Fisheries and Oceans Canada Science | Pêches et Océans Canada Sciences

C S A S

Canadian Science Advisory Secretariat

S C C S

Secrétariat canadien de consultation scientifique

Research Document 2002/056

Document de recherche 2002/056

Not to be cited without permission of the authors *

Ne pas citer sans autorisation des auteurs *

Optical, chemical and biological oceanographic conditions on the Scotian Shelf, in the Gulf of Maine and the Southern Gulf of St. Lawrence in 2001

Conditions océanographiques optiques, chimiques et biologiques sur la plate-forme Scotian, dans le golfe du Maine et dans le sud du golfe du Saint-Laurent en 2001)

G. Harrison[1], D. Sameoto[1], J. Spry[1], K. Pauley[1], H. Maass[1] and / et V. Soukhovtsev[2]

[1]Biological Oceanography Section and / et [2]Coastal Oceanography Section
Ocean Sciences Division
Bedford Institute of Oceanography
Box 1006
Dartmouth, NS
B2Y 4A2

* This series documents the scientific basis for the evaluation of fisheries resources in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

* La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Research documents are produced in the official language in which they are provided to the Secretariat.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au Secrétariat.

This document is available on the Internet at:

Ce document est disponible sur l'Internet à:

http://www.dfo-mpo.gc.ca/csas/

ISSN 1480-4883

Canada

Abstract

Optical, chemical, and biological oceanographic conditions in the Maritimes Region (eastern Gulf of Maine/Bay of Fundy, Scotian Shelf and Southern Gulf of St. Lawrence) during 2001 are reviewed and related to conditions during the preceding year and over the longer-term where applicable. In addition to descriptions of AZMP core data collections (fixed stations, seasonal sections, groundfish surveys, CPR, remote-sensing), some data from outside the Maritimes Region are discussed also to provide the larger, zonal perspective.

Optical properties, nutrients and phytoplankton (abundance and community composition) in 2001 and 2000 were generally comparable. Nutrient and phytoplankton levels in 2001 were also similar to the climatological mean condition where data exist, i.e. the Scotian Shelf. Some oceanographic properties did change between years, however. Summer oxygen saturation in bottom waters of the Scotian Shelf was higher in 2001 than in previous years, particularly on the eastern shelf. On the other hand, fall nutrient concentrations in the Southern Gulf were lower in 2001 than in 2000. Although the overall biomass of phytoplankton in the Maritimes Region was similar in 2001 to levels in 2000, based on remote-sensed ocean colour, the duration of the spring bloom was apparently longer on central Scotian Shelf and shorter on the eastern shelf than during the previous year. Feeding/reproducing zooplankton were somewhat more abundant in the Maritimes Region in 2001 than in 2000 (although community composition was similar) but over-wintering populations were generally lower, and significantly lower in 2001 than the long-term mean abundance in deep-water basins. The CPR data record suggested that the abundance of large phytoplankton on the Scotian Shelf in recent years has been significantly higher than the long-term mean while important components of the zooplankton (*Calanus* species, euphausiids) have declined during the same period.

Résumé

Nous présentons les conditions océanographiques optiques, chimiques et biologiques qui prévalaient en 2001 dans la région des Maritimes (est du golfe du Maine/baie de Fundy, plate-forme Scotian et sud du golfe du Saint-Laurent) et nous les comparons aux conditions observées l'année précédente et, lorsque possible, aux conditions à long terme. En plus de décrire les principales séries de données du PMZA (stations fixes, relevés saisonniers sur transects, relevés du poisson de fond, enregistrement du plancton en continu [EPC] et télédétection), nous présentons des données pour l'extérieur de la région des Maritimes afin d'élargir la perspective régionale.

En général, les propriétés optiques, les concentrations d'éléments nutritifs ainsi que l'abondance et la composition du phytoplancton observées en 2001 étaient semblables à celles de 2000. Les concentrations d'éléments nutritifs et les densités de phytoplancton observées en 2001 étaient également semblables aux moyennes à long terme dans les secteurs pour lesquels on dispose de séries chronologiques, soit sur la plate-forme Scotian. Toutefois, certaines propriétés océanographiques ont varié d'une année à l'autre. Ainsi, le pourcentage de saturation en oxygène dans les eaux de fond de la plate-forme Scotian était plus élevé en 2001 que lors des années précédentes, particulièrement sur l'est de la plate-forme. Par contre, les concentrations automnales d'éléments nutritifs dans le sud du golfe du Saint-Laurent étaient plus basses en 2001 qu'en 2000. Bien que les mesures de la couleur de l'océan par télédétection indiquent que la biomasse du phytoplancton dans la région des Maritimes en 2001 était semblable à celle de 2000, la prolifération printanière semble avoir duré, par rapport à l'année précédente, plus longtemps sur le centre de la plate-forme Scotian et moins longtemps sur l'est de la plate-forme. Dans la région des Maritimes, le zooplancton qui s'alimente et se reproduit était un peu plus abondant en 2001 qu'en 2000 (quoique la composition de la communauté était semblable les deux années), mais les populations hivernales était généralement inférieures (significativement inférieures en 2001) à l'abondance moyenne à long terme dans les bassins d'eau profonde. La série chronologique de données EPC indique qu'au cours des dernières années, l'abondance du phytoplancton de grande taille sur la plate-forme Scotian aurait été significativement plus élevée que la moyenne à long terme, alors que d'importantes composantes du zooplancton (espèces de Calanus et euphausiacés) auraient décliné au cours de la même période.

INTRODUCTION

The Atlantic Zonal Monitoring Program (AZMP) was implemented in 1998 (Therriault et al. 1998) with the aim of: (1) increasing DFO's capacity to understand, describe, and forecast the state of the marine ecosystem and (2) quantifying the changes in ocean physical, chemical and biological properties and the predator-prey relationships of marine resources. A critical element in the observational program of AZMP is an annual assessment of the distribution and variability of nutrients and the plankton they support.

A description of the distribution in time and space of nutrients dissolved in seawater (nitrate, silicate, phosphate, oxygen) provides important information on the water-mass movements and on the locations, timing and magnitude of biological production cycles. A description of the distribution of phytoplankton and zooplankton provides important information on the organisms forming the base of the marine foodweb. An understanding of the production cycles of plankton is an essential part of an ecosystem approach to fisheries management.

The AZMP derives its information on the state of the marine ecosystem from data collected at a network of sampling locations (fixed point stations, cross-shelf sections, groundfish surveys) in each region (Laurentian, Maritimes, Newfoundland) sampled at a frequency of bi-weekly to once annually. The sampling design provides for basic information on the natural variability in physical, chemical and biological properties of the Northwest Atlantic continental shelf. Groundfish surveys and cross-shelf sections provide detailed geographic information but are limited in their seasonal coverage. Critically placed fixed stations complement the geography-based sampling by providing more detailed information on temporal (seasonal) changes in ecosystem properties.

We review here the optical, chemical, and biological oceanographic conditions in the Maritimes Region, including the eastern Gulf of Maine/Bay of Fundy, Scotian Shelf and Southern Gulf of St. Lawrence, during 2001. For some data (CPR, SeaWiFS ocean colour), descriptions will include observations outside the Maritimes Region, i.e. the central and western North Atlantic. Conditions in 2001 will be compared with those observed in the previous year (2000) and over the longer-term where historical information is available.

METHODS

To the extent possible, sample collection and processing conforms to established standard protocols (Mitchell, 2002). Non-standard measurements or derived variables are described.

Sample Collection

Maritimes AZMP sea-going staff participated in 11 missions (seasonal section cruises and groundfish surveys) during the 2001 calendar year in addition to repeat trips to the 3 fixed stations; 762 sites were samples all together (Table 1).

Fixed Stations. The Maritimes Region's three fixed stations, Shediac Valley (Shediac), Halifax-2 (HFX-2) and Prince-5 (P-5) (Fig. 1), are sampled on an approximately semi-monthly basis. Due largely to the availability of resources and difficulties with weather and ice, this sampling frequency is not always achieved. In 2001, Halifax-2 and Prince-5 were sampled on 25 and 21 occasions, respectively. Shediac was sampled only 16 times due to the ice-truncated open water season in that area but this was an improvement over the previous year when only 10 samplings were made.

The standard sampling suite when occupying the fixed stations consists of:

- CTD (SBE25) profile including electronic sensing of pressure, temperature, conductivity, dissolved oxygen, fluorescence, and PAR (photosynthetically active radiation),
- Niskin water bottle samples at standard depths for nutrient, calibration salinity, calibration oxygen, and chlorophyll analyses,
- Niskin water bottle sample for phytoplankton enumeration,

- Vertical ring net tows for zooplankton biomass and enumeration,
- Secchi depth reading.

Seasonal Sections. Four primary transects (Browns Bank Line, Halifax Line, Louisbourg Line, Cabot Strait Line; Fig. 1) and a number of additional lines/stations (Fig. 2) are sampled seasonally in spring (April/May) and fall (October/November). An additional occupation of the Halifax Line is also made in June/July as part of the Labrador Sea program in the Maritimes Region. In 2001, the spring cruise was later (1-25 May) than in previous years (generally early to mid April is the target) and the fall cruise was also somewhat later (23 October-7 November).

The standard sampling suite when occupying section stations consisted of:

- CTD (SBE911 – Ship's Rosette) profile including electronic sensing of pressure, temperature, conductivity, dissolved oxygen, fluorescence, and PAR (photosynthetically active radiation),
- Niskin water bottle samples at standard depths for nutrient, calibration salinity, calibration oxygen, and plant pigment analyses (chlorophyll, HPLC, absorbance),
- Niskin water bottle sample for phytoplankton enumeration,
- Vertical ring net tows for zooplankton biomass and enumeration.

Groundfish Surveys. There are four primary groundfish surveys that AZMP-Maritimes participates in: the late winter (February) Georges Bank survey, the spring (March) eastern Scotian Shelf Survey, the summer (July) Scotian Shelf/eastern Gulf of Maine survey and the fall (September) Southern Gulf of St. Lawrence Survey (Fig. 3). In addition, a limited number of samples (mostly chemistry) have been collected on the eastern Scotian Shelf during the winter (January/February) shrimp surveys.

The standard sampling suite when occupying groundfish survey stations consisted of:

- CTD (SBE25) profile including electronic sensing of pressure, temperature, conductivity, dissolved oxygen, fluorescence, and PAR (photosynthetically active radiation),
- Niskin water bottle samples at surface (5 m) and near bottom depths for nutrient, calibration salinity, calibration oxygen, and chlorophyll analyses,
- Niskin water bottle samples for phytoplankton enumeration,
- Vertical ring net tows for zooplankton biomass and enumeration at a subset of stations (see Fig. 3),
- Sea surface temperature.

Deployment

CTD. The CTD is attached to the end of a hydrographic wire and lowered at ~0.35 m/sec for the portable SBE25 (~0.83 m/sec for the higher resolution SBE911 ship's rosette) to within 2m of the bottom when possible.

Standard depths for water samples:

- Fixed-stations
    1. Halifax-2: 1, 5, 10, 20, 30, 40, 50, 75, 100, 140 m
    2. Shediac: 1, 5, 10, 20, 30, 40, 50, 60, 70, 80 m
    3. Prince-5: 1, 10, 25, 50, 95 m
- Seasonal sections - surface, 10, 20, 30, 40, 50, 60, 70, 80, 100, 250, 500, 1000, 1500, 2000 m (depth dependent)
- Groundfish surveys - 5m, near bottom

Net tows. Ring nets are towed vertically from near bottom to surface at ~1m/sec. In deep offshore waters, maximum tow depth is 1000 m. The net is hosed carefully and sample collected from the cod-end, then preserved in buffered formalin.

Secchi depth. The Secchi disc is lowered and the depth where it can no longer be visually detected is recorded.

Optical properties

Optical properties of the seawater (attenuation coefficient, photic depth) were derived from one or more of, (a) in-water light extinction measurements using a CTD-rosette mounted PAR (photosynthetically active radiation) meter, (b) Secchi depth and (c) chlorophyll biomass profile, according to the following procedures:

1. The downward vertical attenuation coefficient for PAR ($K_{d\text{-}PAR}$) was estimated from the linear regression of $\ln(E_d(z))$ versus depth z (where $E_d(z)$ is the value of downward irradiance at z m) in the depth interval from minimum depth to 50 m (minimum depth is usually around 2 m and is always less than 6 m).

2. The value of K_d from Secchi disc observations was found using:

$$K_{d\_secchi} = 1.44/Z_{sd}\ (m^{-1})$$

where Z_{sd} = depth in m at which the Secchi disc disappears from view. The estimate of euphotic depth was made using the following expression:

$$Z_{eu}\ (m) = 4.6\ /\ K_d$$

Reference values were calculated from all estimates of $K_{d\text{-}PAR}$ and K_{d_secchi}.

3. The value of K_d from chlorophyll biomass profile observations was calculated as:

$$K_{d\_chla} = 0.027 + 0.015 + 0.04 * B_{exp}\ (m^{-1}) \qquad \text{(Platt et al. 1988)}$$

where B_{exp} is the observed values of chlorophyll a concentration B(z) (in mg m^{-3}) for depth interval from zero to z_e, the depth where the downwelling irradiance is 36.79% (e^{-1}) of the surface value. Chlorophyll observations were linearly interpolated each 0.25 m to calculate B_{exp}; K_{d_chla} was calculated over the interval 0 to z_e from:

$$E_d(0) * \exp(-K_{d\_chla} * z_e) = (1/e) * E_d(0), \text{ i.e.,}$$

$$K_{d\_chla} * z_e = \Sigma\ (0.027 + 0.015 + 0.04 * B(z_i)) * dz_i = 1$$

Integrated chlorophyll for the depth intervals 0–50 m and 0–100 m (0–80 m for the Shediac fixed station) were calculated as the sum of products $Chl_i * dd_i$, where Chl_i is chlorophyll concentration measured for the depth z_i and dd_I is the depth interval around z_i: $dd_i = 0.5*(z_{i+1} - z_{i-1})$.

Mixed-layer and stratification Index

Two simple indices of the physical structure (vertical) of the water-column were computed for comparison with optical properties; mixed-layer and stratification.

1. The mixed layer depth was determined from the observations of the minimum depth where the density gradient ($gradient_z$(sigma-t)) was equal to or exceeded 0.01 (kg m^{-4}).

2. The stratification index ($Strat_{Ind}$) was calculated as:

$$Strat_{Ind} = (\text{sig-t}_{50} - \text{sig-t}_{zmin})/(50 - z_{min})$$

where sig-t $_{50}$ and sig-t $_{zmin}$ are interpolated values of sigma-t for the depths of 50 m and z_{min} (the minimum depth of reliable CTD data); usually z_{min} is around 5m and always less then 9 m.

Continuous Plankton Recorder (CPR)

The Continuous Plankton Recorder (CPR) is an instrument that collects phytoplankton and zooplankton at a depth of ~7 m on a long continuous ribbon of silk (~260 μm mesh) while towed from commercial ships (Fig. 4). The position on the silk corresponds to location of the different sampling stations. Historical CPR data are analysed to detect differences in the indices of phytoplankton (colour and numerical abundance) and zooplankton abundance for different years on in the NW Atlantic. The indices are measures of biomass or numbers of plankton collected in CPR samples and represent relative changes in concentrations from year to year. The sampling methods from the first surveys in the NW Atlantic (1961) to the present are exactly the same so that valid comparisons can be made between years.

Satellite remote-sensing of ocean colour

Phytoplankton biomass was also estimated from ocean colour data collected by the Sea-viewing Wide Field-of-view (SeaWiFS) satellite sensor launched by NASA in late summer 1997 (http://seawifs.gsfc.nasa.gov/SEAWIFS.html). Satellite data do not provide information on the vertical structure of phytoplankton in the water column but do provide highly resolved (~1.5 km) data on their geographical distribution in surface waters at the large scale. Bi-weekly composite images of surface chlorophyll for the entire NW Atlantic (39-62.5 N Lat., 42-71 W Lon.) are routinely produced from SeaWiFS data (http://www.mar.dfo-mpo.gc.ca/science/ocean/ias/seawifs/seawifs_1.html). Basic statistics (mean, range, standard deviation, etc.) are extracted from the composites for selected sub-regions (Fig. 5), for the fixed stations (defined as a ~5x5 km box centered on the station location) and for the seasonal sections (defined by the inner and outer-most stations and ~5 km in width).

RESULTS

Fixed Stations

Light. Optical properties and mixing of the upper water column varied by season and location at the Maritimes Region fixed stations in 2001. Vertical light attenuation at the Shediac Valley station (Shediac) varied by a factor of ~10 over the year; maximum attenuance coincided with the maximum in integrated chlorophyll in late spring and was minimum following the crash of the spring bloom and in late fall (Fig. 6). Generally, attenuance estimates derived from Secchi disc readings exceeded estimates based on direct downwelling irradiance (PAR) measurements or those derived empirically from chlorophyll concentrations. An exception was observed during the spring bloom when the chlorophyll-estimated attenuance far exceeded the other two estimates. Depth of the euphotic zone, averaged over the year, ranged from 31 m (Secchi estimate) to 45 m (chlorophyll estimate). The spring bloom apparently preceded the establishment of a stratified water column and shallow mixed-layer. Stratified, shallow mixed layers persisted throughout the summer and early fall.

Vertical light attenuation at the Halifax-2 station (HFX-2) was generally lower and varied less (2-3X) seasonally than at Shediac (Fig. 7). Again, Secchi-based attenuance generally exceeded attenuance based on light measurements and chlorophyll concentrations. Maximum attenuance coincided with the chlorophyll peak in spring but was not as evident as at Shediac. Euphotic zone depths average 42-47 m, somewhat deeper than at Shediac. Rapid decrease in mixed layer and increase in stratification in the spring appeared to coincide with the development of the spring bloom; maximum stratification was not observed until late summer/early fall.

Vertical light attenuance at the Prince-5 station (P-5) did not vary much seasonally (<2X) and was generally higher than at Shediac or HFX-2 (Fig. 8). Estimates based on Secchi and light measurements significantly exceeded those based on chlorophyll concentration. Euphotic zone depths averaged 21-23 m, almost half the photic depths of the other two fixed stations. There was very little seasonal pattern in mixed-layer depth (varying from 60-100 m over the year) and stratification was much lower than at the other stations.

Seasonal patterns of optical and mixing properties at the fixed stations in 2001 were, for the most part, remarkably similar to those observed in 2000; light transparencies (euphotic depths) were greatest at HFX-2 and least at P-5, differing by at least a factor of 2. Shediac optical properties were intermediate. An exception was the absence of a large late spring/early summer phytoplankton bloom at P-5 in 2001 (and consequent high light attenuance) as was seen in 2000.

Nutrients. Distributions of the primary dissolved inorganic nutrients (nitrate, silicate, phosphate) included in the observational program of AZMP strongly co-vary in space and time (Petrie et al. 1999). For that reason and because the availability of nitrogen is most likely to limit phytoplankton growth in our coastal waters (DFO, 2000b), emphasis in this report will be placed on variability in nitrate concentrations.

Rapid reduction in near surface nitrate concentrations was seen at all fixed stations in spring 2001 (Fig. 9). Low surface values persisted throughout the summer at Shediac and HFX-2; concentrations did not increase at the surface again until late fall. The zone of nitrate depletion (i.e. defined as depths where concentrations were ≤ 1 μM) in summer was greater at HFX-2 than at Shediac, by ~5-10 m. The 2001 data record for the latter half of the year at P-5 are unavailable but based on observations made during the first half of the year and in previous years, nitrate concentrations were never reduced to the 1 μM level. The seasonal evolution of the vertical nitrate structure at the fixed stations in 2001 was similar to that seen in 2000 except that reduced surface concentrations appeared to occur somewhat earlier at P-5 in 2001 than in 2000. Seasonal variability in nitrate concentrations in the upper water column (0-50 m) at HFX-2 was similar to the climatology (long-term mean) for the central Scotian Shelf, however, concentrations in the 50-150 m depth range were considerably lower (by 6-10 μM) than the long-term mean (Fig. 10).

Nitrate inventories in the upper 50 m (depth zone over which nutrient dynamics are strongly influenced by biological processes) in 2001 followed similar seasonal patterns at all stations; levels were high in late fall/winter and low in spring/summer as a result of biological consumption (Fig. 11). Averaged over the year, inventories were significantly higher at P-5 than at HFX-2 and Shediac. Seasonal patterns and levels were similar to those observed in 2000 at P-5 and HFX-2 while levels were slightly lower at Shediac in 2001 than during the previous year. Nitrate inventories at HFX-2 in 2001 were considerably lower in winter (by a factor of 2) than the climatological mean levels on the central Scotian Shelf but similar to the climatology during other seasons.

Phytoplankton. A spring phytoplankton "bloom" was evident from the evolution of the vertical chlorophyll structure (Fig. 12) and column-integrated chlorophyll peaks (Fig. 11) at all of the fixed stations in April/May, 2001. A less conspicuous, broader fall bloom was also evident at all stations. Chlorophyll levels in 2001 were similar to levels observed in 2000 at HFX-2 and Shediac but were significantly lower in 2001 at P-5. Additionally, the P-5 spring peak occurred earlier in 2001 (April/May) than in 2000 (May/June). Seasonal chlorophyll variability at HFX-2 was similar to climatological mean conditions on the central Scotian Shelf; i.e. no significant anomalies were detected in 2001 (Fig. 10).

Phytoplankton species counts indicated that total species abundance matched chlorophyll biomass distributions reasonably well at the fixed stations in 2001 (exception was the fall abundance peak in diatoms at P-5 in the absence of a corresponding chlorophyll peak) (Fig. 13). Diatoms dominated during blooms at all stations. There was a general trend of decreasing importance of diatoms (numerically) and increasing importance of flagellates/dinoflagellates from spring to late fall at Shediac and HFX-2; diatoms dominated year-round at P-5. The patterns of seasonal evolution of phytoplankton community structure at all of the fixed stations were remarkably similar to the patterns observed for the previous two years.

Mesozooplankton. A broad summer peak in zooplankton biomass was observed at all of the fixed stations (Fig. 11) although the seasonal increase started at HFX-2 and Shediac at least two months earlier than at P-5. Biomass levels were comparable at all stations in 2001 and 2-3x higher than in 2000. The only long-term quantitative data record of zooplankton biomass and abundance on the Scotian Shelf are the summer collections of over-wintering plankton from Emerald Basin starting in the mid-80s (DFO, 2000a). These data (not shown) show that both biomass and abundance have decreased over the past few years and that levels in 2001 were well below the long-term mean.

