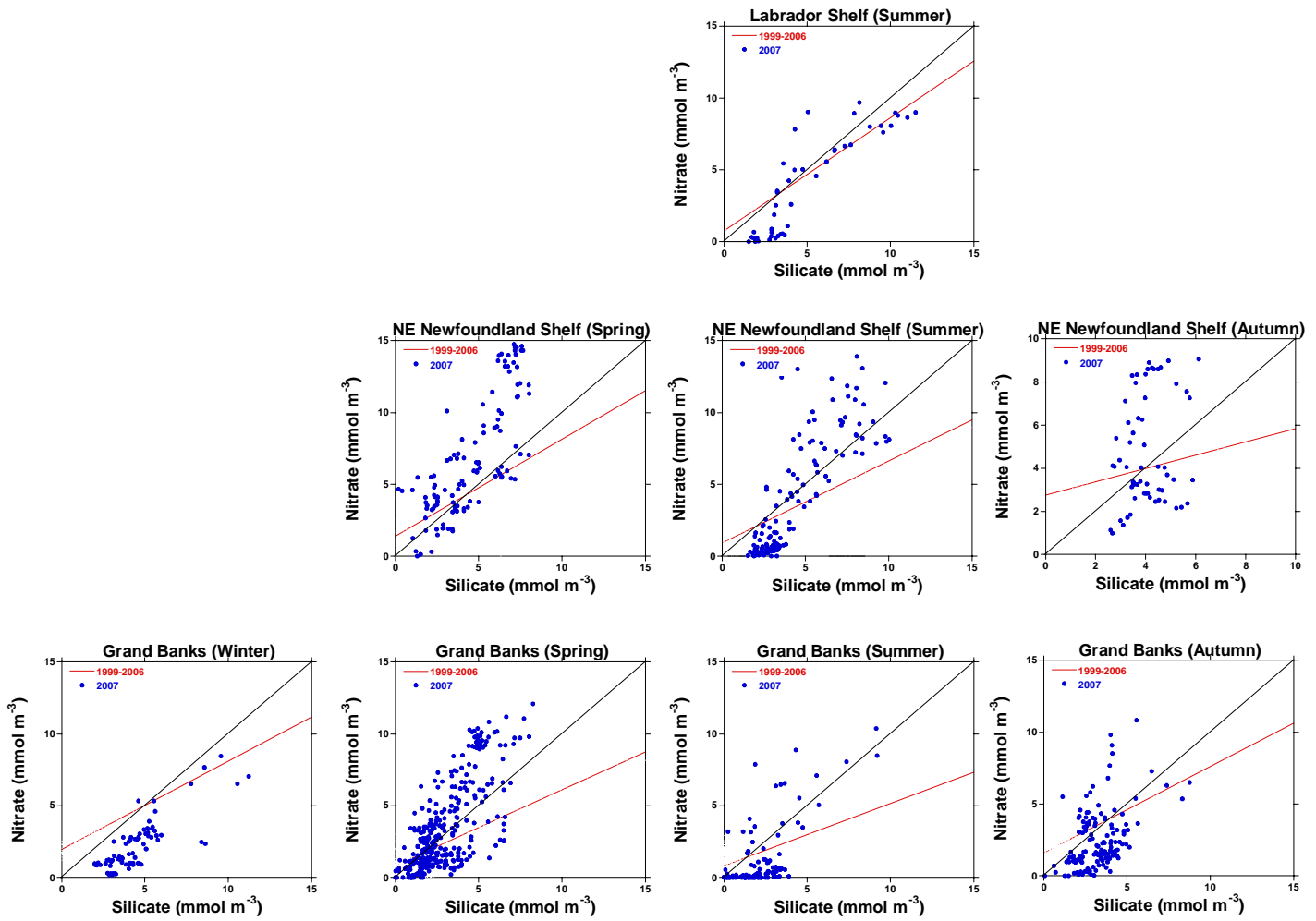


Figure 11. Seasonal variability in near-surface (upper 60 m) concentrations of silicate and nitrate on the Newfoundland and Labrador Shelf during 2007. Solid black line indicates the Redfield Ratio, and solid red line is the linear best fit for 1999-2006.

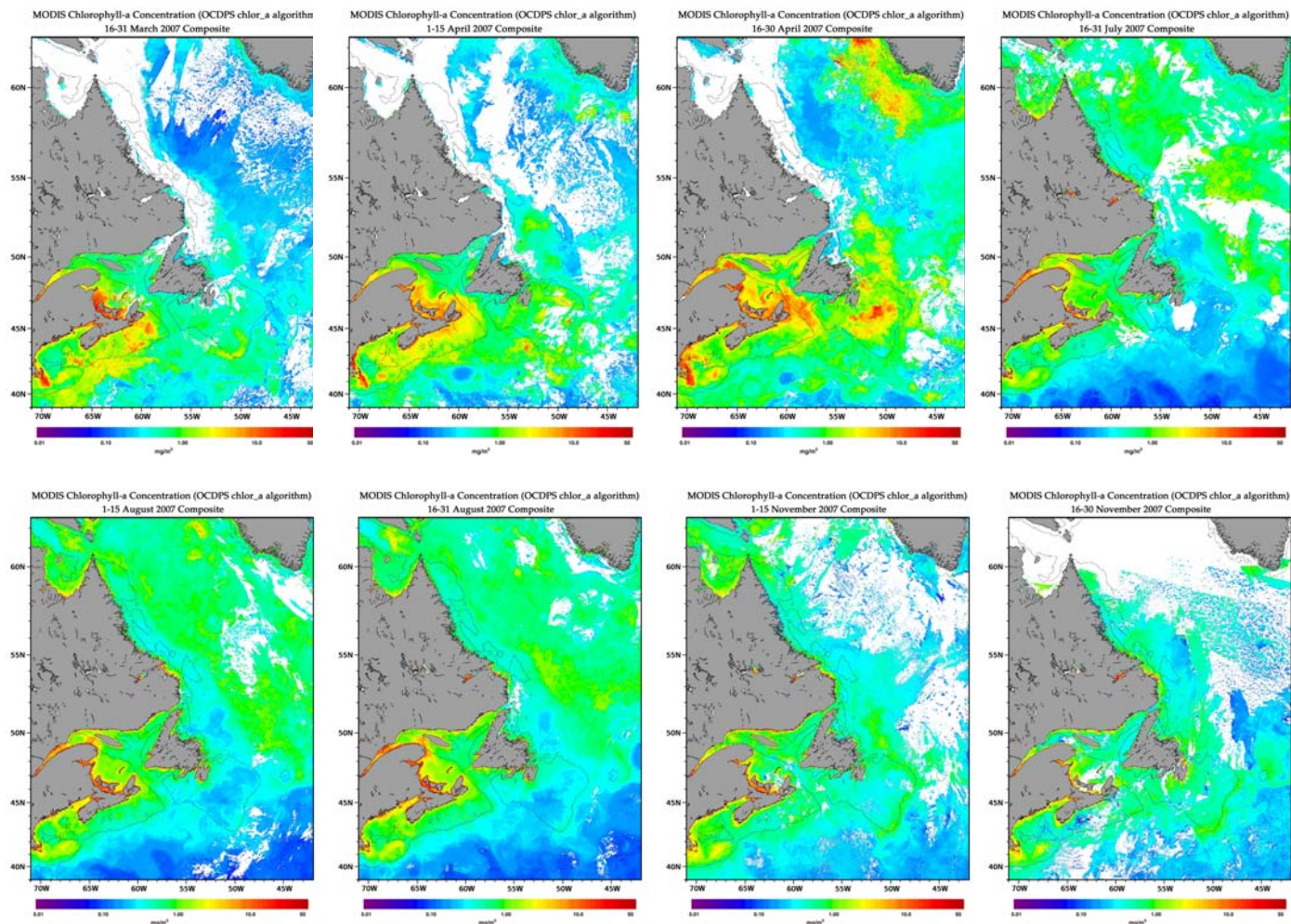


Figure 12. MODIS semi-monthly composite images of surface chlorophyll a concentrations in the NW Atlantic region during AZMP seasonal surveys in 2007. Data resolution is approximately 2 km resolution.

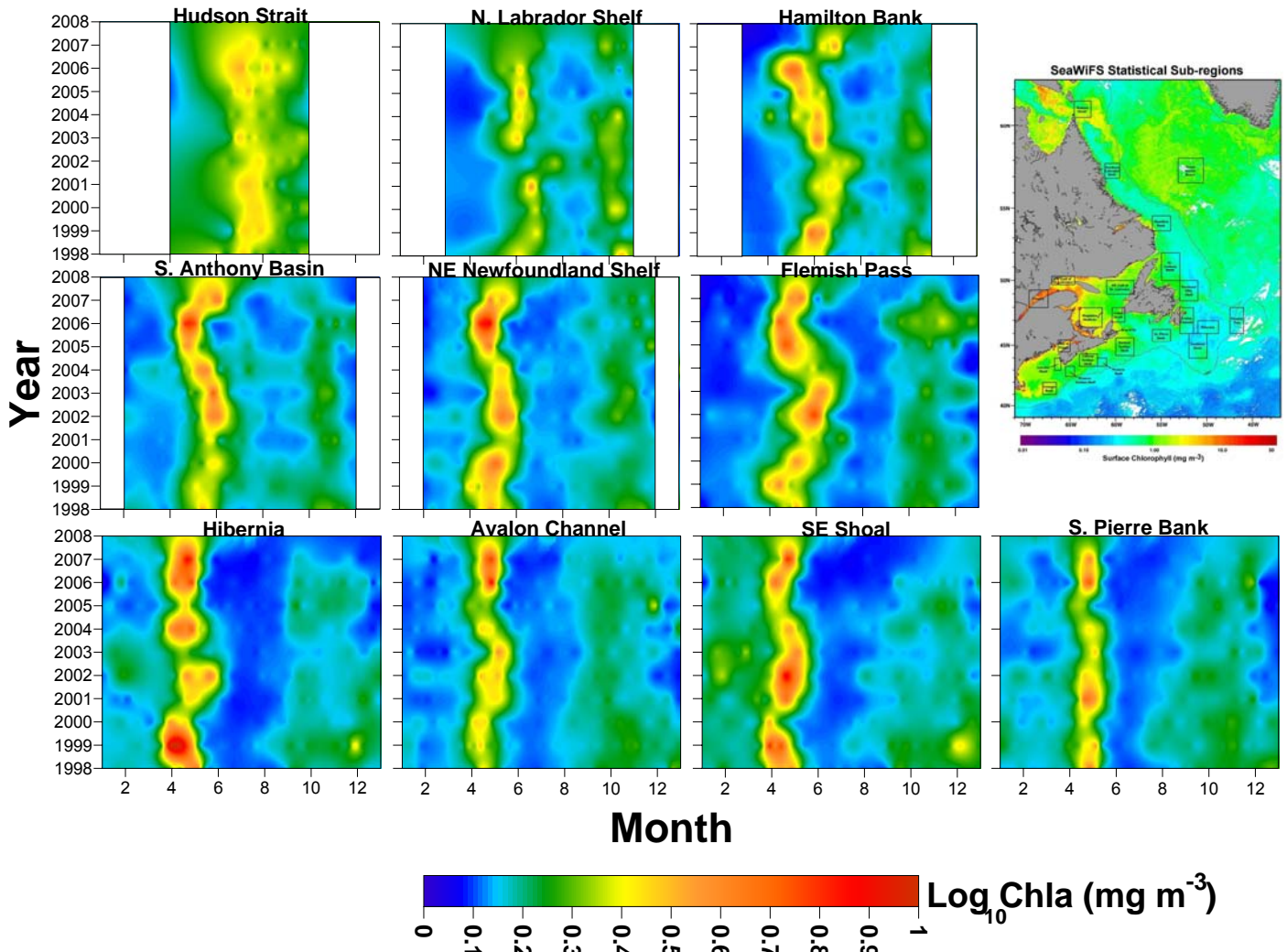


Figure 13. Time series of mean surface chlorophyll a concentrations from SeaWiFS weekly (4 km resolution) ocean colour composites for statistical sub-regions in the Newfoundland and Labrador region during 1998-2007. The locations of the statistical sub-regions are provided.

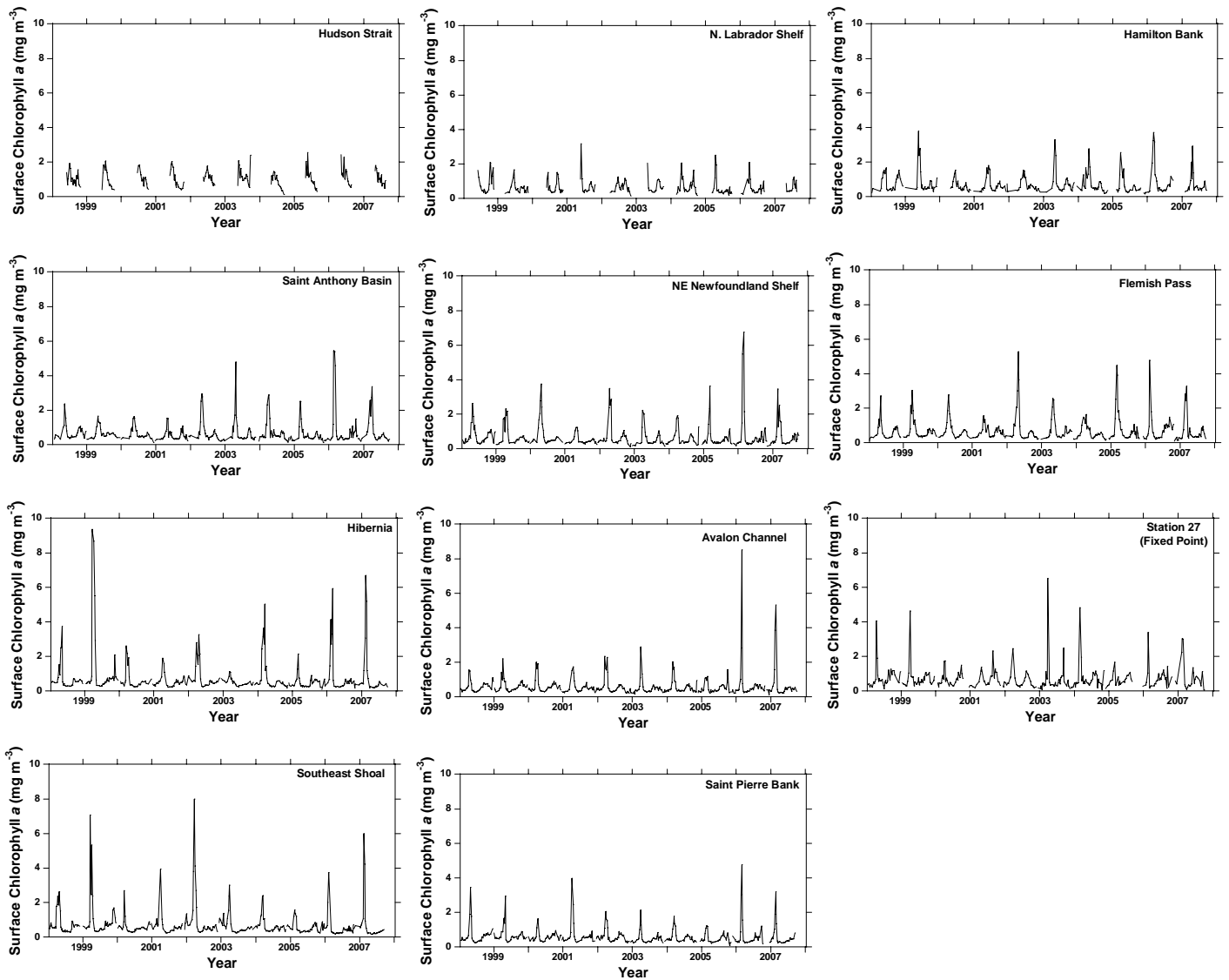


Figure 14. Time series of surface chlorophyll *a* concentrations from weekly SeaWiFS ocean colour composites (4 km resolution) for statistical sub-regions of the Newfoundland and Labrador region 1998-2007. See Fig. 1 for locations of statistical sub-regions in NL.

