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Northwest Atlantic Fisheries Organization

Serial No. N5106 **NAFO SCR Doc. 05/22**

SCIENTIFIC COUNCIL MEETING – JUNE 2005

Biological Oceanographic Conditions in NAFO Subareas 2 and 3 on the Newfoundland and Labrador Shelf During 2004

by

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Abstract

Biological oceanographic observations from a fixed coastal station and oceanographic sections in NAFO Subareas 2 and 3 during 2004 are presented and referenced to previous information from earlier periods when data are available. We review the information concerning the seasonal and interannual variations in inventories of nutrients (nitrate and silicate), chlorophyll a, as well as the abundance of major taxa of phytoplankton and zooplankton collected as part of the Atlantic Zone Monitoring Program (AZMP) and the Continuous Plankton Recorder (CPR) survey.

Higher inventories of nutrients in the upper water column while lower levels were observed at depth in 2004. Despite elevated nutrient inventories observed during the late 1990s and recent years over the Newfoundland and Labrador Shelf, phytoplankton biomass remained relatively stable throughout the time series. Ocean colour imagery indicated variability in the timing, magnitude, and duration of surface blooms across the NW Atlantic. The abundance of many dominant zooplankton reached their lowest levels encountered since routine collections in the late 1990's on the Grand Banks. In contrast, the abundance of many copepod species generally increased on the NE Newfoundland Shelf along oceanographic sections above 48ºN in recent years.

Introduction

We review biological and chemical oceanographic conditions on the Newfoundland and Labrador Shelf during 2004. 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 2004 by the 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 2004 and recent years can be found in Pepin *et al.*, 2005.

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 2004 presented in this document are based on surveys listed in Table 1 and Fig. 1. All combined sample locations for chlorophyll a and nutrient inventories in earlier years are shown in Figure 2. The seasonal distribution of the data prior to the start of the AZMP in 1999 was limited (Fig. 3). 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. Percentage change in 2004 was taken as the difference between current year and combined average value of all available earlier data.

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

Estimates of zooplankton abundance along each oceanographic section were based on general linear models (GLMs) using the form:

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

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

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

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.

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 unchanged since the inception of the Program in 1959 to present. This consistency allows analysis and valid comparisons between years. We chose representative categories from the CPR database for phytoplankton, copepods, and macrozooplankton from the Grand Banks region including NAFO Div. 3L and 3Ps (See Fig. 4 and 5 for spatial and temporal distribution of CPR samples). We computed monthly means of relative abundance over the periods; 1961-70, 1971-78, 1991-00, and compared these near-decadal trends with the most recent years 2001-03.

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

Annual mean nitrate and silicate inventories in the upper water column (0-50 m integral), where active photosynthesis takes place, generally increased during 2004 along a latitudinal gradient with the largest percentage increase occurring further north on the Labrador Shelf (2GHJ) and decreasing southward to the Grand Banks (3LNO) (Fig. 4, 6). In addition, the inventories observed in 1997 increased synoptically 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 across the Newfoundland and Labrador Shelf (Fig. 5). Deep nitrate inventories reached higher levels in 1997 through till 1999 throughout Subareas 2 and 3, again with the exception of the Grand Banks (3LNO). The elevated nitrate inventories observed in the late 1990's were not apparent in silicate, with the exception of the Labrador Shelf. Silicate inventories in the deep layer also declined across Subareas 2 and 3 consistent with the pattern observed for nitrate (Fig. 7). In addition, deep inventories of silicate were also elevated during the late 1990's in the same areas but showed consistent downward trends after 1999 similar to nitrate inventories. Annual mean chlorophyll *a* inventories in 2004 were near or slightly below the long-term average (Fig. 8). 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 (3K) and Grand Banks (3LNO). Despite the elevated nutrient inventories observed in the late 1990s, phytoplankton biomass remained relatively stable throughout this period.

Satellite Imagery in the Northwest Atlantic

We used SeaWiFS[3] satellite imagery from the Bedford Institute of Oceanography (Dartmouth, NS) to obtain sea surface chlorophyll *a* biweekly composite plots across 10 statistical sub-regions on the Newfoundland and Labrador Shelf (Fig. 9). Time series of bi-weekly surface chlorophyll *a* concentrations from the Newfoundland and Labrador sub-regions showed a regular seasonal bimodal pattern with strong blooms during the spring and autumn in all areas. Time series of surface chlorophyll *a* concentrations for the Newfoundland and Labrador statistical sub-regions provided some insight into the magnitude, duration, and timing of surface blooms across the NW Atlantic (Fig. 10).

[2] http://192.171.163.165/

[3] http://seawifs.gsfc.nasa.gov/SEAWIFS.html

In 2004, large surface blooms were observed predominately through April and May in southern regions (St. Pierre Bank and Southeast Shoal), and along the NE Newfoundland Shelf (Hibernia, Avalon Channel, St. Anthony Basin), in contrast to weaker surface blooms further north on the Labrador Shelf. The timing of surface blooms has varied across the statistical sub-regions during the time series from 1998-2004 (Fig. 10). The most striking change in the timing of surface blooms has been in the Flemish Pass. Staring in 1999, surface blooms in this sub-region have shifted progressively later in time by almost two months until 2004, when bloom times shifted back to that observed in the late 1990s. Although the delay in timing was not as prominent in the other statistical sub-regions, less significant delays in the timing of surface blooms were apparent in the southern areas of the Newfoundland and Labrador Shelf (Fig. 10). The most northerly sub-regions (Hudson Strait and Northern Labrador) displayed lower chlorophyll *a* concentrations and a less intense bloom than other regions but the duration of the bloom lasted several months, extending into the autumn period compared to southerly sub-regions.

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

The overall abundance patterns for the main zooplankton assemblage observed at Station 27 (3L) continue to show significant changes since the inception of the AZMP in 1999. The annual abundance of *Calanus finmarchicus*, *Metrida* spp., *Pseudocalanus* spp., *Microcalanus* spp., larvaceans and euphausiids are at their lowest levels observed during this short time series (Figure 11). The production of large calanoid nauplii, and the copepods *Oithona* spp. and *Calanus glacialis* have also declined noticeably in recent years. The only notable increase in zooplankton abundance in recent years were gastropods in 2004, and the copepod *Temora* spp., which continues an increasing trend following a large decrease from 1999 to 2001 (Fig. 11). Of the main zooplankton assemblage, only *Pseudocalanus* spp., *C. glacialis*, *Metridia* spp., and *Temora* spp.

showed statistically significant inter-annual differences in seasonally adjusted abundance among years.

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

Seasonal and inter-annual variability in the abundance of many of the dominant copepods is becoming apparent on the Newfoundland and Labrador Shelf in recent years (Table 2). In general, the results of the GLM's indicate higher abundance of copepods along sections above 48ºN latitude (Fig. 12). The exception to this spatial trend is for *Pseudocalanus* spp. which is significantly higher in abundance on the southeast Grand Banks compared to the northerly sections, particularly during the spring surveys. *Calanus finmarchicus* and *Oithona* spp. show significant inter-annual variations in all seasons and along all sections (Fig. 12). Production of the copepod *Oithona* spp. has been steadily increasing on the Newfoundland and Labrador Shelf since monitoring began in 1999. *Calanus glacialis* and *Calanus hyperboreus*, and large calanoid nauplii show significant inter-annual variations in abundance in spring and summer, but not during the autumn. *Pseudocalanus* spp. shows significant inter-annual variations in summer and autumn.

