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Optical, chemical and biological oceanographic conditions in the Maritimes/Gulf regions in 2004

Conditions océanographiques optiques, chimiques et biologiques dans les régions des Maritimes et du Golfe en 2004

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ABSTRACT

Optical, chemical, and biological oceanographic conditions in the Maritimes/Gulf regions (Georges Bank, eastern Gulf of Maine, Bay of Fundy, Scotian Shelf and Southern Gulf of St. Lawrence) during 2004 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/Gulf regions are discussed also to provide the larger, zonal perspective.

Optical properties at the Maritimes/Gulf fixed stations in 2004 differed by site but were, for the most part, comparable to conditions observed in previous years. Mixed-layer depths at the Halifax-2 station in 2004 were deeper in early spring and late fall than observed previously. In addition, onset of stratification was later in spring and break-up earlier in fall than typically observed at this station.

Nitrate concentrations in surface waters in 2004 were higher in winter at the Halifax-2 and Prince-5 fixed stations and lower in summer at Halifax-2 than seen in previous years. Below surface (>50 m) nitrate concentrations were lower than observed in previous years at all fixed stations in 2004 and considerably lower than the climatological mean. Nitrate concentrations were also lower than observed previously in bottom waters of the Scotian Shelf in summer 2004 while concentrations were higher in bottom waters of the Southern Gulf in fall. The springtime reduction in surface nitrate concentrations at the Prince-5 fixed station occurred almost 2 month earlier in 2004 than in previous years.

The most prominent feature of the phytoplankton in the Maritimes/Gulf regions in 2004 was the widespread and strong spring bloom; peak chlorophyll concentratioins were close to the record high levels observed in 2003. High spring chlorophyll concentrations were most evident at the Halifax-2 fixed station, along the spring section survey on the eastern and western Scotian Shelf and in the Southern Gulf and on Georges Bank from satellite ocean colour data. At the Prince-5 fixed station, the bloom, although not as strong as in 2003, occurred almost two months earlier than in previous years. Surface chlorophyll levels were lower on the Scotian Shelf in summer and higher in the Southern Gulf in fall in 2004 than in the previous year. CPR data continue to show that contemporary phytoplankton levels are at or above the long-term average and that the seasonal growth cycle starts earlier in the year than observed during the decade of the 1960s/1970s when observations began.

Zooplankton biomass and *C. finmarchicus* abundance were lower in 2004 than in the previous year at the Shediac Valley fixed station and on the central and western Scotian Shelf (in spring). Biomass and *C. finmarchicus* abundance were higher in 2004 than in 2003 on Georges Bank in winter and on the central and eastern Scotian Shelf and in the Southern Gulf in fall. In 2004, the timing of *C. finmarchicus* reproduction at Halifax-2 appeared to be earlier than in the previous years. At all fixed stations, but most prominent at Prince-5, the contribution of *Calanus* to the copepod community has steadily increased over the past several years. CPR data continue to show that contemporary zooplankton levels are at or well below numbers observed during the decade of the 1960s/1970s when observations began.

RÉSUMÉ

On passe en revue les propriétés optiques, chimiques et biologiques de l'océan dans les régions des Maritimes et du Golfe (banc Georges, est du golfe du Maine, baie de Fundy, plate-forme Scotian et sud du golfe du Saint-Laurent) en 2004, puis on les compare aux conditions durant l'année précédente et à long terme s'il y a lieu. En plus de descriptions des séries de données de base du PMZA (stations fixes, transects saisonniers, relevés du poisson de fond, enregistreurs de plancton en continu [EPC], télédétection), on examine un certain nombre de données provenant de l'extérieur de ces régions afin de donner une vue d'ensemble de la zone.

Les propriétés optiques aux stations fixes des régions des Maritimes et du Golfe en 2004 différaient de l'une à l'autre, mais elles étaient pour la plupart comparables aux conditions observées les années précédentes. La profondeur de la couche de mélange à la station Halifax-2 en 2004 était plus grande au début du printemps et à la fin de l'automne que selon les observations précédentes. De plus, le début de la stratification a été plus tardif au printemps et la déstratification à l'automne, plus précoce que d'habitude à cette station.

Les teneurs en nitrate des eaux de surface en 2004 étaient plus élevées en hiver aux stations fixes Halifax-2 et Prince-5 et plus basses en été à Halifax-2 que les années précédentes. Les teneurs en nitrate sous la surface à toutes les stations fixes en 2004 étaient plus faibles que celles des années précédentes et considérablement inférieures à la moyenne climatologique. Les teneurs en nitrate étaient aussi inférieures aux observations antérieures dans les eaux de fond de la plate-forme Scotian à l'été 2004, tandis qu'elles étaient supérieures dans les eaux profondes du sud du Golfe à l'automne. La raréfaction printanière de la teneur en nitrate dans les eaux de surface à la station fixe Prince-5 s'est produite presque deux mois plus tôt en 2004 que les années précédentes.

La caractéristique dominante du phytoplancton dans les régions des Maritimes et du Golfe en 2004 a été l'ampleur et l'étendue de l'efflorescence printanière; les teneurs maximales en chlorophylle ont presque atteint les niveaux record observés en 2003. Les teneurs printanières élevées ont surtout été observées à la station fixe Halifax-2, le long du transect du relevé printanier dans les parties est et ouest de la plate-forme Scotian et dans le sud du Golfe, ainsi que sur le banc Georges, selon les données satellitaires sur la couleur de l'océan. À la station Prince-5, l'efflorescence du phytoplancton, bien qu'elle n'ait pas été aussi forte qu'en 2003, s'est produite presque deux mois plus tôt que les années précédentes. Les teneurs en chlorophylle de surface étaient inférieures sur la plate-forme Scotian en été et supérieures dans le sud du Golfe à l'automne 2004 à celles de l'année précédente. Les données fournies par les EPC continuent à indiquer que les niveaux d'abondance récents du phytoplancton sont équivalents ou supérieurs à la moyenne à long terme et que le cycle de croissance saisonnière commence plus tôt pendant l'année que ce n'était le cas au cours de la première décennie d'observations des années 1960 à 1970.

La biomasse de zooplankton et l'abondance de *C. finmarchicus* étaient inférieures en 2004 à celles de l'année précédente à la station fixe de la vallée Shediac et sur les parties centrales et ouest de la plate-forme Scotian (au printemps). La biomasse et l'abondance de *C. finmarchicus* étaient supérieures en 2004 à celles de 2003 sur le banc Georges en hiver, et sur les parties centrale et est de la plate-forme Scotian, ainsi que dans le sud du Golfe, à l'automne. En 2004, il semble que le début de la reproduction de *C. finmarchicus* à Halifax-2 se soit produit plus tôt que les années précédentes. À toutes les stations fixes, mais de façon plus marquée à Prince-5, la contribution de *C. finmarchicus* à la communauté des copépodes a augmenté de façon régulière au cours des quelques dernières années. Les données fournies par les EPC continuent de montrer que les niveaux d'abondance récents du zooplancton sont égaux ou inférieurs à ceux qui ont été observés pendant la décennie des années 1960 à 1970, qui a marqué le début des observations.

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 (Quebec, Maritimes/Gulf, 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/Gulf regions, including the Georges Bank/Gulf of Maine/Bay of Fundy system, the Scotian Shelf and the Southern Gulf of St. Lawrence, during 2004. For some data (CPR, SeaWiFS ocean colour), descriptions will include observations outside the Maritimes/Gulf, i.e. the central and western North Atlantic. Conditions in 2004 will be compared with those observed during recent years 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/Gulf AZMP sea-going staff participated in 7 missions (seasonal section cruises and groundfish surveys) during the 2004 calendar year in addition to repeat trips to the 3 fixed stations; 576 station occupations were the total sampled all together (Table 1).

Fixed Stations. In 2004 the Maritimes/Gulf regions' three fixed stations, Shediac Valley, Halifax-2 and Prince-5 (Fig. 1), were sampled on a minimum monthly basis (Prince-5) with attempted semi-monthly sampling during the spring bloom period. Due largely to the availability of resources and difficulties with weather and ice, this sampling frequency was not always achieved. In 2004, Halifax-2 and Prince-5 were sampled on 21 and 12 occasions, respectively. Shediac was sampled only 5 times. By definition this station has an ice-truncated open water season but, as well, changes in Coast Guard operations in 2004 adversely affected the availability of platforms in that area. Fixed station occupations were, again, further reduced from our high in 2002. As in 2003 the combined effects of ice coverage, difficulty obtaining suitable platforms and the decision to reduce effort were the major factors controlling sampling in 2004.

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) as the common suite.
- Niskin water bottle samples at standard depths for nutrient, calibration salinity, calibration oxygen, and chlorophyll analyses as the minimum common suite of measurements.
- Niskin water bottle sample for phytoplankton enumeration.
- Vertical ring net tows for zooplankton biomass and enumeration,
- Secchi depth reading when possible.

Shelf 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 attempted in May/July period as part of the Labrador Sea program in the Maritimes Region. In 2004, the spring cruise was carried out normally with some extra along-shelf-break sampling. However, thefall section survey was allocated the absolute minimum of time to accomplish the core program. The four core transects were occupied in the end.

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, POC 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/Gulf 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). The March eastern Scotian Shelf mission was cancelled for 2004 because platforms were not available.

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 (as a minimum but 25m and 50m samples taken when possible) for nutrient, calibration salinity, calibration oxygen, and chlorophyll analyses,
- Niskin water bottle samples for phytoplankton enumeration at fixed station sites only,
- Vertical ring net tows for zooplankton biomass and enumeration at a subset of stations (see Fig. 3),
- Sea surface temperature recorder, trawl mounted depth/temperature recorders.

Deployment

CTD. The CTD is attached to the end of a hydrographic wire (or conducting cable for the rosette system) 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 – near-surface, 10, 20, 30, 40, 50, 60, 80, 100, 250, 500, 1000, 1500, 2000 m (depth dependent)
- Groundfish surveys - 5m, near bottom (minimum sample set)

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 slowly 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 typically 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); typically 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 relative numerical abundance) and zooplankton relative abundance for different years on in the northwest 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 northwest Atlantic (1961) to the present are exactly the same so that valid comparisons can be made between years. Data are available approximately one year after collection, i.e. 2003 data will be reported here.

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

Mixing and Optics. Mixing and optical properties of the upper water column varied by season and location at the Maritimes/Gulf fixed stations (Figs. 6 & 7). Seasonal development of the mixed-layer and upper water-column stratification was most evident at the Shediac Valley and Halifax-2 stations (Fig. 6); shallow mixed layers (~10 m) and maximum stratification (~0.1 kg m^{-4}) were evident throughout the summer and early fall months (May-September). Limited sampling 2004 at the Shediac station did not permit a complete seasonal analysis of mixing properties, however, the observations that were made (May-September) were consistent with those made in previous years. Mixed-layer depths were somewhat more variable and maximum summer stratification less intense at Halifax-2 than at Shediac. Mixed-layers at Halifax-2 in early spring in 2004 were considerably deeper (up to 148 m in March) than observed in previous years; deeper than usual mixed-layers were also observed in November 2004. There was also some indication that springtime development of stratification might have been delayed in 2004 compared with previous years and that stratification broke down earlier in the fall than observed previously. In marked contrast to the other fixed stations, stratification was extremely low (<0.01 kg m^{-4}) at Prince-5. Mixed-layer depths are highly variable and difficult to determine at this station due to the very small vertical density differences, although estimates ranged from <20 m in spring and later in summer to full depth in winter in 2004.

Maximum vertical light attenuation at all stations coincided with the maximum in integrated chlorophyll in late spring and was minimum following the decline of the seasonal bloom (not shown). Generally, attenuance estimates derived from Secchi disc readings and direct downwelling irradiance (PAR) measurements were comparable and exceeded those derived empirically from chlorophyll concentrations (except during peak bloom conditions). The discrepancy is most notable at Prince-5 where water properties (dissolved and particulate substances) other than phytoplankton dominate the attenuation of light. At the Shediac Valley station, despite limited sampling in 2004, euphotic depths were relatively invariant during the spring-fall period (~20-40 m) and comparable to observations from previous years (Fig. 7). At Halifax-2, euphotic depths were generally deeper (40-70 m) and much more variable than at Shediac. No clear seasonal cycle was discernible. At Prince-5, euphotic depths in 2004 were remarkably constant at (~15-25 m), showed little variability and no seasonality. In general, seasonal patterns and magnitudes of optical properties in 2004 at Halifax-2 and Prince-5 were similar to those observed in previous years.

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, 2000), emphasis in this report will be placed on variability in nitrate concentrations.

Rapid spring/early summer reduction in near surface nitrate concentrations was seen at all Maritimes/Gulf fixed stations in 2004 (Fig. 8). Low surface values persisted throughout the summer at Shediac Valley (evident despite limited sampling) and Halifax-2; concentrations did not increase at the surface again until late fall (only observable at Halifax-2). The zone of nitrate depletion (i.e. defined as depths where concentrations were ≤ 1 mmol m^{-3}) in summer is generally greater at Halifax-2 (~30 m) than at Shediac Valley (~20 m). Summer nitrate depletion depths in 2004 at Halifax-2 were significantly greater (almost 40 m) than observed since 2001. Near surface nitrate concentrations at Prince-5 were never reduced below ~4 mmol m^{-3}. Limited sampling in 2004 precluded an evaluation of the seasonal nutrient cycle at the Shediac Valley station. The seasonal evolution of the vertical nitrate structure at Halifax-2 in 2004 was similar to that observed in previous years except that concentrations at depth (50-100 m) were notably lower in 2004 than the previous 2 years. Nitrate anomaly plots for Halifax-2 showed that near surface concentrations in 2004 were comparable to the climatological mean but concentrations at depth were substantially below the long-term average (-6 to –8 mmol m^{-3}) and comparable to concentrations observed in 1999 and 2001.

Strong seasonal variability in nitrate inventories of the upper 50 m (depth zone over which nutrient dynamics are strongly influenced by biological processes) is evident at all of the Maritimes/Gulf fixed stations (Fig. 9). Nitrate levels at the Shediac Valley Station in 2004 were comparable to levels observed previously, despite limited sampling. Although the seasonal pattern of variability in nitrate at Halifax-2 in 2004 was similar to that observed in previous years, wintertime inventories in 2004 were among the highest observed (>300 mmol m^{-2}) since AZMP sampling started in 1999 and summer/fall inventories were among the lowest (<10 mmol m^{-2}). Like Halifax-2, winter nitrate inventories at Prince-5 were higher in 2004 than observed previously whereas summer/fall levels, never depleted, were comparable to levels observed in over the past 6 years. The summer decline in nitrate at Prince-5 in 2004 started almost 2 months earlier (March versus May) than in the previous 2 years. A trend of increasing wintertime nitrate inventories at this station has been evident for the past 4 years (430 to 550 mmol m^{-2}). Overall, annual nitrate inventories continue to be greatest at Prince-5 and lowest at Halifax-2.

Phytoplankton. Distinctly different seasonal phytoplankton growth cycles are evident at the three Maritimes/Gulf fixed stations (Fig. 10). Because of the presence of ice in the Southern Gulf in the spring, only the latter phase of the spring bloom is normally caught in sampling at the Shediac Valley station. This in addition to limited sampling during the ice-free period meant that little could be said about the magnitude and variability of phytoplankton biomass (chlorophyll), vertical distribution and community composition in 2004. Chlorophyll inventories at Shediac during the limited sampling in 2004 were consistent with levels observed previously (Fig. 11). Similarly, evolution of the phytoplankton community composition at Shediac in 2004 was consistent with observations from earlier years, i.e. a shift from diatom to flagellated dominated populations as the year progressed (Fig. 12). The record high spring bloom observed at Halifax-2 in 2003 was less pronounced in 2004 although still strong compared to previous years. Anomaly plots suggested that the 2004 spring bloom, as was the case in 2003, was also higher than historical levels. The timing of the spring bloom at Halifax-2 in 2004 was similar to observations made previously (peak chlorophyll: 7 April or YD 97), however, the duration was shorter (~24 d in 2004 compared with ~48 d average from 1999-2003). Phytoplankton community composition at Halifax-2 in 2004 differed from previous years in that flagellates dominated (>60%) throughout the year except for the short period of the spring bloom where diatoms were most prevalent. Diatoms, in particular, generally dominate in the winter/spring months at this station. The phytoplankton growth cycle at Prince-5 in 2004, in contrast to Halifax-2; was characterized by a relatively sustained burst of growth beginning in early summer and lasting until fall and characterize by two peaks. Chlorophyll inventories were generally comparable to 2003 levels, however, the biomass maximum was observed almost 2 months earlier in 2004 (April versus June) than in the previous 2 years. As has been noted previously, the phytoplankton community at Prince-5 are almost exclusively comprised of diatoms (>90%), year-round. With the exception of 2003, Prince-5 sustains the largest phytoplankton inventories, on an annual basis, of the 3 Maritimes/Gulf fixed stations.

Zooplankton. Zooplankton biomass at all of the Maritimes/Gulf fixed stations was comparable or lower in 2004 than levels observed in previous years (Fig. 13). The record high biomass observed at the Shediac Valley station in 2003 was not observed in 2004, although sampling in 2004 was limited. Biomass at Halifax-2 in 2004 was slightly lower than 2003 levels, exhibiting a broad peak of ~60 g wet wt m^{-2}. Similarly, zooplankton biomass at Prince-5 in 2004 was comparable to 2003 levels, ~6 g wet wt m^{-2}. Zooplankton biomass at Prince-5 is typically only a small fraction (10-20%) of the biomass at the other fixed stations and peaks later in the year.

As was the case for zooplankton biomass, *Calanus finmarchicus* abundance at all the fixed stations in 2004 was comparable to or lower than 2003 levels (Fig. 14). *C. finmarchicus* abundance at the Shediac Valley station in 2004 reverted from the record peak abundance observed in 2003 (>500,000 ind m^{-2}) to levels more typical of the region (~30,000 Ind m^{-2}). At Halifax-2, *C. finmarchicus* abundance in 2004 was comparable to 2003 levels that reversed a downward trend observed in the previous 3 years. *C. finmarchicus* abundance at Prince-5 , same as the case for zooplankton biomass, was relatively unchanged in 2004 from levels observed in 2003.. *C. finmarchicus* abundance at Prince-5 is only a small fraction of the counts of that species at the other fixed stations.

Hierarchical community analysis revealed that copepods continued to numerically dominated the zooplankton year-round at all of the Maritimes/Gulf fixed stations in 2004 (Fig. 15). The recurring pulse of echinoderm and barnacle larvae and euphausiids observed during the spring and summer at Prince-5 was observed again in 2004. In addition, a pulse of jellies and appendicularia were also observed in summer at this station for the first time. The copepods were dominated (>50% much of the year) at all the fixed stations by small species (*Oithona*, *Pseudocalanus*, *Paracalanus*, *Clausocalanus*, *Centropoges* and *Temora* sp.) in 2004 as in previous years (Fig. 16). The relative importance of the larger *Calanus sp* appears to have been increasing at all fixed stations since AZMP sampling began in 1999. This is most evident at Prince-5 where *Calanus spp.* have steadily increased from <10% in 1999 to a record high of up to ~80% in late 2003/early 2004. Also at Prince-5, “other” copepod species (e.g. *Acartia sp*., harpacticoids) comprise a significant fraction (up to >60%) of the copepods in summer whereas they play a minor role (<10%) at Shediac and Halifax-2. Stage distribution of *C. finmarchicus* in 2004 revealed that reproduction (indicated by presence of early developmental stages, I-III) was generally confined to the spring/early summer period at Halifax-2 but was spread more broadly over the year at the Shediac Valley and Prince-5 stations (Fig. 17). However, the major reproductive activity appeared to occur in spring at all stations as in previous years. The timing of reproduction at Halifax-2 appeared to start earlier in 2004 than in 2003 based on first appearance of young stages, i.e. late February versus late March, although the peak abundance of small stages occurred at about the same time in both years (May).

Shelf Sections

Nutrients. Vertical distributions of nitrate in spring and fall were generally similar along the Scotian Shelf sections in 2004, i.e. concentrations were low (<1 mmol m^{-3}) in near surface waters (<50 m), as a result of phytoplankton consumption, and increased with depth (Figs. 18, 19). Deep-water concentrations were highest in basins (>12 mmol m^{-3}) and in slope waters off the edge of the shelf. As in the previous year (Harrison et al. 2004), nitrate levels in surface waters were already significantly depleted by the spring survey in April (1 mmol m^{-3} depth horizon: 20-40 m). Likewise, surface nitrate concentrations were still low during the fall survey in October (1 mmol m^{-3} depth horizon: 20-50 m), showing no evidence of seasonal mixing of nutrients from depth into surface waters. Nitrate inventories in the upper 50 m in 2004 were comparable to or slightly lower than levels observed in previous years (Table 3).

