NOT TO BE CITED WITHOUT PRIOR
REFERENCE TO THE AUTHOR (S)

Northwest Atlantic Fisheries Organization

**Serial No. N5234** **NAFO SCR Doc. 06/18**

**SCIENTIFIC COUNCIL MEETING – JUNE 2006**

# Biological Oceanographic Conditions in NAFO Subareas 2 and 3 on the Newfoundland and Labrador Shelf During 2005

by

G. L. Maillet, P. Pepin, S. Fraser, and D. Lane

Department of Fisheries and Oceans, P.O. Box 5667
St. John's, Newfoundland, Canada A1C 5X1

## Abstract

Biological oceanographic observations from a fixed coastal station and oceanographic transects in NAFO Subareas 2 and 3 during 2005 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 and silicate), chlorophyll *a*, as well as the abundance of major taxa of zooplankton collected as part of the Atlantic Zonal Monitoring Program (AZMP) and the Continuous Plankton Recorder (CPR) survey.

The annual mean nitrate and silicate inventories in the upper water column on the Newfoundland and Labrador Shelf were generally near the long-term mean, while deep inventories were slightly lower than the long-term mean in recent years. The annual mean chlorophyll *a* inventories in 2005 were slightly below the long-term mean.

The abundance of many dominant zooplankton in the Avalon Channel reached their lowest levels encountered since routine collections began in the late 1990s on the Grand Banks. In contrast, the abundance of many copepod species generally increased on the NE Newfoundland and Labrador Shelf along oceanographic sections above 48ºN in 2005. The abundance of these same copepods collected during the CPR survey dating back 3 decades indicated relatively large inter-annual variability, particularly during the 1960s through the 1970s limiting the detection of any trends. In contrast, the abundance of large calanoid copepods (*C. finmarchicus* and *C. glacialis*) increased while the abundance of small copepods (*Oithona* spp. and *Paracalanus*/*Pseudocalanus* spp.) together with nauplii production declined significantly in the late 1990s and recent years. 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 2005. More frequent directed sampling from research vessels and Ships of Opportunity at Station 27 and the completion of three surveys on the Newfoundland Shelf during 2005 by the Atlantic Zonal Monitoring Program (AZMP[1]) provided good spatial and temporal series coverage of standard variables which provides a foundation for comparison with previous years. Further details regarding biological oceanographic conditions on the Newfoundland and Labrador Shelf in 2005 and recent years can be found in Pepin *et al*., 2005.

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

## 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 2005 presented in this document are based on surveys listed in Table 1. All combined sample locations for chlorophyll *a* and nutrients (nitrate and silicate) 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 (Fig, 2). Annual mean time series for nutrient and chlorophyll *a* inventories were computed from all available seasonal data going back to 1993 within NAFO Div. 2GHJ, 3M, 3K, and 3LNO. Estimates of nutrient inventories, chlorophyll *a*, 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 # $m^{-2}$, $\alpha$ is the intercept, $\beta$ and $\delta$ are categorical effects for year and month, and $\varepsilon$ is the error, and

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

for each of the section, where $\delta$ 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.

The Continuous Plankton Recorder (CPR) Survey[2] provides an assessment of long-term changes in abundance and geographic distribution of planktonic organisms ranging from small phytoplankton cells to larger macrozooplankton (Warner and Hays, 1994). The CPR taxon categories varied from species to subspecies, while others are identified at coarser levels such as genus or family. The methods used to collect and enumerate plankton samples collected as part of the CPR Survey have remained largely unchanged since the inception of the Program in 1959 to present. This consistency allows analysis and valid comparisons between years. We chose similar categories from the CPR database to evaluate changes in abundance of the dominant mesoplankton (copepods) from the northeast Newfoundland Shelf and the Grand Banks including NAFO Div. 3K, 3L and 3Ps (See Fig. 3 and 4 for spatial and temporal distribution of CPR samples). We used the same GLM model (categorical effects for year and month) described earlier to compute seasonally-adjusted estimates of mean abundance of copepods during the available time series from 1961-79 and 1991-2004. Abundance is log-transformed to deal with the skewed distribution of observations. All analyses were based on NAFO-specific Divisions (3K, 3L and 3Ps) of abundance by species.

## Seasonal Variability in Nutrient Levels 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 at or near the long-term mean (1993-2005) during 2005 in all NAFO Divisions (Fig. 5). 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 in 1997 across the Newfoundland and Labrador Shelf with the exception of the Grand Banks (3LNO). Deep (50-150 m integral) nitrate inventories, which in part represents the nutrient pool for the following year, were slightly lower than the long-term mean across the Newfoundland and Labrador Shelf in 2005 and earlier years back to 2000, particularly for 3LNO (Fig. 5). 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 (Fig. 5).

Annual mean silicate inventories in the upper layer in 2005 were similar to nitrate levels with inventories near the long-term mean (Fig. 6). The elevated nitrate inventories observed in the late 1990's in the upper water-column were not observed in silicate across the different NAFO Divisions. Silicate inventories in the deep layer also declined across Subareas 2 and 3, consistent with the general timing observed for nitrate (Fig. 6). In addition, the

[2] http://192.171.163.165/

deep inventories of silicate were also elevated during the late 1990s in the same areas but showed consistent downward trends after 1999 similar to nitrate inventories across the NAFO Divisions. Significant inter-annual variations in both shallow and deep silicate inventories were observed on the Newfoundland and Labrador Shelf. Seasonally-adjusted annual mean chlorophyll *a* inventories (0-100m integral) in 2005 were slightly below the long-term mean (Fig. 7). 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), Grand Banks (Div. 3LNO), and Labrador Shelf (Div. 2GHJ). Chlorophyll *a* inventories were also elevated in 1997-99 on the Flemish Cap (Div. 3M) and Labrador Shelf (Fig. 7). 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*) (Fig. 8). The abundance of all species of *Calanus* (*finmarchicus, glacialis, hyperboreus*), *Metridia* spp., euphausiids and larvaceans in 2005 were at or near the lowest value recorded since 1999 while the abundance of large calanoid nauplii was high. These species all showed a decreasing trend in abundance which started in 2003 or earlier. The generalized linear model which included year and month effects explained 37% to 91% of the overall variance in log-transformed abundance of the zooplankton taxa (mean 61%). Over the 1999-2005 observation period, most taxa exhibited approximately a 3-fold variation in abundance in average annual abundance.