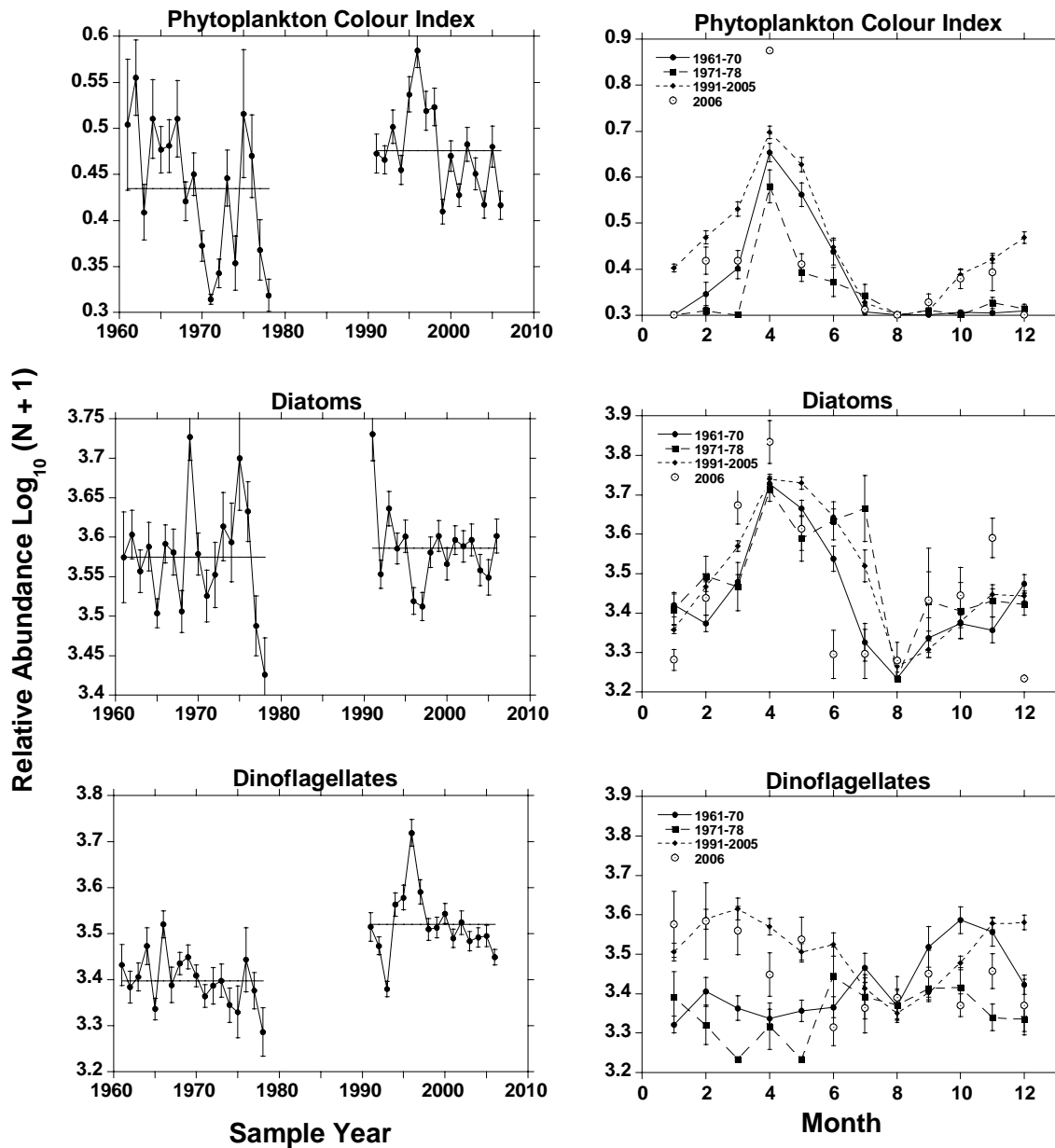


Figure 15. Time series of relative CPR phytoplankton biomass (phytoplankton colour index – PCI), and diatom and dinoflagellate relative annual abundances (overall means during 1961-78 and 1991-2005 are shown as solid lines) and corresponding seasonal cycle on the Grand Banks and northeast Newfoundland Shelf (NAFO Div. 3LMNOPs) from CPR surveys during 1961-2006. Monthly means for the 1960s, 1970s, 1991-2005, and sample year 2006 shown for comparison. Vertical bars are standard errors.

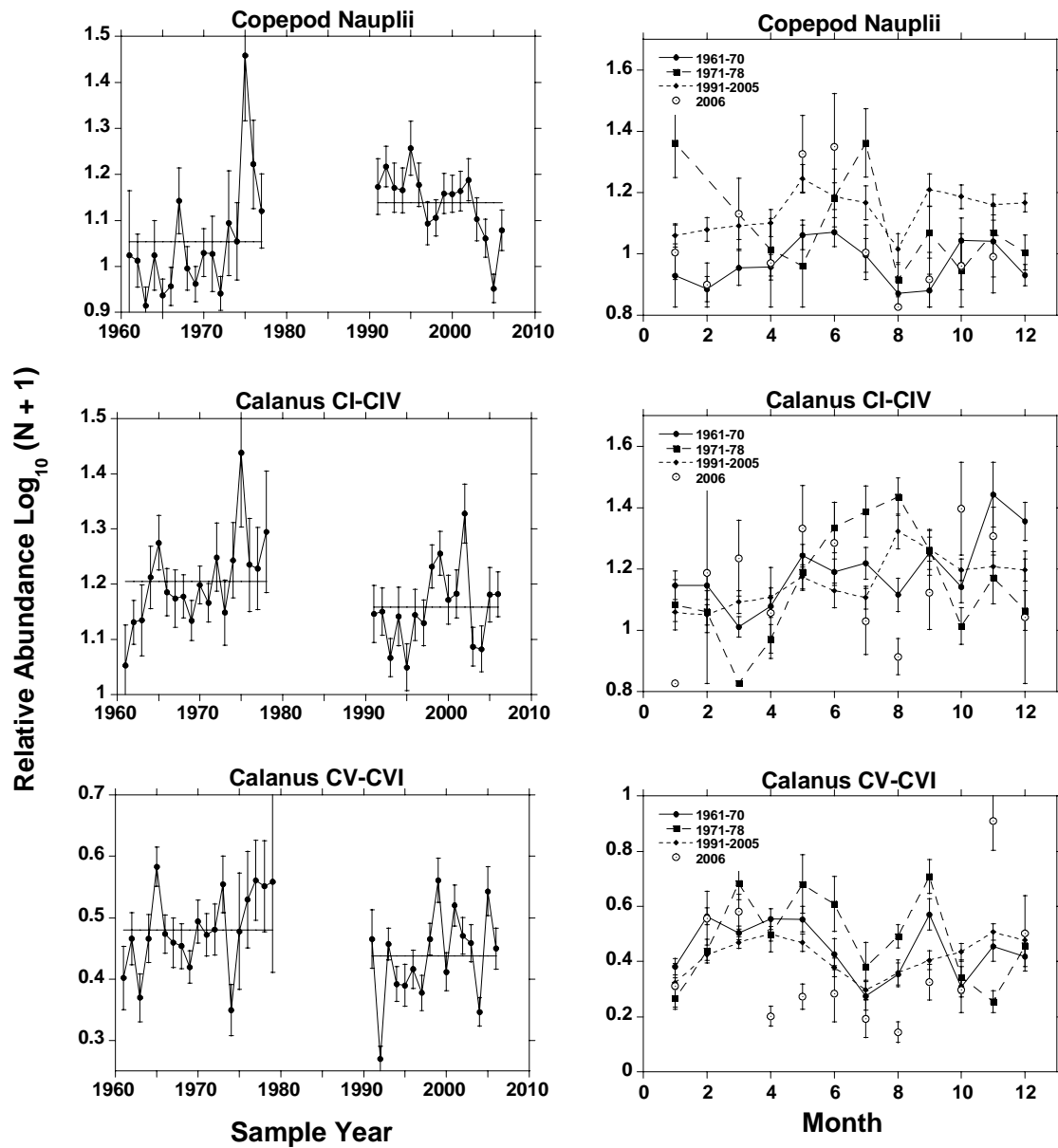


Figure 16. Time series of different life stages of CPR calanoid copepods; nauplii stages (larvae) Calanus CI-IV (copepodite, or juvenile stages), and Calanus CV-VI (last juvenile and adult stages) relative annual abundances (overall means during 1961-78 and 1991-2005 are shown as solid lines) and corresponding seasonal cycle on the Grand Banks and northeast Newfoundland Shelf (NAFO Div. 3LMNOPs) from CPR surveys during 1961-2006. Monthly means for the 1960s, 1970s, 1991-2005, and sample year 2006 shown for comparison. Vertical bars are standard errors.

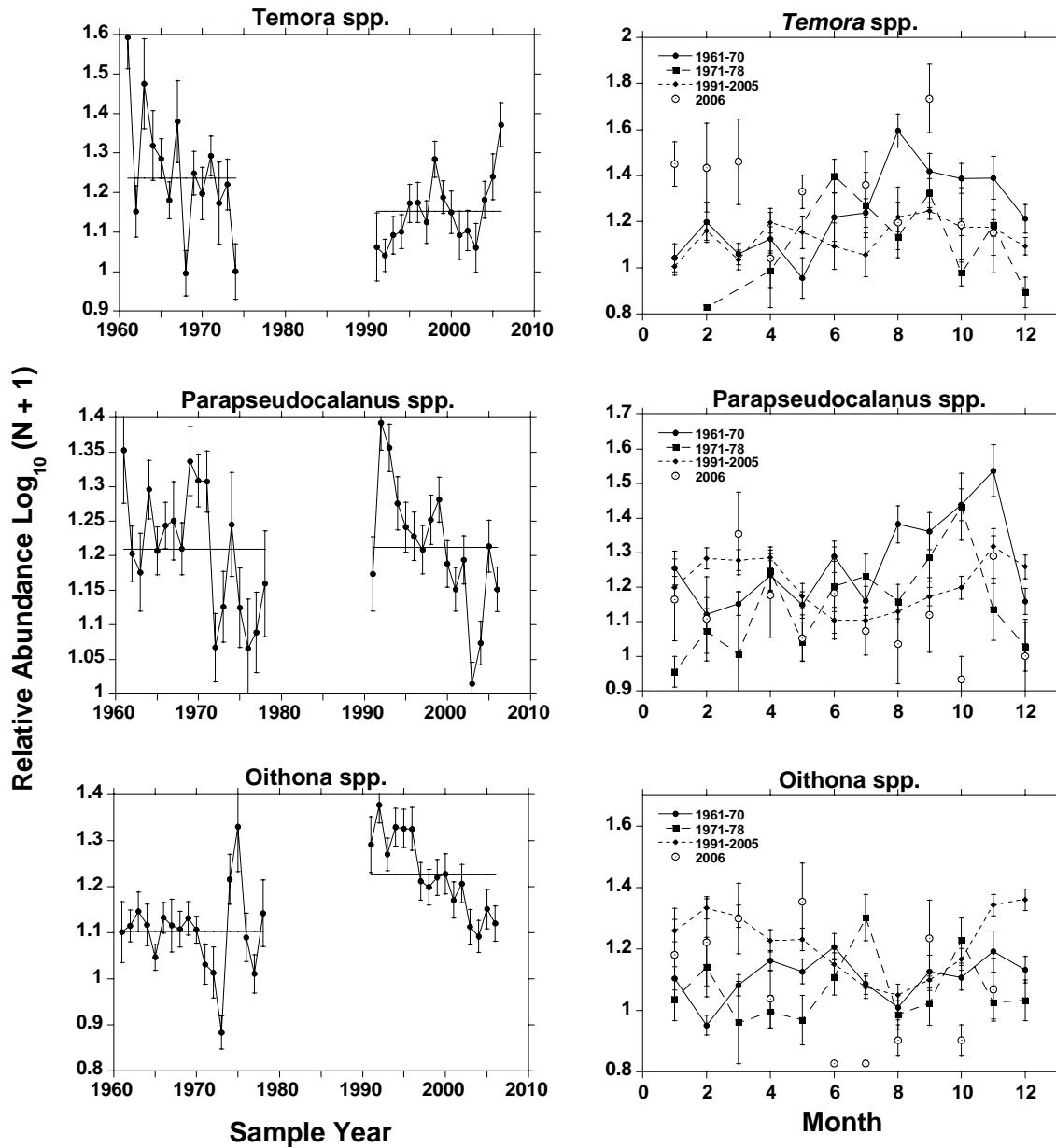


Figure 17. Time series of relative annual abundances of selected CPR copepods and corresponding seasonal cycle on the Grand Banks and northeast Newfoundland Shelf (NAFO Div. 3LMNOPs) from CPR surveys during 1961-2006. Monthly means for the 1960s, 1970s, 1991-2005, and the 2006 sample year are shown for comparison. Vertical bars are standard errors.