Phytoplankton. Chlorophyll levels during the spring 2004 (>8 mg m^{-3} or ~200-400 mg m^{-2}) survey were near the record high concentrations observed in 2003 (>10 mg m^{-3} or ~300-700 mg m^{-2}) along all sections except Halifax (Fig. 20, Table 3). As observed in previous years, chlorophyll inventories were generally higher on the eastern shelf than on the western shelf in spring. Concentrations during the fall 2004 survey, in contrast, were an order of magnitude lower (<1 mg m^{-3} or ~25-35 mg m^{-2}) and typical for that time of year (Fig. 21, Table 3). Generally, a pronounced subsurface chlorophyll maximum layer is observed at stations along the Scotian Shelf sections in fall (Harrison et al. 2004), however, highest concentrations in 2004 survey appeared to be confined to surface waters as observed in 2003. Chlorophyll inventories in fall 2004 were comparable along all sections and slightly lower than 2003 inventories.

Zooplankton. Zooplankton biomass and *C. finmarchicus* abundance were generally higher in spring 2004 than in fall, as observed in previous years (Table 3). Although biomass levels are similar along the shelf, *C. finmarchicus* are generally more abundant on the western shelf in spring than on the eastern shelf. *C. finmarchicus* abundance along the Halifax and Brown's Bank sections in spring 2004 (~10,000-30,000 ind m^{-2}) were lower than levels observed in 2003 (>50,000 ind m^{-2}). In contrast, biomass levels along the Cabot and Halifax sections were significantly higher (~70-270 g wet wt m^{-2}) in fall 2004 than levels observed in 2003 (~30-80 g wet wt m^{-2}). *C. finmarchicus* abundance was also higher in fall 2004 along the Louisbourg section (23,000 ind m^{-2}) than observed in 2003 (~7,000 ind m^{-2}).

Groundfish Surveys

Nutrients. Bottom water nitrate concentrations on the Scotian Shelf in the July, 2004 (Avg: 10.35 mmol m^{-3}) were lower than levels observed in 2003 (Avg: 11.01 mmol m^{-3}) (Table 2). Concentrations increased with water depth with highest levels observed in the deep basins on the shelf (e.g. Emerald Basin) and in slope waters off the shelf edge (Fig. 22). Bottom water nitrate concentrations in the Southern Gulf in September were higher overall in 2004 (Avg: 9.73 mmol m^{-3}) than in 2003 (Avg: 8.19 mmol m^{-3}). Highest concentrations were found in the western basin and in deep waters of the Laurentian Channel. Bottom water oxygen saturation on the Scotian Shelf in summer 2004 (Avg: 81% sat) was somewhat higher than saturation levels observed in 2003 (Avg: 78% sat); lowest saturations were found in deep basins and deep waters off the shelf edge where nutrients are highest. Bottom water oxygen saturation in the Southern Gulf was the same on average as levels observed in 2003 (Avg: 71% sat). Saturation levels in the Southern Gulf were minimum in the western basin and in the Laurentian Channel where nutrients were highest.

Phytoplankton. Near-surface chlorophyll levels during the 2004 summer Scotian Shelf survey were uniformly low (<1 mg m^{-3}) over most of the central and eastern shelf. Elevated concentrations (>2 mg m^{-3}) were observed near the coast off SW Nova Scotia and approaches to the Bay of Fundy (Fig. 23), as observed in previous years. These areas are generally characterized by strong vertical mixing. Overall, summer surface chlorophyll concentrations on the Scotian Shelf in 2004 (Avg: 0.56 mg m^{-3}) were lower than concentrations observed in 2003 (Avg: 0.72 mg m^{-3}) (Table 2). Surface chlorophyll concentrations observed during the fall 2004 groundfish survey in the Southern Gulf (Avg: 1.89 mg m^{-3}) were higher than values observed in 2003 (Avg: 1.13 mg m^{-3}). Concentrations tended to be highest in the western basin as has been observed in previous years.

Zooplankton. Zooplankton biomass distribution observed during the major winter/spring and summer/fall groundfish surveys can be characterized as highly variable in space and time (Figs. 24, 25). Generally, however, biomass is highest in deep basins and deep waters off the edge of the shelf or in channels (e.g.

Northeast Channel off Georges Bank, Laurentian Channel bounding the Southern Gulf). Additionally, during the summer surveys, biomass has consistently been higher on the western Scotian Shelf than on the eastern shelf. This is in contrast to the east-west uniformity in biomass observed during the spring and fall surveys (Table 3). In 2004, survey mean zooplankton biomass in February on Georges Bank (~25 g wet wt m^{-2}) was significantly higher than mean biomass in 2003 (~10 g wet wt m^{-2}) and reversed the declining trend observed over the previous 4 years (Fig. 24). No trends were observed in mean biomass levels observed during the summer surveys over the past 5 years; levels have varied from 27 to 46 g wet wt m^{-2}. Similarly, mean biomass levels during the fall Southern Gulf surveys were relatively stable at 31-48 g wet wt m^{-2} from 1999-2003, however, 2004 levels were significantly higher than observed previously, i.e. 74 g wet wt m^{-2} (Fig. 25). A disproportionate number of samples collected in the Laurentian Channel in 2004, however, may have contributed to the high average biomass observed there. Zooplankton species data for most of the groundfish surveys are not yet available.

Remote-sensing of Ocean Colour

Satellite ocean colour (SeaWiFS) data provide a valuable alternative means of assessing surface phytoplankton biomass (chlorophyll) at the AZMP fixed stations, along the seasonal sections, and at larger scales (Northwest Atlantic). SeaWiFS data in the vicinity of the fixed stations, for example, showed high chlorophyll levels (>15 mg m^{-2}) during the spring bloom at the Shediac Valley station immediately following ice-out and second only to the record high levels (>20 mg m^{-2}) of 2003 (Fig. 26). This feature has been systematically missed due to the severely limited conventional sampling possible at this station, particularly in 2004. Interestingly, the satellite did not pick up the strong spring bloom at Halifax-2 observed during conventional sampling in 2004. However, it did show that the timing of the blooms at Shediac and Halifax-2 were similar to the timing observed in previous years and it showed the earlier than usual bloom at Prince-5 (Figs. 10, 11). Satellite imagery also showed that the early development of the 2004 spring bloom began on the outer shelf in March, an observation made during previous spring groundfish surveys (Harrison et al. 2004) (Fig. 27). Imagery also showed that the strong spring bloom seen at Shediac Valley in 2004 in April was widespread, extending over the entire southern Gulf.

An equally informative application of the satellite-based chlorophyll fields is to generate graphical representations of the seasonal chlorophyll dynamics along the shelf sections. It is evident from the satellite-data, for example, that surface chlorophyll concentrations are generally higher on the eastern Scotian Shelf (Cabot Strait and Louisbourg lines) than on the central and western shelf (Halifax and Browns Bank lines) (Fig. 28). The nature of the onset, duration and termination of the spring and fall blooms are also revealed in this type of graphical presentation and it shows where across the shelf phytoplankton biomass accumulates in surface waters. Spring blooms on the Scotian Shelf can be viewed as discrete, short-lived events whereas the fall blooms appear to be more diffuse and time-varying. This graphical representation also show, for example, that the spring blooms along the Halifax and Browns Bank lines were strong in 2004 but less intense than in 2003. It is also apparent that the onset and duration of the blooms in 2004 was not noticeably different from 2003.

At the larger scale (i.e. statistical sub-regions in the Maritimes/Gulf, see Fig. 5), a record high spring bloom was observed in the Magdalen Shallows in 2004 (Fig. 29; see also Fig. 27). Strong, although not the highest on record, blooms were also noted for other sites on the Scotian Shelf and Georges Bank. Considering annual mean conditions, it is apparent that 2004 was a significant year for phytoplankton production in the Southern Gulf and, despite strong spring blooms, a year of net decline on the eastern/central Scotian Shelf and along the SW coast of Nova Scotia (i.e. Lurcher Shoal) (Fig. 30).

Continuous Plankton Recorder (CPR)

The CPR is the longest data record available on plankton in the Northwest Atlantic (see Fig. 4). CPR data analysis lags AZMP reporting by one year; thus, only data up to 2003 are currently available. Nonetheless, the phytoplankton colour index and abundance of large diatoms and dinoflagellates on the Scotian Shelf (57º-66ºW) have been dramatically higher starting in the early 1990s and continuing into the 2000s than levels observed in the 1960s/1970s (Fig. 31). A similar pattern has been observed in the Northwest Atlantic (45º-53ºW); in that region, however, dinoflagellate increases have been more prominent than on the Scotian Shelf. On the shorter time scale, the phytoplankton color index on the Scotian Shelf has been relatively stable (and above the long-term mean) over the past few years. Diatoms and dinoflagellate abundances, on the other hand, decreased in 2003. Similarly, phytoplankton abundances in the Northwest Atlantic declined in 2003; for diatoms and dinoflagellates 2003 continued a 3-year trend of decreasing abundances. The inconsistent patterns seen between the color index and diatom/dinoflagellate counts (Scotian Shelf 2003) could be accounted for by the fact that the color index may also include phytoplankton species smaller than are routinely counted, i.e. the CPR retains particles smaller than the nominal 260 μm mesh of the silk gauze (C. Reid, pers. comm.). In 2003, the abundance and seasonal cycle of phytoplankton aligned more closely with the pattern observed in the 1990s than in the 1960s/1970s (Fig.32). There appeared to be a shift in phytoplankton abundance in more recent years to earlier months compared with the 1960s/1970s. Although the timing of peak abundance (April) did not change, much higher levels, particularly of diatoms, were observed in February/March in 2003 compared to levels observed during the 1960s/1970s.

While phytoplankton were increasing on the Scotian Shelf and the Northwest Atlantic in the 1990s, zooplankton were generally decreasing, particularly during the early to mid 1990s (Fig. 33). During the last several years, zooplankton numbers have recovered from the mid-1990s lows for some species on the Scotian Shelf, however, counts for other species are still down. Most noteworthy for the latter were the almost record low abundances of *Paracalanus/Pseudocalanus spp.* in 2003*,* as observed in 2002, well below the long-term mean. Euphausiid numbers, on the other hand, were up dramatically in 2003 from the 2002 lows and near the long-term mean abundance levels. *C. finmarchicus* numbers in 2003 were steady, close to the long-term mean. In the Northwest Atlantic, zooplankton numbers were largely unchanged in 2003 from the last few years except for *Paracalanus/Pseudocalanus spp* numbers that decreased significantly in 2003, below the long-term mean for the first time in since the early 1990s. The seasonal abundance cycles for zooplankton species in 2003 could not be as easily aligned with the patterns of the 1960s/1970s and 1990s as was the case for phytoplankton (Fig. 34). The seasonal cycle of *C*. *finmarchicus* and *Paracalanus/Pseudocalanus spp.* in 2003 appeared similar to the pattern observed for the 1990s, (although abundances for the latter species were well below the 1990s levels). The 2003 euphausiids cycle was more similar to the pattern observed in the 1960/1970s.

DISCUSSION

Sufficient data now exists from AZMP to begin to document recurring spatial and temporal patterns in optical, chemical and biological properties of the Maritimes/Gulf regions and to describe changes (trends) in oceanographic properties. Although many of the oceanographic features in the Maritimes/Gulf regions in 2004 were similar to observations from previous years a number of differences were noteworthy.

<u>Mixing and optics</u>. The seasonal development of the mixed-layer, stratification and optical properties of the upper water-column are remarkably recurrent features at the Maritimes/Gulf fixed stations and distinctly different for each station. The annual reproducibility of the hydrographic properties (mixed-layer depths, stratification indices) is particularly evident at the Shediac Valley and Halifax-2 stations and the optical properties (euphotic depths) at Prince-5. The most notable feature in these physical properties in 2004 was evidence of deeper than usual mixing in early spring and delayed development of stratification at Halifax-2. Deeper than usual mixed-layers were also noted at this station in late fall as were indications of early breakdown in stratification. The deep winter mixing could account for the near record high winter-time nitrate inventories and subsequent near record high phytoplankton bloom the following spring at Halifax-2.

The delayed development of stratification might influence the timing of the spring phytoplankton bloom but there was no evidence that the bloom in 2004 was later than usual. Furthermore, there is evidence from previous observations in this region that blooms may start before the apparent onset of stratification. There were no chemical or biological consequences of the late fall mixing and breakdown of stratification evident at Halifax-2. Stratification was weak year-round at Prince-5, however, shallow mixed-layers were evident in spring and again in late summer. Optical properties at all of the Maritimes/Gulf fixed stations in 2004 were indistinguishable from properties observed in previous years.

Nutrients. Winter maxima in surface nutrients and summer-time reduction in concentrations is a common feature in the Maritimes/Gulf regions. For the most part, the seasonal cycles of nutrients, vertical structure and regional variations were similar in 2004 to previous years; there were some differences, however. Deep-water (>50 m) nitrate concentrations at Halifax-2 were lower in 2004 than in 2003 and well below the climatological mean. Bottom water nitrate concentrations observed during the summer groundfish survey on the Scotian Shelf were also lower than concentrations observed in 2003.

Winter nitrate inventories in near surface waters (<50 m) at Halifax-2 in 2004 were higher than usual but lower than the record inventories of 2003. Winter nitrate levels were also up at Prince-5 in 2004. The high winter nitrate levels at Halifax-2 could be linked to the deep winter/spring mixing and strong spring bloom as discussed above. In contrast to Halifax-2, changes in vertical mixing at Prince-5 could not explain the increase in surface nitrate inventories observed in 2004; mixing to the bottom in winter is a common feature at Prince-5 (and nutrient levels are uniform surface to bottom). Advective processes would have to be at play to explain variations in winter nutrient levels.

In addition to the high winter nitrate inventories in 2004, summertime nitrate inventories at Halifax-2 were lowest on record (since sampling began in 1999) and nitracline depths were the deepest observed over that period. Either greater demand (i.e. more phytoplankton) or less mixing of nitrate into surface waters from depth, or both, would be needed to explain the low summer nitrate levels in surface waters. Since the chlorophyll concentrations were not unusually high in summer 2004 at Halifax-2, reduced vertical mixing must have accounted for the low surface nutrients. Another line of evidence that might support the reduced summer mixing hypothesis was the presence of unusually high concentrations of flagellates in the phytoplankton community at Halifax-2 in summer. Typically, diatoms are associated with well-mixed, nutrient-rich environments whereas flagellated forms are more characteristic of stratified, low-nutrient waters. Patterns of summer nitrate consumption were also noteworthy for Prince-5 in 2004. In this case, biological consumption started much earlier (~2 months) than observed in previous years. This is obviously linked with the earlier than usual growth of phytoplankton which may have been fueled by more favorable light conditions brought on by the coincident spring shallowing of the mixed-layer.

Phytoplankton. Despite the fact that phytoplankton variability (both temporal and spatial) is characteristically high in coastal waters, the development of a pronounced spring/summer (and less conspicuous fall) phytoplankton bloom is evident from observations at the Maritimes/Gulf fixed stations, seasonal sections, groundfish surveys, CPR and remote-sensing data. Recurring spatial patterns such as elevated chlorophyll concentrations off southwest Nova Scotia, the eastern Gulf of Maine/Bay of Fundy and the western Southern Gulf of St. Lawrence are also observed yearly.

There were, however, some features of the phytoplankton growth cycle in the Maritimes/Gulf regions distinctive for 2004, the most prominent of which was the strong spring bloom. Near record high levels of chlorophyll during the spring bloom was particularly evident at the Halifax-2 fixed station, on the eastern and western Scotian Shelf from section surveys and in the Southern Gulf and on Georges Bank from satellite ocean colour data. Fixed station and satellite ocean colour data suggested that the timing and duration of the 2004 bloom was not different from earlier years.

Bloom timing (initiation) is regulated largely by the phytoplankton's light environment that is, in turn, determined by incident irradiance and upper-ocean mixing. At the Shediac Valley station, the presence of ice in winter strongly influences bloom dynamics in this region. Bloom magnitude and duration is regulated largely by nutrient supply. Since, generally speaking, the timing of the 2004 spring bloom in the Maritimes/Gulf region was not an issue but the magnitude and duration were, one should be looking for changes (increases) in nutrient inventories (principally in the winter preceding) to explain the strong spring blooms observed in 2004. Unfortunately, AZMP-Maritimes/Gulf monitors winter nutrient levels only at the Halifax-2 and Prince-5 fixed stations thus a broad-scale assessment of winter nutrient levels is not possible. Nonetheless, winter nitrate inventories at both these fixed stations were higher in 2004 than observed previously. The magnitude of the spring bloom was also particularly strong in the Southern Gulf in 2004 based on satellite ocean colour data, suggesting a larger than usual supply of nutrients in that region also. In 2003, winter inventories of nitrate at Halifax-2 were not considered sufficient to account for the record high spring bloom observed there (Harrison et al. 2004). Moreover, climatological nitrate levels off Halifax are much higher than observed in 2003 or 2004 but climatological chlorophyll levels are much lower than in observed 2003 and 2004. Clearly, more must be involved in determining the magnitude of the spring bloom than winter nutrient levels. Alternatively, the link may be there but our conventional AZMP sampling strategies may simply be inadequate to provide the appropriate data to test the hypothesis.

Another factor that could determine bloom magnitude and duration would be on the loss side, i.e. “top-down” control from zooplankton grazing. It has been suggested that the apparent delay in *C. finmarchicus* reproduction at Halifax-2 in 2003 might delay or reduce grazing during the bloom period, allowing for greater phytoplankton biomass (chlorophyll) accumulation, resulting in a larger spring bloom than in previous years (Harrison et al. 2004). However, the delayed grazing hypothesis would be less tenable in this case since *C. finmarchicus* reproduction apparently occurred earlier than usual at Halifax-2 in 2004. Some progress in answering these important questions on bloom dynamics could be addressed through modelling (scenario-testing).

On the longer term based on CPR data, it appears that the spring phytoplankton bloom on the Scotian Shelf for the last decade has been much larger and started earlier in the year than blooms during the first decade of the CPR measurements beginning some 30 years ago.

Recurrent patterns in the seasonal succession of phytoplankton communities at the Maritimes/Gulf fixed stations also occur. At the Shediac and Halifax-2 stations, a clear transition from diatom-dominated communities in winter/spring to flagellate-dominated communities in summer/fall is evident. At the Prince-5 station, in contrast, diatoms dominate year-round. The only noteworthy feature with regard to phytoplankton community composition in 2004 was the prevalence of flagellates at Halifax-2 for most of the years, including the winter/early spring period when diatoms usually dominant. An explanation for the change in community structure in winter is unclear, however, the summer prevalence of flagellates could be linked to decreased vertical mixing of nutrients as discussed above.

Zooplankton. Like phytoplankton, zooplankton in the Maritimes/Gulf regions are characterized by high spatial and temporal variability. Despite that, recurring patterns in distribution and growth cycles are emerging from AZMP Maritimes/Gulf data. Both biomass and numerical abundance of zooplankton are: (1) generally higher in spring than in fall, (2) higher (summer and fall) on the western Scotian Shelf/eastern Gulf of Maine and Southern Gulf than on the eastern shelf and (3) higher in the deep basins and off the edge of the shelves than in shallow waters and on banks. At the Maritimes/Gulf fixed stations, lowest levels of zooplankton (and the important copepod, *C. finmarchicus*) have been observed at Prince-5 and highest at Halifax-2. Community composition, in a broad sense, has remained relatively unchanged within stations since AZMP observations began in 1999, e.g. the prevalence of copepods in the zooplankton community and importance of small copepod species (e.g. *Oithona*) at all stations year-round. The very regular and predictable seasonal emergence of barnacle/echinoderm larvae in the late spring at Prince-5 is another example.

Some features of the zooplankton community were notable in 2004, however. Zooplankton biomass and abundance of *C. finmarchicus* at the Shediac Valley fixed station in 2004 reverted to more typical levels compared with the record highs observed in 2003. Zooplankton biomass in the Southern Gulf, along Cabot Strait, on the central Scotian Shelf (Halifax Section) in fall and on Georges Bank in winter, were higher in 2004 than observed previously. *C. finmarchicus* abundance was lower than in spring 2004 on the central and eastern Scotian Shelf than seen in previous years. Causes for these biomass changes are unclear and whether this reflects true (annual) changes or seasonal shifts in abundance is unknown at this point. The timing of *C. finmarchicus* reproduction at Halifax-2 appeared to start earlier in 2004 than usual based on the appearance of young developmental stages, although the peak abundance of young stages occurred at about the same time as in previous years. It is hard to reconcile this with the food supply (phytoplankton), however, since the spring bloom at Halifax-2 did not start earlier in 2004 than observed in previous years. At all fixed stations, the contribution of *Calanus* to the complement of copepod species has apparently been on the increase since AZMP sampling began in 1999 with the increase has been most striking at Prince-5. The causes of these changes in species composition are unknown at present.