## 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 in recent years showed important north-to-south differences in the significance of inter-annual variations. Along the southeast Grand Banks transect (Div. 3LNO), which is surveyed only in the spring and fall, only large calanoid nauplii exhibited statistically significant inter-annual variations, with 2000 and 2005 showing high abundances while 2001-04 were generally lower (Fig. 9). The remaining six taxa (*C. finmarchicus, C. glacialis, C. hyperboereus, Metridia* spp., *Oithona* spp., and *Pseudocalanus* spp. showed fluctuations in abundance that were not statistically different among years.

The abundance of copepods along the Flemish Cap transect (Div. 3L and 3M) showed a little more variability than on the southeast Grand Banks. *Calanus finmarchicus*, *C. glacialis, Pseudocalanus* spp. and large calanoid nauplii showed significant inter-annual variations in abundance. For these four taxa, the abundance in 2005 was at or near the highest levels recorded since 2000. In the case of large calanoid nauplii, the abundance in 2005 was three times higher than in 2004 while the abundance of *C. finmarchicus* in 2005 was three times higher than in 2000 (Fig. 9).

Our observations from the Bonavista Bay transect (Div. 3K), which is sampled three times per year, showed that five of the 7 dominant copepod taxa exhibited statistically significant inter-annual variations in abundance based on the GLM (Fig. 9). Only in the case *C. glacialis* and large calanoid nauplii were inter-annual variations in abundance not statistically resolvable. However, in all taxa, with the exception of *Metridia* spp., the abundance in 2005 was at (or very near) the highest levels recorded since the inception of the AZMP. The abundance of *Metridia* spp. along the Bonavista transect has been decreasing since 2003.

Copepod abundance along the Seal Island transect (Div. 2J), which is sampled only in July, was at (*Metridia* spp.) or near (*C. finmarchicus, C. glacialis, C. hyperboreus,* calanoid nauplii, *Oithona* spp, *Pseudocalanus* spp.) the highest levels recorded since the inception of AZMP (Fig. 9). In all taxa, abundances showed statistically significant inter-annual variations. Most species showed a slight decline from abundances recorded in 2004 (or 2003 for *C. hyperboreus*) but in most instances the decrease was not statistically significant. In the case of *C. finmarchicus*, the abundance in 2005 was nearly 19 times higher than the lowest levels recorded in 2000. Most other species showed a 4 to 9-fold variation in overall abundance. Along all other transects, the overall variation in the seasonally-adjusted mean abundance for individual species is of the order of 1.5 to 3-fold between maximum and minimum densities.

We evaluated longer-term time series in the mean abundance of dominant copepod species from collections based on the CPR Survey during 1961-2004. The seasonally-adjusted estimates of mean abundance of the dominant copepods showed differences among the NAFO Div. 3Ps, 3L, and 3K and significant inter-annual variations among all taxa (Fig. 10). The largest changes between maximum and minimum abundance of copepods collected by the CPR survey was observed for *C. hyperboreus*, Copepoda nauplii, *Oithona* spp. and *Paracalanus*/*Pseudocalanus* spp., while *C. finmarchicus*, *C. glacialis*, and *Metridia* spp. displayed lower variability overall. In general, higher inter-annual variations in abundance of copepods were observed during the early period (1961-79 series) in contrast to the latter period (1991-2004). Only relatively small differences were observed in the average abundance between the two periods during 1961-79 and 1991-2004 among all copepod taxa examined (Fig. 10). Only *C. finmarchicus* showed a consistent downward trend in long-term mean abundance during the early (1961-79) compared to the later (1991-2004) period among all NAFO Divisions, while the long-term mean abundance of *C. glacialis*, *Oithona* spp. and *Paracalanus* / *Pseudocalanus* spp. showed the reverse trend. The pattern for *C. hyperboreus*, Copepoda nauplii, and *Metridia* spp. showed mixed trends during the time series (Fig. 10). *C. finmarchicus* showed an increasing trend in abundance in 3Ps during the 1990s and recent years while no large changes were observed for *C. glacialis*, *C. hyperboreus*, and *Metridia* spp. in 3K and 3L. Smaller copepods such as *Oithona* spp. and *Paracalanus/Pseudocalanus* spp., and larval stages (copepod nauplii) have shown downward trends in abundance for these species in 3L and 3Ps throughout the 1990s and recent years (Fig. 10).

## Summary and Conclusions

- In general, annual mean nutrient inventories have remained at or near the long-term mean (1993-2005) in the upper layer in 2005 on the Newfoundland and Labrador Shelf compared to earlier years.

- Deep inventories of nutrients remained under the long-term mean in 2005, following a pattern that started in the late 1990s.

- Higher nutrient inventories observed during the late 1990s 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 (1993-2005) in 2005.

- Although elevated nutrient levels may explain higher phytoplankton biomass observed in the late 1990s 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 many dominant zooplankton at Station 27 (3L) in 2005 reached their lowest levels encountered since routine collections began in the late 1990s.

- In contrast, the abundance of many copepod species were generally at their highest levels on the northeast Newfoundland Shelf along oceanographic transects above 48ºN in 2005.

- The seasonally-adjusted estimates of mean abundance of the dominant copepods collected by the CPR survey showed differences among the NAFO Div. 3Ps, 3L, and 3K and significant inter-annual variations among all taxa.

- CPR estimates of the abundance of small copepods *Oithona* spp. and *Paracalanus* / *Pseudocalanus* spp. and *Oithona* spp. indicate steadily decreasing abundance in NAFO Div. 3L and 3Ps throughout the 1990s and recent years. The abundance for *C. finmarchicus*, *C. glacialis*, and Copepoda nauplii showed the opposite trend, with increasing levels during the late 1990s and recent years in 3Ps.

## Summary and Conclusions (continued)

- 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.

## Acknowledgements

We thank the staff at the Northwest Atlantic Fisheries Centre (NWAFC) Biological and Physcial Oceanography Section for their acquisition, quality control and archiving of the data. We also wish to thank the efforts of Tim Shears and the many Scientific Assistants and Science Staff at the NWAFC in St, John's, CCG Officers and Crew for their invaluable assistance at sea. The expertise of Gerhard Pohle, Mary Greenlaw, and Mary Kennedy was crucial to the completion of this work.