Two broad peaks in *Calanus finmarchicus* abundance were observed at HFX-2: one in spring and one in late summer (Fig. 11). At P-5 and Shediac, only the late summer peak was observed. Maximum abundances were similar at all stations. Overall, *C. finmarchicus* was less abundant at HFX-2, similar at Shediac and substantially more abundant (~6X) at P-5 in 2001 compared with the previous year.

Hierarchical community analysis revealed that copepods numerically dominated the zooplankton year-round at all fixed stations (Fig. 14). However, significant numbers of bivalve larvae were seen at Shediac in late summer and a significant pulse of echinoderm and barnacle larvae were observed at P-5 in spring. The copepods were dominated year-round at all the fixed stations by small species (*Oithona*, *Pseudocalanus*, Paracalanus, *Clausocalanus*, *Centropoges* and *Temora* sp.; Fig. 15). The larger *Calanus* sp. accounted for 20% or less of the total copepod abundance and were most abundant generally in the first half of the year. Stage distribution of *C. finmarchicus* revealed that reproduction (indicated by presence of early developmental stages, I-III) was generally confined to the spring of the year at HFX-2 but was spread more broadly over the year at Shediac and P-5 (Fig. 16). However, the major reproductive activity appeared to occur in spring at all stations. In general, zooplankton community structure (i.e. rank order of relative abundance) at Shediac and HFX-2 in 2001 was similar to observations during 2000. At P-5 however, as mentioned previously, *C. finmarchicus* abundance was much higher and its contribution to the copepod community more significant in 2001 than in 2000, particularly in late summer.

Seasonal Sections

Nutrients. Vertical distributions of nitrate were generally similar along the four seasonal sections on the Scotian Shelf in spring and fall in 2001, i.e. concentrations were low in near surface waters (<50 m), as a result of phytoplankton consumption, and increased with depth (Fig. 17). Deep-water concentrations were highest in the basins and in slope waters off the edge of the shelf. Distribution patterns were similar to those seen in 2000 except that the shelf-wide zone of nitrate depletion (depth where concentrations ≤ 1 μM) in spring 2001 was deeper (by ~10 m) than in 2000, likely due to the fact that the 2001 survey was a month later than in 2000. Anomaly maps (i.e. year 2001 values minus the long-term mean) for the Halifax section suggested that concentrations in the upper 50 m were similar in 2001 to the long-term mean but somewhat lower in deep basin waters (spring) and offshore (fall) than the norm (Fig. 18).

Nitrate inventories in the upper 50 m were low in spring 2001 along all sections; levels were substantially higher in fall (Fig. 19). In 2000, the opposite was observed, i.e. spring nitrate inventories were substantially higher than in the fall. Shelf-wide, spring 2001 levels were ¼ of 2000 levels while fall 2001 levels were 4X 2000 levels. The fact that both the spring and fall surveys were later (by as much as a month) in 2001 than in 2000 may help explain this reversal in pattern. The extent of near surface nitrate depletion (and thus lower nitrate inventories) would be expected to be more pronounced in May (2001) than in April (2000) due to biological consumption. On the other hand, higher nitrate levels in fall 2001 may have indicated earlier onset of the autumnal overturn (and surface nutrient replenishment) than in 2000.

Phytoplankton. Chlorophyll concentrations were high along all the major sections in spring 2001 (Figs. 20, 21). On the Cabot Strait line, offshore on the Halifax line and inshore on the Browns Bank line, concentrations were highest at the surface. On the Louisbourg line in particular, highest concentrations were well below the surface, peaking as deep as 50 m. During the fall survey, chlorophyll concentrations were significantly and uniformly lower than in spring except along the Browns Bank line where elevated chlorophyll levels were detected near the surface. The elevated surface chlorophyll along the Cabot Strait line in spring can be seen in satellite imagery of ocean colour (see Fig. 2). However, other surface features seen in the section data are not as apparent in the satellite imagery, i.e. elevated surface concentrations offshore on the Halifax line in spring and along Browns Bank line in fall. The satellite results suggested that highest surface chlorophyll levels in spring were east of the Louisbourg line. A more general discussion of the remote-sensing data appears below.

Shelf-wide, chlorophyll levels in spring 2001 were only about half of the levels observed in 2000, however, the fact that the 2001 survey occurred well after the major spring bloom period in April (time of 2000 survey) could account for this difference. High subsurface chlorophyll concentrations, as seen along the sections in 2001, are also indicative of post-bloom conditions. Chlorophyll levels in fall 2001 were similar to 2000 levels.

Mesozooplankton. Zooplankton biomass distribution on the shelf was highly variable both geographically and with season (Fig. 22). Spring levels were about a factor of two higher than fall levels except along the Cabot Strait line where spring and fall biomass levels were comparable. Irrespective of season, biomass appeared to be persistently high at stations overlying deep basins (e.g. Emerald Basin on the Halifax Line) off the edge of the shelf and in deep waters of Cabot Strait. These high biomass levels represent predominantly over-wintering populations residing at depth. Compared with biomass levels observed in spring 2000, levels in 2001 were about 2-fold higher along all of the sections. Again, this difference may be attributable to the fact that the 2001 survey was later by a month than in 2000; zooplankton biomass increases during the spring and doesn't peaks until summer, at least on the central shelf (Fig. 11). Fall levels in 2001 were similar to those in 2000.

Patterns in *C. finmarchicus* distribution were similar to zooplankton biomass in that high concentrations were observed in the basins, off the shelf and in deep waters of Cabot Strait (Fig. 23). Whereas high zooplankton biomass was observed in Cabot Strait in both spring and fall, *C. finmarchicus* was abundant only in the fall along this line. Spring concentrations were ~2X higher than fall concentrations shelf-wide. *C. finmarchicus* was slightly more abundant in spring and fall in 2001, compared with 2000. Survey timing (later in 2001 than in 2000) could have contributed to the differences observed, however, because of strong seasonality in the biological cycles of the region (Fig. 11).

Groundfish Surveys

Nutrients. Profiles of nitrate taken during the eastern Scotian Shelf shrimp survey in winter showed that surface concentrations were reduced relative to concentrations in deep (> 50 m) waters (Fig. 24). This suggests that vertical mixing was not intense enough to redistribute nutrients uniformly in the water column or that significant biological consumption was already occurring at the surface. Near surface nitrate concentrations during the summer groundfish survey were uniformly low over the entire shelf and eastern Gulf of Maine, similar to concentrations seen in previous years (Fig. 25). Bottom water concentrations were substantially higher than near surface concentrations but somewhat lower than bottom water concentrations observed in 2000 (Table 2). Concentrations increased with water depth such that highest concentrations were observed in the deep basins on the shelf (e.g. Emerald Basin) and in slope waters at the shelf edge. Bottom water nutrient concentrations in 2001 were higher off the edges of the shelf and in deep waters of the eastern Gulf of Maine and lower on the inner shelf compared with the long-term mean; surface concentrations shelf-wide were similar to the climatology. Bottom water oxygen saturation in summer, particularly on the eastern shelf, was somewhat higher in 2001 than during the previous 3 years (Fig. 26, Table 2).

Near surface nitrate concentrations during the fall groundfish survey in the Southern Gulf of St. Lawrence were likewise uniformly low (Fig. 27). Bottom water concentrations were elevated compared to surface concentrations and depth dependent, i.e. highest concentrations were seen in the western Gulf and deep waters of the Laurentian Channel. Overall, surface and bottom water nitrate concentrations in the Southern Gulf were lower in 2001 than in 2000 (Table 2).

Phytoplankton. Near surface chlorophyll levels on the Scotian Shelf during the summer groundfish survey were low. No distinct distribution pattern was observed except for a few isolated "hot spots" near the coast of central and SW Nova Scotia, Western Bank and approaches to the Bay of Fundy (Fig. 28). Most of these areas are characterized by strong vertical mixing. Similar chlorophyll hot spots were observed in 2000. Bottom water concentrations in 2001 were uniformly low; similar to what has been seen in previous years. Overall, surface chlorophyll concentrations were comparable to or slightly higher than the long-term mean.

Near surface chlorophyll hot spots were also observed in the Shediac Valley region (western Gulf), in the eastern Gulf off Prince Edward Island (PEI) and around the Magdalen Islands during the fall Southern Gulf groundfish survey (Fig. 29). Similar but more conspicuous hot spots were observed in 2000. Overall, surface chlorophyll in the Southern Gulf was lower in 2001 than in 2000 (Table 2). In general, bottom water chlorophyll levels were uniformly low as seen in previous years, however, elevated concentrations were observed in 2001 off SE PEI where vertical mixing is strong.

Mesozooplankton. Analysis of the groundfish survey zooplankton data has lagged that of chemical and other biological variables; only the 1999 summer Scotian Shelf and fall Southern Gulf of St. Lawrence survey samples have been completed. In the mean, zooplankton biomass and *C. finmarchicus* abundances were remarkable similar between the two 1999 surveys (Table 2).

Remote-sensing of Ocean Colour

An assessment of surface phytoplankton biomass (chlorophyll) at the fixed stations, along the seasonal sections and in the greater NW Atlantic as a whole was also derived from satellite ocean colour (SeaWiFS) data. Spring and late summer maxima (blooms) were observed at Shediac and P-5 but no pronounced surface blooms were obvious at HFX-2 in 2001 (Fig. 30). Although variable, seasonal patterns in 2001 were similar to the mean conditions derived from SeaWiFS over the past 4 years. Comparing satellite-derived chlorophyll with measured values at the fixed stations (Fig. 12) revealed that the satellite captured many (but not all) of the features of the seasonal cycle. Perhaps a more immediately useful application of the satellite-based chlorophyll fields is to characterise the larger spatial-temporal scales of variability in chlorophyll to aid in interpreting the more conventional time-space restricted field-sampling activities of AZMP. For example, spatially-synoptic images of surface chlorophyll give an indication of where the seasonal survey lines lies with respect to the larger scale surface chlorophyll distribution at the time of sampling (Fig. 2). The satellite-derived chlorophyll data can also be used to generate graphical representations of the seasonal chlorophyll dynamics along the section lines. It is evident from the satellite-data, for example, that the May 2001 surveys of the Halifax and Louisbourg lines were too late to catch the major surface spring bloom (Fig. 31). This figure also reveals the nature of the onset, duration and termination of the spring and fall blooms and shows where across the shelf phytoplankton biomass accumulates in the surface. Compared with 2000, the spring bloom along the Halifax line in 2001 lasted longer and was confined more offshore; the bloom along the Louisbourg line in 2001, in contrast, was of a much shorter duration than in 2000. At the larger scale, i.e. the Maritimes Region, the levels of surface chlorophyll and seasonal patterns in 2001 as revealed from satellite-based chlorophyll were not significantly different in general from previous years (Fig. 32). There is some suggestion, however, that the spring surface bloom in Cabot Strait has been less pronounced in last two years than previously and that the general surface chlorophyll levels in the Bay of Fundy may have increased over this same period. Viewed from the entire Atlantic Zone (Hudson Strait to Georges Bank), regional differences in annual mean surface chlorophyll far exceeded inter-annual variations within regions (Fig. 33). Annual chlorophyll levels were slightly higher (10-15% higher than the 1998-2001 mean) at the northern and southern limits of the Atlantic Zone and slightly lower (10-20% below the 4-yr mean) in other regions in 2001, but these differences are not considered significant.

Continuous Plankton Recorder (CPR)

The CPR is the longest data record available on plankton in the NW Atlantic. CPR data analysis lags AZMP reporting by one year; thus, only data up to 2000 are currently available. Nonetheless, the phytoplankton colour index and adundance of large diatoms and dinoflagellates on the Scotian Shelf have been dramatically higher starting in the early 1990s and continuing into the 2000s when compared with levels seen in the 1960s and early 1970s (Fig. 34). A similar pattern has been observed in the western Atlantic; in this region, however, dinoflagellate increases have been more prominent than on the Scotian Shelf. On the shorter time scale, phytoplankton colour index and diatom abundance on the Scotian Shelf decreased in 2000 relative to 1999 (dinoflagellates increased slightly) while colour, diatoms and dinoflagellates all increased in 2000 in the western Atlantic. In the 1990s and early 2000s, there also appeared to be a shift toward earlier months for the seasonal (spring) peak in abundance compared to the 1960s and 1970s (Fig. 35). A shift in peak abundance of *C. finmarchicus* to earlier in the year in the 1990s was also apparent on the Scotian Shelf but not in the western Atlantic.

While phytoplankton were increasing on the Scotian Shelf in the 1990s, zooplankton were generally decreasing, particularly during the early to mid 1990s (Fig. 36). In the last 3-4 years, however, zooplankton trends have reversed and numbers appear to be recovering. In the western Atlantic, trends are less evident although numbers were down slightly in 2000 compared to 1999. Euphausiids have been an exception, showing a fairly consistent decrease in abundance during the entire decade of the 1990s in the western Atlantic.

DISCUSSION

A rough comparison of the mean optical, chemical and biological oceanographic conditions in the Maritimes Region and adjacent waters in 2001 with the conditions in 2000 and over the long-term is summarized in Table 3. Many of the oceanographic properties observed in 2001, based on the core AZMP measurements (fixed stations, seasonal sections, groundfish surveys, remote-sensing), were similar to properties observed in 2000 or, if they differed, could be explained to some extent by sampling bias.

Nitrate concentrations at the fixed stations and the summer Scotian Shelf groundfish survey did not change significantly between 2000 and 2001. On the other hand, concentrations observed during the seasonal sections were substantially lower in spring and higher in fall 2001 than in 2000. The timing of the 2000 and 2001 seasonal sections, however, may explain these differences. In 2001, the surveys were later (by as much as a month) than in 2000. Since nutrient concentrations decrease in surface waters in spring, reach minimum values in late summer and increase again in the fall as vertical mixing intensifies, the later surveys in 2001 would be expected to sample lower nutrient waters in the spring and higher nutrient waters in the fall than in 2000. A similar explanation can be used to reconcile the lower chlorophyll concentrations observed on the 2001 spring section survey compared with the 2000 survey, i.e. chlorophyll levels would be expected to be lower in May (2001) than in April (2000). Thus, adjusted for sampling time, survey nutrients and chlorophyll were likely not different between years. Satellite remote-sensing suggested that the annual mean biomass of phytoplankton in surface waters for the entire Atlantic zone was similar in 2001 to biomass levels 2000. In addition, phytoplankton community composition, where assessed (fixed stations), was essentially the same in 2001 as in 2000. Only for a few selected properties can yearly conditions be compared with the long-term climatological mean. Sufficient nutrient and chlorophyll data exists to generate a climatology; in 2001, nitrate and chlorophyll concentrations were similar to the long-term mean on the Scotian Shelf.

Year-to-year differences in some oceanographic properties were considered to be real. Oxygen saturation in bottom waters of the Scotian Shelf during the summer survey, for example, was higher in 2001 than in 2000. On the other hand, concentrations of nutrients and chlorophyll in the southern Gulf during the fall survey were lower in 2001 than in 2000. Although the overall biomass of phytoplankton in the Maritimes Region was similar in 2001 to levels in 2000, based on remote-sensed data, the duration of the spring bloom was apparently longer on central Scotian Shelf and shorter on the eastern shelf than during the previous year. The longest continuous biological (plankton) record in the Maritimes Region comes from the CPR. CPR-phytoplankton data for the Scotian Shelf are not yet available for 2001 but trends over the past few years have shown declining abundance, although levels remain well above the long-term mean. A shift in the timing of the spring bloom (earlier in more recent years) has also been evident. Similar long-term patterns in phytoplankton were observed outside the AZMP region ("NW Atlantic" in Table 3, see Fig. 4).

Some of the observed differences in zooplankton between 2000 and 2001 could be attributed to survey timing as described above (i.e. zooplankton were higher in May, 2001 than in April, 2000 because populations usually do not peak until summer), however, most differences appear to be real. Surface-feeding and reproducing zooplankton were somewhat more abundant in the region in 2001 than in 2000 but over-wintering populations (Emerald Basin) were generally lower. Community composition (fixed stations) was generally comparable between the two years although *C. finmarchicus* contributed considerably more to the zooplankton at P-5 in 2001 than seen previously. The decade-long record of over-wintering zooplankton (Emerald Basin) indicates that abundances in 2001 were significantly lower than the long-term mean in this deep-water basin. In a similar way, the multi-decade CPR data record suggests that the abundance of some components of the zooplankton (*Calanus* sp., euphausiids) were on a declining trend in 2001, and well below the climatological mean, while others (*Paracalanus sp*, *Pseudocalanus sp*.) have been increasing and are currently above the climatological mean. As in the case of phytoplankton, the CPR data (Scotian Shelf) suggest that the zooplankton peak abundance is now occurring earlier in the year than in the past.

ACKNOWLEDGEMENTS

The authors wish to thank the sea-going staff of the Biological Oceanography Section, and the officers and crew of the CCGS Opilio, Hudson, Alfred Needler and SAR vessels for their able assistance in successfully completing the Maritimes Region's 2001 field program. Michel Starr provided a comprehensive and constructive review of this manuscript.

REFERENCES

DFO, 2000a. State of phytoplankton, zooplankton and krill on the Scotian Shelf in 1998 DFO Science Stock Status Report G3-02(2000).

DFO, 2000b. Chemical and biological oceanographic conditions 1998 and 1999 – Maritimes region. DFO Science Stock Status Report G3-03 (2000).

DFO. 2001. Chemical and biological oceanographic conditions in 2000 – Maritime Region. DFO Science Stock Status Report G3-03 (2001).

Mitchell, M. (ed). 2002. Atlantic Zonal Monitoring Program: Sampling Protocol. Can. Tech. Rep. Hydrogr. Ocean Sci. xxx, xx pp

Petrie, B., P. Yeats and P. Strain. 1999. Nitrate, silicate and phosphate atlas for the Scotian Shelf and the Gulf of Maine. Can. Tech. Rep. Hydrogr. Ocean Sci. 203, 96 pp.

Platt, T., S. Sathyendranath, C.M. Caverhill, and M.R. Lewis. 1988. Ocean primary production and available light: further algorithms for remote sensing. Deep-Sea Res. *35(6):* 855-879.

Therriault, J.C., et al. (11 co-authors). 1998. Proposal for a Northwest Atlantic Zonal Monitoring Program. Can. Tech. Rep. Hydrogr. Ocean Sci. 194, 57 pp.

Table 1. AZMP Sampling Missions in the Maritimes Region, 2001.

Group	Location	Mission ID	Dates	# Hydro Stns	# Net Stns
Groundfish Surveys	Sydney Bight	2001001	Jan 15 – Jan 27	8	0
	Eastern Shelf	2001002	Jan 30 – Feb 12	8	0
	Georges Bank	2001003	Feb 14 - Feb 25	80	12
	Eastern Shelf	2001004	Feb 27 - Mar 14	91	19
	SGSL	2001026	Jun 17 – Jun 27	13	0
	Scotian Shelf	2001032	Jul 03 – Jul 15	98	19
	Scotian Shelf	2001037	Jul 16 – Jul 31	110	18
	SGSL	2001050	Sep 04 – Sep 28	156	17
Seasonal Sections	Scotian Shelf	2001009	May 01 – May 25	67	67
	Scotian Shelf	2001022	May 30 – Jun 01	7	7
	Scotian Shelf	2001061	Oct 23 – Nov 07	62	62
Fixed Stations	Shediac	-	Apr 26 – Dec 12	16	16
	HFX-2	-	Jan 05 – Dec 08	25	25
	P-5	-	Jan 02 – Nov 30	22	20
			Total:	**763**	**282**

Table 2. Chemical and biological properties of the 1999-2001 summer Scotian and fall Southern Gulf of St. Lawrence groundfish surveys. Statistics: mean, (range), #obs.

Survey	Year	Chlorophyll (mg m^{-3}) Surface (5 m)	Nitrate (mmol m^{-3}) Bottom	Oxygen (% Saturation) Bottom	Zoopl Biomass (gm wtwt m^{-2})	C. finmarchicus (# m^{-2})
Scotian Shelf						
	1999	**0.93** (0.10-7.07) 137	**13.22** (2.12-24.06) 163	**-** (-) -	**45.9** (0.2-228.2) 32	**20,872** (91-143,060) 33
	2000	**0.67** (0.11-6.17) 220	**12.87** (3.27-22.97) 178	**87** (43-121) 203		
	2001	**0.78** (0.03-4.08) 206	**11.75** (1.72-21.76) 155	**82** (40-107) 206		
Southern Gulf						
	1999	**1.65** (0.03-4.97) 185	**9.87** (0.35-22.92) 178	**84** (38-114) 180	**37.4** (5.1-112.0) 17	**18,101** (0-56,354) 17
	2000	**1.56** (0.16-6.35) 197	**11.45** (0.37-24.57) 192	**79** (33-117) 175		
	2001	**1.04** (0.04-3.60) 149	**8.93** (0.19-23.94) 155	**98** (68-118) 8		

Table 3. Optical, chemical and biological conditions in the Maritimes Region in 2001: short (comparison with 2000) and long-term (comparison with climatological mean) changes. Observations: FS = Fixed Stations, SS = Seasonal Sections (Spr =Spring, Fall), GF = Groundfish Surveys (Sum=Summer, Fall). ⇑ = higher, ⇓ = lower, ⇔ = no change.