At the larger scale and over the long-term, the CPR data record shows that contemporary zooplankton abundance, in general, has been considerably lower over the past decade than it was during the decade following the initiation of the CPR surveys in the 1960s. The explanation for this fundamental shift (decrease) in zooplankton in recent years (some species appear to be recovering, however) in the presence of an abundant food supply (CPR phytoplankton abundance is well above levels observed in the 1960s/1970s) is still a major unknown.

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Table 1. AZMP Sampling Missions in the Maritimes/Gulf regions, 2004.

Group	Location	Mission ID	Dates	# Hydro Stns	# Net Stns
Groundfish Surveys	Georges Bank	TEM2004004	Feb 05 - 17	33	10
	Eastern Shelf	No Mission	March	-	-
	Scotian Shelf	TEL2004529	Jul 05 – 16	89	18
	Scotian Shelf	TEL2005530	Jul 18 – 30	116	16
	SGSL	TEL2004534	Sep 07 – 28	182	16
Seasonal Sections	Scotian Shelf	HUD2004009	Apr. 18 – May 08	75	73
	Scotian Shelf	HUD2004016	May 15 – 16	7	7
	Scotian Shelf	HUD2004055	Oct 19 – 29	36	30
Fixed Stations	Shediac	BCD2004668 +	May 14* – Sept 16	5	5
	Halifax-2	BCD2004666 +	Jan 13 – Dec 16	21	18
	Prince-5	BCD2004669	Jan 13 – Dec 14	12	11
			Total:	**576**	**204**

Table 2. Chemical and biological properties of the 1999-2004 summer Scotian and fall Southern Gulf of St. Lawrence groundfish surveys. Statistics: means, (ranges), #obs.

Survey	Year	Chlorophyll (mg m^{-3}) Surface (5 m)	Nitrate (mmol m^{-3}) Bottom	Oxygen (% Saturation) Bottom	Zoopl Biomass (g wet wt m^{-2})	*C. finmarchicus* (Ind m^{-2})
Scotian Shelf						
	1999	**0.93**	**13.22**	**76.7**	**45.9**	**20,872**
		(0.10-7.07)	(2.12-24.06)	(41.9-106.7)	(0.2-228.2)	(91-143,060)
		137	163	197	32	33
	2000	**0.67**	**12.87**	**87**	**34.0**	**-**
		(0.11-6.17)	(3.27-22.97)	(43-121)	2.7-158.6	
		220	178	203	38	
	2001	**0.78**	**11.75**	**82**	**34.4**	**-**
		(0.03-4.08)	(1.72-21.76)	(40-107)	(1.2-144.8)	
		206	155	206	38	
	2002	**0.51**	**10.96**	**74**	**27.0**	**-**
		(0.08-4.17)	(0.32-22.66)	(28-109)	(1.0-120.1)	
		303	215	215	38	
	2003	**0.72**	**11.01**	**78**	**32.2**	**-**
		(0.03-6.65)	(0.14-23.27)	(34-109)	(1.07-252.5)	
		214	213	217	36	
	2004	**0.56**	**10.35**	**80.65**	**36.89**	**-**
		(0.12-5.25)	(0.14-24.28)	(35.6-110.3)	(2.51-182.2)	
		185	193	191	38	
Southern Gulf						
	1999	**1.65**	**9.87**	**84**	**37.4**	**18,101**
		(0.03-4.97)	(0.35-22.92)	(38-114)	(5.1-112.0)	(0-56,354)
		185	178	180	17	17
	2000	**1.56**	**11.45**	**79**	**44.9**	**36,840**
		(0.16-6.35)	(0.37-24.57)	(33-117)	(4.5-223.7)	(221-248,753)
		197	192	175	17	17
	2001	**1.04**	**8.93**	**98**	**30.6**	**-**
		(0.04-3.60)	(0.19-23.94)	(68-118)	(2.9-142.0)	
		149	155	8	18	
	2002	**2.36**	**10.91**	**68**	**42.5**	**-**
		(0.75-5.97)	(0.37-24.94)	(28-95)	(4.5-153.0)	
		176	175	175	18	
	2003	**1.13**	**8.19**	**71**	**48.2**	**61,452**
		(0.07-2.78)	(0.23-24.53)	(27-90)	(7.6-129.9)	(3,378-162,075)
		83	79	79	7	7
	2004	**1.89**	**9.73**	**71**	**74.3**	**-**
		(.078-9.65)	(0-24.18)	(28-100)	(2.15-225.8)	
		170	164	155	16	

Table 3. Chemical and biological properties of the 1999-2004 spring and fall Scotian Shelf sections. Statistics: section means (average of all stations).

	Nitrate 0-50m ($mmol\ m^{-2}$)		CHL 0-100m ($mg\ m^{-2}$)		Zoopl Biomass ($g\ wet\ wt\ m^{-2}$)		*C. finmarchicus* ($Indx10^3\ m^{-2}$)	
Year	**Spring**	**Fall**	**Spring**	**Fall**	**Spring**	**Fall**	**Spring**	**Fall**
Cabot								
1999	133	140	423	47	23	40	17	38
2000	92	31	549	38	29	33	5.3	29
2001	31	120	137	35	90	86	6.2	28
2002	-	238	-	69	-	-	-	-
2003	-	76	-	38	-	85		39
2004	98	81	326	26	79	271	8.3	34
Louisbourg								
1999	99	91	177	53	17	8.8	68	10
2000	94	24	378	38	13	8.4	23	3.0
2001	29	72	152	39	95	34	13	13
2002	-	37	-	41	-	43	-	27
2003	81	71	710	39	90	16	15	6.7
2004	48	77	405	29	47	30	10	23
Halifax								
1999	144	93	53	36	17	10	65	8.0
2000	90	22	165	45	18	14	47	8.9
2001	29	99	126	31	90	25	52	8.2
2002	-	38	-	25	-	21	-	7.0
2003	51	53	313	35	80	29	54	8.9
2004	44	56	77	34	53	71	33	8.8
Browns								
1999	124	143	58	83	12	28	75	2.8
2000	239	26	154	45		17	25	5.4
2001	30	175	116	59	89	26	59	16
2002	-	109	-	36	-	34	-	15
2003	157	145	545	58	74	42	49	31
2004	133	118	219	26	34	26	28	4.5

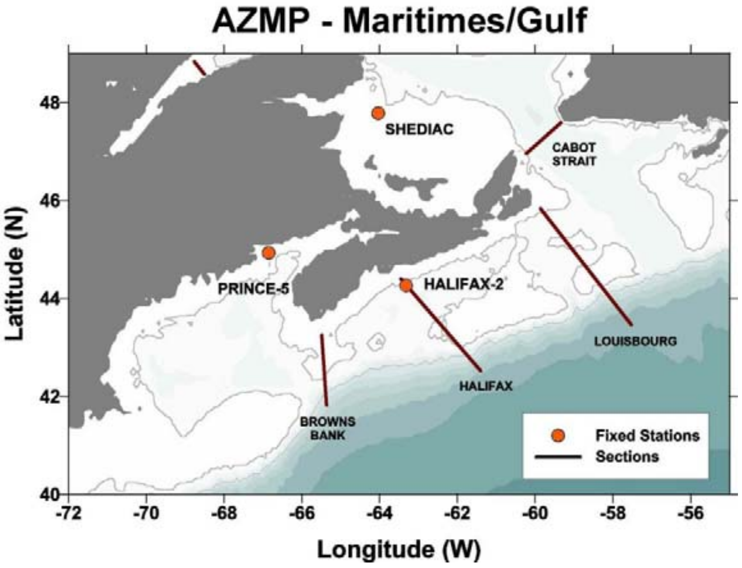


Figure 1. Primary sections and fixed stations sampled in the Maritimes/Gulf regions.

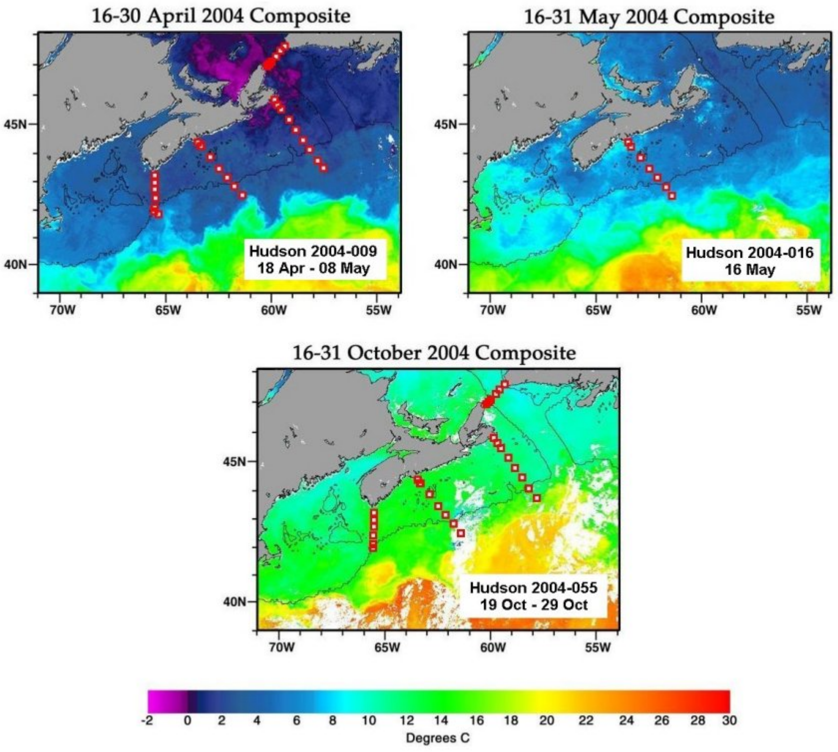


Figure 2. Stations sampled during the 2004 spring, summer and fall section surveys. Station locations superimposed on bi-weekly SST composite images.

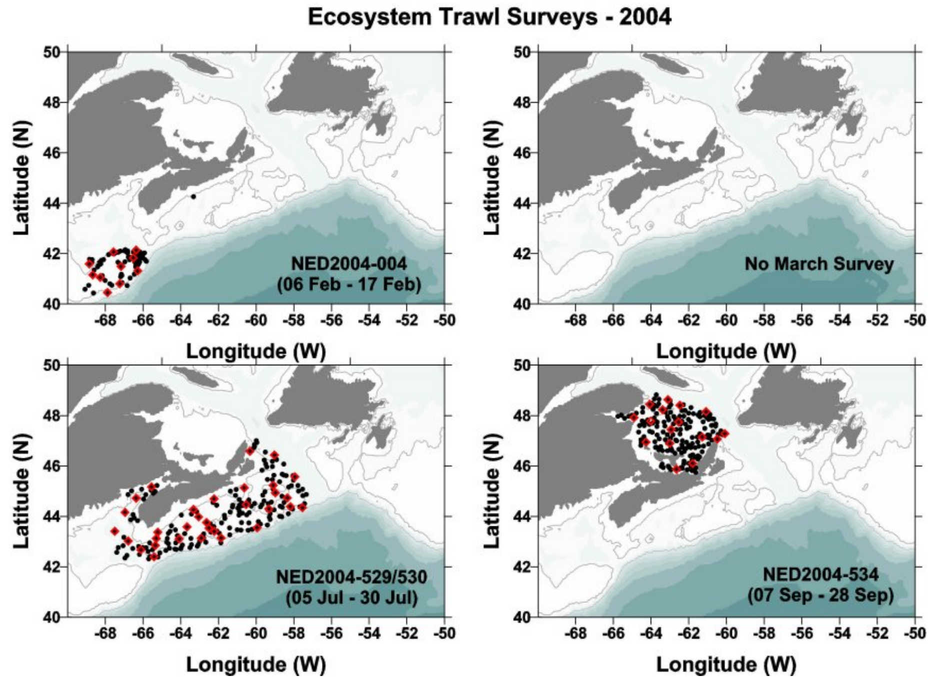


Figure 3. Stations sampled during major groundfish surveys in 2003. Black symbols are hydrographic stations; red symbols are stations where vertical nets hauls were taken in addition to hydrographic measurements.

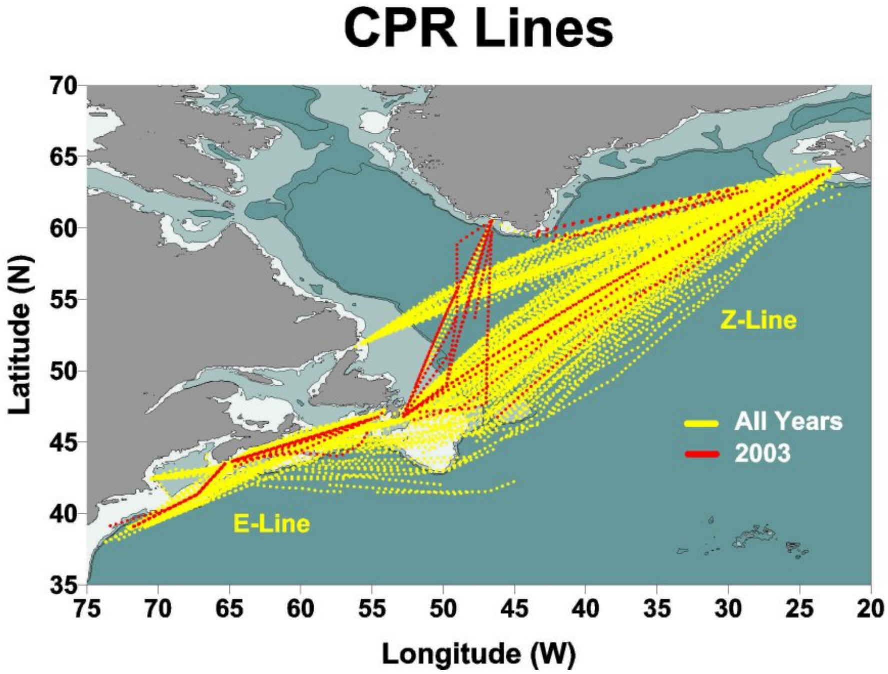


Figure 4. CPR lines and stations, 1961 to 2003 (2003 highlighted).

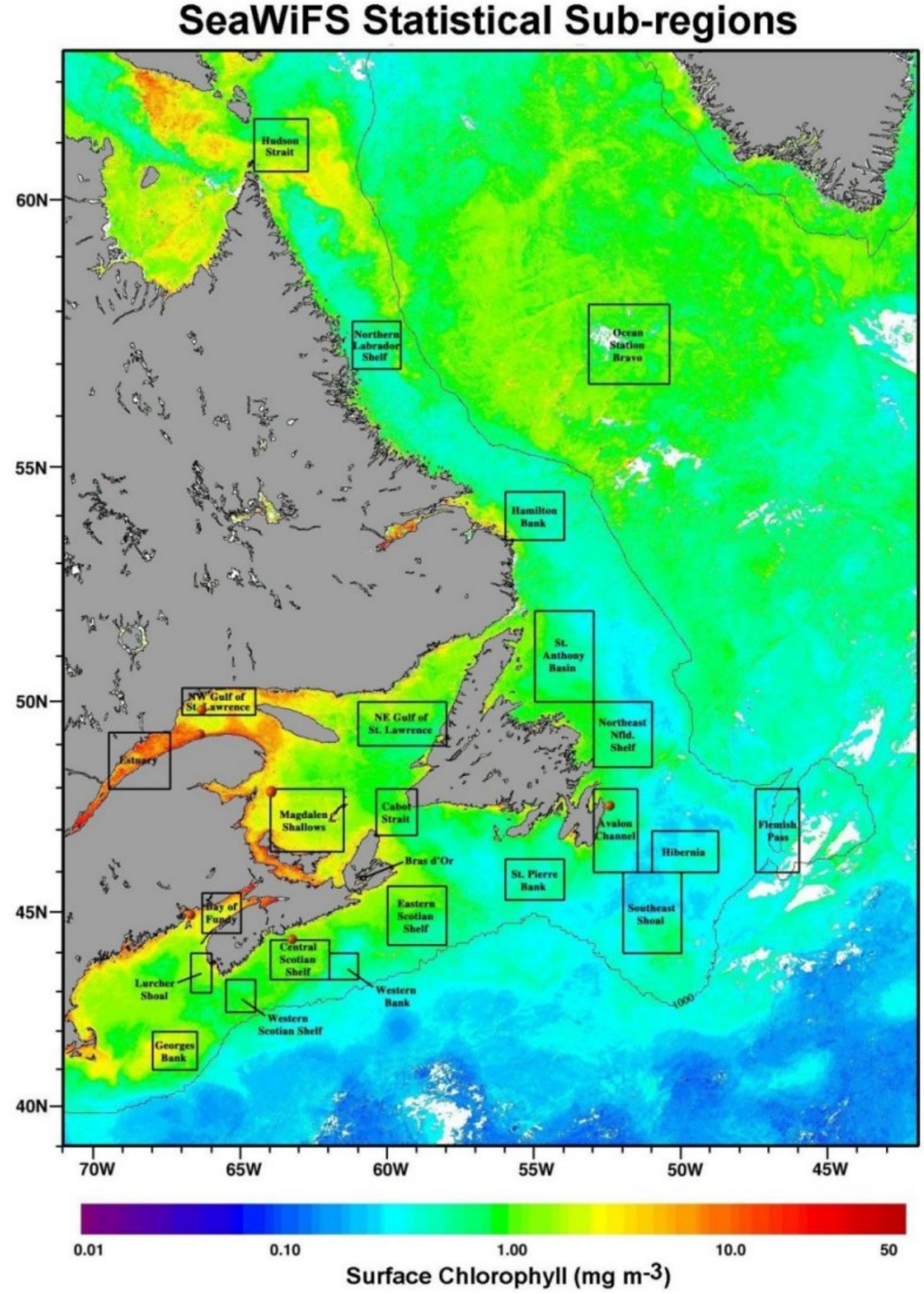


Figure 5. Statistical sub-regions in the Northwest Atlantic identified for spatial/temporal analysis of SeaWiFS ocean colour data.

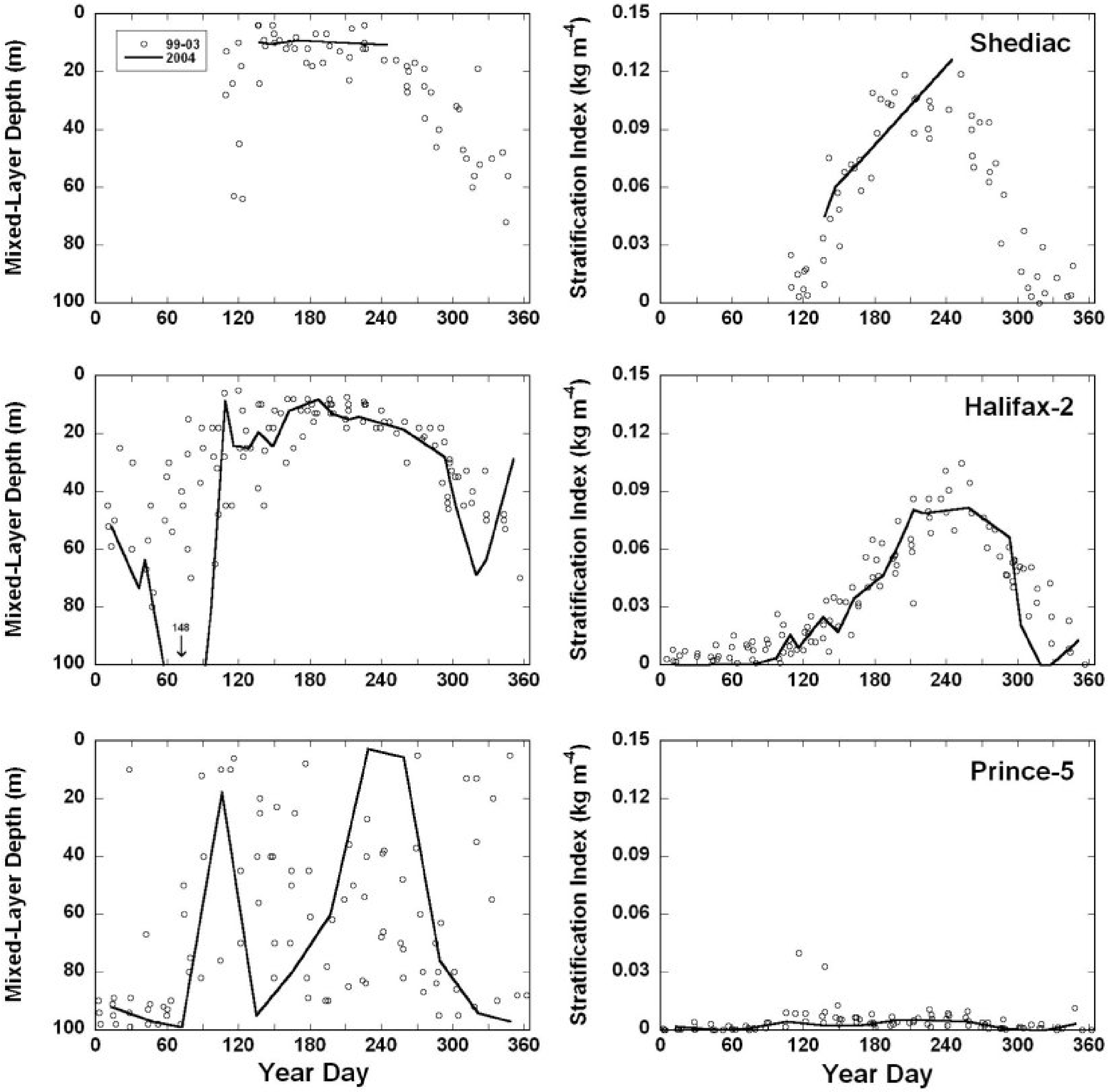


Figure 6. Mixing properties (mixed-layer depth, stratification index) at the Maritimes/Gulf fixed stations. 2004 data (solid line) compared with observations from 1999-2003 (circles).

