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Biological Oceanographic Conditions in NAFO Subareas 2 and 3 on the Newfoundland and Labrador Shelf During 2002

by

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Abstract

Biological oceanographic observations from a fixed coastal station and oceanographic sections in NAFO Subareas 2 and 3 during 2002 are presented and referenced to previous information from earlier periods when data are available. The spring bloom at Station 27 in 2002 was much stronger compared to previous years. The trend in optical conditions at Station 27 were not consistent with the general reduction in attenuation across different oceanographic sections and seasons in 2002, leading to deeper euphotic depths. Water column stability and heating, inferred from stratification and integrated temperature, showed consistent trends between the seasonal occupations at Station 27 and oceanographic sections. The seasonal inventories of silicate and nitrate in the upper 50m were 2-3-fold higher along most oceanographic sections compared to earlier years (2000-01). Similar positive trends in the deep inventories were apparent for the southern Grand Banks, but smaller differences were observed along the other sections. Although the spring inventories of chlorophyll a (proxy of phytoplankton biomass) were higher in 2002 at Station 27 compared to earlier years, the pattern at the fixed station was not reflected in the offshore waters, where a negative trend was observed along the sections. The abundance of the copepodite stage of small and large copepod species was comparable to previous years. The development and production of dominant copepod species in 2002 was similar to 2000 and earlier than observed in 2001. The relative abundance and occurrence of copepod species normally found in colder waters increased in contrast to warm water species.

Introduction

This report presents an overview of the biological oceanographic conditions in the Newfoundland and Labrador Regions during 2002. We investigate the linkages of selected optical, meteorological, chemical, and physical variables with biological conditions. The information presented for 2002 is derived from sampling at Station 27 throughout the year from ships of opportunity and measurements made along standard cross-shelf transects during seasonal oceanographic surveys (Pepin and Maillet, 2003).

Materials and Methods

Collections of oceanographic data are based on sampling protocols outlined by the Steering Committee of the Atlantic Zonal Monitoring Program (AZMP)[1]. A number of non-standard AZMP variables are also presented for additional information. Protocols for additional measures are described in Pepin and Maillet (2001).

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

Results

Seasonal and Interannual Variability in Optical Measures

Station 27 (Division 3L)

A total of 23 biological sampling profiles were collected in the Avalon Channel at Station 27 in 2002 (Fig. 1). Optical measures can provide useful information regarding biological dynamics. We investigated time series of the following optical measures:

(1) Vertical Attenuation Coefficient (K_d), which is related to coloured and dissolved substances and particulate matter in seawater (average of 5-50m depths)
(2) Euphotic Depth, defining the boundary to which significant penetration of light occurs to allow photosynthesis.
(3) Incident Photosynthetic Active Radiation (PAR), the visible spectrum of light (400-700 nm) that plants utilize in photosynthesis.

Time series of K_d increased rapidly in response to the onset of the spring bloom from initial background levels of 0.1 m^{-1}(Fig. 2a). The magnitude and duration of K_d was related principally to the observed increase in chlorophyll a concentration linked to the production cycle. The trend in K_d indicated higher extinction of light (by a factor of 2) in the water column in 2002 compared to the production cycle observed in earlier years. Periodically, smaller variations were observed in K_d during the summer and early fall associated with transient productivity after the main bloom.

Time series of euphotic depth varied seasonally at Station 27 with shallow depths of approximately 20 m during the height of spring bloom with deeper values extending to depths in excess of 80 m thereafter (Fig. 2b). The range in euphotic depth was greatest during 2002 with the observed spring bloom values of <20 m and post-bloom values of >80 m for several weeks in duration compared to the earlier time series.

Time series of total daily incident PAR shows a strong seasonal component and high variability throughout the annual cycle (Fig. 2c). The average of daily incident PAR and standard deviation, total PAR and total daily insolation for each month of the year during 2002 showed that December had the lowest average total daily PAR at 5.95 moles m^{-2} and highest in July at 40.23 mol m^{-2} (Table 1). Monthly time series of global solar radiation obtained from Environment Canada and converted (Ting and Giacomelli 1987) to PAR from 1964-1998 showed a maximum annual variability of ca. 25% (Fig. 3a). The annual climatology for solar radiation suggested that recent PAR measurements collected at NWAFC station during 2001-02, were among the highest recorded during the available time series for the months of April through to October (Fig. 3b). At present, we have not yet compared our optical measures with Environment Canada data due to a lack of a suitable overlap period and we exercise caution until such time when an adequate comparison can be made.

Variability of optical measures in the vertical attenuation coefficient and euphotic depth during 2002 indicated that spring (March-May) shows the largest change compared to other seasonal time periods (Fig. 4). The mean percent seasonal change in 2002 showed an increase of 60% in the vertical attenuation coefficient and 35% reduction in euphotic depth during Spring compared to earlier years. Smaller differences were observed in optical measures during the other seasonal periods in 2002 in relation to earlier years.

Seasonal and Interannual Variability in Water Column Structure

We investigated time series of the following physical measures:

(1) Stratification Index, taken as the difference in density within the upper 50 m: (Sigma-t_{50m} – Sigma-t_{5m})/45m.
(2) Mixed Layer Depth, taken as the depth centre of the pycnocline
(3) Wind Stress, average daily (estimated from hourly observations) time series
(4) Integrated Temperature, integrated within the upper 50 m using the trapzoidal method.

The magnitude, timing, and duration of stratification showed similar trends during the 2000-02 time series. The stratification index reached maxima in late August-early September and minima in December through March.

Although the magnitude of stratification was slightly greater in 2002, the duration and onset of stratification was shorter and delayed compared to earlier years (Fig. 5a). The mixed layer depth (mld) series, taken as the depth centre of the pyncocline, revealed apparent maxima in January-April, followed by a abrupt shoaling in late Spring (May-June) and then gradually increasing during the Fall (Fig. 5b). Larger, prolonged maxima in mld were observed in 2001-02 compared to 2000. Deepening and prolonged deep mld is likely related to reduced water column stability due to increased wind stress observed during the Winters of 2001-02 and may contribute to observed variation in the timing and magnitude of phytoplankton blooms (Fig. 5c). The upper 50m integrated temperature series displayed a strong seasonal cycle with maxima reached in September-October and minima in March-April (Fig. 5d). The integrated temperature series displayed small interannual variation in the timing and magnitude at the fixed station. On average thermal conditions in the upper 50m were cooler in 2002 compared to earlier years at Station 27.

The percent change in the stratification index in 2002 varied seasonally with positive trends during Winter and Summer and negative trends during Spring and Fall when compared to earlier years (Fig. 6). The percent change in integrated temperature revealed a strong negative change (>300%) in 2002 during Winter compared to earlier years, but this difference gradually declined during the intervening seasons although remained negative throughout the year (Fig. 6**).**

Seasonal and Interannual Variability in Nutrient Inventories

Time series of nutrient inventories at Station 27 showed substantial differences between years (Fig. 7). Silicate and nitrate inventories in the upper mixed layer (<50 m) showed expected seasonal trends with winter and fall maxima, rapid depletion during the spring bloom, and occasional periodic intrusions during the summer (Fig. 7a). Sources of these periodic nutrient intrusions may be related to shoaling of deep pools below the mixed layer, wind-induced mixing from passage of storms, and advective transport from the inshore branch of the Labrador current. Both nutrient inventories showed coherence throughout much of the time series. Depletion of upper inventories of nitrate and silicate were more prominent in 2000 during the Spring and Summer compared to the 2001-02 period. Deep inventories for both nutrients also displayed a substantial (near 2-fold) reduction in 2001-02 compared to the 2000 time series (Fig. 7b)

Trends in the upper 50 m silicate and nitrate inventories were negative in 2002 during Winter-Spring (5-60 %), reversed during the Summer with a positive trend (30-60%), and increased for silicate but, decreased for nitrate during the Fall compared to earlier years (Fig. 8a). The pattern for the silicate deep inventory was negative in 2002 during the Fall-Winter and positive during Spring-Summer, while the deep nitrate inventory showed a consistent negative trend across all seasons compared to earlier years (Fig. 8b).

Time series measures of integrated chlorophyll during 2000-02 re-iterated the importance of Spring Bloom periods in the seasonal dynamics of phytoplankton abundance at Station 27 (Fig. 9a). Integration of chlorophyll *a* at the shallow depth strata (0-50 m) captured the main trends, but revealed significant amounts of phytoplankton biomass that occur in deeper strata (>50 m), particularly during the Spring Blooms. The magnitude of phytoplankton production increased during the 3-year series peaking in 2002. The time series of integrated (calibrated) fluorescence revealed nearly identical trends to extracted chlorophyll *a* fluorescence measures during 2000-02, except for peak levels > 1 000 mg m^{-3} in early to mid April 2002, when only *in-situ* chlorophyll *a* fluorescence data were available. Time series measures of daily primary production rates at Station 27 showed elevated values from Spring through the Fall period, but tended to remain low during late Fall and Winter (Fig. 9b). An abrupt increase in the rates of primary production was observed in April-May 2002. Our estimates of photosynthetic parameters coincided with high surface irradiance values (>1 000 μmol photons m^{-2} s^{-1}) and elevated chlorophyll *a* concentrations in the range of 5-12 mg m^{-3} throughout the euphotic zone resulting in these elevated production rates (Fig. 9b). Measurements of primary production at 10m and integrated production estimates have increased from the start of the time series. This increased productivity may account for the observed increase in phytoplankton biomass during this time period. The seasonal differences in chlorophyll *a* inventories showed lower Fall-Winter values (40% less), and higher (10-30%) Spring-Summer concentrations in 2002 compared to earlier years (Fig. 9c).

Standard Monitoring Transects

Observations presented in this section are based on standard oceanographic monitoring stations along transects in the Northwest Atlantic Ocean as part of the Atlantic Zonal Monitoring Program established in 1999, and additional transects occupied annually mid-summer on an annual oceanographic survey conducted by the Department of Fisheries and Oceans in the Newfoundland Region (Colbourne and Fitpatrick, 2002). A total of 63, 56, and 50 oceanographic stations were sampled for biological and chemical variables respectively during the spring (April 20-May 5), summer (July 12-28) and fall (November 7-22) 2002 survey's (Fig. 1).

Seasonal and spatial variability in the vertical attenuation coefficient was observed along oceanographic sections in 2002 (Fig. 10). The spring period showed the highest attenuation as expected, being strongly influenced by the production cycle. Regional differences were apparent in the vertical attenuation coefficient, with the southerly sections (southeast Grand Banks) showing higher extinction of light compared to northerly sections (Bonavista Bay) during the spring. In general, higher attenuation values were observed along the inshore stations and near slope water regions during this period, and remained at background levels of ca. 0.05-0.10 during the latter part of the year across the Newfoundland and Labrador Shelf sections (Fig. 10). The depth of the euphotic zone (depth of 1% PAR) deepened gradually from southern to northern sections along the expected gradient in the production cycle during spring (Fig. 11). Values during the spring varied from ca. 20-40 m, compared to ca. 40-80 m during the summer and fall occupations. The Labrador Sections, only occupied during summer, were an exception to this general pattern, in which the euphotic zone extended to shallower depths due to higher levels of light extinction (Fig. 11). The trend in percent change of the attenuation coefficient in 2002 compared to earlier years was negative across southerly oceanographic sections (Grand Banks and NE Newfoundland Shelf), while positive for the Labrador sections occupied during summer, leading to an inverse relationship with euphotic depth (Fig. 12).

Indices of physical structure, including stratification and integrated temperature in the upper 50 m, varied by season and location across the oceanographic sections in 2002. Stratification was typically low during the spring and fall periods with values <0.02 Kg m^{-4} along the sections (Fig. 13). Water column stability was maximal during summer with values approaching 0.07 Kg m^{-4}, and evidence of a latitudinal gradient in stratification was observed from the southern to northern sections. The stability of the water column also displayed a cross-Shelf gradient during the summer, particularly along the NE Newfoundland and southern Labrador Shelf, with higher stratification along the inshore stations and lower values near the slope water regions (Fig. 13). The stratification index was noticably weaker for the northern-most sections including Makkovik Bank and Beachy Island. The thermal conditions in the upper mixed layer (<50m) during spring 2002 were <0^{o}C over much of the inner and mid-Shelf regions on the NE Newfoundland Shelf, the exception being the southeast Grand Bank section, in contrast to the warmer conditions along the outer Shelf being influenced by the North Atlantic Slope waters (Fig. 14). The thermal cross-Shelf gradient was still evident during the later occupations in summer and fall across all sections. The percent change in the stratification index along sections showed negative trends on the Newfoundland and Labrador Shelf during 2002, with only the summer occupations on the White Bay and Seal Island sections deviating from the pattern (Fig. 15). The percent change in integrated temperature revealed large negative percent changes in 2002 compared to earlier years across all sections and seasons, consistent with the pattern observed in the Avalon Channel (Fig. 15).

Seasonal and spatial differences in major nutrient inventories in the upper 50 m and deeper layers (50-150 m) were evident along the oceanographic sections in 2002. Silicate inventories in the upper 50 m were lower along the southerly section and tended to increase northward during the spring occupations (Fig. 16). This is likely related to the difference in timing of biological consumption of this limiting nutrient by Diatoms during the spring bloom. The upper 50 m water column depletion of silicate inventories was evident along the Flemish Cap section during summer, but was not as extensive for sections further north. A cross-Shelf gradient in silicate inventories was evident during the spring and fall along the Flemish Cap section, with local maxima apparent near the position of the offshore branch of the Labrador Current. The fall silicate inventories indicated extensive mixing along the southern Grand Banks and NE Newfoundland Shelf, but was reduced along the Flemish Cap and Pass areas and along the entire Bonavista Bay section. Seasonal and spatial variability in nitrate inventories in the upper 50 m were coupled with the observed pattern for silicate (Fig. 17). Nitrate inventories were slightly lower compared to silicate levels over the inner and mid-Shelf for the Labrador and Bonavista Bay sections during the spring and summer. Cross-Shelf gradients in silicate and nitrate inventories were evident for the Flemish Cap and Bonavista Bay sections during spring and fall with higher levels observed along the outer Shelf and across the Flemish Cap.

The deep (50-150 m) inventories of major nutrients along the inner and mid-Shelf showed substantially lower levels in contrast to the outer Shelf region, during all seasonal occupations for the southeast Grand Banks and Flemish Cap sections (Fig. 18, 19). Depletion of these nutrient inventories, can be attributed to the shallow nature of the Shelf (bottom depth typically <100m) in these locations. Deep inventories of major nutrients remained relatively stable seasonally with the exception of silicate levels along the mid to outer Shelf of the Bonavista Bay section during the Fall which were approximately one-half of the levels during the spring-summer period. Cross-Shelf gradients were observed along the Labrador sections for both major nutrients, although the trends for silicate and nitrate inventories were opposite.