## References

G. Han and J. Li. 2004. Sea Surface Height and Current Variability on the Newfoundland Slope from TOPEX/Poseidon Altimetry. Can. Tech. Rep. Hydrogr. Ocean Sci. 234 viii + 40 p.

Pepin, P., G.L. Maillet, S. Fraser, D. Lane. 2005. Biological and chemical oceanographic conditions on the Newfoundland Shelf during 2005. Canadian Science Advisory Secretariat, Research Document 2005/015, 66 pp.

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

Warner, A.J., G.C. Hays. 1994. Sampling by the Continuous Plankton Recorder survey. Progress in Oceanography, 34: 237-256.

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

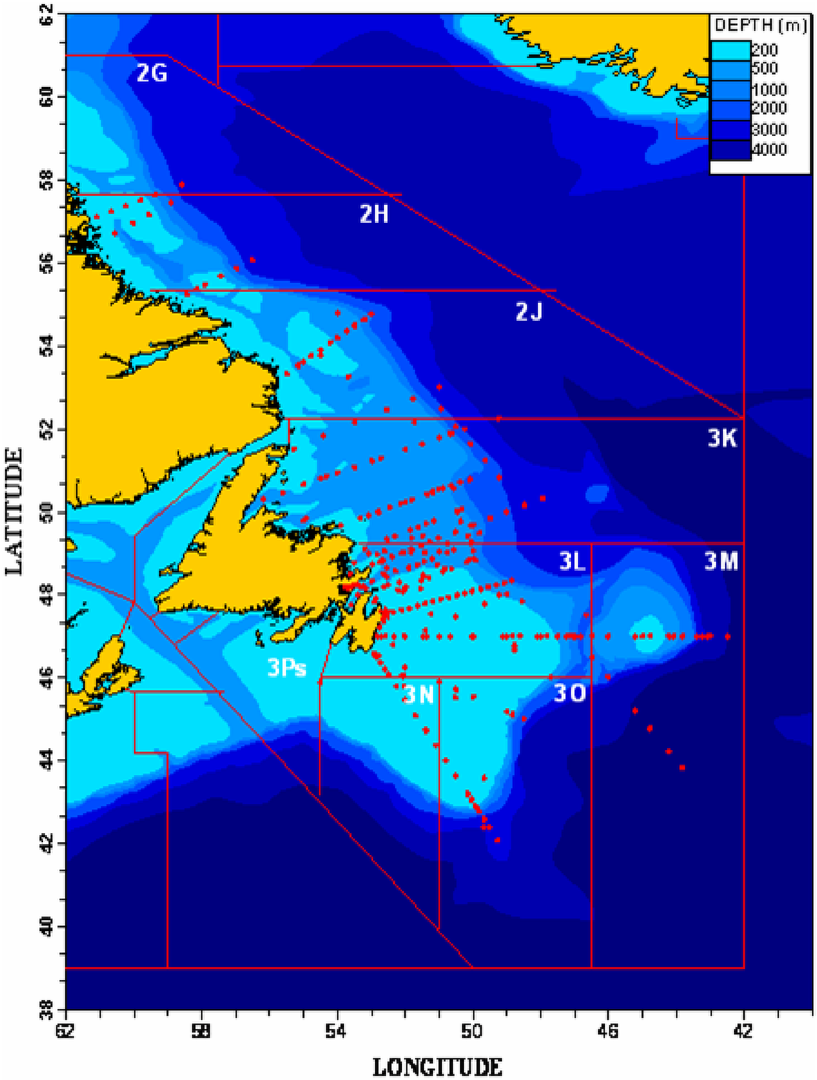


Fig. 1. Station locations for discrete chlorophyll *a* and nutrient collections in NAFO Subareas 2 and 3 during 1993-2005.

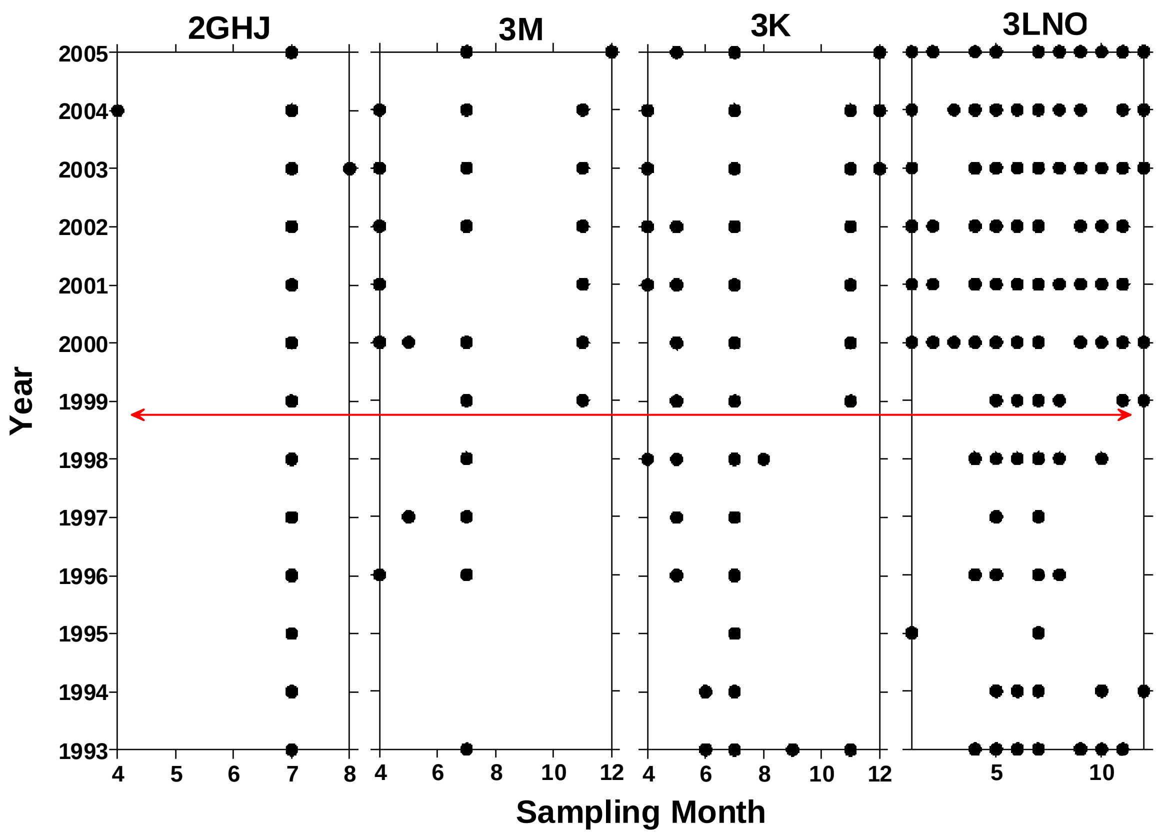


Fig. 2. Temporal coverage for discrete chlorophyll *a* and nutrient collections in NAFO Subareas 2 and 3 during 1993-2005. Red line marks the period from irregular seasonal coverage during the early to mid-1990s to more regular sampling from the late 1990s to present.

