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Biological and Chemical Oceanographic conditions on the Newfoundland Shelf during 1998 and 1999 with comparisons to the (1993-97) observations

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Abstract

We review the information concerning the seasonal and internannual variations in the concentrations of chlorophyll *a*, nitrates, phosphates and silicates as well as the abundance of major taxa of zooplankton measured from Station 27 and standard oceanographic transects on the Newfoundland Shelf. We focus on the conditions during 1998 and 1999 but contrast those observations with previous information from the period of 1993-1997. Fluctuations in chlorophyll and nitrate levels around recent average conditions, from positive to negative anomalies about the average seasonal cycle, appear to take place on the scale of a few months in contrast to variations in the physical environment which appear to occur on longer time scales. We found evidence that the summer zooplankton community underwent substantial changes during the period of 1996-98 in contrast to previous years, largely du to increases in the abundance of small copepods which significantly reduced species diversity. Preliminary results from 1999 indicate that large copepods, which make up most of the biomass, have now increased in both relative and absolute abundance.

Résumé

Ce document présente une analyse de l'information concernant les variations saisonnières et interannuelles des concentrations en chlorophylle *a*, en nitrates, en phosphates et en silicates ainsi que de l'abondance des principaux taxons de zooplancton recensés à la Station 27 et avec des transects oéanographiques de la Plate-forme de Terre-Neuve. Nous mettons l'accent sur les conditions de 1998 et 1999 et les comparons avec les données d'observations de 1993-1997. Les fluctuations des niveaux de chlorophylle et de nitrates reliées aux conditions moyennes récentes, allant d'anomalies positives à négatives relativement au cycle saisonnier moyen, semblent survenir à l'échelle de quelques mois à l'opposé des variations de l'environnement physique qui semblent se manifester sur de plus grandes échelles de temps. Nous avons la preuve que la communauté estivale de zooplancton a subi des changements importants au cours de la période de 1996-1998 comparativement aux années antérieures, ce qui est attribuable en grande partie à des augmentations de l'abondance de petits copépodes qui ont considérablement réduit la diversité des espèces. Des résultats préliminaires obtenus en 1999 montrent que les grands copépodes, qui constituent la majeure partie de la biomasse, ont maintenant augmenté en abondance relative et absolue.

INTRODUCTION

We review the chemical and biological oceanographic conditions on the Newfoundland Shelf for the period of 1998 and 1999. Collections and measurements of nutrient and chlorophyll concentrations as well as phyto- and zooplankton abundance are based on the protocols outlined by the Steering Committee of the Zonal Monitoring Program.

Observations presented in this document are based on surveys listed in Table 1, as well as frequent but, unscheduled sampling of Station 27.

To place the observations in some context, the 1998 and 1999 conditions are contrasted with observations obtained during the period of 1993-97 and 1993-98 respectively. Anomalies were estimated relative to the previous mean conditions for each station that was sampled routinely.

FIXED STATION

The occupation of Station 27 for oceanographic monitoring allowed us to develop a representative view of conditions during the months of April-August in 1998 and May-August in 1999 at this stage of the Zonal Monitoring Program (ZMP).

In April of 1998, nitrate/nitrite concentrations were depleted to nearly undetectable levels in the surface layer (<50m) (Figure 2, difficult to differentiate between April and October symbols in graph) which resulted in ~ 2ΦM anomaly below the long term (1993-97) mean for the site (Figure 3). Concentrations in deeper layers (>50m) were close to the long term mean (± 1ΦM). During the remainder of the year, surface nitrate concentrations remained at low (depleted) levels, near normal conditions for the principal part of the phytoplankton production cycle. Nitrate concentrations below 50m increased from May through August (Figure 2), reaching levels between 2-6ΦM above the 1993-97 mean (Figure 3). Similar patterns in the anomalies were also apparent in phosphate and silicate levels (Figure 3): concentrations were below or near the 1993-97 mean during April in both surface and bottom layers but concentrations in the bottom layer increased above the long term mean from May through August. Low and depleted nutrient concentrations in April were indicative that the spring phytoplankton bloom had already taken place. This was confirmed in the vertical profile for 24-April-1998 which showed that chlorophyll concentrations were highest in the deeper layers suggesting that the spring bloom had already begun to sink out of the surface layer (Figure 2). High concentrations of chlorophyll were observed at or below 40m in May and June, suggesting there was substantial settling of material for an extended period in 1998. Surface concentrations of chlorophyll in May and June were below 5 mg m^{-3}. This was followed by a slight increase in July (~1 mg m^{-3}).

In 1999, the spring bloom was well developed on 4-May-1999, with chlorophyll concentrations reaching 2-3 mg m^{-3} throughout much of the upper 100m (Figure 2). Nine days later, chlorophyll concentrations in the surface 40m were below 1 mg m^{-3} but chlorophyll levels below 40m were between 5-10 mg m^{-3}, indicating sinking of the spring phytoplankton bloom. From May through August, chlorophyll concentrations were generally less than 1 mg m^{-3} throughout the water column with evidence of a sub-surface chlorophyll maximum between 20-40m. Deep (>100m) nitrate levels were slightly above the 1993-1998 average at the start of the year but moved to near normal concentrations later in the summer (Figure 4) although they were substantially below average in July. Nitrate concentrations were generally below normal in waters less than 100m throughout 1999. Similar patterns were also apparent in phosphate and silicate concentrations although the low concentrations appeared to be more uniformly distributed throughout the water column in the case of silicates.

Integrated chlorophyll concentrations (0-100m) were below previous observations in April of 1998 and slightly above normal in May of 1999 (excluding the 1994 value which was extremely high, with concentrations ~12-24 mg m^{-3}) (Figure 5). Integrated levels from June through August were approximately normal but well below observations from 1996.

TRANSECTS

In the spring of 1998, the spring phytoplankton bloom was still in progress during the period of the survey. Along the Southeast Grand Bank Line, chlorophyll concentrations are higher on the Bank close to the coast and decrease as one moves offshore and onto the Southeast Shoal (Figure 6) where chlorophyll concentrations appear to be uniform throughout the water column although nutrients do not show a similar pattern with depth. Nitrate levels are low (1-2 ΦM) but not yet depleted. The nutricline is located between 30 and 40m. Phosphate concentrations are reduced in the surface layer but their depth distribution is relatively uniform along the entire transect. Silicate levels are below 1ΦM in surface waters at the extremes of the transect but higher over the Southeast Shoal (Figure 6). Chlorophyll concentrations are lower than previous observations, and so are the nitrate levels, until one reaches the SE Shoal where concentrations appear to be higher than our data from 1993-1997 (Figure 7).

On the Flemish Cap Line, peak chlorophyll concentrations reached 6 mg m^{-3} on top of the bank with very high levels (7-10 mg m^{-3}) being found in the offshore branch of the Labrador current (Figure 6). The distribution of chlorophyll followed the distribution of nitrates closely with areas of mixing having higher concentrations of chlorophyll/low concentrations of nitrate close to the surface and vice versa. There is some evidence of surface depletion of nitrates in the top 20 m of the water column, with concentrations ~0.5-1 ΦM (Figure 6). Similarly, patterns of depletion were also apparent for phosphate and silicate, with the latter showing a greater degree of depletion between surface (20m) and deep (100m) layers relative to the former (Figure 6). Conditions during this period suggest that surface nitrate levels are lower than in the past and that chlorophyll levels are low from the coast and out to the top of the bank, 200 km out (Figure 7), at which point concentrations appear to be higher than the 1993-1997 average.

Along the Bonavista Bay Line in the spring of 1998, the spring phytoplankton bloom is still in progress, with peak concentrations on the shelf exceeding 8 mg m^{-3} (Figure 6). Nitrate levels are not yet depleted and there is considerable evidence of mixing along portions of the transect. As a result, the distribution of chlorophyll is more patchy than on the Grand Banks, with integrated concentrations high in areas of limited mixing and low where mixing continues to be strong.

Surface chlorophyll levels are near normal along most of the transect but inshore concentrations (>20m) appear low (Figure 7). The intensity of the inshore concentrations is low relative to the recent past. Most nitrate concentrations are near normal, with the exception of a zone of mixing that results in an apparent peak in anomalies (Figure 7). Surface concentrations of phosphate and silicate are relatively high along the entire transects and show limited evidence of being depleted.

During the summer of 1998, the nutricline is relatively stable at a depth of ~60m across the entire Grand Banks after which it rises toward the surface in the offshore area (Figure 8). Chlorophyll is patchily distributed along the Flemish Cap transect and the highest concentrations of chlorophyll can be found in a subsurface maxima that follows the horizontal changes in the depth of the nutricline (Figure 8). Where the nutricline is closer to the surface (i.e. offshore areas), the extent and stability of regions of chlorophyll > 1 mg m^{-3} are less patchy (Figure 8). Surface levels of phosphate are low (0.1-0.4 ΦM) but follow the general pattern of distribution of nitrate levels (Figure 8). Surface concentrations of silicate are low along the entire length of the Flemish Cap Line (Figure 8). Chlorophyll levels appear to be generally near the average conditions from our previous observations (Figure 9) while surface levels of nitrate are generally low.

Summer 1998 conditions along the Bonavista Bay Line show considerable spatial variability. The depth of the nutricline is ~30m close to the coast and in the offshore arm of the Labrador current whereas it occurs at ~45m on the shelf (Figure 8). A band of subsurface chlorophyll maxima (> 1 mg m^{-3}) follows the spatial distribution of the nutricline with the greatest vertical extent in areas where the latter is closer to the surface. Nitrate concentrations throughout the water column tend to be slightly higher than those found on the Flemish Cap Line at the same depth. Phosphate levels in the top 40 m of the water column on the Bonavista Bay Line are relatively uniform across the entire shelf and slope area (0.1-0.5 ΦM). Silicate levels are higher than on the Flemish Cap Line and show no evidence of significant depletion (most concentrations above 3 ΦM) (Figure 8). Chlorophyll levels appear to be near the average concentrations observed during our from our previous sampling of the transect (Figure 9) whereas nitrate concentrations throughout the water column are generally below the 1993-1997 average.

In the summer of 1998, conditions along the Seal Island Line were in marked contrast with those further south. Chlorophyll concentrations were very low (peak ~ 1 mg m^{-3}) and these were widely distributed throughout the water column (maximum ~50m) (Figure 8). The nutricline is similar in extent and intensity to that found in other areas, and surface levels of nitrate appear to be depleted. As in other areas, the nutricline tends to rise toward the surface in areas where the strength of the current is greatest (inshore and offshore regions). Silicate and phosphate levels follow a spatial distribution pattern similar to that of nitrate with one notable difference in that concentrations in the deep water off the shelf tend to be low relative to that observed at the same depth on the shelf, a pattern opposite to that of nitrate concentrations which increase with depth along the entire transect (Figure 8). The conditions observed in 1998 appear to be anomalous relative to the past, with surface chlorophyll concentrations somewhat below the long term

(1993-1997) mean (Figure 9). Surface nitrate concentrations are also below the 1993-97 average, while the opposite is true in waters below 60m.

The seasonal progression of conditions along the Bonavista Bay Line show that much of the spatial variability in conditions occurs at depth rather than in the surface layer (Figure 10). During May of 1999, we find evidence of surface depletion of nitrates in areas extending to the shelf-slope with a similar distribution also found in silicate concentrations (Figure 10). Chlorophyll concentrations are highest at depth (~30-60m) on most of the shelf with higher concentrations following the rise of the nutricline toward the surface on the shelf and slope regions (Figure 10). Phosphate concentrations are relatively high during the spring survey, with levels fluctuating between 0.3-0.7 ΦM in the top 30m of the water column. Surface depletion of nitrate levels continues during the summer months with a strong cline in concentrations from 20 to 40m. There are high concentrations of nitrates at depth in offshore areas but levels are relatively low on the shelf (Figure 10). Phosphate levels are relatively high (0.3-0.5 ΦM) but their depth distribution mirrors that of nitrate. Silicate concentrations are higher that those observed during the spring cruise, with some evidence of depletion in areas within 150 km of the coast but offshore areas showing concentrations of 1-2 ΦM in. The strength of the nutricline for silicates is not as marked as that found for nitrates but the deep distributions (high off shelf – low on shelf) mirrors that of nitrates. By November 1999, nitrate levels in the surface waters have reached 4-8 ΦM but the distribution does not show complete mixing of the column (Figure 10). The vertical distribution of nitrates contrasts that of silicate and phosphate concentrations which are much more uniformly distributed within the water column (surface – deep contrast of 1.5-2× versus >3× for nitrates). Overall concentrations of chlorophyll are low (0.6-1 mg m^{-3}) and widely distributed throughout the water column but still show evidence of biological activity. Areas with lower nitrate levels tend to be associated with higher chlorophyll concentrations (Figure 10). Relative to past observations, chlorophyll concentrations during the May and July period are lower than average but appear to be higher in the fall (Figure 11). Overall, spring surface nitrate concentrations were lower than the 1993-1997 average but these were generally above normal at depths > 80m (Figure 11). The surface nitrate anomaly became positive during July and November surveys but concentrations below 60m were slightly (~ 0.5-2 ΦM) below normal in late fall (Figure 11).

During the summer of 1999, conditions along the Flemish Cap Line are somewhat different than on the Bonavista Bay Line. Surface concentrations of chlorophyll are comparable to that observed on the Bonavista Bay Line but the surface maximum is more intense (concentrations > 1 mg m^{-3}) and is more broadly distributed both horizontally and vertically (Figure 12). Nitrate levels are depleted along the entire length of the transect, with some limited evidence of pumping in areas with high current flows. Phosphate concentrations in the surface layer are comparable to previous observations (0.2-0.5 ΦM) (Figure 12). Surface levels of silicate are not depleted (1-2 ΦM) except past the Flemish Cap. The deep distribution of all nutrients is comparable to that observed in other regions.

Conditions on the Seal Island Line show evidence of an ongoing phytoplankton bloom, with chlorophyll concentrations in excess of 2 mg m^{-3}, reaching subsurface levels between

4-16 mg m^{-3} (Figure 12). The nutricline is not sharply defined and surface waters are not yet depleted of nitrate. Phosphate concentrations in the surface layer are comparable to other transects but silicate levels are generally greater than in other areas.

In comparing 1999 summer conditions with the average from 1993-1997, there is considerable spatial variability on the Newfoundland Shelf. Chlorophyll conditions on the Flemish Cap Line appear to be higher than average whereas they are generally below average on the Bonavista Bay Line (Figure 13). The converse pattern of anomalies appears for nitrate concentrations (Figure 13).

In the fall of 1999, conditions on the southern Grand Banks are substantially different that those observed along the Bonavista Bay Line (Figure 14). Surface concentrations of nitrate still show evidence of depletion and chlorophyll concentrations are generally above 1.5 mg m^{-3} across the entire transect. There is evidence of mixing (or pumping) of the water column in inshore and offshore areas associated with the strong flows of the Labrador current. Phosphate and silicate concentrations in the surface waters are above 0.5 ΦM and 3 ΦM respectively, but the spatial pattern in the depth of the nutricline of these nutrients is similar to that of nitrate (Figure 14). On the limited portion of the Flemish Cap Line sampled in 1999, surface chlorophyll concentrations are elevated (>3 mg m^{-3}) and the depth of the nutricline is ~ 60m. Surface concentrations of nitrate are above 2 ΦM while concentrations of phosphate and silicate are generally ~1ΦM and ~4ΦM (Figure 14). Along the Bonavista Bay Line, concentrations of both surface chlorophyll and nitrates are higher than the 1993-1997 average but deep nitrate levels are low (Figure 15). It was not possible to produce an anomaly view for the other transects sampled in the fall.