The percent change in the upper 50m nutrient inventories in 2002 indicated substantially higher levels for both silicate and nitrate across all oceanographic sections compared to earlier years (Fig. 20). The elevated levels of these major nutrients in 2002 were greatest during the spring and fall occupations across most sections. The percent change in deep inventories for both nutrients also showed higher levels along the southeast Grand Banks section during spring and fall occupations and likely contributed to the enhanced levels observed in the upper water column through mixing processes. This same explanation did not apply to the other sections, which either showed small positive or negative trends in the deep inventories in 2002 compared to earlier years (Fig. 20). Small differences in timing between surveys conducted annually during 2000-02 and changes in the production cycle may contribute to the observed patterns in nutrient dynamics.

Chlorophyll *a* inventories in the upper 100 m followed the expected seasonal pattern, reaching levels >100 mg m^{-2} "bloom criteria" only during the spring period (Fig. 21). In addition, cross-Shelf gradients in chlorophyll *a* concentration were observed along the southeast Grand Banks and Flemish Cap sections during spring. The later seasons showed little variability across the Newfoundland and Labrador sections and low integrated chlorophyll *a* concentrations, typically <50 mg m^{-2}. The percent change in chlorophyll *a* inventory in 2002 was largely negative compared to earlier years across all sections (Fig. 22). The exception to this pattern occurred during the spring occupation of the southeast Grand Bank section, and summer occupations of White Bay and Beachy Island, which displayed the only positive trends in 2002 compared to earlier years.

Fixed Station - Zooplankton

Since 1999, the general pattern of seasonality in overall zooplankton abundance at Station 27 has been low numbers of organisms at the start of the year with the highest abundance occurring in late fall (Fig. 23). In 2002, the overall abundance of zooplankton was comparable to levels observed in the three previous years but the seasonality was markedly reduced because of high numbers of zooplankton present in the late fall of 2001 and early winter of 2002. The increased abundance during the winter was due to higher numbers of *Oithona* sp. and *Pseudocalanus* sp. copepodites than had been previously observed at this site. The greatest changes in zooplankton community structure since 1999 has been the growing frequency of occurrence and relative abundance of *Calanus glacialis* and *Calanus hyperboreus* as well as *Microcalanus* sp. during the late spring and early summer and the gradual decrease in relative occurrence and abundance of *Temora longicornis*. Although the overall abundance levels of these species appear to be in line with previous observations, the principle difference has been in the occurrence of the four taxa, with cold water species appearing more consistently throughout the year while the warmer water *T. longicornis* appears less frequently. The change in occurrence of cold and warm water species of copepods is relatively consistent with the changes in water mass characteristics, which have taken place since the late-1990s.

The overall abundance of *Calanus finmarchicus* at Station 27 was comparable to previous years although somewhat lower than concentrations observed in 1999 (Fig. 24). In contrast to 2001, the seasonal succession of copepodite stages did not show a delay, with the CI stages beginning to appear in large numbers by the end of May. This return to the pattern of succession found in 1999/2000 relative to 2001 when the spring bloom was delayed suggests that the onset of the spring bloom may play an important role in the seasonal development of cohorts for this species. However, in contrast with previous years, early stage copepodites were effectively absent from the zooplankton community by the end of August whereas there has normally been low numbers occurring throughout the fall.

Oceanographic Sections - Zooplankton

Total zooplankton abundance in the fall of 2001 was generally higher than in the previous two years (Fig. 25). The largest concentrations occurred in the offshore areas of the Bonavista and Southeast Grand Banks sections where higher abundances were notable across most of the Flemish Cap section. In general, the higher abundance of zooplankton was due principally to larger overall abundance of *Oithona* sp., as observed at Station 27. Further offshore, along the continental slope, the abundance of *C. finmarchicus* was often enhanced by 2-4 fold over previous years. In the area of the Flemish Pass, a few stations had high abundance's of *Fritillaria borealis* and *Oikopluera* sp., two larvacean species, as well as high abundances of bivalve larvae and pelagic gastropods. *Oithona* sp. was the dominant copepod across all sections, ranging from ~40-80% of all copepods, even in offshore areas. *Pseudocalanus* sp. was present only in the Shelf areas and was absent from stations located in slope waters. The relative abundance of *C. finmarchicus* was greatest in offshore areas but notable abundance's were found across the entire Bonavista Bay section and in the Avalon Channel along the Flemish Cap and Southeast Grand Banks sections.

During the spring of 2002, the overall abundance of zooplankton was often 3 to 10 fold lower than in 2000 but generally comparable to levels observed in 2001 (Fig. 26). The greatest differences occurred on the Southeast Shoal where overall abundance of calanoid nauplii, *Oithona* sp., *Pseucalanus* sp. and larvaceans were generally lower than observations from the survey in 2000. Furthermore, there were high abundance's of *T. longicornis* in 2000 which were ~10 times less abundant in 2001 and 2002. Across most of the Flemish Cap section, abundance levels were comparable to those observed in previous years. Abundance levels were also low in the offshore portion of the Bonavista Bay section, where numbers of calanoid nauplii, *C. finmarchicus*, *Oithona* sp. and *Pseudocalanus* sp. were generally lower than in previous years. The lower abundance of these major groups of copepods resulted in an apparent increase in the relative importance of other taxa, such as *C. glacialis* and *C. hyperboreus* as well as *Metridia* sp., which were found at abundance levels comparable to previous years. In offshore areas, *C. finmarchicus* was an important component of the copepod community, making up ~20-50% of the overall number of individuals. Large calanoid nauplii and *Pseudocalanus* sp.were relatively more abundant on the Shelf rather than in offshore areas.

During the summer 2002 surveys, the overall abundance of zooplankton was generally comparable to levels observed in previous years (Fig. 27). There were a few instances along the Flemish Cap section where the abundance in 2001 was substantially higher than in 2002 but in general these were single instances of a high catch for a single species. There was a more consistent difference along the outer portions of the Bonavista Bay section and across the entire Seal Island section where the overall abundance of zooplankton was 2-4 times higher in 2002 than in previous years. In general, the increase was due to greater numbers of *C. finmarchicus*, *Metridia* sp., and large calanoid nauplii. However, the overall zooplankton abundance along the Makkovik Bank section was similar to that found in previous years. There was a increase in the relative abundance of calanoid nauplii along the Seal Island and Bonavista sections but a corresponding decrease along the Flemish Cap transect. The overall abundance of both *C. finmarchicus*, *C. glacialis* and *Metridia* sp. was generally higher than in previous years as was the abundance of *Microcalanus* sp. in offshore areas (their abundance on the Shelf was at comparable densities to previous observations).

Summary

- Nutrient inventories in the surface layer (top 50 m) at Station 27 in 2002 were lower compared to those of 2000-2001.
- Near bottom nutrient concentrations at Station 27 were similar to 2001 but 1.5-2 times lower than in 2000, similar to conditions on the Newfoundland Shelf but not on the Grand Banks.
- There was no evidence of a fall bloom at Station 27 based on water collections, but on a large scale satellite observations indicate that a fall bloom occurs almost every year throughout the region.
- The timing of the spring bloom was similar to that observed in 2000, although the duration was shorter, but earlier than 2001 by approximately 30 days.
- The abundance of the copepodite stage of small and large copepod species was generally comparable to previous years.
- The development and production of the dominant copepod species was similar to 1999 and 2000 and earlier than observed in 2001.
- The relative abundance and occurrence of copepod species normally found in colder waters appear to have increased while the relative abundance of one important warm water species has decreased during the period 1999-2002.

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References

Colbourne, E. and C. Fitzpatrick. 2002. Physical Oceanographic Conditions in NAFO Subareas 2 and 3 on the Newfoundland and Labrador Shelf during 2001. NAFO SCR Doc. 02/41, Ser. No. N4652. 27p.

Pepin, P. and G.L. Maillet. 2001. Biological and chemical oceanographic conditions on the Newfoundland Shelf during 2000 with comparisons with earlier observations. Canadian Science Advisory Secretariat, Res. Doc. 2001/073, 46p.

Pepin, P. and G.L. Maillet. 2003. Biological and chemical oceanographic conditions on the Newfoundland Shelf during 2002. Canadian Science Advisory Secretariat, Res. Doc. 2003/WP9, 72p.

Ting, K.C., G.A. Giacomelli. 1987. Availability of Solar Photosynthetically Active Radiation. Transactions of the ASAE, 30(5):1453-1457.

Table 1. Average and standard deviation (SD) of daily photosynthetic active radiation (PAR), total monthly radiation in moles and total daily insolation obtained in 2002 from Li-Cor PAR sensor located at NWAFC (47.52 N Latitude , -52.78 W Longitude), St. John's, Newfoundland.

Month (Julian Day)	**Avg. Daily Moles m^{-2}**	**Avg. Daily SD**	**Total Moles**	**Total Daily Insolation Moles d^{-1}**
January (1-31)	8.23	4.55	255.23	0.17
February (32-59)	12.96	6.62	362.89	0.30
March (60-90)	19.96	9.10	618.66	0.54
April (91-120)	29.28	10.28	878.31	0.92
May (121-152)	36.52	15.69	1132.22	1.27
June (153-181)	40.23	16.30	1206.77	1.47
July (182-212)	43.58	13.48	1350.87	1.56
August (213-243)	36.22	10.77	1122.86	1.19
September (244-273)	24.98	11.99	749.49	0.72
October (274-304)	16.60	6.41	340.58	0.41
November (305-334)	7.60	4.18	227.92	0.16
December (335-365)	5.95	2.85	184.54	0.12

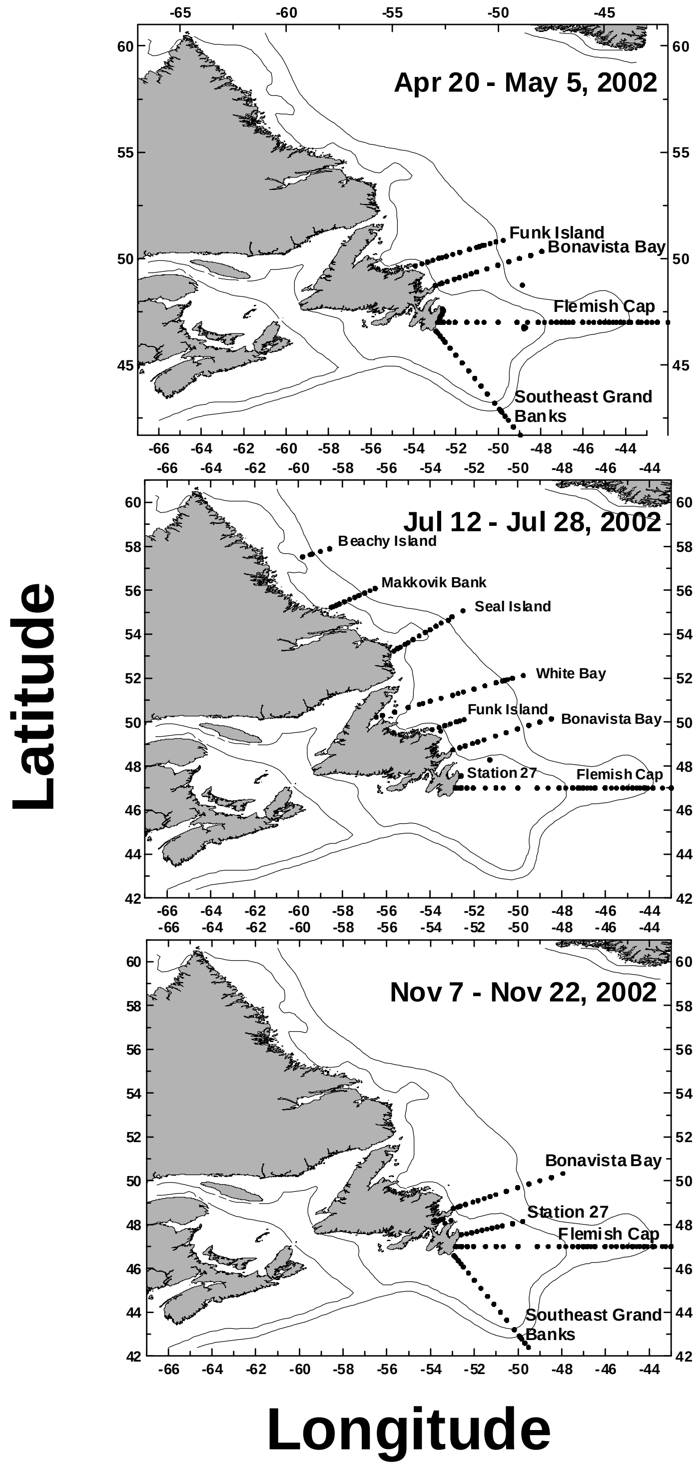

Fig. 1. Station occupations during AZMP Seasonal Sections on the Newfoundland and Labrador Shelf.

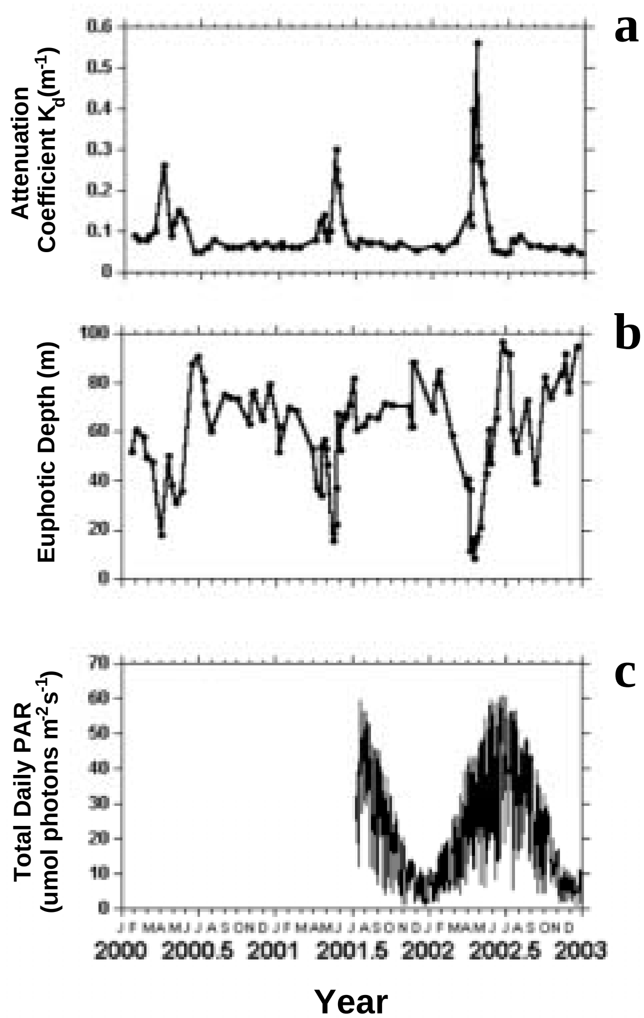

Fig. 2. Biweekly time series of optical measures at Station 27 showing (a) vertical attenuation coefficient K_dPAR (estimated from Platt *et al*. 1988 model), (b) euphotic depth (depth of 1 % PAR), and (c) total average daily PAR obtained from Li-Cor (SA-192A) irradiance sensor located at NWAFC, St. John's, NL.