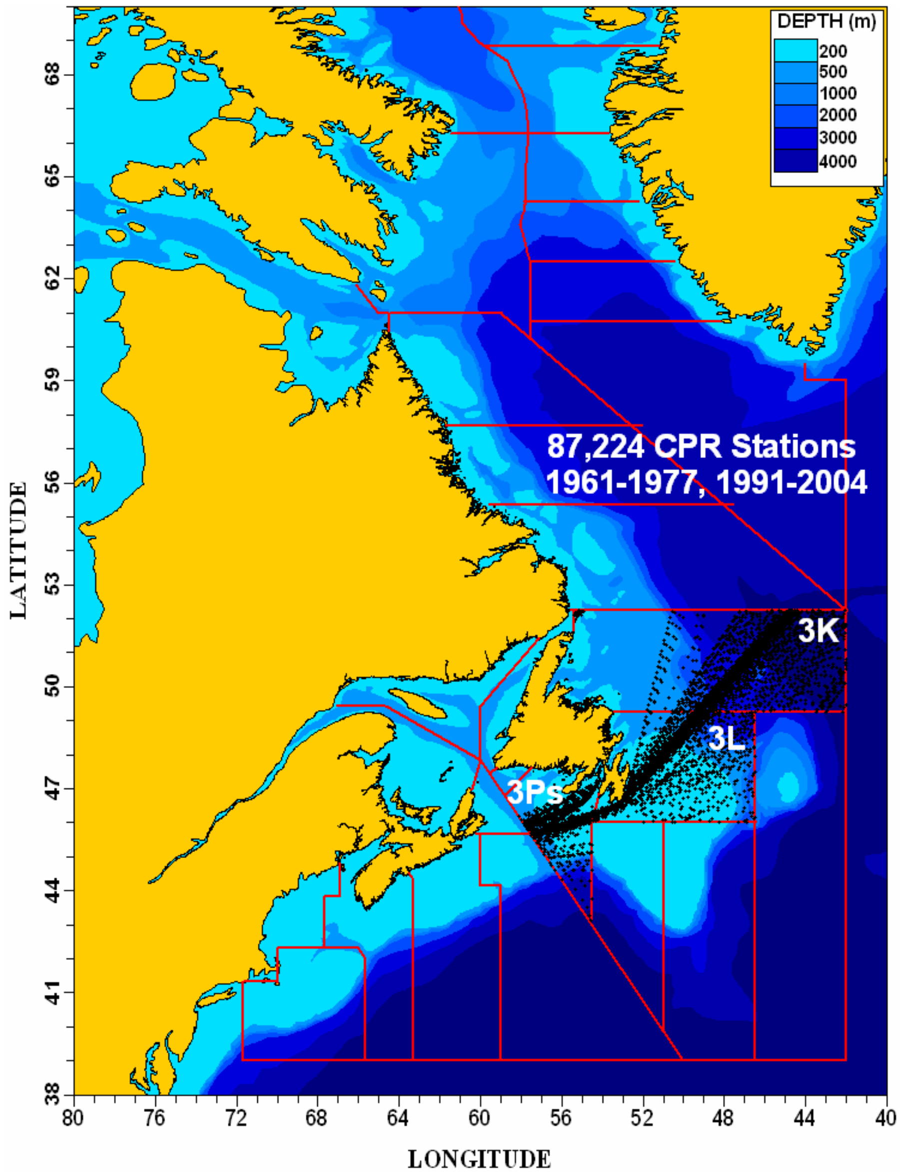


Fig. 3. Overlay of Continuous Plankton Recorder (CPR) stations within NAFO Div. 3K (northeast Newfoundland Shelf), 3L and 3Ps (Newfoundland Grand Banks) during 1961-2004. Note the main commercial shipping lanes across the northeast Shelf and the Grand Banks.