Throughout 1998 and 1999, an analysis of silicate to nitrate relationships along individual transects and seasons (plots not shown) suggested that depletion of the latter was the primarily element limiting phytoplankton.

ZOOPLANKTON

Total numbers of copepodites in 1998 were slightly higher than in 1999 and both were comparable overall to abundance levels observed in 1996 and 1997 (Figure 16). Levels were much higher than in 1993 and 1994 when the overall levels were approximately 3050% of those observed in the late 90s. There are significant seasonal and interannual variations in the relative abundance of large (*Calanus* sp.) copepods relative to smaller species (*Oithona* sp, *Pseudocalanus* sp., *Centropages* sp. *Metridia* sp. and *Temora* sp.). Seasonally, small species appear to dominate in the spring and fall whereas larger copepod species are approximately equal in abundance, relative to small copepods, during the summer period (Figure 17). The relative abundance of larger species was approximately 5-10 times greater in 1993/94 than during the later part of the 90s. The lowest levels of large-to-small copepods was observed during the 1996/97, with levels returning back to 1993/94 levels in 1998 and 1999, with the latter showing a greater degree of overlap with observations in the earlier part of the 90s (Figure 17).

Changes in overall abundance reflect important changes in species composition. Since 1993, there has been a significant decreasing trend in summer species diversity, with the reduction being most pronounced in the southern areas (Figure 18). The trend reflects the increasing dominance of a single species, *Oithona similis* (see below) while the most recent increase is associated with an increasing trend in the abundance of the Genus *Calanus*, dominated by *C. finmarchicus*.

The seasonal trend in total copepodite abundance for individual species was somewhat difficult to interpret because fluctuations during the April-May period may be due to seasonality or they may be caused by inter-annual variations in production (Figure 19). This ambiguity exists because the timing of spring surveys has been highly variable since 1993. However, in most instances, the abundance copepods caught by the vertical hauls consisted principally of Stage I and V copepodites in most of the calanoid species. Patterns of variation in total copepod abundance during the summer surveys are easier to define because the timing of this sampling period has been more consistent due to past oceanographic programs.

Most of the overall changes in total copepod abundance appear to be driven by fluctuations in the numbers of species with smaller body sizes (Figure 19). Species such as *Calanus finmarchicus* show seasonal and inter-annual variations in abundance but the scatter about the seasonal cycle (based on the three transects surveyed consistently) appears to be largely similar throughout the 90s. There is some indication of an increase in 1998 and 1999 but this is largely due to the increased coverage afforded by the Zonal Monitoring Program. Catches of *Calanus hyperboreus* appear to be lower in 1999 and in the previous year in both the spring and summer surveys (Figure 19). It is not possible to interpret patterns of catches for *Calanus glacialis* because of problems in species identification during the 96-98 period. *Oithona similis* has shown the greatest overall change in abundance since 1993/94: an almost ten-fold increase in the southern range with a more limited increase on the northeast Newfoundland and Labrador shelves (see below).

The distribution patterns of copepodite abundance for *Calanus finmarchicus* appears to have been similar in 1998 and 1999 (Figure 20). During the summers of 1998 and 1999, *C. finmarchicus* showed a widespread distribution across the northeast Newfoundland and Labrador shelves. The pattern of distribution shows a strong association with the Labrador current along the Flemish Cap Line, with the highest abundances being found in the inshore and offshore branches of the current in all years sampled. There appears to be no strong distributional pattern during spring surveys, with *C. finmarchicus* being abundant across the entire shelf. The population along the Bonavista Line in the spring of 1999 was in a more advanced stage of development when surveyed than in 1998 (Figure 21). In 1999, *C. finmarchicus* consisted mostly of Stage I and VI copepodites whereas the population consisted exclusively of Stage V copepodites in 1998. The sampling interval between the two years was about 3 weeks but, sampling in 1994, conducted during a period similar to 1998, showed a state of development similar to 1999. During the summer of 1998, *C. finmarchicus* consisted mostly of C-I and C-III stages on both the Flemish Cap and Bonavista Lines while C-I dominate on the Seal Island Line. A few Stage V copepodites are found on the northern and southern most Lines but these are largely confined to the offshore portion of the Labrador current. In contrast, the *C. finmarchicus* population in the summer of 1999 is more evenly distributed across all stages of copepodite development on both the BB and FC Lines. Stage V individuals are highly abundant in the offshore arm of the Labrador current.

Oithona similis is the most abundant and variable species of copepod captured by the surveys of the Monitoring Program. This species is approximately 10 times more abundant than any of the other dominant copepods (Figure 19). However, the only stages that are effectively sampled by our protocol appear to be the Stage V and VI copepodites, thus precluding an assessment of seasonal and inter-annual variations in development of the sampled population. The species is generally more abundant close to the coast and on the shelf, with a general decrease in numbers as one moves past the 300 m isobath into the offshore core of the Labrador current (Figure 22). Most of the increase in total copepod abundance from 1993/94 to the present is due to changes in the abundance of this species. Summer abundance levels were highest in 1998 with 1999 numbers being second highest on the Grand Banks but somewhat average further north (Figure 22).

Pseudocalanus sp. is the second most abundant species of copepods (Figure 19) and found in highest numbers in proximity to the coast, with a consistent decrease in abundance as one moves away onto the shelf (Figure 23). Their greatest overall variability is found on the Grand Banks but peaks levels are comparable to other regions of the shelf (~ 100 individuals m^{-3}). In 1998, the distribution of this species appears to have been more abundant and widespread during the summer survey than in previous years, with the greatest increase appearing on the Grand Banks, with abundance levels comparable to observations in 1993 (Figure 23). In contrast, abundance of *Pseudocalanus* sp. on the Grand Banks appears to have been lowest in 1999 with abundance levels comparable to previous years as one moves further north. There is no evidence of major shifts in the timing of development, as measured during the summer surveys, for any of the years sampled (Figure 24).

The zooplankton community structure from the summer surveys form 1993-1999, as determined from a canonical discriminant analysis of relative abundance composition, can be divided into 4 major clusters which separate groups both along and across the shelf (Figure 25). The cluster nearest to shore has greater proportions of *Pseudocalanus* sp. (34%), *Acartia* sp., *Microcalanus* sp. and *Balanus* sp. with *Oithona similis* making up approximately 20% of the overall abundance within the group (Table 2). This group also has a tendency of being distributed further north in the study range. The three species of *Calanus* copepodites (*C. finmarchicus, C. glacialis, C. hyperboreus*) are also abundant in this group (3-15%) although they dominate a second group. This second group, which is also more abundant in northern regions but has a widespread distribution across the shelf consist primarily of *C. finmarchicus* and its two sister species, and *Metridia* sp. The third group is found predominantly in the southern portion of the survey region and consists predominantly of *Oithona similis* as well as a number of other small copepod genera (*Centropages*, *Paracalanus* and *Temora*) and *Aglantha digitale*. It dominates on the Grand Banks and in the centre of the northeast shelf in certain years. The final group consists of an offshore assemblage, in which the three species of *Calanus* are present as well as various species of mysids and small euphausiids, chaetognaths and species of *Metridia*. Larvaceans appear to be widely distributed across the entire shelf.

In 1993 and 1994, the summer zooplankton communities dominated by *Pseudocalanus* and *Calanus* were found across the central Newfoundland shelf (Grand Banks and NE Newfoundland Shelf) but the community dominated by *O. similis* became more abundant on the Grand Banks in 1994 (Figure 26). The regional distribution of the latter community expanded during 1996 and dominated all but the coastal and offshore regions in 1997 and 1998. The expansion in 1996 and 1997 was largely the result of large increase in the abundance of *O. similis* but in 1998 there was a substantial increase in the abundance of other small copepods, particularly *Centropages hamatus* (Figure 19). However, in 1999, the community dominated by *Calanus* species once again expanded onto the northeast Newfoundland shelf and the community dominated by *O. similis* was once again restricted primarily to the Grand Banks, with the community dominated by *Pseudocalanus* sp. increasing in abundance in coastal areas (Figure 26).

PHYTOPLANKTON

During most of 1999, flagellates dominate the phytoplankton community and there is slight evidence of a decrease in abundance as one move from inshore areas toward the shelf break (Figure 27 & 28). Dinoflagellates generally rank second in abundance with the exception of the spring bloom when the abundance of diatoms peaks to equal or greater concentrations. Both flagellates and dinoflagellates are present in approximately equal concentrations from the period of May to November across most of the Newfoundland shelf. Diatoms show the greater seasonal fluctuations in abundance with widely distributed peaks during bloom conditions and highly patchy distributions during the summer. Increases in chlorophyll concentrations from the summer into the fall of 1999 appear to have been associated with increases in the abundance and distribution of diatoms rather than flagellates or dinoflagellates (Figure 27 & 28). Conditions at station 27 during the fall of 1999 did not appear to mimic the increase in diatom abundance found on the remainder of the shelf although they did appear to reflect general conditions during the spring and summer.

DISCUSSION

With the limited time series available to us, it has been difficult to place the observations gathered in 1998 and 1999 into a thorough perspective. However, when coupled with the limited observations from 1993-1997, we have been able to reach a number of conclusions relating to the state of the biotic environment in 1998 and 1999:

1. Chlorophyll levels in the spring and summer of 1998 appear to be below average while deep nutrient concentrations appeared to increase throughout the year until they leveled off in late summer when they ended being above the 1993-1997 average.
2. In 1999, chlorophyll concentrations on the Northeast Newfoundland shelf were low during the spring and summer relative to the average from previous years whereas summer conditions on the Grand Banks appear to have been above average.

3. There appears to have been substantial depletion of nitrate in deep waters during the spring which may explain the relatively low concentrations in deep waters observed in the fall of 1999 on the Grand Banks and on the Northeast Newfoundland shelf.
4. In November of 1999, phytoplankton concentrations inf the Grand Banks were high(1.5-3 mg m^{-3}), giving an indication of a fall bloom in the area. There was a substantial increase in the abundance of diatoms at that time.
5. The abundance of copepodites in 1998 was higher than in previous years in many areas of the Newfoundland. The high abundance was due in large part to increases in the abundance of small species, dominated by *Oithona similis* and *Centropages hamatus*, which are generally more abundant on the Grand Banks than in areas further north. Overall zooplankton species diversity was lowest in 1998 relative to the 1993-1999 period.
6. There was a slight decrease in the total abundance of copepodites in 1999 relative to the previous year but the species composition also shifted to larger species, with *Calanus finmarchicus* becoming more dominant.

The monitoring activities have also permitted us to make a number of general observations concerning the chemical and biological conditions in the Newfoundland region. As previous workers have suggested, there is a south-to-north progression in the onset of the spring bloom. The concentration of all nutrients at depths of 100m or more tends to show an increase during the summer and into the fall period, preceding the fall increase in the surface layer that is associated with the breakdown of stratification. Phosphate and silicate concentrations in the surface layer show a seasonal cycle similar to that of nitrate but the former rarely appear to reach depleted levels (near zero concentrations), with the exception of silicate concentrations on the Grand Banks. Finally, the inshore and offshore arms of the Labrador current are generally marked with shallow nutricline and relatively high concentrations of chlorophyll relative to other areas of the shelf, suggesting that variations in current speed and shear may influence the flux of nutrients into surface layers during the summer months.

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Table 1. Listing of surveys, dates and transects included in the analysis. (The transects are: Southern Grand Banks [SEGB]; Flemish Cap [FC]; Bonavista Bay [BB]; Seal Island [SI]; and White Bay [WB] (See Figure 1)).

Year	Day	Transects	Comment
1998	114-122 (spring)	SEGB – FC – BB	
	203-215 (summer)	FC – BB – SI	WB transect also sampled.
1999	133-135 (spring)	BB	Piggy-back on capelin hydro acoustic survey.
	197-213 (summer)	FC – BB – SI	Other transects also sampled (WB, Nain).
	321-331 (fall)	SEGB – FC – BB	Sampling along FC line restricted because of mechanical problems.

Table 2. Cluster mean relative abundance of zooplankton as determined from a canonical discriminant analysis of the transect data from 1993-1999.

Taxon	Dominant Cluster	Cluster 1 (Offshore)	Cluster 2 (N. Shelf)	Cluster 3 (GB)	Cluster 4 (Coastal)
Pseudocalanus sp.	Coastal	0.022	0.092	0.11	0.34
Acartia sp.	Coastal	0.0005	0.0003	0.0014	0.0023
Balanus sp.	Coastal	0.0008	0.0005	0.0010	0.0034
Calanus finmarchicus	N. Shelf	0.099	0.40	0.075	0.15
other *Calanus* species	N. Shelf	0.0013	0.10	0.019	0.10
Oithona similis	Grand Bk.	0.16	0.13	0.62	0.22
Centropages hamatus	Grand Bk.	0.007	0.0004	0.02	0.0016
Temora longicornis	Grand Bk.	0.0033	0.0003	0.012	0.0016
Aglantha digitale	Grand Bk.	0.0005	0.0001	0.0019	0.0006
Paracalanus sp.	Grand Bk.	0.0001	0.0002	0.0047	0.0001
Euphausiids	Offshore	0.02	0.01	0.002	0.002
Metridia sp.	Offshore	0.02	0.017	0.0042	0.0059
Sagitta sp.	Offshore	0.0084	0.0049	0.0021	0.0007
Oikopleura sp.	–	0.031	0.018	0.023	0.033

Figure 1. Map of transects sampled as part of Zonal Monitoring activities in the Newfoundland region. All stations were sampled for temperature, conductivity and fluorescence but only a limited subset were used in the sampling of biological and chemical oceanographic variables.