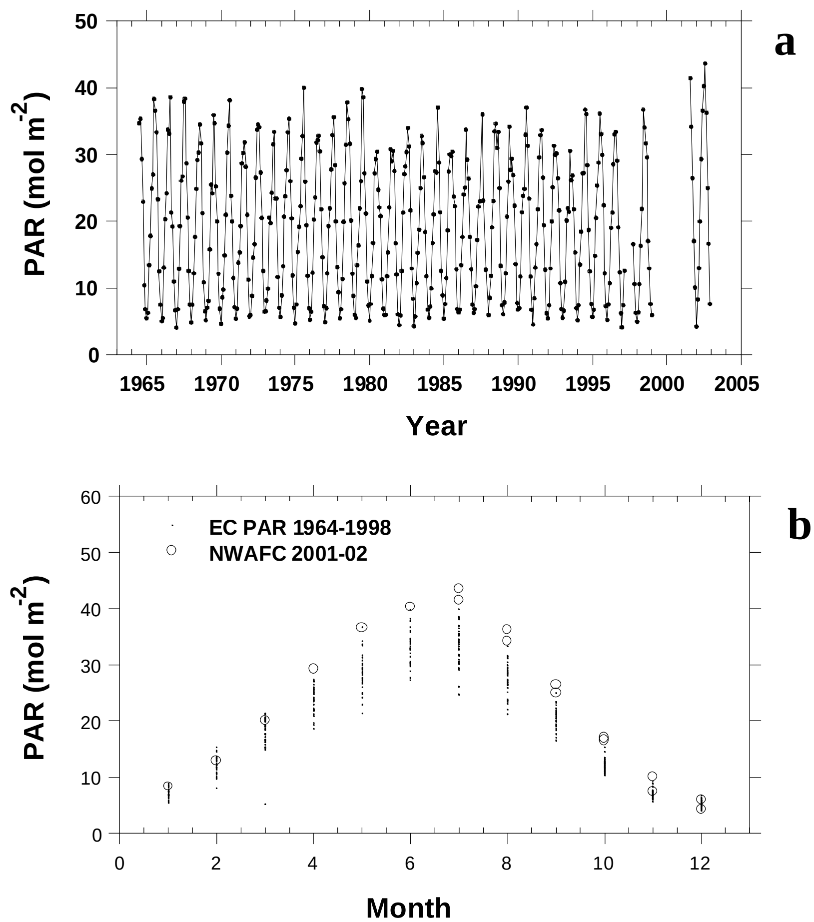

Fig. 3. (a) Time series of average monthly values of photosynthetic active radiation (PAR) in St. John's, NL obtained from Environment Canada 1964-1998, and Northwest Atlantic Fisheries Centre 2001-02. Two gaps exist in the current time series; April-August 1997, and January-June 1999-2001. (b) Monthly climatology of PAR showing recent measurements were among the highest recorded during the available time series for months of April through to October.

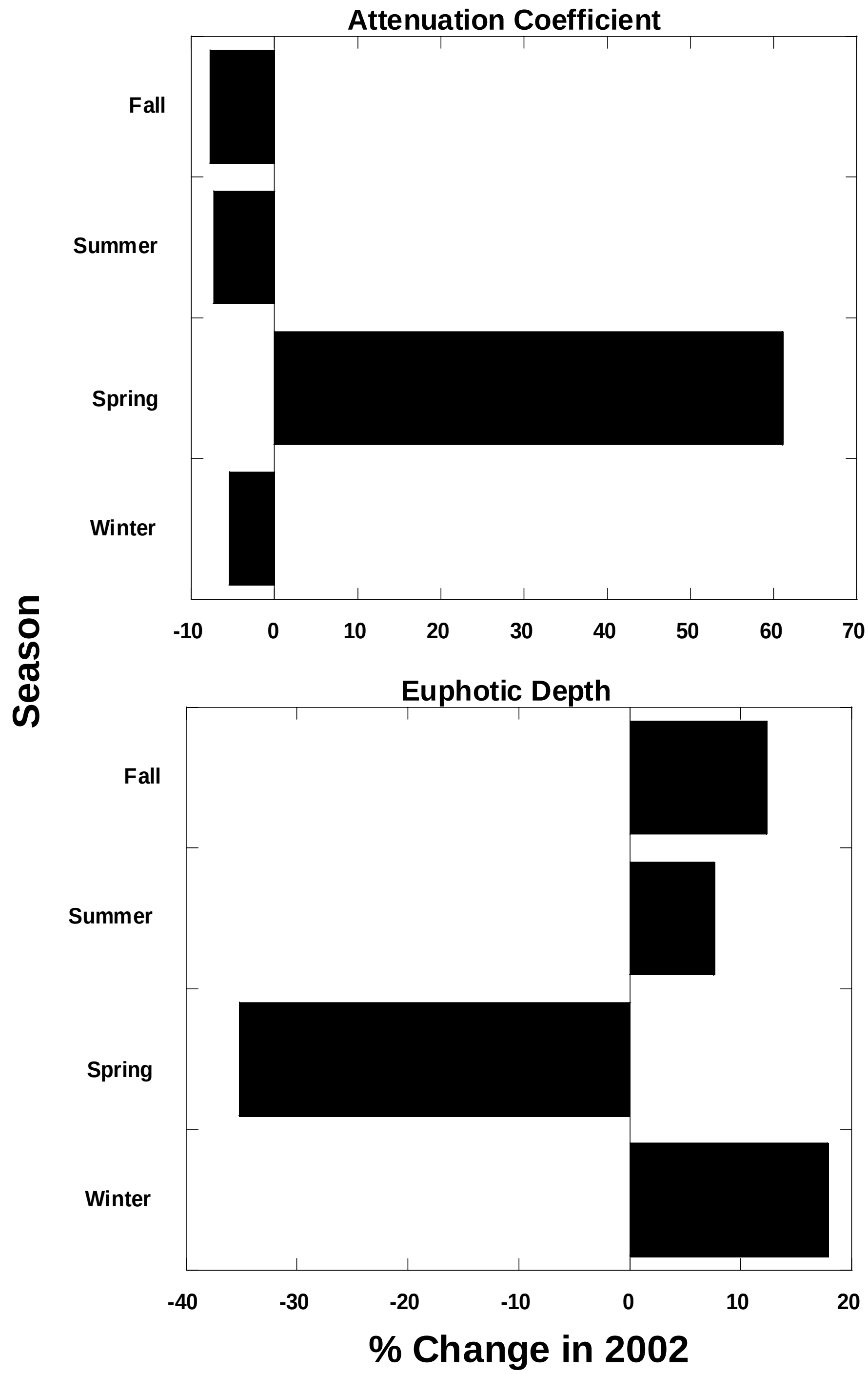

Fig. 4. The mean percent change in vertical attenuation coefficient and euphotic depth (1% light level) in 2002 compared to earlier years (2000-01) at Station 27 during different seasons (Winter; Dec-Feb, Spring; Mar-May, Summer; Jun-Aug, Fall; Sep-Nov).

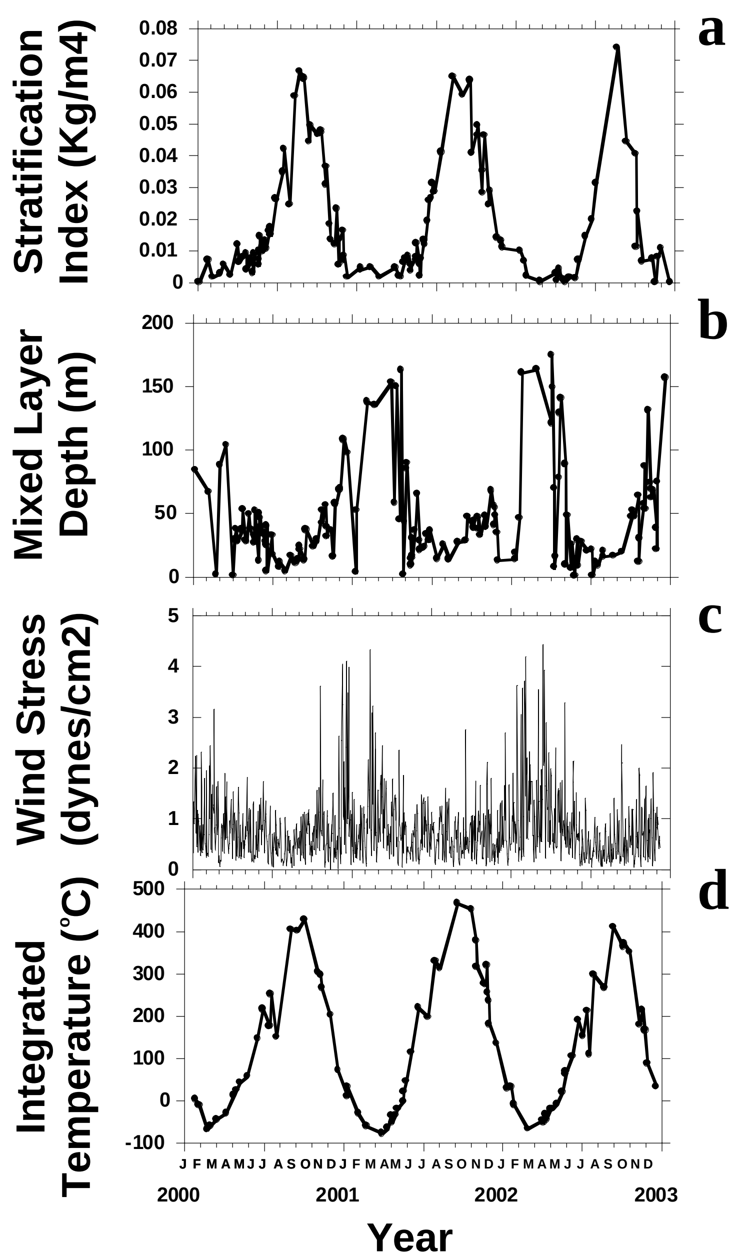

Fig. 5. Biweekly time series of stability measures at Station 27 during 2000-02 showing (a) stratification index ((Sigma-t 50 m - Sigma-t 5 m)/45 m), (b) mixed layer depth (taken as the depth centre of the pynocline), (c) average daily wind stress ($0.02 \times$ wind speed^2) estimated from hourly observations at a ground station (47.56^{o}N latitude, -57.21^{o}W longitude), and (d) integrated temperature in the upper 50 m using the trapezoidal method.

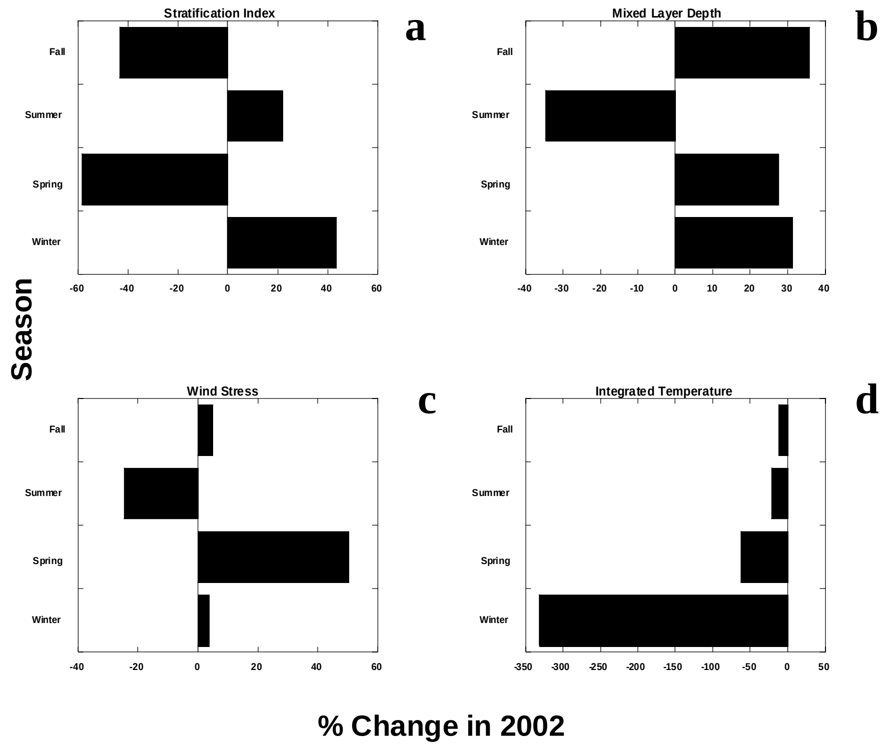

Fig. 6. The mean percent change in (a) stratification index (difference in Sigma-t between 50 and 5 m), (b) mixed layer depth (taken as the depth centre of the pycnocline), (c) wind stress (0.02 * WS^2), and (d) integrated temperature (0-50 m) in 2002 compared to earlier years (2000-01) at Station 27 during different seasons (Winter; Dec-Feb, Spring; Mar-May, Summer: Jun-Aug, Fall; Sep-Nov).

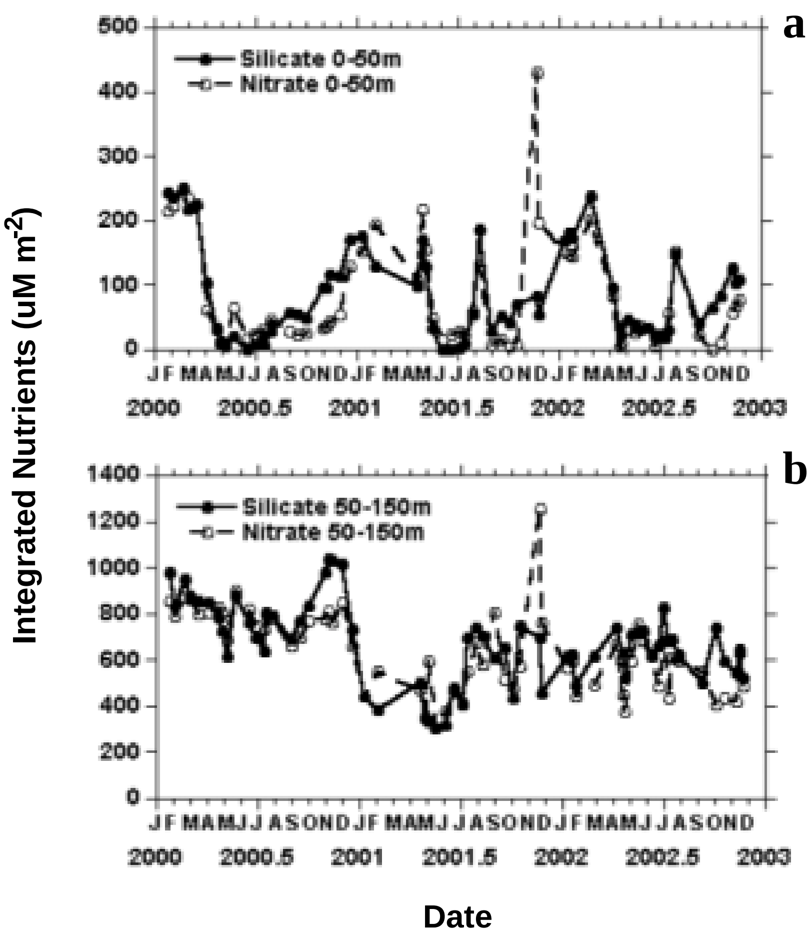

Fig. 7. Time series of major nutrient inventories at Station 27 during 2000-02 showing integrated concentrations of silicate and nitrate at (a) 0-50 m and (b) 50-150 m depth strata.