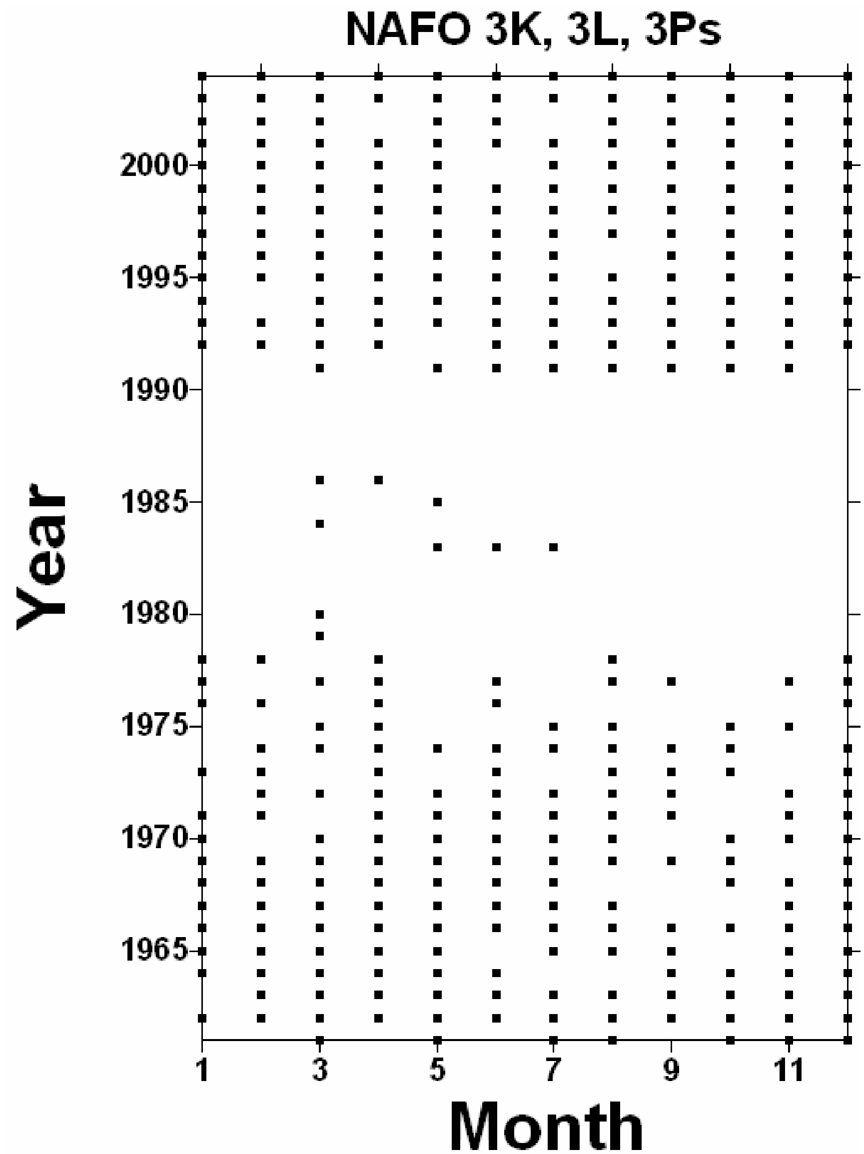


Fig. 4. Temporal coverage of Continuous Plankton Recorder (CPR) stations in NAFO Div. 3L and 3Ps (Newfoundland Grand Banks) during 1961-2004. Note the small monthly data gaps evident during time series and data void between 1978 and 1990.

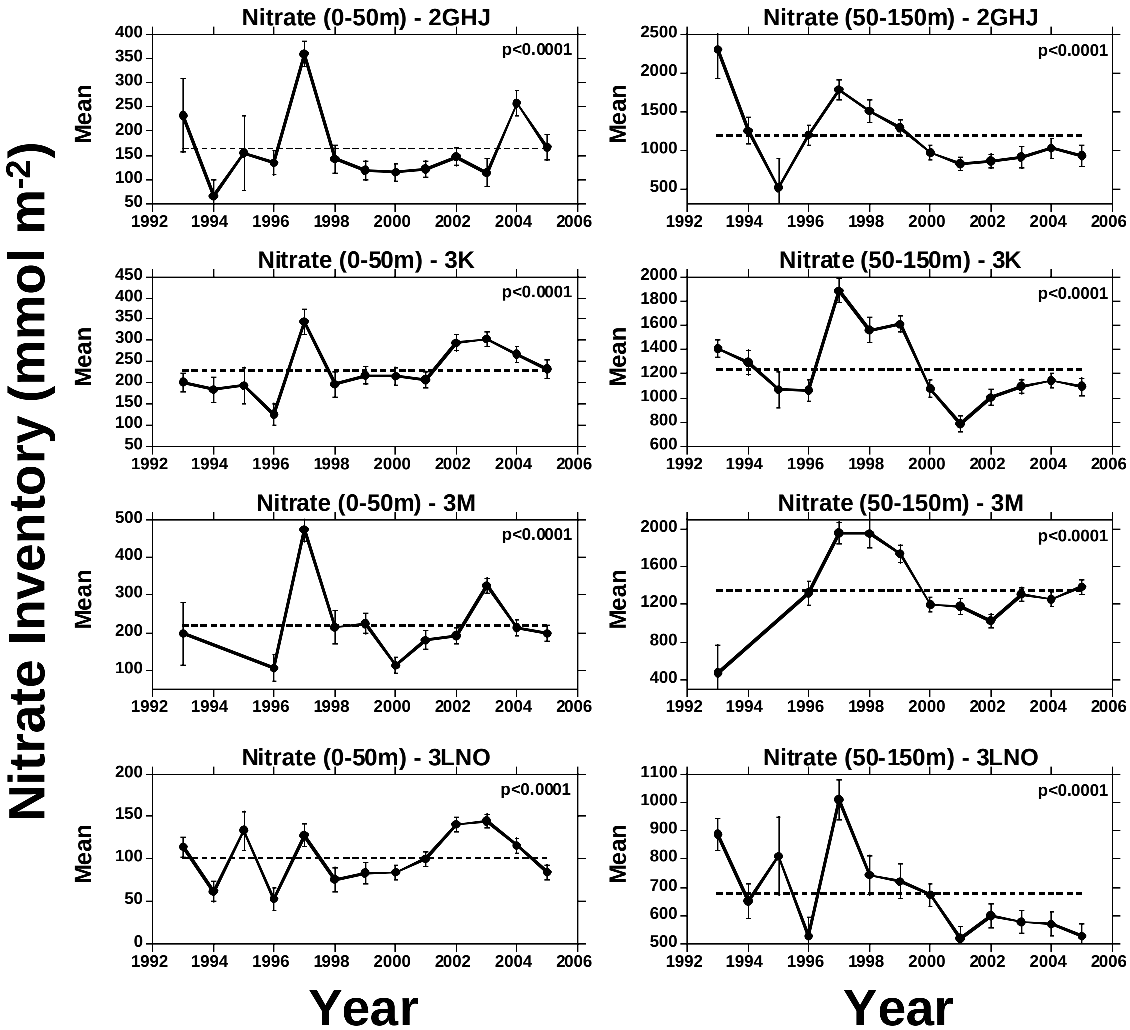


Fig. 5. Seasonally-adjusted mean estimates of upper layer (0-50 m integral) and deep (50-150 m) nitrate (combined nitrite and nitrate) inventories (± SE) in NAFO Subareas 2 and 3. Significance levels are in the upper-hand corner.