Ecosystem Property	Observation	Y2000	Long-term (Climatology)	Comments
Light	FS	⇔	-	
Nutrients				
Nitrate	FS	⇔	⇔	Winter climatology higher
	SS-Spr	⇓	⇔	2001 survey later than 2000
	SS-Fall	⇑	⇔	2001 survey later than 2000
	GF-Sum	⇔	⇔	
	GF-Fall	⇓	-	
Oxygen	GF-Sum	⇑	-	Bottom waters
Phytoplankton				
Chlorophyll	FS	⇔	⇔	P-5 (2001)<(2000)
	SS-Spr	⇓	-	
	SS-Fall	⇔	-	
	GF-Sum	⇔	⇔	
	GF-Fall	⇓	-	
Composition	FS	⇔	-	
Zooplankton				
Biomass	FS	⇑	-	
	SS-Spr	⇑	-	
	SS-Fall	⇔	-	
	Emerald Basin	⇓	⇓	Over-wintering populations
Abundance	Emerald Basin	⇓	⇓	Over-wintering populations
C. finmarchicus	FS	⇑	-	P-5 only
	SS-Spr	⇑	-	
	SS-Fall	⇑	-	
Composition	FS	⇔	-	C. fin at P-5 (2001)>(2000)
Ocean Colour	FS	⇔	⇔	4-yr "climatology"
	SS-Spr	⇔	⇔	4-yr "climatology"
	SS-Fall	⇔	⇔	4-yr "climatology"
	Maritimes	⇔	⇔	4-yr "climatology"
	AZMP	⇔	⇔	4-yr "climatology"
CPR (2000)*			-	
Colour Index	Scotian Shelf	⇓	⇑	
Diatoms	Scotian Shelf	⇓	⇑	
Dinoflagellates	Scotian Shelf	⇓	⇑	
C. fin 1-4	Scotian Shelf	⇔	⇓	
C. fin 5-6	Scotian Shelf	⇑	⇔	6-yr upward trend
Para/Pseudo Cal	Scotian Shelf	⇑	⇑	4-yr upward trend
Euphausiids	Scotian Shelf	⇑	⇓	4-yr upward trend
Colour Index	NW Atlantic	⇑	⇑	
Diatoms	NW Atlantic	⇔	⇑	
Dinoflagellates	NW Atlantic	⇑	⇑	
C. fin 1-4	NW Atlantic	⇓	⇓	
C. fin 5-6	NW Atlantic	⇓	⇓	
Para/Pseudo Cal	NW Atlantic	⇓	⇑	
Euphausiids	NW Atlantic	⇓	⇓	6-yr downward trend
Spr Bloom Timing	Scotian Shelf	-	Earlier in 90s	
	NW Atlantic	-	Earlier in 90s	
Zooplankton Peak	Scotian Shelf	-	Earlier in 90s	
	NW Atlantic	-	⇔	

*Due to the time required for sample processing, the CPR data are not available until the year after collection. The comparisons in this table, therefore, are between 2000 and 1999 and 2000 and the long-term mean.

Figure 1. Primary sections and fixed stations sampled in the Maritimes Region.

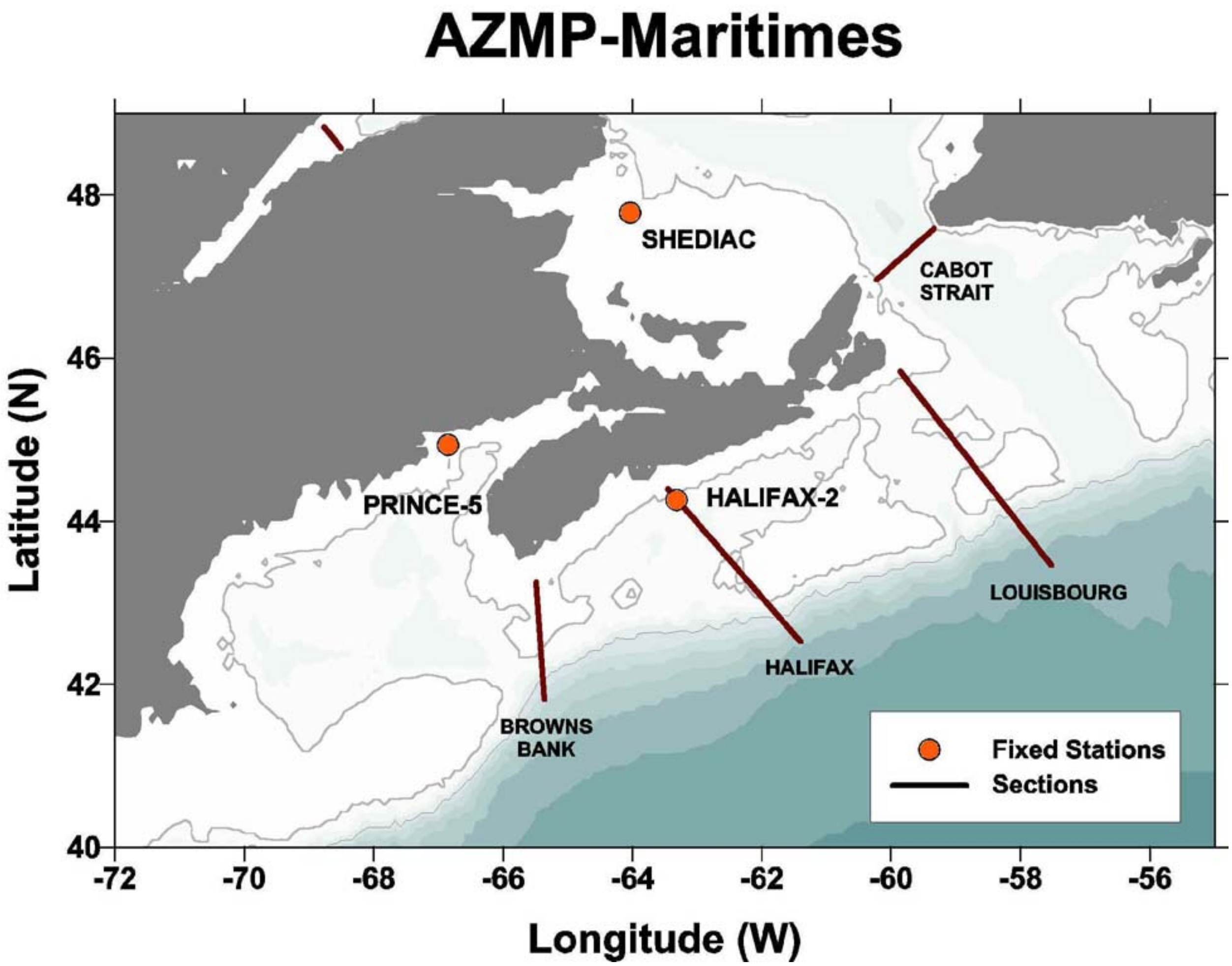


Figure 2. Stations sampled during the 2001 spring and fall section surveys. Black symbols are stations occupied on the four primary sections (see Fig. 1); blue symbols are additional sections/stations occupied. Station locations superimposed on SeaWiFS bi-weekly colour composite images for comparable time periods (spring: 1-15 May composite, fall: 16-31 October composite).

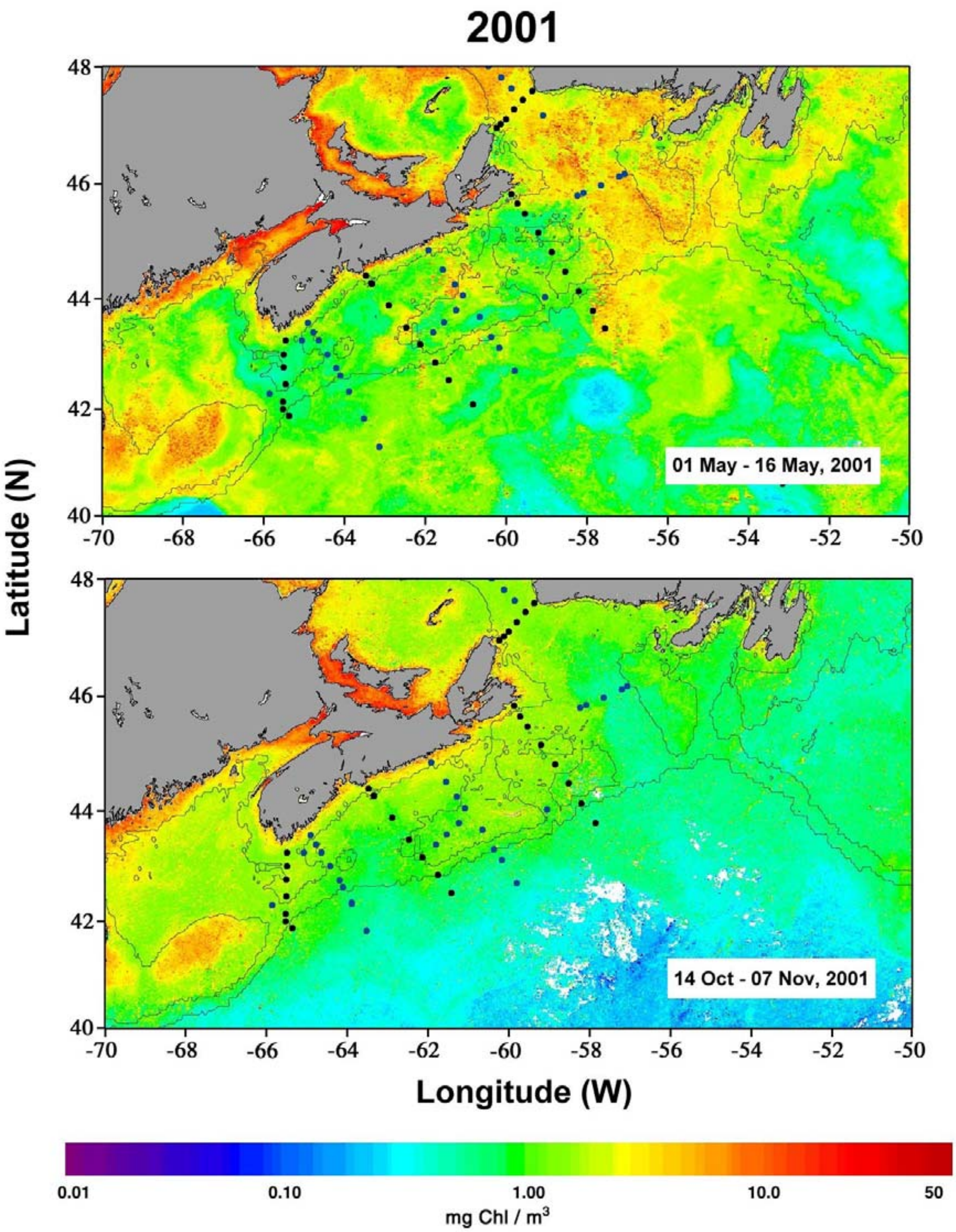


Figure 3. Stations sampled during major groundfish surveys in 2001. Black symbols are hydrography stations; red symbols are stations where vertical nets hauls were taken in addition to hydrographic measurements.

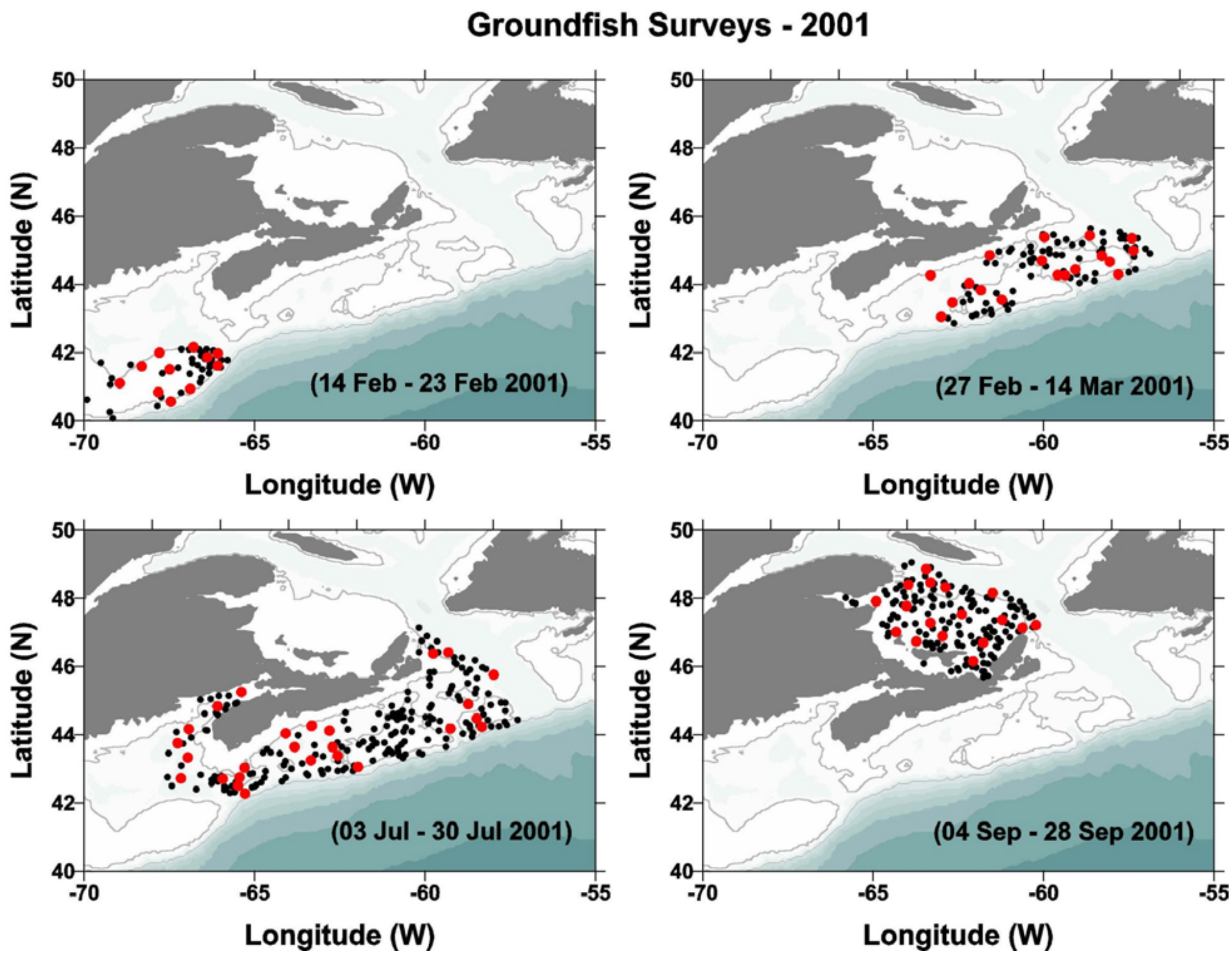


Figure 4. Cumulative display of CPR sampling lines occupied from 1961 to 2000. Scotian Shelf represented by samples collected between the Gulf of Maine and Laurentian Channel; Western Atlantic represented by samples collected between the Newfoundland/Labrador coast and the 46° W Longitude.

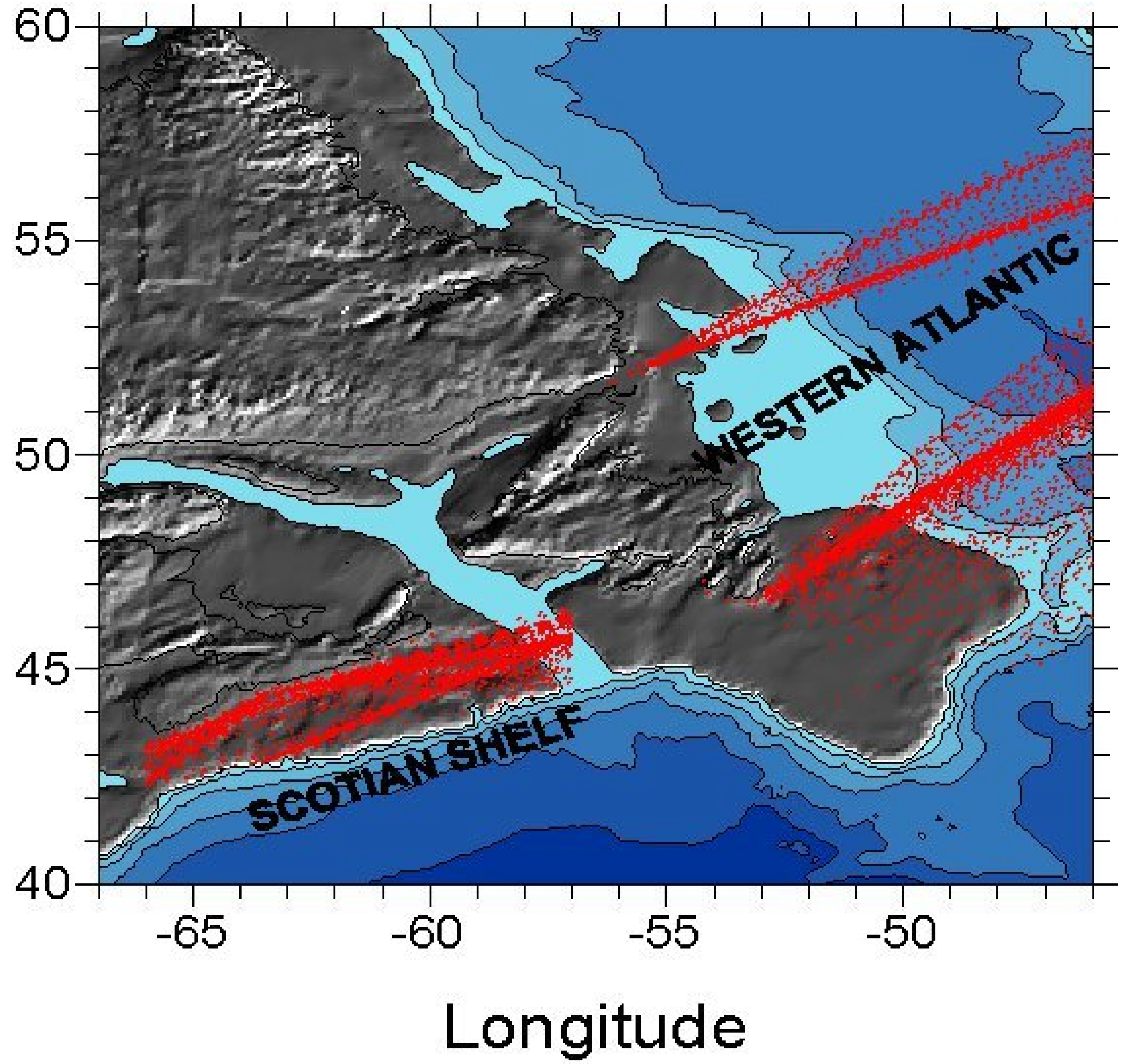


Figure 5. Statistical sub-regions (24) in the NW Atlantic identified for spatial/temporal analysis of SeaWiFS ocean colour data.

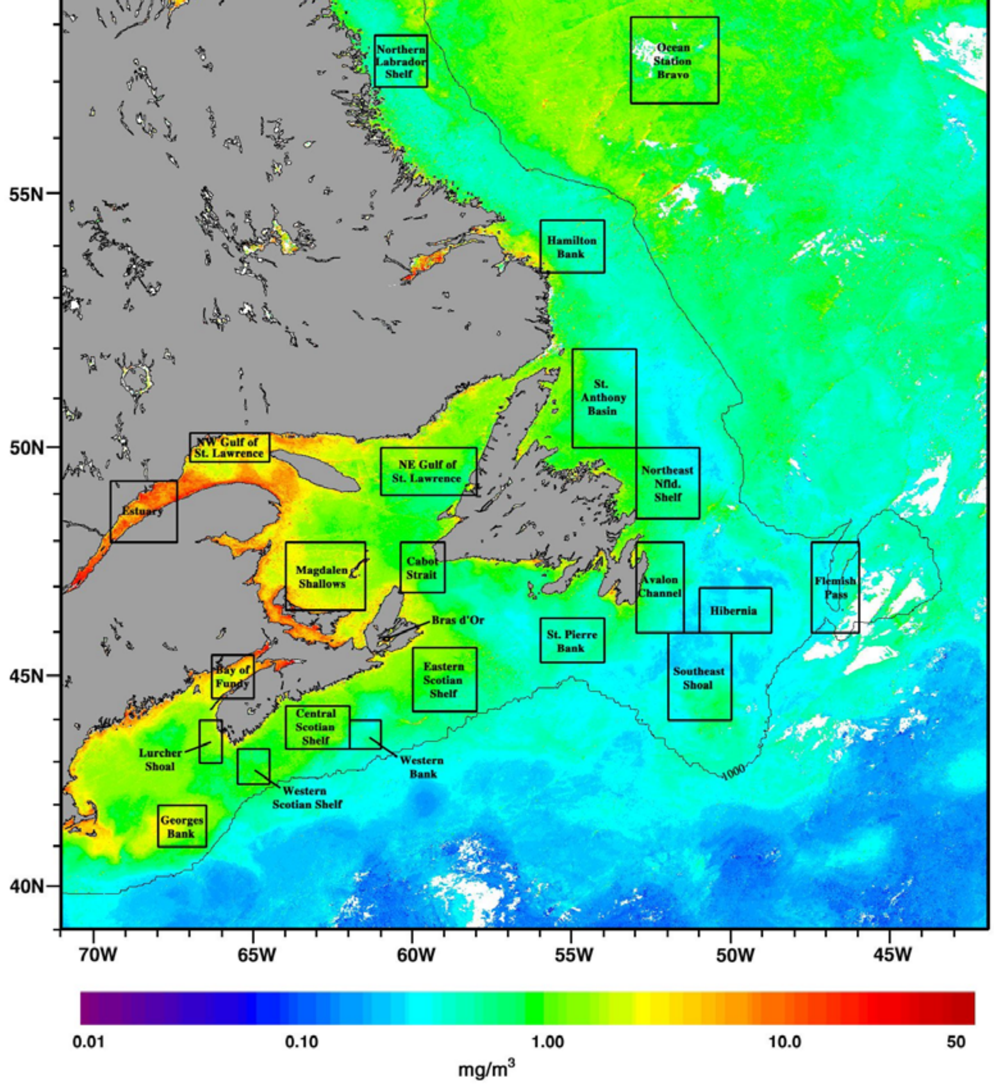


Figure 6. Seasonal variations in optical properties (vertical attenuation coefficient, euphotic depth), mixed-layer depth and stratification at the Shediac Valley fixed station in 2001.

