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Biological Oceanographic Conditions in NAFO Subareas 2 and 3 on the Newfoundland and Labrador Shelf During 2006

by

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Abstract

Biological oceanographic observations from a fixed coastal station and oceanographic transects in NAFO Subareas 2 and 3 during 2006 are presented and referenced to previous information from earlier periods when data are available. We review the information concerning the seasonal and inter-annual variations in inventories of nutrients (nitrate), chlorophyll *a*, as well as the abundance of major taxa of zooplankton collected as part of the Atlantic Zone Monitoring Program (AZMP).

The seasonally-adjusted annual mean nitrate inventories in the upper (0-50m) and lower (50-150m) water column on the Newfoundland and Labrador Shelf were generally below the long-term mean in 2006. Although there were statistically significant inter-annual variations in nitrate inventories across all NAFO Divisions, this appears to be primarily driven by elevated levels during the late 1990's and early 2000's. The seasonally-adjusted annual mean chlorophyll *a* inventories across all NAFO Divisions were slightly below the long-term mean in 2006 and all Divisions displayed significant inter-annual variation.

The abundance of *Calanus glacialis*, *C. hyperboreus*, and larvaceans in the Avalon Channel reached their lowest levels encountered since routine collections began in the late 1990's on the Grand Banks. In contrast, the abundance of *C. finmarchicus*, *Metridia* spp., and euphausiids increased substantially in 2006 following earlier declining trends.

The seasonally-adjusted annual mean abundance of the dominant copepod species showed large north-to-south differences in the significance of inter-annual variations. While many of the dominant copepod species were at or near their lowest abundance along the southern transect across the Grand Banks, the standing stocks generally increased on the NE Newfoundland and Labrador Shelf along oceanographic sections above 48° N in 2006. The differences between the abundance of inshore (Station 27, 3L) and offshore (oceanographic transects, 3LNO, 3K, 3M, 2J) zooplankton standing stocks may be related to highly dynamic coastal processes in contrast to broad oceanographic bio-physical interactions that govern the patterns of abundance further on the Shelf.

Introduction

We review biological and chemical oceanographic conditions on the Newfoundland and Labrador Shelf during 2006. 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 2006 by the Atlantic Zone Monitoring Program (AZMP[1]) provided good spatial and temporal series coverage of standard variables which provides a foundation for

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

comparison with previous years. Further details regarding biological oceanographic conditions on the Newfoundland and Labrador Shelf in 2006 and recent years can be found in Pepin et al. 2006.

Methods

Collections and standard AZMP variables are based on sampling protocols outlined by the Steering Committee of the AZMP (Mitchell et al. 2002). Observations for 2006 presented in this document are based on surveys listed in Table 1. All combined sample locations for chlorophyll *a* and nitrate concentrations in earlier years are shown in Figure 1. The seasonal distribution of the data prior to the start of the AZMP in 1999 was limited (Figure 2). Annual mean time series for nitrate and chlorophyll *a* inventories were computed from all available seasonal data going back to 1993 within NAFO Divisions 2GHJ, 3M, 3K, and 3LNO. 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 and supported by our *in-situ* observations, we only report on variability in nitrate concentrations.

Estimates of nitrate and chlorophyll *a* inventories, and zooplankton abundance along each oceanographic section and NAFO Divisions were based on general linear models (GLMs) using the form:

$$Ln\ (Density) = \alpha + \beta_{year} + \delta_{Month} + \varepsilon$$

for the fixed station (Station 27, Div. 3L), where Density is in units of # m^{-2}, α is the intercept, β and δ are categorical effects for year and month, and ε is the error, and

$$Ln\ (Density) = \alpha + \beta_{year} + \delta_{Station\ ID} + \varepsilon$$

for each of the section, where δ takes into account the effect of station location. The effect of station ID is included to represent the general consistency in the distribution of a species. The model uses an unbalanced design to deal with gaps in observations. Density is log-transformed to deal with the skewed distribution of observations. All analyses were based on section-specific estimates of density by species.