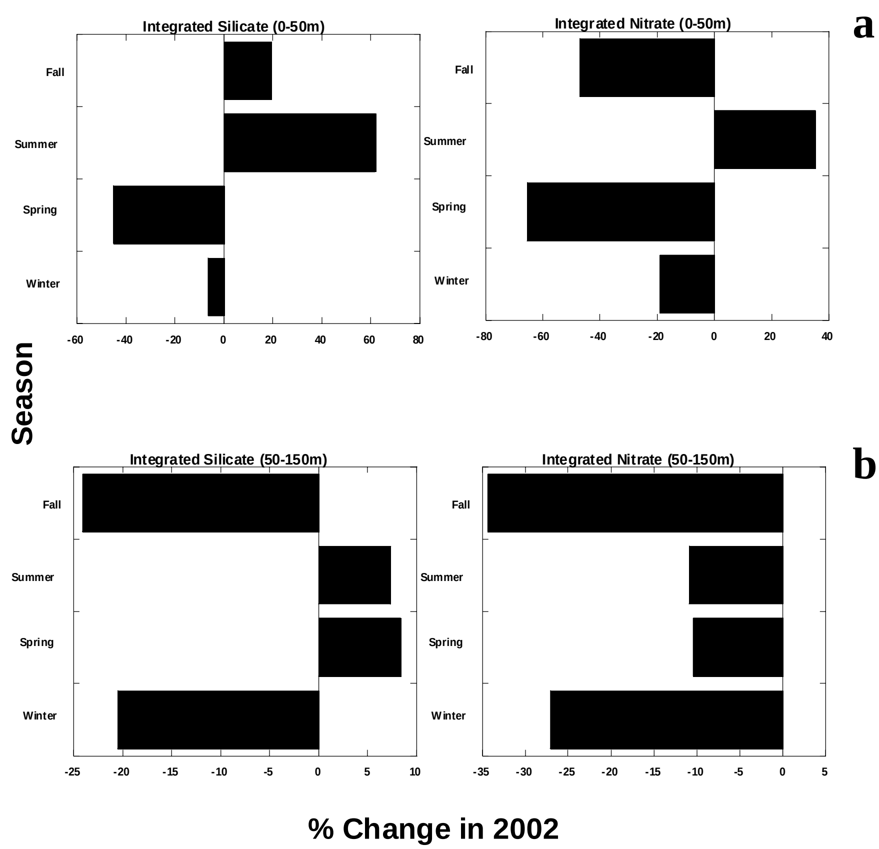

Fig. 8. The mean percent change in silicate and nitrate inventories in (a) shallow 0-50 m and (b) deep 50-150 m strata in 2002 compared to earlier years (2000-01) at Station 27 during different seasons (Winter; Dec-Feb, Spring;.Mar-May, Summer; Jun-Aug, Fall; Sep-Nov).

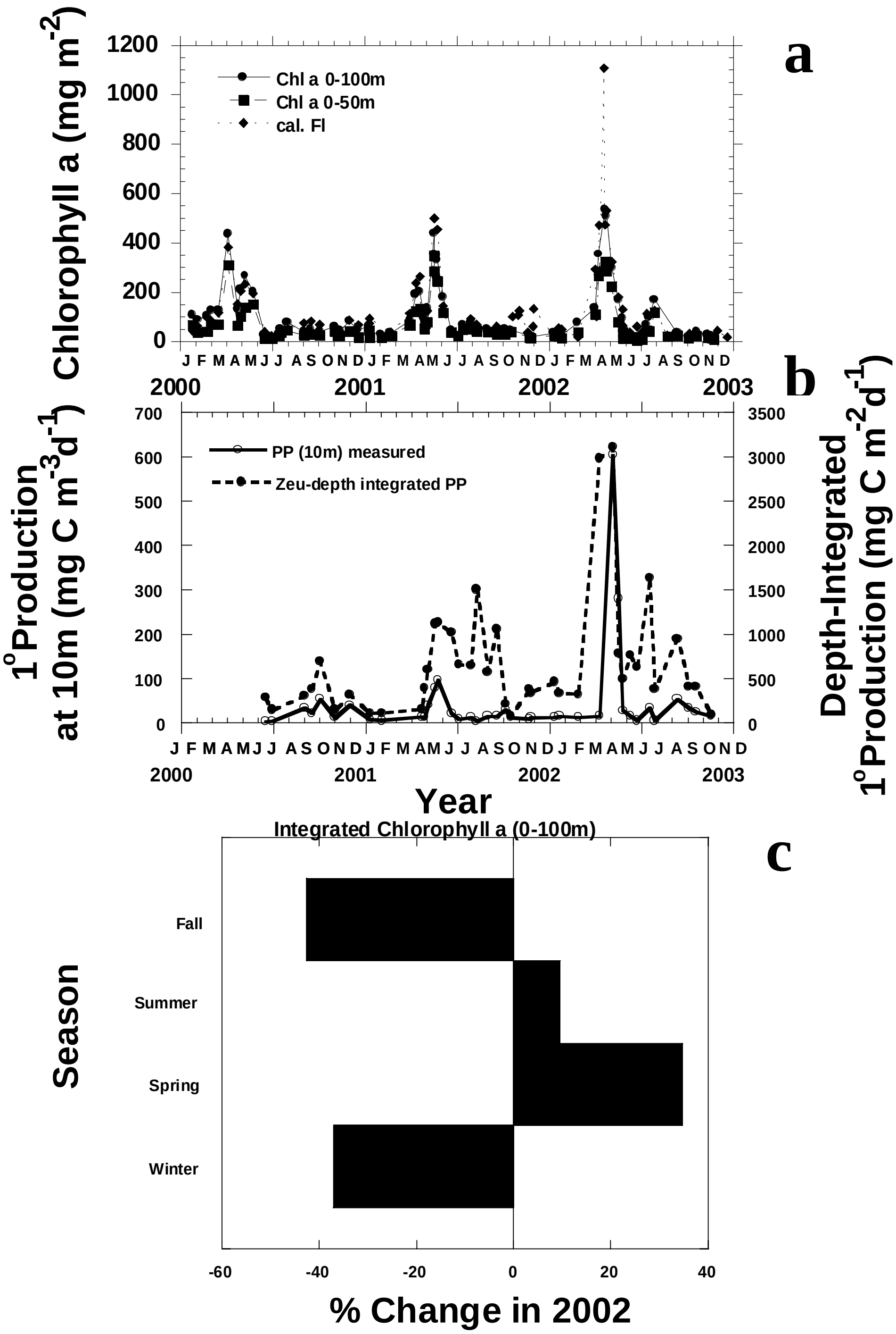

Fig. 9. Time series of (a) chlorophyll a inventories and fluorescence (calibrated against extracted chlorophyll a) at two depth strata, (b) measured daily primary production (PP) at 10 m and estimated euphotic-depth integrated primary production (Zeu-PP), and (c) mean percent change in chlorophyll a inventory (0-100 m integral) in 2002 compared to earlier years at Station 27.

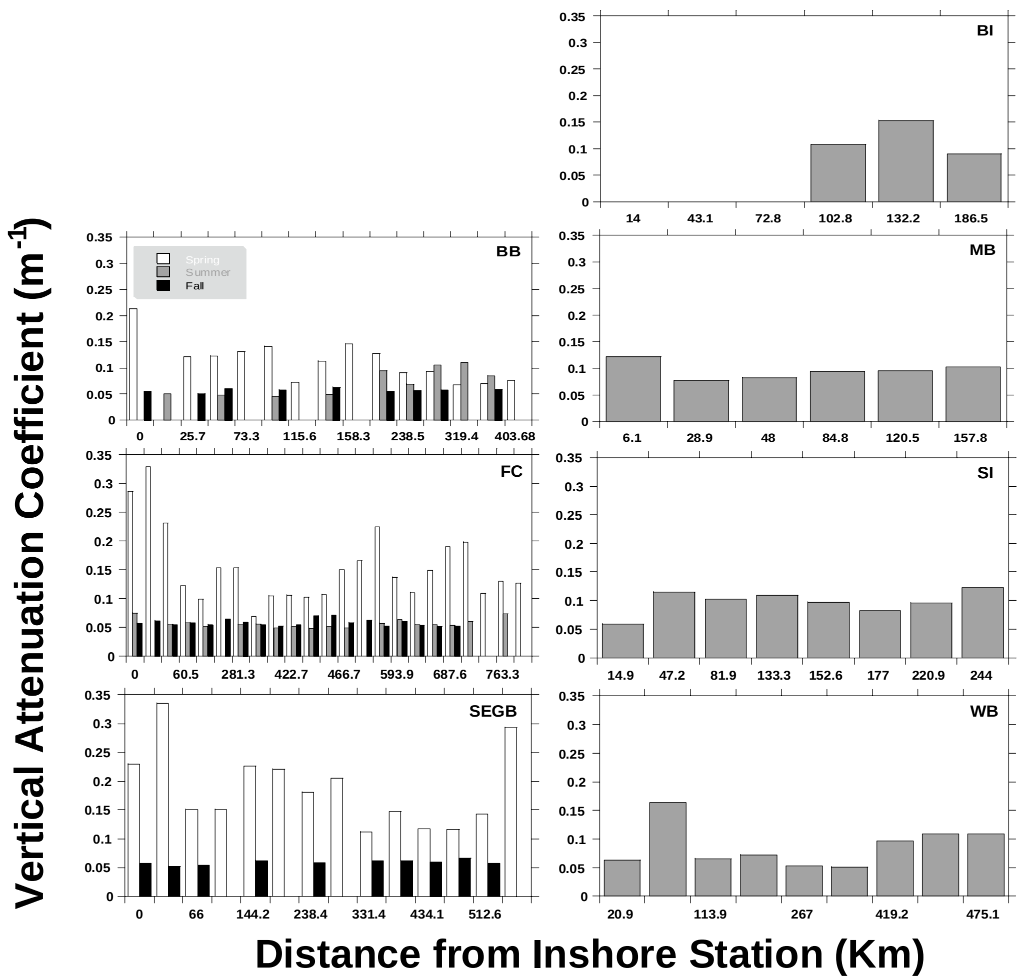

Fig. 10. Variability in the vertical attenuation coefficient along section lines during seasonal section occupations in 2002. Sections include Southeast Grand Banks (SEGB); Flemish Cap (FC); Bonavista Bay (BB); White Bay (WB); Seal Island (SI); Makkovik Bank (MB); and Beachy Island (BI). See Fig. 1 for detailed station locations.

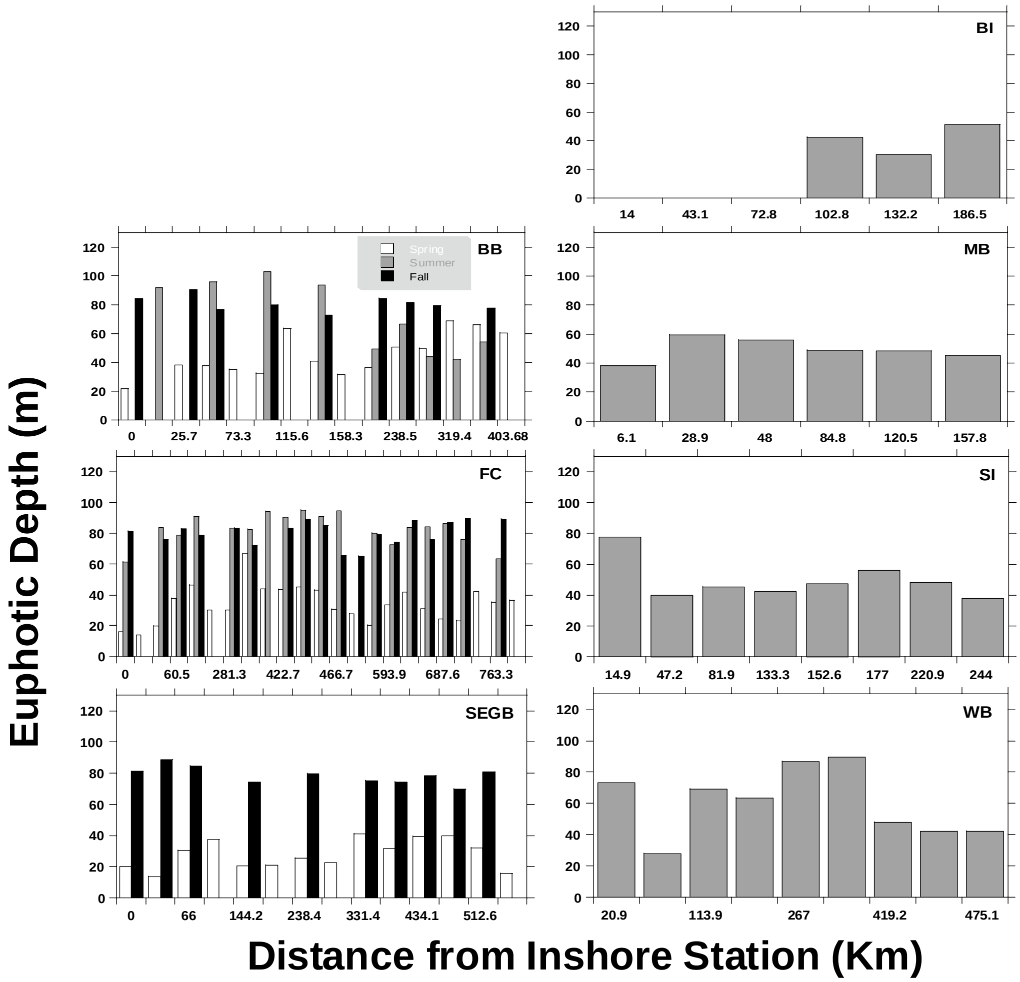

Fig. 11. Variability in euphotic depth (1% light level) along sections during seasonal occupations in 2002. Sections include Southeast Grand Banks (SEGB), Flemish Cap (FC), Bonavista Bay (BB), White Bay (WB), Seal Island (SI), Makkovik Bank (MB), and Beachy Island (BI). See Fig. 1 for locations of sections.