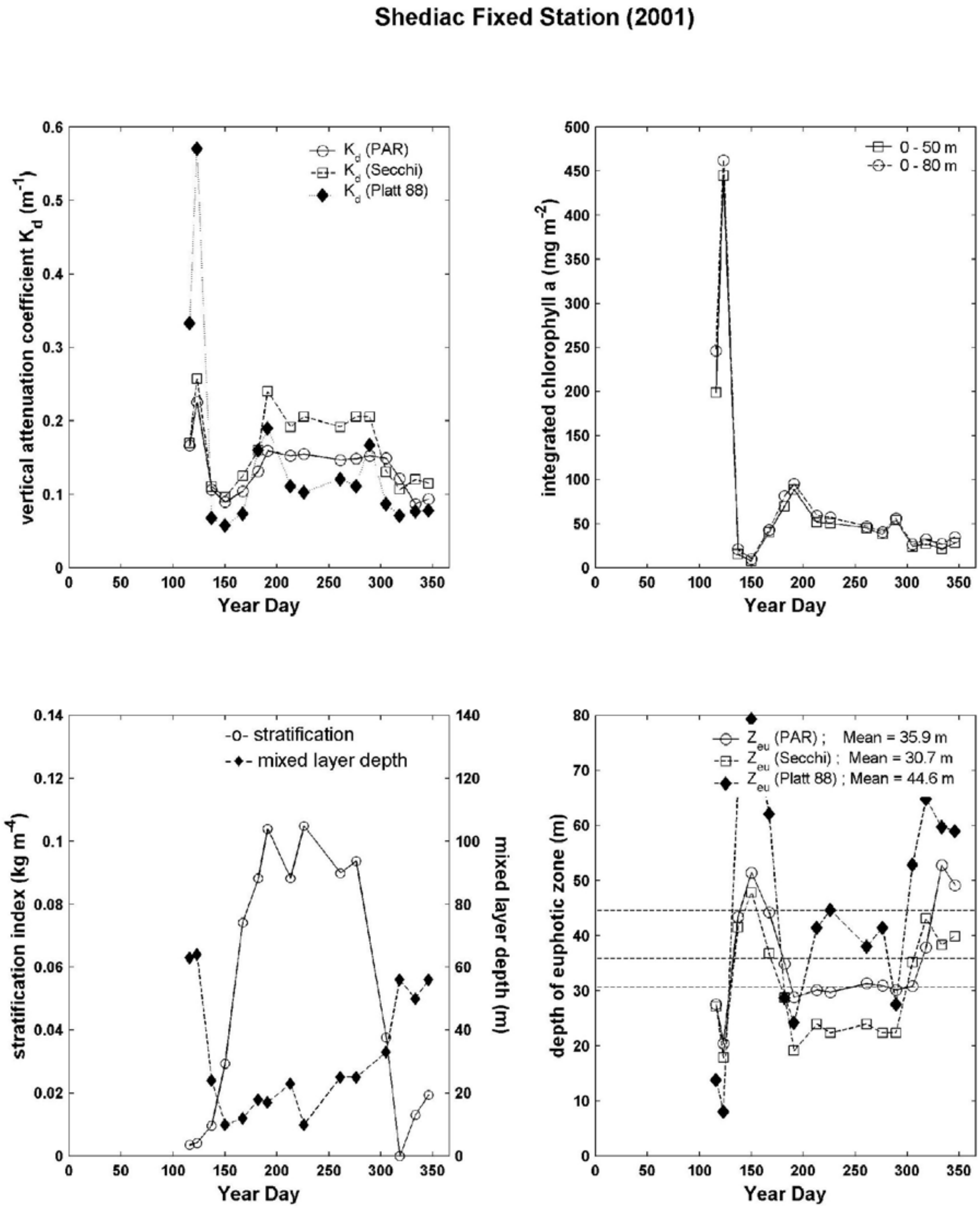


Figure 7. Seasonal variations in optical properties (vertical attenuation coefficient, euphotic depth), mixed-layer depth and stratification at the Halifax-2 fixed station in 2001.

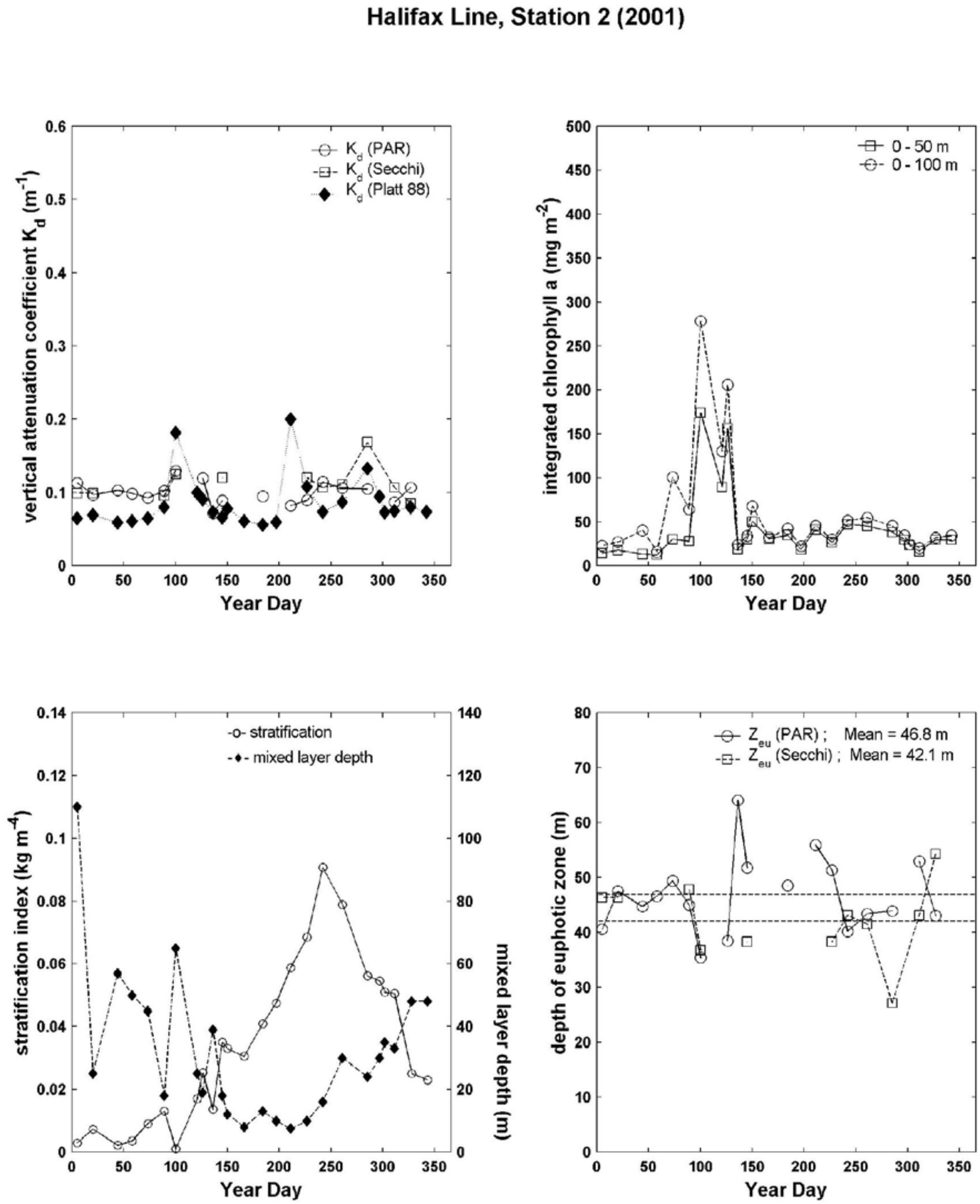


Figure 8. Seasonal variations in optical properties (vertical attenuation coefficient, euphotic depth), mixed-layer depth and stratification at the Prince-5 fixed station in 2001.

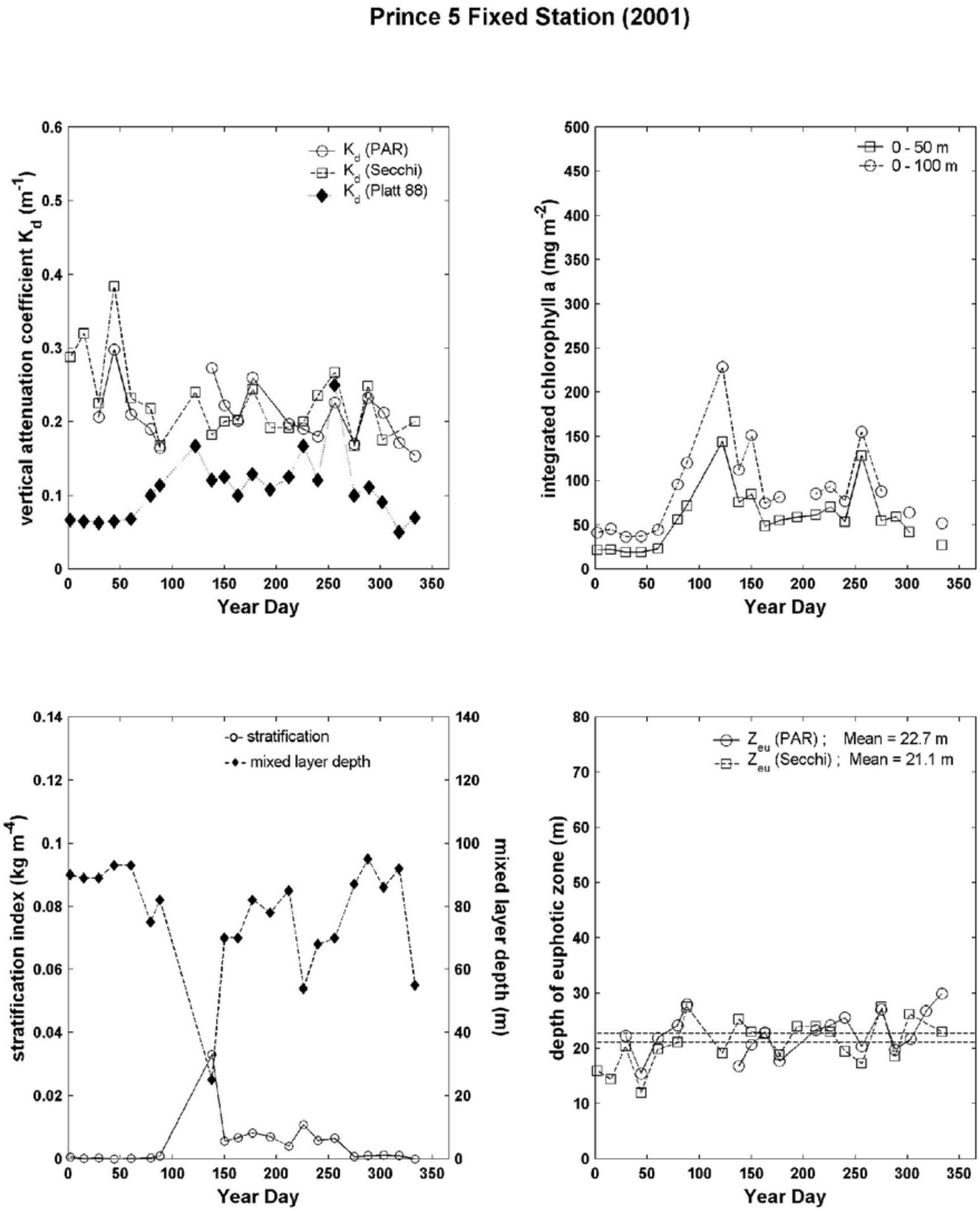


Figure 9. Seasonal variations in vertical nitrate structure at the Maritimes Region fixed stations in 2001. Dots at bottom of graphs show sampling dates.

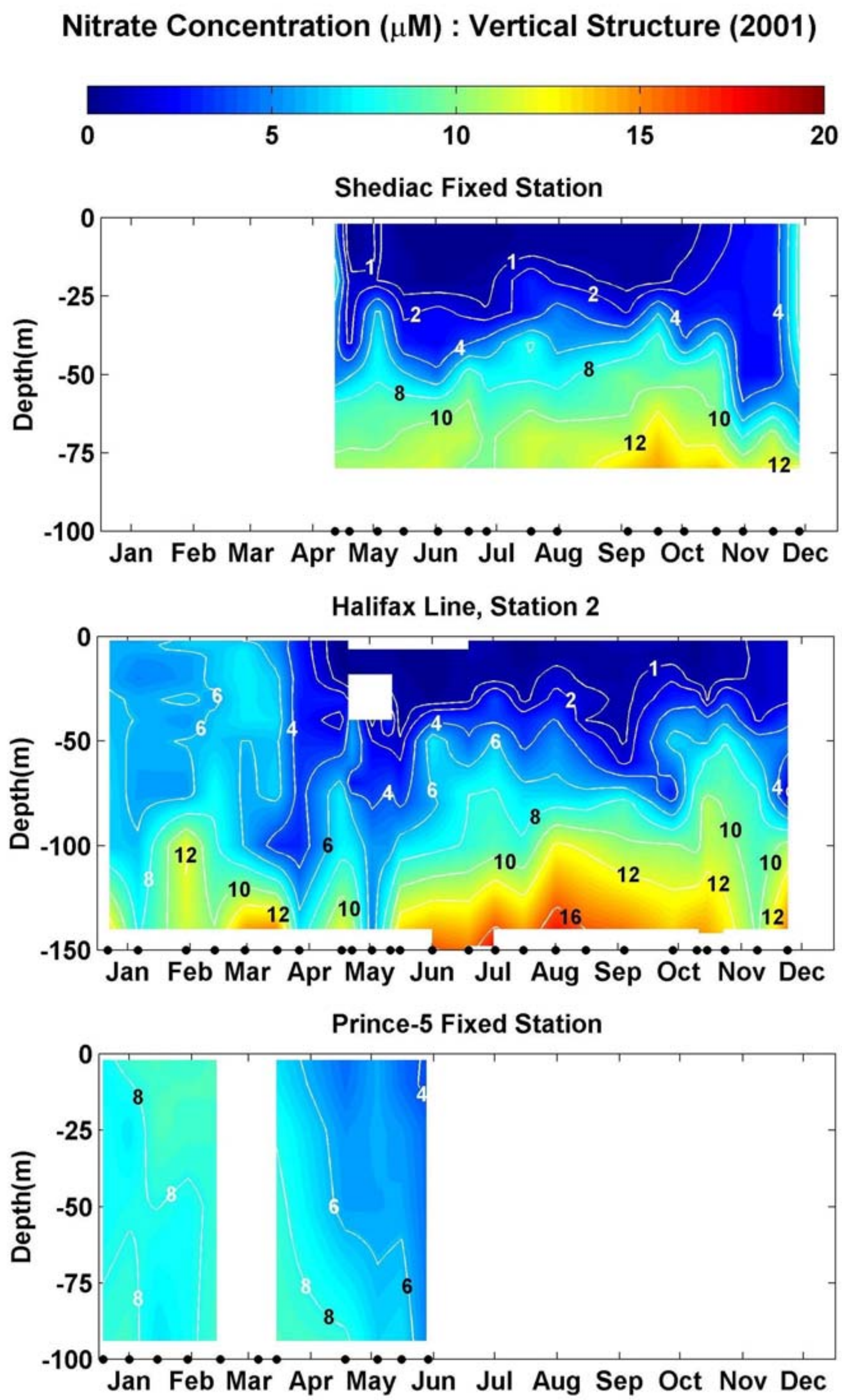


Figure 10. Vertical nitrate and chlorophyll anomalies (values in 2001 minus the long-term mean) at the Halifax-2 fixed station in 2001. Dots at bottom of graphs show sampling dates.

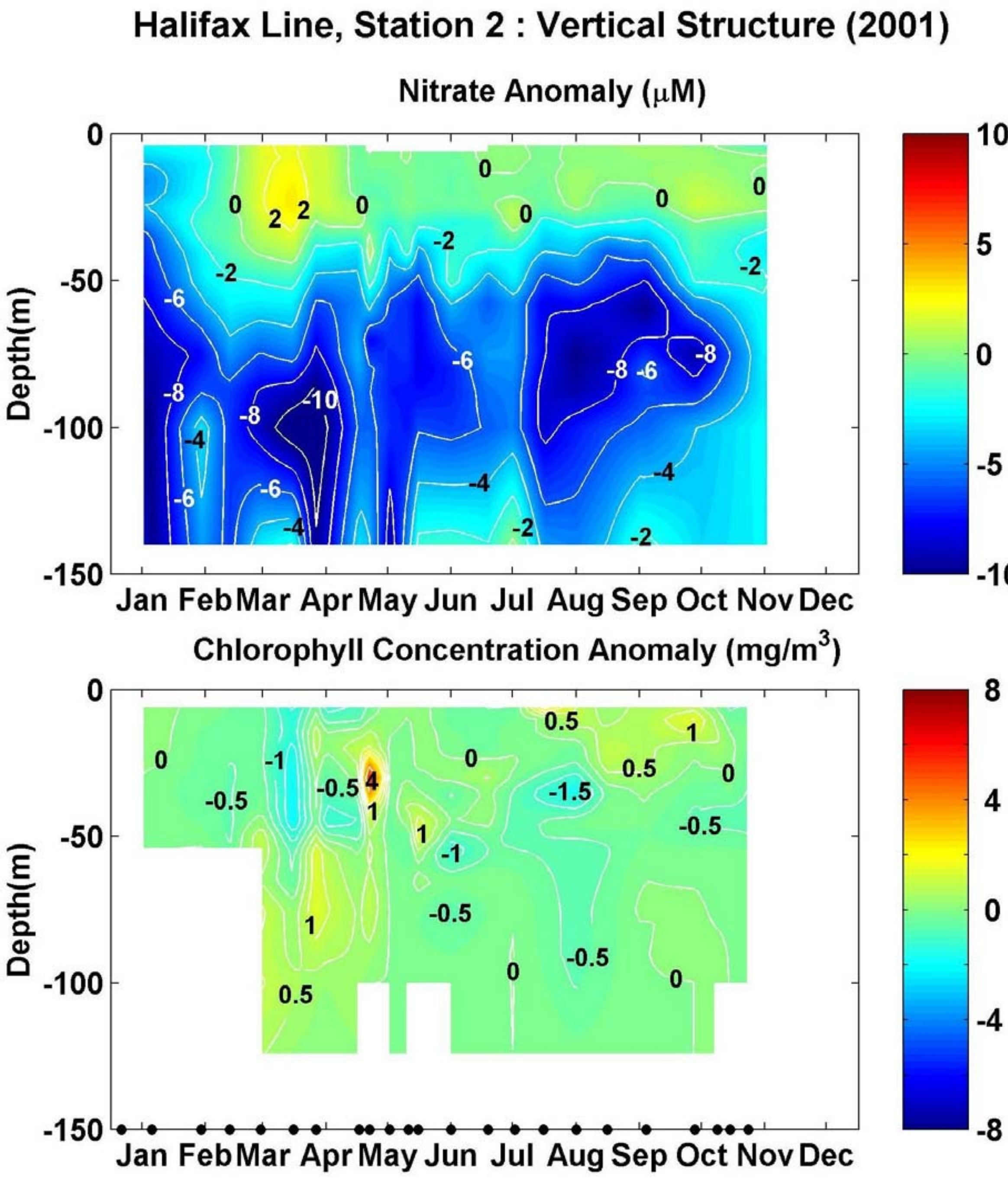


Figure 11. Seasonal variations in nitrate inventory, chlorophyll concentration, zooplankton biomass and *C. finmarchicus* abundance at the Maritimes Region fixed stations in 2001.

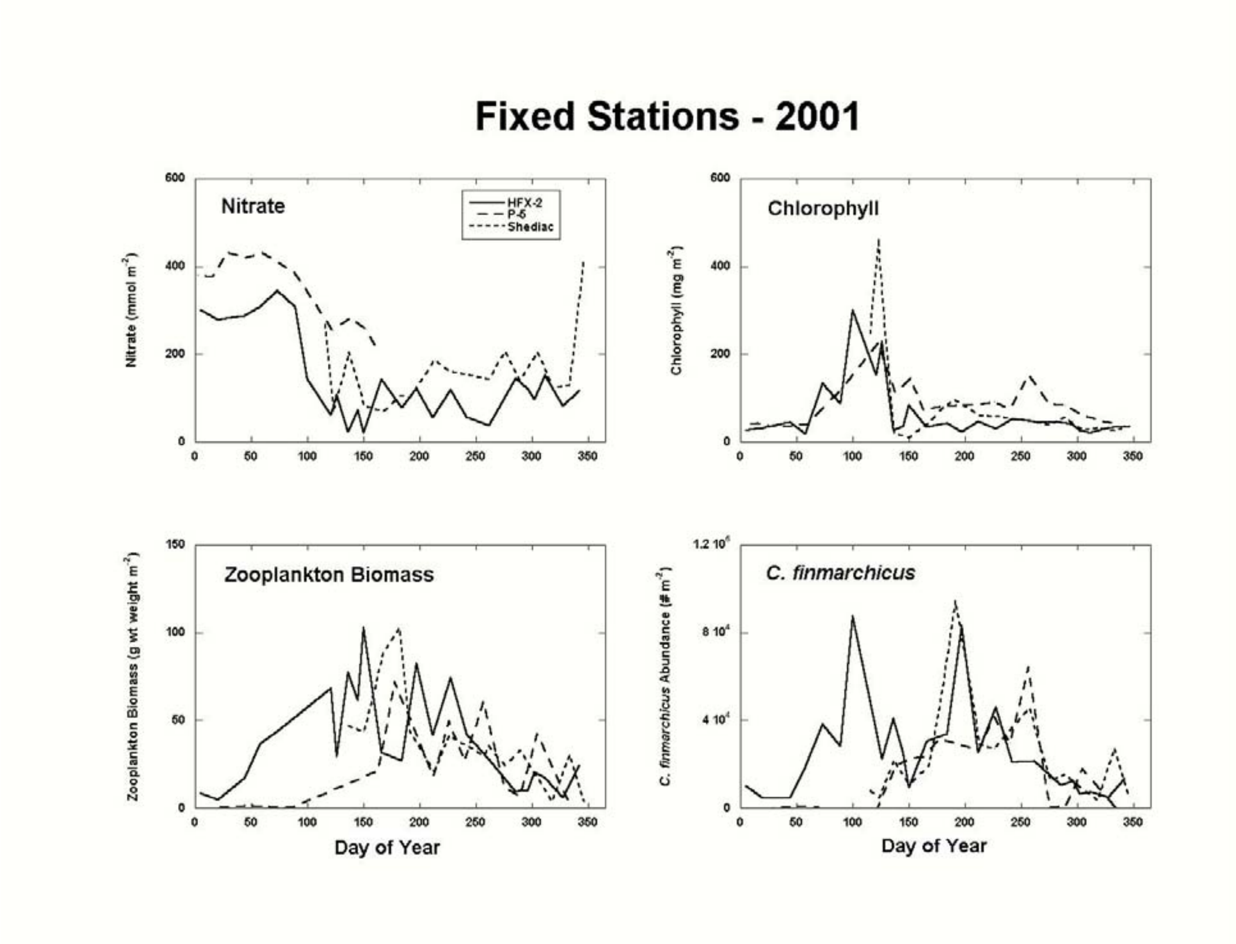


Figure 12. Seasonal variations in vertical chlorophyll structure at the Maritimes Region fixed stations in 2001. Dots at bottom of graphs show sampling dates.