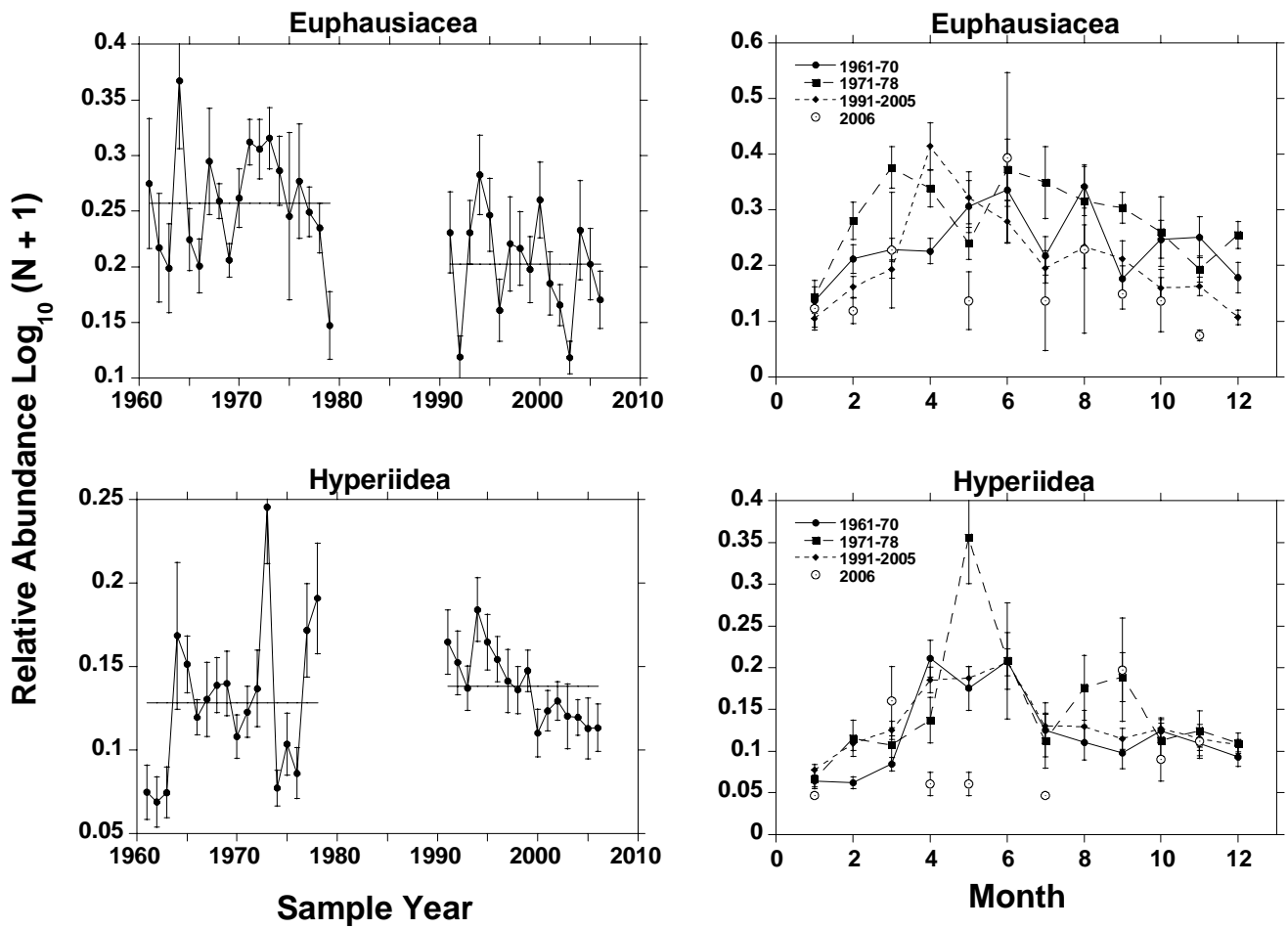


Figure 18. Time series of relative annual abundances of selected CPR macrozooplankton and corresponding seasonal cycle on the Grand Banks and northeast Newfoundland Shelf (NAFO Div. 3LMNOPs) from CPR surveys during 1961-2006. Monthly means for the 1960s, 1970s, 1991-2005, and the 2006 sample year are shown for comparison. Vertical bars are standard errors.

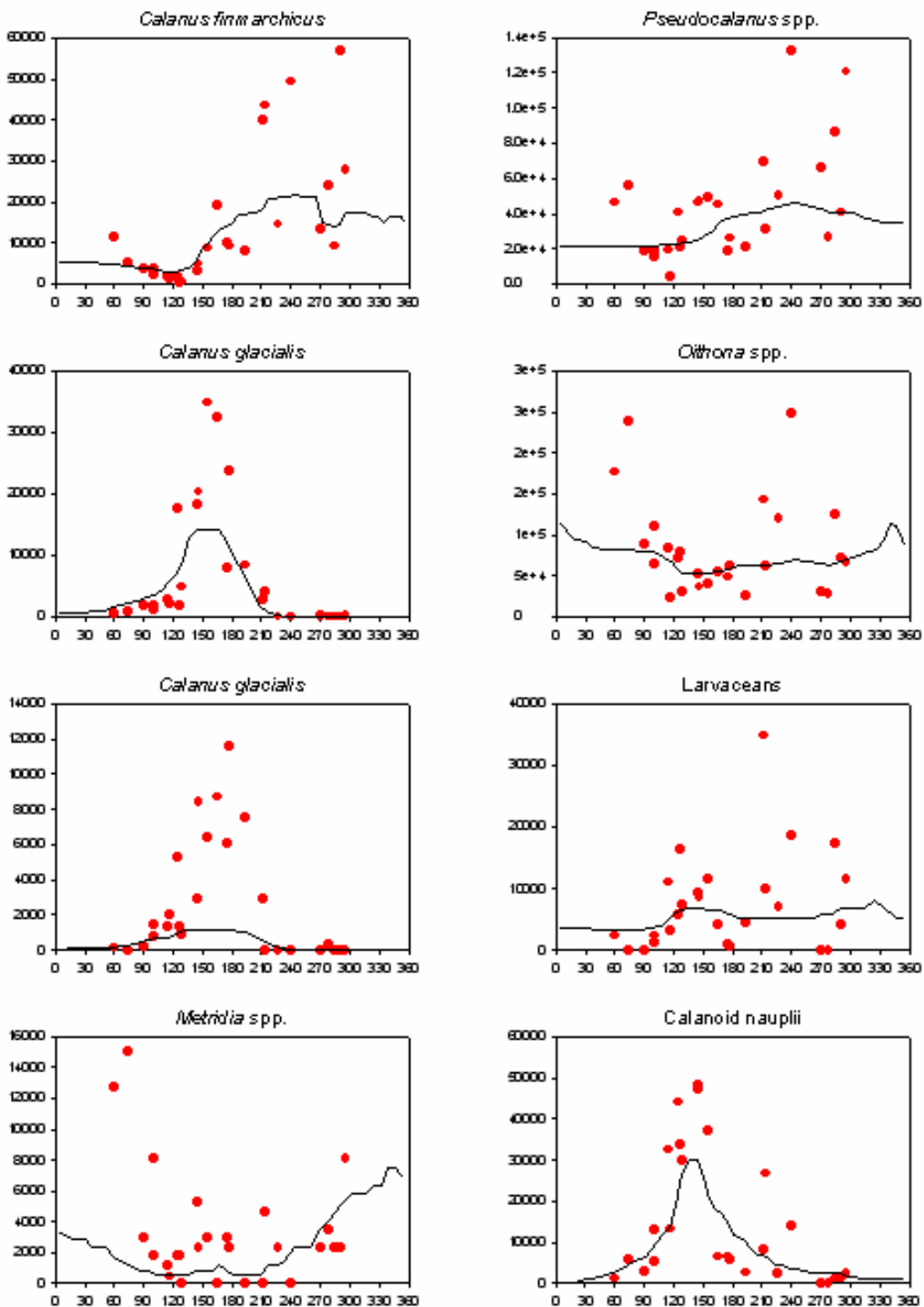


Figure 19. Seasonal cycle in abundance of eight dominant taxa from Station 27. The thick black line represents the median abundance estimated using non-parametric local density estimators based on all observations 1999-2007; the solid red circles represent the observations for 2007.

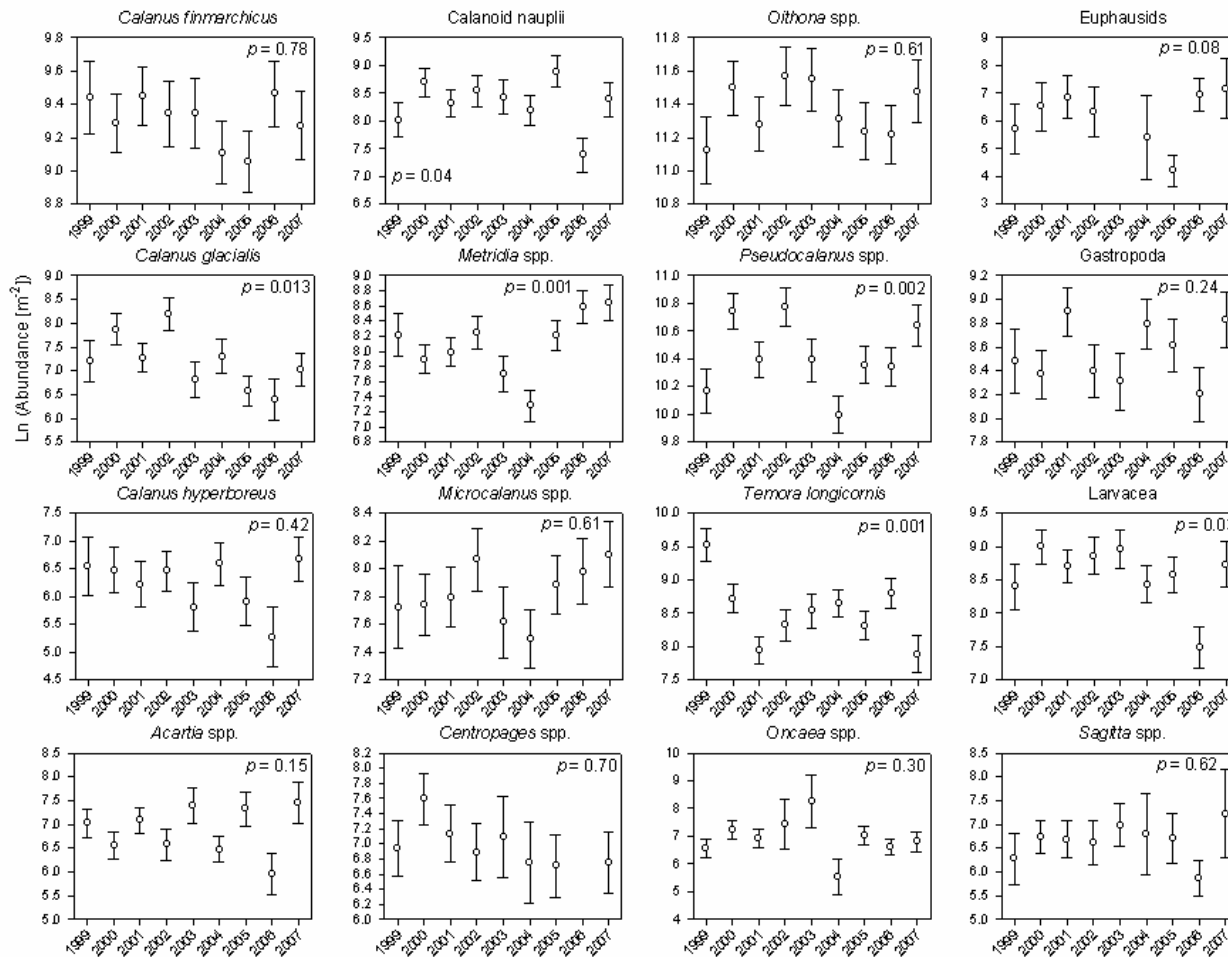


Figure 20. Seasonally-adjusted estimate of the mean abundance of twelve dominant zooplankton taxa from Station 27 for the period 1999-2007. The error bars represent standard errors. The p -value in the upper right hand corner indicates the probability of significant interannual variations in abundance based on type III sums of squares.

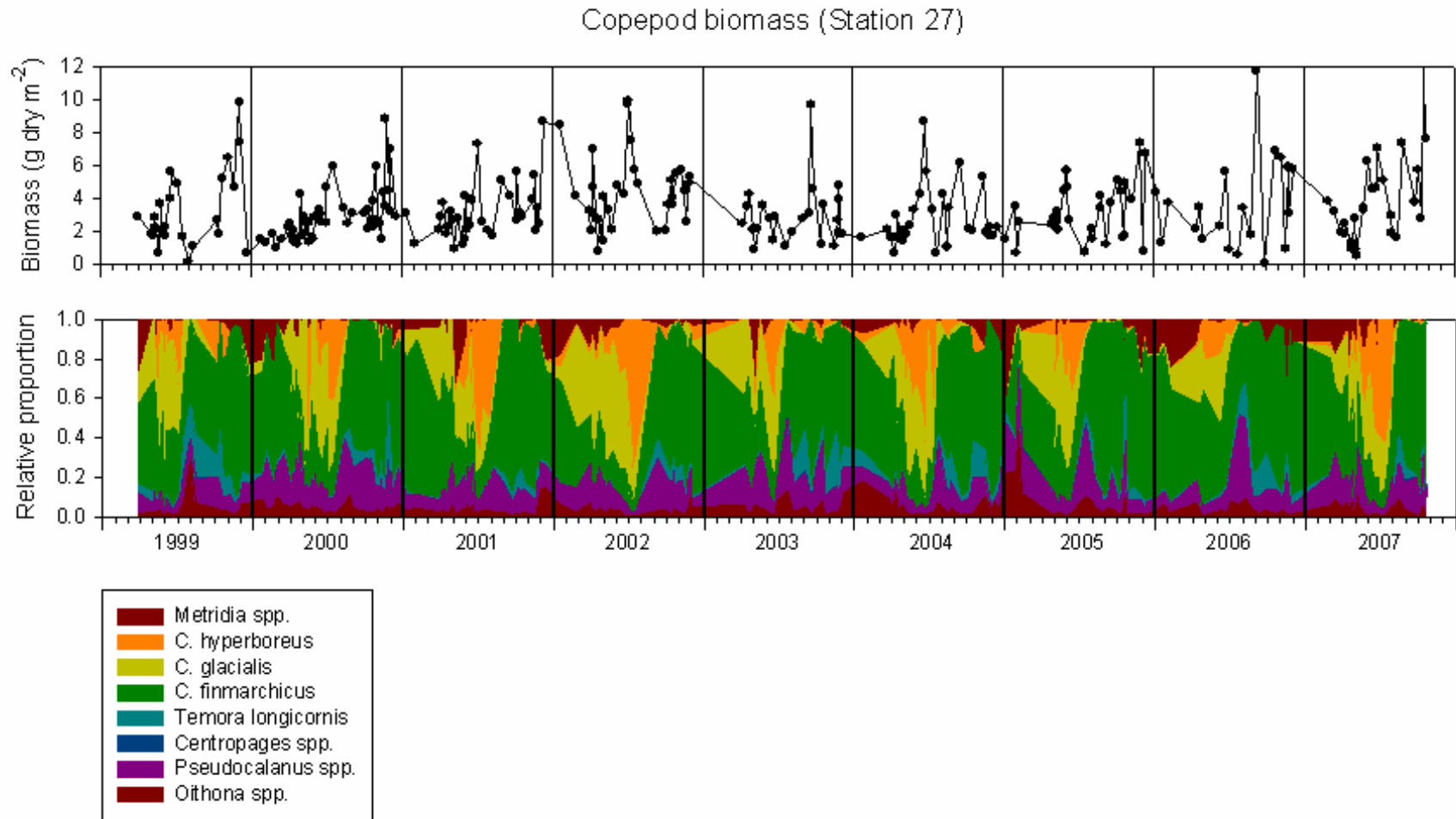


Figure 21. Seasonal cycle of total biomass and species distribution of the dominant copepods at Station 27 for the period 1999-2007. The vertical order of the species in the lower panel is the same as in the legend.