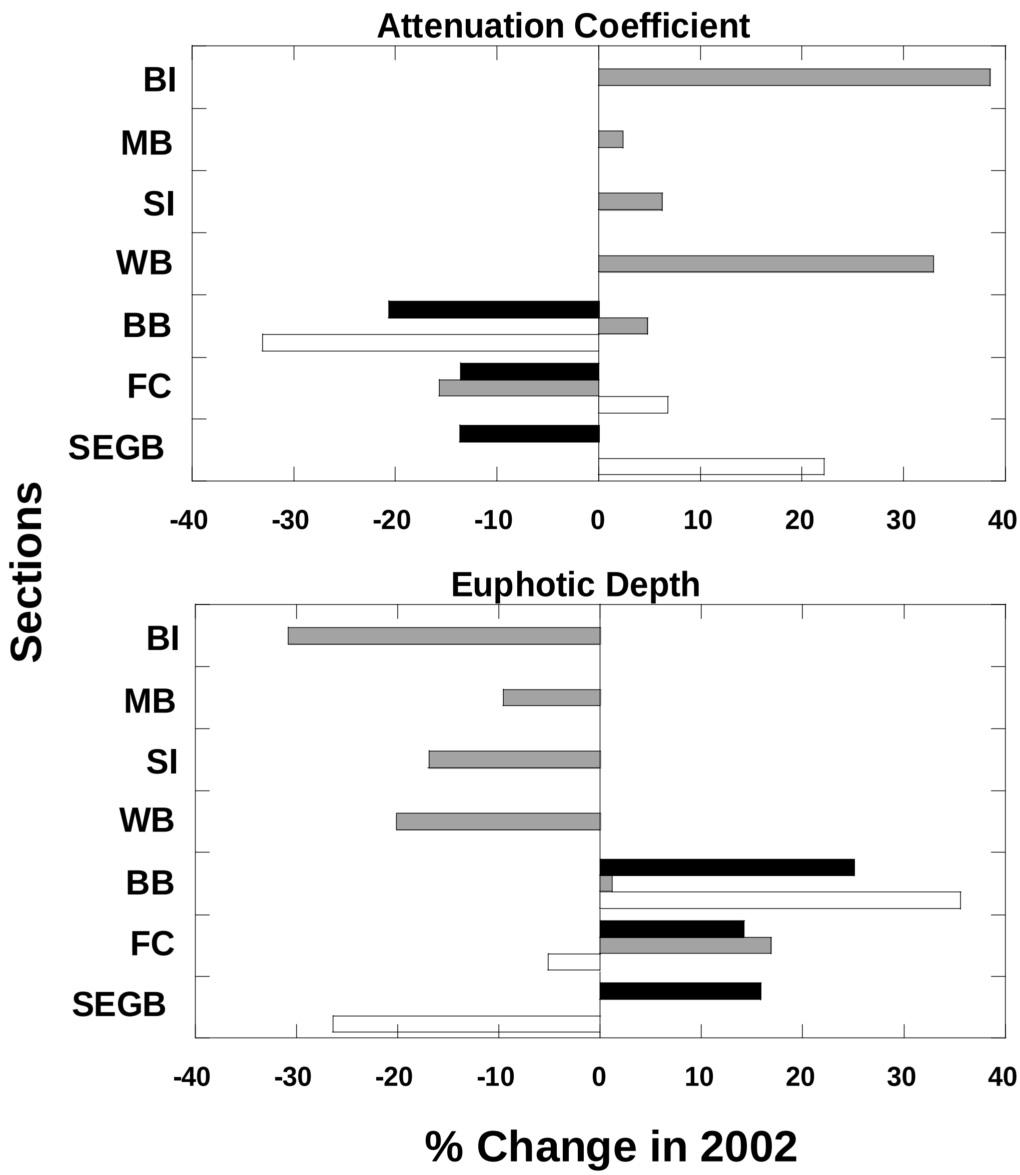

Fig. 12. The percent change in the vertical attenuation coefficient and euphotic depth in 2002 compared to earlier years (2000-01) along sections during seasonal occupations. Shading as in Fig. 11.

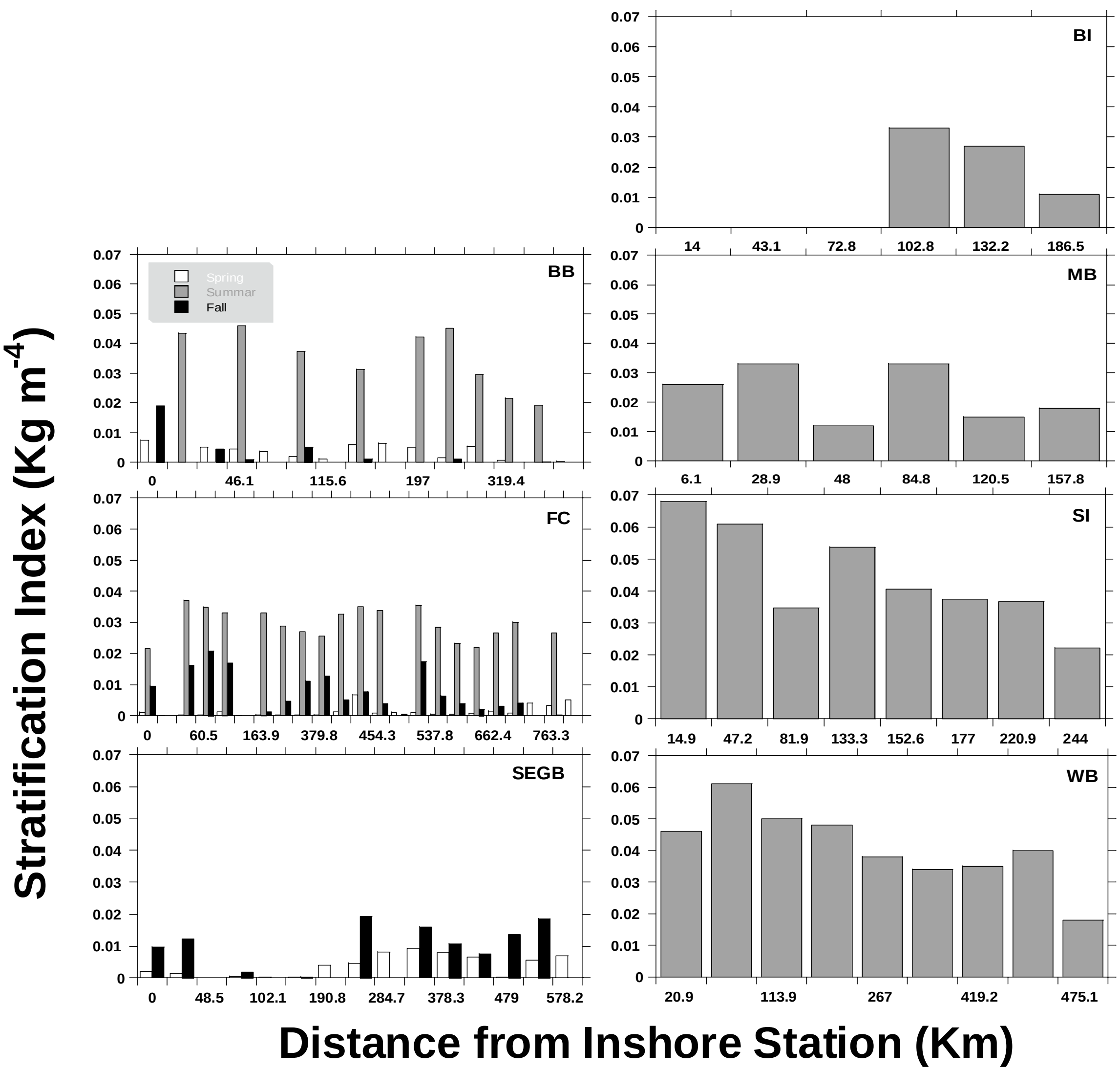

Fig. 13. Variability in the stratification index along sections during seasonal occupations in 2002. Sections include Southeast Grand Banks (SEGB), Flemish Cap (FC), Bonavista Bay (BB), White Bay (WB), Seal Island (SI), Makkovik Bank (MB), and Beachy Island (BI). See Fig. 1 for locations of sections.

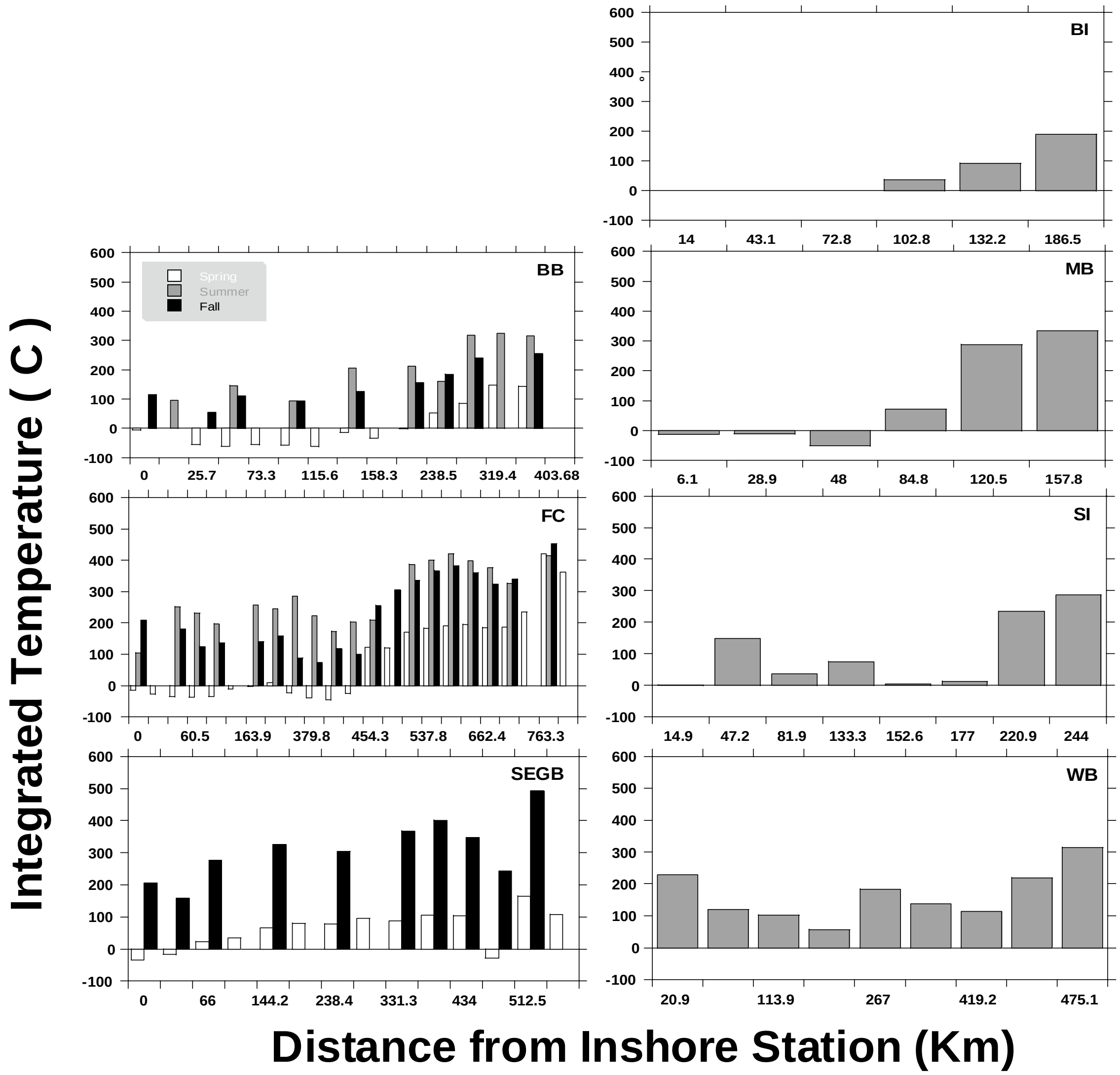

Fig. 14. Variability in the integrated temperature (0-50 m integral) along sections during seasonal occupations in 2002. Sections include Southeast Grand Banks (SEGB), Flemish Cap (FC), Bonavista Bay (BB), White Bay (WB), Seal Island (SI), Makkovik Bank (MB), and Beachy Island (BI). See Fig. 1 for locations of sections.

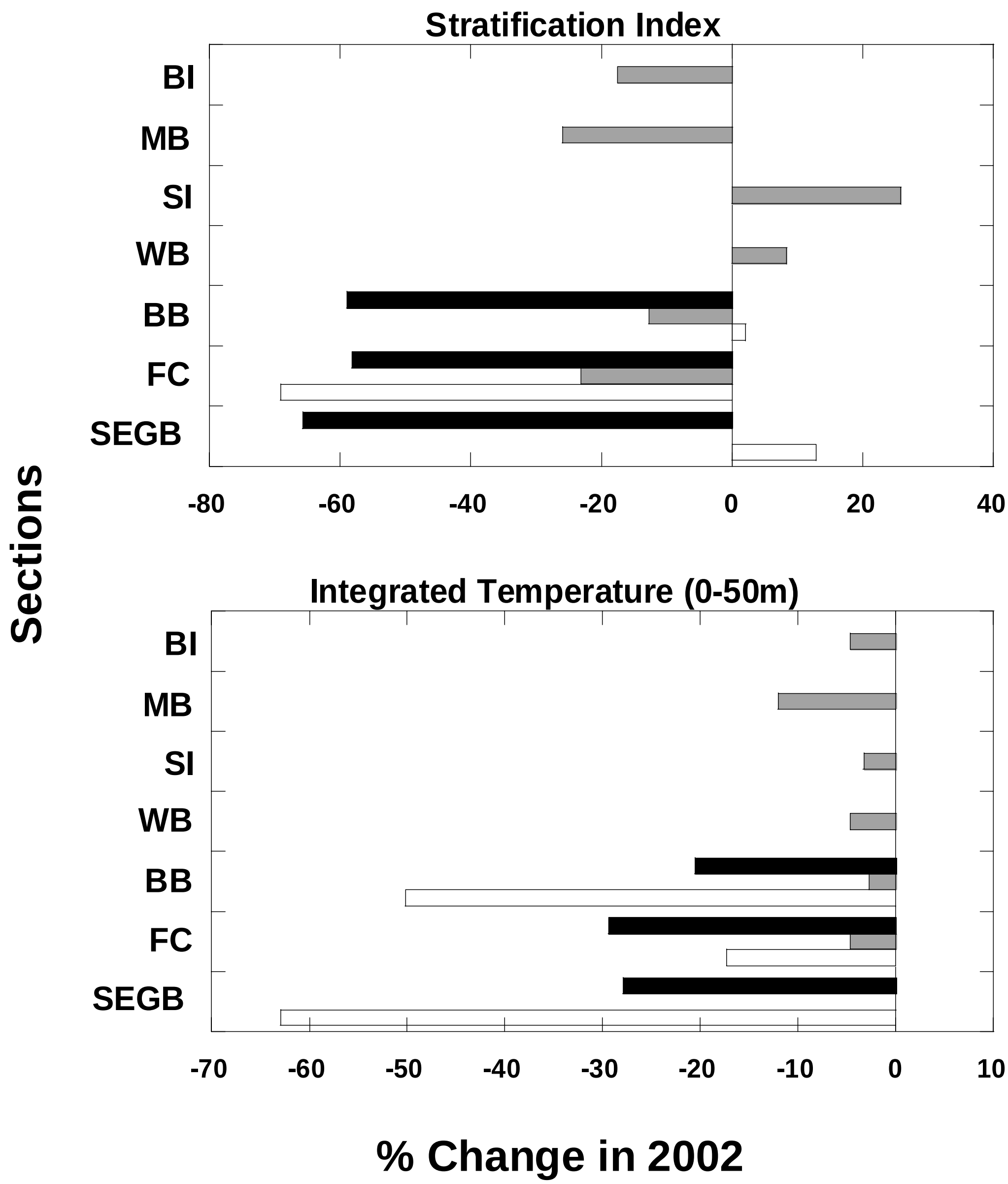

Fig. 15. The percent change in the stratification index and integrated temperature (0-50 m integral) in 2002 compared to earlier years (2000-01) along sections during seasonal occupations. Shading as in Fig. 14.