Seasonal Variability in Nitrate and Chlorophyll *a* Inventories in NAFO Subareas 2 and 3

The seasonally-adjusted annual mean nitrate inventories in the upper water column (0-50m integral), where active photosynthesis takes place, were generally below the long-term mean (1993-2006) during 2006, particularly in 3K and 3LNO Divisions (Figure 3). The general decline in annual inventories of nitrate within these regions began in 2003. The magnitude of variation in the upper-water column inventories varied from 2-4-fold during 1993-2006. Although there were statistically significant inter-annual variations in mean nitrate inventories in the upper water-column, this appears to be primarily driven by the elevated values observed during the late 1990's and early 2000's across the Newfoundland and Labrador Shelf. Deep (50-150m integral) nitrate inventories, which in part represents the nutrient pool for the following year, were also below the long-term mean across the Newfoundland and Labrador Shelf in 2006 and earlier years back to 2000, particularly for 3K and 3LNO (Figure 3). Statistically significant inter-annual variations in seasonally-adjusted deep nitrate inventories were also apparent during the time series. We also noted above average deep inventories of nitrate in 1997 through till 1999 throughout the Newfoundland and Labrador Shelf (Figure 3).

Seasonally-adjusted annual mean chlorophyll *a* inventories (0-100m integral) in 2006 were slightly below or near the long-term mean (Figure 4). The chlorophyll *a* inventories showed relative stability throughout the time series, with the exception of 1994 where elevated concentrations were observed on the northeast Newfoundland Shelf (Div. 3K) and the Grand Banks (Div. 3LNO). Chlorophyll *a* inventories were also elevated in 1997-99 on the Flemish Cap (Div. 3M) and Labrador Shelf (Figure 4). Despite the elevated nutrient inventories observed in the late 1990's within NAFO Subareas 2 and 3, phytoplankton biomass remained relatively stable throughout this period on the northeast Newfoundland Shelf and Grand Banks.

Station 27 (NAFO Division 3L) Fixed Station - Zooplankton

The overall abundance patterns for the main zooplankton assemblage observed at Station 27 (Div. 3L) continue to show significant changes since the inception of the AZMP in 1999. 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 5). The abundance of *Calanus glacialis, C. hyperboreus,* and larvaceans were at or near the lowest value recorded since 1999. In contrast, the abundance of *C. finmarchicus*, *Metridia* spp., and euphausids appeared to increase substantially in 2006, following general periods of decline since 2002/03. 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 1999-2006 observation period, most taxa exhibited approximately a 3-fold variation in abundance in average annual abundance.

Zooplankton Abundance Patterns Along Seasonal Oceanographic Transects and the Continuous Plankton Recorder in NAFO Subareas 2 and 3

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 and *Metridia* spp. exhibited statistically significant inter-annual variations, with the former showing high abundances in 2000 and 2005 while the latter was notably lower in 2006 (Figure 6). The remaining five taxa (*C. finmarchicus, C. glacialis, C. hyperboereus, Oithona* spp., and *Pseudocalanus* spp. showed fluctuations in abundance that were not statistically different among years. Despite the lack of statistical significance, most of these five taxa were at or near their lowest abundance since 2000.

The abundance of copepods along the Flemish Cap transect showed a little more variability than on the southeast Grand Banks. The Flemish Cap transect is sampled during spring, summer, and fall and captures the peak of the secondary production cycle that typically occurs during summer. All taxa, with the exception of *C. hyperboreus*, showed significant inter-annual variations in abundance. In contrast with the southeast Grand Banks, the abundance of all seven taxa in 2006 was at or near their highest seasonally-adjusted abundance levels since 2000.

Our observations from the Bonavista Bay transect, which is also 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 6). Only in the case *Pseudocalanus* spp. and large calanoid nauplii were inter-annual variations in abundance not statistically resolvable. In previous years, *Pseudocalanus* spp. had exhibited significant inter-annual variability, but additional information from 2006 showed that the pattern of variations could not be distinguished from the influence of seasonal or spatial factors. However, in all taxa, with the exception of *Metridia* spp. and *Pseudocalanus* spp., the abundance in 2006 was at (or very near) the highest levels recorded since the inception of the AZMP.