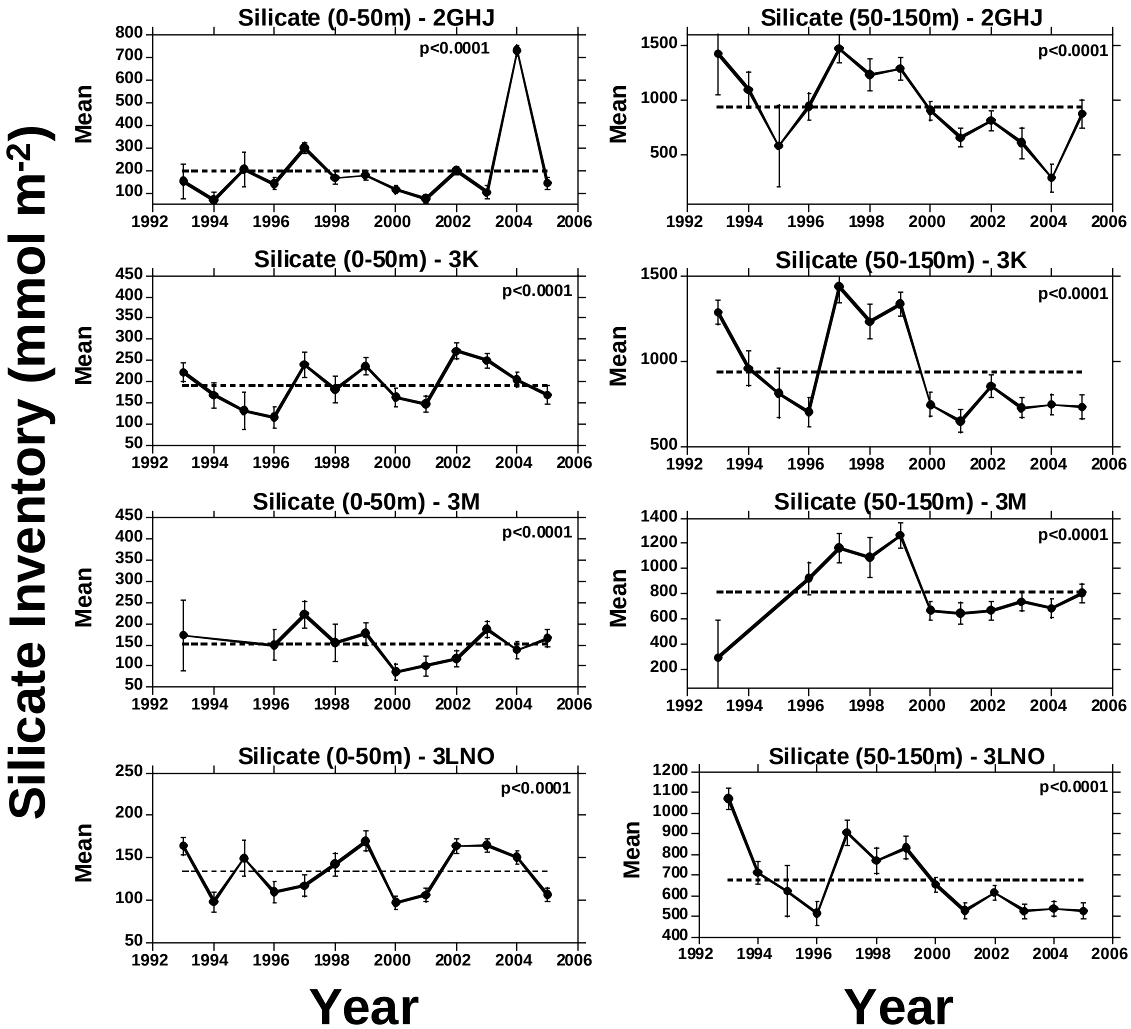


Fig. 6. Seasonally-adjusted mean estimates of upper layer (0-50 m integral) and deep (50-150 m) silicate inventories (± SE) in NAFO Subareas 2 and 3. Significance levels are in the upper-hand corner.

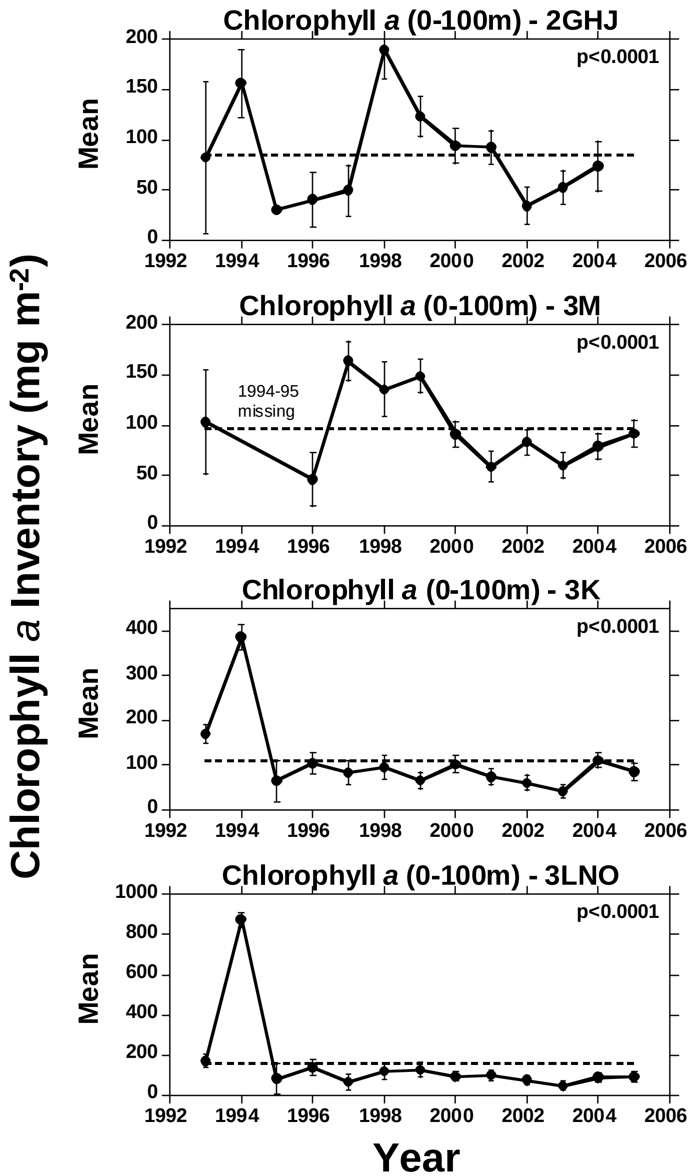


Fig. 7. Seasonally-adjusted mean estimates of chlorophyll *a* (0-100 m integrals) inventories (± SE) in NAFO Subareas 2 and 3. The error bars represent standard errors. The *p*-value in the upper right hand corner indicates the probability of significant inter-annual variations in abundance based on type III sums of squares.