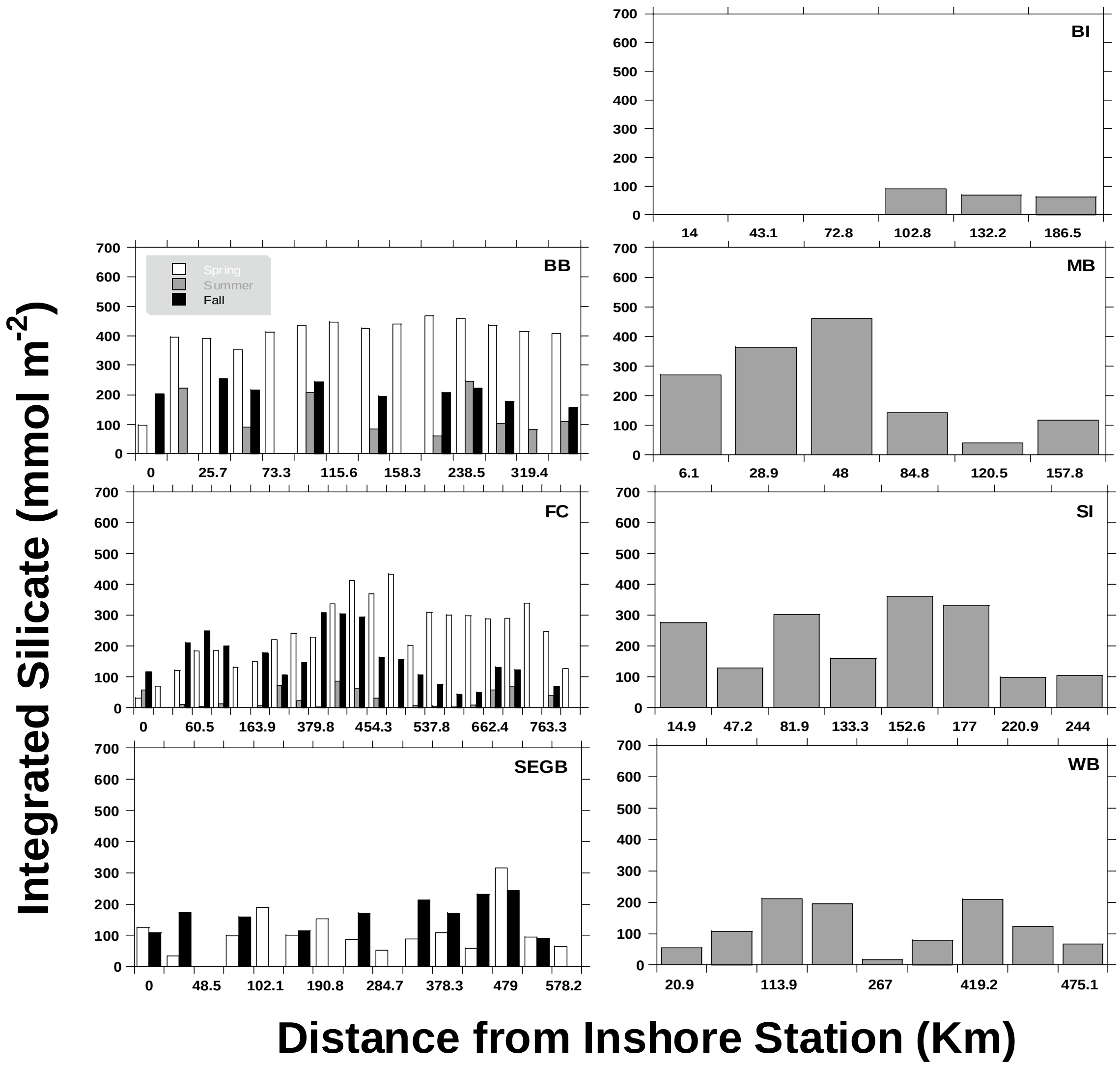

Fig. 16. Variability in the silicate inventories (0-50 m integral) along sections during seasonal occupations in 2002. Sections include Southeast Grand Banks (SEGB), Flemish Cap (FC), Bonavista Bay (BB), White Bay (WB), Seal Island (SI), Makkovik Bank (MB), and Beachy Island (BI). See Fig. 1 for locations of sections.

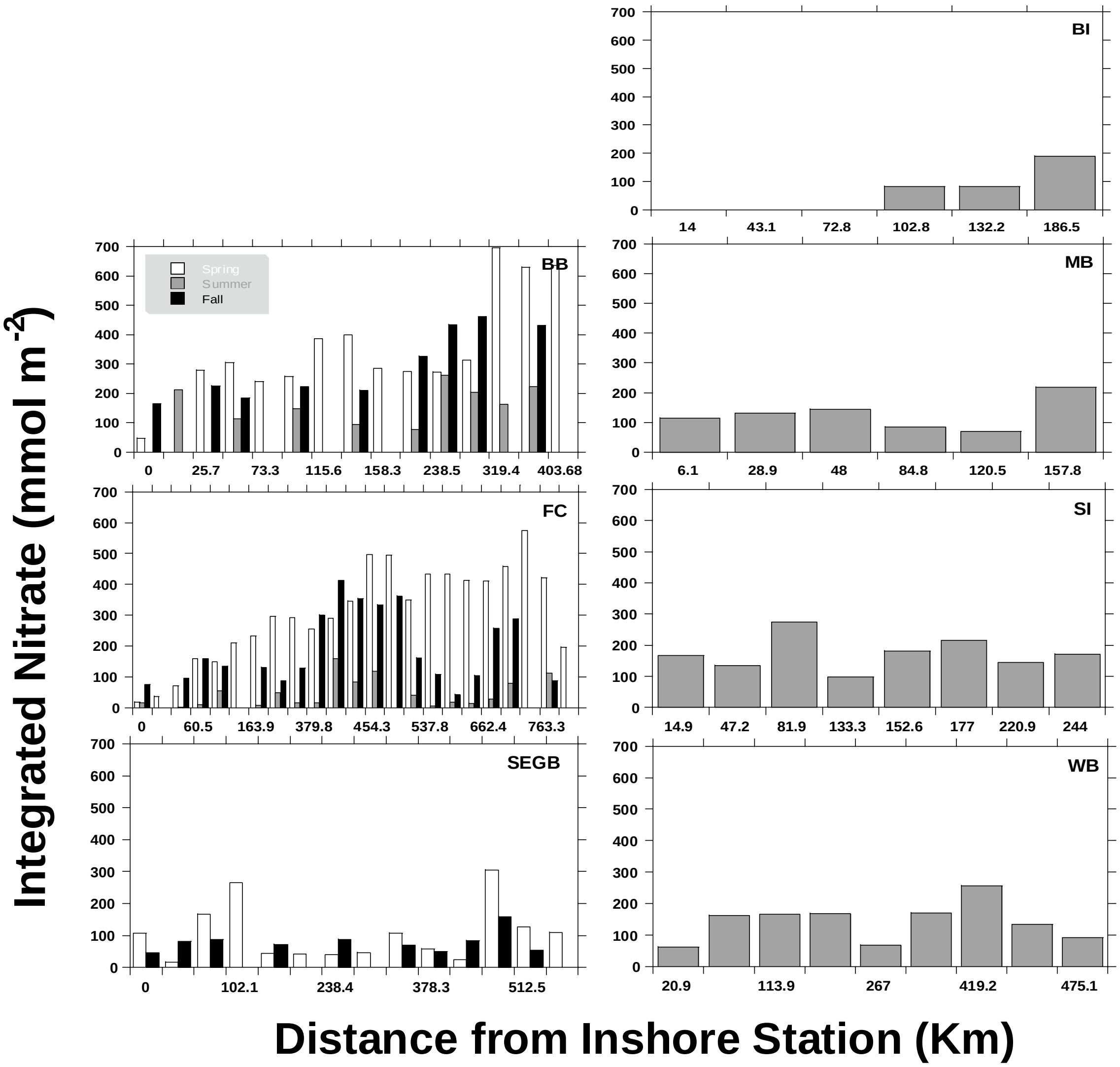

Fig. 17. Variability in the nitrate inventories (0-50 m integral) along sections during seasonal occupations in 2002. Sections include Southeast Grand Banks (SEGB), Flemish Cap (FC), Bonavista Bay (BB), White Bay (WB), Seal Island (SI), Makkovik Bank (MB), and Beachy Island (BI). See Fig. 1 for locations of sections.

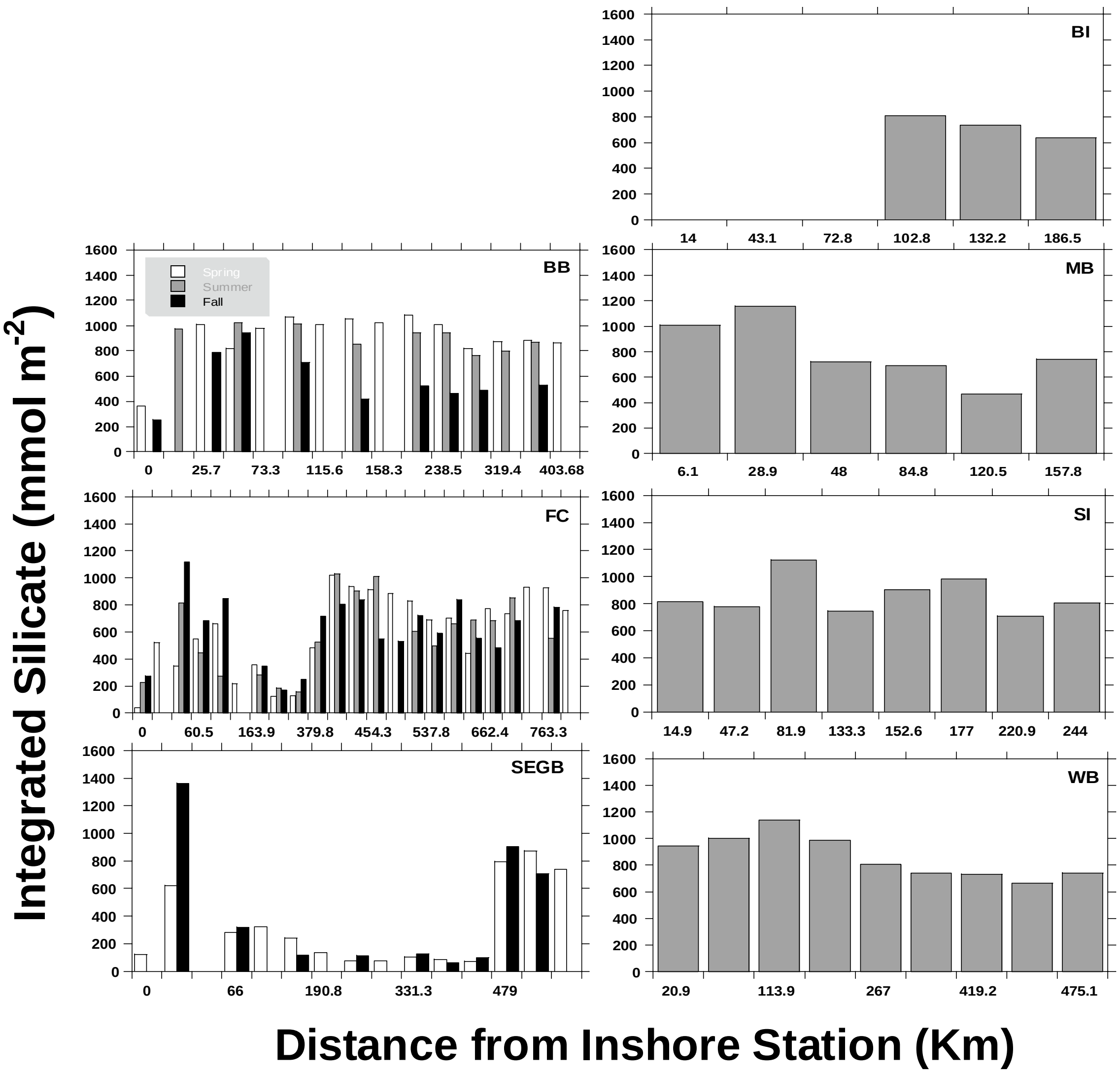

Fig. 18. Variability in the silicate inventories (50-150 m integral) along sections during seasonal occupations in 2002. Sections include Southeast Grand Banks (SEGB), Flemish Cap (FC), Bonavista Bay (BB), White Bay (WB), Seal Island (SI), Makkovik Bank (MB), and Beachy Island (BI). See Fig. 1 for locations of sections.