Although copepod abundance along the Seal Island transect, which is sampled only in July, is generally higher than the long term AZMP average, all three *Calanus* species, along with *Metridia* spp. and *Pseudocalanus* spp. have shown slight decreases in the last one or two years (Figure 6). In all but one taxa (*C. hyperboreus*), 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 among years.

Summary and Conclusions

- In 2006, the seasonally-adjusted annual mean inventories of nitrate in the upper layer were below the long-term average (1993-2006) on the Newfoundland and Labrador Shelf compared to earlier years.

- Deep inventories of nitrate remained under the long-term mean in 2006, following a pattern that started in the late 1990's, particularly for the Grand Banks and the northeast Newfoundland Shelf.

- Higher nitrate levels observed during the late 1990's coincided with intensification of the Labrador Current on the northeast and southwest slope of the Newfoundland Shelf (Han and Li 2004).

- Annual mean chlorophyll a inventories, a proxy of phytoplankton biomass, declined slightly below the long-term mean (1993-2006) in 2006.

- Although elevated nutrient levels may explain higher phytoplankton biomass observed in the late 1990's on the Flemish Cap (Div. 3M) and Labrador Shelf (2GHJ), biomass remained relatively stable on the northeast Newfoundland Shelf and the Grand Banks during this same time period.

- The abundance of *Calanus glacialis*, *C. hyberboreus*, and larvaceans at Station 27 (3L) in 2006 reached their lowest levels encountered since routine collections began in the late 1990's.

- In contrast, the abundance of *C. finmarchicus*, *Metridia* spp., and euphausiids appeared to increase substantially in 2006 at Station 27 (3L) following a negative trend since 2002/03.

- The abundance of many copepod species were generally at their highest levels on the northeast Newfoundland Shelf along oceanographic transects above 48º N in 2005/06.

- Zooplankton abundance off Labrador and on Newfoundland Shelf in 2006 is near or at highest levels observed although *C. finmarchius*, *C. hyperboreus* and *Metridia* spp. have declined since 2005.

- Most copepods along the Bonavista and Flemish Cap transects are at their highest levels since 2000.

- The discrepancy between the abundance of inshore (Station 27, 3L) and offshore (oceanographic transects, 3LNO, 3K, 3M, 2J) zooplankton standing stocks may be related to highly dynamic coastal processes in contrast to broad oceanographic bio-physical interactions that govern the patterns of abundance further on the Shelf.

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Table 1. Listing of AZMP Sampling Missions in the Newfoundland and Labrador Region in 2006. The transects are Southeast Grand Banks (SEGB), Flemish Cap (FC), Trinity Bay (TB), Bonavista Bay (BB),White Bay (WB), Seal Island (SI), and the fixed coastal station (Station 27). See Figure 1 for station locations along sections and fixed coastal station. Total numbers of hydrographic (CTD) and biological (nutrients, plant pigments, phytoplankton, zooplankton, and including partial occupations) profiles provided for each seasonal section and fixed station occupations.

Mission ID	Dates	Sections/Fixed	# Hydro Stns	# Bio Stns
TEL670	Apr 22-May 2, 2006	SEGB, FC, BB, FI	71	61
WT675	Jul 25-Aug 7, 2006	FC, BB, WB, SI	75	49
Hud731	Nov 18-Dec 5, 2006	SEGB, FC, BB, TB	71	47
Fixed	Jan-Dec 2006	Station 27	45	18