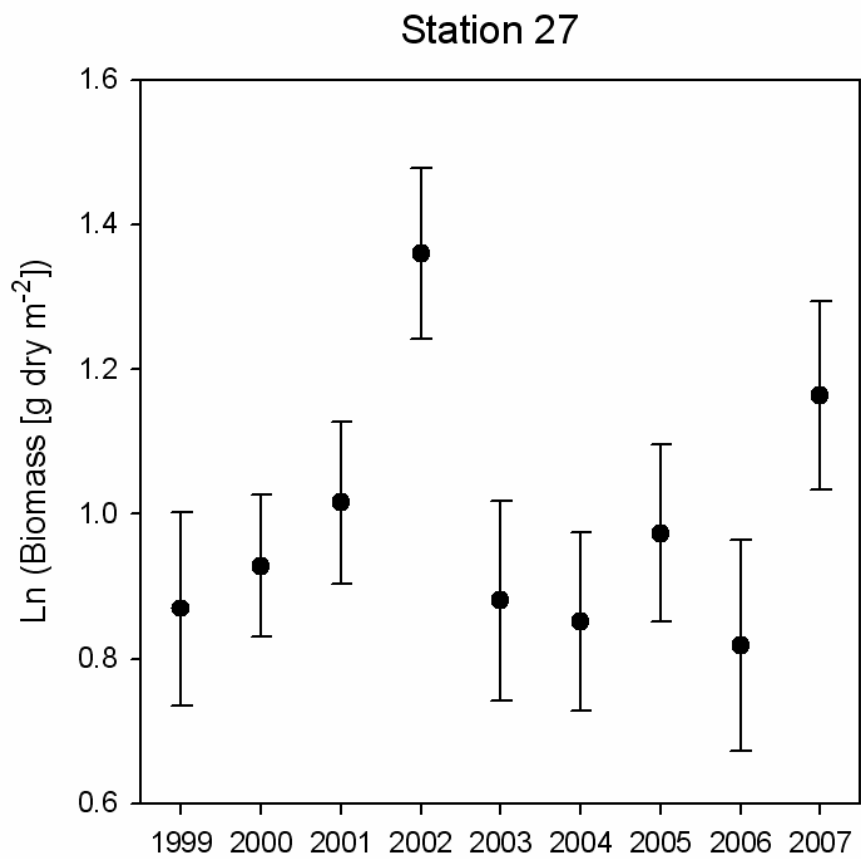


Figure 22. Seasonally-adjusted estimates of the mean biomass of 8 dominant copepod species from Station 27 for the period 1999-2007. The error bars represent standard errors.

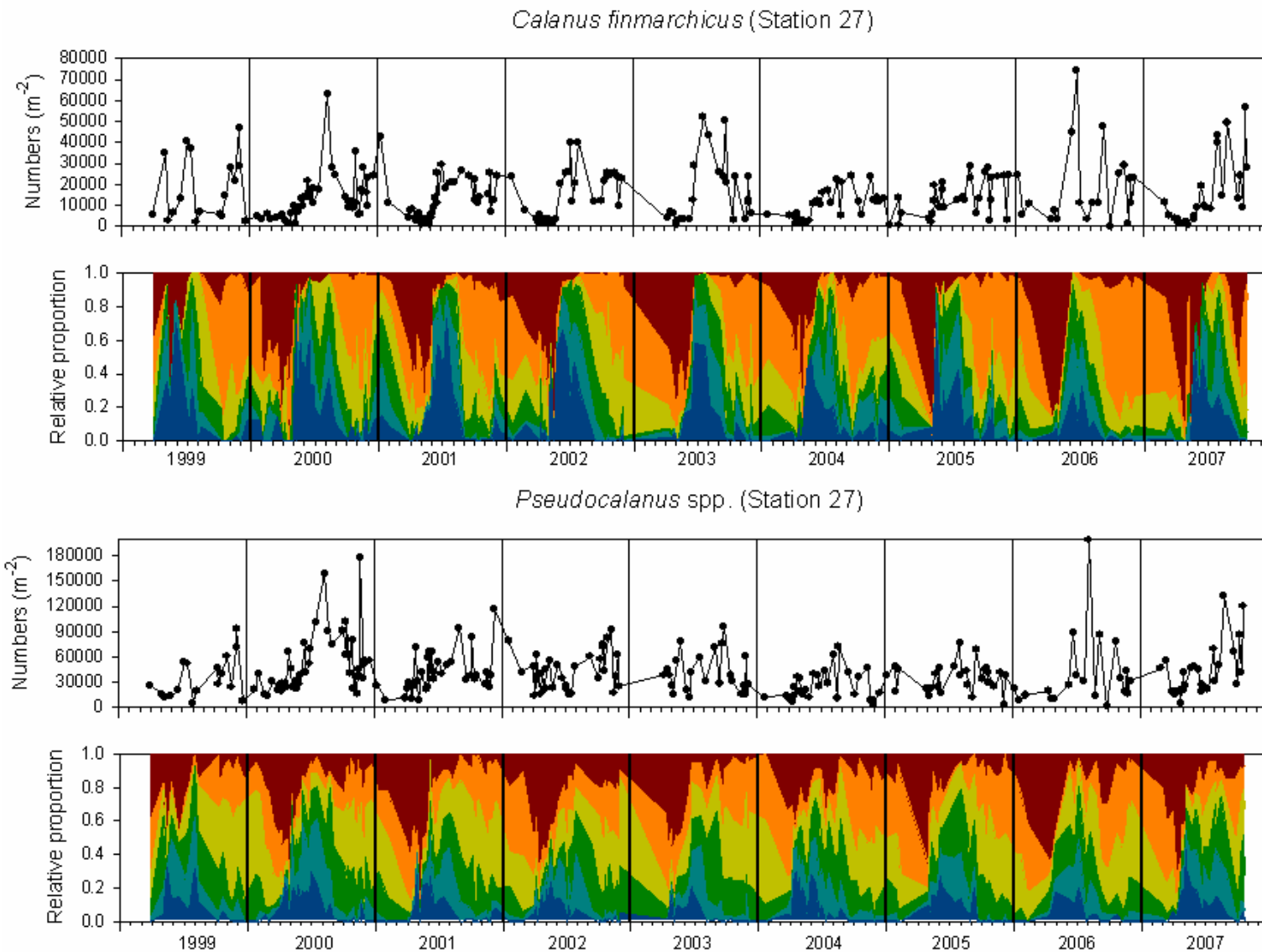


Figure 23. Seasonal cycle of abundance and stage distribution of *Calanus finmarchicus* and *Pseudocalanus* spp. at Station 27 for the period 1999-2007. (Stage CI (blue), CII (teal), CIII (green), CIV (yellow), CV (orange), CVI (brown)).

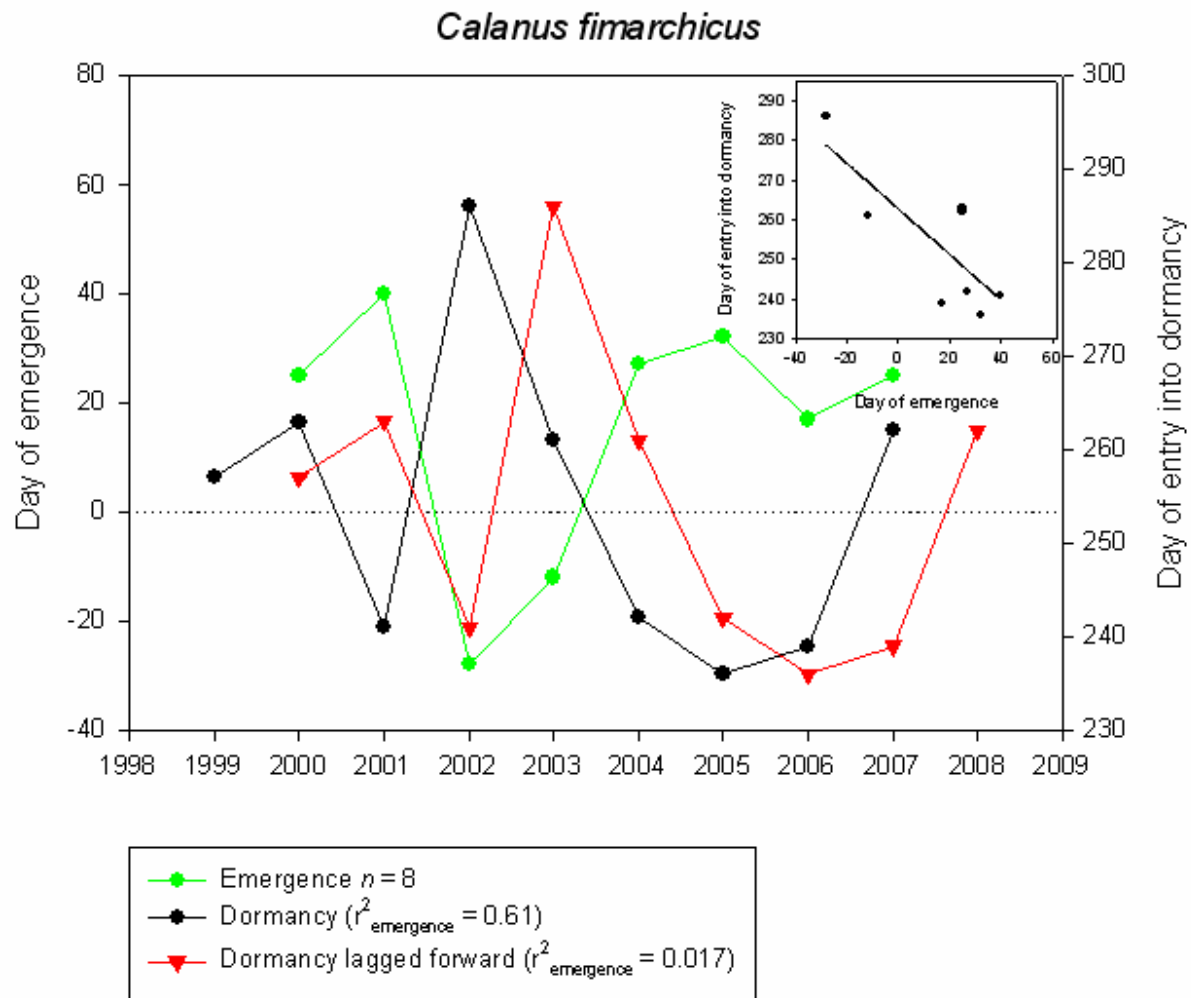


Figure 24. Day of emergence and dormancy of *Calanus finmarchicus* at Station 27 estimated using the criteria of Johnson et al. (2008). The green line indicates the trends in day of emergence from diapause in the year of observation while the black and red lines indicate the day of dormancy for the current and previous year. The inset indicates shows the relationship between the day of emergence and dormancy for the same year.