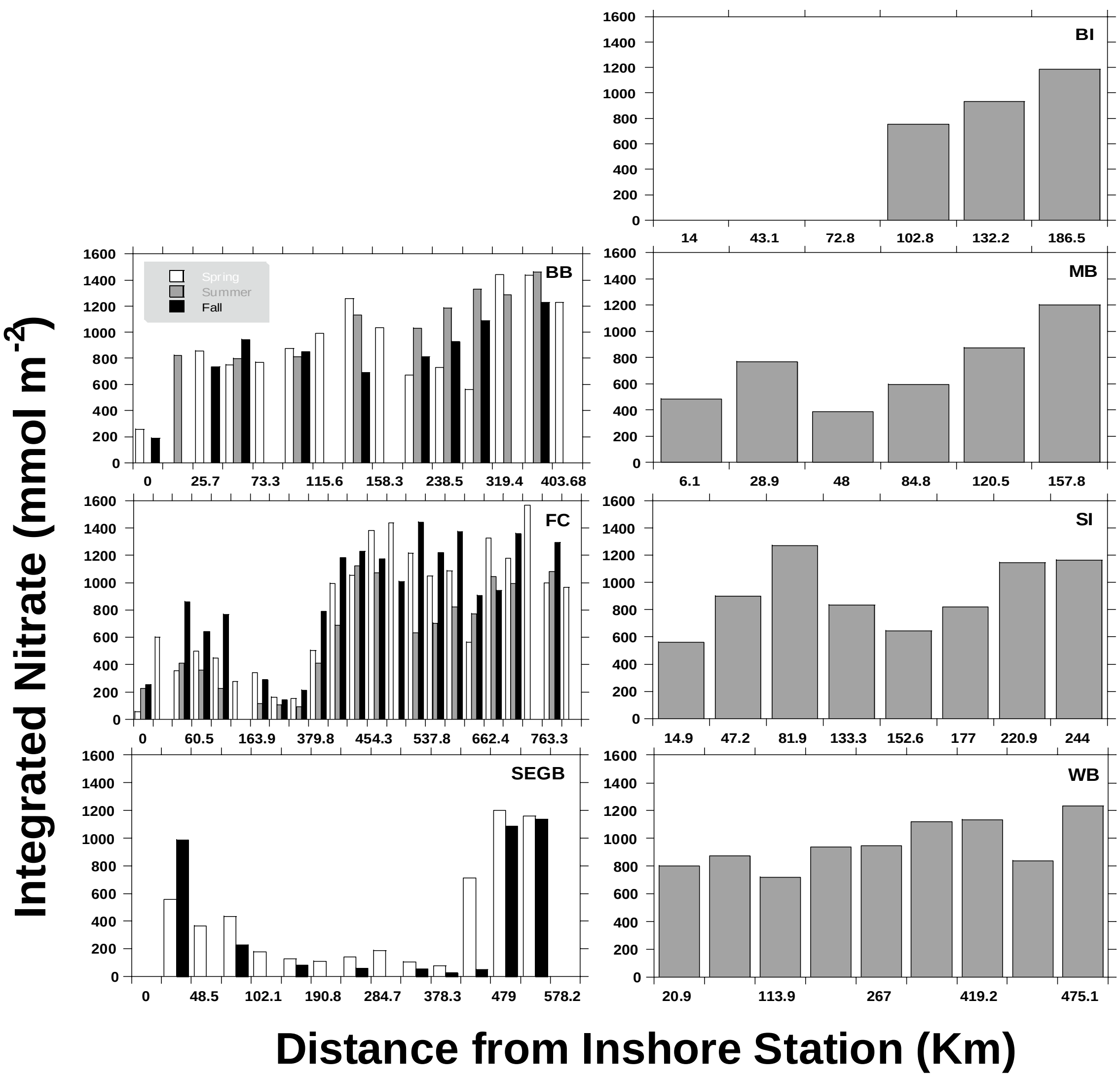

Fig. 19. Variability in the nitrate inventories (50-150 m integral) along sections during seasonal occupations in 2002. Sections include Southeast Grand Banks (SEGB), Flemish Cap (FC), Bonavista Bay (BB), White Bay (WB), Seal Island (SI), Makkovik Bank (MB), and Beachy Island (BI). See Fig. 1 for locations of sections.

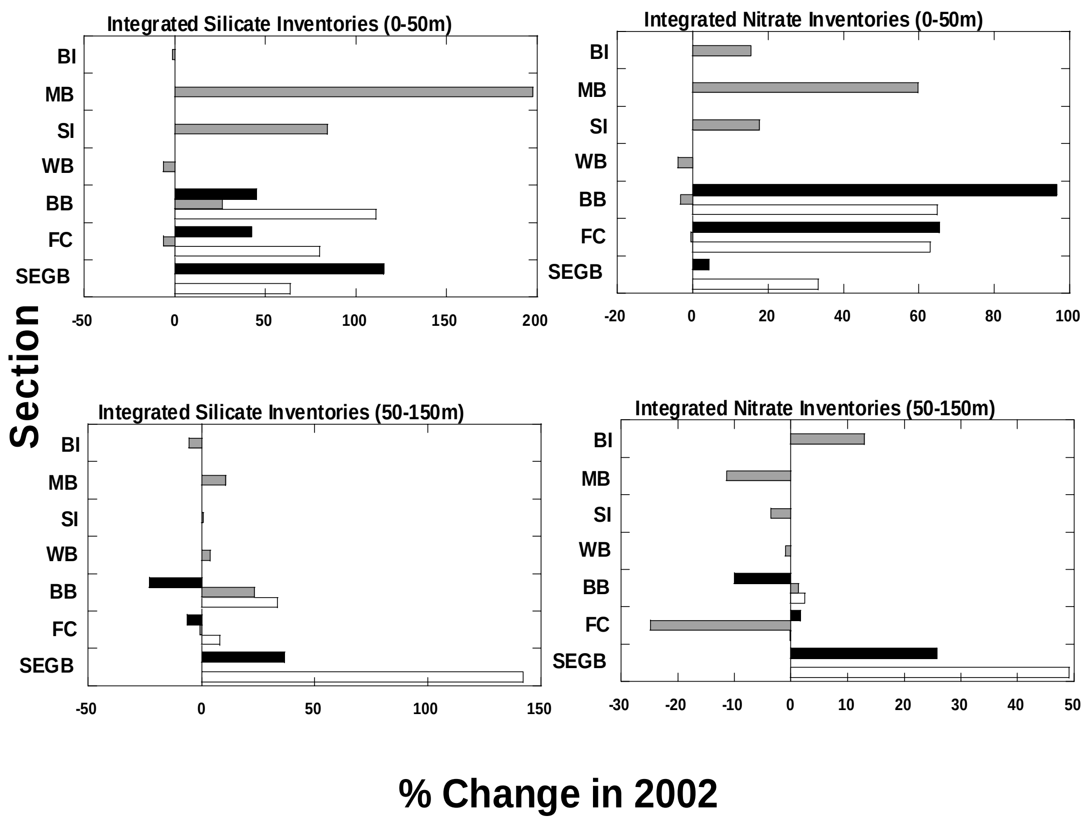

Fig. 20. The percent change in major nutrient inventories in 2002 compared to earlier years (2000-01) along sections during seasonal occupations. Sections include Southeast Grand Banks (SEGB), Flemish Cap (FC), Bonavista Bay (BB), White Bay (WB), Seal Island (SI), Makkovik Bank (MB), and Beachy Island (BI). See Figure 1 for locations of sections. Same shading as in Fig. 19.

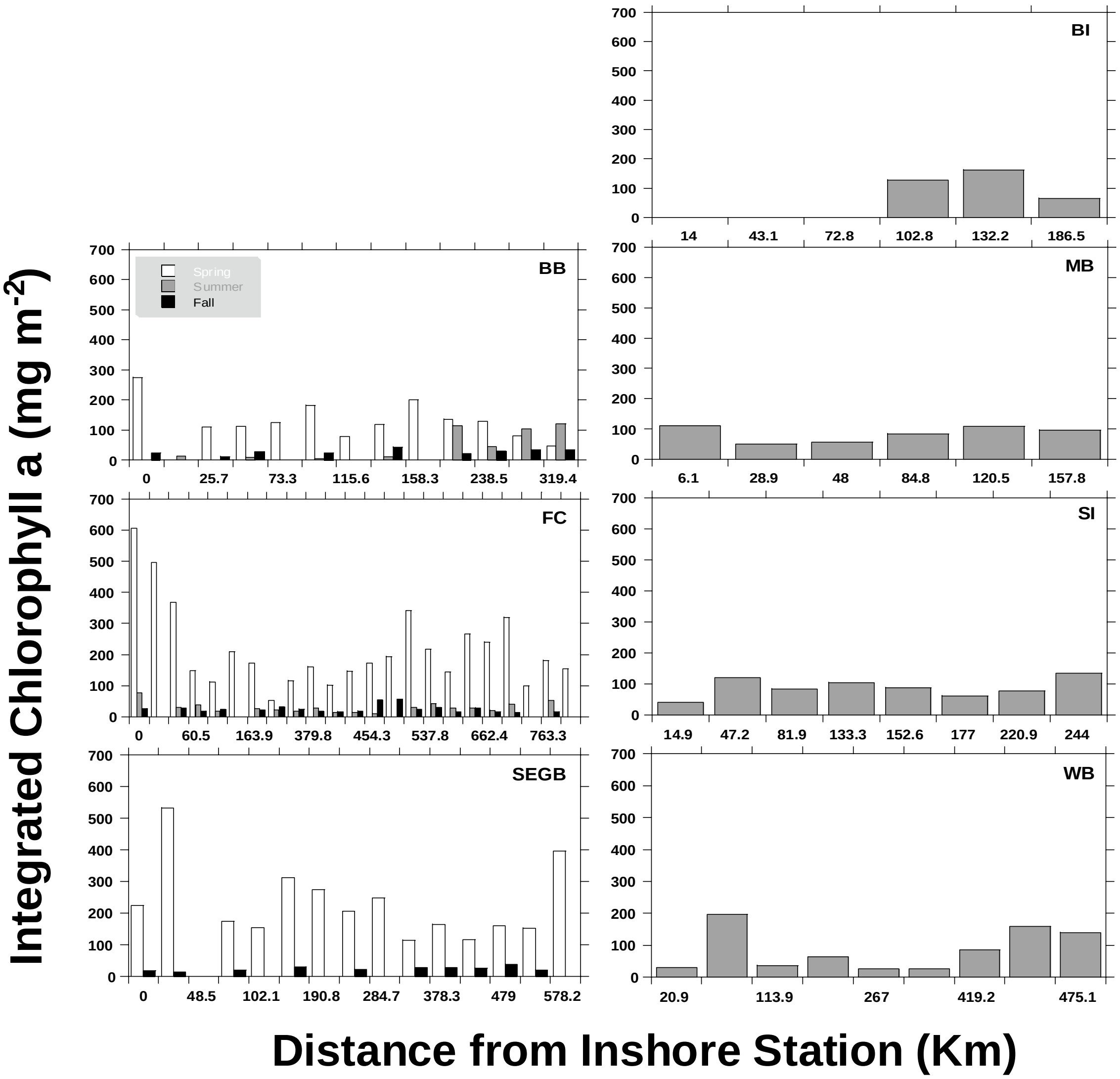

Fig. 21. Variability in the chlorophyll a inventories (0-100 m integral) along sections during seasonal occupations in 2002. Sections include Southeast Grand Banks (SEGB), Flemish Cap (FC), Bonavista Bay (BB), White Bay (WB), Seal Island (SI), Makkovik Bank (MB), and Beachy Island (BI). See Fig. 1 for locations of sections.

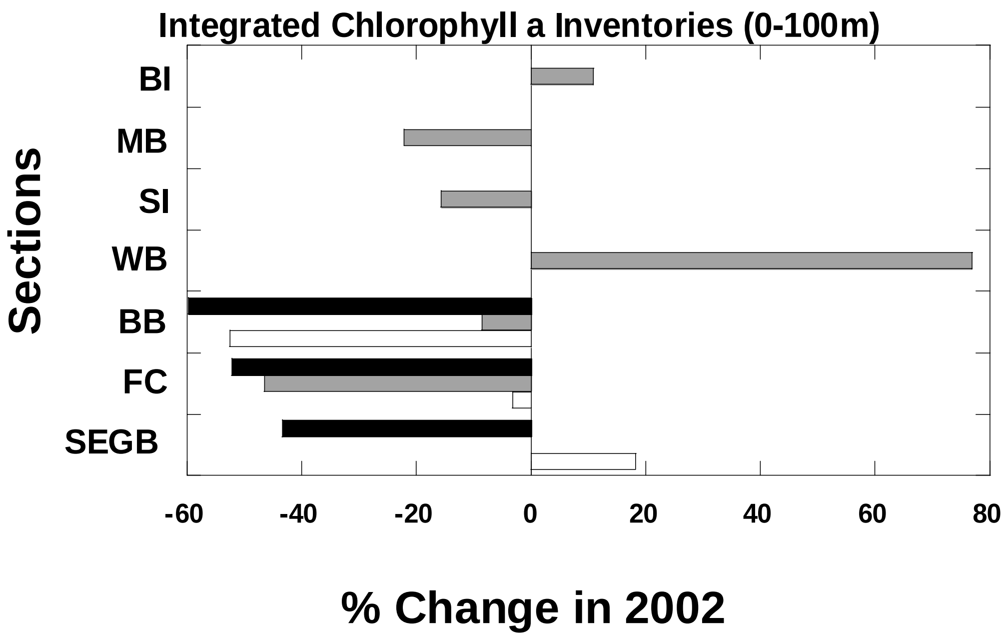

Fig. 22. The percent change in the Chlorophyll a inventories in 2002 compared to earlier years (2000-01) along sections during seasonal occupations. Same shading as in Fig. 21.