The distribution of monthly means of phytoplankton indicate peak abundance in the spring and smaller magnitude blooms during the autumn (Fig. 13). The relative abundance of large diatom cells (*Chaetoceros* spp.) and dinoflagellates (*Ceratium arcticum*) have increased in the 1990s and most recent years from lower levels observed during the 1960-1970s (Fig. 13). Although changes in abundance of diatoms and dinoflagellates has increased during the late 90's and recent years compared to earlier decades, these changes have not been reflected in the bulk phytoplankton colour index which has remained relatively unchanged according to the long-term mean (Fig. 13).

The distribution of monthly means of calanoid copepods (*Calanus finmarchicus*; all stages CI-CVI) indicate bi-modal peaks in abundance similar to the patterns observed in phytoplankton, while smaller copepods (*Pseudocalanus / Paracalanus* and *Oithona* spp.) were present throughout the year (Fig. 14). While *C. finmarchicus*, a ubiquitous copepod in the NW Atlantic, were generally increasing during the 1990s, the abundant smaller copepods have shown a systematic decline from record high abundances in the early 1990s to recent years, particularly in the case of *Pseudocalanus* / *Paracalanus* spp. Recently, *C. finmarchicus* has also declined in abundance in recent years (Fig. 14).

The distribution of monthly means of selected macrozooplankton categories (all stages) over the decades have shown some shifts in timing of occurrence (Fig. 15). The abundance of Chaetognatha generally peaks during the summer during the 1960-70s, while since the 1990s their seasonal occurrence is more limited and the timing of peak abundance appears to be highly variable. Annual mean abundance of this CPR group has been relatively stable compared with the long-term mean with an increasing trend observed in recent years. The Euphausiacea which represent an important potential prey source to higher trophic levels, have declined significantly during the 1990s compared to abundances observed in the 1960-70s (Fig. 15). A continued systematic decrease in abundance of this macrozooplankton has occurred since 2000 reaching the lowest level recorded in the CPR time series. The abundance of the Hyperiidea, which represent an important planktonic predator and prey source to higher trophic levels, show relatively stable levels throughout the time series with a slight downward trend since the mid-1990s (Fig. 15).

Summary and Conclusions

- In general, annual mean nitrate and silicate inventories have increased in the upper layer in 2004 on the Newfoundland and Labrador Shelf compared to earlier years.
- Deep inventories of nutrients declined in 2004, following a downward trend since the late 1990's.
- Synoptic increase in shallow and deep nitrate inventories observed on the Newfoundland and Labrador Shelf during the 1997-99.
- 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).
- Phytoplankton biomass remained relatively stable throughout the late 1990s and recent years despite evidence of elevated nutrient inventories.
- The timing of surface phytoplankton blooms revealed from ocean colour imagery has shifted progressively later by several weeks from 1999 to 2003 on the central Newfoundland and southern Labrador Shelf but, in 2004 has returned back to an early bloom period as was observed in 1999.
- Zooplankton abundance at Station 27 (3L) in 2004 was generally low for most of the dominant species but few changes are statistically significant. This pattern follows a general decreasing trend since 2000 and consistent with summer observations from oceanographic surveys on the Flemish Cap section and CPR observations.
- The only notable increase in zooplankton abundance at Station 27 (3L) in 2004 and recent years were gastropods and the copepod *Temora* spp.
- The abundance of the most dominant copepod species along the oceanographic sections has been stable or has shown a general increase above 48ºN.
- The production of the copepod *Oithona* spp. has been steadily increasing on the Newfoundland and Labrador Shelf since AZMP surveys began in 1999.
- CPR estimates of the abundance of *Calanus finmarchicus, Pseudocalanus* spp. and *Oithona* spp. indicate lower abundance over Grand Banks during the 1990s and recent years. The trend for *Oithona* spp. is not entirely consistent with observations from oceanographic surveys which indicate higher seasonal and annual production of this copepod in recent years.
- CPR surveys may indicate some decoupling between phytoplankton and zooplankton abundance trends in late 1990s and recent years.
- Dominant macrozooplankton on the Grand Banks have declined in abundance in the 1990s, with the exception of *Chaetognatha*, which have increased in recent years.
- Estimates of abundance of *C. finmarchicus, Pseudocalanus* spp., *Microcalanus* spp., *Metrida* spp., larvaceans, *Paracalanus/Pseudocalanus* spp., and Euphausiacea in the Avalon Channel and on the Grand Banks have reached their lowest level recorded in the time series from the respective AZMP and CPR surveys in 2003-04.

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 the many

Scientific Assistants and Science Staff at the NWAFC in St, John's, CCG Officers and Crew for their invaluable assistance at sea. Glen Harrison, Heidi Maass, and Trevor Platt provided the bi-weekly composite information of surface chlorophyll derived from satellite collections. The expertise of Joe Craig, Gerhard Pohle, Cynthia McKenzie, Mary Greenlaw, and Mary Kennedy was crucial to the completion of this work.

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Table 1. Listing of AZMP Sampling Missions in the Newfoundland and Labrador Region in 2004. The transects are Southeast Grand Banks (SEGB); Flemish Cap (FC); Smith Sound (SS), Trinity Bay (TB), Bonavista Bay (BB); Funk Island (FI); White Bay (WB); Seal Island (SI), and the fixed station (Station 27). 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
TEL524	Apr 17-May 2, 2004	SEGB, FC, BB, SS	100	48
WT552	Jul 21-Aug 3, 2004	FC, BB, WB, SI	75	44
Hud586	Nov 19-Dec 5, 2004	SEGB, FC, BB, FI, SS, TB	148	60
Fixed	Jan-Dec 2004	Station 27	55	21

Table 2. Results from significance tests for inter-annual variability in the mean abundance (# m^{-2}) of dominant copepods (*Calanus finmarchicus* – CALFIN, *Calanus glacialis* – CALGLA, *Calanus hyperboreus* – CALHYP, copepod nauplii – NAUPLI, *Metrida* spp. - METRID, *Oithona* spp. - OITHON, and *Pseudocalanus* spp. - PSEUDO) along the oceanographic sections (southeast Grand Banks-SEGB, Flemish Cap-FC, Bonavista Bay-BB, and Seal Island-SI) during 2000 to 2004.