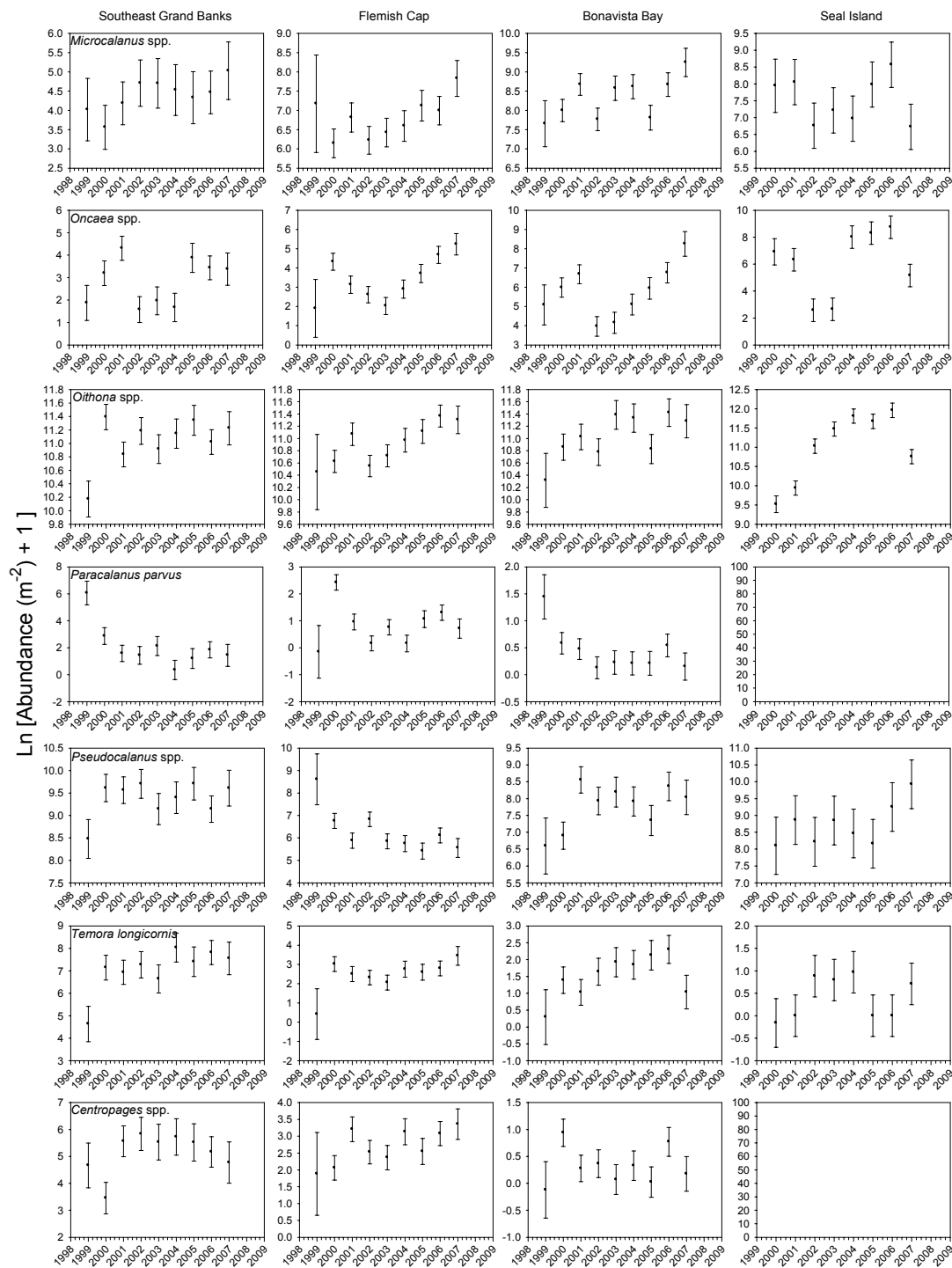


Figure 25. Seasonally-adjusted estimate of the mean abundance of small copepods from the oceanographic transects for the period 2000-07. The error bars represent standard errors. Values from the Southeast Grand Banks are based on two occupations per year (spring, fall); values from the Flemish Cap and 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).

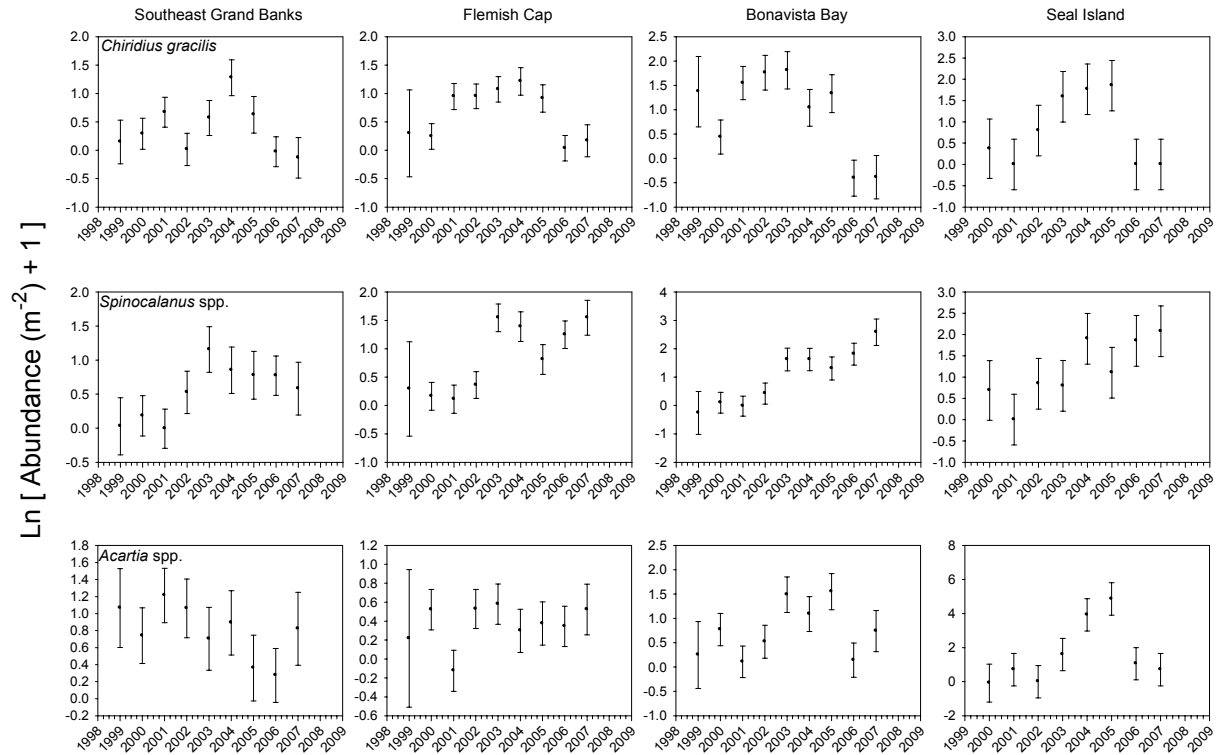


Figure 25 (Cont'd.)

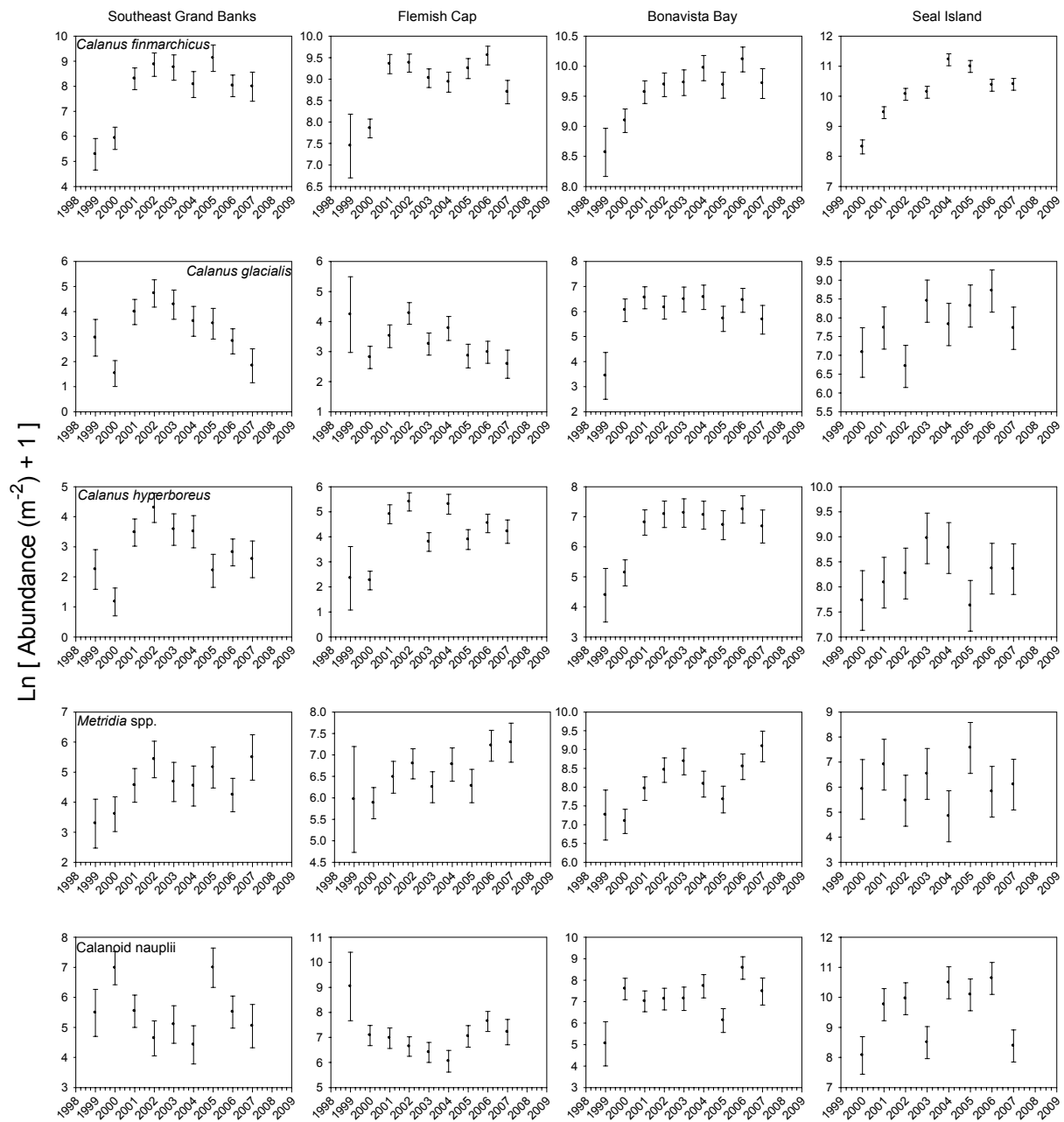


Figure 26. Seasonally-adjusted estimate of the mean abundance of large copepods from the oceanographic transects for the period 2000-07. The error bars represent standard errors. Values from the Southeast Grand Banks are based on two occupations per year (spring, fall); values from the Flemish Cap and 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).

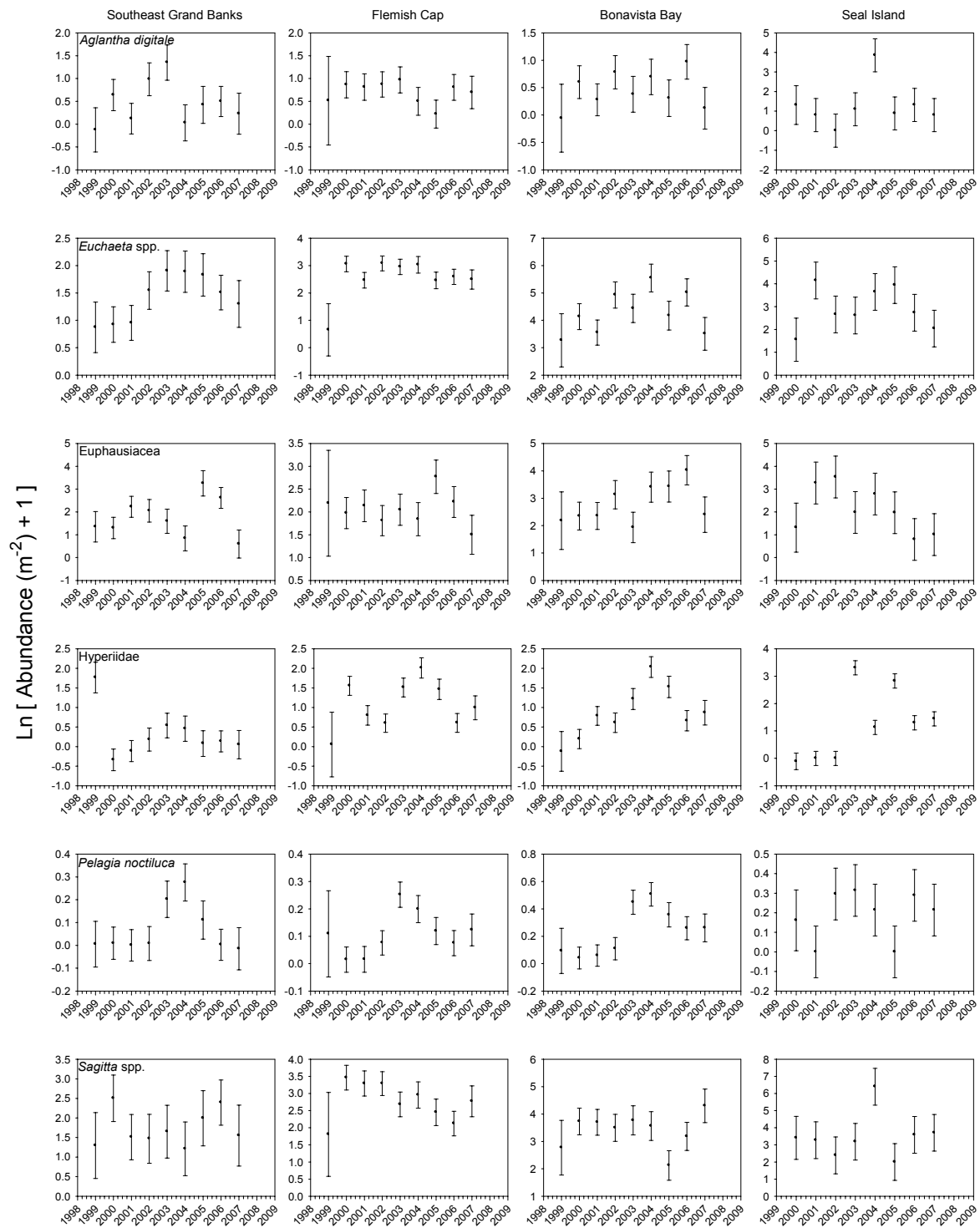


Figure 27. Seasonally-adjusted estimate of the mean abundance of carnivorous zooplankton from the oceanographic transects for the period 2000-07. The error bars represent standard errors. Values from the Southeast Grand Banks are based on two occupations per year (spring, fall); values from the Flemish 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).