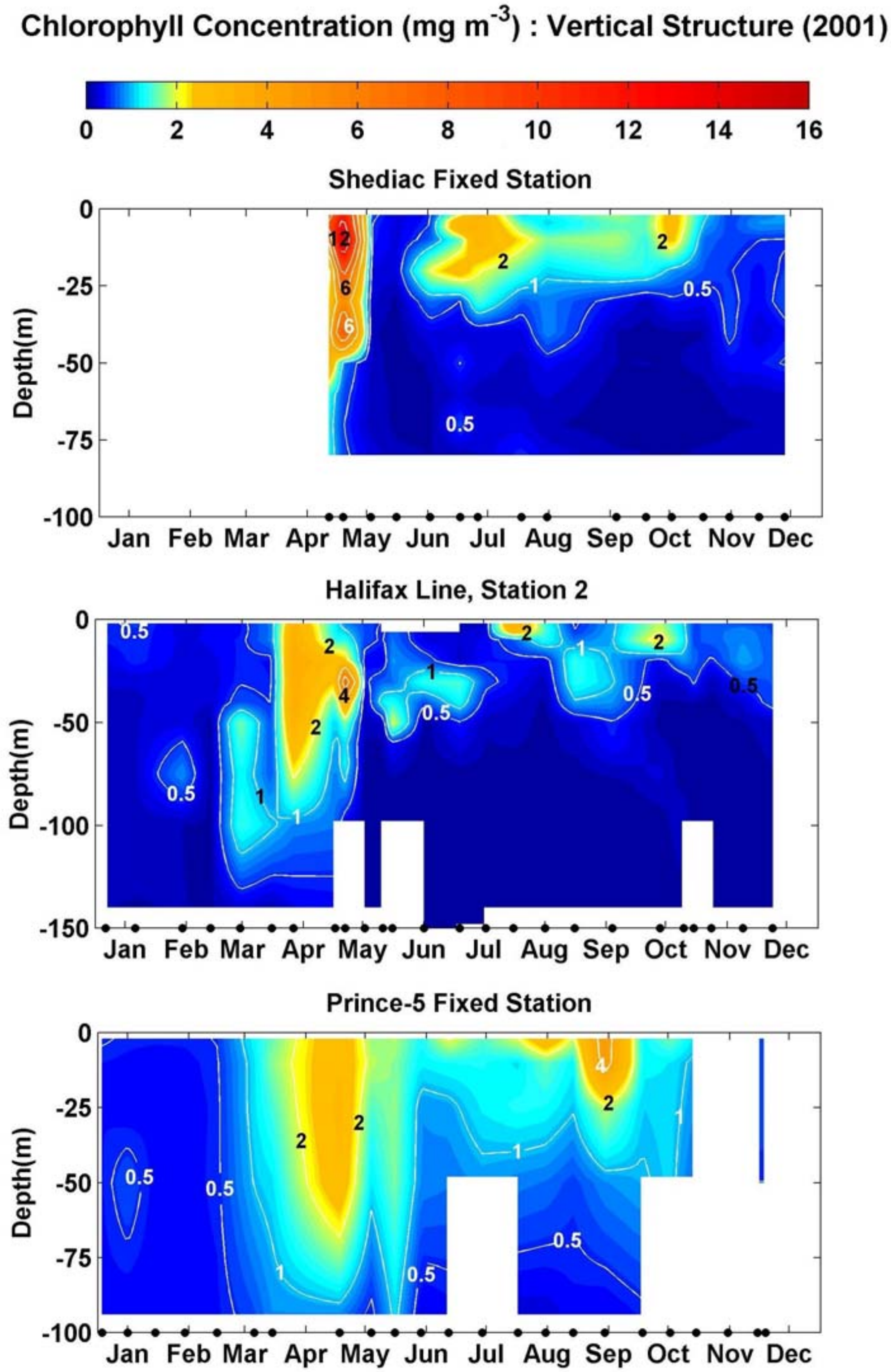


Figure 13. Seasonal variations in phytoplankton abundance and community composition at the Maritimes Region fixed stations in 2001.

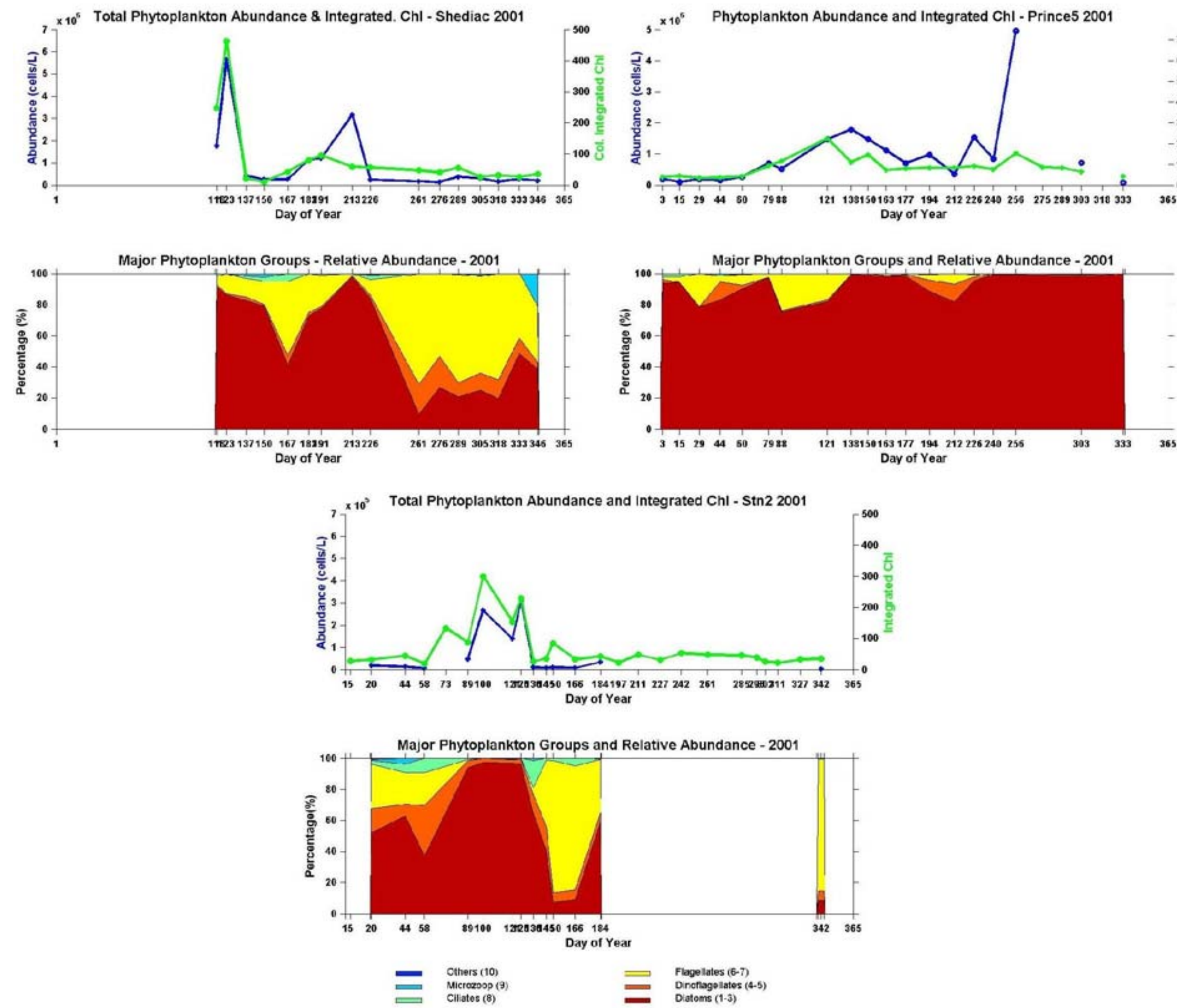


Figure 14. Seasonal variations in zooplankton abundance and community composition at the Maritimes Region fixed stations in 2001.

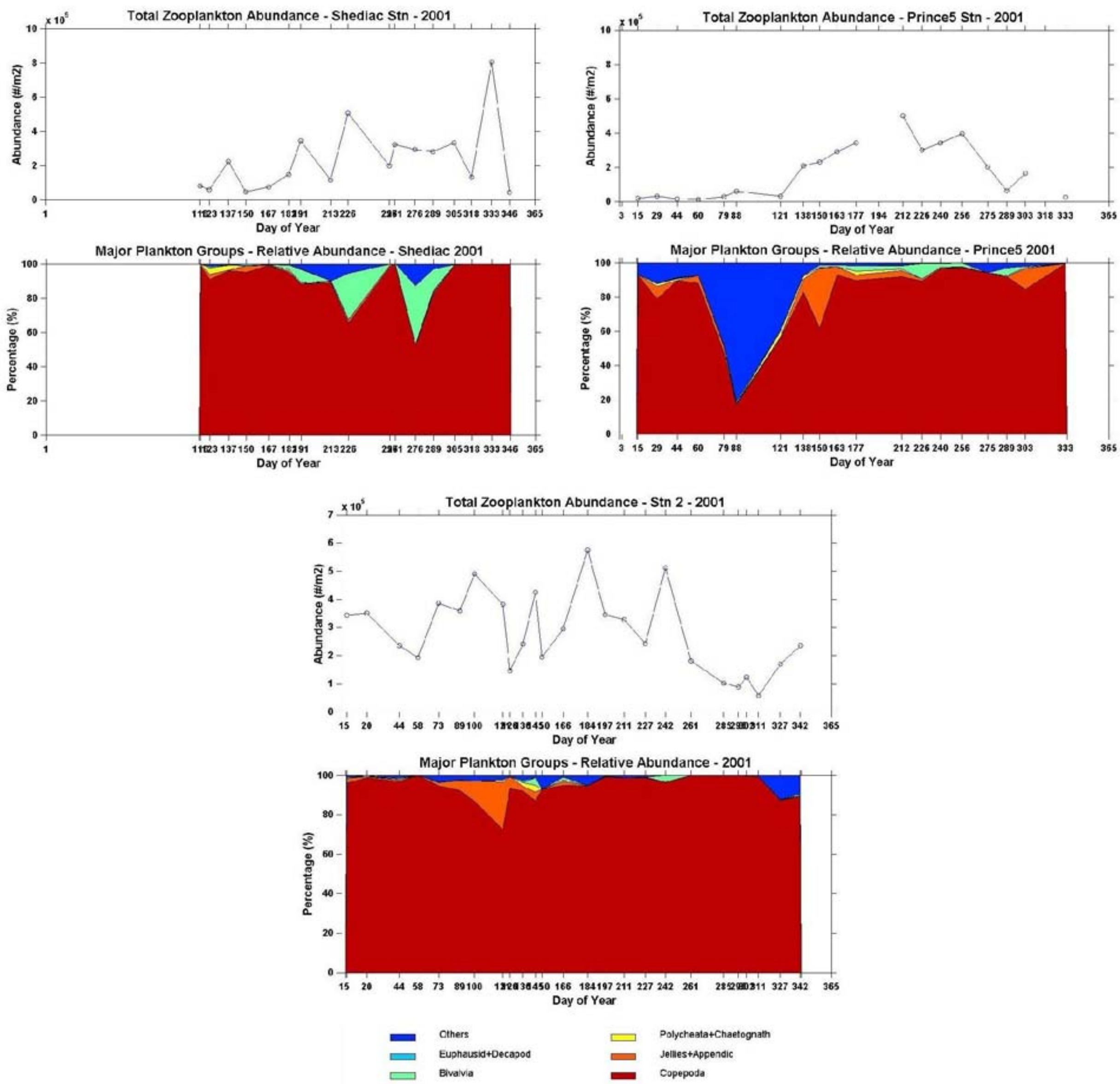


Figure 15. Seasonal variations in copepod abundance and community composition at the Maritimes Region fixed stations in 2001.

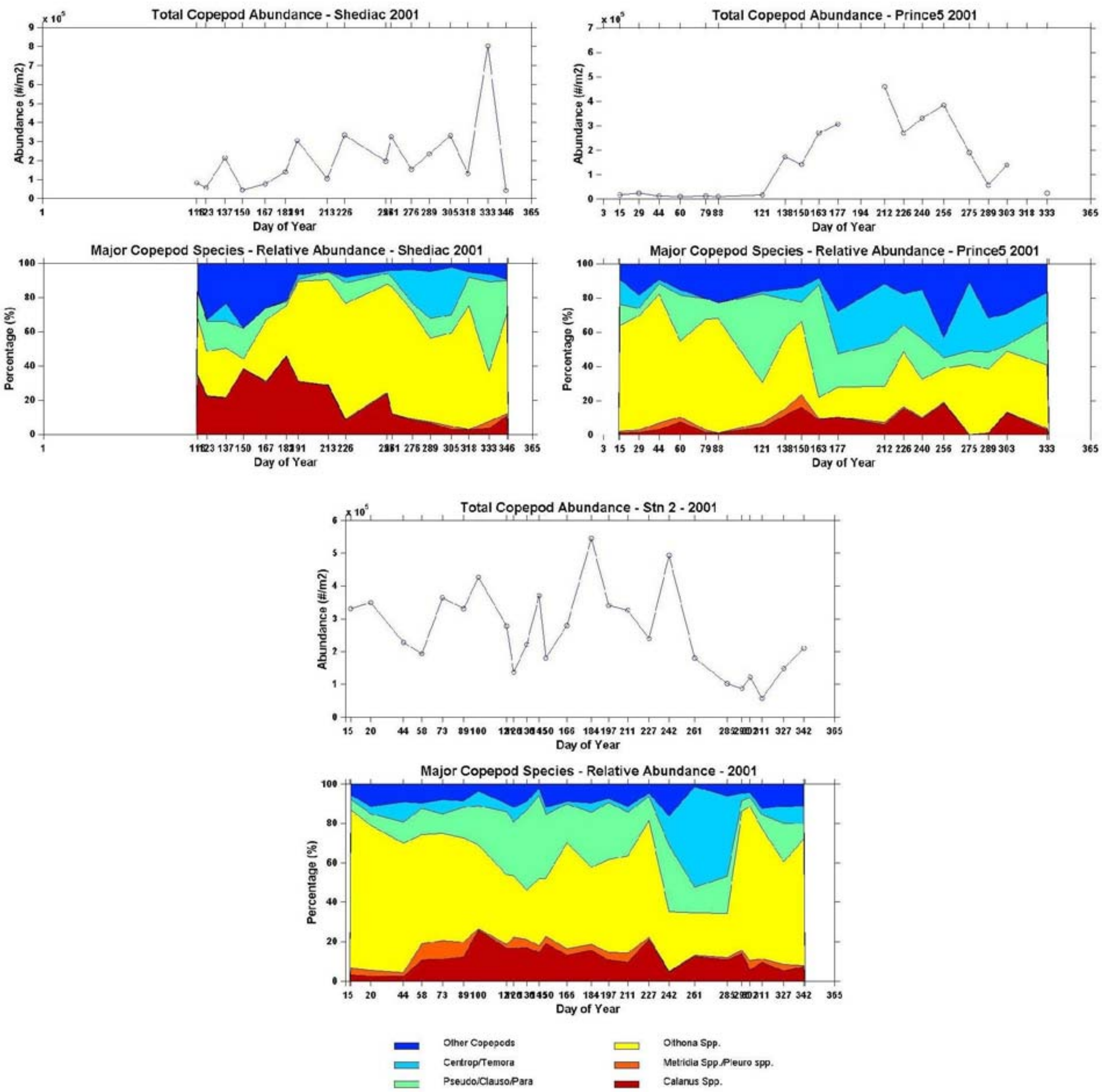


Figure 16. Seasonal variations in *C. finmarchicus* abundance and developmental stages at the Maritimes Region fixed stations in 2001.

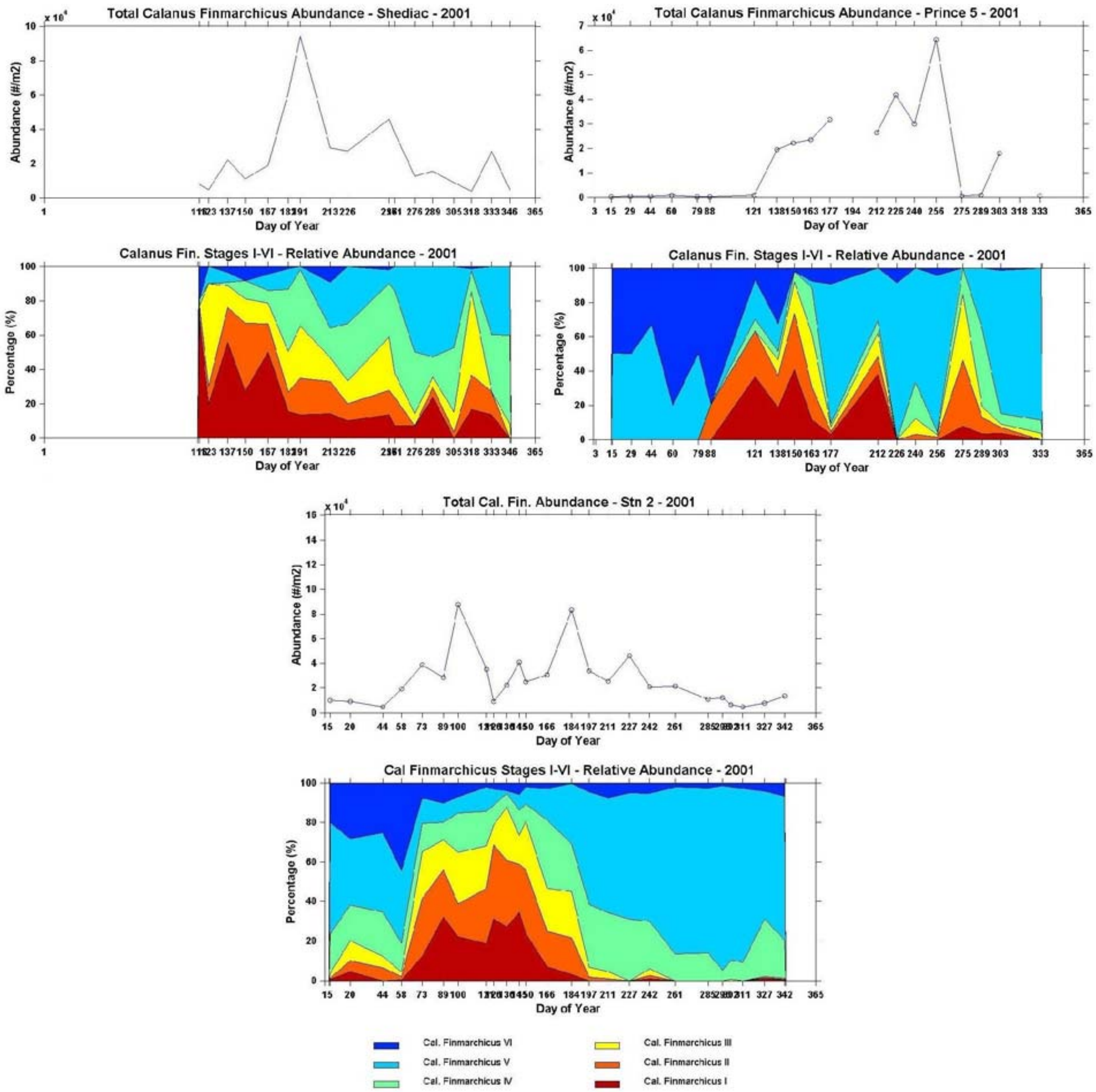


Figure 17. Vertical nitrate structure along the section lines during the spring and fall surveys in 2001. Sampling depths indicated.

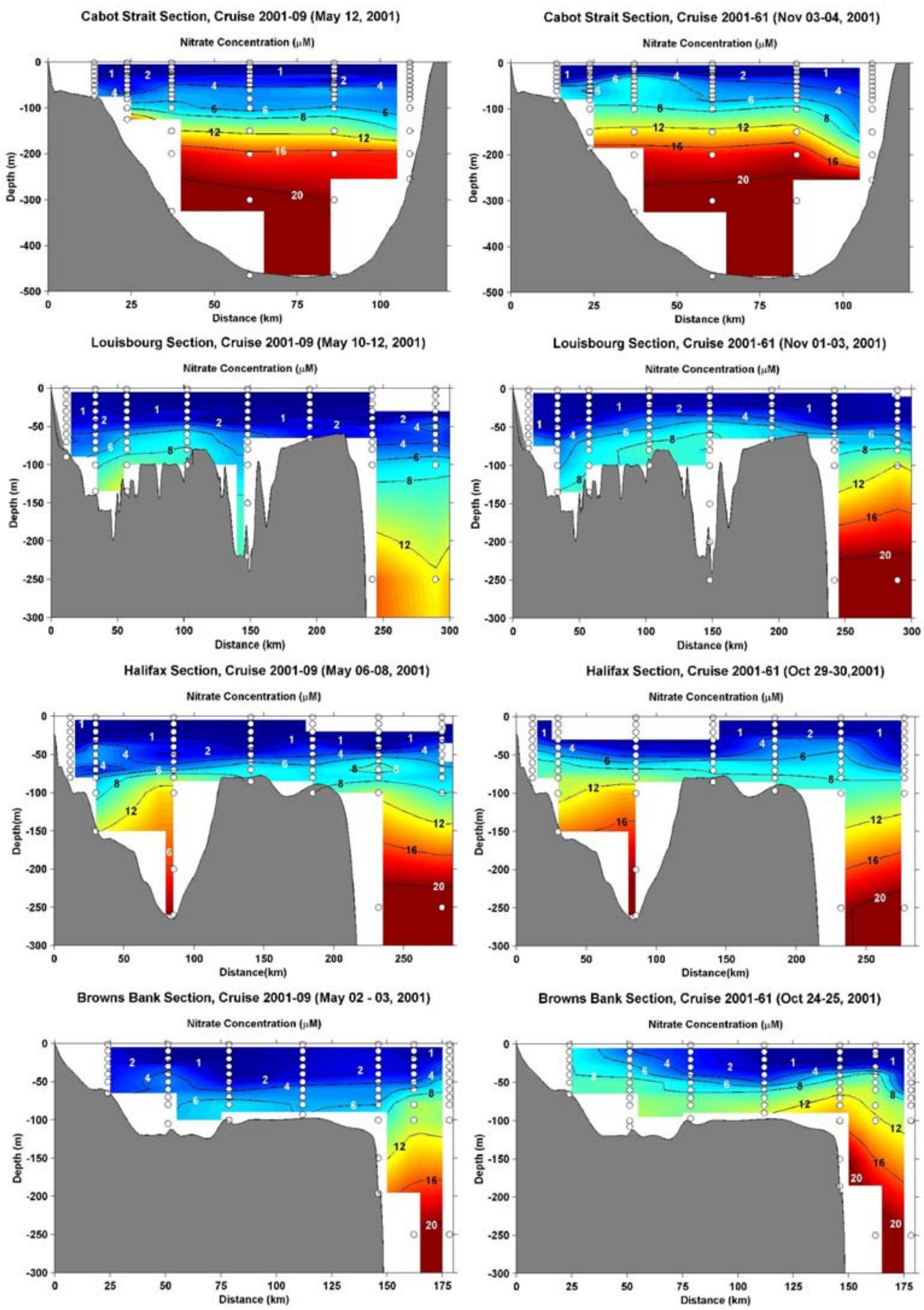


Figure 18. Nitrate anomalies (values in 2001 minus the long-term mean) along the Halifax line during the spring and fall surveys in 2001. Triangles at top of graphs indicate station locations.