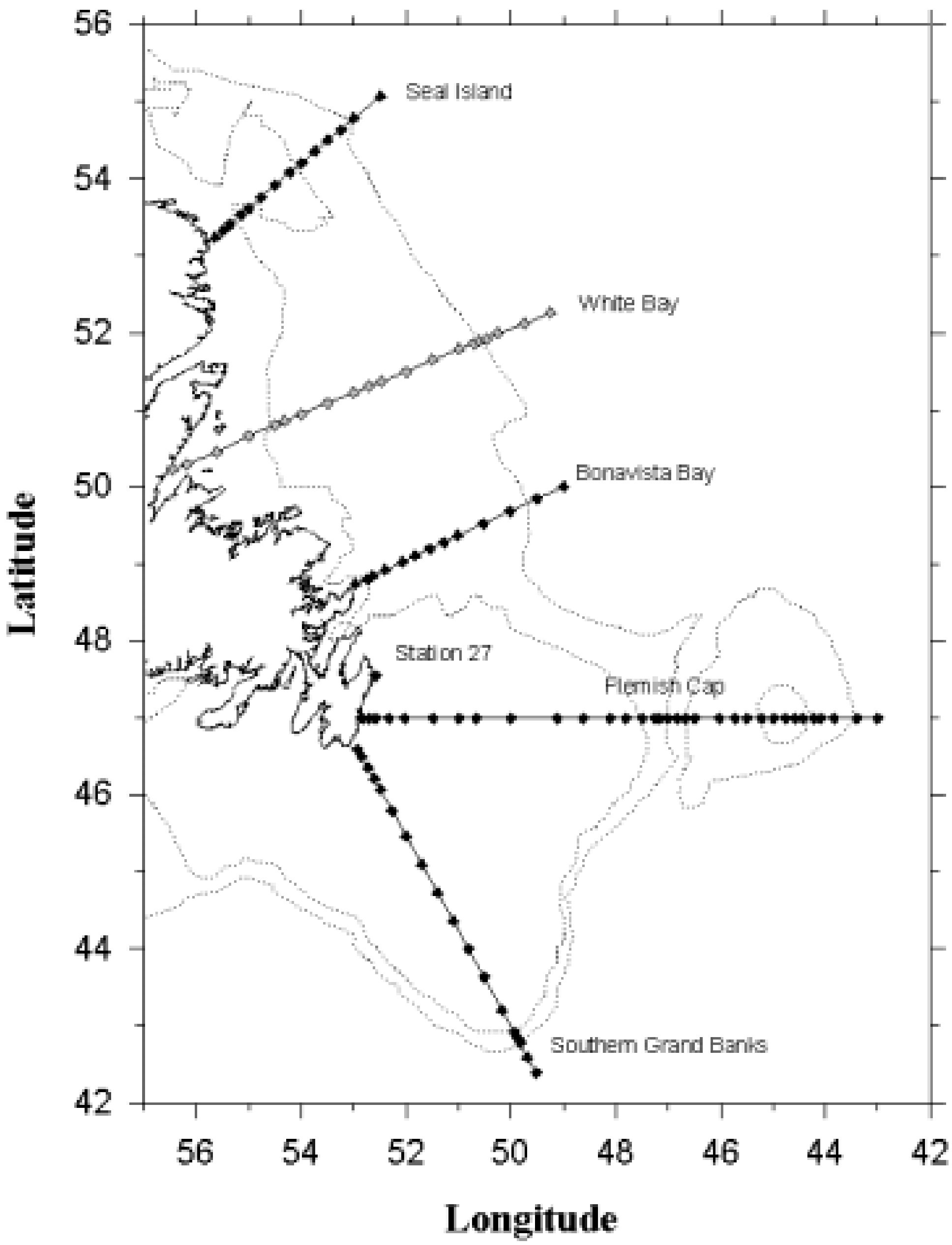

Figure 2. Depth profiles of Chlorophyll and nitrate concentrations for 1998-1999 Station 27. Note the detailed sampling of the site during May of 1999.

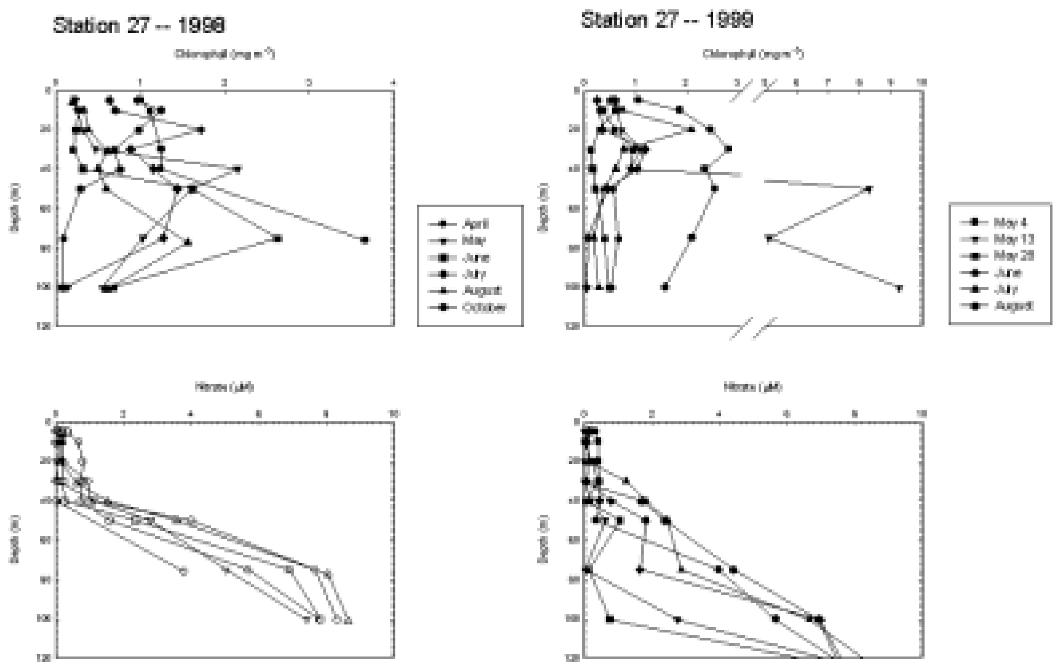

Figure 3. The 1998 monthly anomaly profiles of chl a, nitrate (plus nitrite), phosphate, and silicate concentrations from near-surface to bottom relative to the monthly means for 1993-97 for station 27.

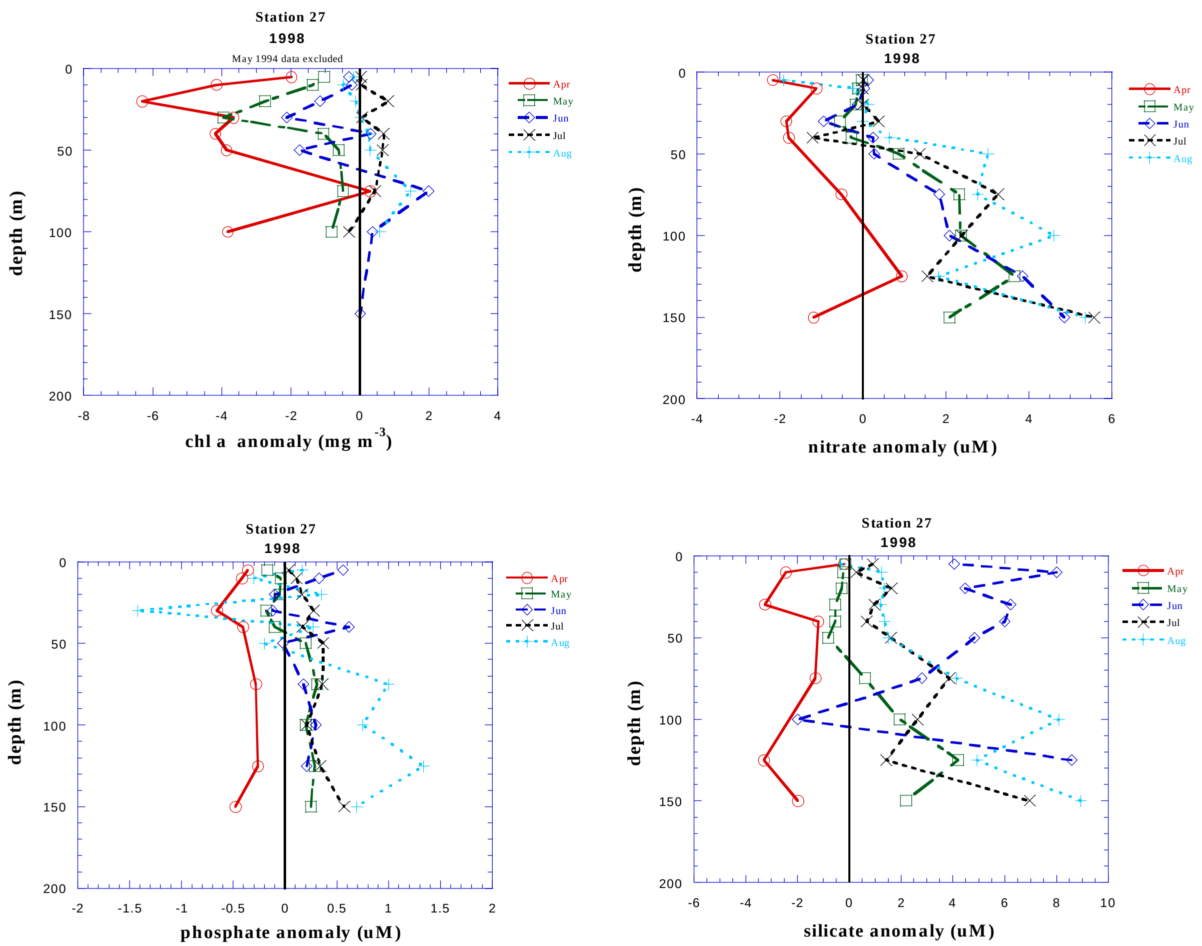

Figure 4. The 1999 monthly anomaly profiles of chl a, nitrate (plus nitrite), phosphate, and silicate concentrations from near-surface to bottom relative to the monthly means for 1993-98 for station 27.

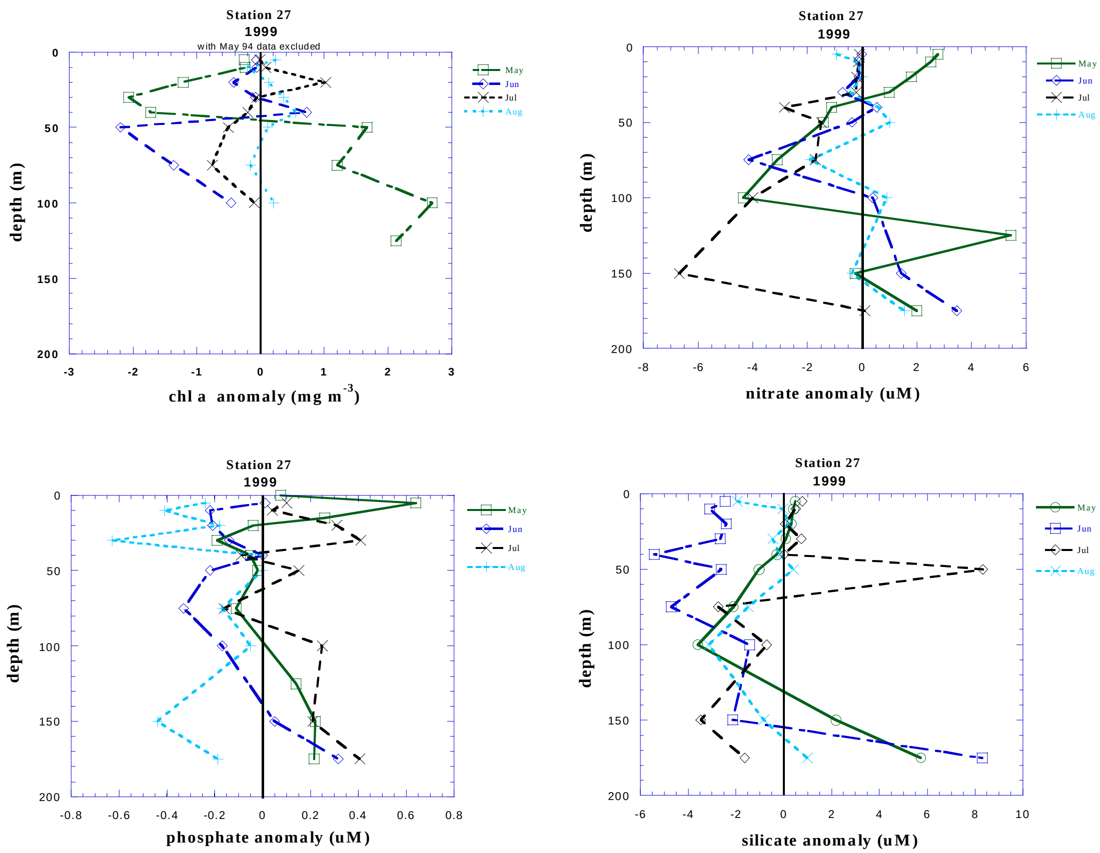

Figure 5. Monthly depth-integrated (0-100m) chl a concentrations for station 27 from April through August during 1993-99.

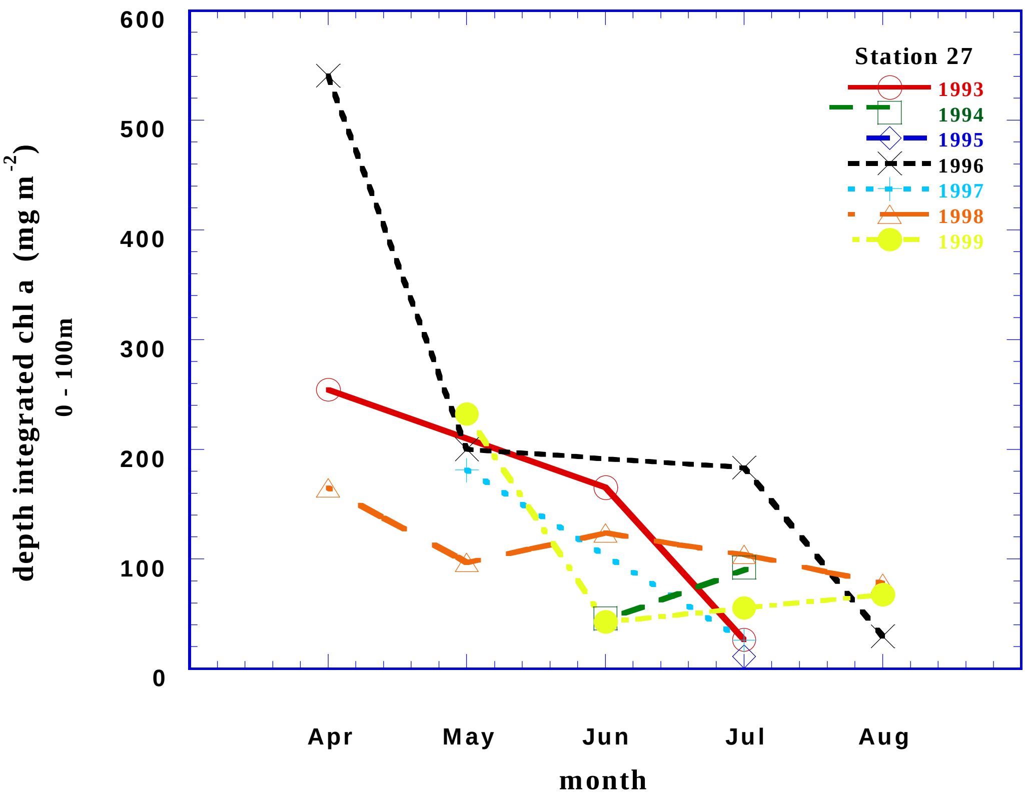

Figure 6. The 1998 concentrations of chlorophyll a overlaid on contours of nitrate+nitrite (colour scale; left column, arrows indicate station locations), phosphate (middle column), and silicate (right column) versus depth along transects across Bonavista Bay (BB; top row), Flemish Cap (FC; middle row), and southeast Grand Banks (SEGB; bottom row) during April and May. Bottom bathymetry shown in black.