Season	Section	CALFIN	CALGLA	CALHYP	NAUPLI	METRID	OITHON	PSEUDO
Autumn	**SEGB**	NS	NS	NS	NS	NS	$P<0.01$	$P<0.05$
	FC	$P<0.01$	NS	NS	NS	NS	$P<0.05$	NS
	BB	$P<0.01$	NS	$P<0.01$	NS	$P<0.05$	$P<0.01$	$P<0.01$
Spring	**SEGB**	NS	NS	NS	$P<0.01$	$P<0.05$	$P<0.01$	NS
	FC	$P<0.05$	$P<0.01$	$P<0.01$	$P<0.01$	$P<0.01$	$P<0.05$	NS
	BB	$P<0.05$	$P<0.05$	$P<0.01$	$P<0.01$	$P<0.05$	$P<0.05$	NS
Summer	**FC**	$P<0.01$	$P<0.01$	NS	$P<0.01$	NS	NS	$P<0.01$
	BB	NS	$P<0.05$	NS	$P<0.05$	$P<0.01$	$P<0.01$	NS
	SI	$P<0.01$	$P<0.01$	$P<0.05$	$P<0.01$	NS	$P<0.01$	$P<0.01$

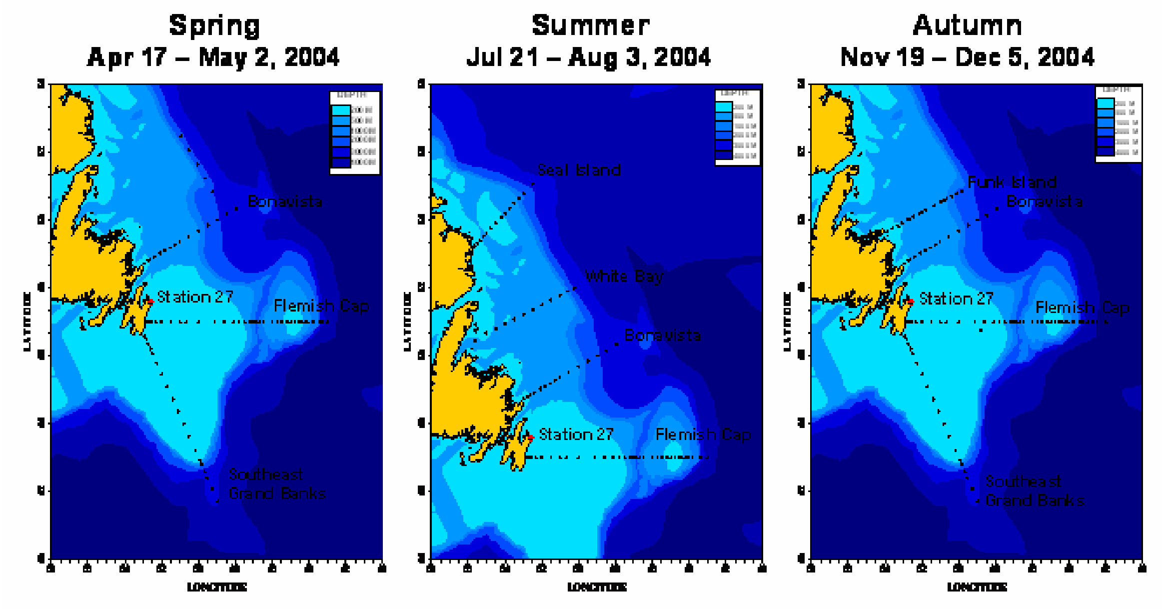

Fig. 1. Biological and physical occupations during AZMP seasonal sections on the Newfoundland and Labrador Shelf in 2004.

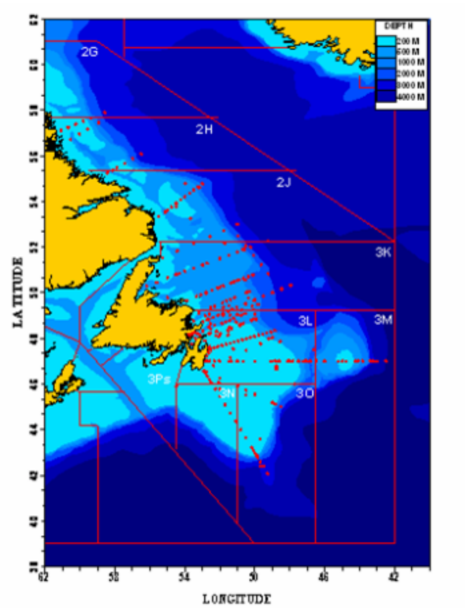

Fig. 2. Station locations for discrete chlorophyll *a* and nutrient collections in NAFO Subareas 2 and 3 during 1993-2004.

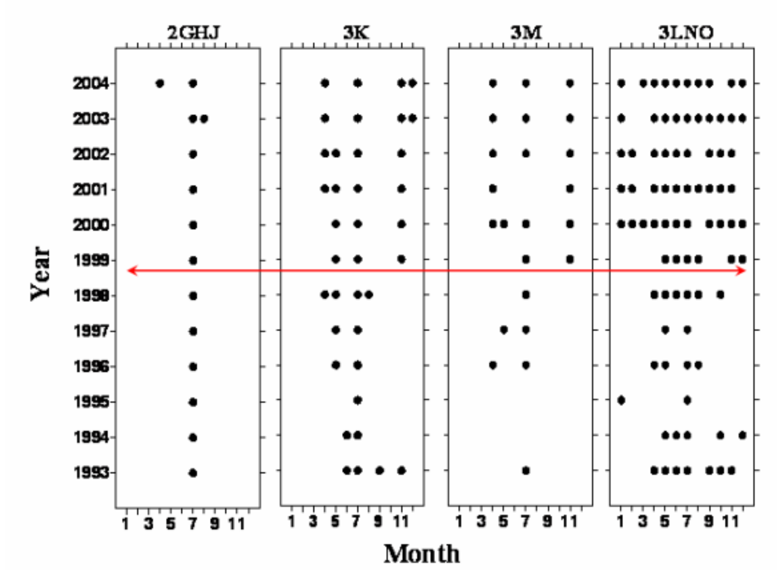

Fig. 3. Temporal coverage for discrete chlorophyll *a* and nutrient collections in NAFO Subareas 2 and 3 during 1993-2004. Red line marks the period from irregular seasonal coverage during the early to mid-1990s and more regular sampling from the late 1990s to present.

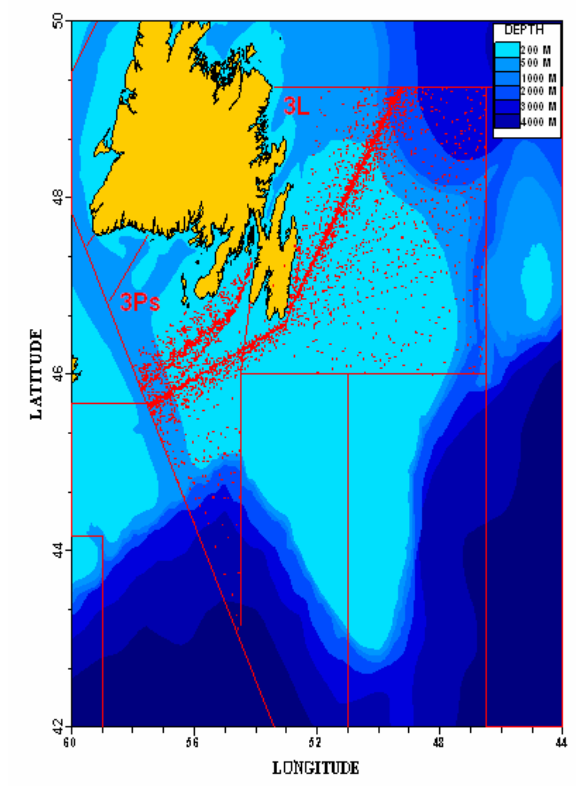

Fig. 4. Overlay of Continuous Plankton Recorder (CPR) stations within NAFO Div. 3L and 3Ps (Newfoundland and Grand Banks) during 1961-2003. Note the main commercial shipping lanes across the Grand Banks.