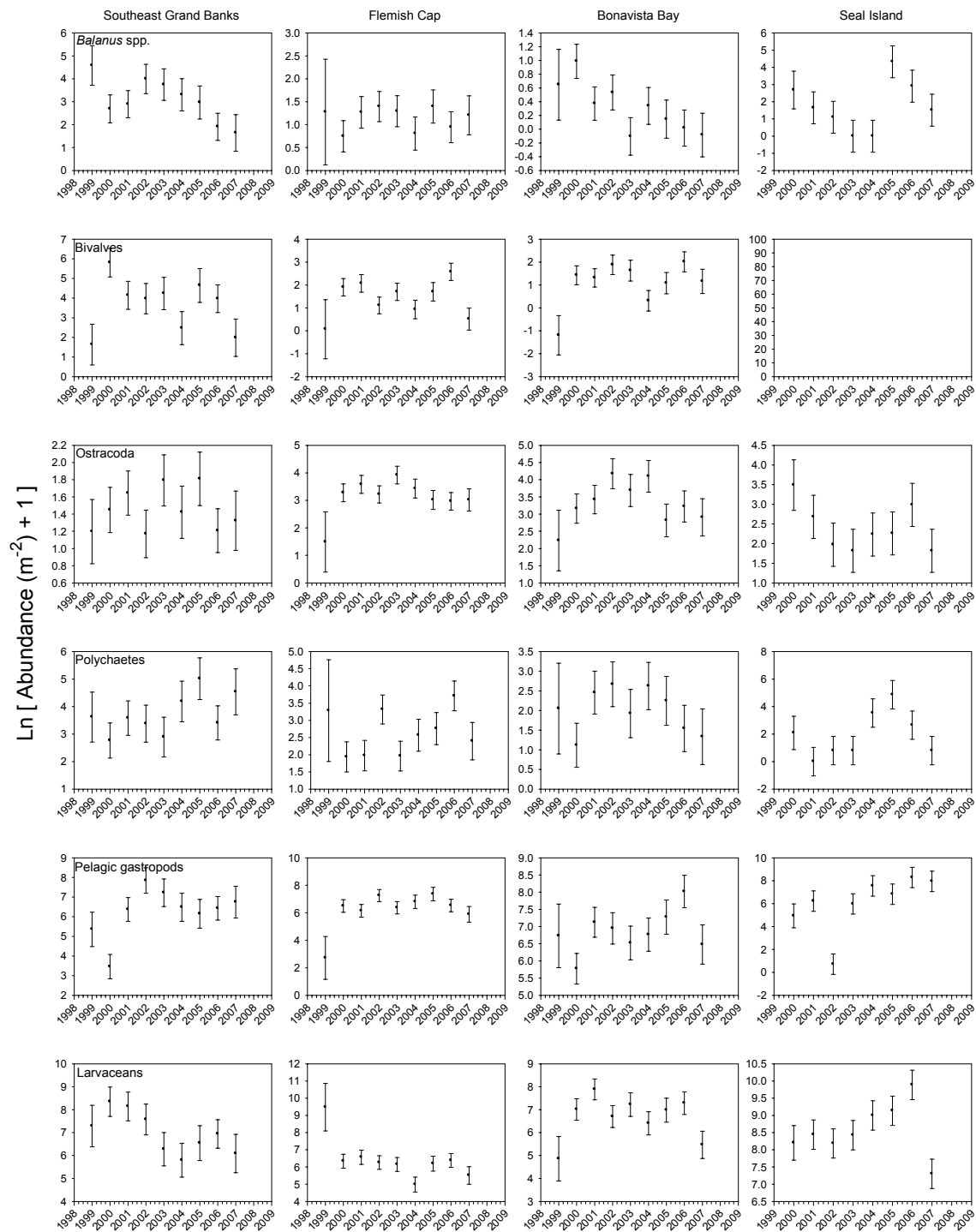


Figure 28. Seasonally-adjusted estimate of the mean abundance of meroplankton and other taxa from the oceanographic transects for the period 2000-07. The error bars represent standard errors. Values from the Southeast Grand Banks are based on two occupations per year (spring, fall); values from the Flemish 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).

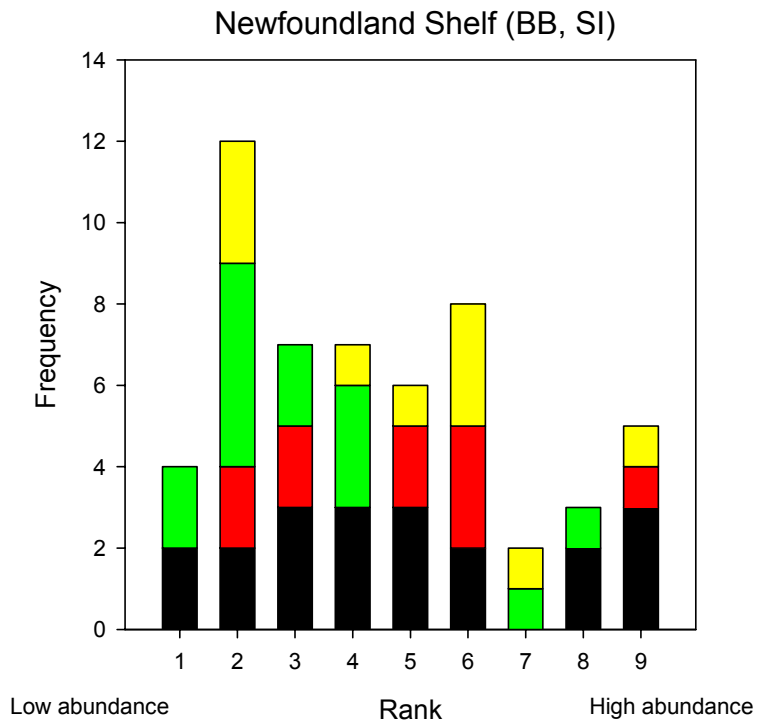
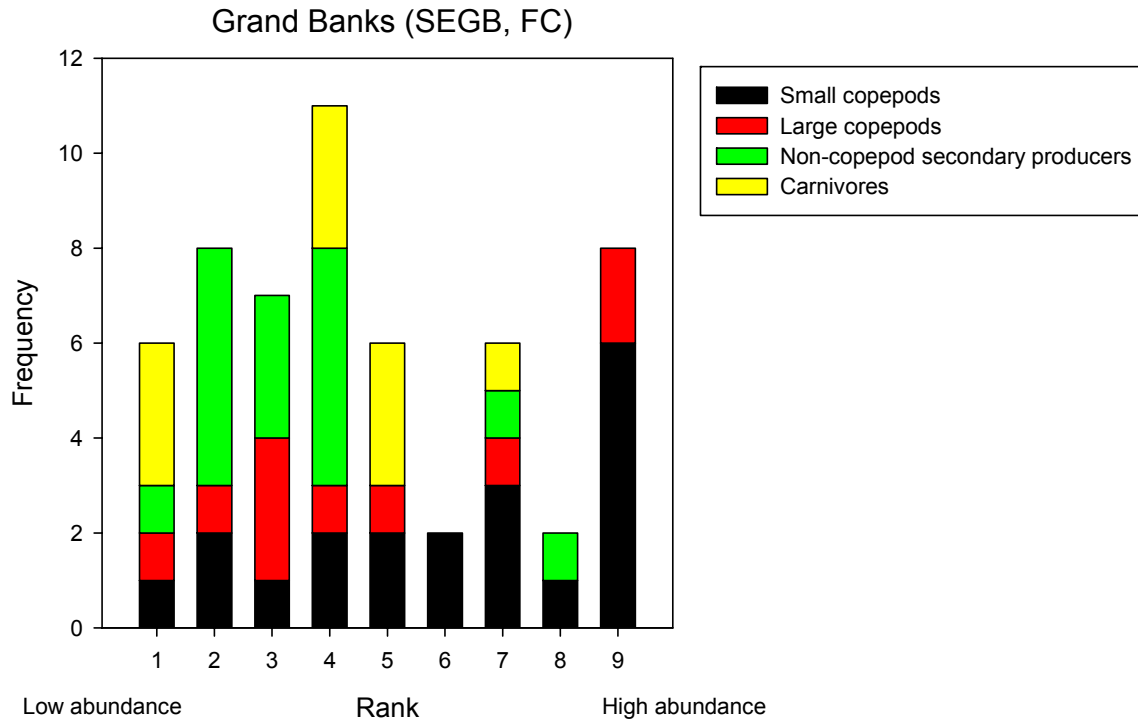


Figure 29. Distribution of ranks of the seasonally-adjusted estimate of the mean abundance for the four major categories of zooplankton on the Grand Banks (top panel – Southeast Grand Banks and Flemish Cap sections) and Newfoundland Shelf (bottom panel – Bonavista Bay and Seal Island sections).

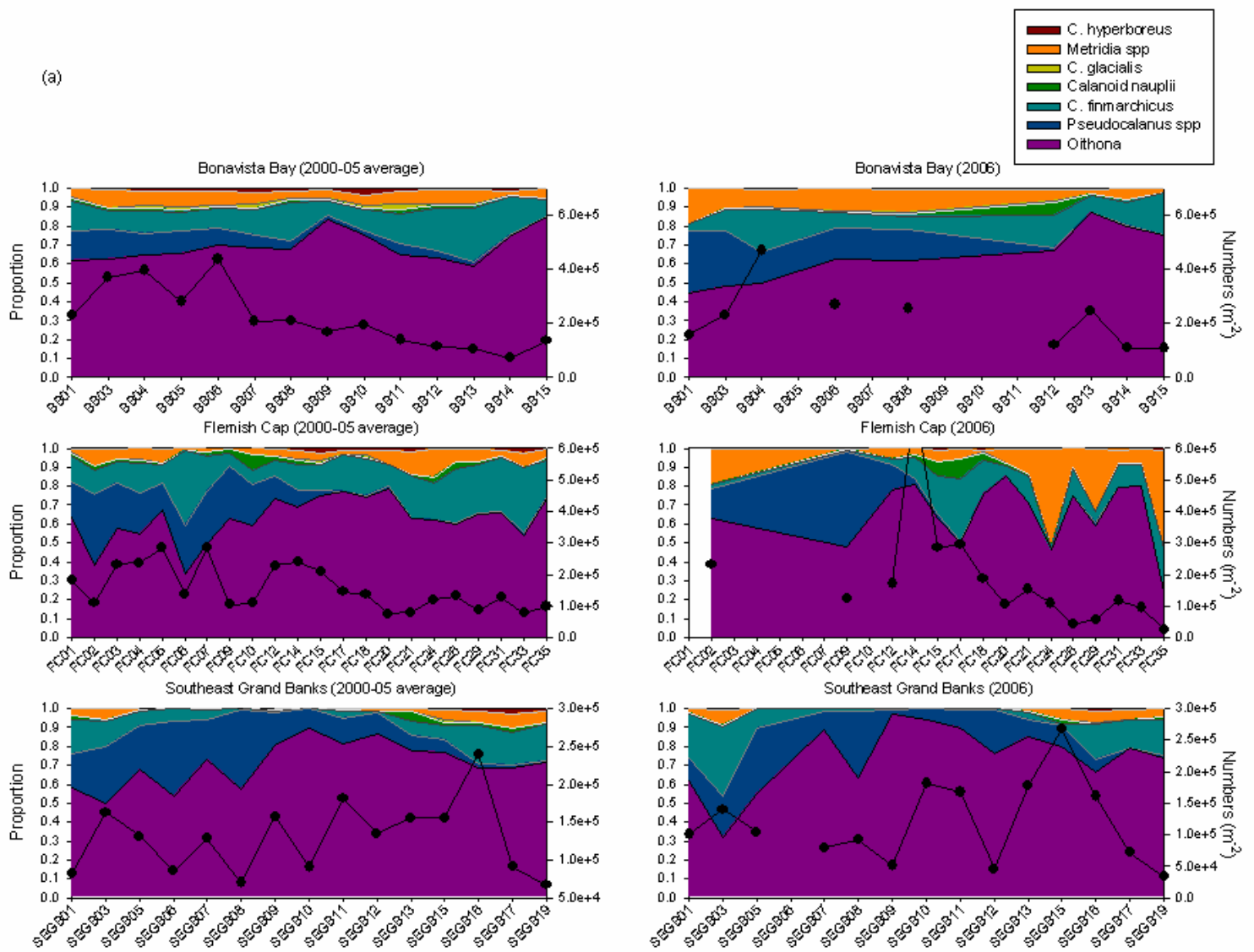


Figure 30. Spatial distribution in (a) abundance, (b) biomass, and species composition for the seven dominant copepod taxa collected along oceanographic transects sampled in the fall surveys. The left-hand panels show the average distribution for 2000-05 while the right-hand panels shows the observations for 2006.

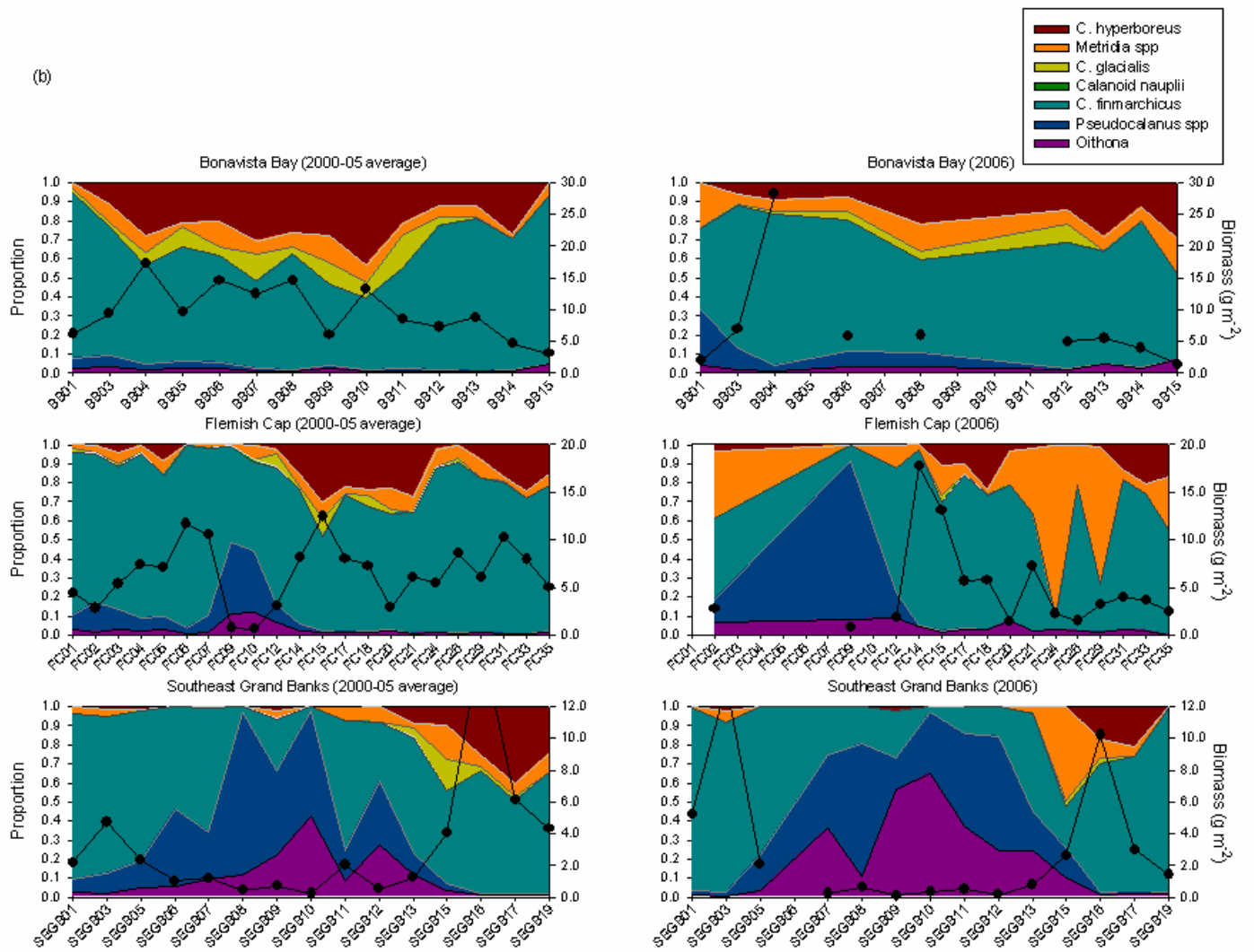


Figure 30. (Cont'd.)