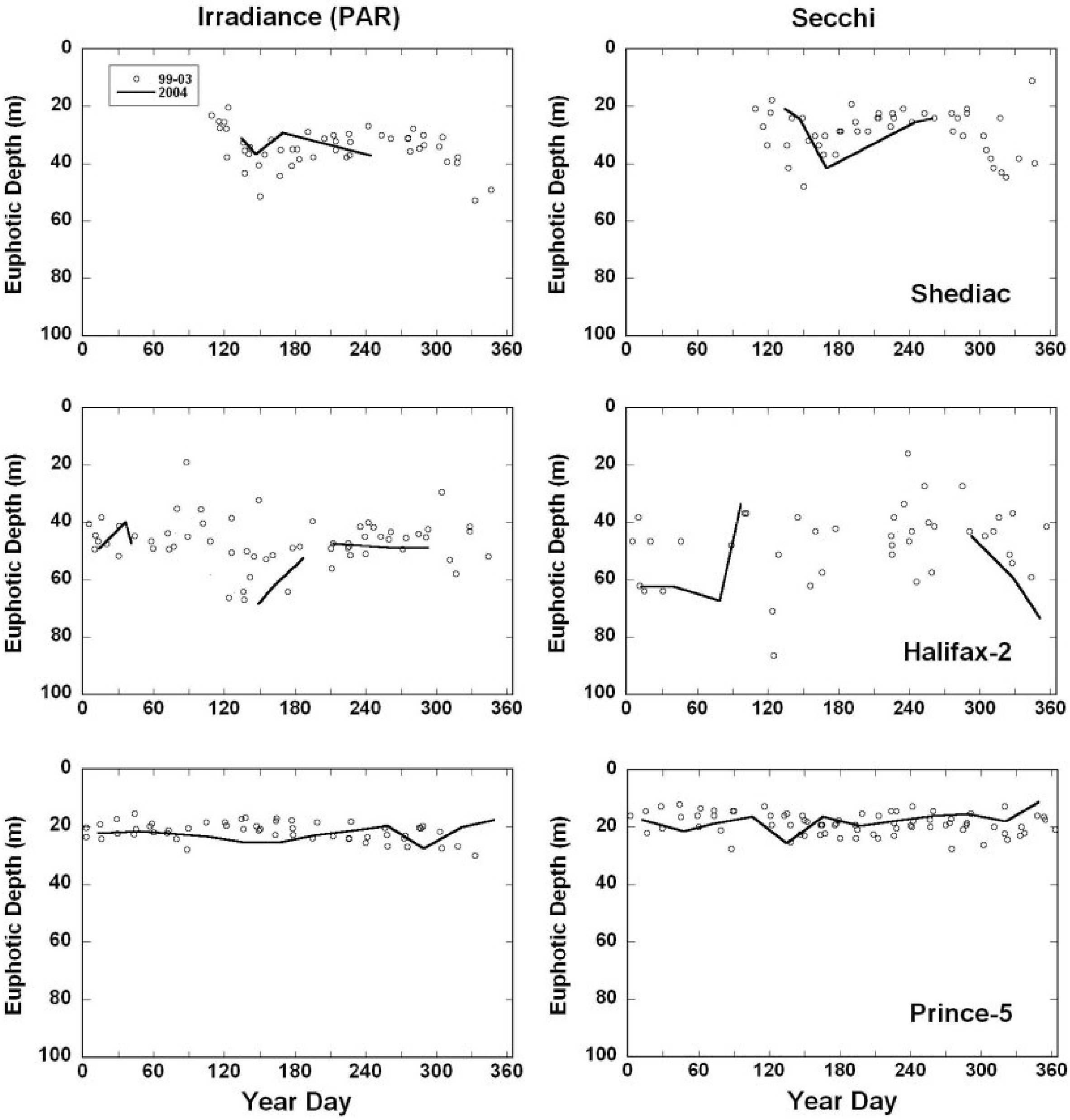


Figure 7. Optical properties (euphotic depth from PAR irradiance meter and Secchi disc) at the Maritimes/Gulf fixed stations. 2004 data (solid line) compared with observations from 1999-2003 (circles).

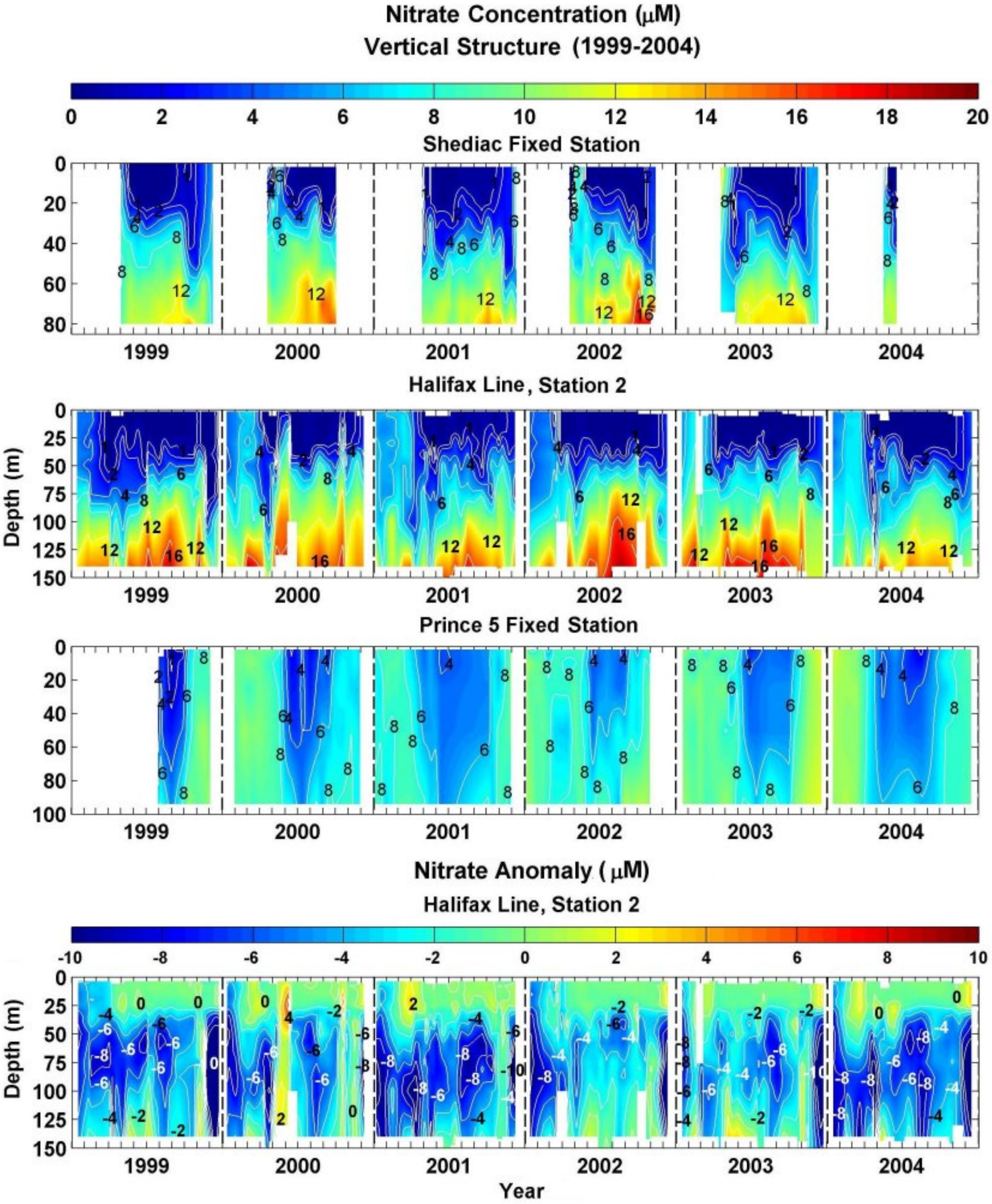


Figure 8. Time-series of vertical nitrate structure at the Maritimes/Gulf fixed stations, 1999-2004. Bottom panel: nitrate anomaly (2004 values minus long-term mean).

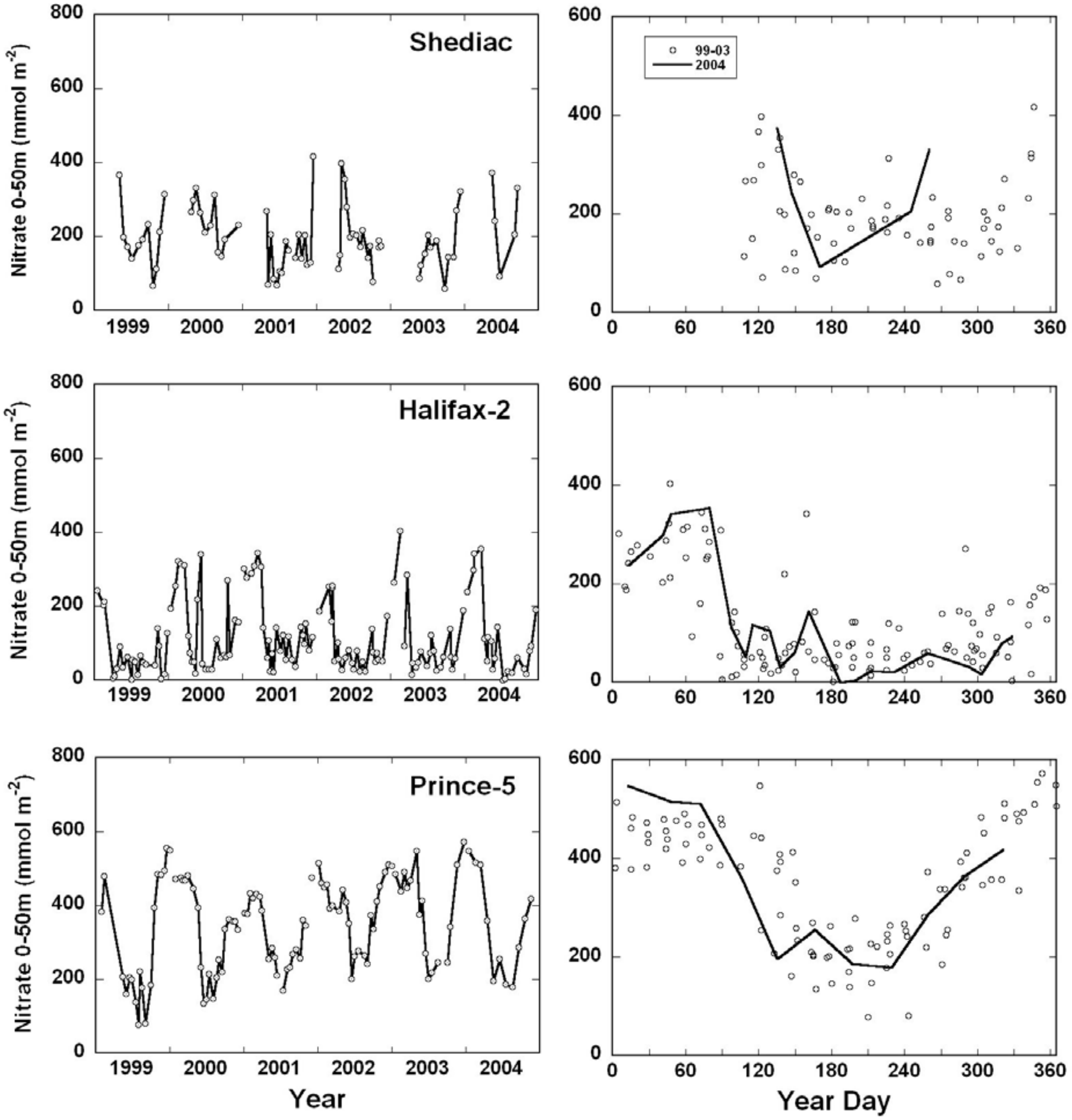


Figure 9. Nitrate inventories (surface-50 m integrals) at the Maritimes/Gulf fixed stations, 1999-2004. Right panels: 2004 data (solid line) compared with observations from 1999-2003 (circles).

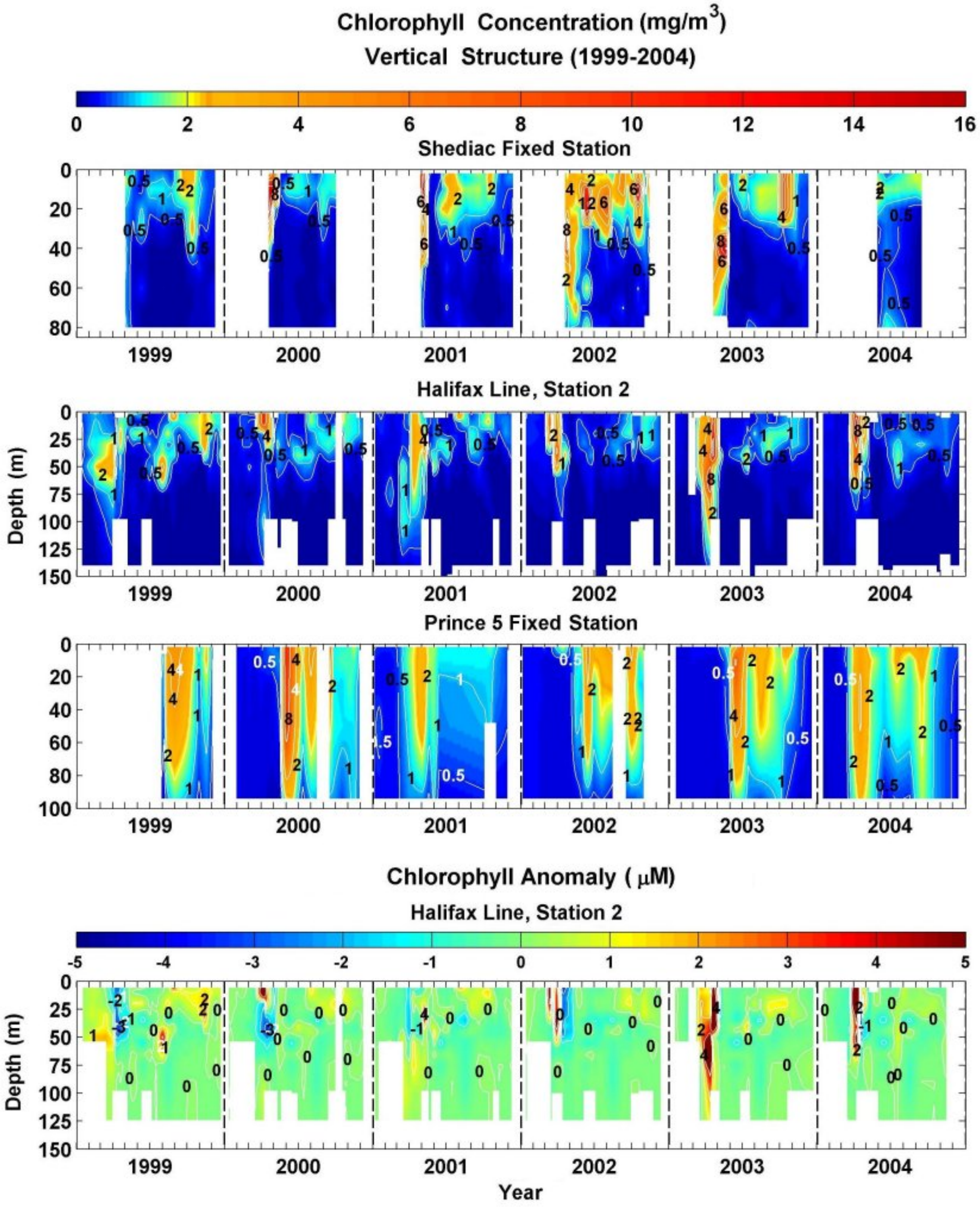


Figure 10. Time-series of vertical chlorophyll structure at the Maritimes/Gulf fixed stations, 1999-2004. Bottom panel: chlorophyll anomaly (2004 values minus long-term mean).

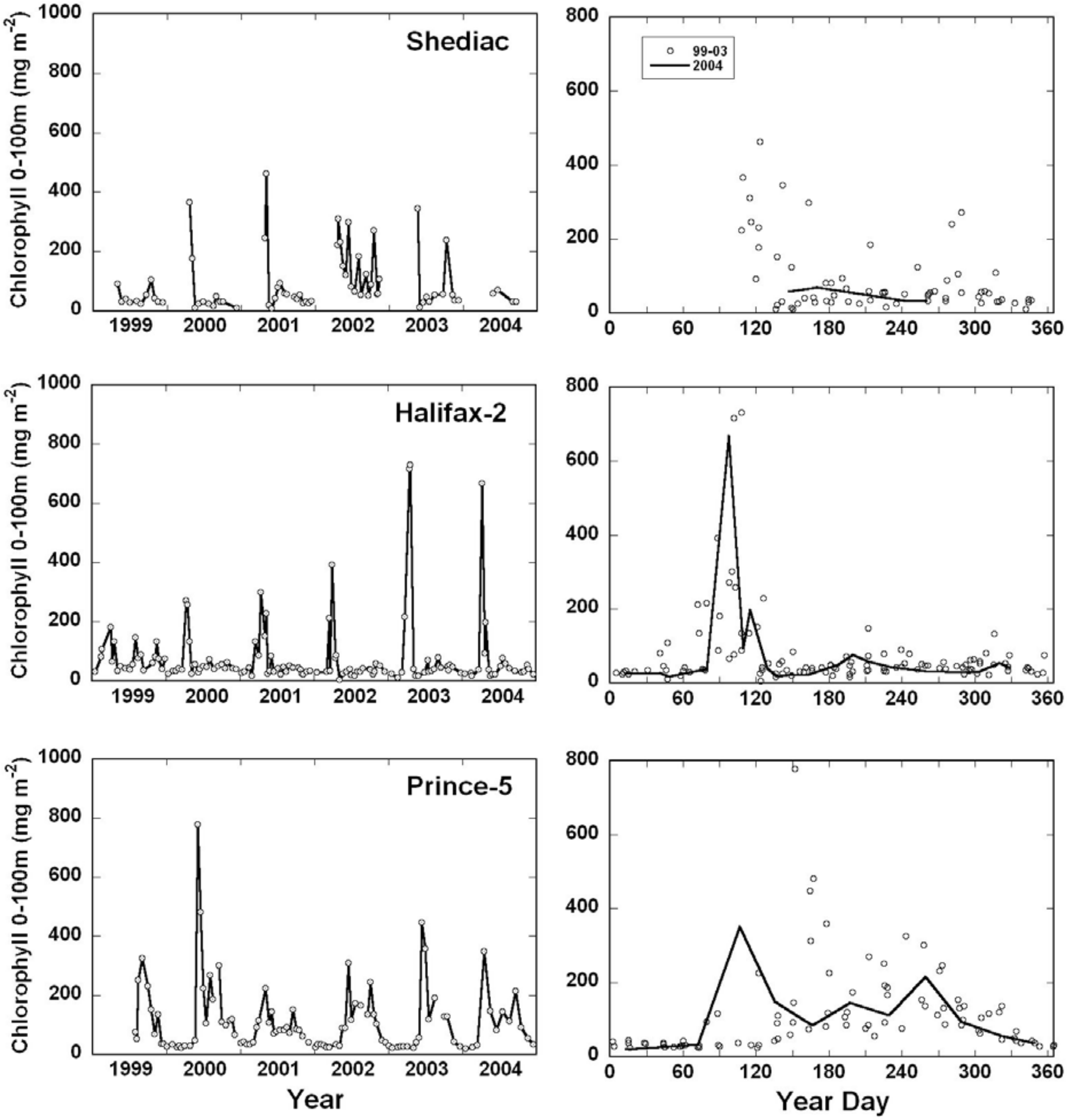


Figure 11. Chlorophyll inventories (surface-100 m integrals) at the Maritimes/Gulf fixed stations, 1999-2004. Right panels: 2004 data (solid line) compared with observations from 1999-2003 (circles).