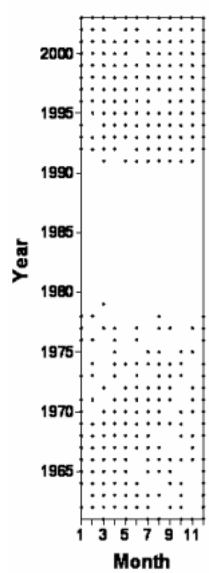

Fig. 5. Temporal coverage of Continuous Plankton Recorder (CPR) stations in NAFO Div. 3L and 3Ps (Newfoundland Grand Banks) during 1961-2003. Note the small monthly data gaps evident during time series and data void between 1978 and 1990.

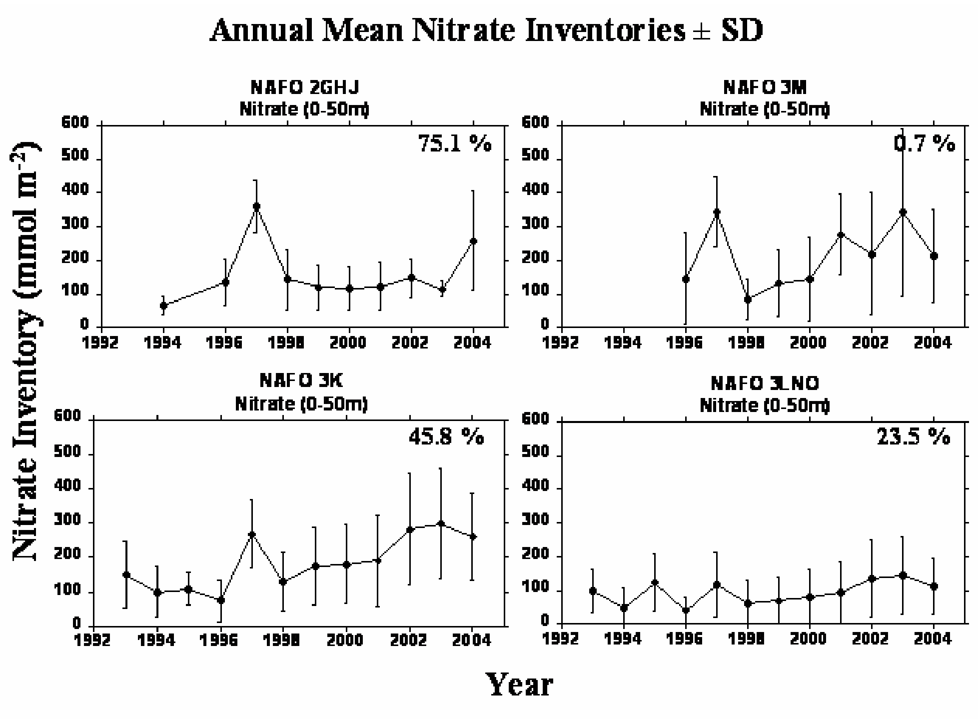

Fig. 4. Annual mean upper layer (0-50 m integral) nitrate inventory (± SD) in NAFO Subareas 2 and 3. Percentage in upper right corner refers to the difference between 2004 and earlier combined mean value of time series.

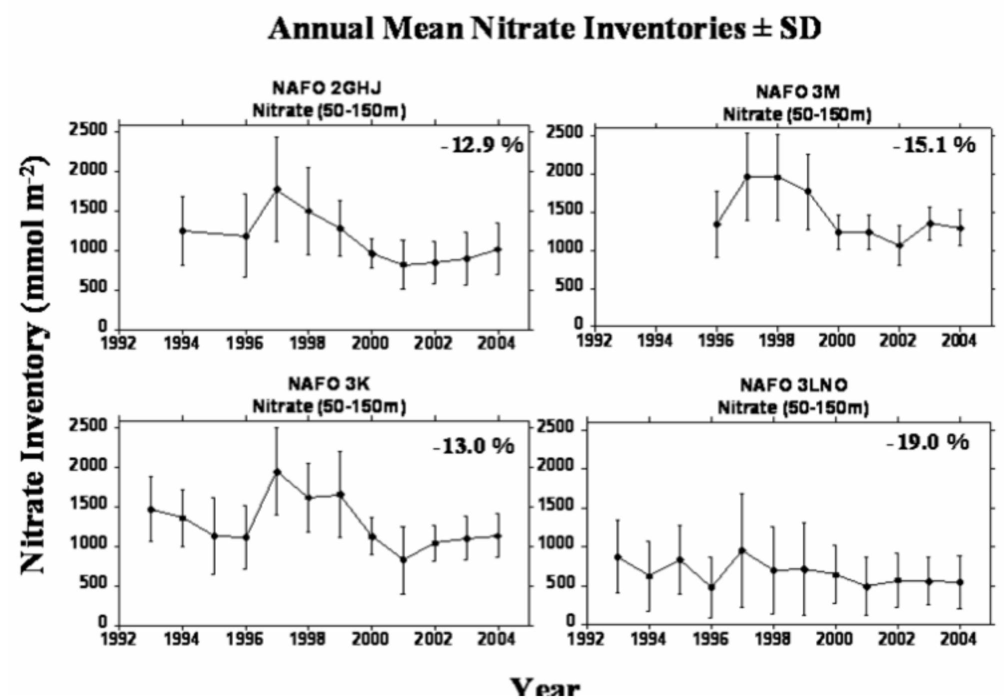

Fig.5. Annual mean lower layer (50-150m integral) nitrate inventory (± SD) in NAFO Subareas 2 and 3. Percentage in upper right corner refers to the difference between 2004 and earlier combined mean value of time series.