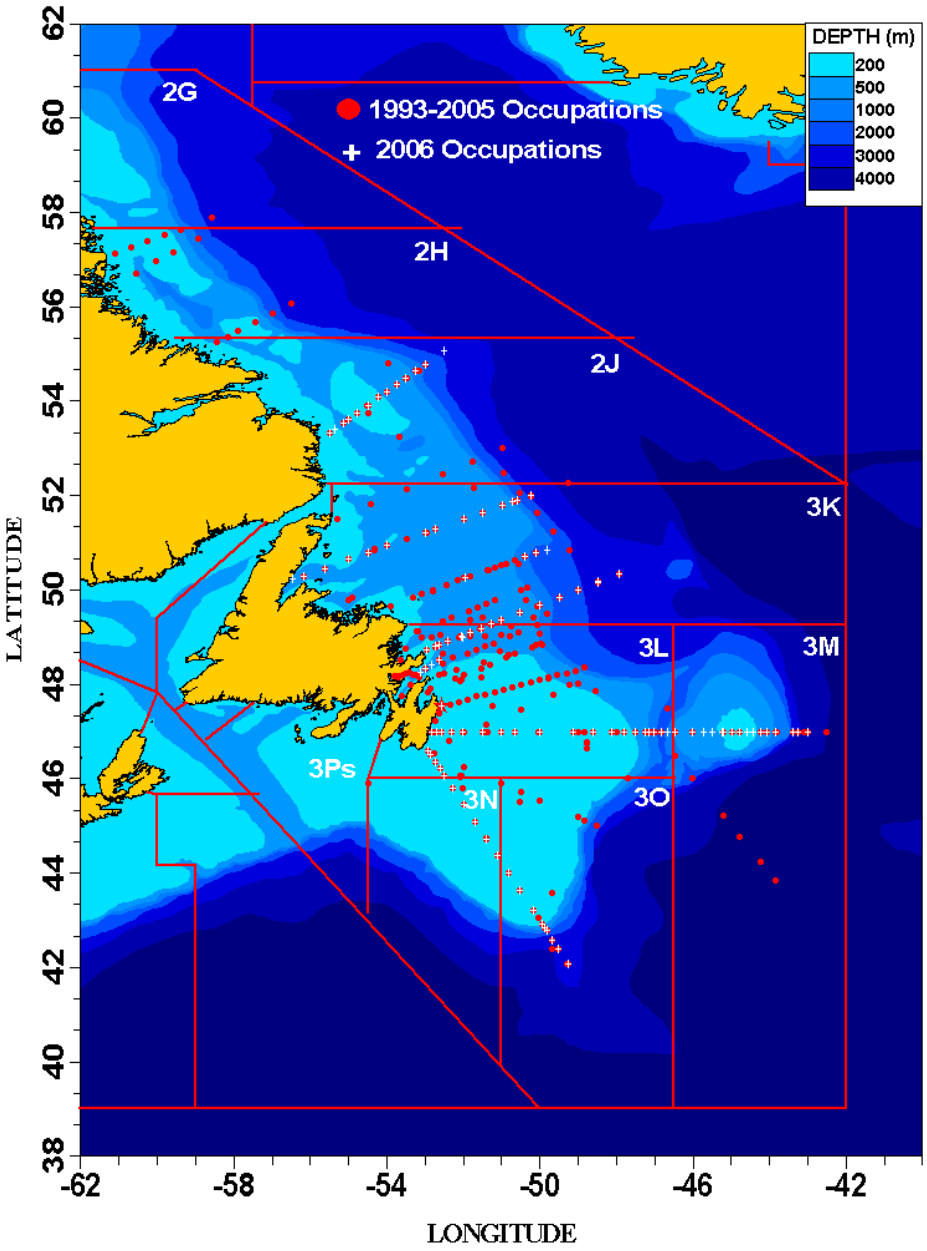

Figure 1. Station locations for nitrate and chlorophyll *a* inventories in NAFO Subareas 2 and 3 during 1993-2006.