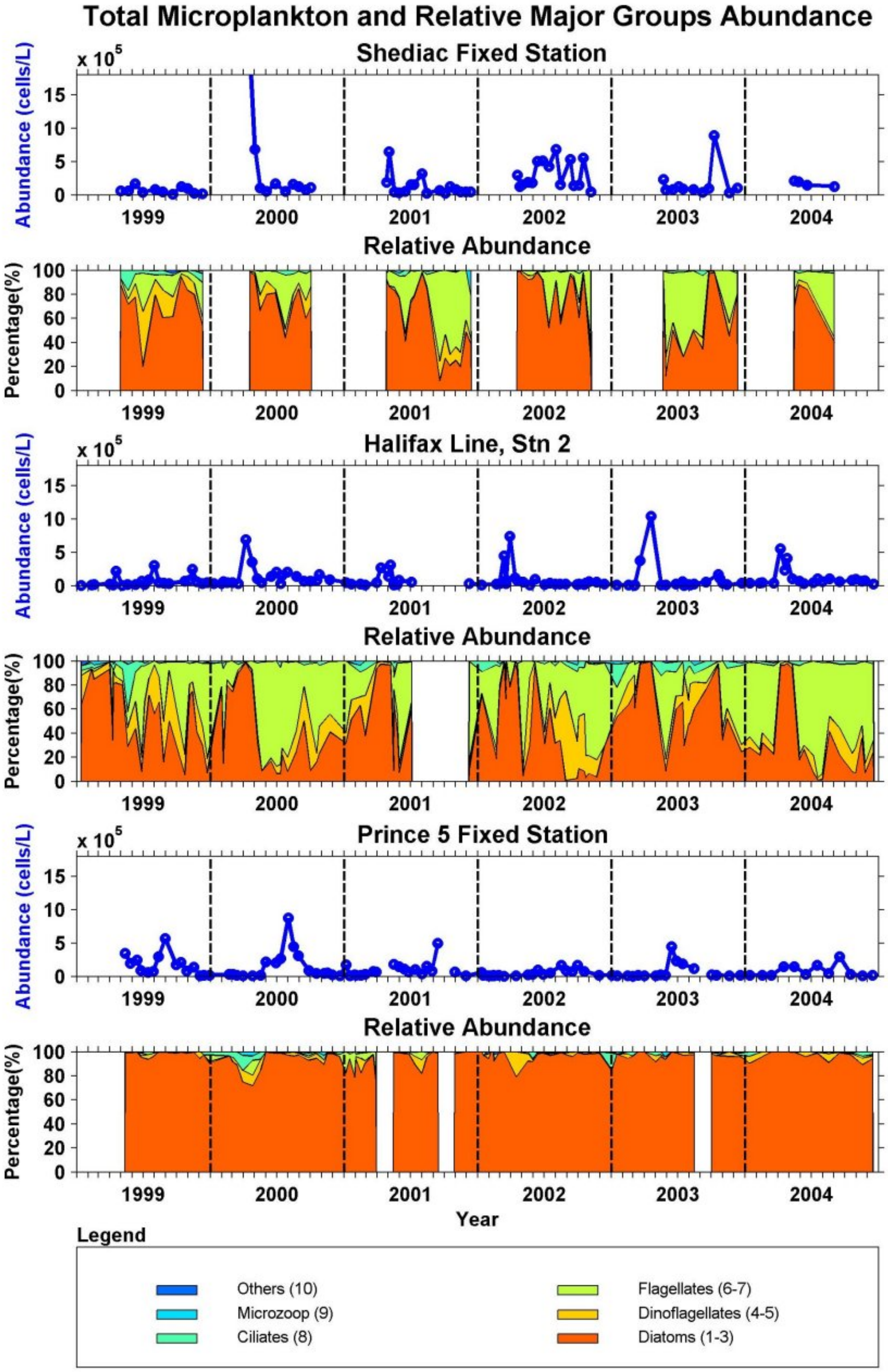


Figure 12. Time-series of microplankton abundance and community composition at the Maritimes/Gulf fixed stations, 1999-2004.

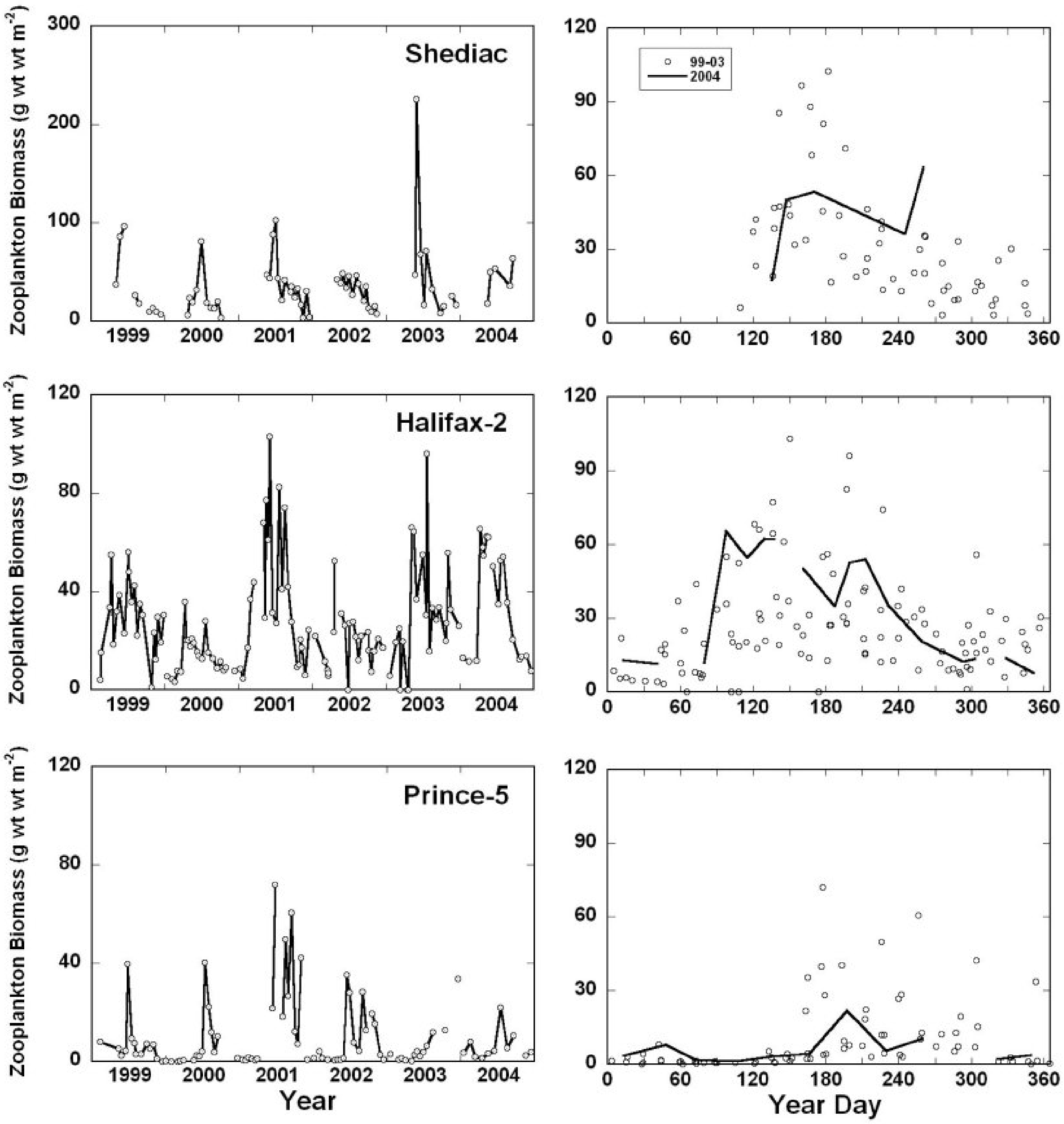


Figure 13. Time-series of zooplankton biomass (surface-bottom) at the Maritimes/Gulf fixed stations, 1999-2004. Right panels: 2004 data (solid line) compared with observations from 1999-2003 (circles).

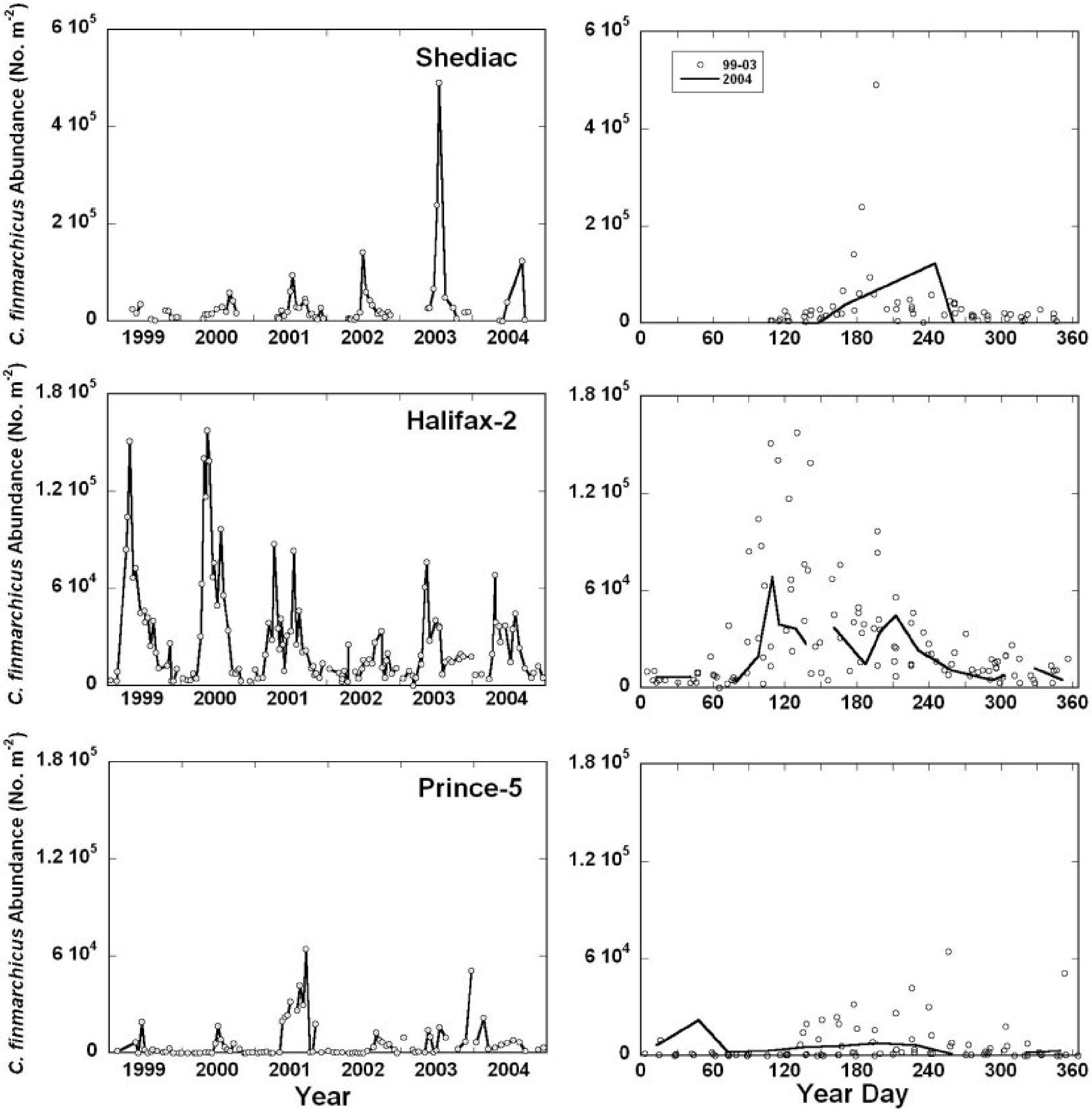


Figure 14. Time-series of *C. finmarchicus* abundance (surface-bottom) at the Maritimes/Gulf fixed stations, 1999-2004. Right panels: 2004 data (solid line) compared with observations from 1999-2003 (circles).

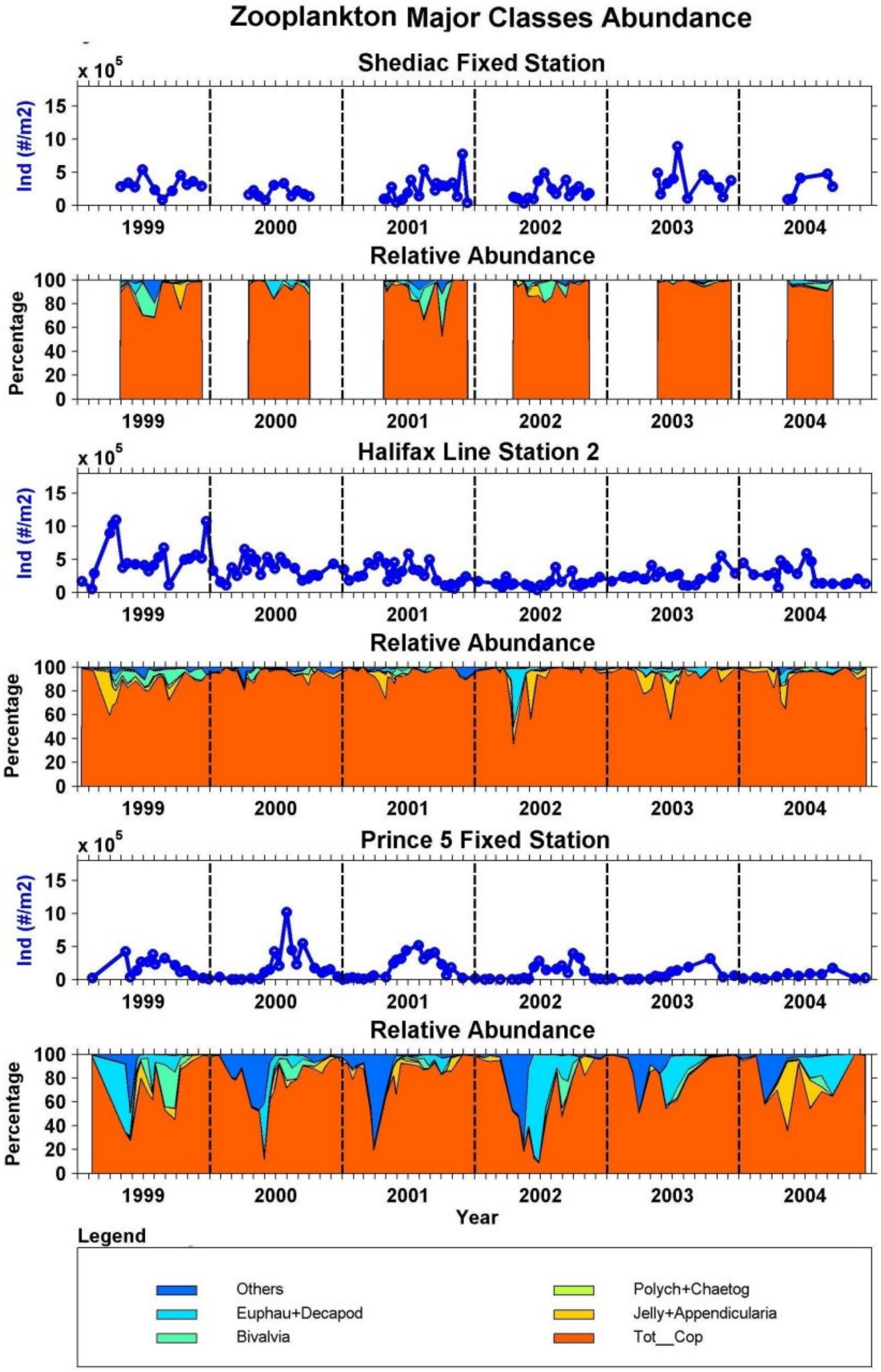


Figure 15. Time-series of zooplankton abundance and community composition at the Maritimes/Gulf fixed stations, 1999-2004.

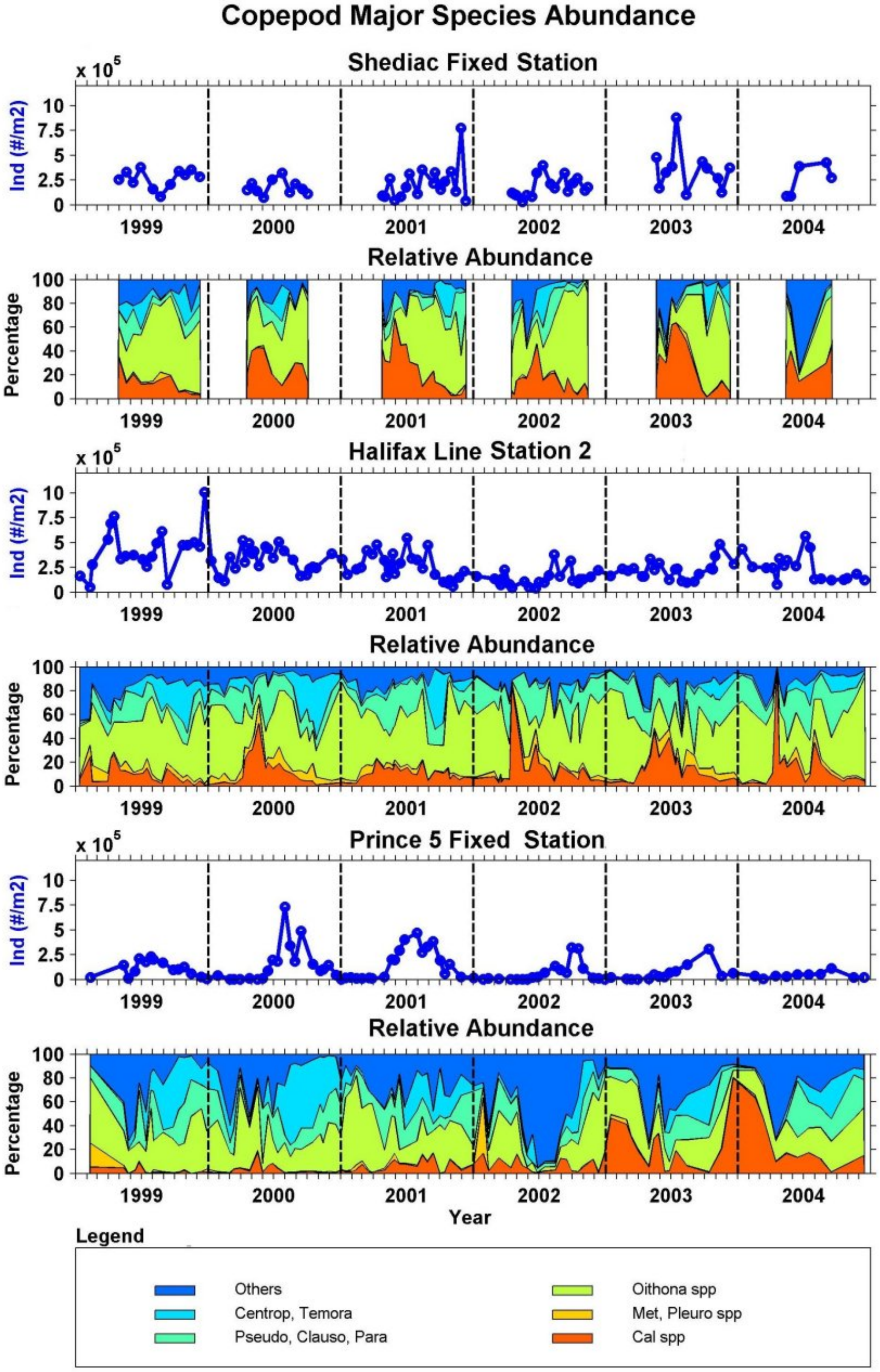


Figure 16. Time-series of copepod abundance and community composition at the Maritimes/Gulf fixed stations, 1999-2004.