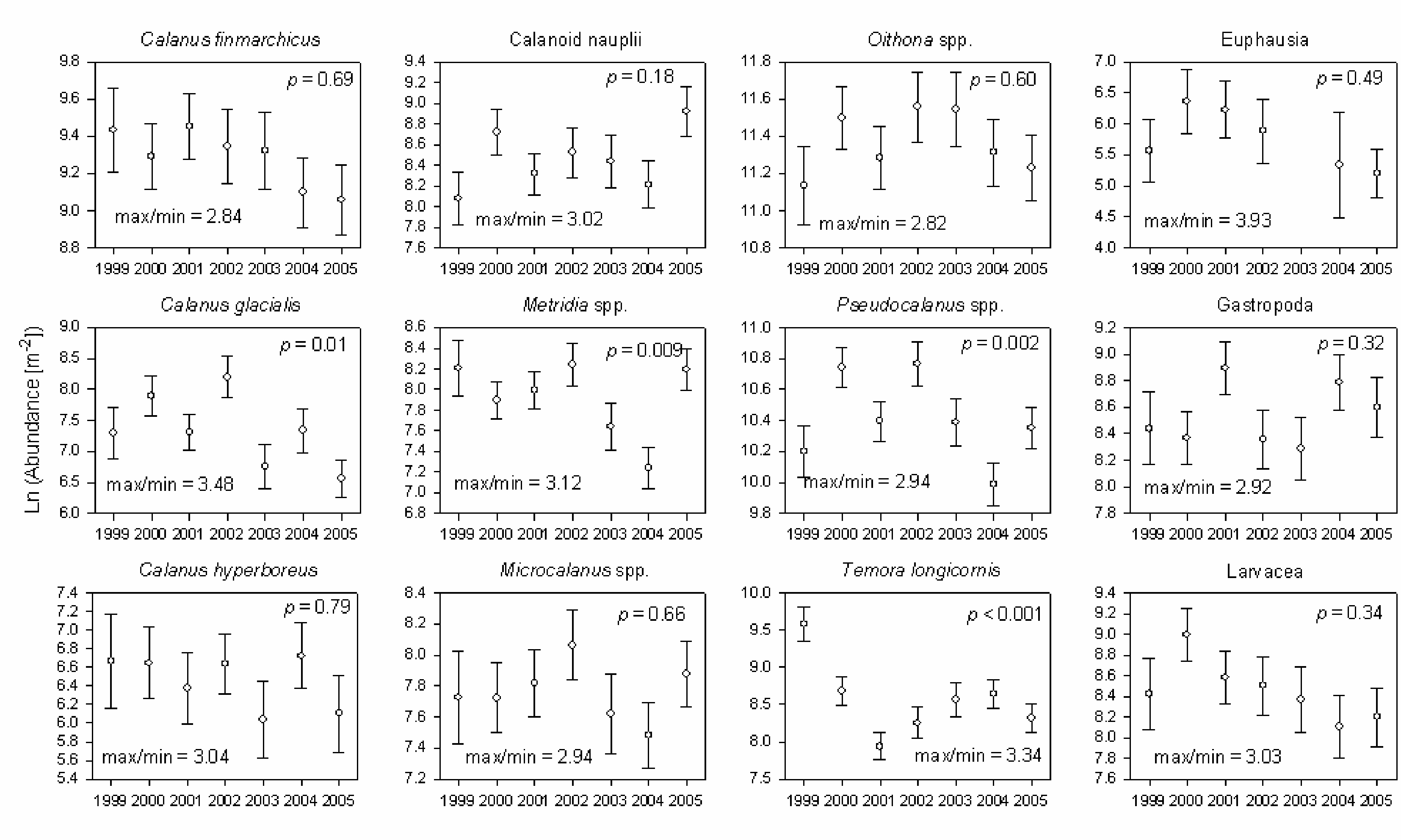


Fig. 8. Seasonally-adjusted estimate of the mean abundance of twelve dominant zooplankton taxa from Station 27 (NAFO Div. 3L) for the period 1999-2005. The error bars represent standard errors. The *p*-value in the upper right hand corner indicates the probability of significant inter-annual variations in abundance based on type III sums of squares. The maximum-to-minimum ratio in the lower left hand corner indicates the magnitude of the variation in abundance during the six year period.