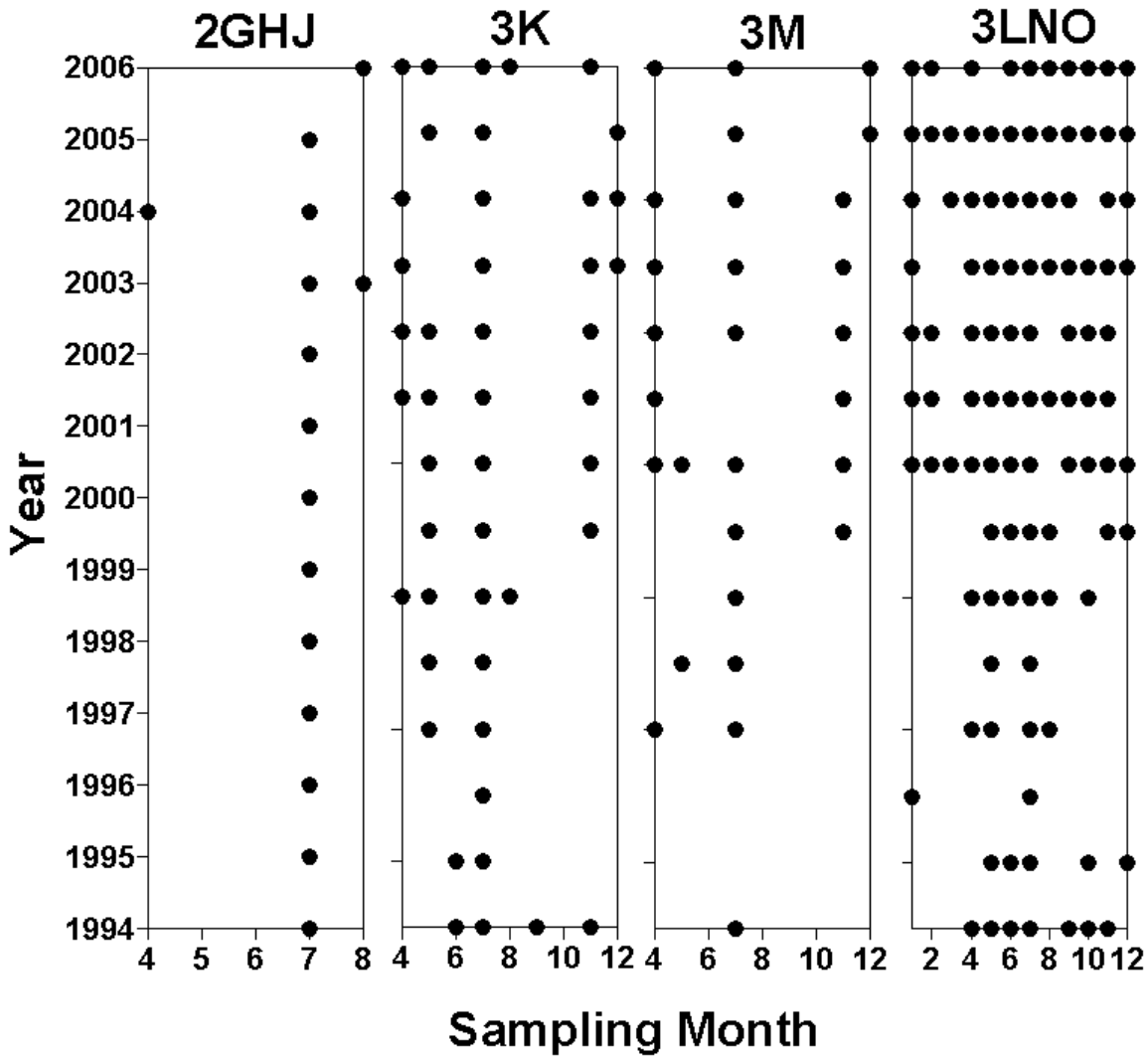

Figure 2. Temporal coverage for nitrate and chlorophyll *a* inventories in NAFO Subareas 2 and 3 during 1993-2006.