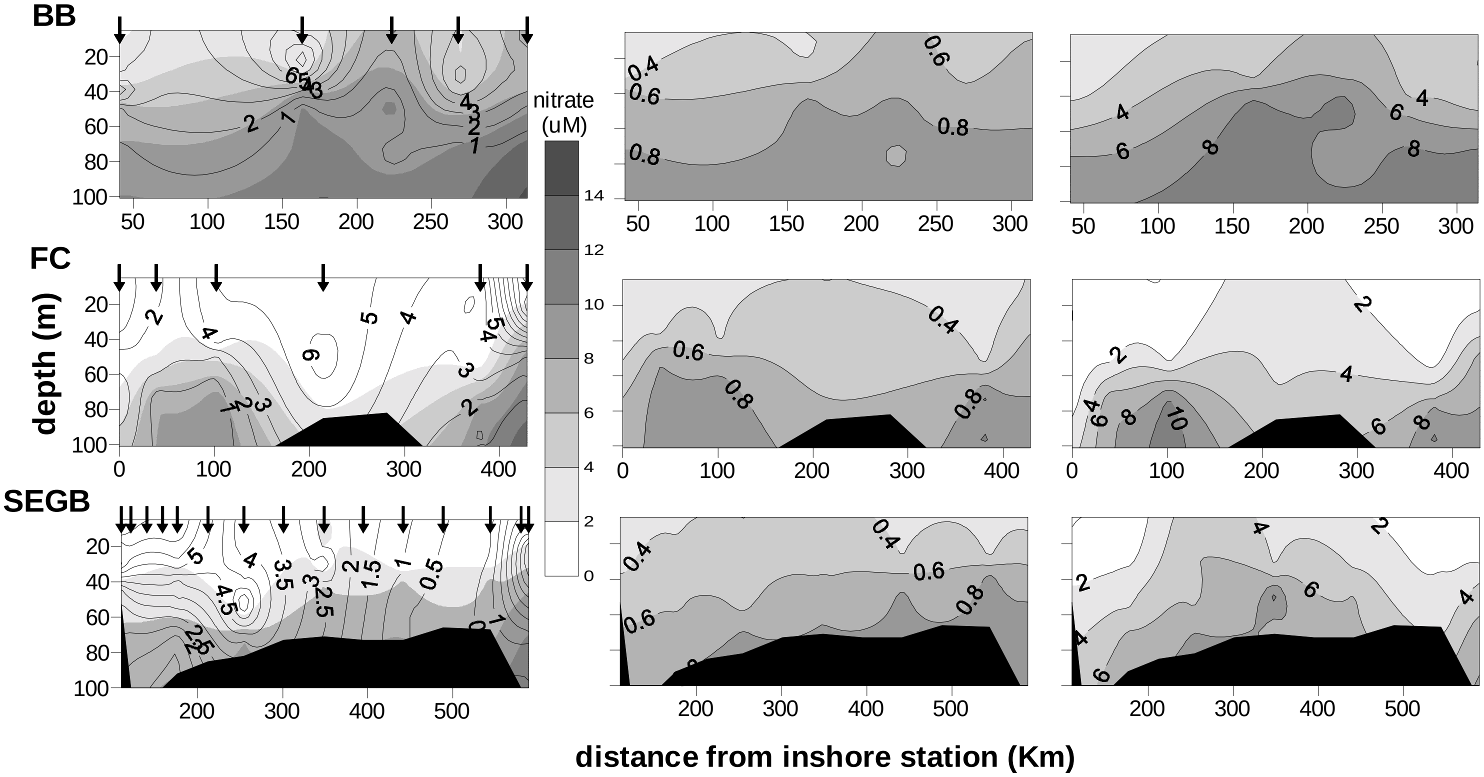

Figure 7. The 1998 anomalies of chlorophyll a (left column) and nitrate+nitrite (right column) concentrations versus depth relative to the means for 1993-97 along transects across Bonavista Bay (BB; top row), Flemish Cap (FC; middle row), and southeast Grand Banks (SEGB; bottom row) during April and May. Bottom bathymetry shown in black.

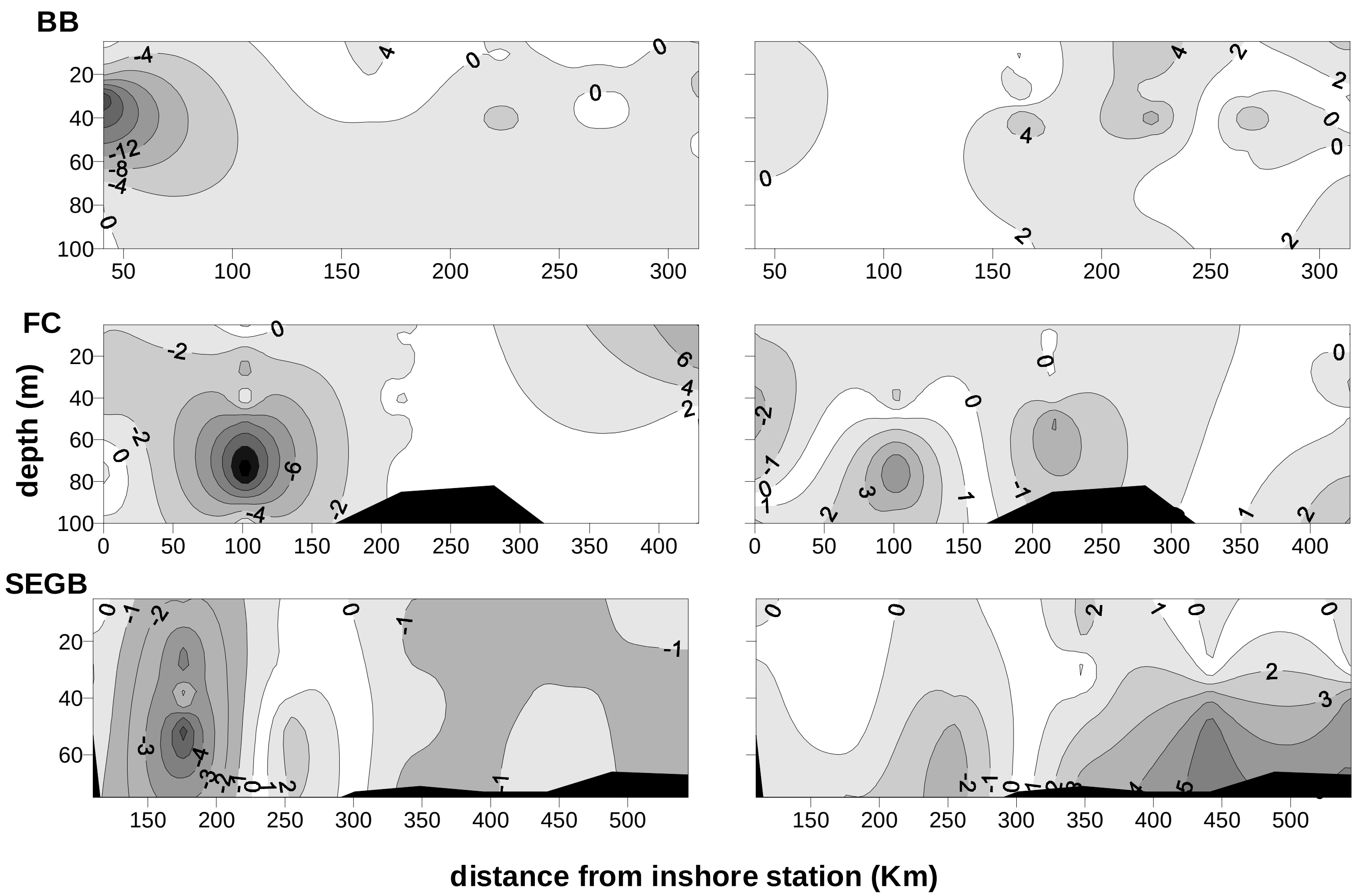

Figure 8. The 1998 concentrations of chlorophyll a overlaid on nitrate+nitrite (colour scale; left column, arrows indicate station locations), phosphate (middle column), and silicate (right column) versus depth along transects across Seal Island (SI; top row), Bonavista Bay (BB; middle row), and Flemish Cap (FC; bottom row) during July and August. Bottom bathymetry shown in black.

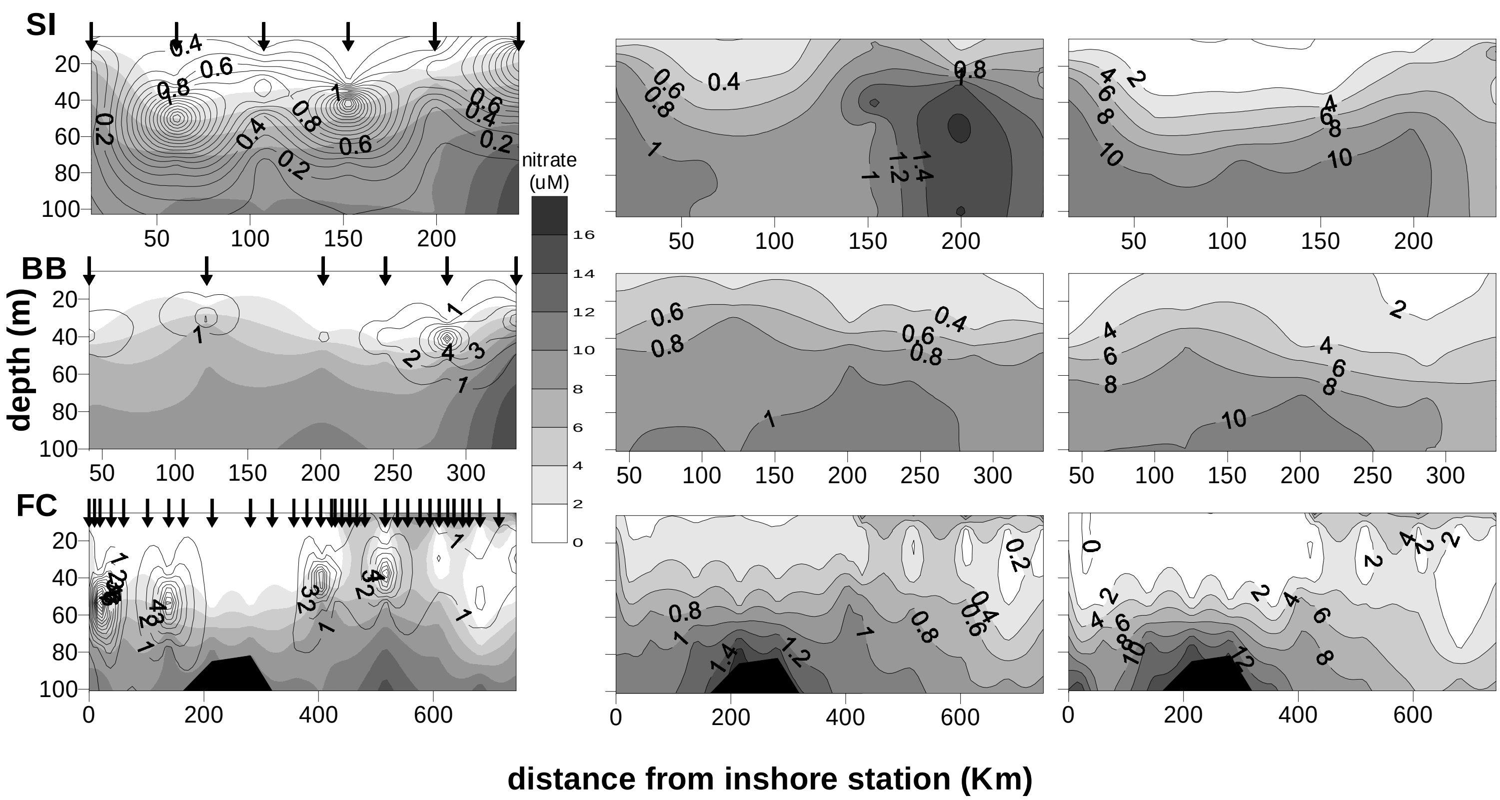

Figure 9. The 1998 anomalies of chlorophyll a (left column) and nitrate+nitrite (right column) concentrations versus depth relative to the means for 1993-97 along transects across Seal Island (SI; top row), Bonavista Bay (BB; middle row), and Flemish Cap (FC; middle row) during July and August. Bottom bathymetry shown in black.

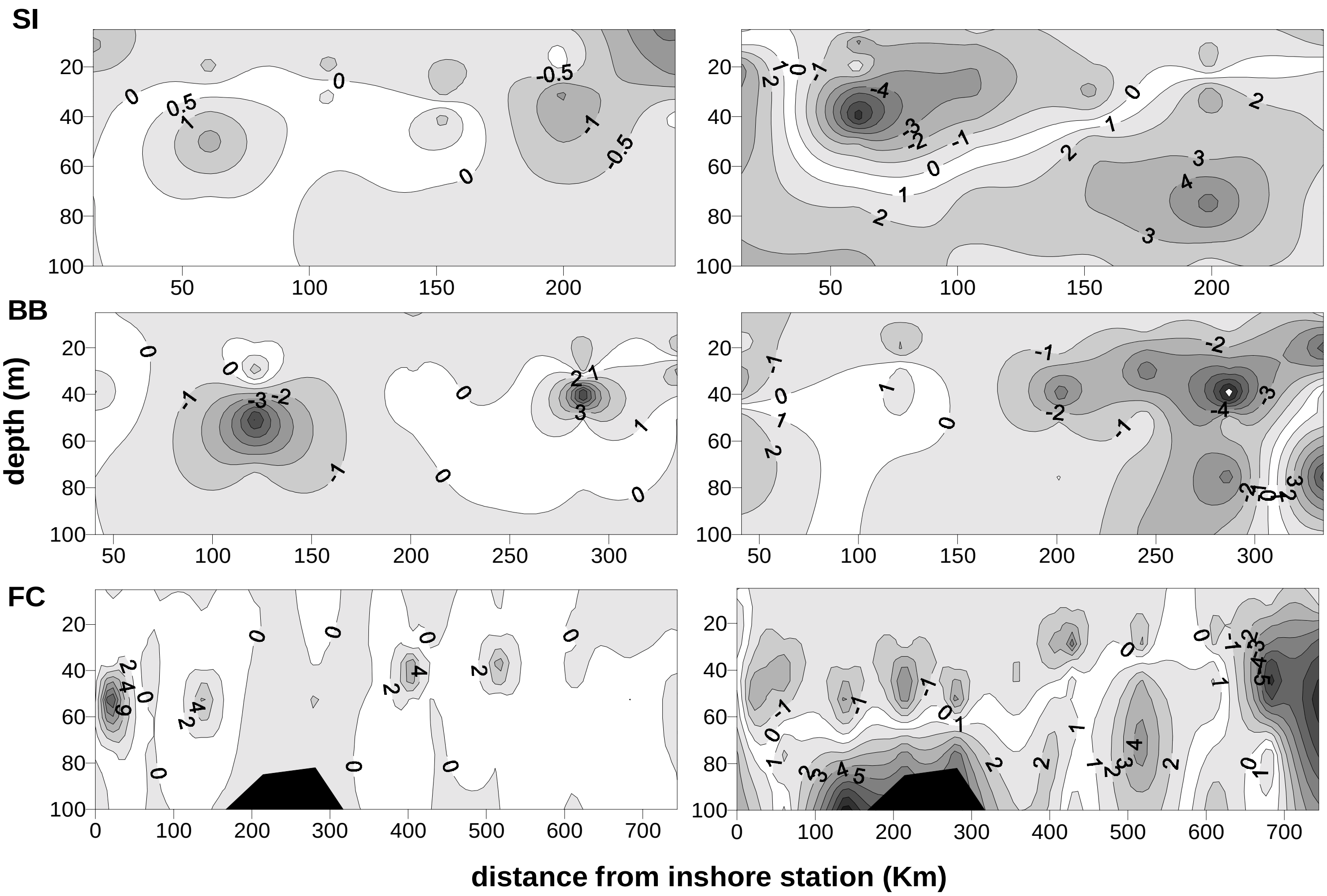

Figure 10. The 1999 concentrations of chlorophyll a overlaid on nitrate+nitrite (colour scale; left column, arrows indicate station locations), phosphate (centre column), and silicate (right column) versus depth along transects across Bonavista Bay during April-May (BB; top row), July-August (centre row), and November (bottom row).