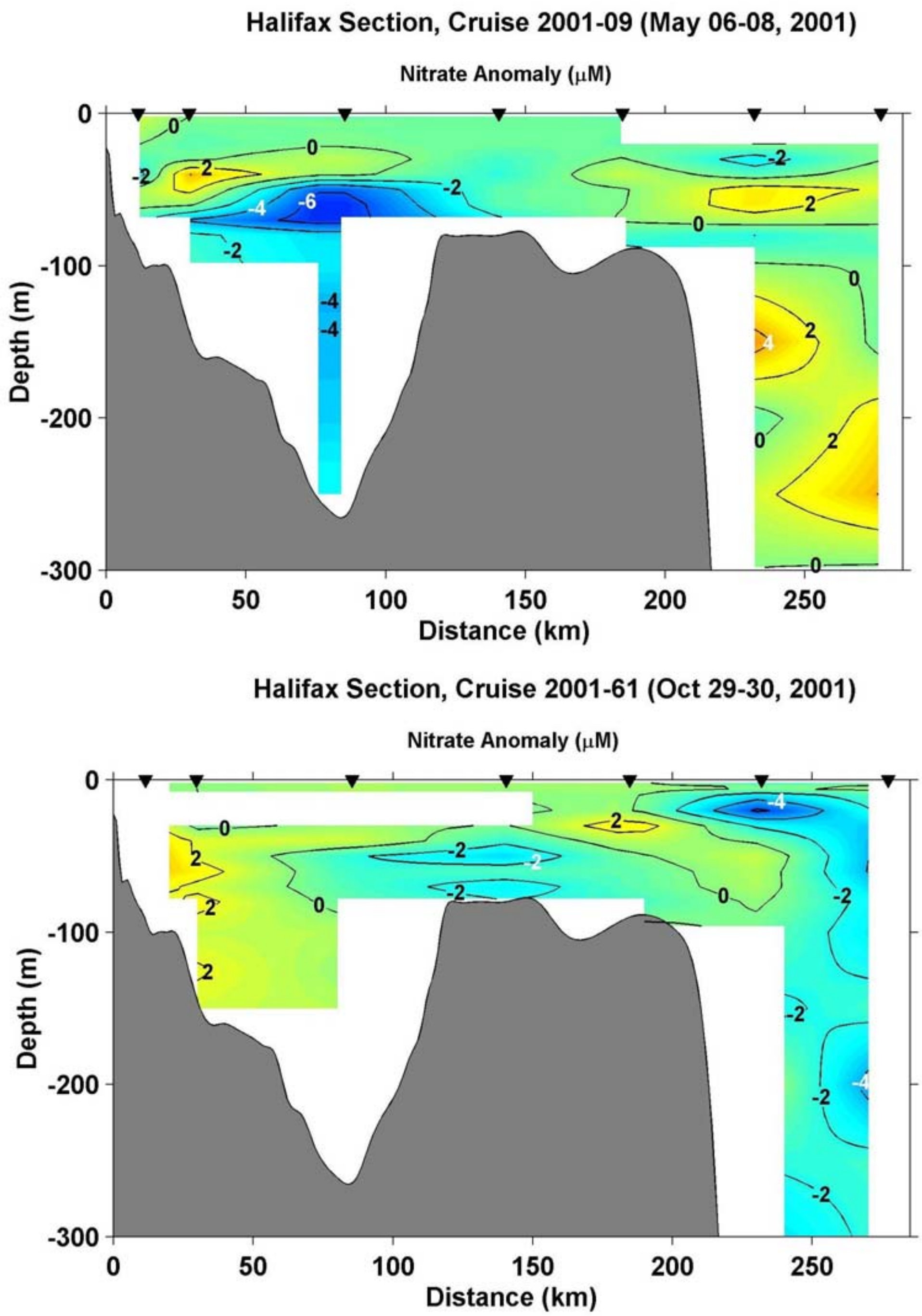


Figure 19. Variability in nitrate inventories (0-50 m integral) along the section lines during the spring and fall surveys in 2001. Stations numbered inshore to offshore (see Fig. 2 for station locations).

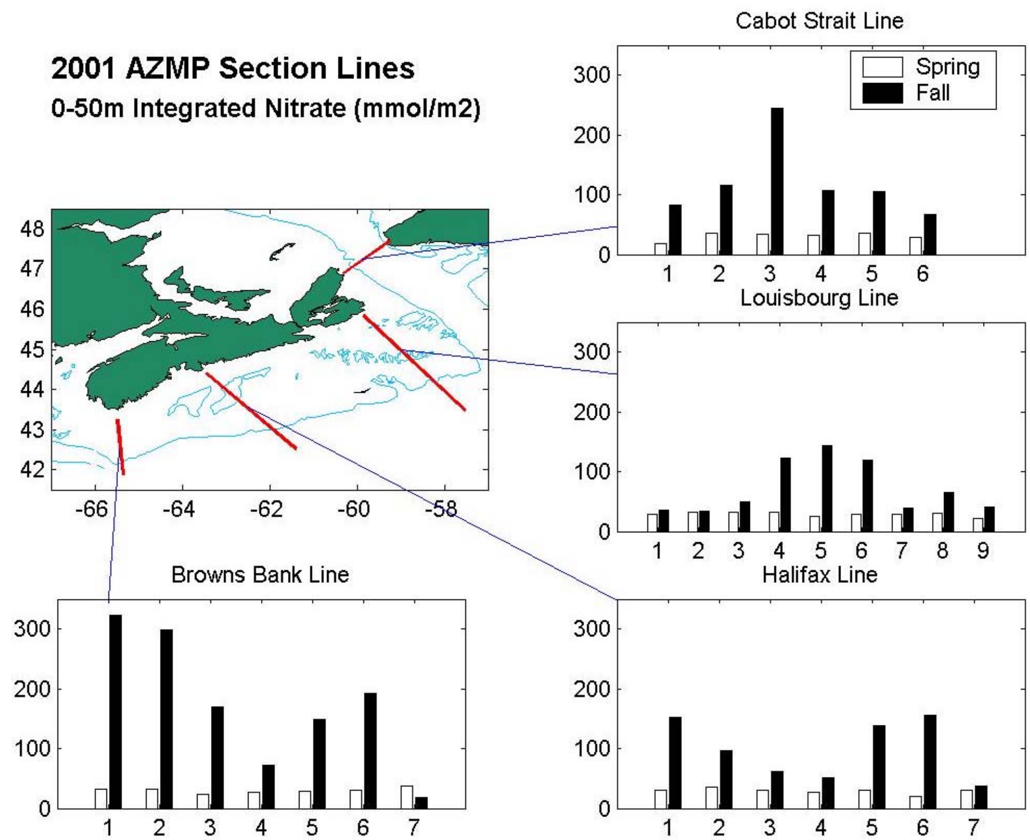


Figure 20. Vertical chlorophyll structure along the section lines during the spring and fall surveys in 2001. Sampling depths indicated.

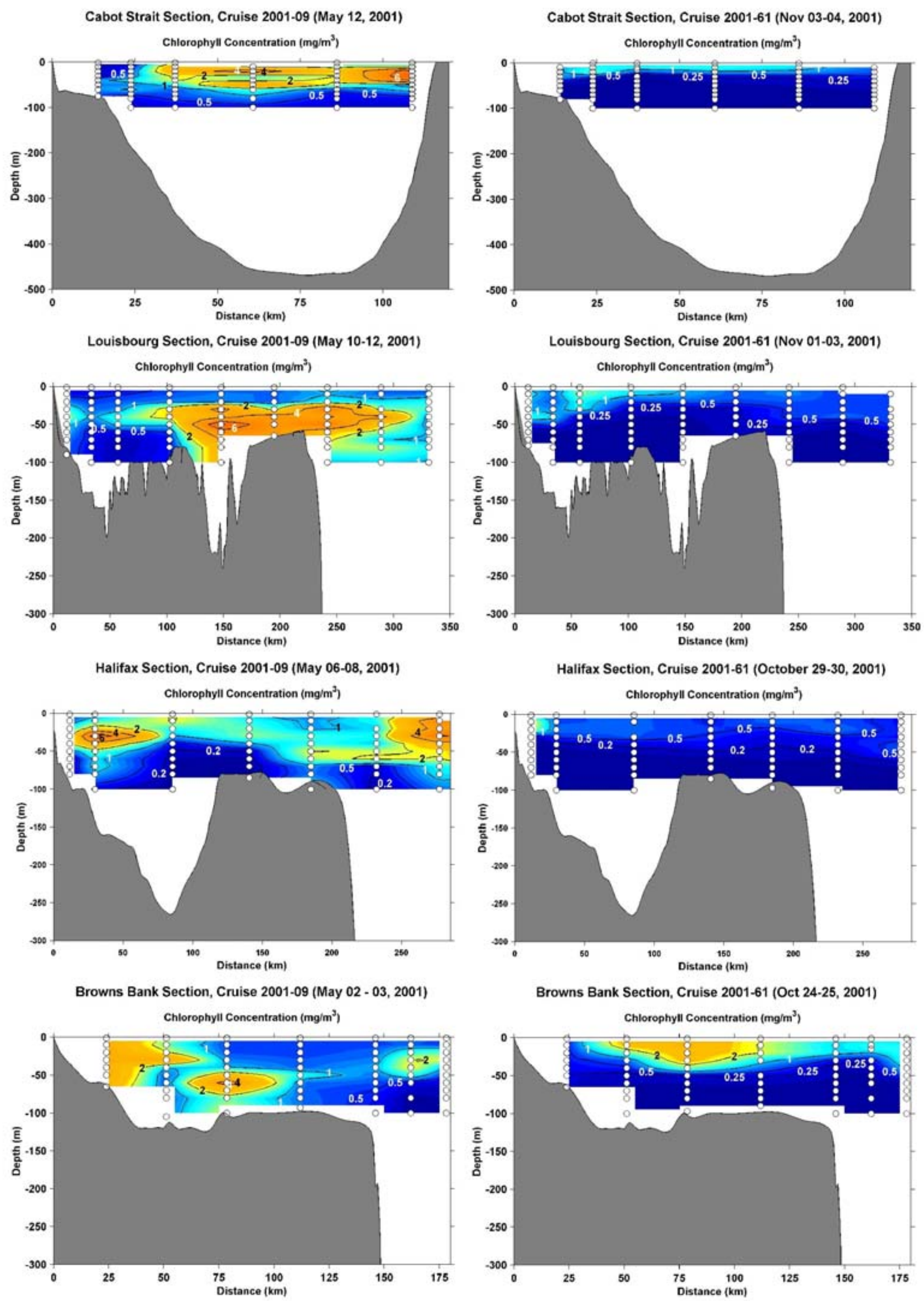


Figure 21. Variability in integrated chlorophyll concentrations (0-100 m) along the section lines during the spring and fall surveys in 2001. Stations numbered inshore to offshore (see Fig. 2 for station locations).

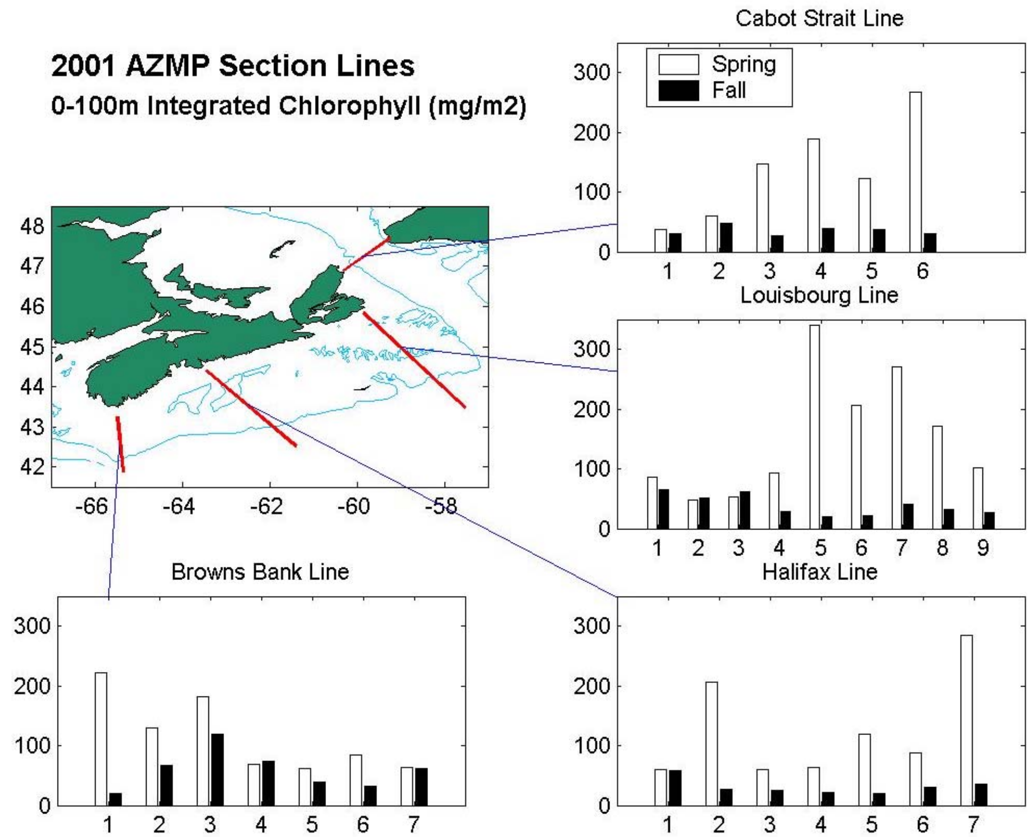


Figure 22. Variability in zooplankton biomass along the section lines during the spring and fall surveys in 2001. Stations numbered inshore to offshore (see Fig. 2 for station locations).

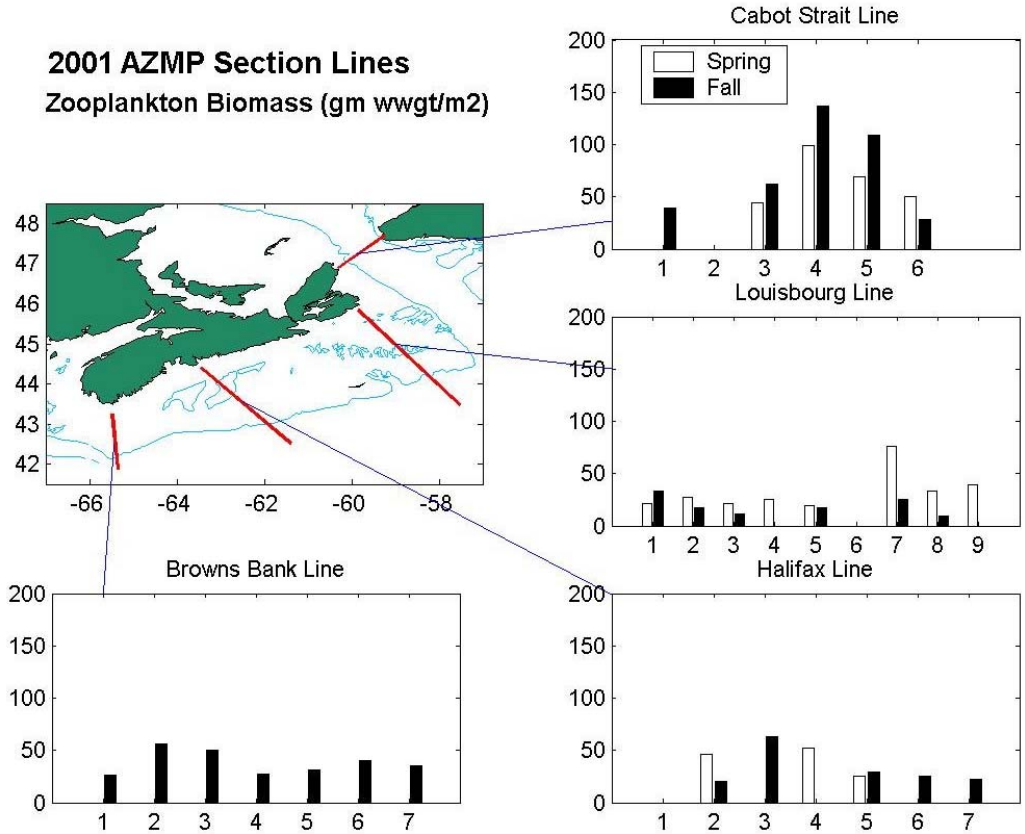


Figure 23. Variability in *C. finmarchicus* abundance along the section lines during the spring and fall surveys in 2001. Stations numbered inshore to offshore (see Fig. 2 for station locations).

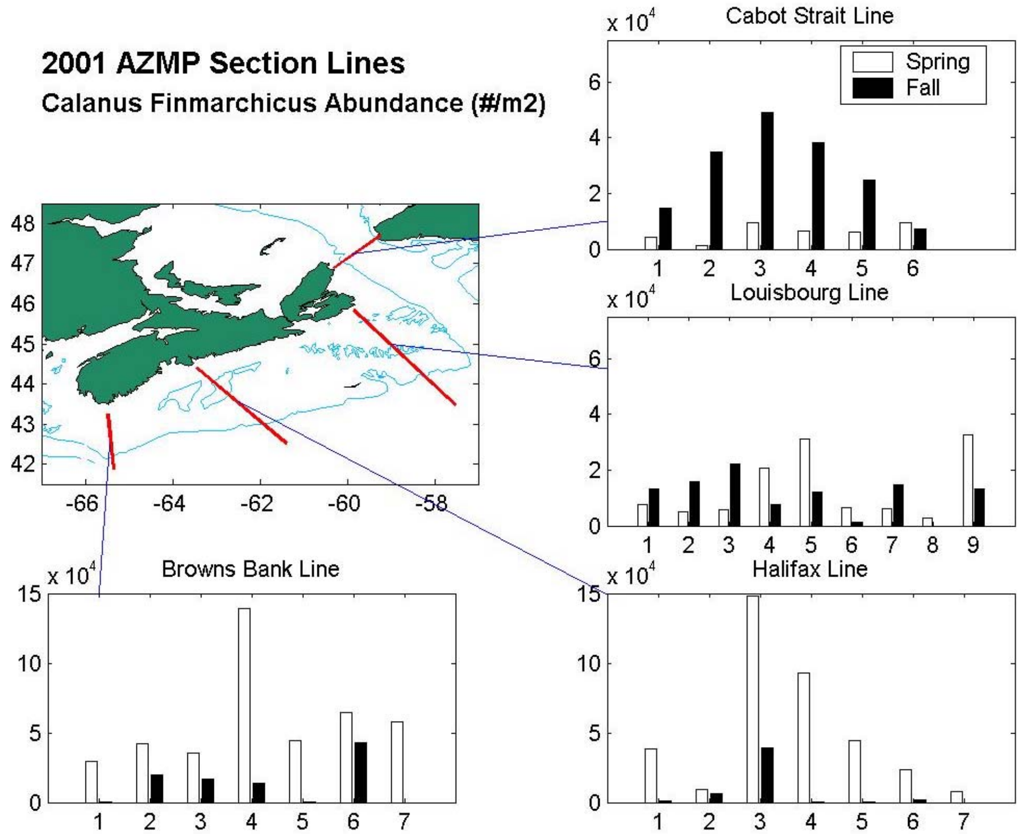


Figure 24. Vertical nitrate structure on the Eastern Scotian Shelf during the 2001winter groundfish survey.