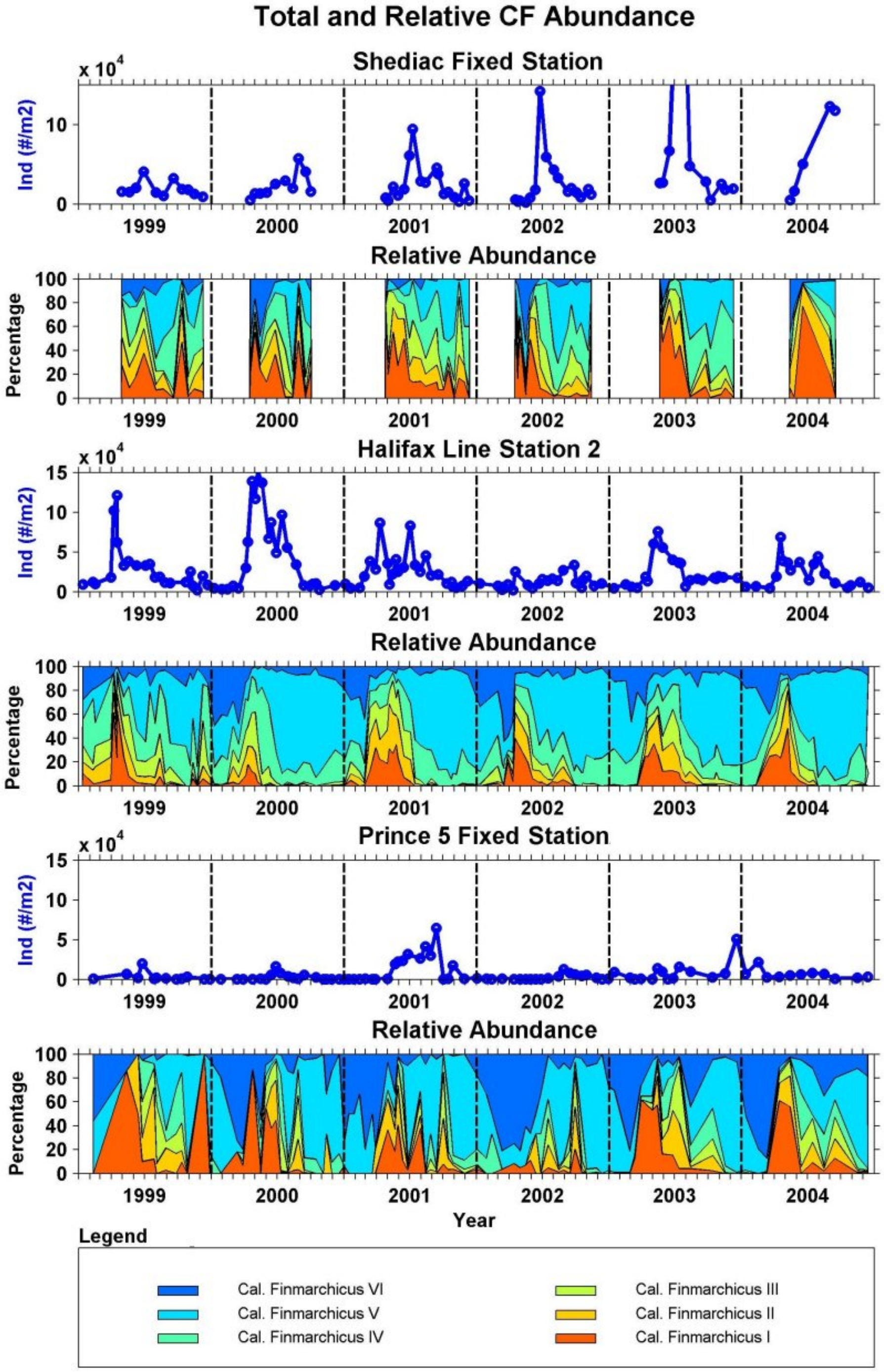


Figure 17. **Time-series of *C. finmarchicus* abundance and developmental stages at the Maritimes/Gulf fixed stations, 1999-2004.**

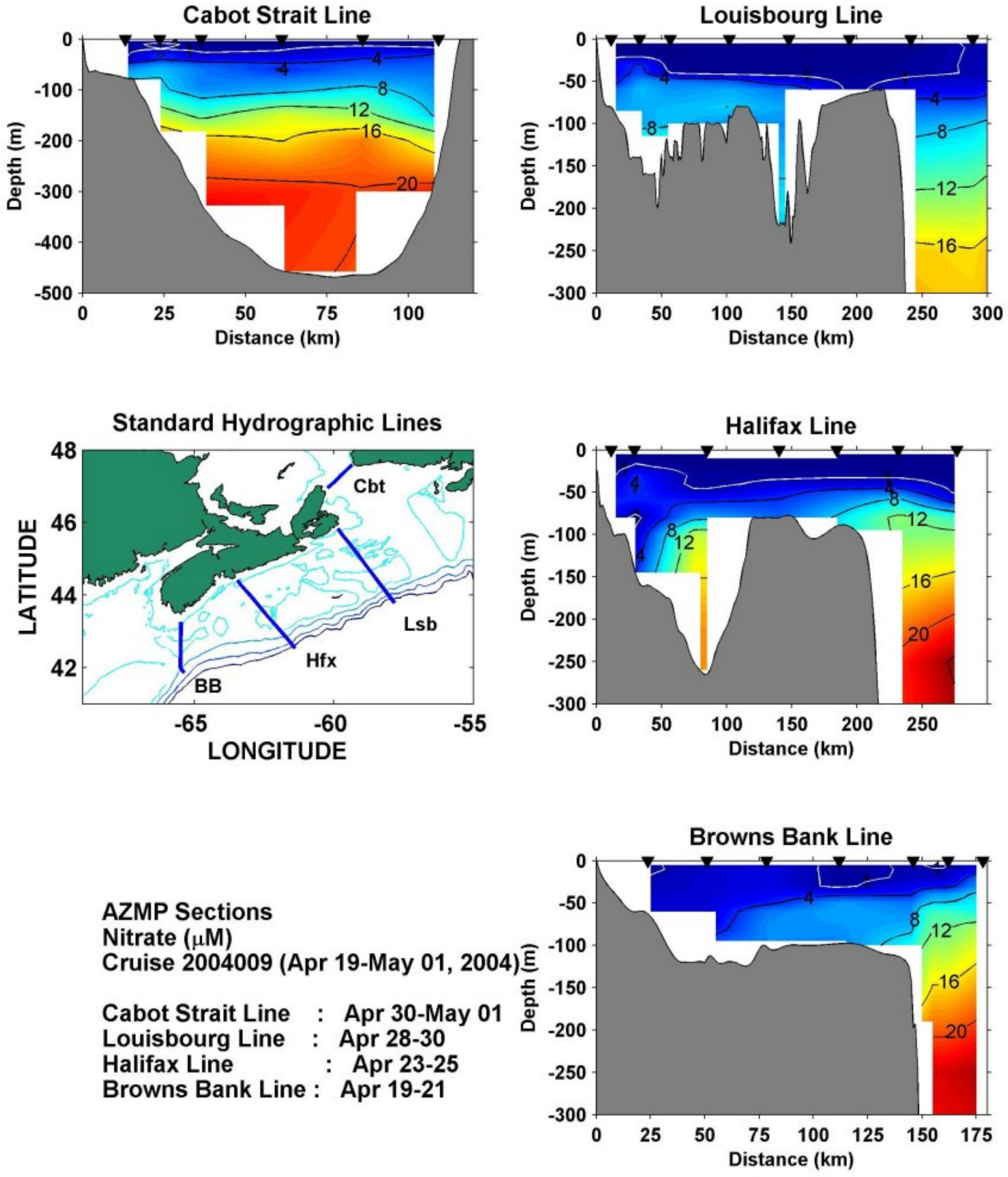
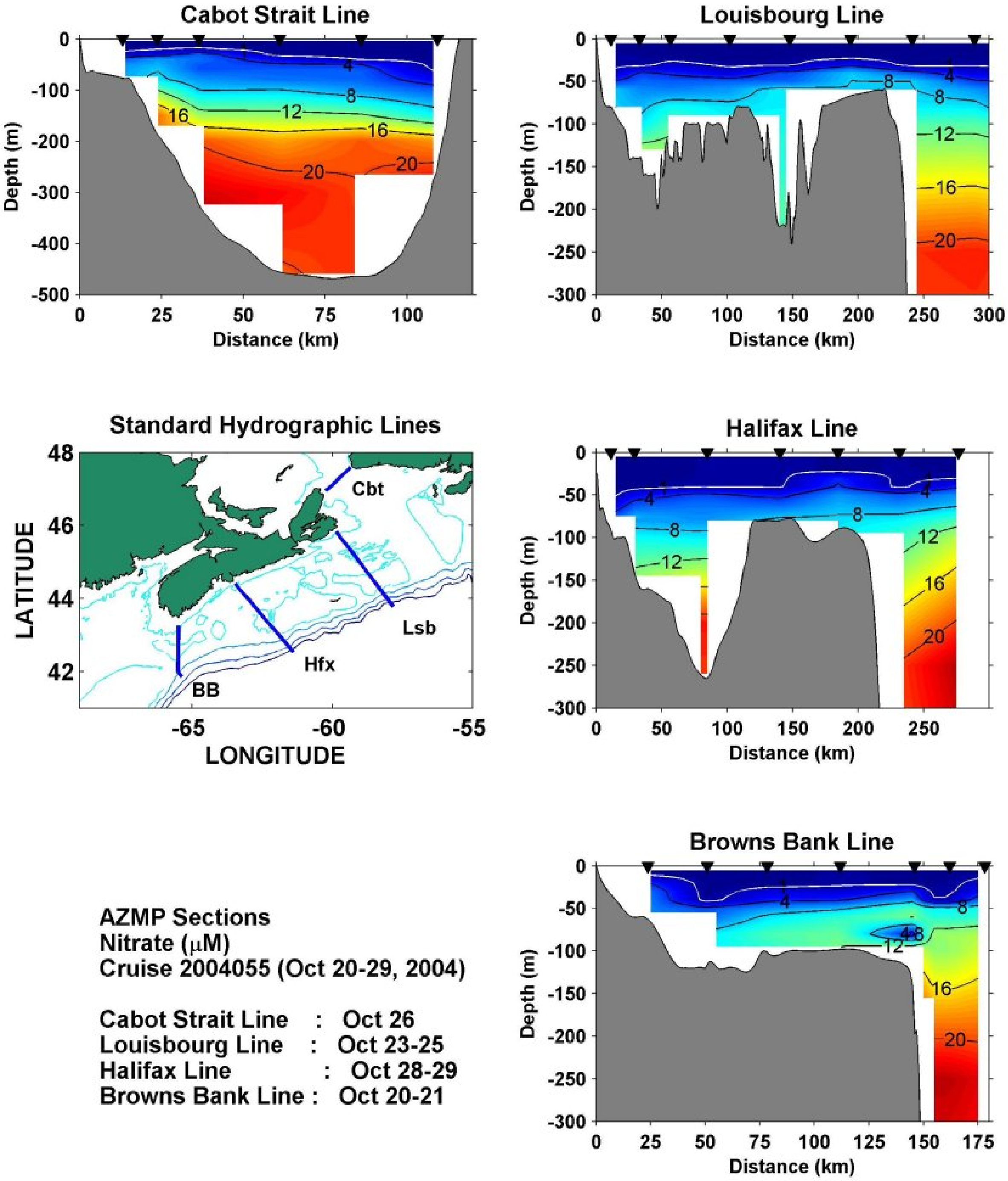


Figure 18. Vertical nitrate structure along the Scotian Shelf sections during the spring survey in 2004.



AZMP Sections
Nitrate (μM)
Cruise 2004055 (Oct 20-29, 2004)

Cabot Strait Line : Oct 26
Louisbourg Line : Oct 23-25
Halifax Line : Oct 28-29
Browns Bank Line : Oct 20-21

Figure 19. Vertical nitrate structure along the Scotian Shelf sections during the fall survey in 2004.

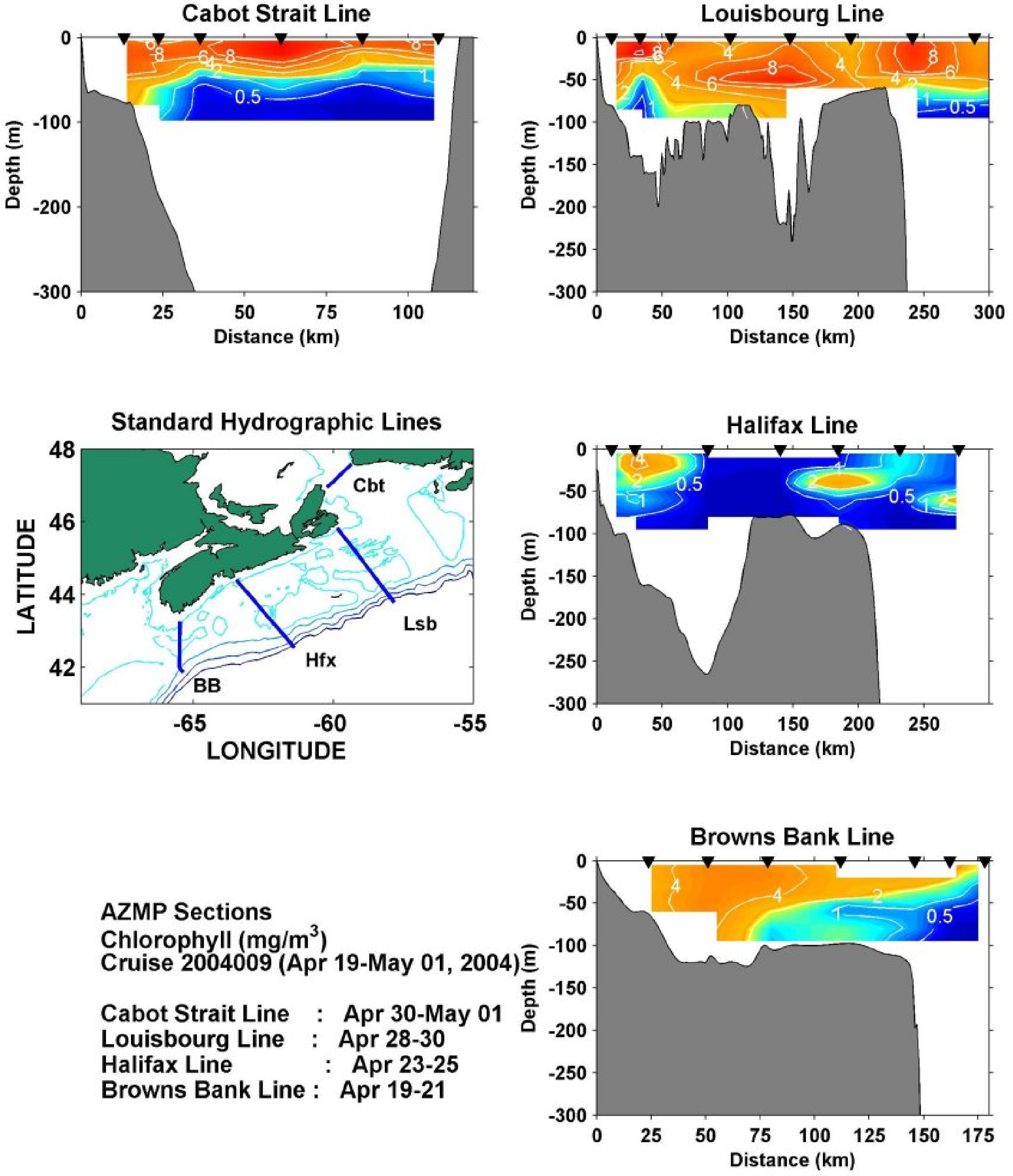


Figure 20. Vertical chlorophyll structure along the Scotian Shelf sections during the spring survey in 2004.

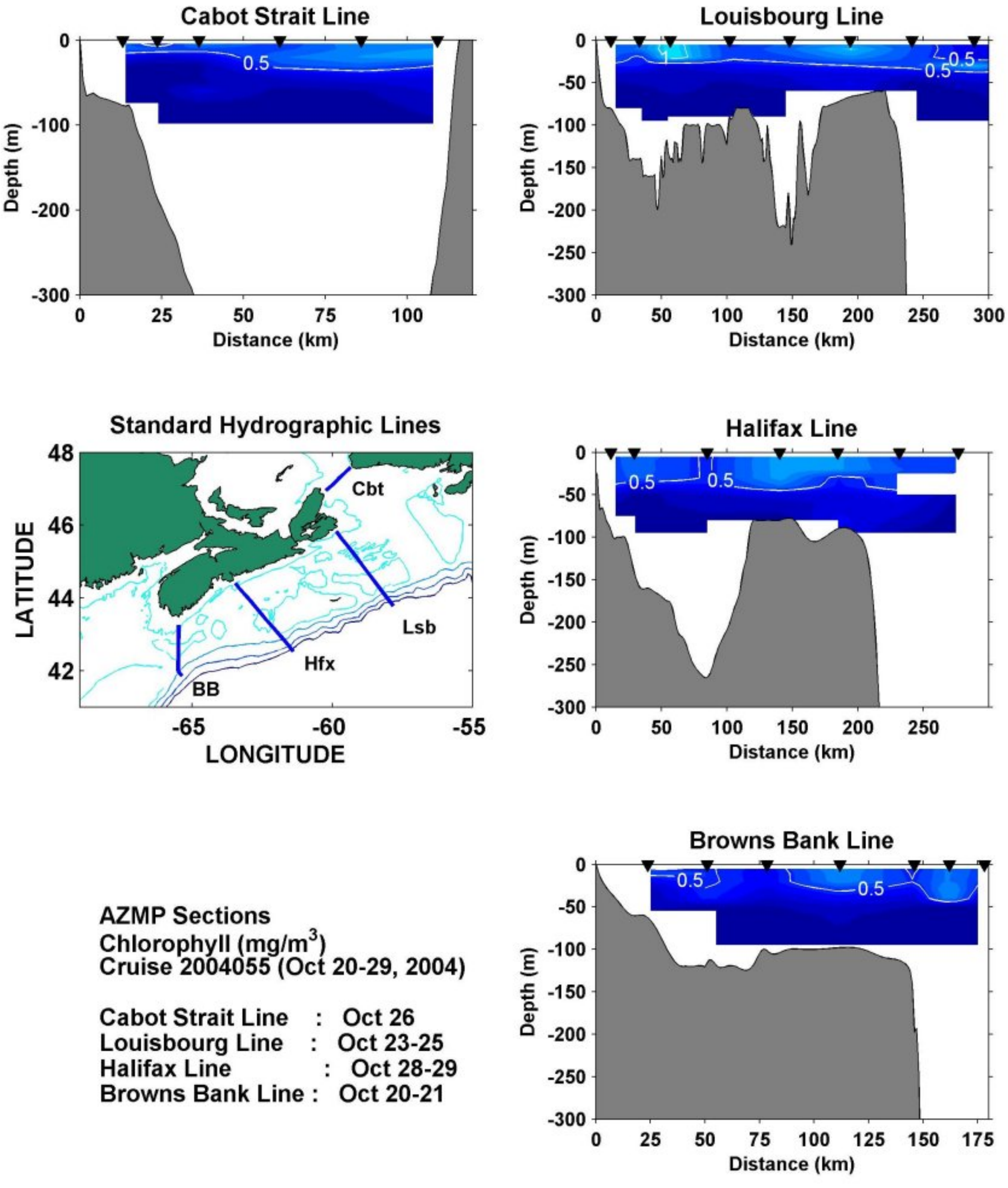


Figure 21. Vertical chlorophyll structure along the Scotian Shelf sections during the fall survey in 2004.