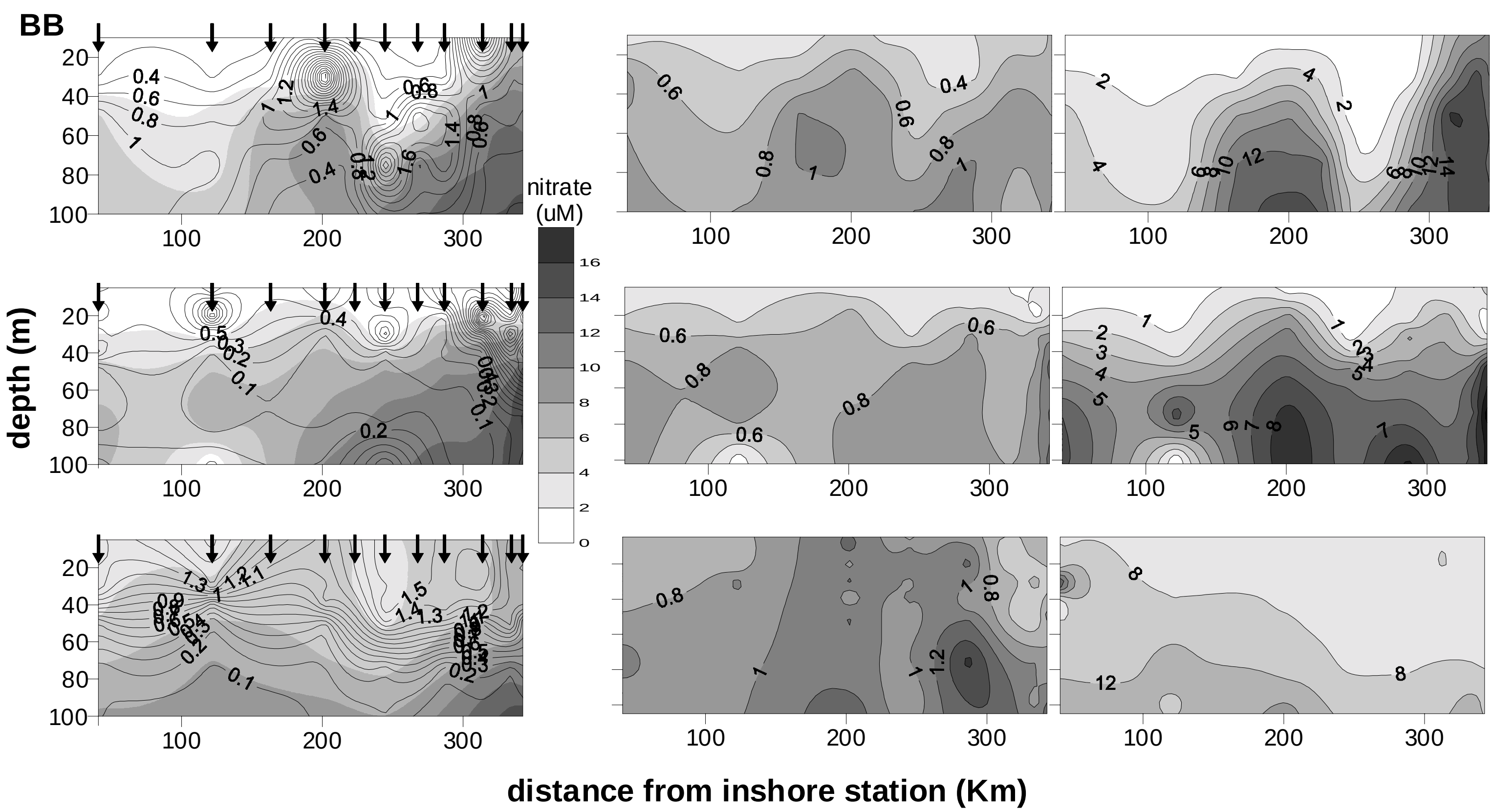

Figure 11. The 1999 anomalies of chlorophyll a (left column) and nitrate+nitrite (right column) concentrations versus depth relative to the means for 1993-98 along transects across Bonavista Bay during April-May (BB; top row), July-August (middle row), and November (bottom row).

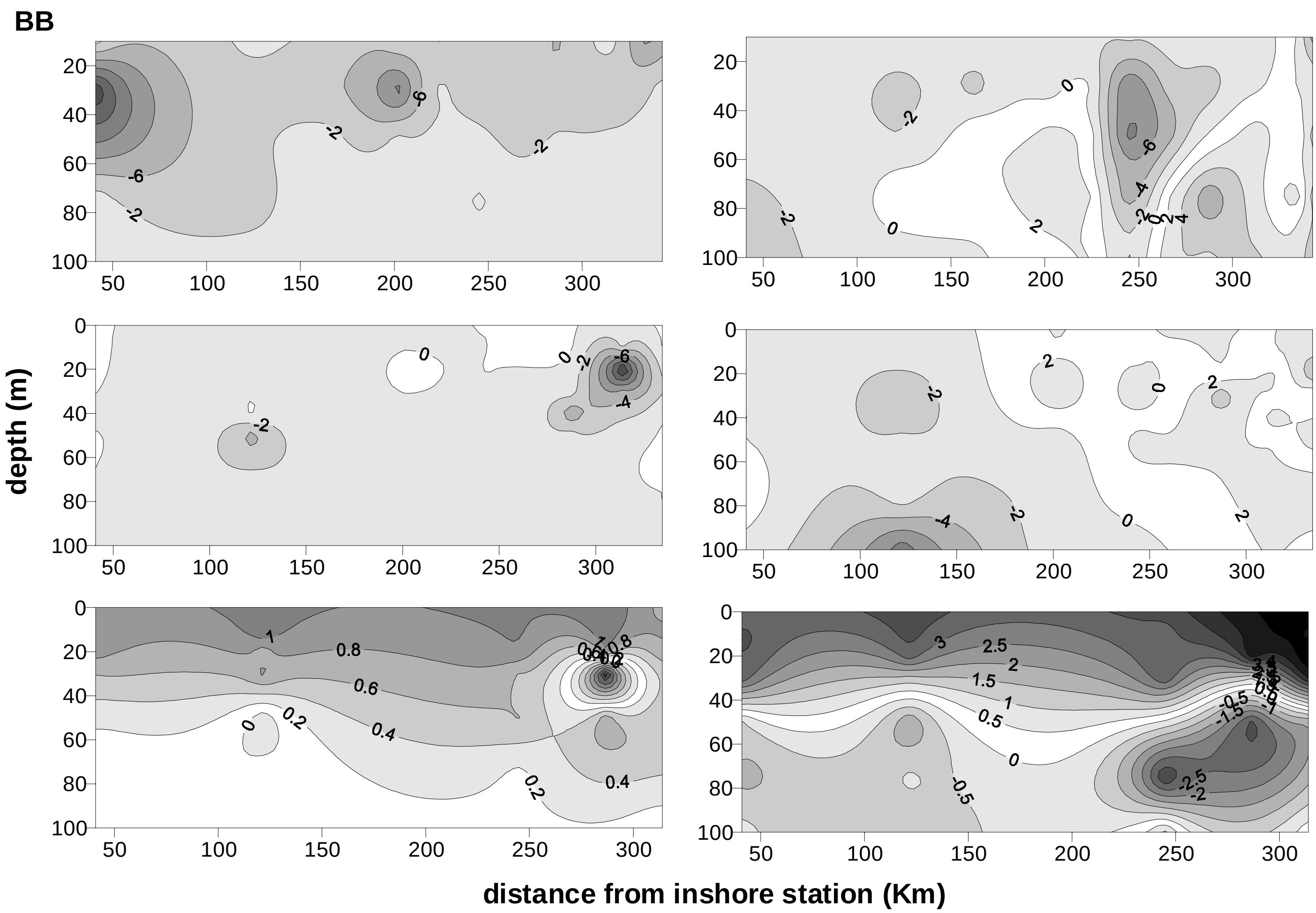

Figure 12. The 1999 concentrations of chlorophyll a overlaid on nitrate+nitrite (colour scale; left column, arrows indicate station locations), phosphate (centre column), and silicate (right column) versus depth along transects across Seal Island (SI; top row), White Bay (WB; middle row), and Flemish Cap (FC; bottom row) during July and August. Bottom bathymetry shown in black.

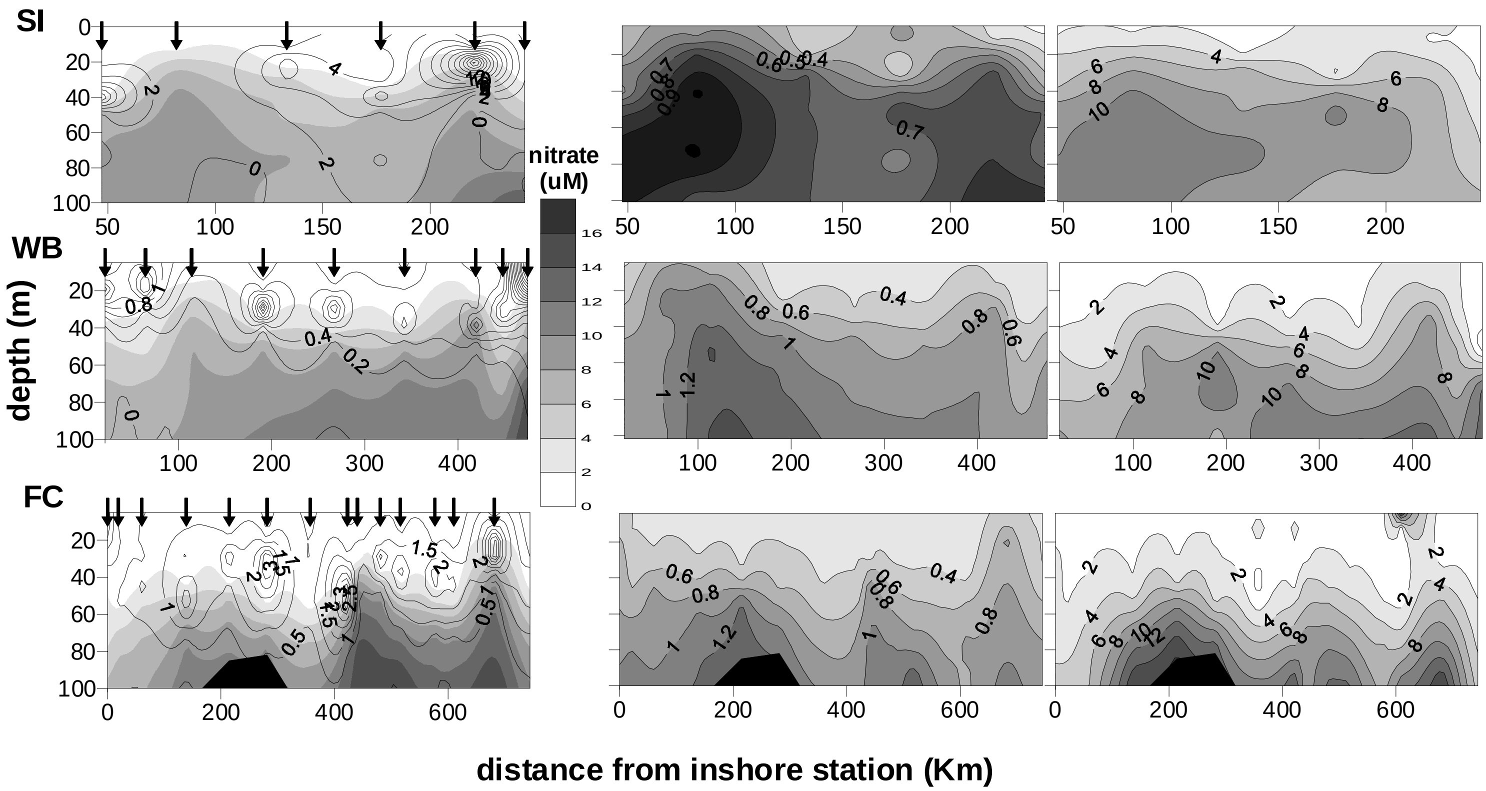

Figure 13. The 1999 anomalies of chlorophyll a (left column) and nitrate+nitrite (right column) concentrations versus depth relative to the means for 1993-98 along transects across White Bay (WB; top row), and Flemish Cap (FC; bottom row) during July and August. The anomalies for Seal Island transect were not available due to few overlapping stations. Bottom bathymetry shown in black.

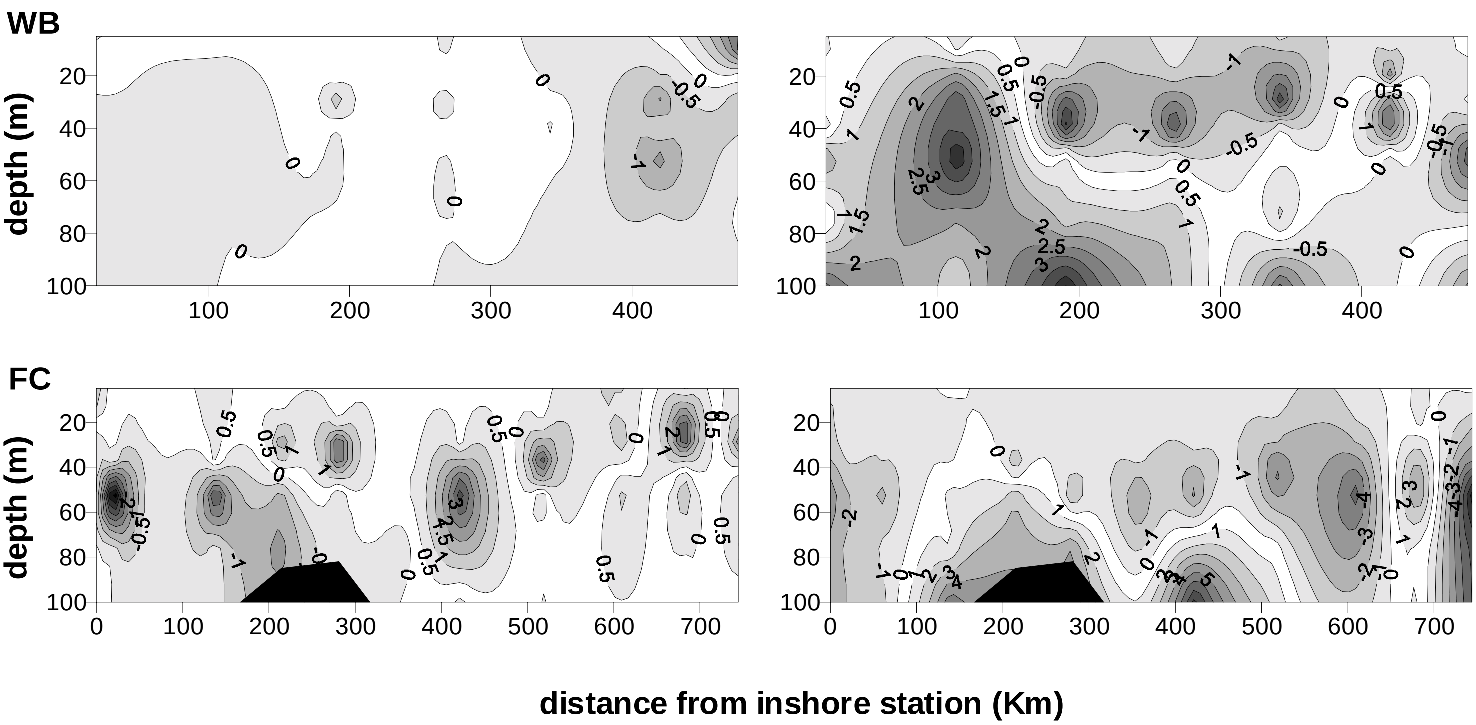

Figure 14. The 1999 concentrations of chlorophyll a overlaid on nitrate+nitrite (colour scale; left column, arrows indicate station locations), phosphate (middle column), and silicate (right column) versus depth along transects across Bonavista Bay (BB; top row), Flemish Cap (FC; middle row), and southeast Grand Banks (SEGB, bottom row) during November. Bottom bathymetry shown in black.