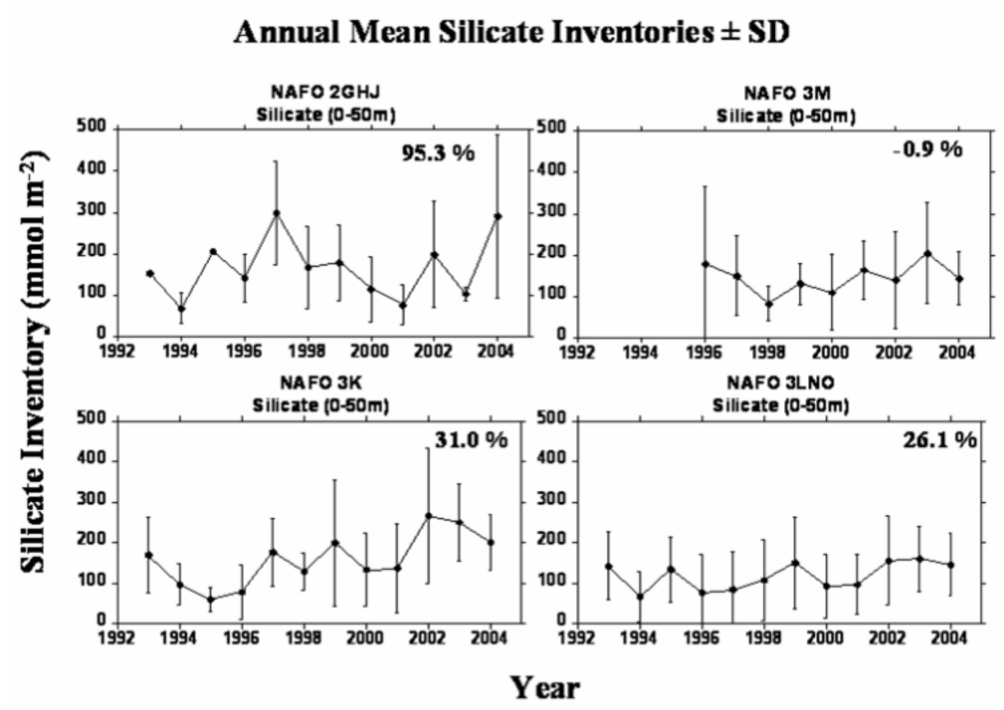

Fig. 6. Annual upper layer (0-50m integral) mean silicate inventory (± SD) in NAFO Subareas 2 and 3. Percentage in upper right corner refers to the difference between 2004 and earlier combined mean value of time series.

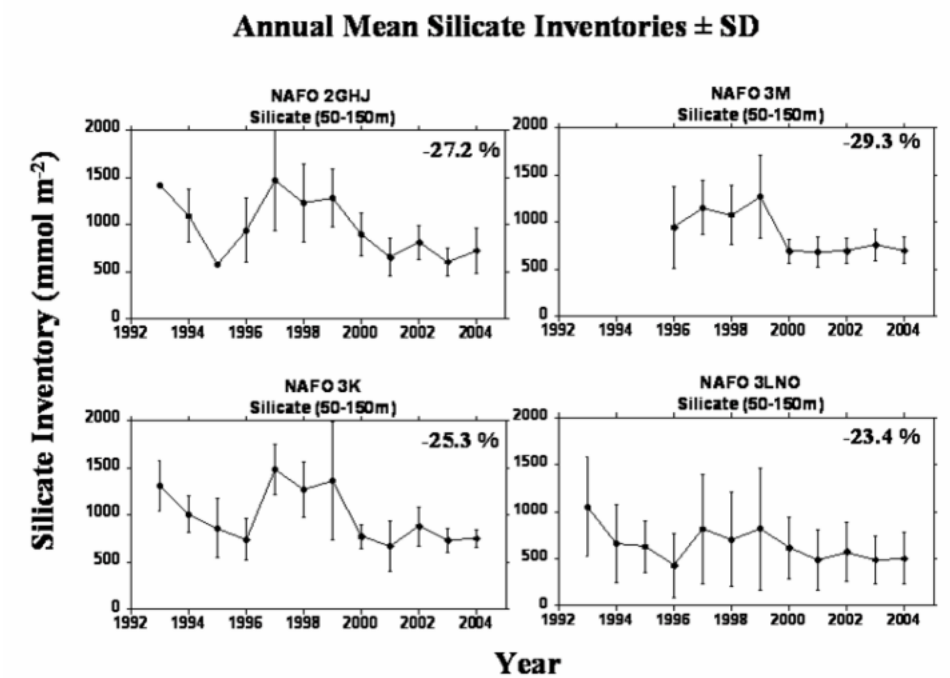

Fig. 7. Annual mean lower layer (50-150m integral) silicate inventory (± SD) in NAFO Subareas 2 and 3. Percentage in upper right corner refers to the difference between 2004 and earlier combined mean value of time series.

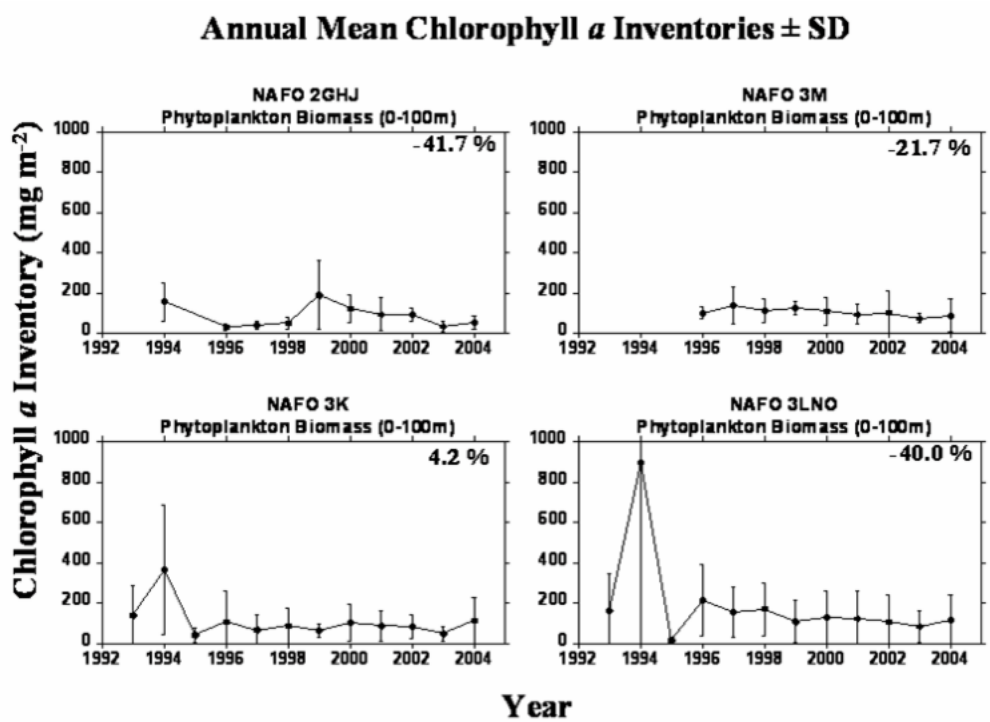

Fig. 8. Annual mean chlorophyll *a* inventory (± SD) in NAFO Subareas 2 and 3. Percentage in upper right corner refers to the difference between 2004 and earlier combined mean value of time series.