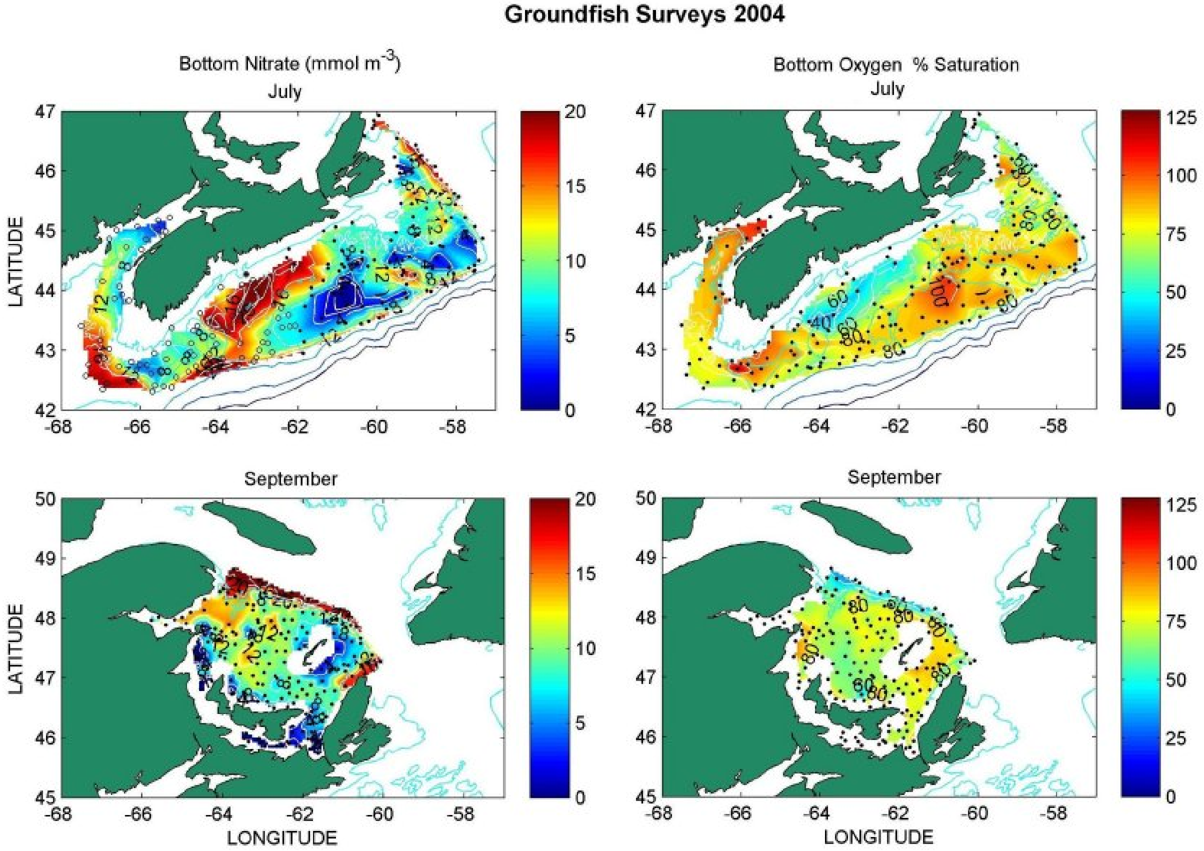


Figure 22. Bottom nitrate concentrations and oxygen saturation on the Scotian Shelf and in the Southern Gulf of St. Lawrence during the annual July and September groundfish surveys in 2004.

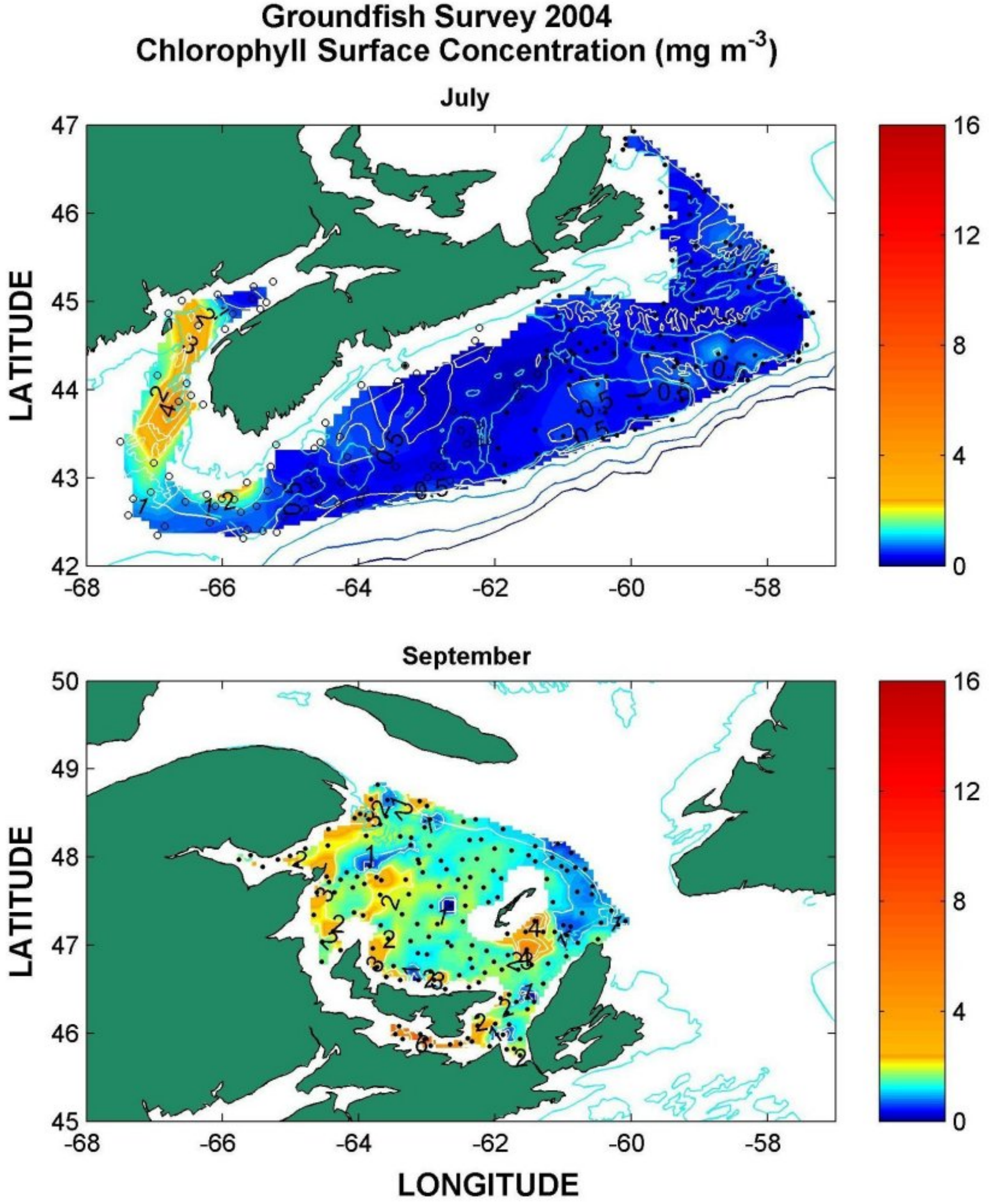


Figure 23. Surface chlorophyll concentrations on the Scotian Shelf and in the Southern Gulf of St. Lawrence during the annual July and September groundfish surveys in 2004.

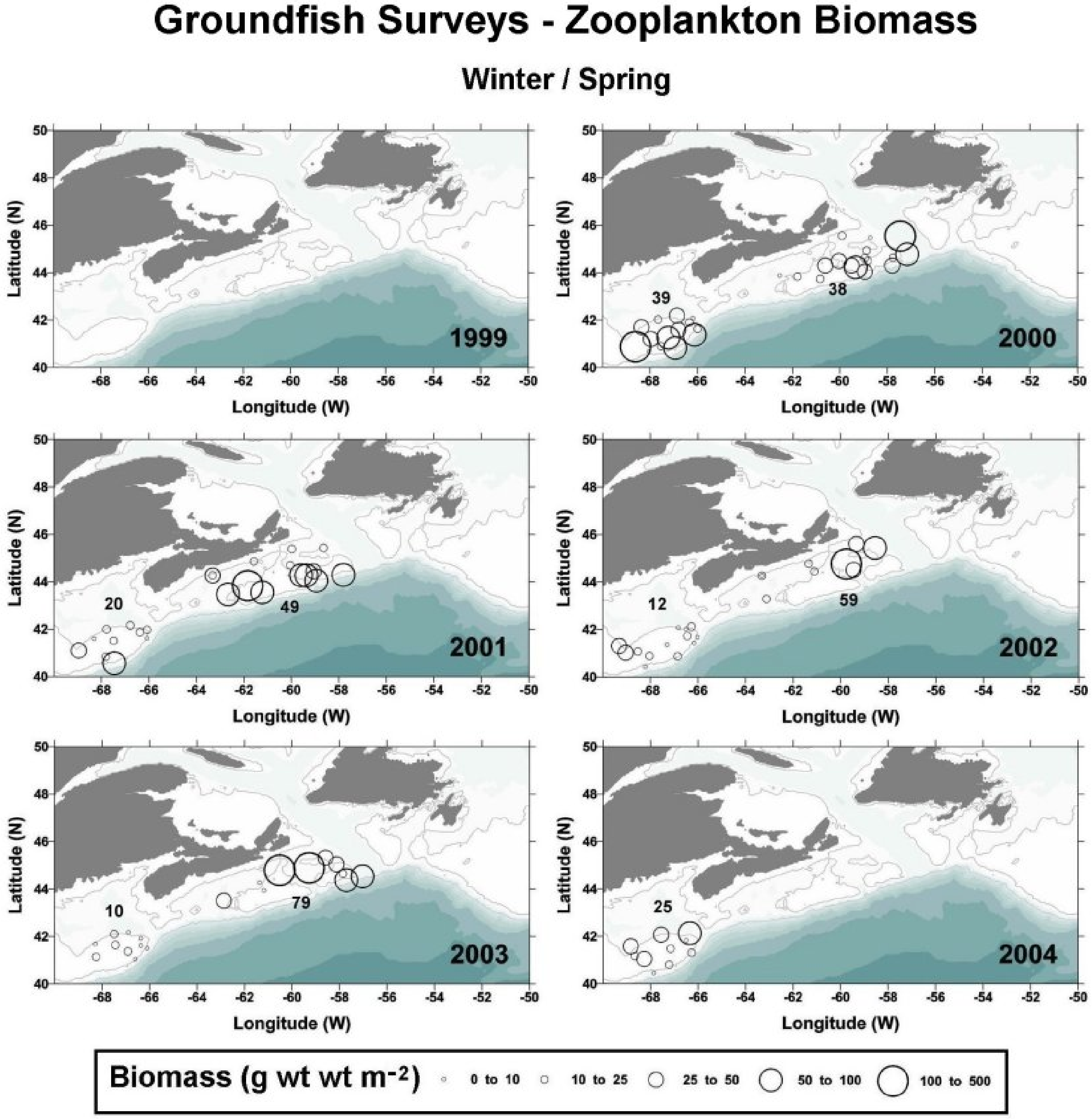


Figure 24. Zooplankton biomass on Georges Bank (February) and the eastern Scotian Shelf (March) during the annual groundfish surveys, 1999-2004. Numbers are survey average biomass (g wt wt m^{-2}).

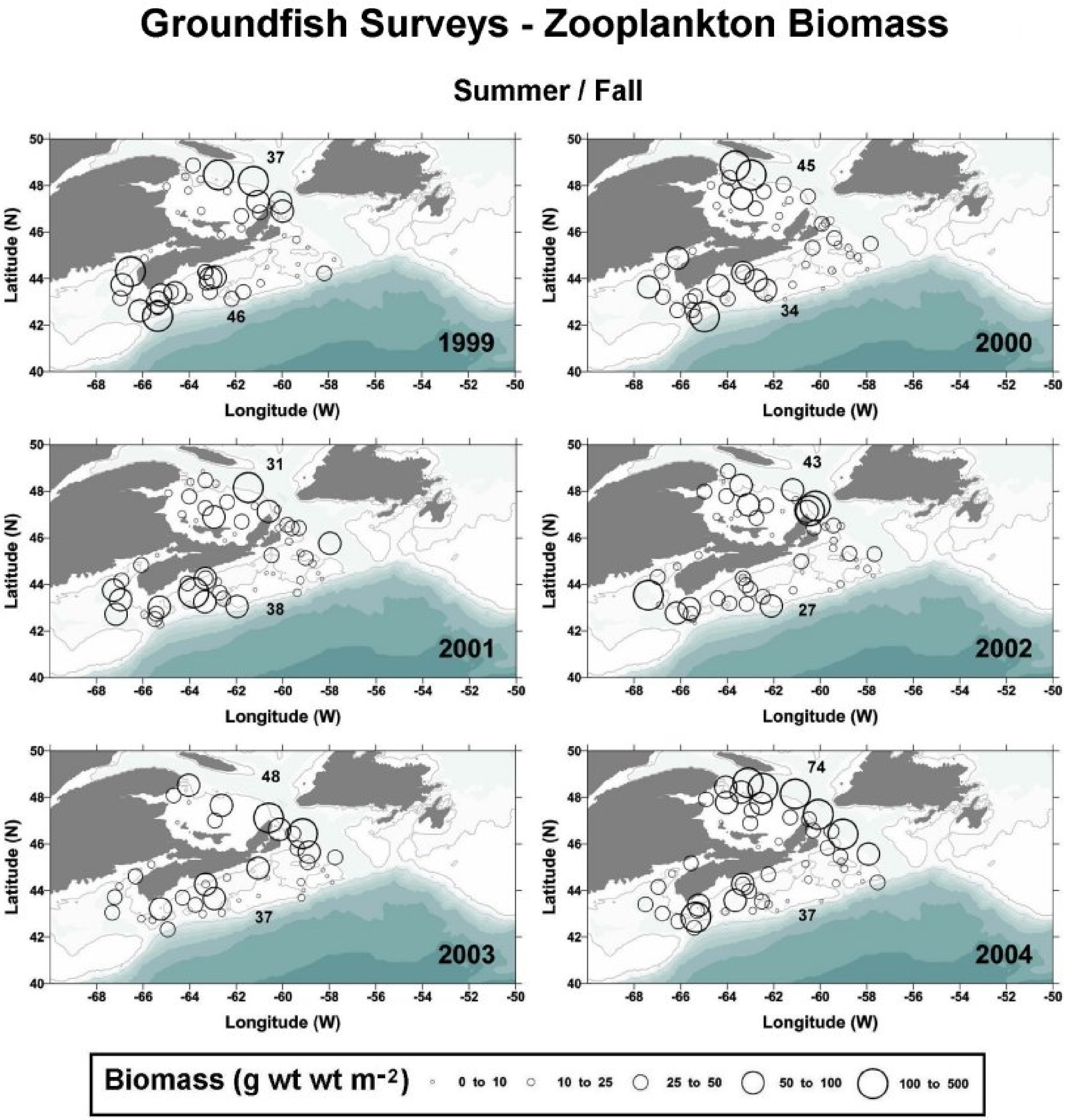


Figure 25. Zooplankton biomass on the Scotian Shelf (July) and the southern Gulf of St. Lawrence (September) during the annual groundfish surveys, 1999-2004. Numbers are survey average biomass (g wt wt m^{-2}).

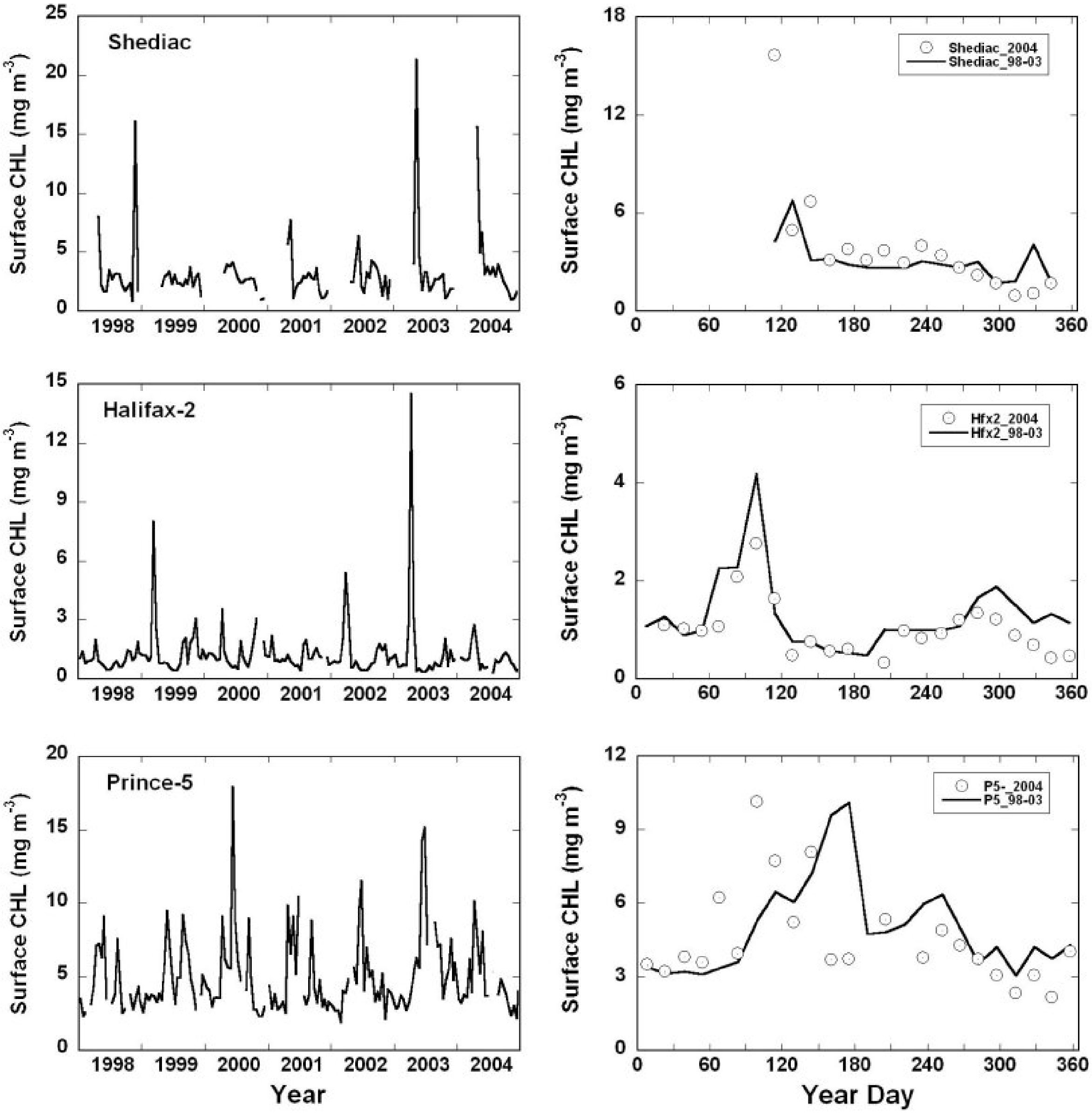


Figure 26. Time-series of surface chlorophyll concentrations (from SeaWiFS bi-weekly ocean colour composites) at the three Maritimes/Gulf regions' fixed stations, 1998-2004.

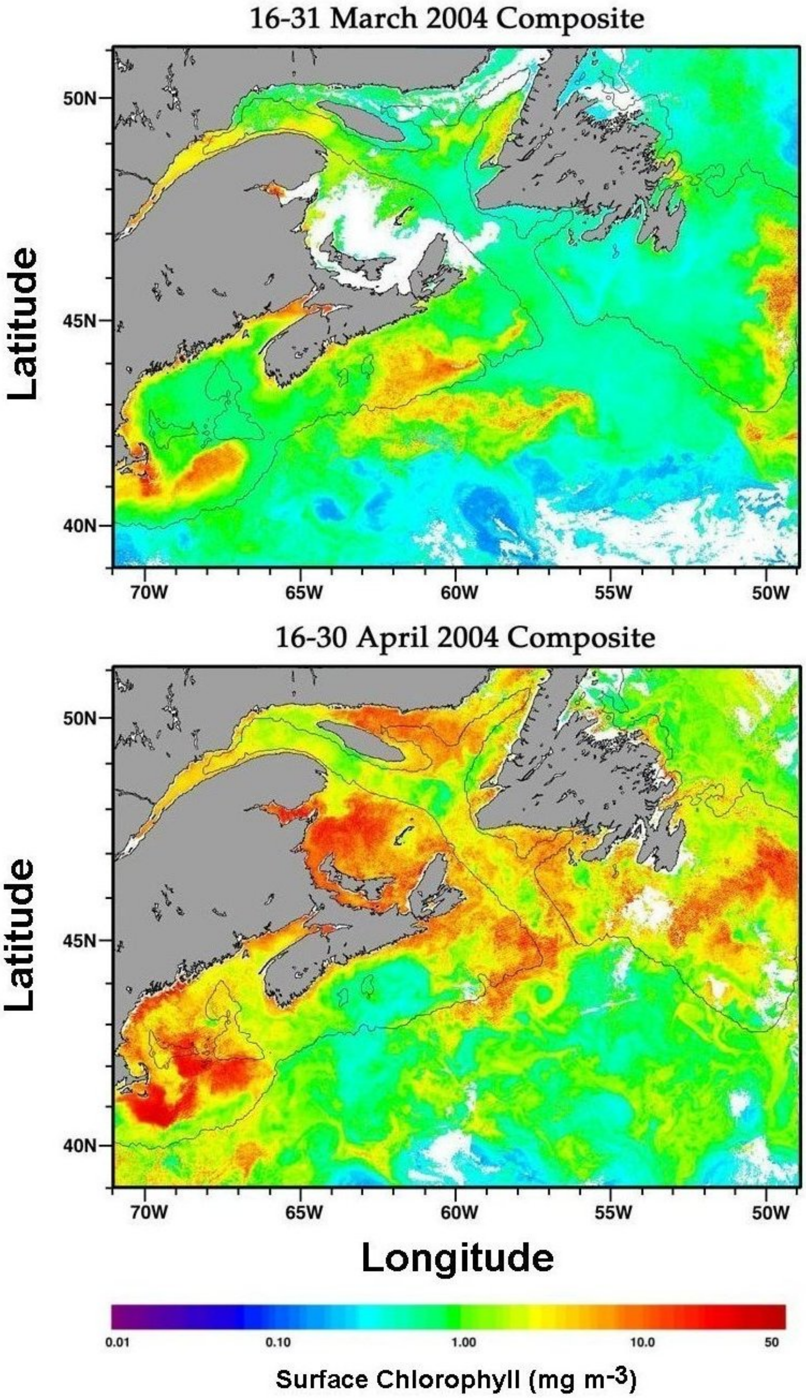


Figure 27. SeaWiFS bi-weekly composite images of surface chlorophyll in late March and April, 2004 in the Maritimes/Gulf Regions. The upper panel shows the outer-shelf early development of the spring bloom on the Scotian Shelf. The lower panel shows the extensive and wide-spread April bloom in the Southern Gulf.