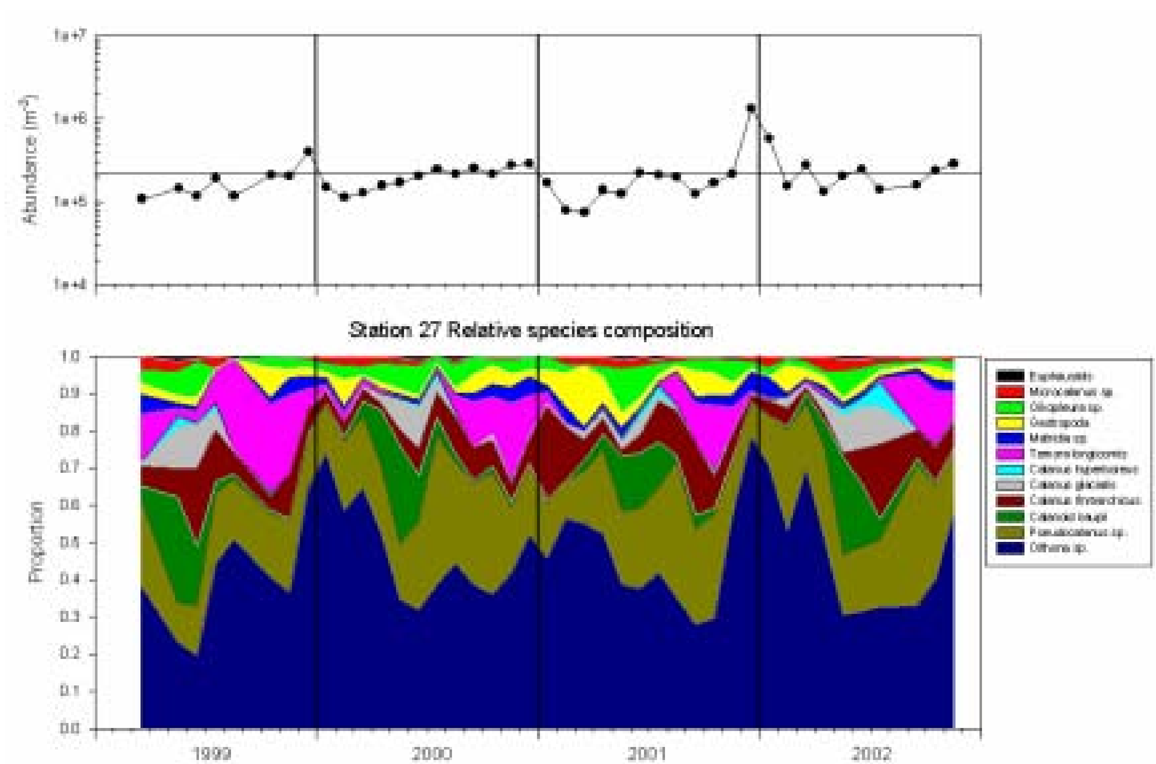

Fig. 23. Time series of total zooplankton abundance (upper panel) and relative species composition (lower panel) from vertical net collections performed at Station 27 since the inception of the AZMP.

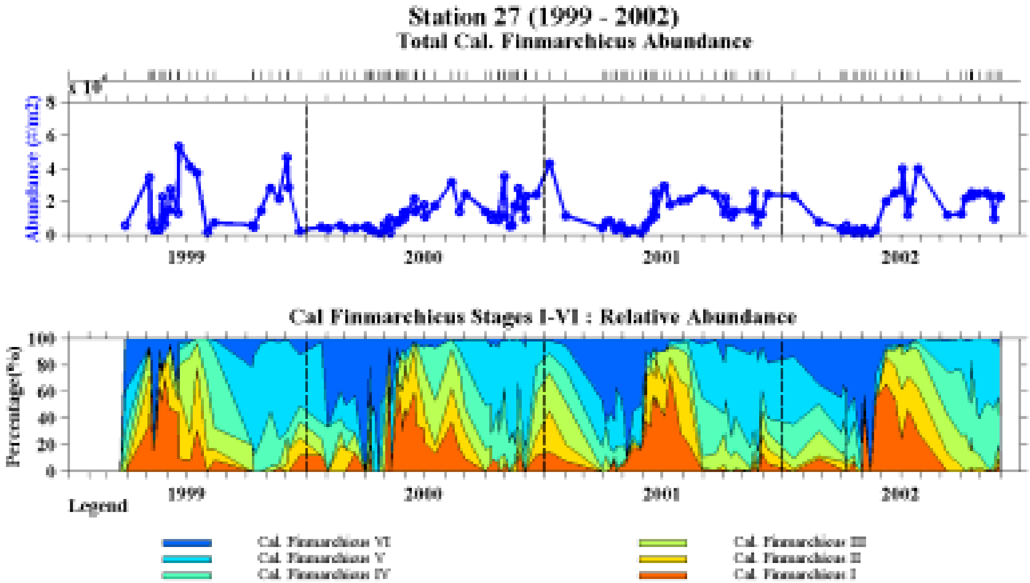

Fig. 24. Time series of abundance and copepodite relative stage composition of *Calanus finmarchicus* at Station 27. The tick marks at the top of the figure indicates the collection times of samples.

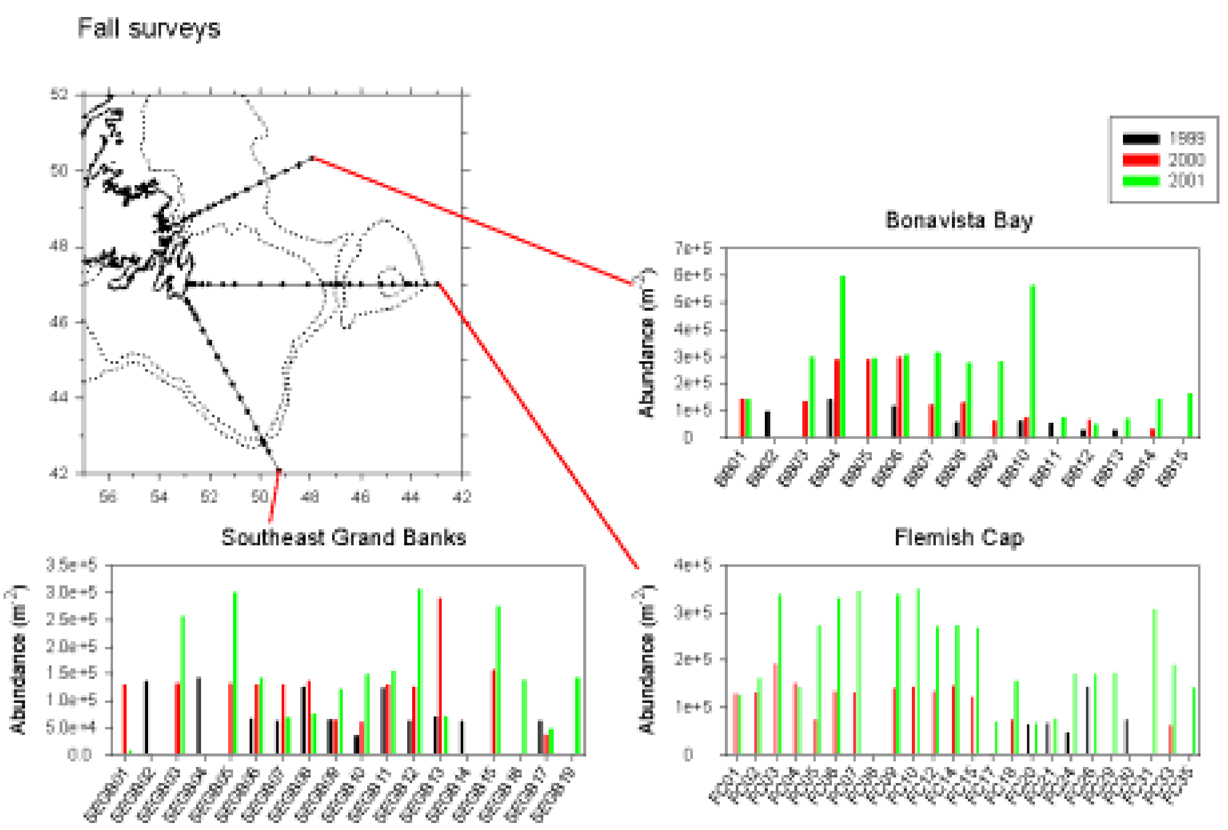

Fig. 25. Total zooplankton abundance during fall surveys of the Newfoundland Shelf for the period 1999-2001. Station locations are indicated on the corresponding map. Missing bars indicate that a station was not sampled in a given year and do not indicate the absence of zooplankton at that site.

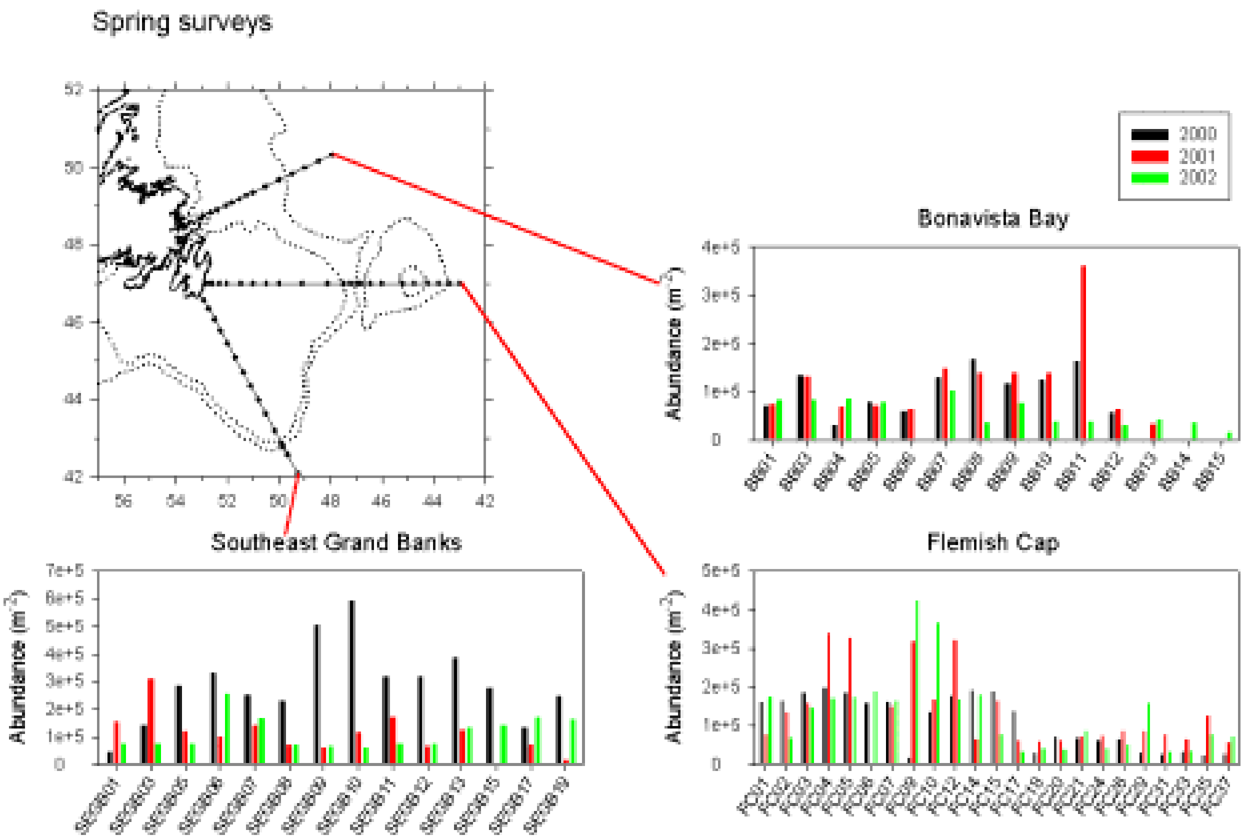

Fig. 26. Total zooplankton abundance during spring surveys of the Newfoundland Shelf for the period 2000-2002. Station locations are indicated on the corresponding map. Missing bars indicate that a station was not sampled in a given year and do not indicate the absence of zooplankton at that site.

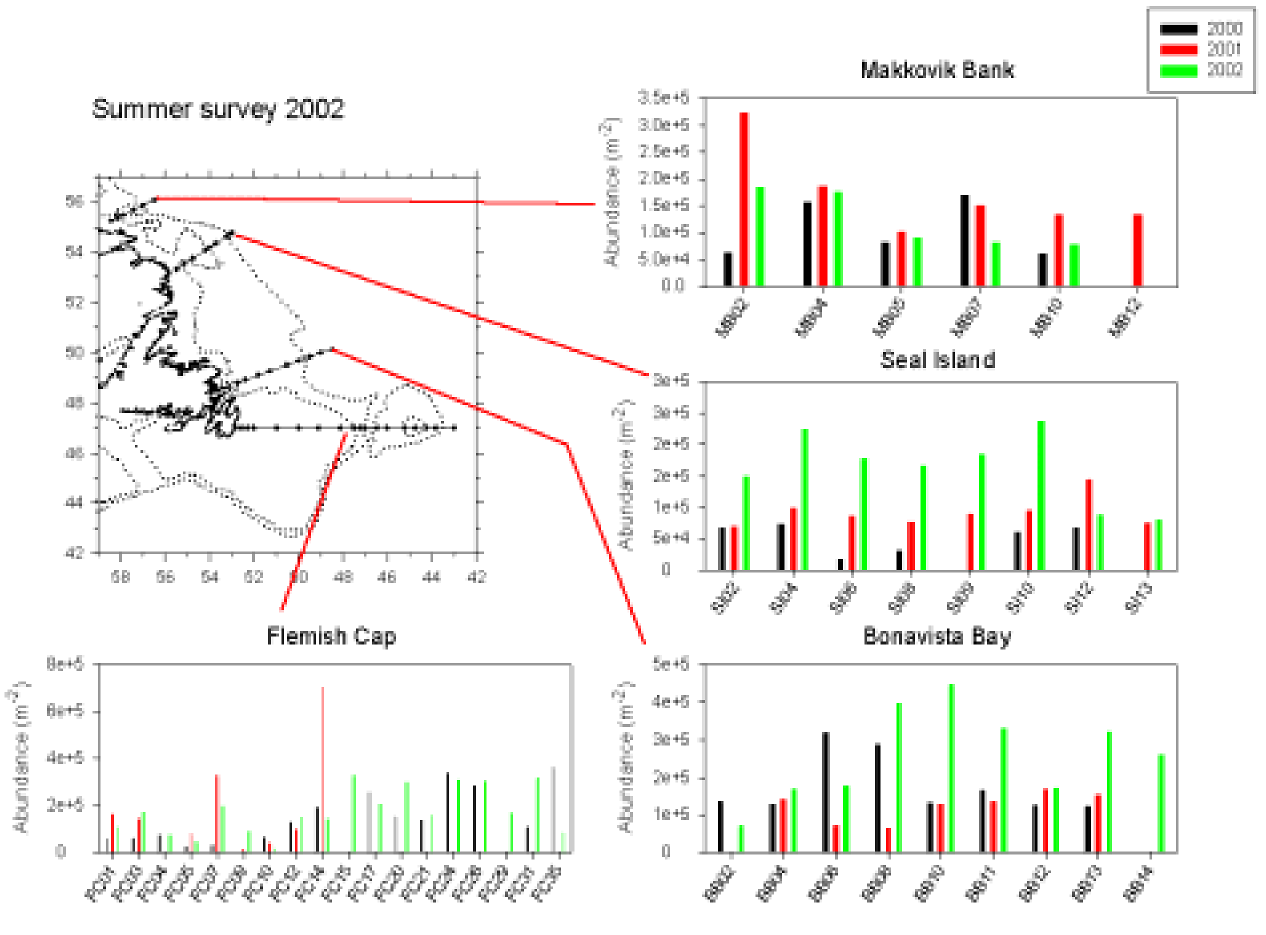

Fig. 27. Total zooplankton abundance during summer surveys of the Newfoundland Shelf for the period 1999-2001. Station locations are indicated on the corresponding map. Missing bars indicate that a station was not sampled in a given year and do not indicate the absence of zooplankton at that site.