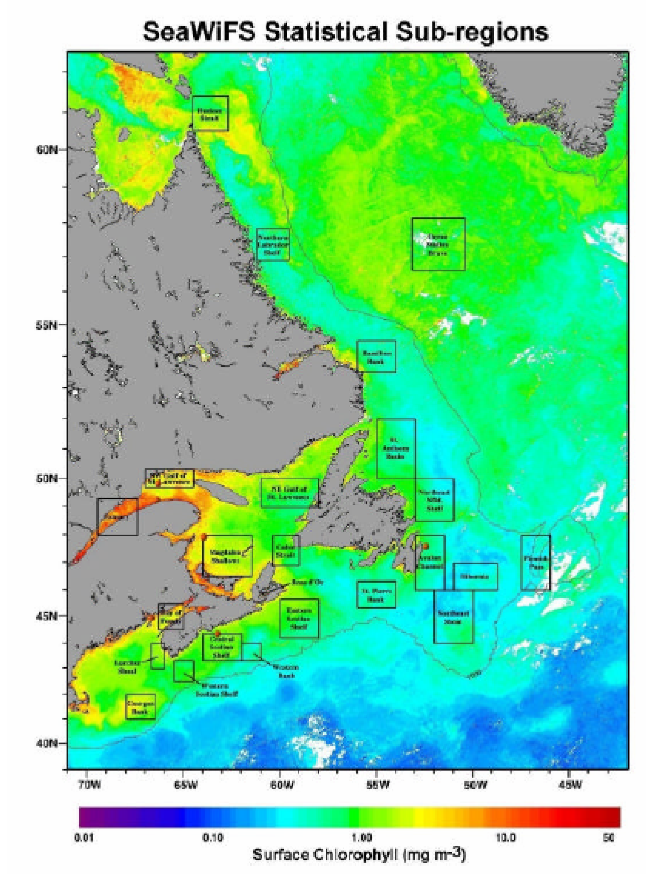

Fig. 9. SeaWiFS statistical sub-regions used in production of sea surface chlorophyll *a* bi-weekly composite plots.

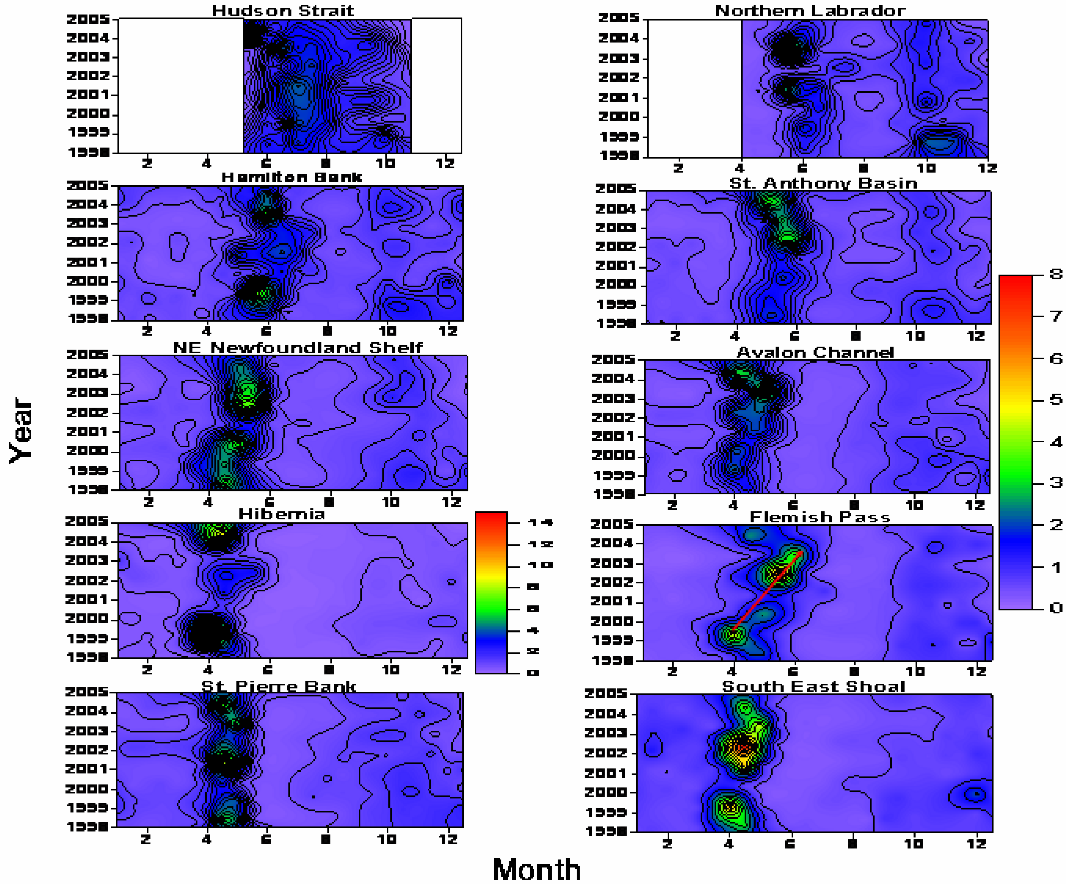

Fig. 10. Time series of surface chlorophyll *a* concentrations (mg m^{-3}) from SeaWiFS bi-weekly ocean colour composites, along the Newfoundland and Labrador Statistical Sub-regions from 1998-2004.

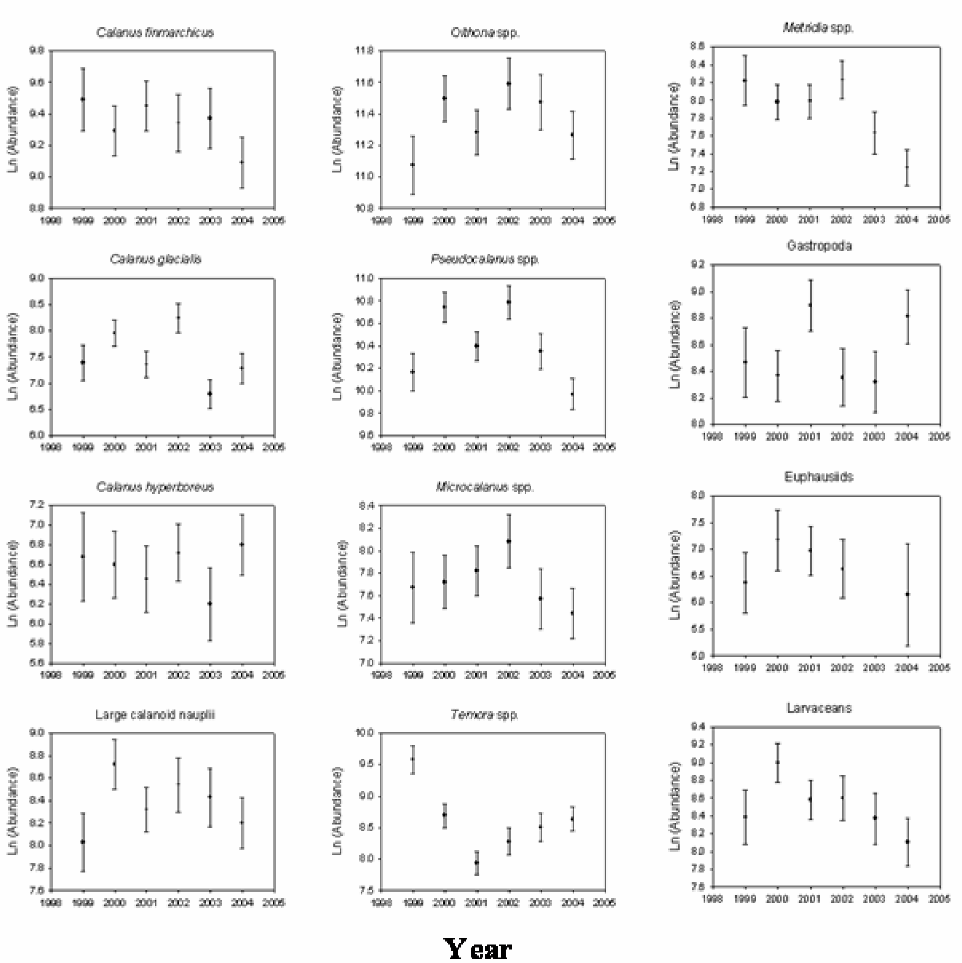

Fig.11. Estimates of abundance (natural log-transformed) of the dominant zooplankton assemblage at Station 27 (NAFO Division 3L) during 1999-2004.