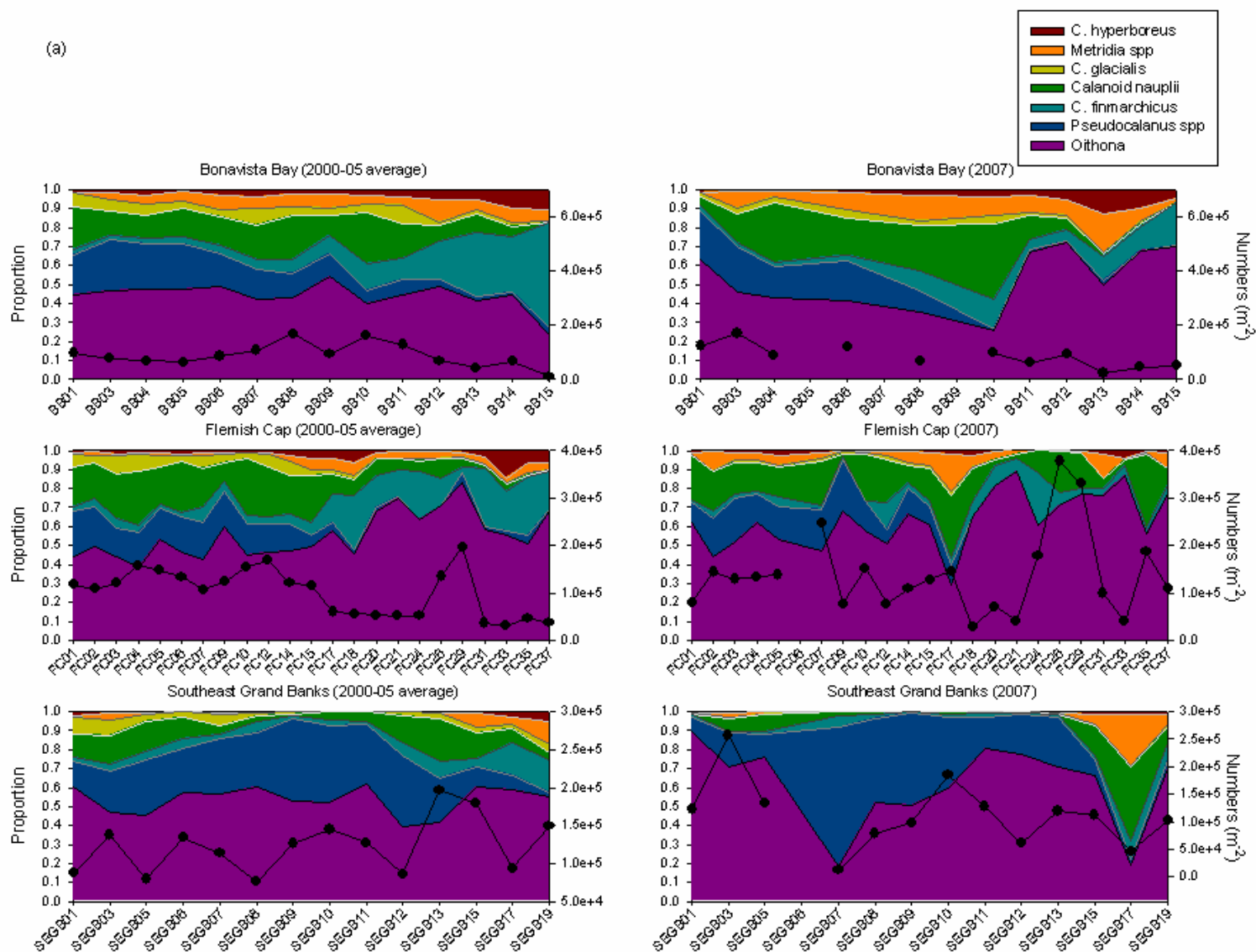


Figure 31. Spatial distribution in (a) abundance, (b) biomass, and species composition for the seven dominant copepod taxa collected along oceanographic transects sampled in the spring surveys. The left-hand panels show the average distribution for 2000-05 while the right-hand panels shows the observations for 2007.

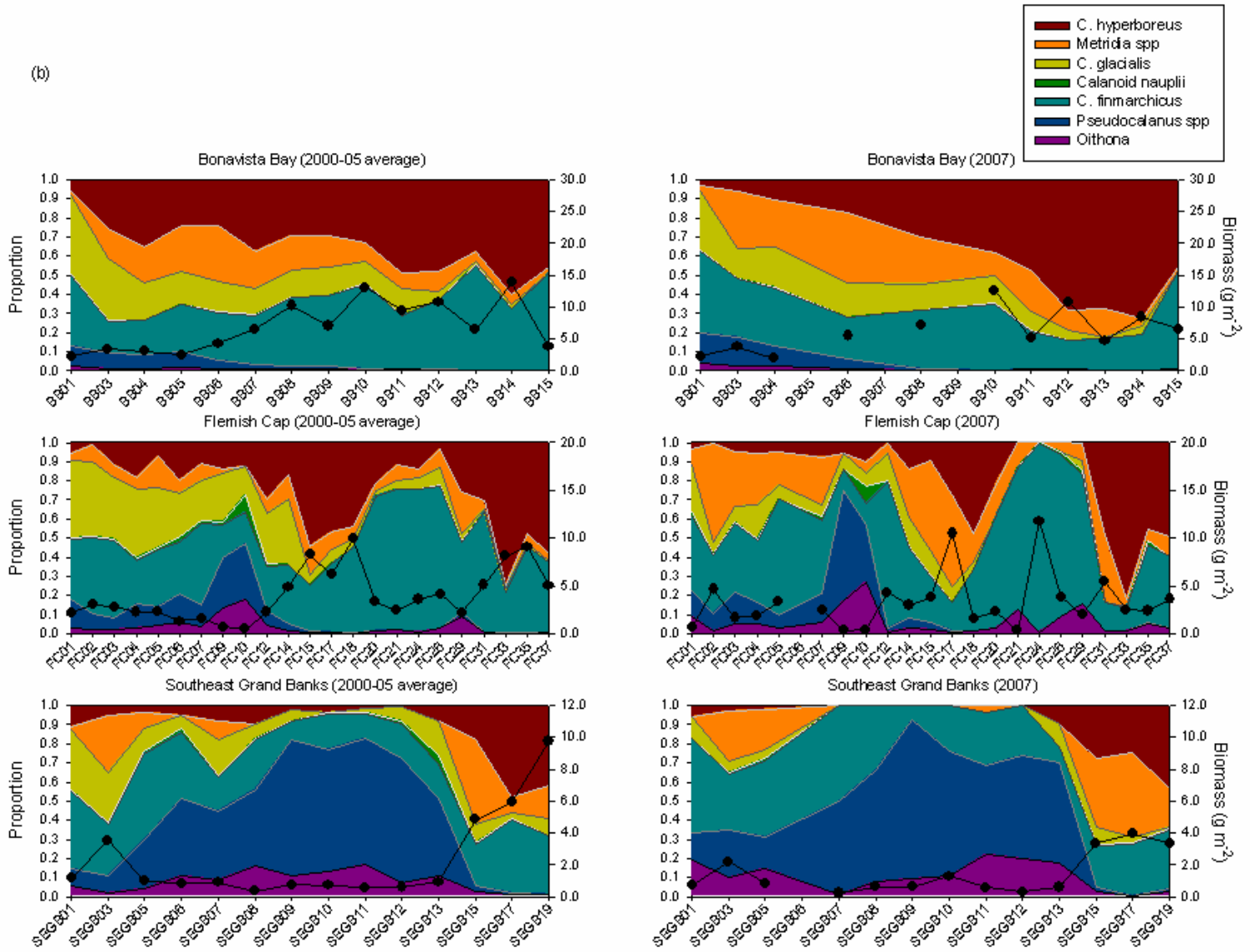


Figure 31. (Cont'd.)

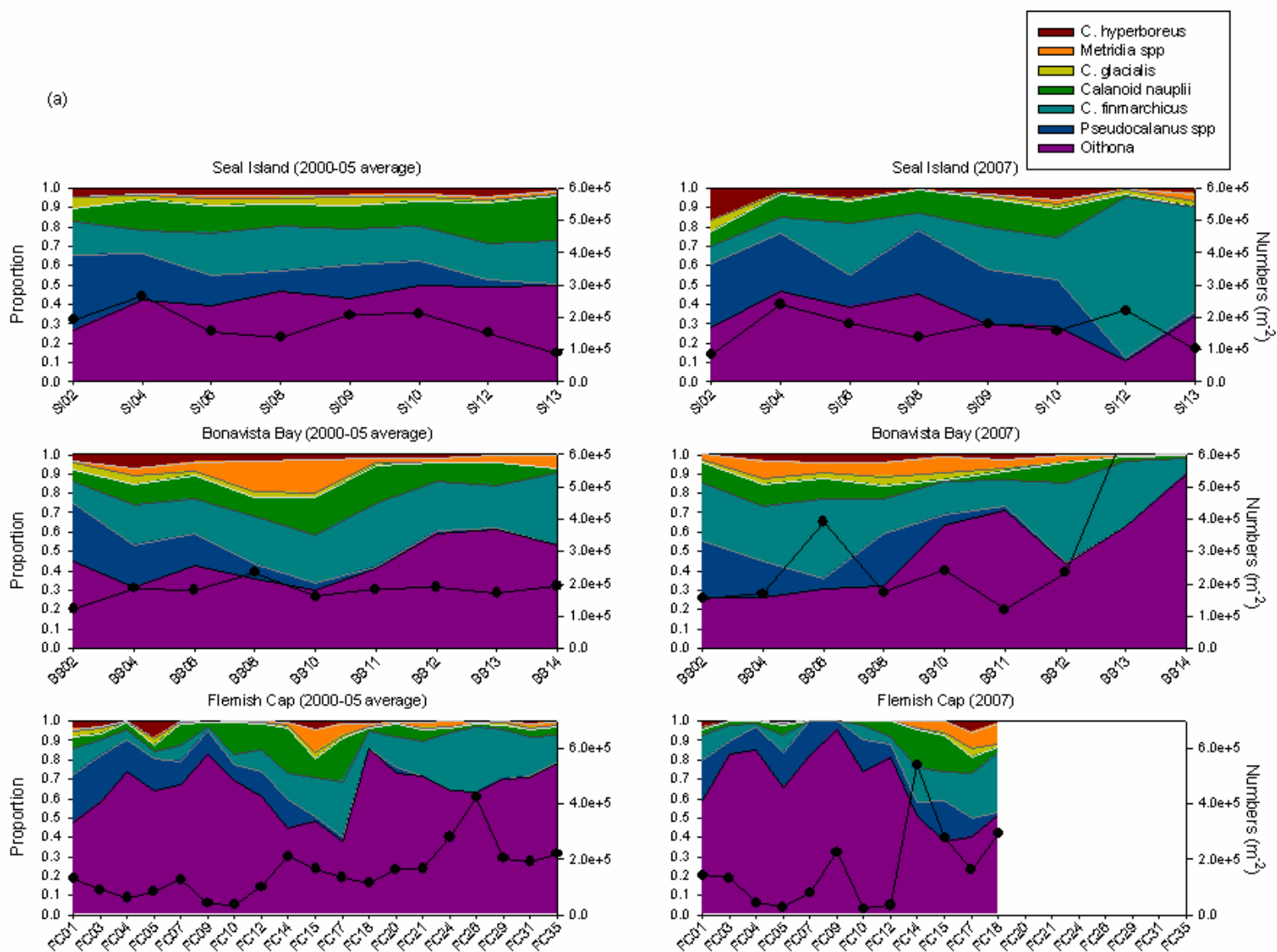


Figure 32. Spatial distribution in (a) abundance, (b) biomass, and species composition for the seven dominant copepod taxa collected along oceanographic transects sampled in the summer surveys. The left-hand panels show the average distribution for 2000-05 while the right-hand panels shows the observations for 2007.