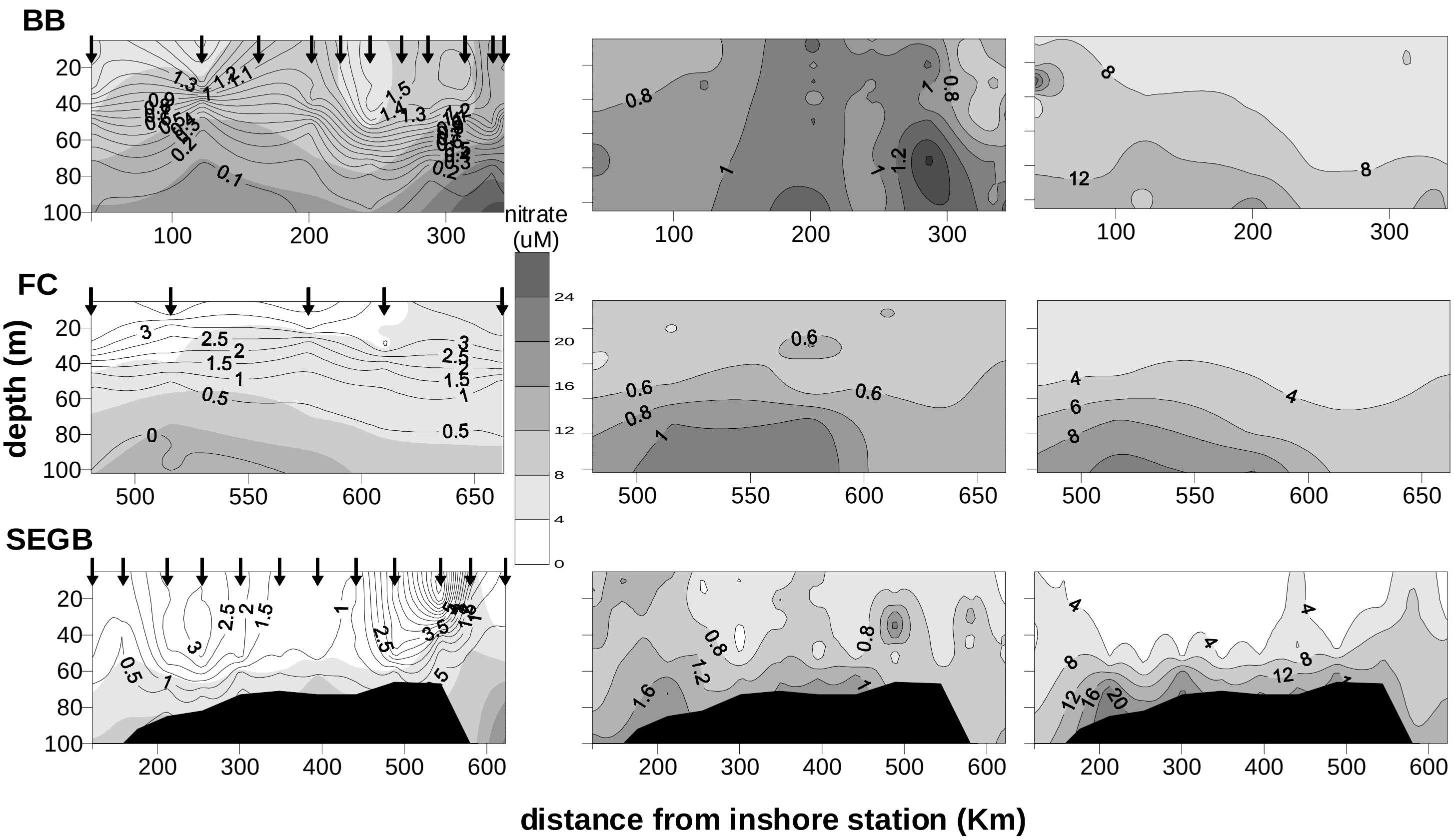

Figure 15. The 1999 anomalies of chlorophyll a (top panel) and nitrate+nitrite (bottom panel) concentrations versus depth relative to the means for 1993-98 along a transect across Bonavista Bay (BB) during November. The anomalies for the Flemish Cap and southeast Grand Banks were not available due to few overlapping stations.

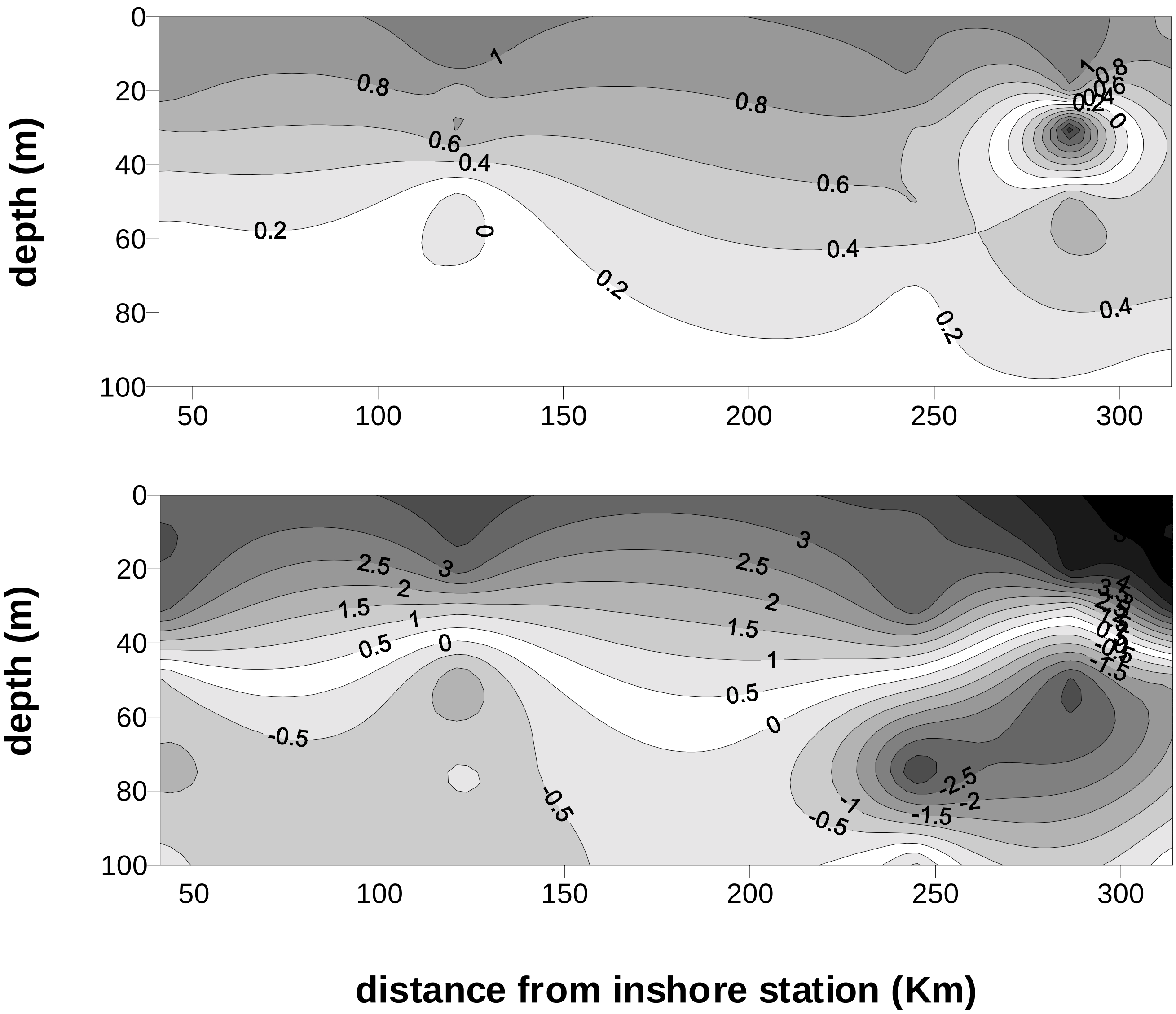

Figure 16. Seasonal cycle of total copepod abundance from all monitoring stations sampled on the Newfoundland shelf since 1993.

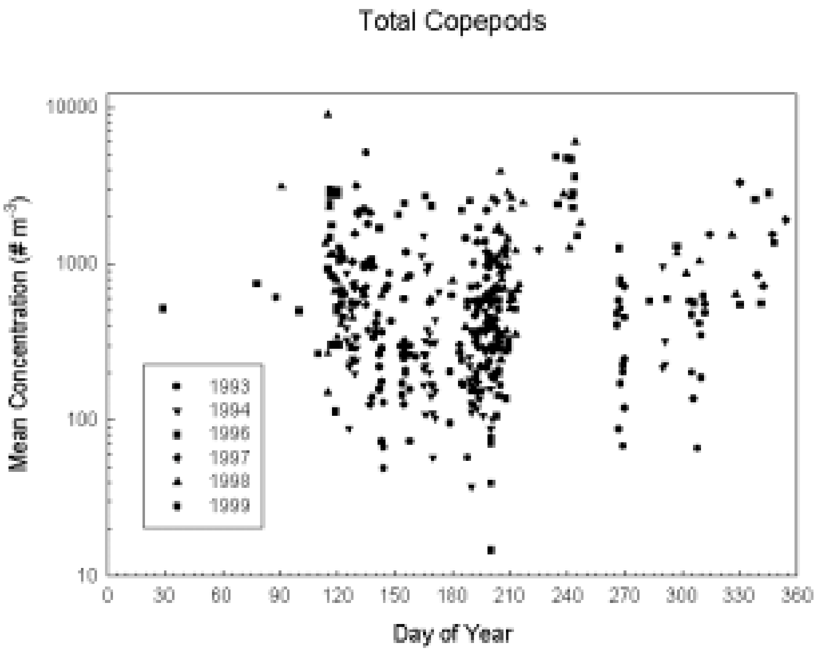

Figure 17. Seasonal cycle in the ration of large-to-small copepods from all monitoring stations sampled on the Newfoundland shelf since 1993.

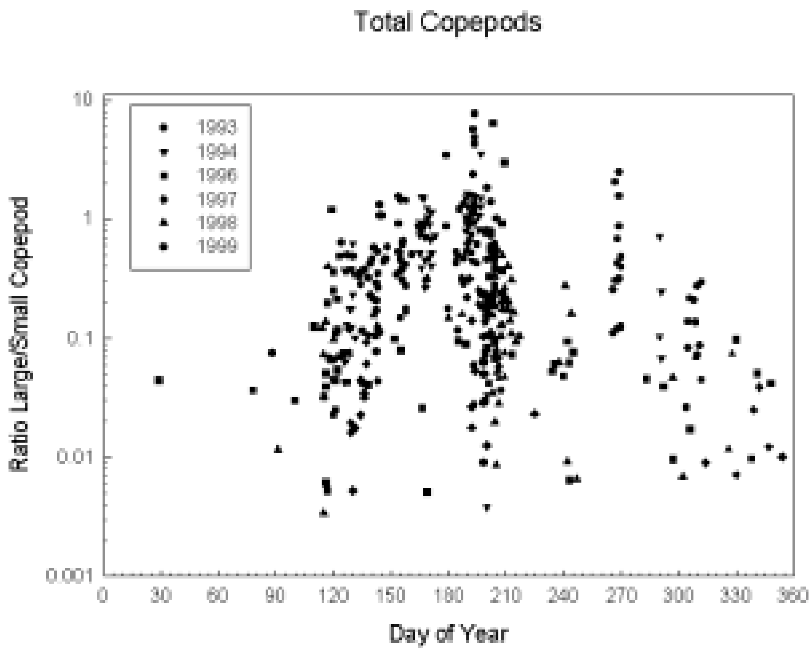

Figure 18. Estimates of the Shanon-Weiner Diversity index (H = -Γ p_i ln p_i) for all zooplankton sampled at monitoring sites along the Flemish Cap, Bonavista Bay and Seal Island Lines since 1993. Error bars represent the standard deviation of the data.

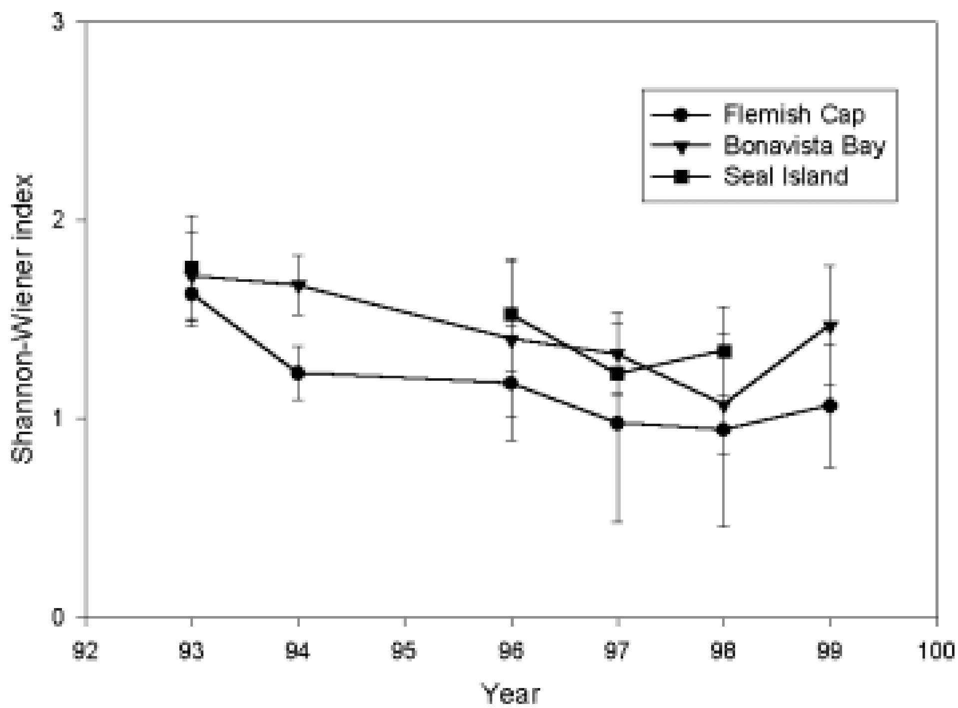

Figure 19. Seasonal cycle of the ten dominant species of zooplankton from monitoring samples along the Southastern Grand banks, Flemish Cap, Bonavista Bay and Seal Island Lines.