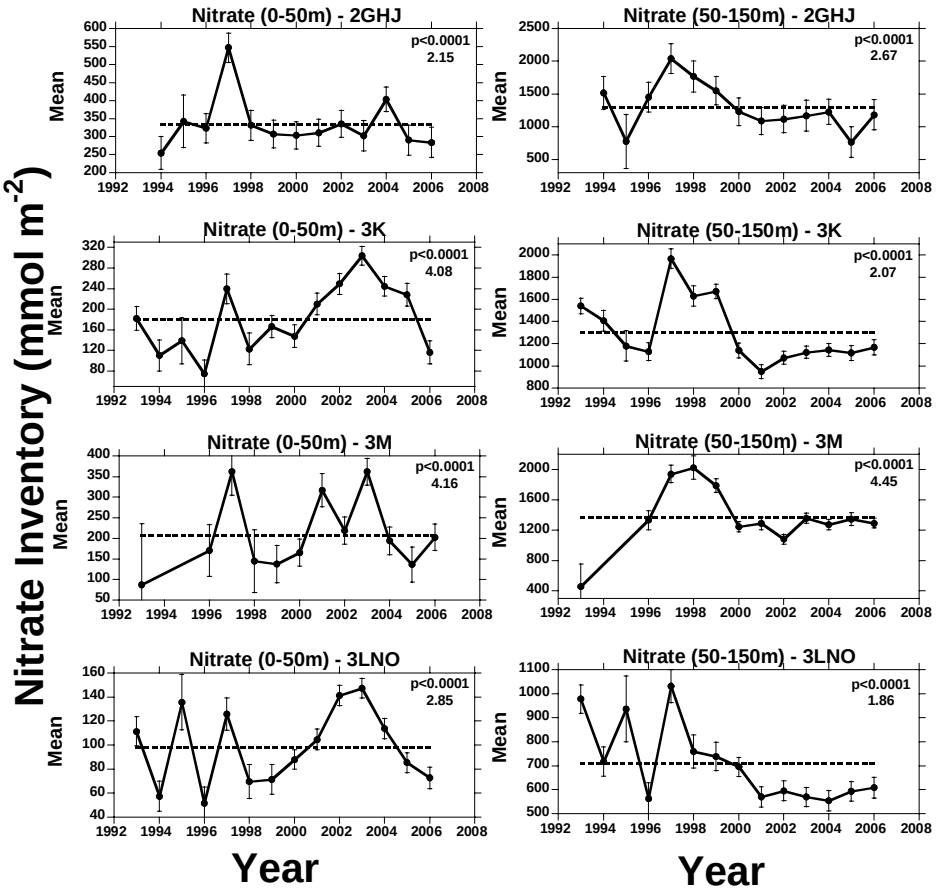

Figure 3. Seasonally-adjusted mean estimates of upper layer (0-50m integral) and deep (50-150m) nitrate (combined nitrite and nitrate) inventories in NAFO Subareas 2 and 3 during 1993-2006. The error bars represent standard errors. The *p*-value in the upper right hand corner indicates the probability of significant inter-annual variations in abundance based on type III sums of squares. The maximum-to-minimum ratio in the upper right hand corner indicates the magnitude of the variation in the inventories of nitrate.

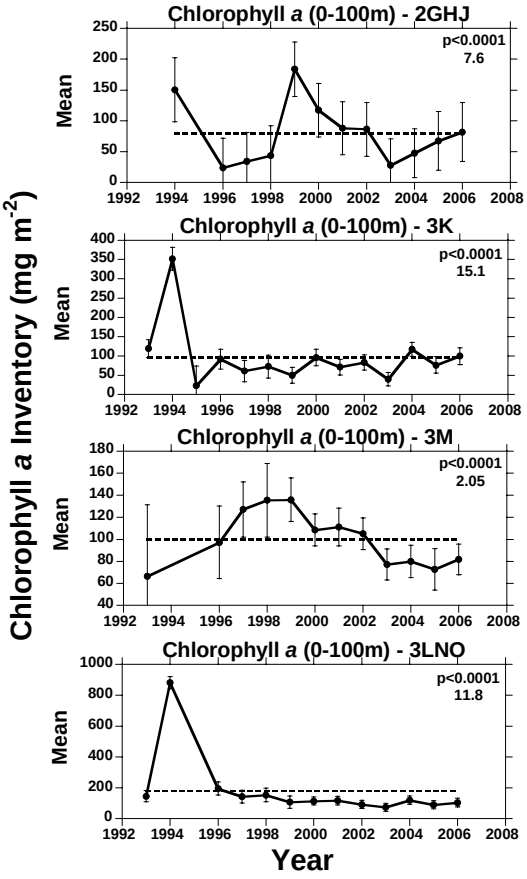

Figure 4. Seasonally-adjusted mean estimates of chlorophyll *a* (0-100m integrals) inventories in NAFO Subareas 2 and 3 during 1993-2006. The error bars represent standard errors. The *p*-value in the upper right hand corner indicates the probability of significant inter-annual variations in abundance based on type III sums of squares. The maximum-to-minimum ratio in the upper right hand corner indicates the magnitude of the variation in the inventories of chlorophyll *a*.