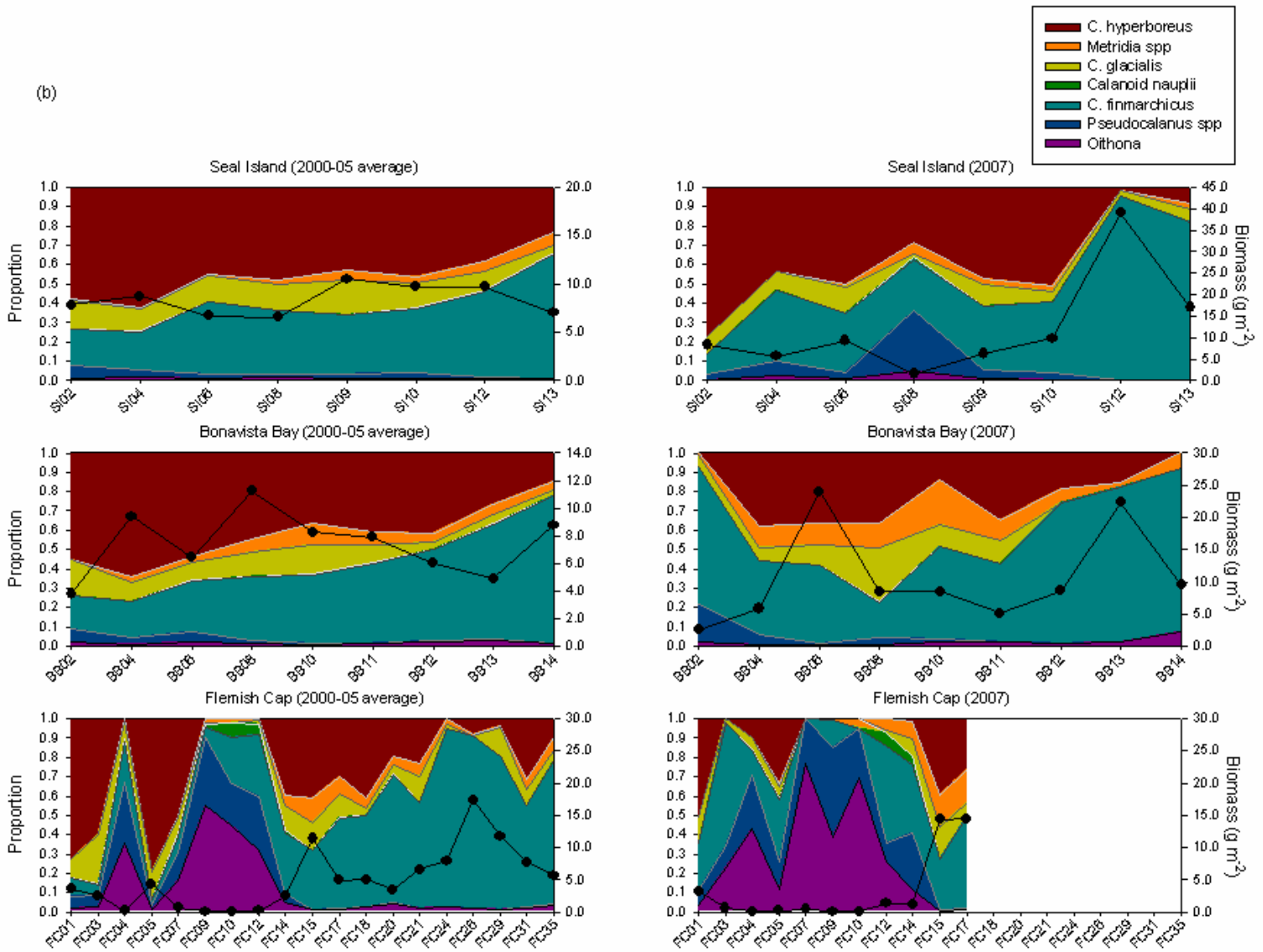


Figure 32. (Cont'd.)

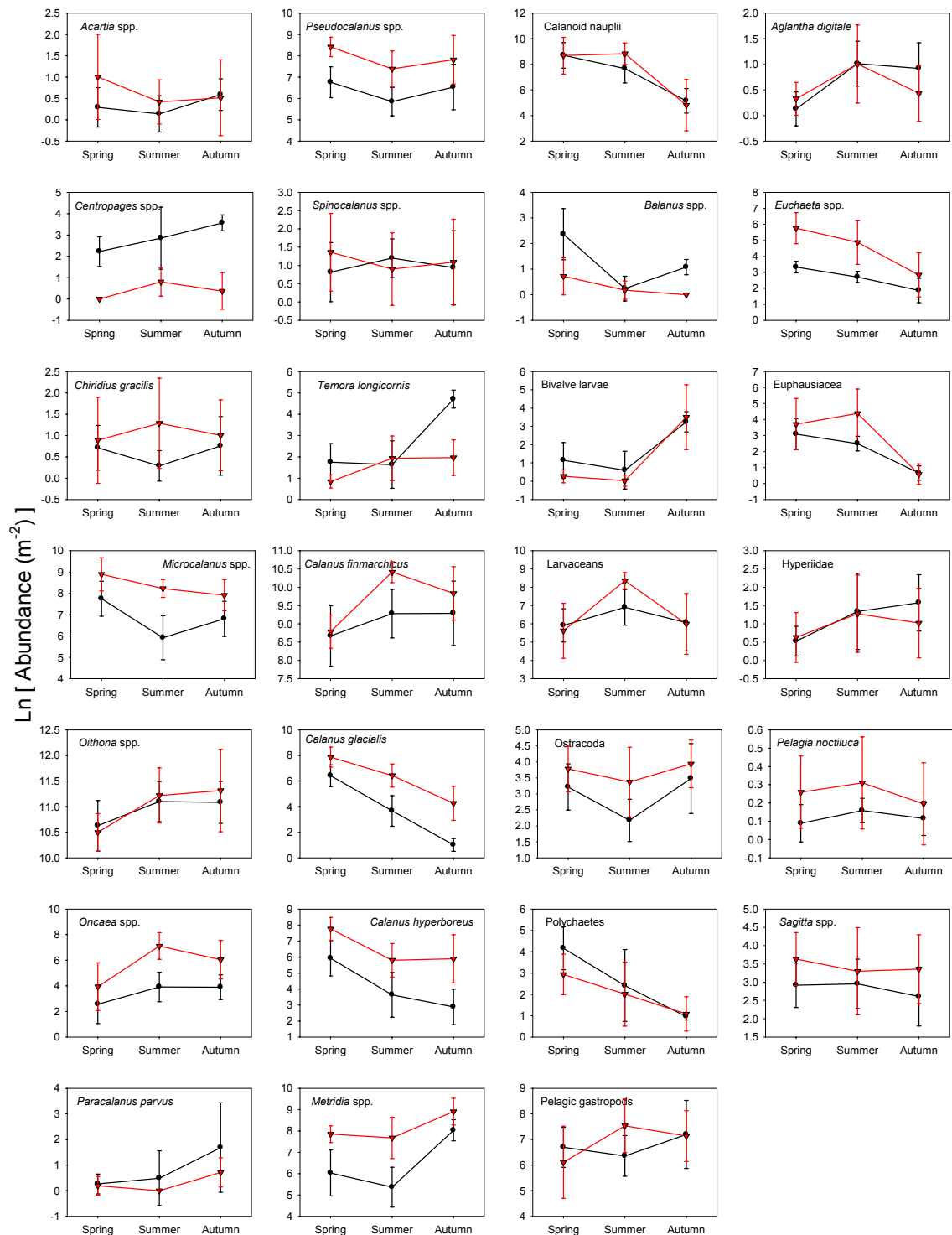


Figure 33. Seasonal cycle in estimated GLM mean abundance of key taxa from the Flemish Cap and Bonavista Bay oceanographic sections. Black lines are for the Flemish Cap section, red lines are for the Bonavista Bay section.

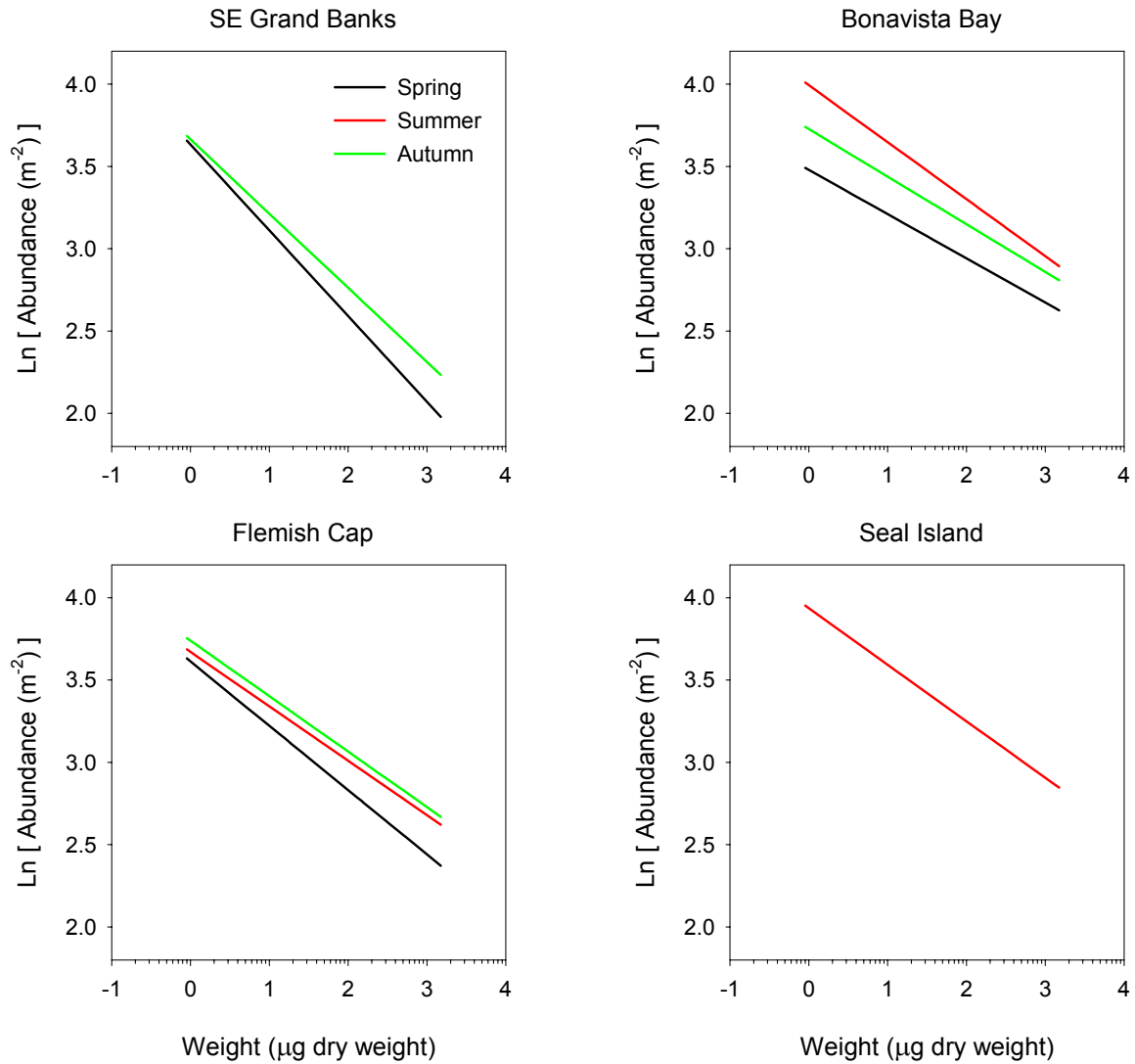


Figure 34. Average seasonal abundance spectrum (number of individuals m⁻²) of the eight dominant copepods (*Oithona* spp., *Pseudocalanus* spp., *Temora longicornis*, *Centropages* spp., *Calanus finmarchicus*, *Calanus glacialis*, *Calanus hyperboreus*, and *Metridia* spp.) along the four major oceanographic transects.

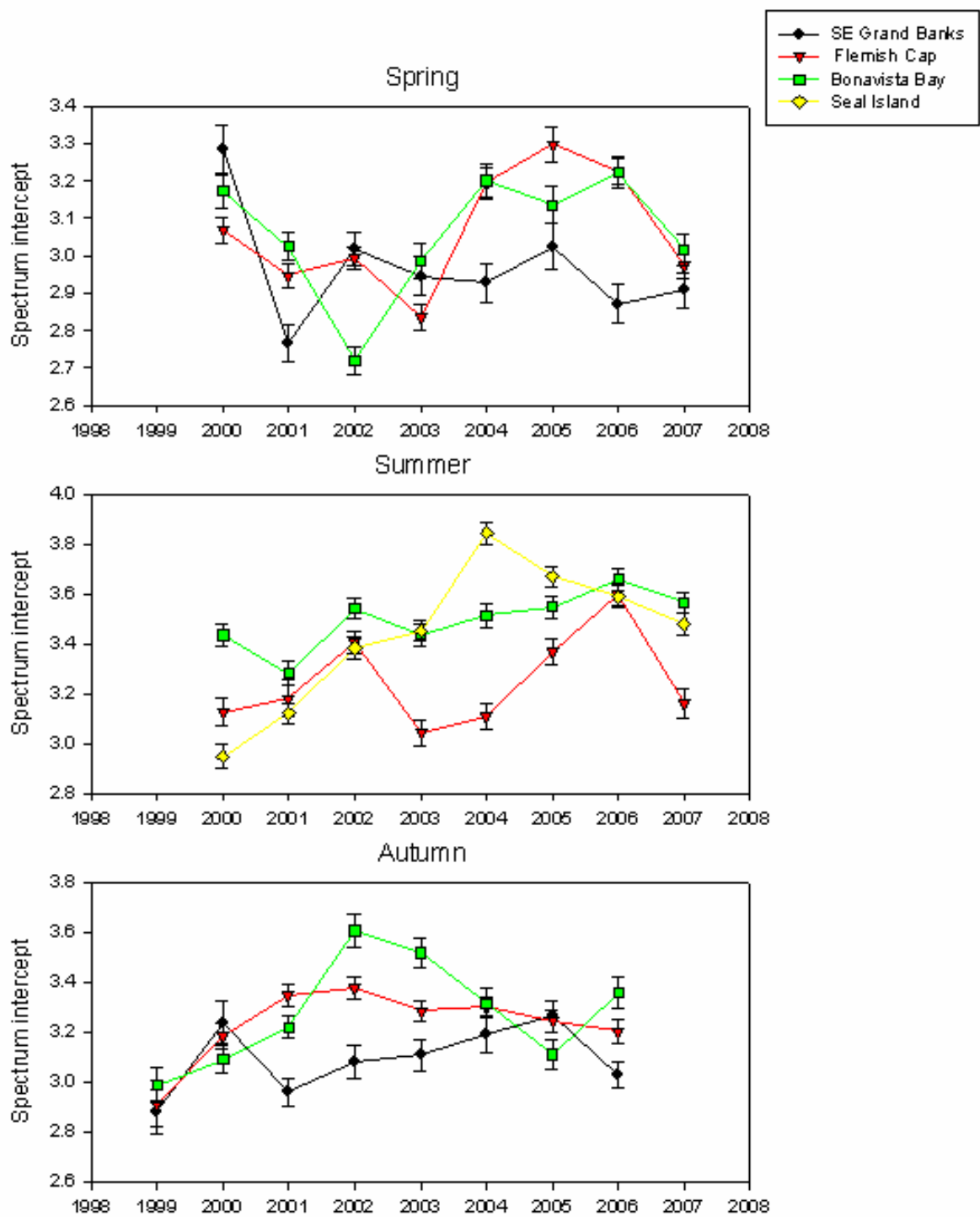


Figure 35. Seasonal variation in the annual estimated intercept of the abundance spectrum of the eight dominant copepods along the four oceanographic transects.