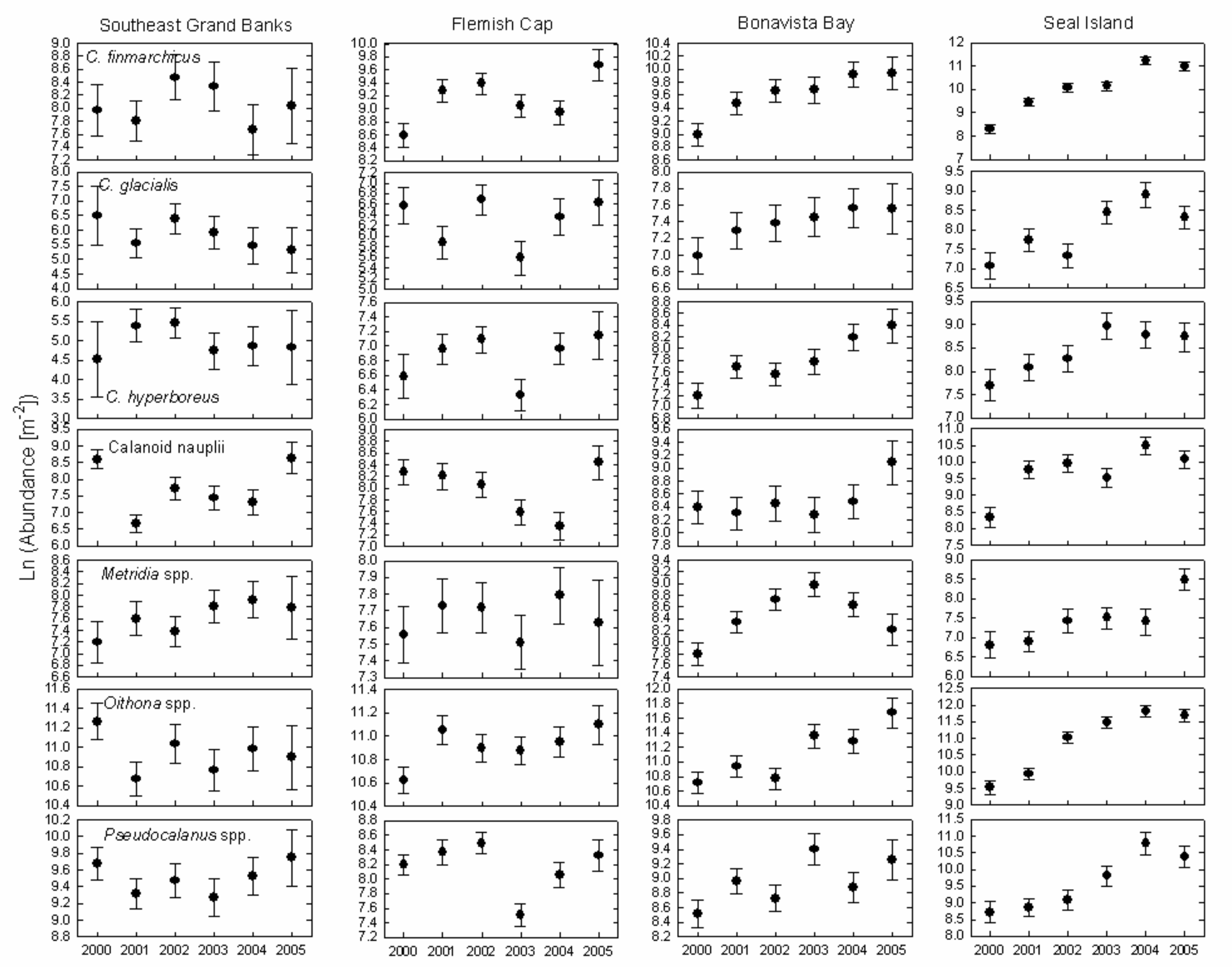


Fig. 9. Seasonally-adjusted estimate of the mean abundance of seven dominant copepod taxa from the oceanographic transects for the period 2000-2005. The error bars represent standard errors. Values from the Southeast Grand Banks (Div. 3LNO) are based on two occupations per year (spring, fall); values 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).

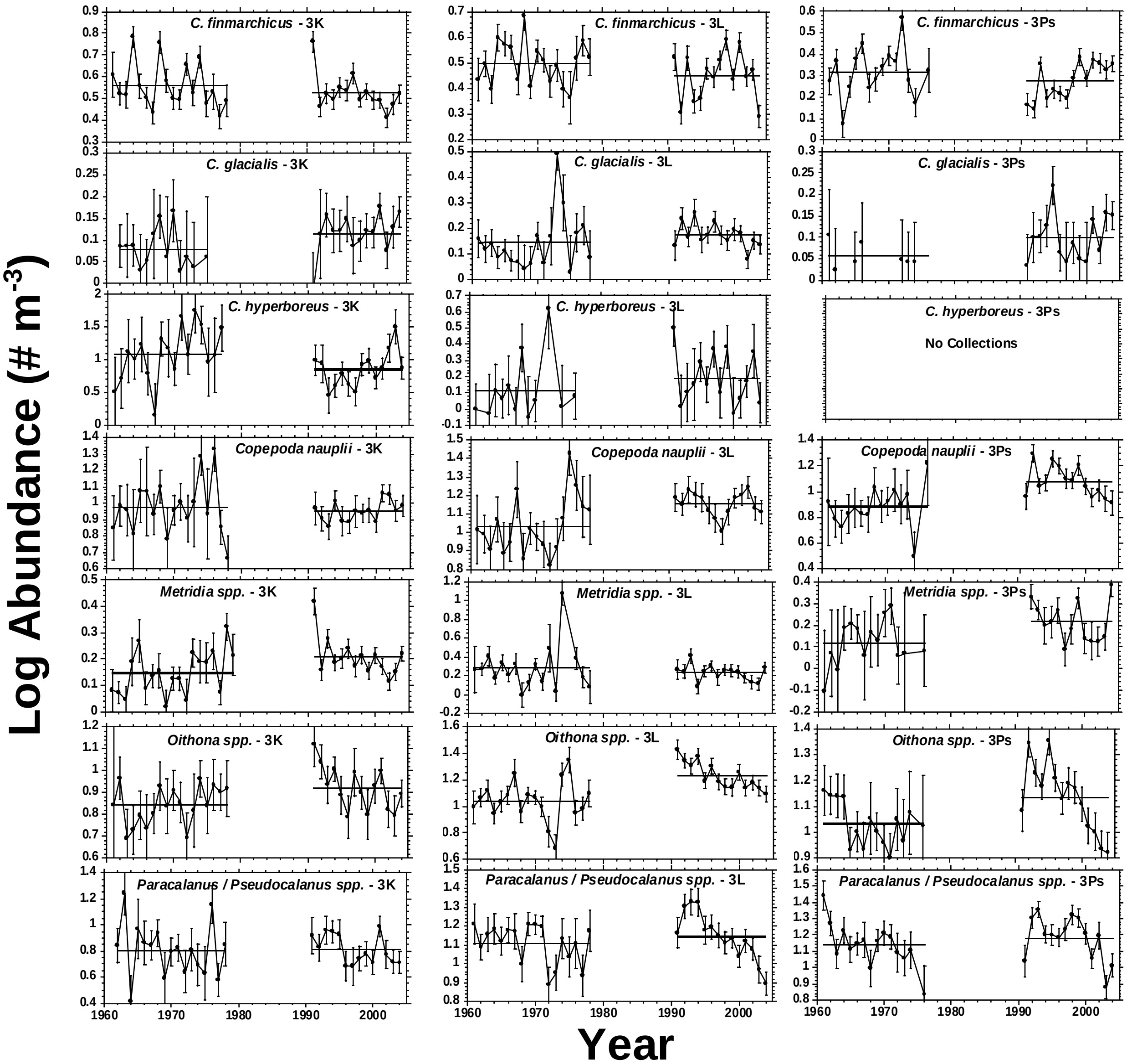


Fig. 10. Seasonally-adjusted estimate of the mean abundance of dominant copepod taxa from the CPR survey for the period 1961-2004 in NAFO Div. 3K, 3L, and 3Ps. The error bars represent standard errors. The solid lines through each time series (1961-79) and (1991-2004) represent the overall means for the respective time periods.