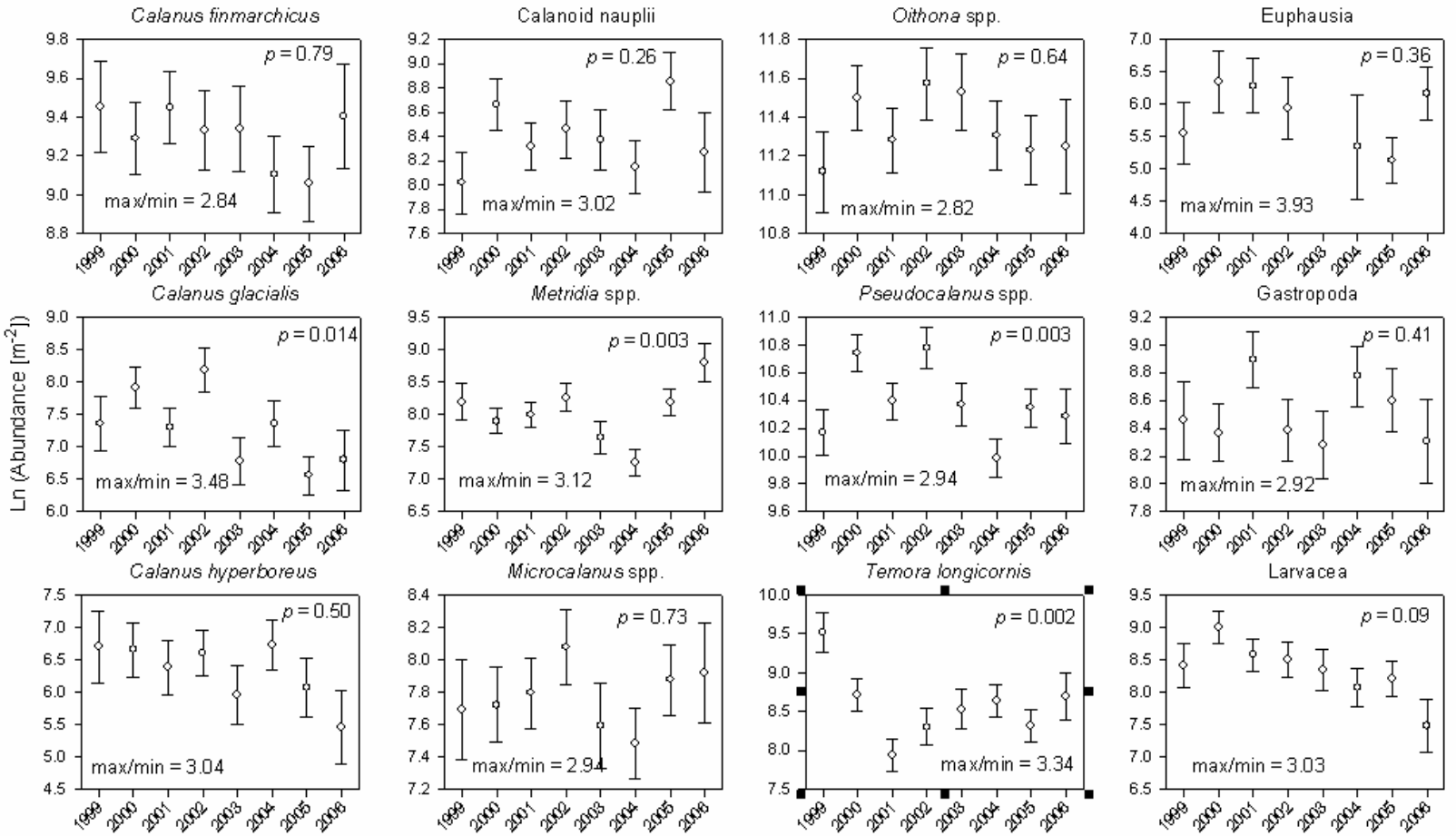

Figure 5. Seasonally-adjusted estimate of the mean abundance of twelve dominant zooplankton taxa from Station 27 (NAFO Div. 3L) for the period 1999-2006. The error bars represent standard errors. The p-value in the upper right hand corner indicates the probability of significant inter-annual variations 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