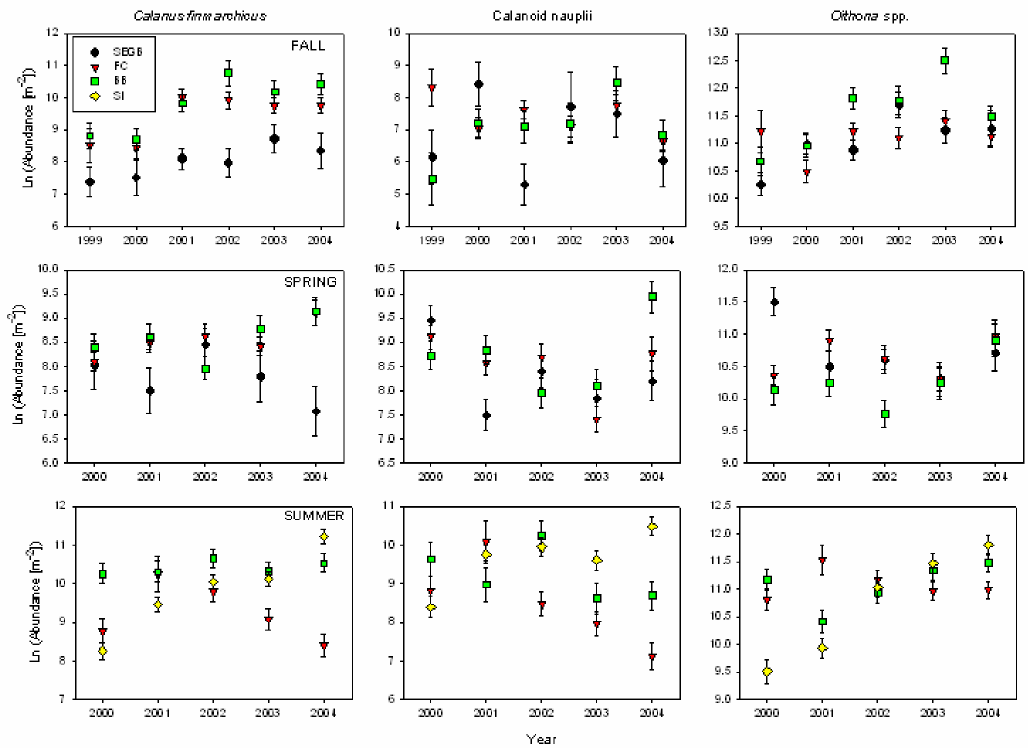

Fig. 12. Estimates of abundance of the dominant copepod assemblage along oceanographic sections [(Southeast Grand Banks-SEGB (3LNO); Flemish Cap-FC (3L and 3M); Bonavista Bay-BB (3K); and Seal Island-SI (2J)] based on General Linear Model.

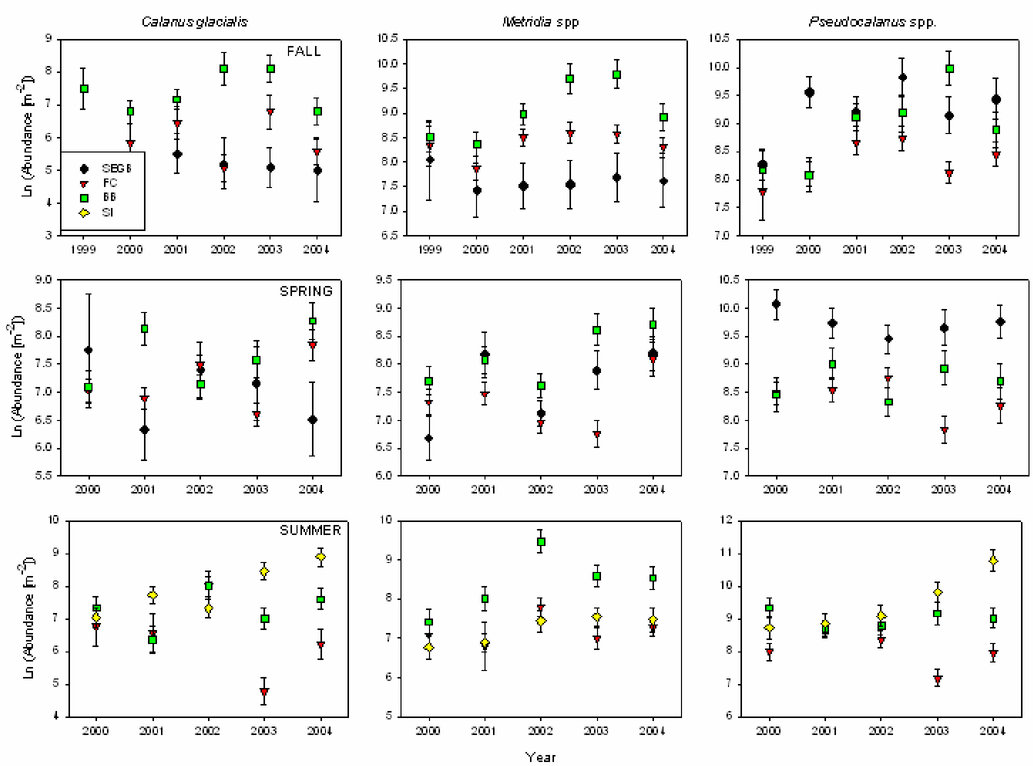

Fig. 12. Continued.