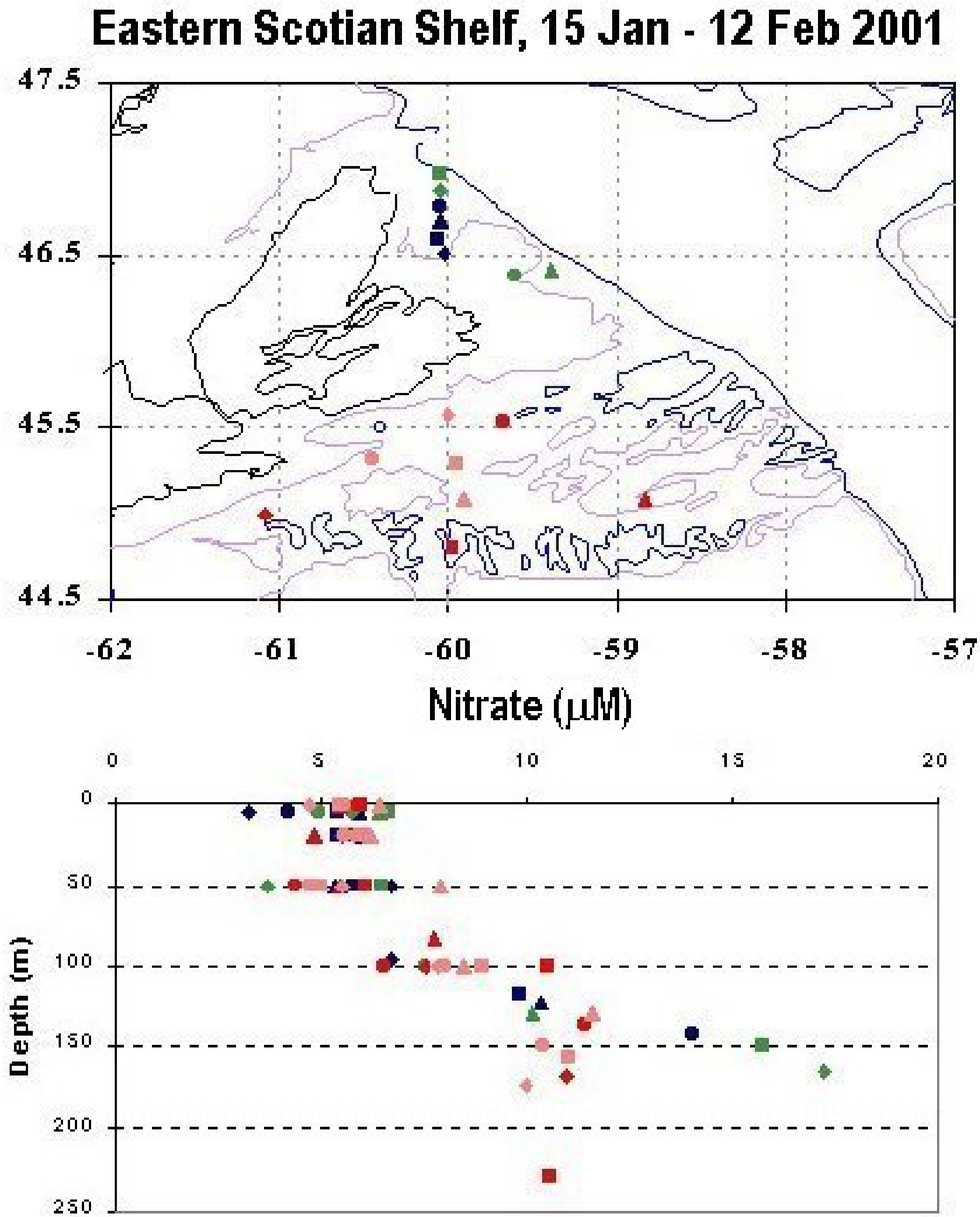


Figure 25. Surface (5 m) and bottom nitrate concentrations and anomaly (values in 2001 minus the long-term mean) maps for the Scotian Shelf during the annual summer groundfish survey (3-31 July 2001).

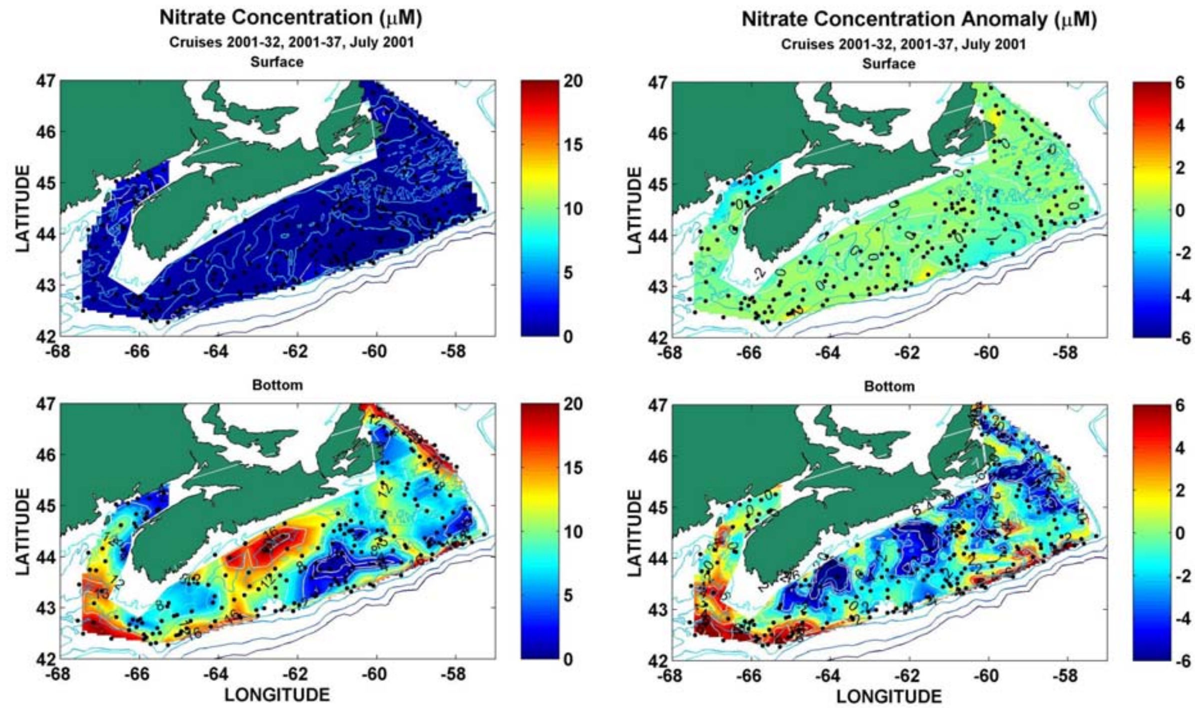


Figure 26. Bottom oxygen concentrations (% saturation) on the Scotian Shelf during the annual summer groundfish surveys (1998-2001).

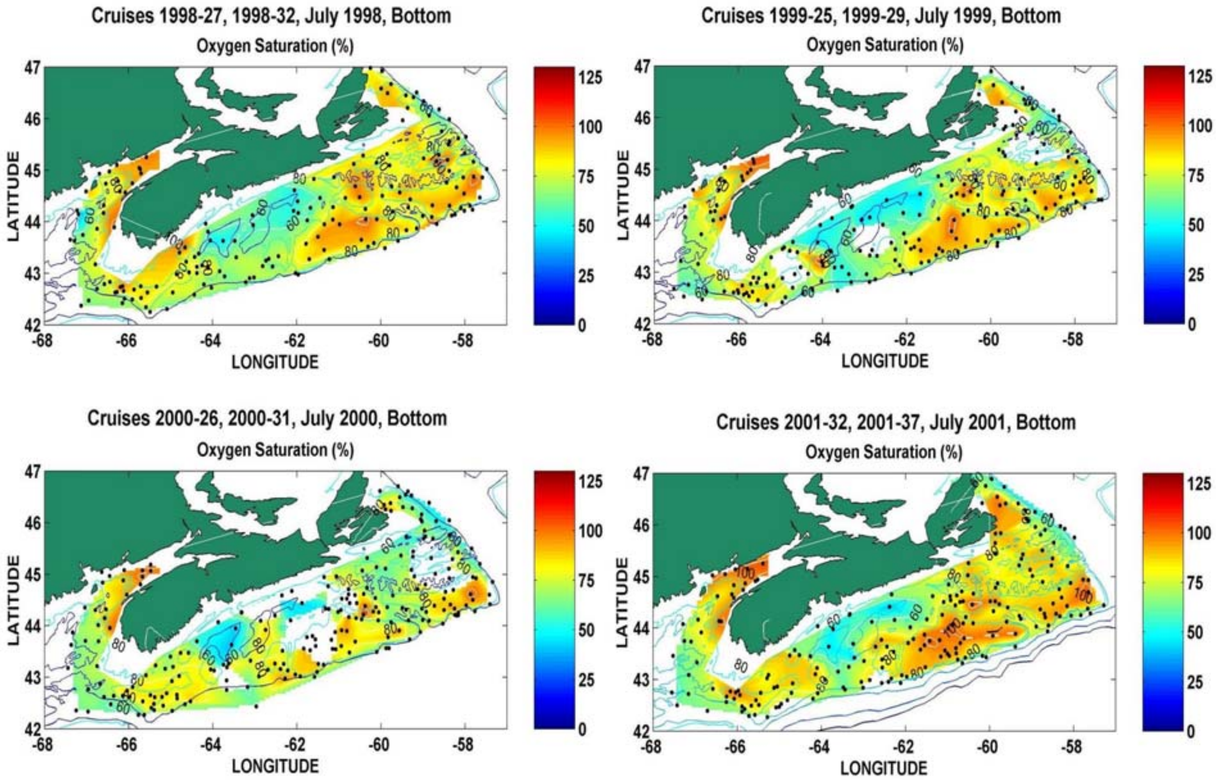


Figure 27. Surface (5 m) and bottom nitrate concentrations for the Southern Gulf of St. Lawrence during the annual fall groundfish survey (4-28 September, 2001).

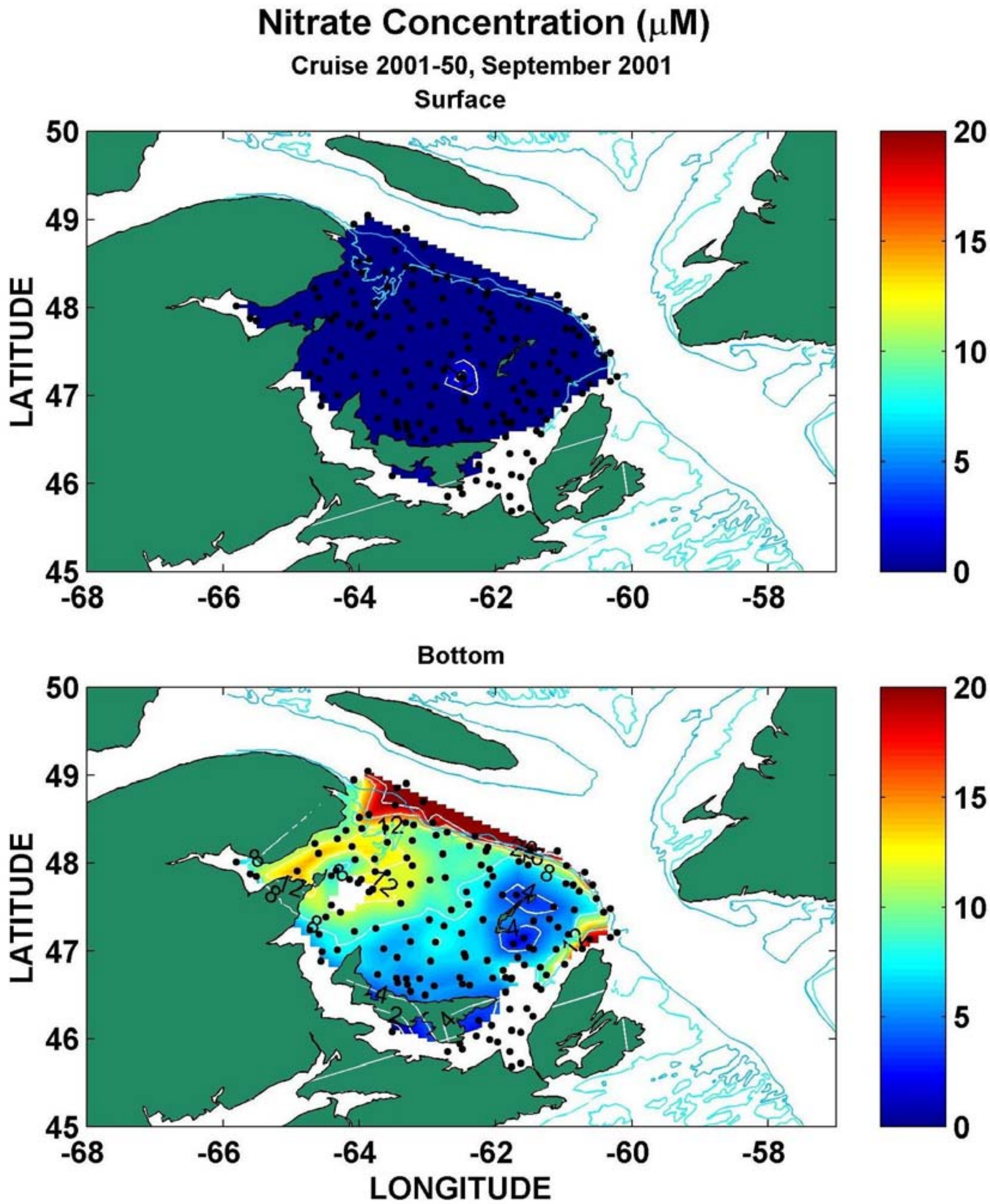


Figure 28. Surface (5 m) and bottom chlorophyll concentrations and anomaly (values in 2001 minus the long-term mean) maps for the Scotian Shelf during the annual summer groundfish survey (3-31 July, 2001).

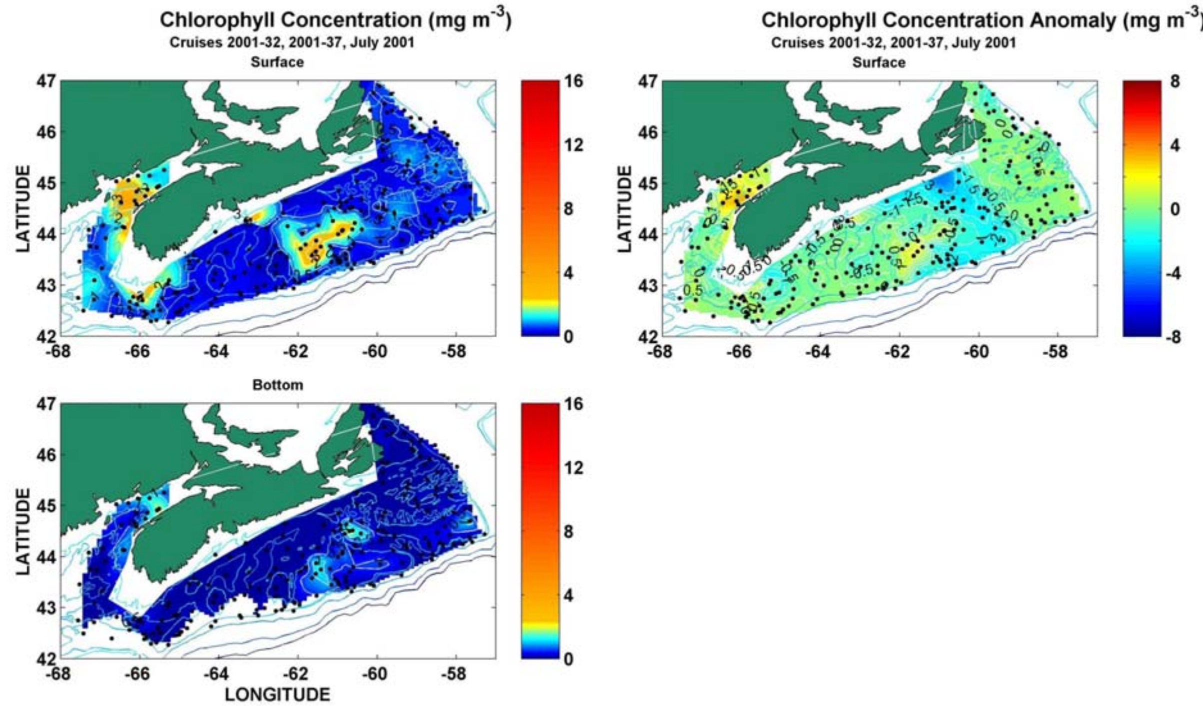


Figure 29. Surface (5 m) and bottom chlorophyll concentrations for the Southern Gulf of St. Lawrence during the annual fall groundfish survey (4-28 September, 2001).

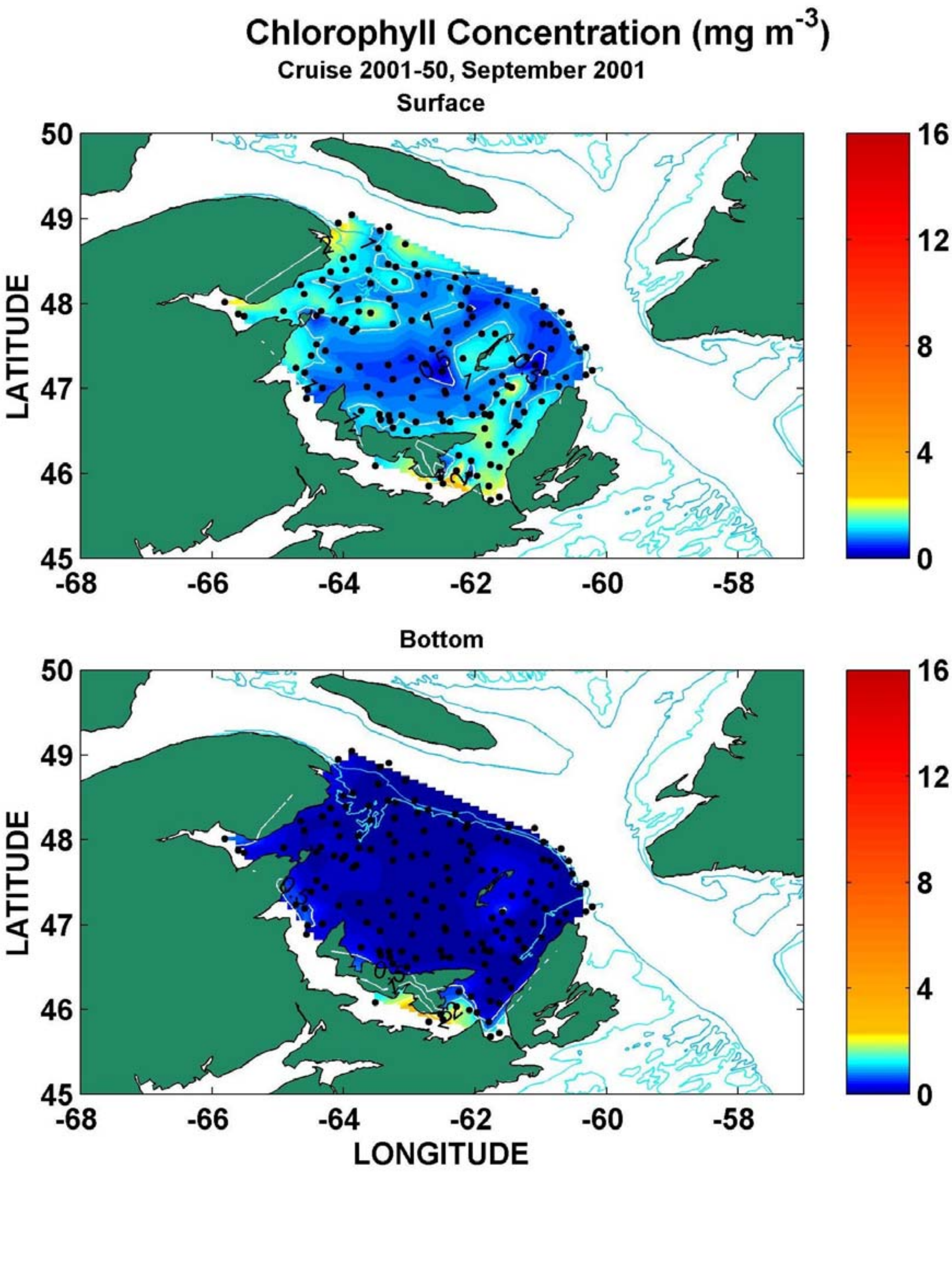


Figure 30. Seasonal variability in surface chlorophyll concentrations (from SeaWiFS bi-weekly ocean colour composites) at the Shediac Valley (Shediac), Halifax-2 (HFX-2) and Prince-5 (P-5) fixed stations. Levels in 2001 compared with 4-year (1998-2001) means.