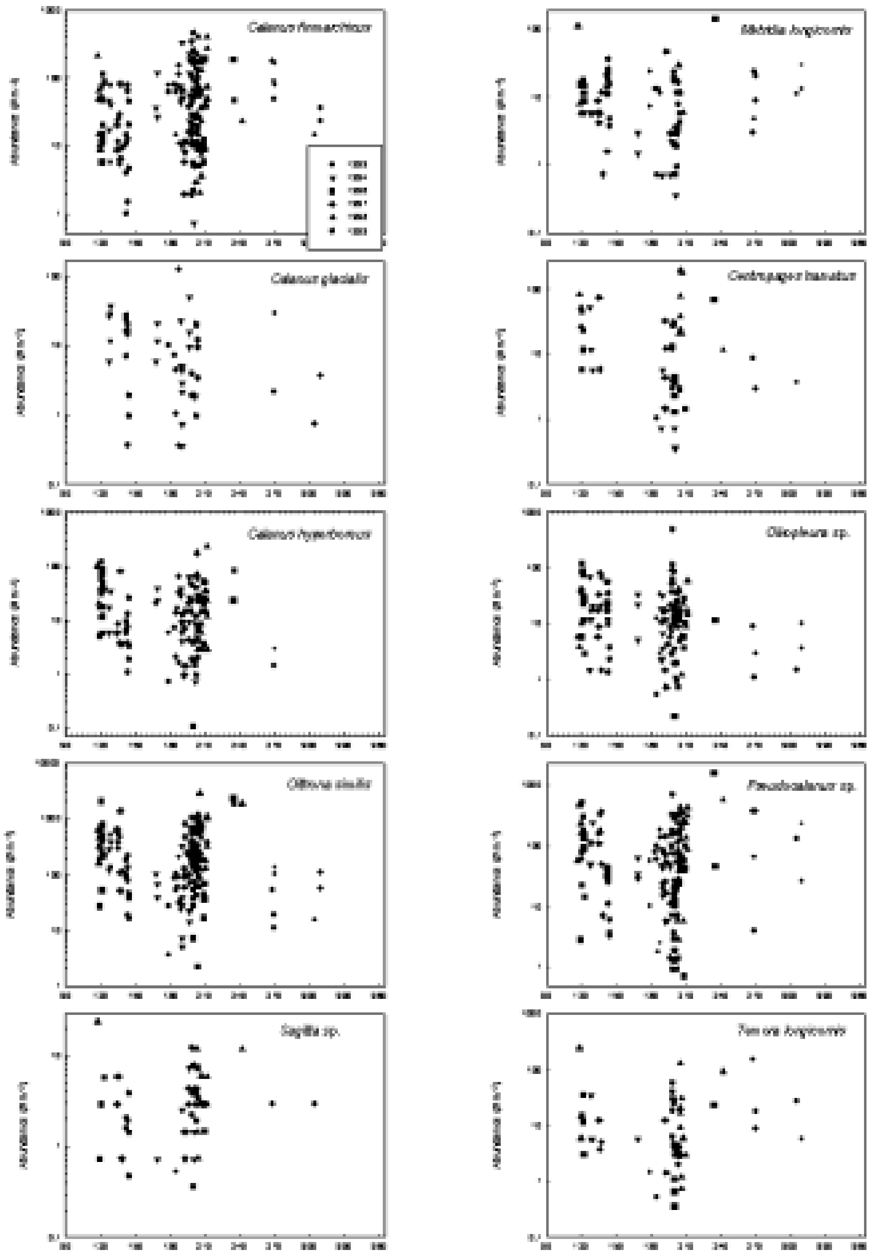

Figure 20. Inter-annual variation in along transect abundance of *Calanus finmarchicus*.

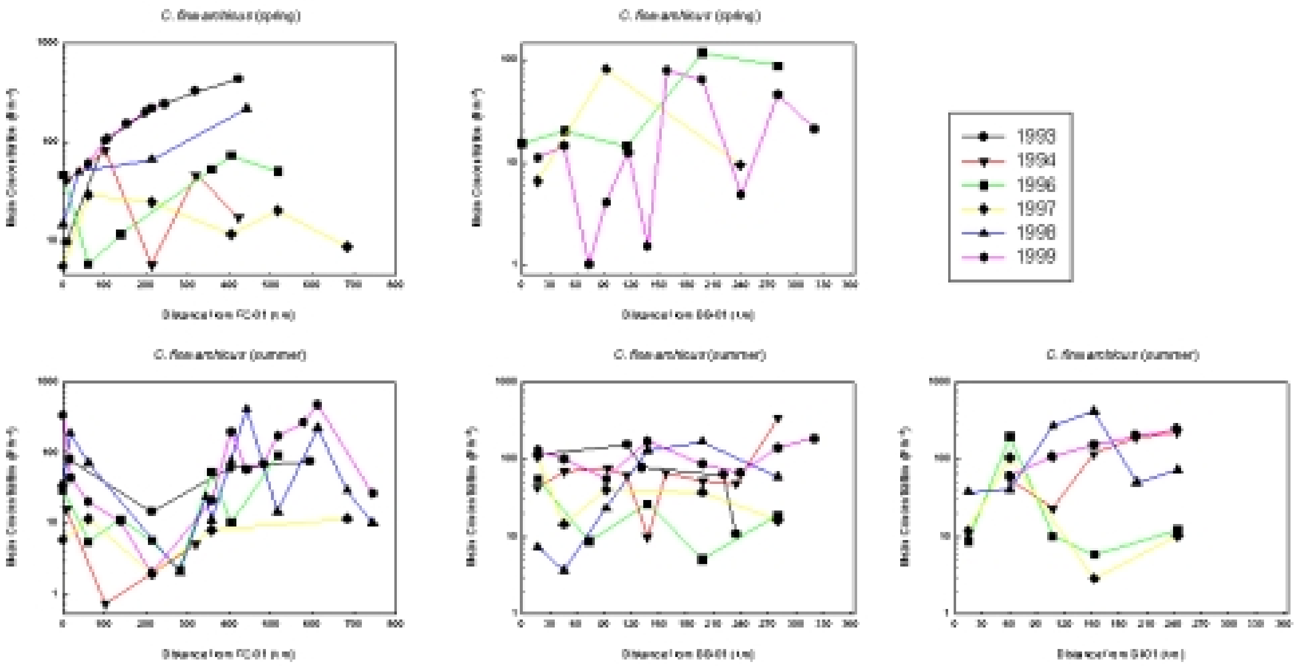

Figure 21. Inter-annual variations in the seasonal development of *Calanus finmarchicus* from monitoring transects.

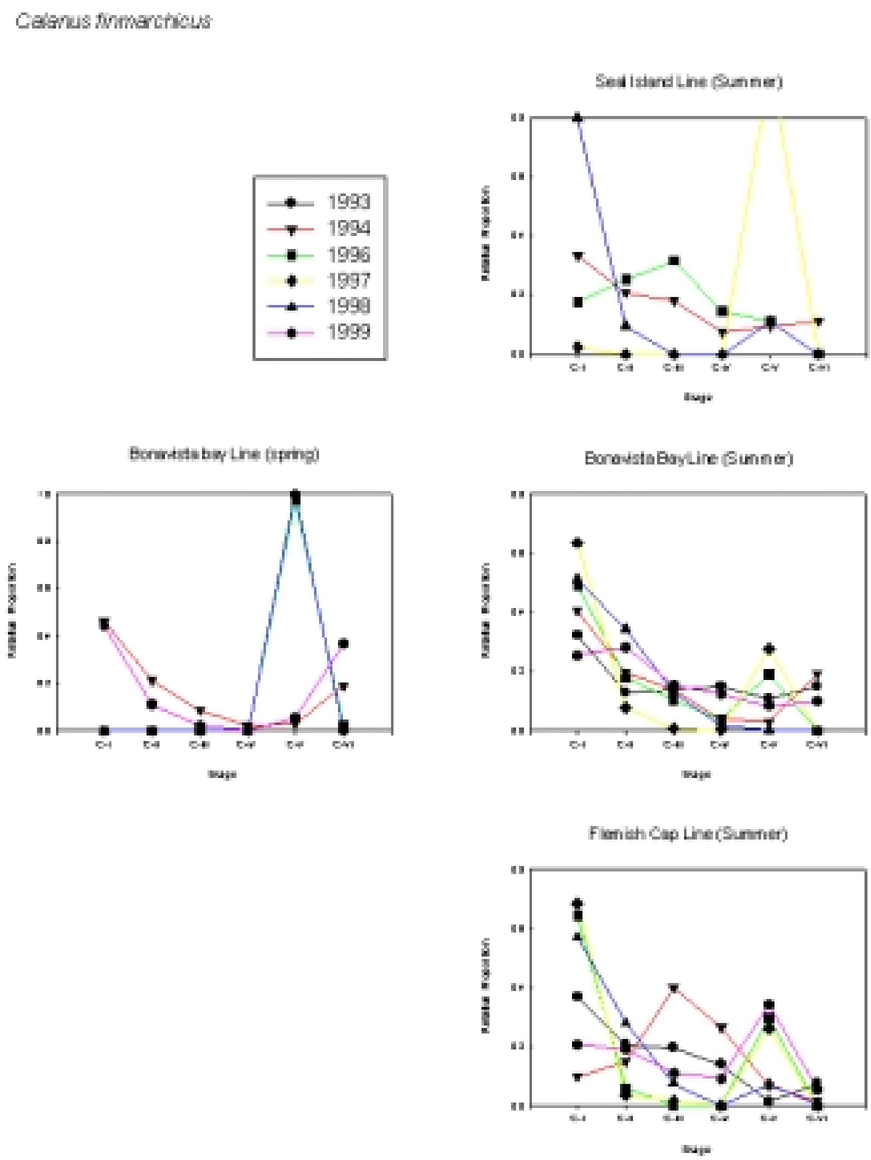

Figure 22. Inter-annual variation in along transect abundance of *Oithona similis*.

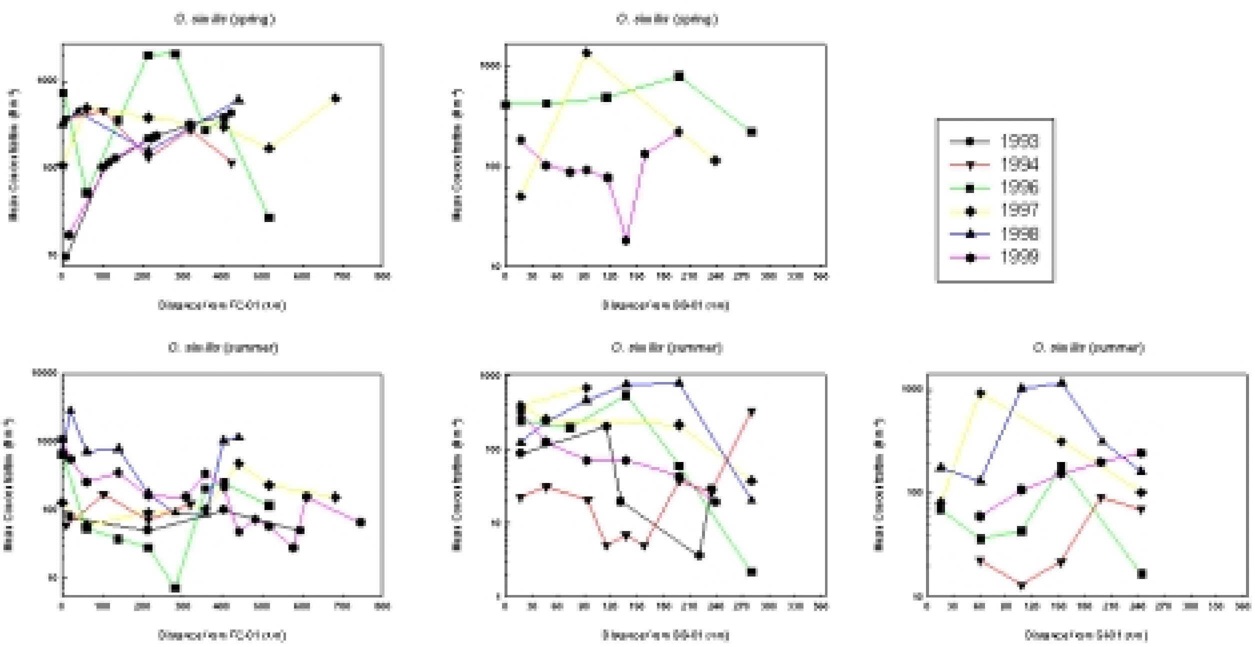

Figure 23. Inter-annual variation in along transect abundance of *Pseudocalanus* sp.

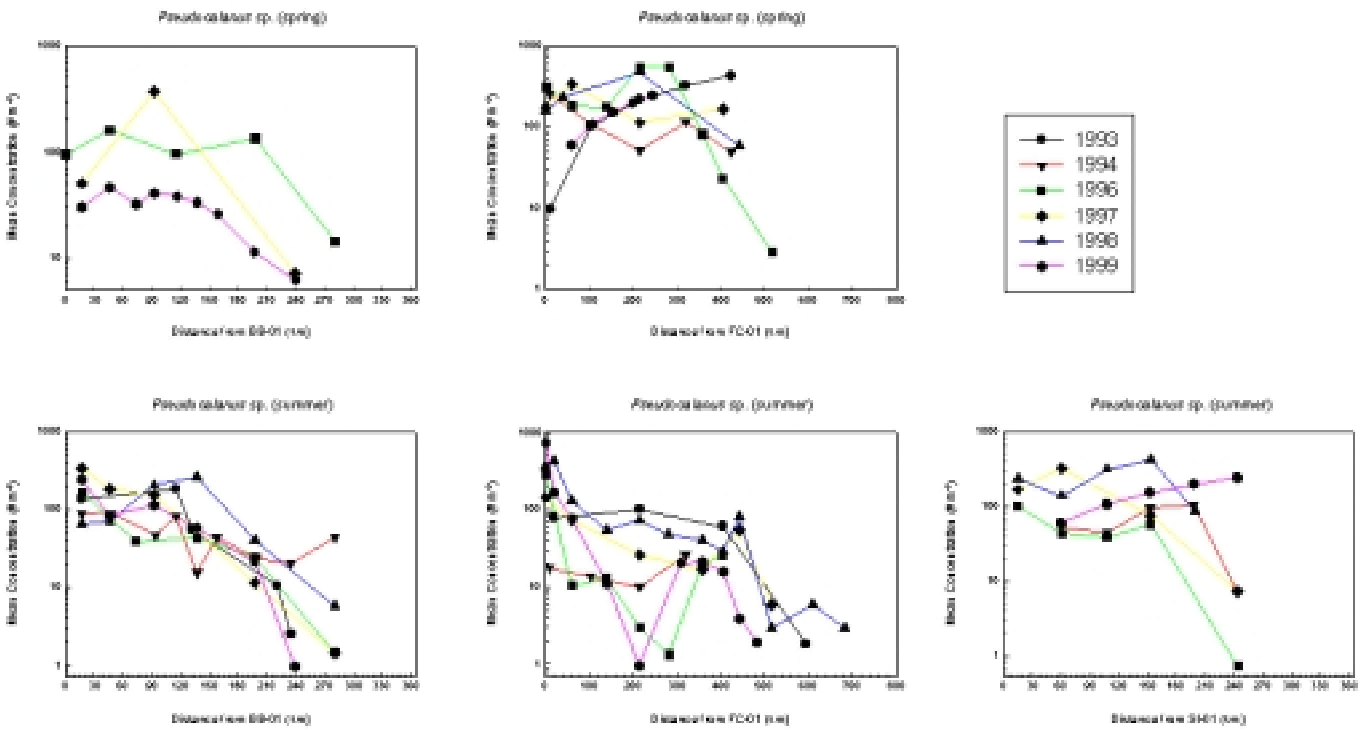

Figure 24. Inter-annual variations in the development of *Pseudocalanus* sp. from summer collections along the monitoring transects.