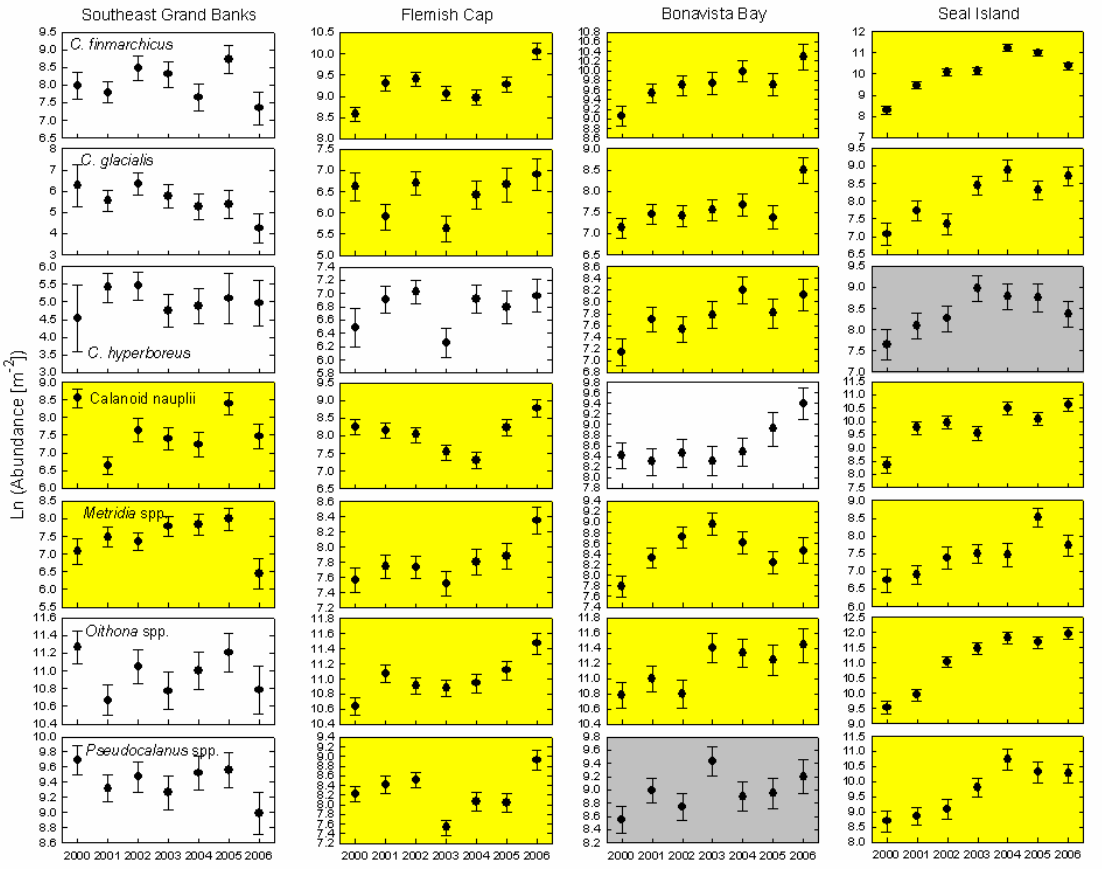

Figure 6. Seasonally-adjusted estimate of the mean abundance of seven dominant copepod taxa from the oceanographic transects for the period 2000-2006. The error bars represent standard errors. Values from the Southeast Grand Banks (Div. 3LNO) are based on two occupations per year (spring, fall); values from the Flemish Cap (Div. 3L and 3M) and Bonavista (Div. 3K) transects are based on three occupations per year (spring, summer, fall); values from the Seal Island (Div. 2J) transect are based on one occupation per year (summer). Yellow backgrounds indicate significant inter-annual differences in abundance. Grey Backgrounds indicate that variations in abundance were significant in 2005 but not in 2006.