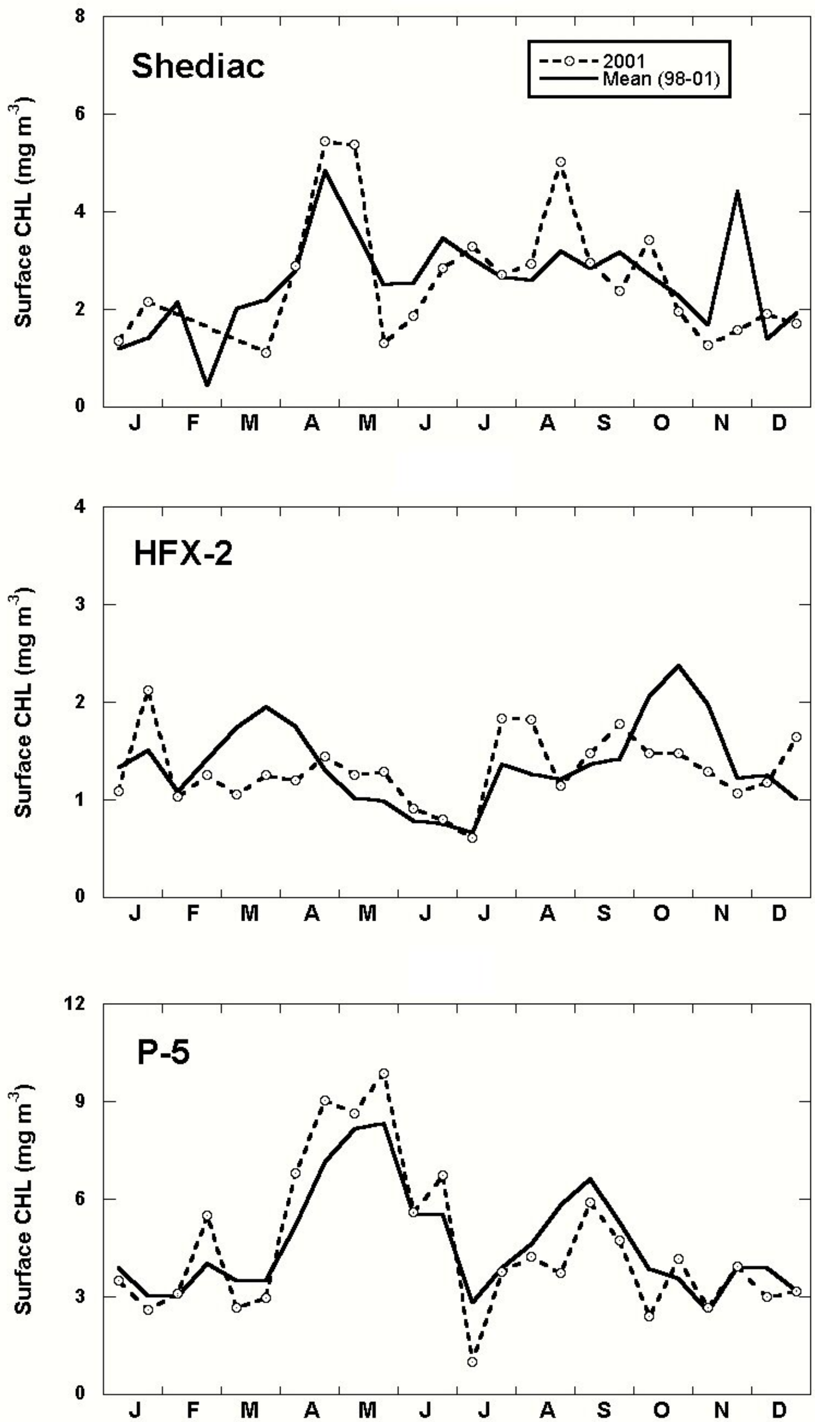
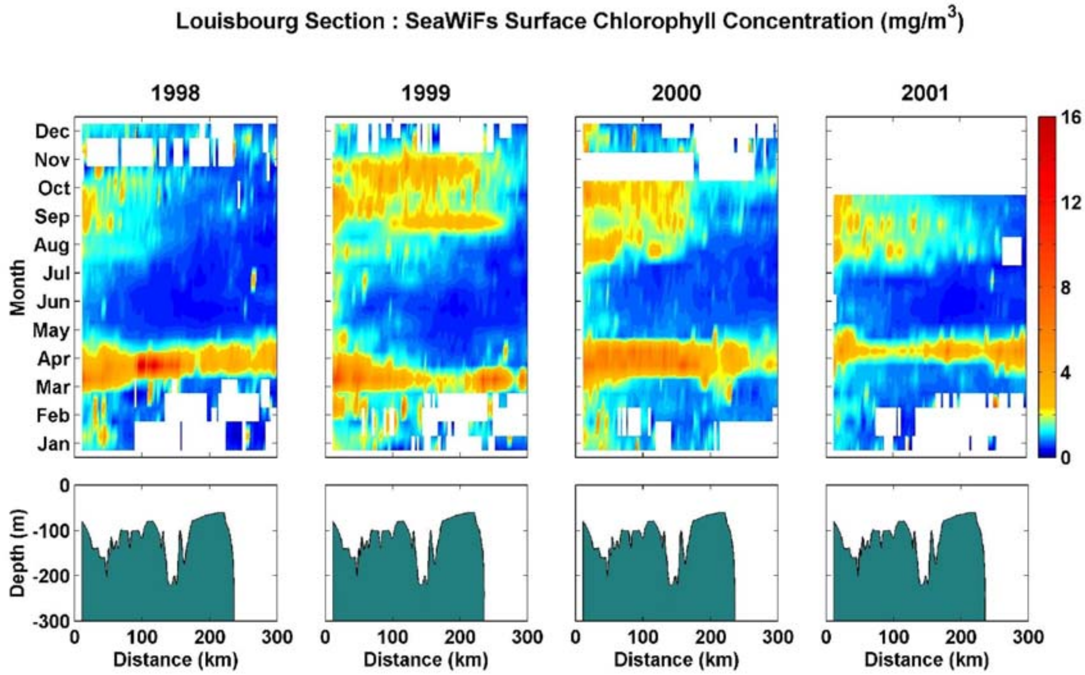


Figure 31. Seasonal variability in surface chlorophyll concentrations (from SeaWiFS bi-weekly ocean colour composites) along the Halifax and Louisbourg Lines, 1998-2001.



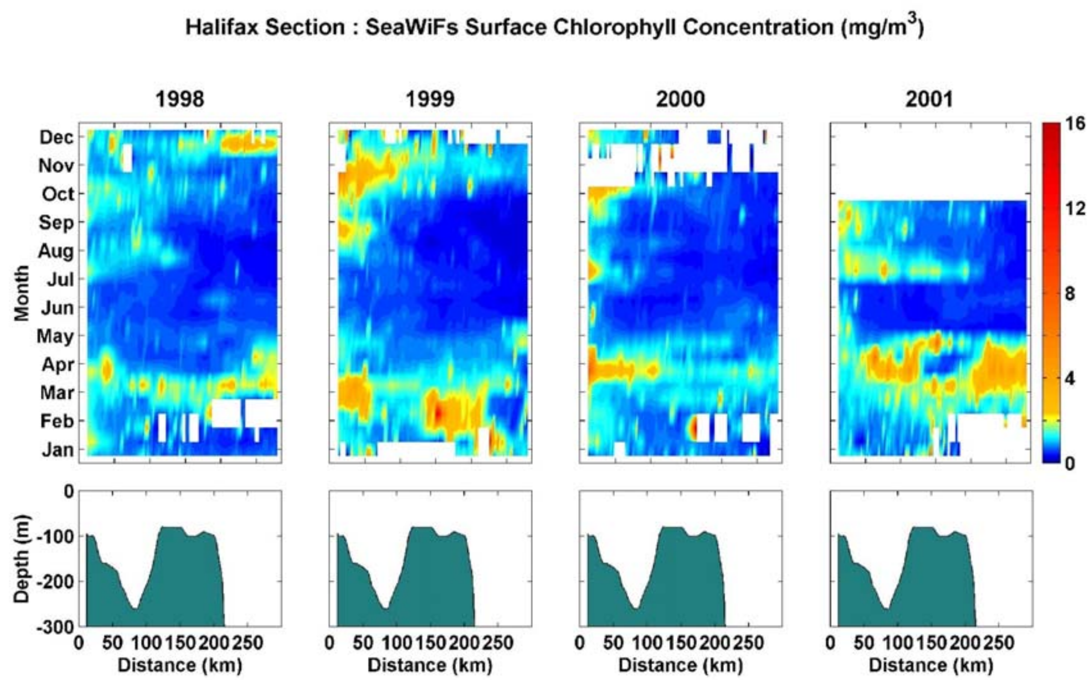


Figure 32. Time-series of surface chlorophyll concentrations (from SeaWiFS bi-weekly ocean colour composites) for selected sub-regions of the Maritimes Region (see Fig. 5), 1998-2001.

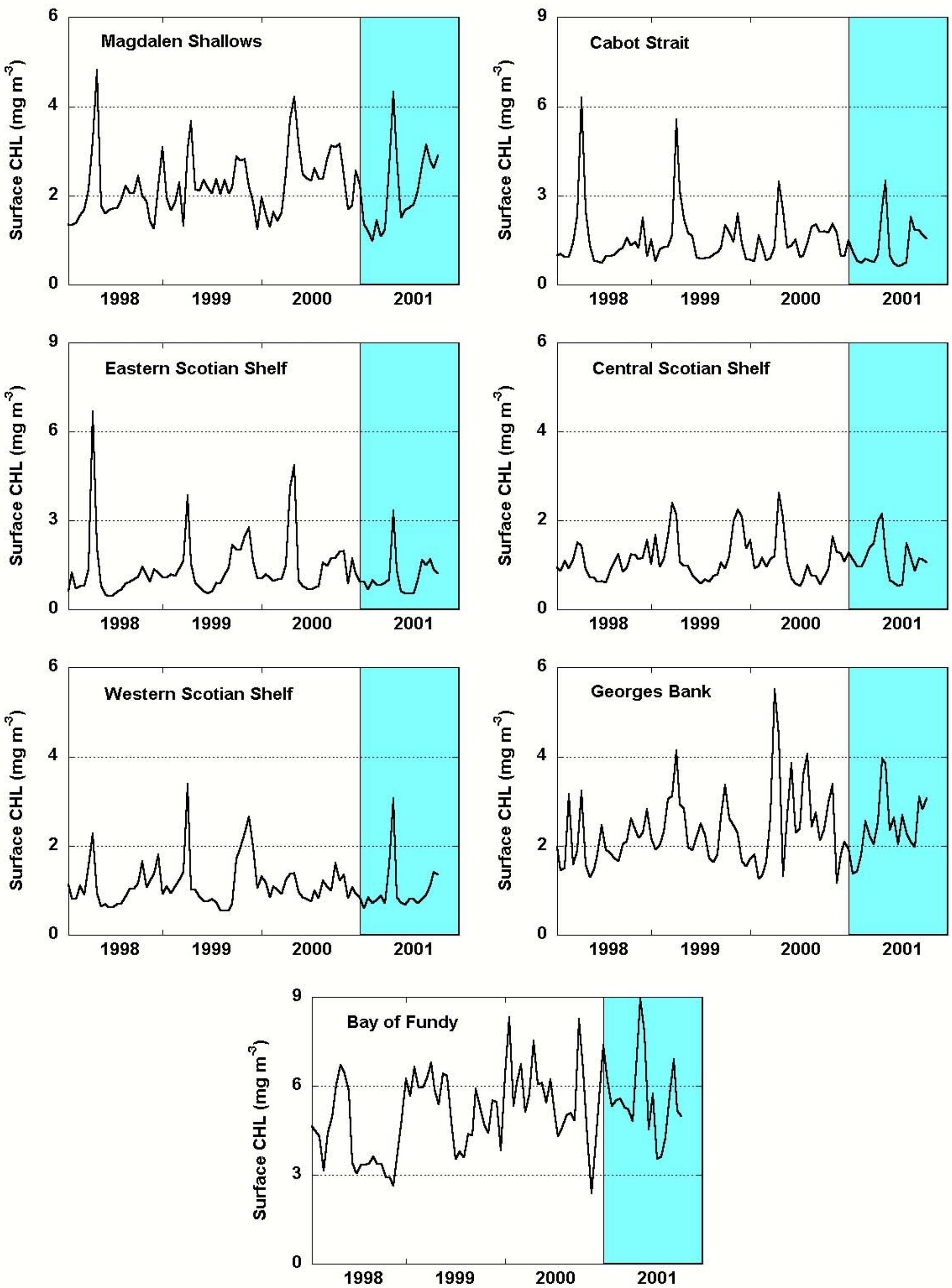


Figure 33. Top panel: Regional and interannual variability in annual mean surface chlorophyll concentrations (from SeaWiFS bi-weekly ocean colour composites) for selected sub-regions of the NW Atlantic (see Fig. 5). Bottom panel: Chlorophyll concentrations in 2001 compared with mean concentrations for the SeaWiFS period, 1998-2001.

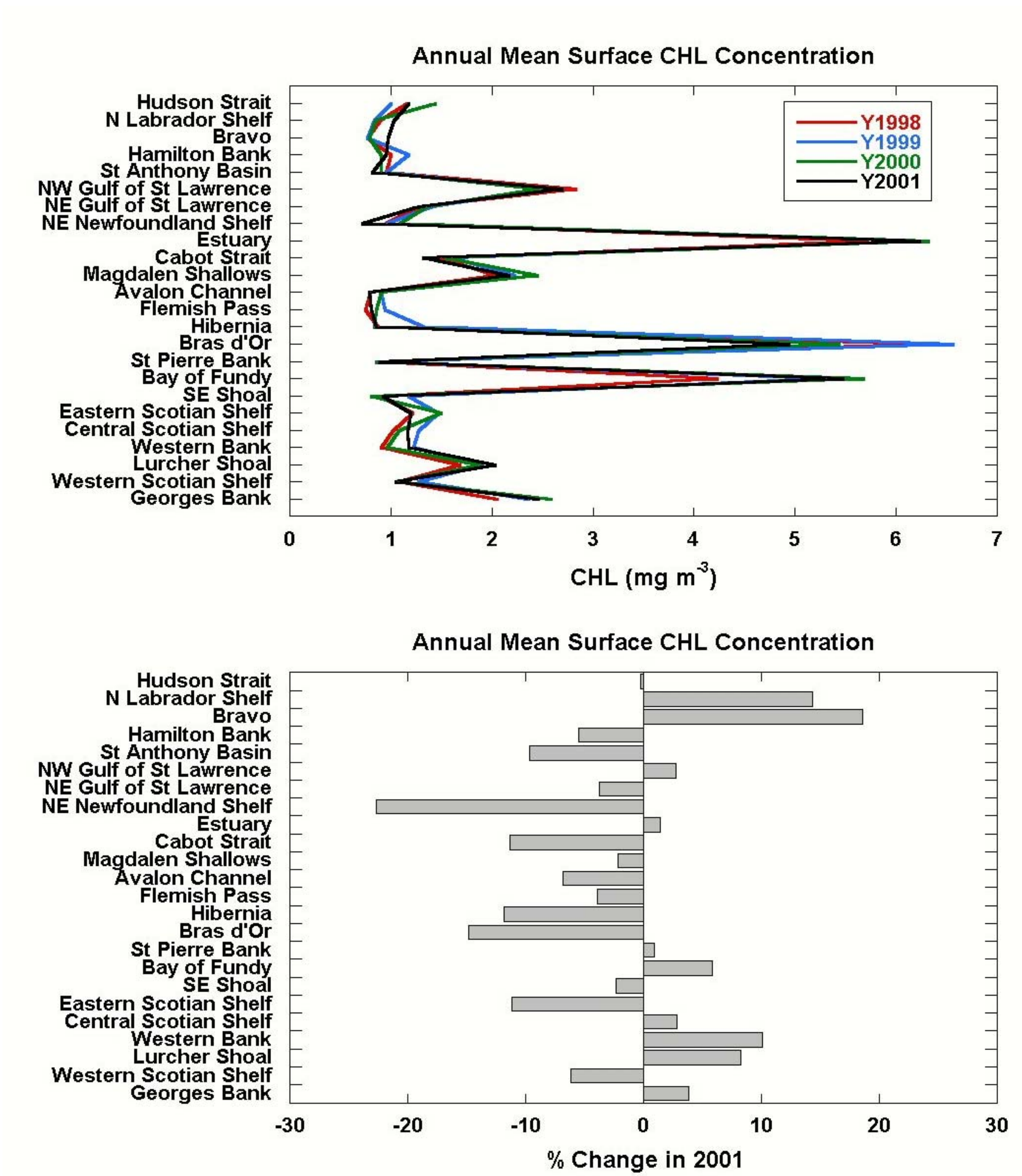


Figure 34. Interannual variability in phytoplankton biomass (colour index), diatom and dinoflagellate abundances (annual means) on the Scotian Shelf and the western North Atlantic collected from CPR surveys, 1961-2000 (see Fig. 4 for area coverage). Vertical bars are standard errors.

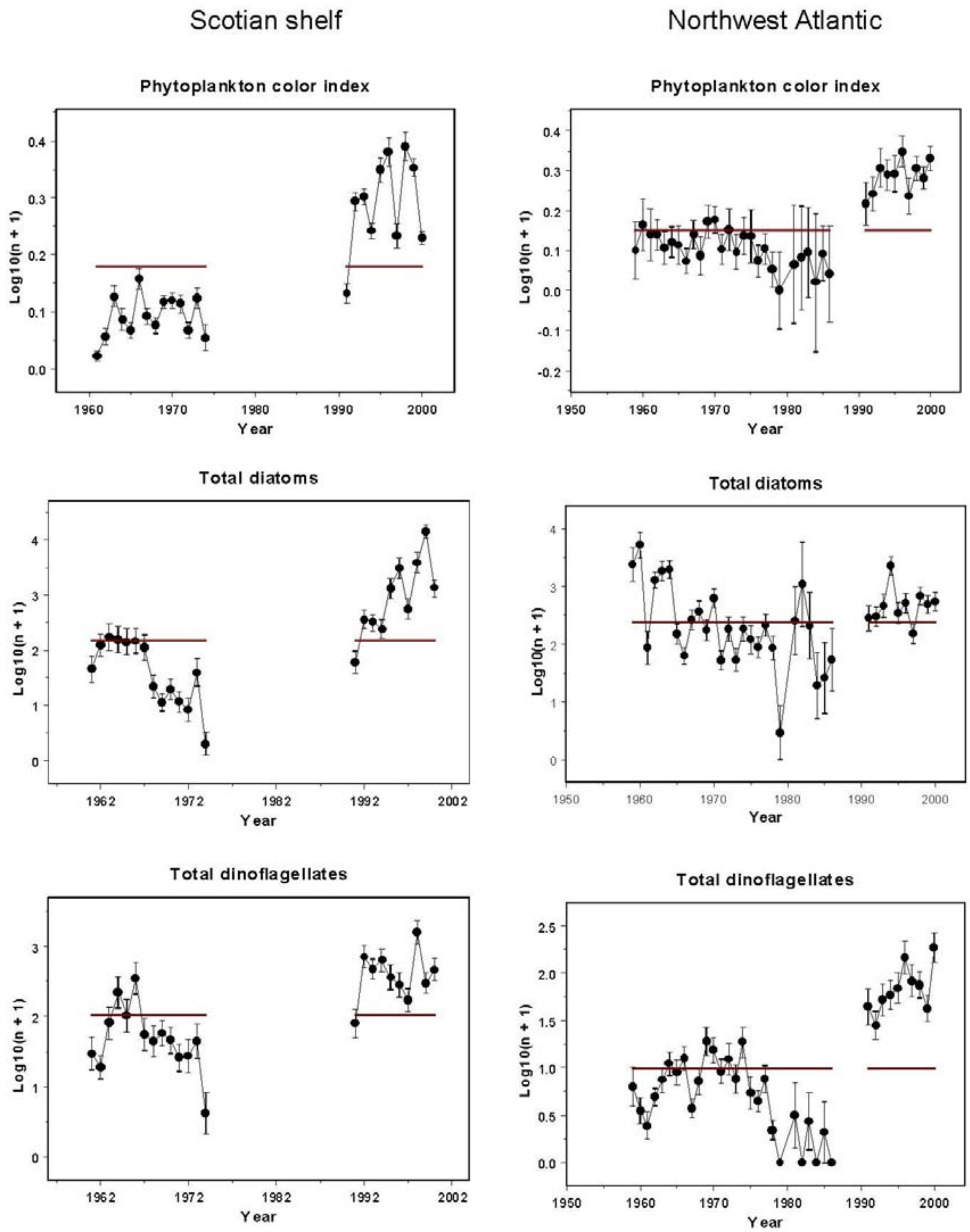


Figure 35. Contour plots of phytoplankton biomass (colour index), diatom, dinoflagellate and *C. finmarchicus* adundances on the Scotian Shelf and western North Atlantic from CPR surveys, 1961-2000 (see Fig. 4 for area coverage) showing interannual variability in seasonal abundance peaks.

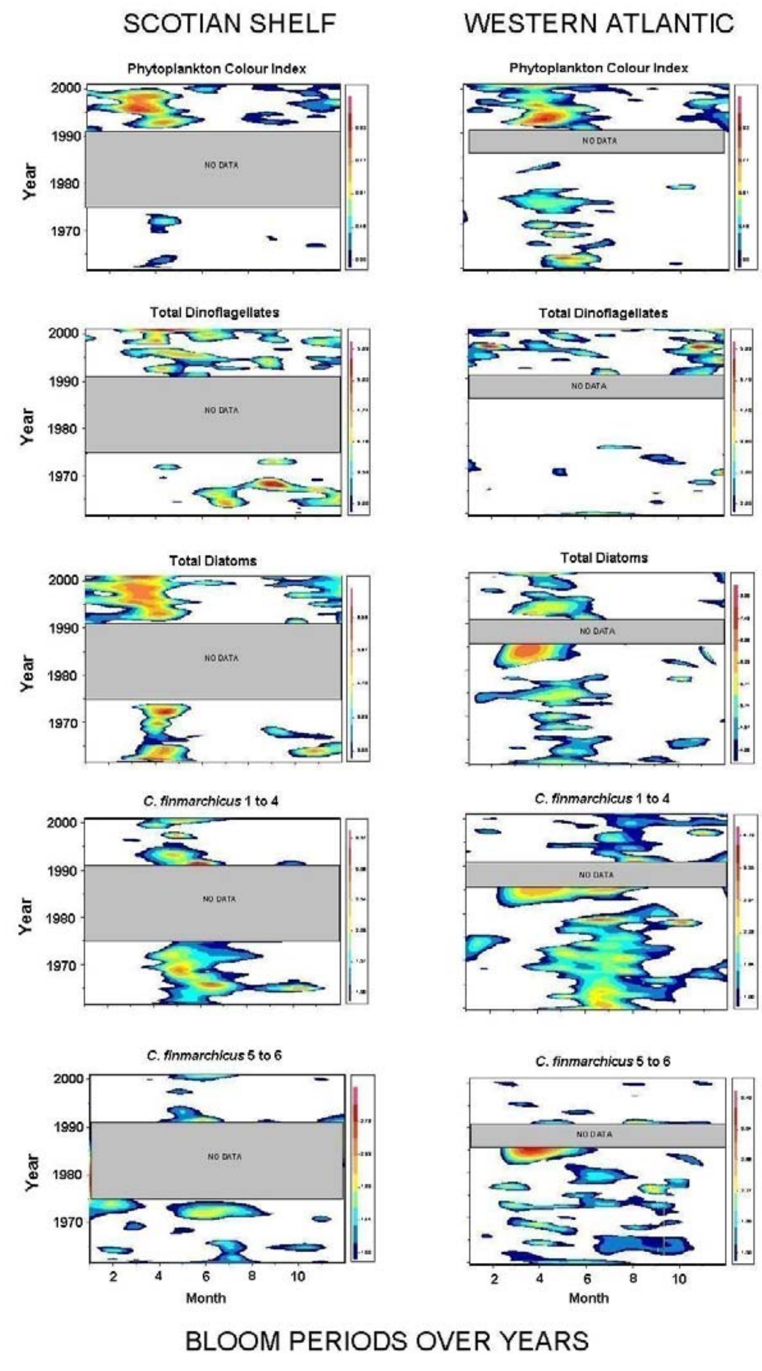


Figure 36. Interannual variability in abundance of selected zooplankton species (annual means) on the Scotian Shelf and the western North Atlantic collected from CPR surveys, 1961-2000 (see Fig. 4 for area coverage). Vertical bars are standard errors.