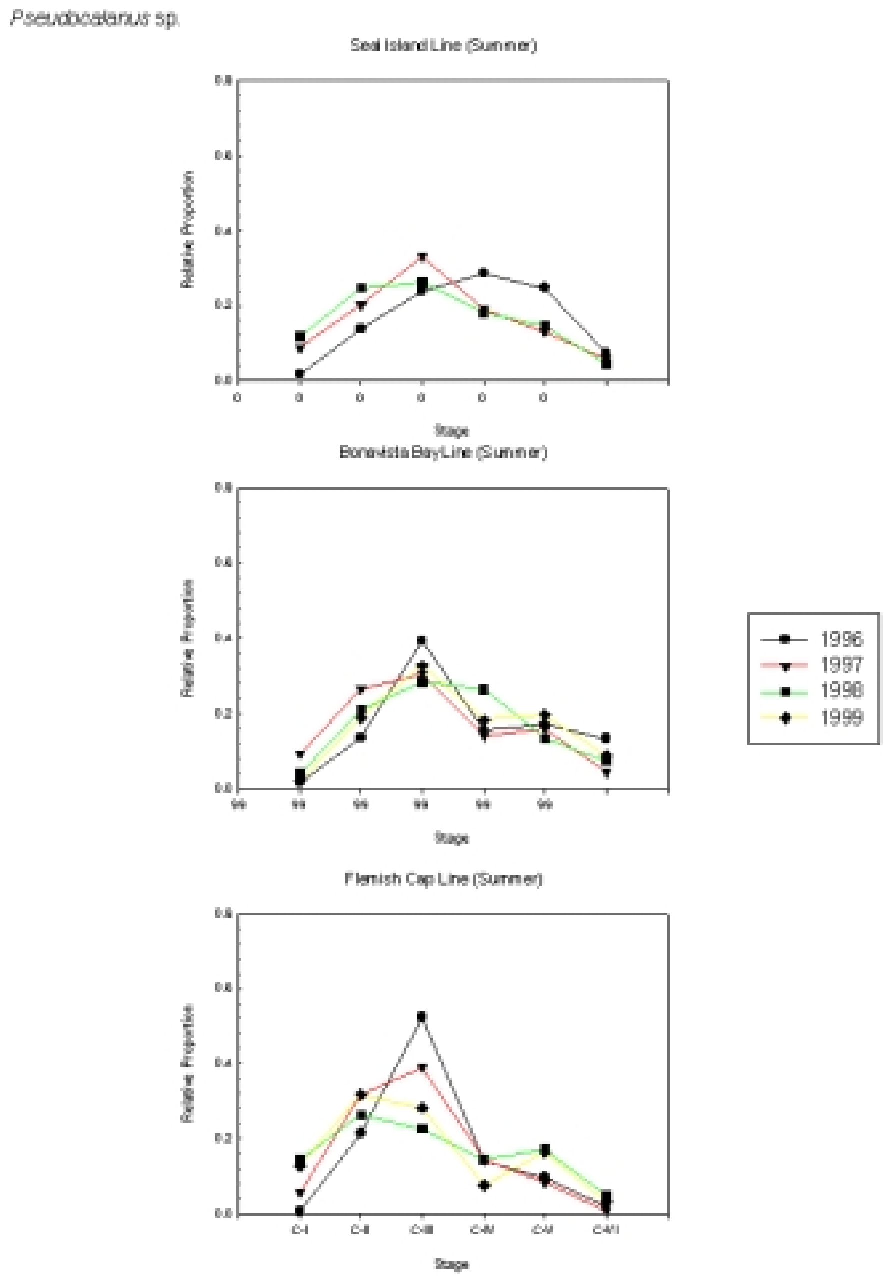

Figure 25. Cluster distribution and separation along the first two canonical variables from a discriminant analysis. The legend indentifies the communities based on their general locations on the Newfoundland Shelf.

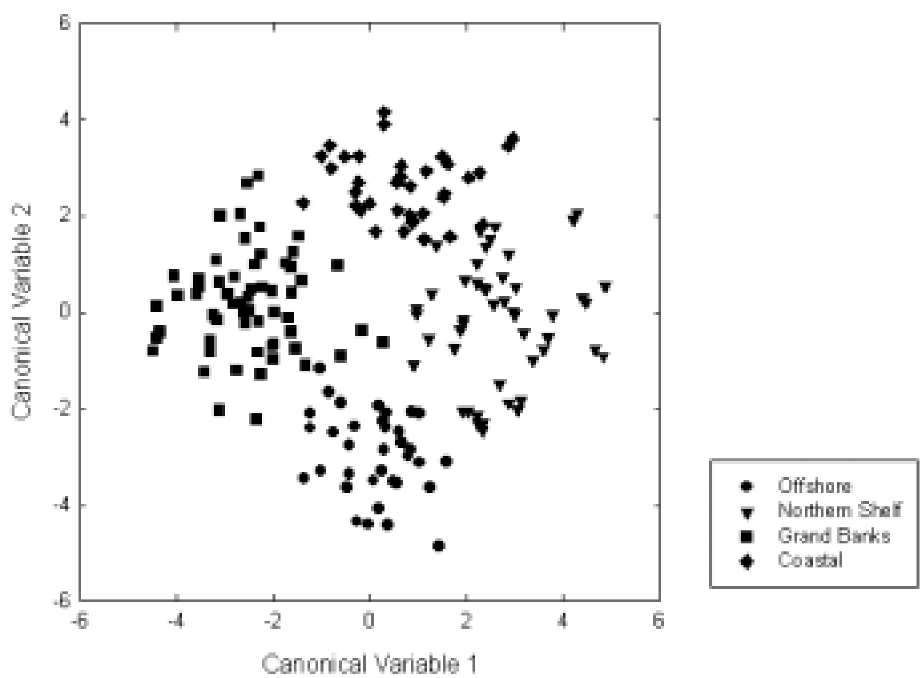

Figure 26. Inter-annual variations in the summer (late July-early August) distribution of the 4 dominant zooplankton communities determined from a canonical discriminant analysis.

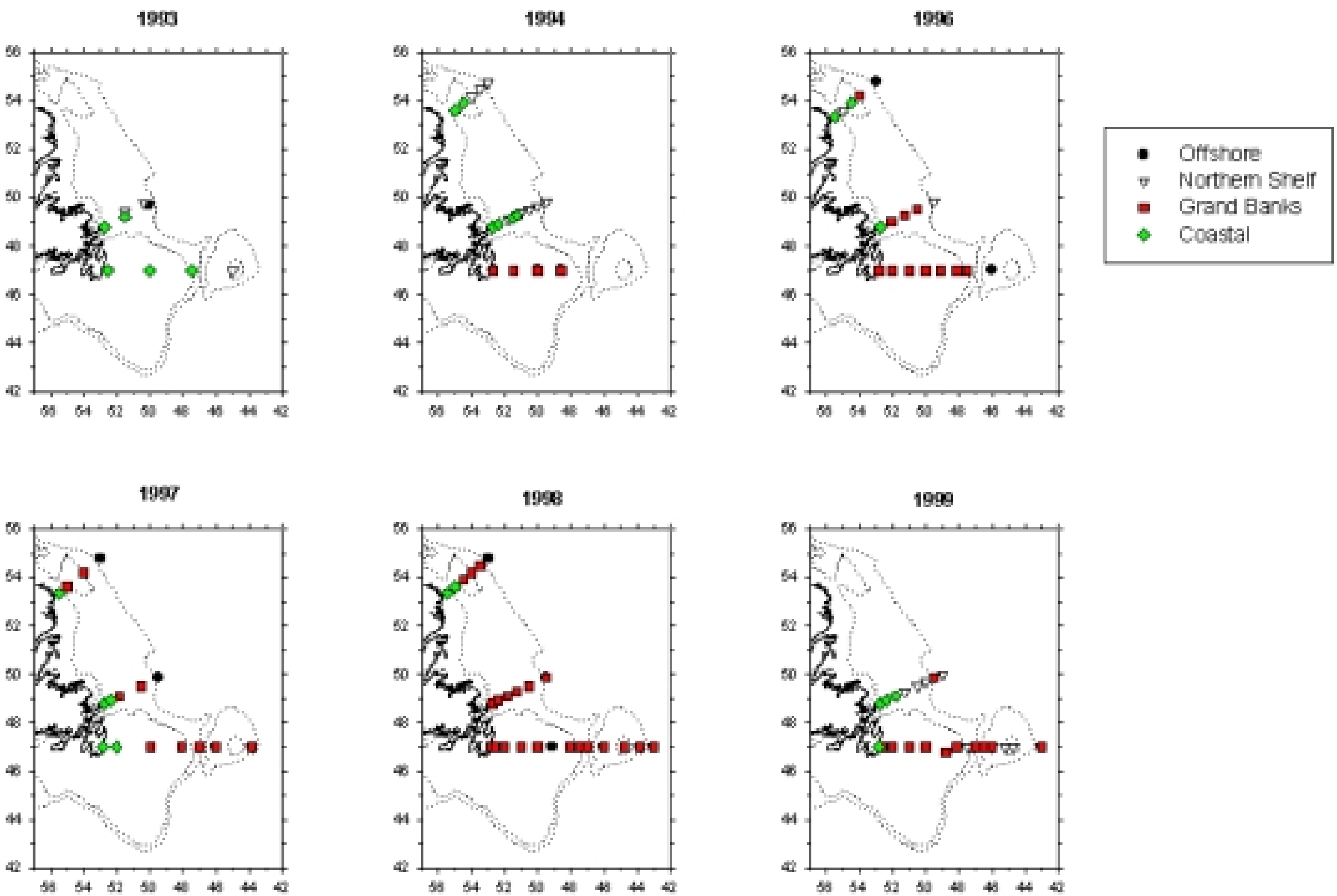

Figure 27. Abundance of major phytoplankton groups for 1999 transect (open symbols) across Bonavista Bay collected at 10m during Spring (May), Summer (July, August), and Fall (November) months. Corresponding data for major groups at station 27 (filled symbols) collected either just before or after transect collections.

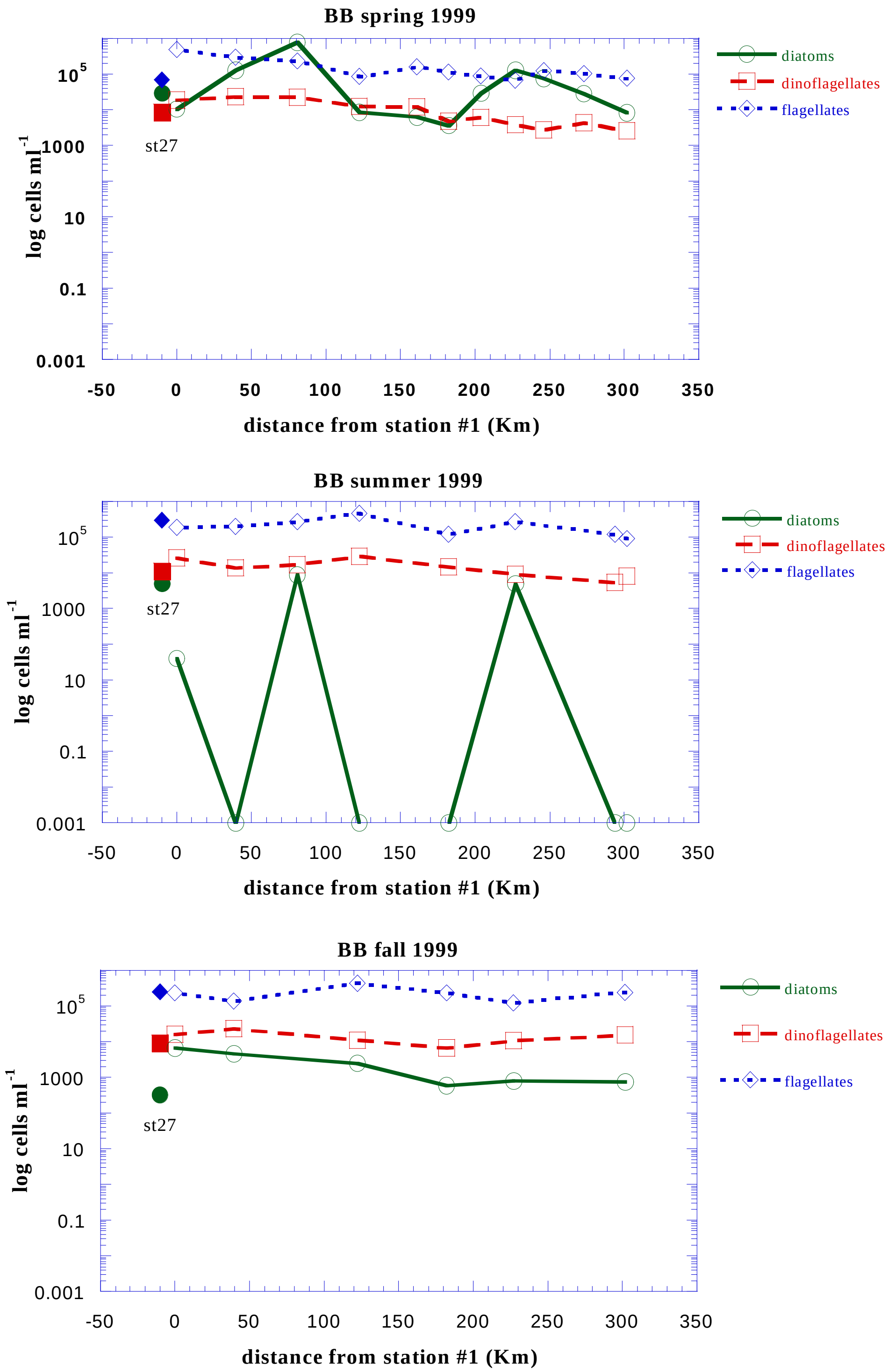

Figure 28. Abundance of major phytoplankton groups for 1999 transects (open symbols) across Seal Island (top), Flemish Cap (middle), and southeast Grand Banks (bottom) collected at 10m during Summer (July, August) and Fall (November) months. Corresponding data for major groups at station 27 (filled symbols) collected either just before or after transect collections.