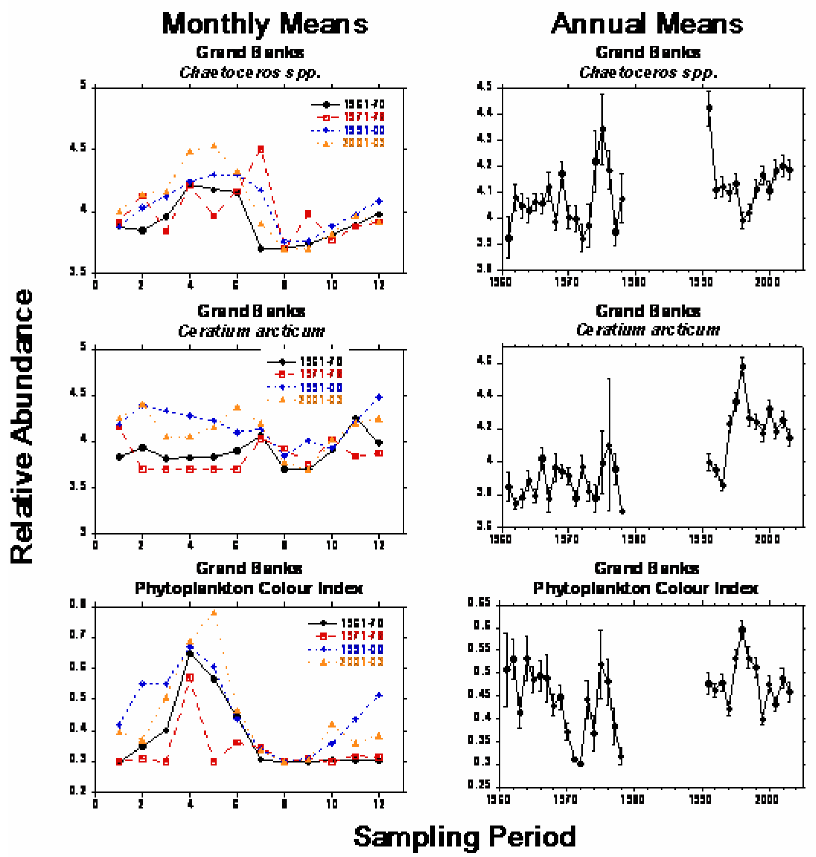

Fig. 13. Time series of relative abundance (monthly and annual means ± SE) of selected phytoplankton categories from the Grand Banks (NAFO Divisions 3L and 3Ps) from the CPR Surveys 1961-2003. Vertical bars are standard errors.

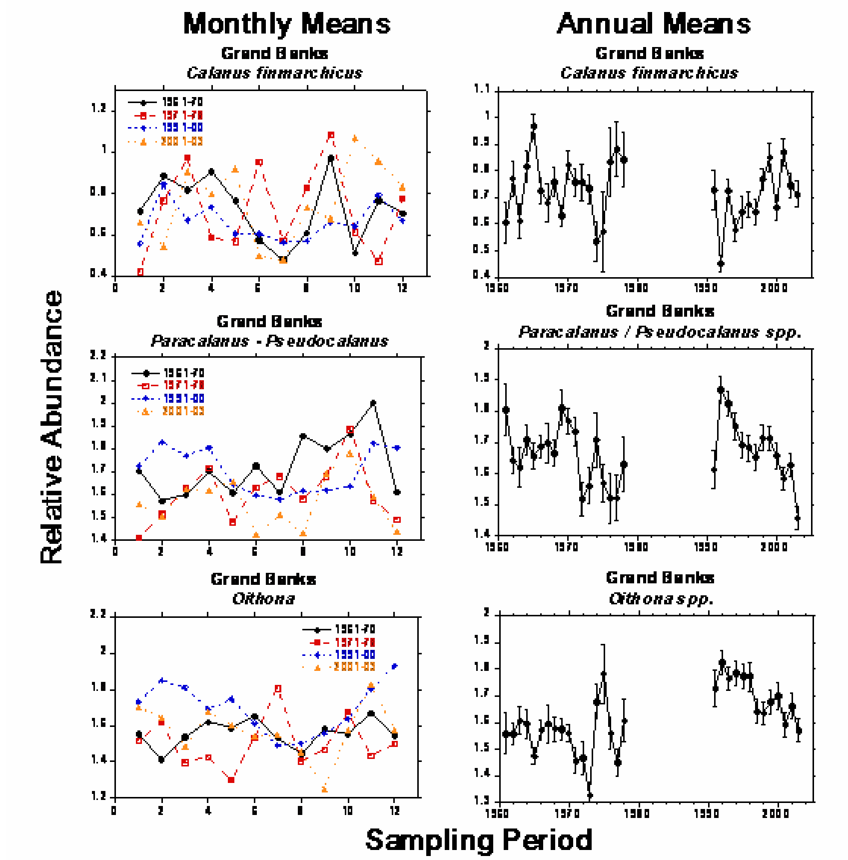

Fig 14. Time series of relative abundance (monthly and annual means ± SE) of selected copepods (all stages) from the Grand Banks (NAFO Divisions 3L and 3Ps) from the CPR Surveys 1961-2003. Vertical bars are standard errors.

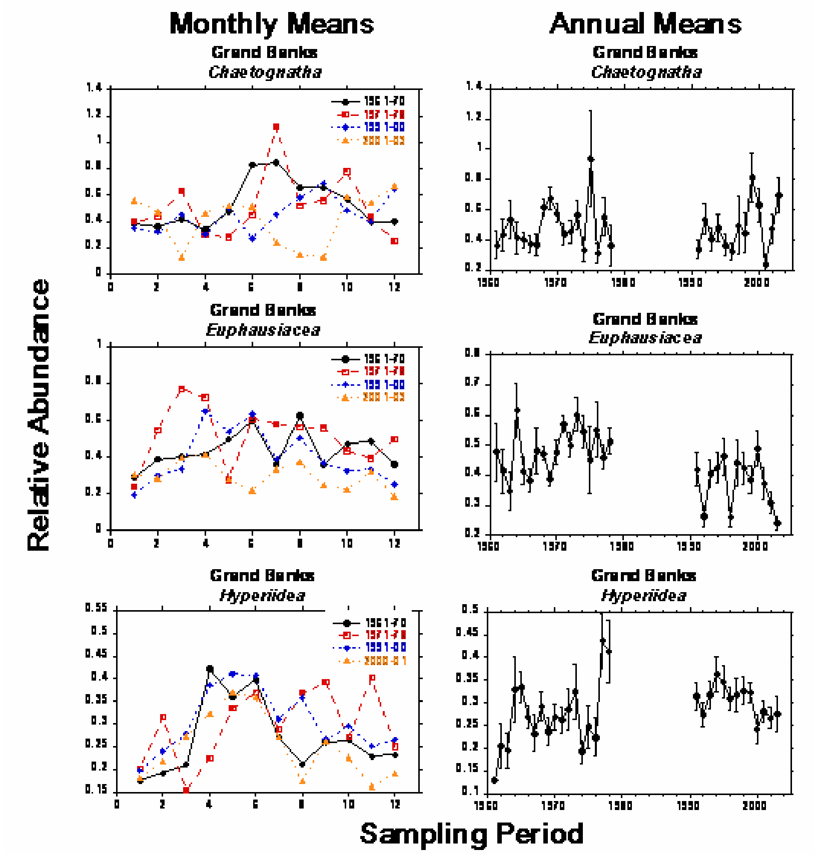

Fig.15. Time series of relative abundance (monthly and annual means ± SE) of selected macrozooplankton (all stages) from the Grand Banks (NAFO Divisions 3L and 3Ps) from the CPR Surveys 1961-2003. Vertical bars are standard errors.