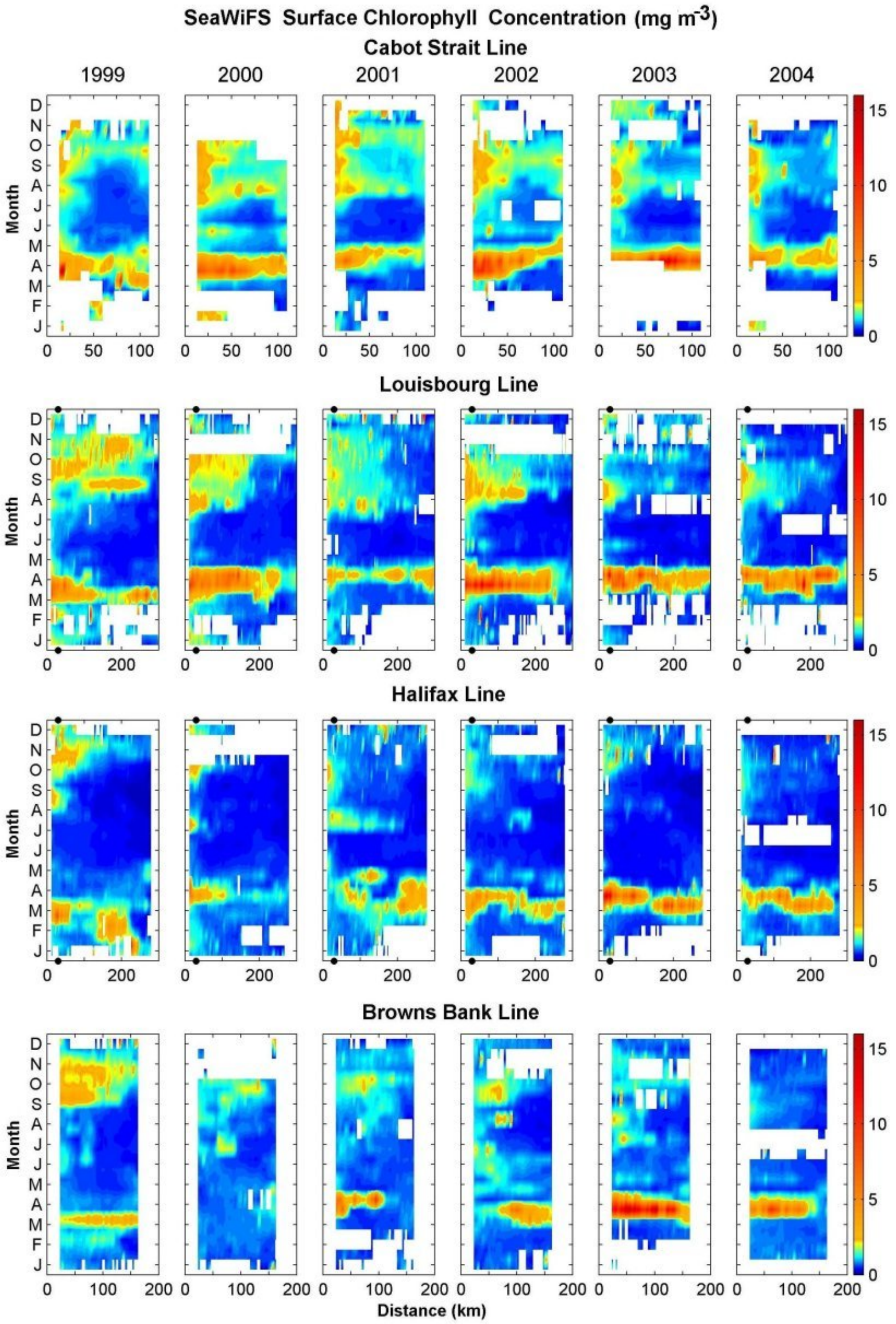


Figure 28. Time-series of surface chlorophyll concentrations (mg m^{-3}), from SeaWiFS bi-weekly ocean colour composites, along the Maritimes/Gulf sections (see Fig. 1), 1998-2003. Horizontal axes running south to north (Cabot line) or west to east (Louisbourg, Halifax, Browns Bank lines).

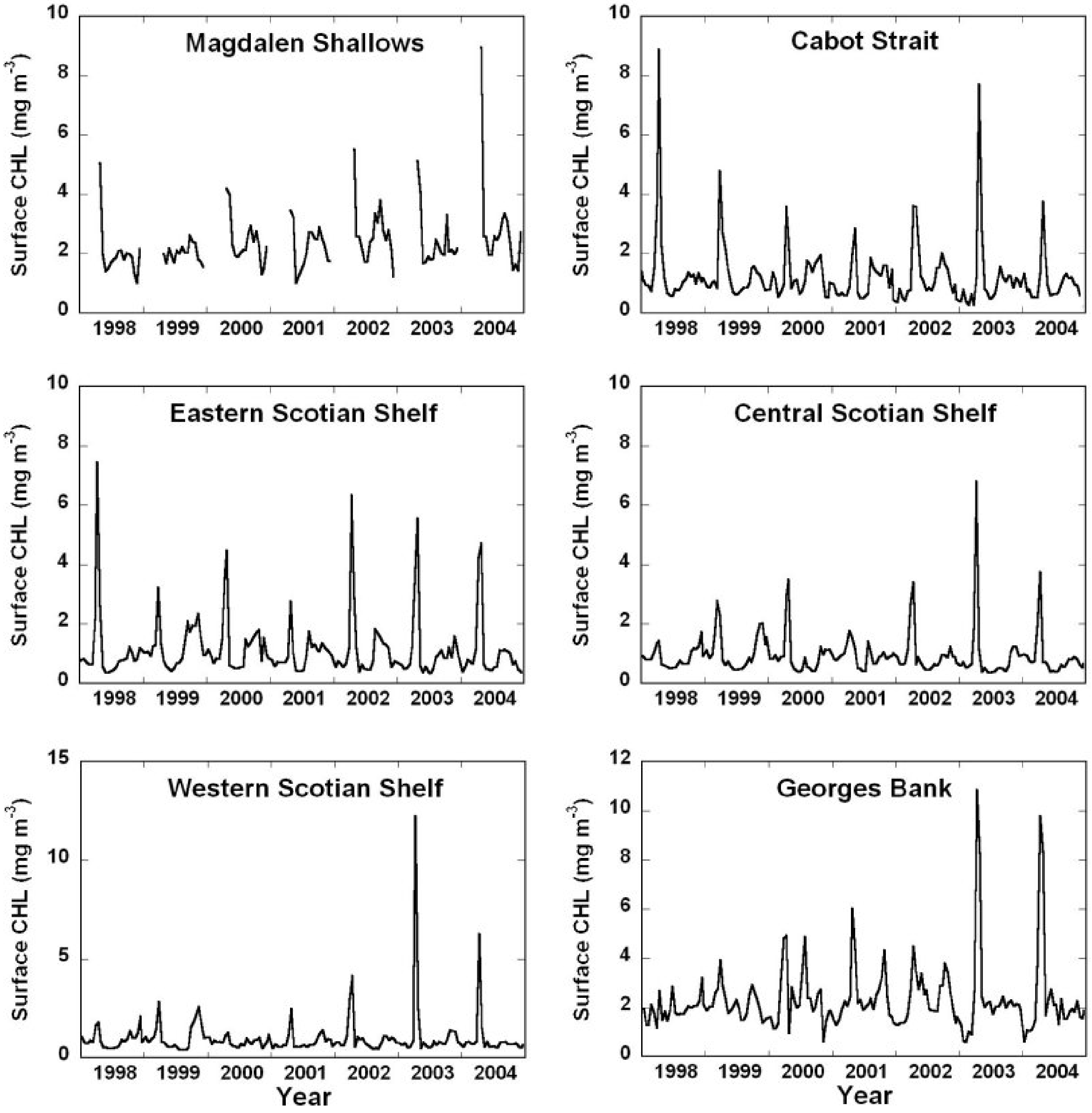


Figure 29. **Time-series of surface chlorophyll concentrations (from SeaWiFS bi-weekly ocean colour composites) for statistical sub-regions of the Maritimes/Gulf regions (see Fig. 5), 1998-2004.**

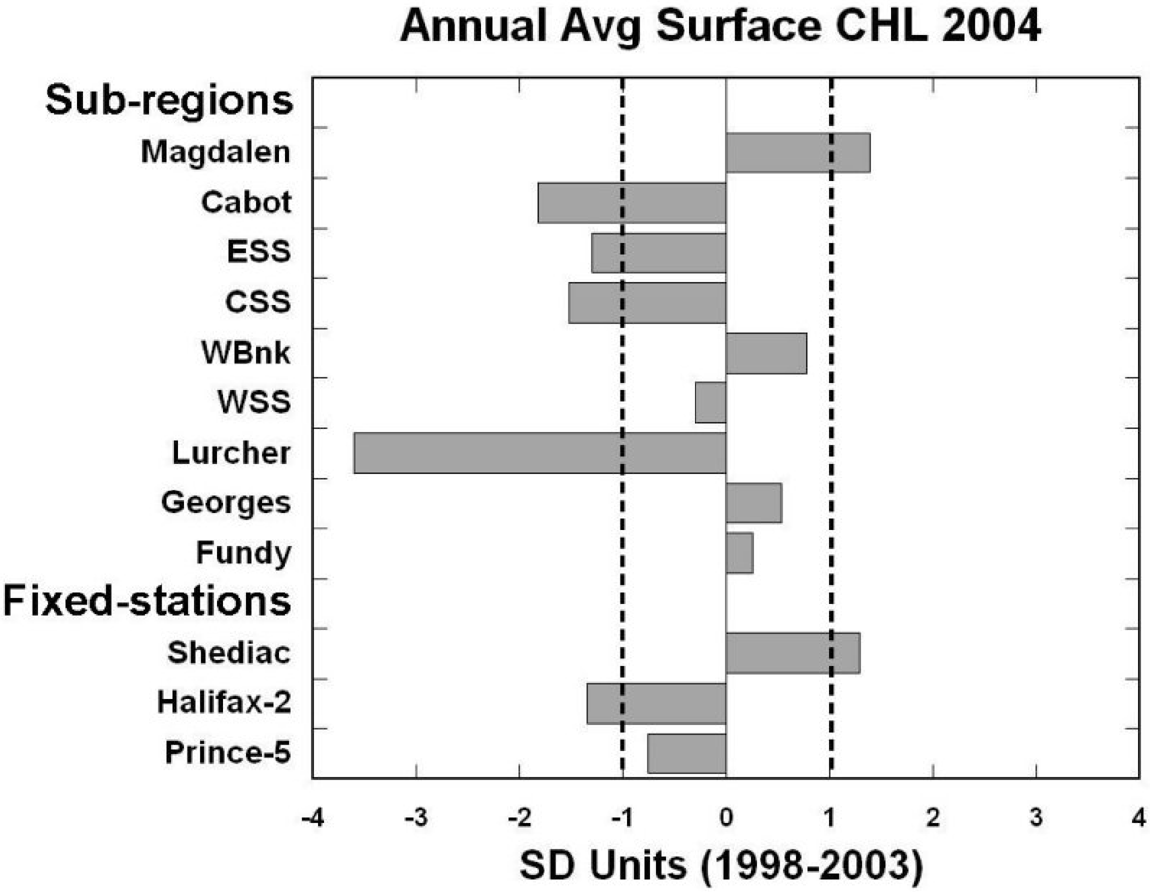


Figure 30. Surface chlorophyll conditions in the northwest Atlantic in 2004 from SeaWiFS composite images. Mean concentrations in 2004 for the 6 fixed stations and 24 statistical sub-regions (see Fig. 5) were compared with means concentrations for the total data record and expressed as standard deviation units. Dashed lines are +/- one standard deviation of the 1998-2003 data record.

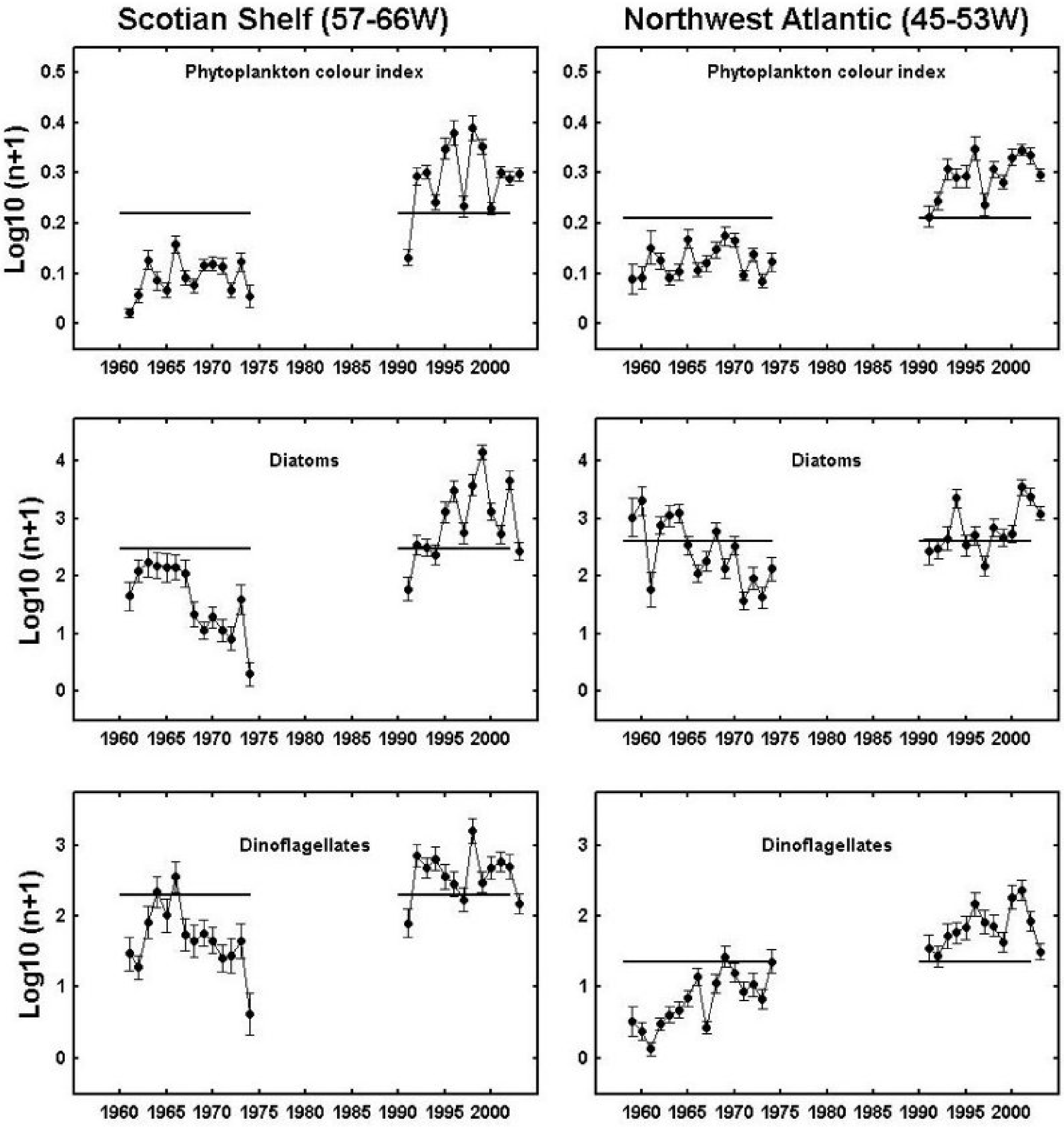


Figure 31. Time-series of phytoplankton biomass (colour index), diatom and dinoflagellate relative abundances (annual means) on the Scotian Shelf (57-66º W) and the Northwest Atlantic (45-53º W) from CPR surveys, 1961-2003 (see Fig. 4 for area coverage). Vertical bars are standard errors.

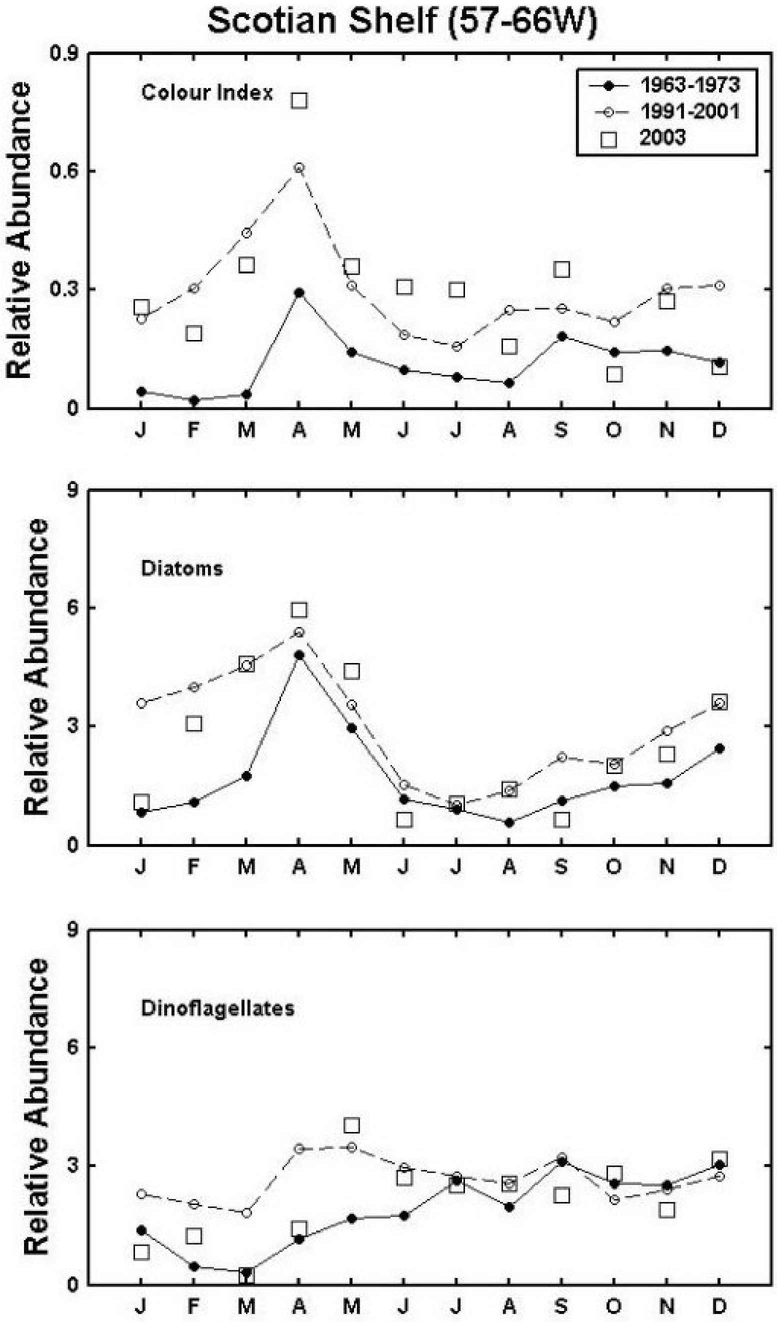


Figure 32. Monthly means of phytoplankton adundance on the Scotian Shelf in 2003 from CPR surveys. Means for the decades of the 1960s and 1990s shown for comparison.

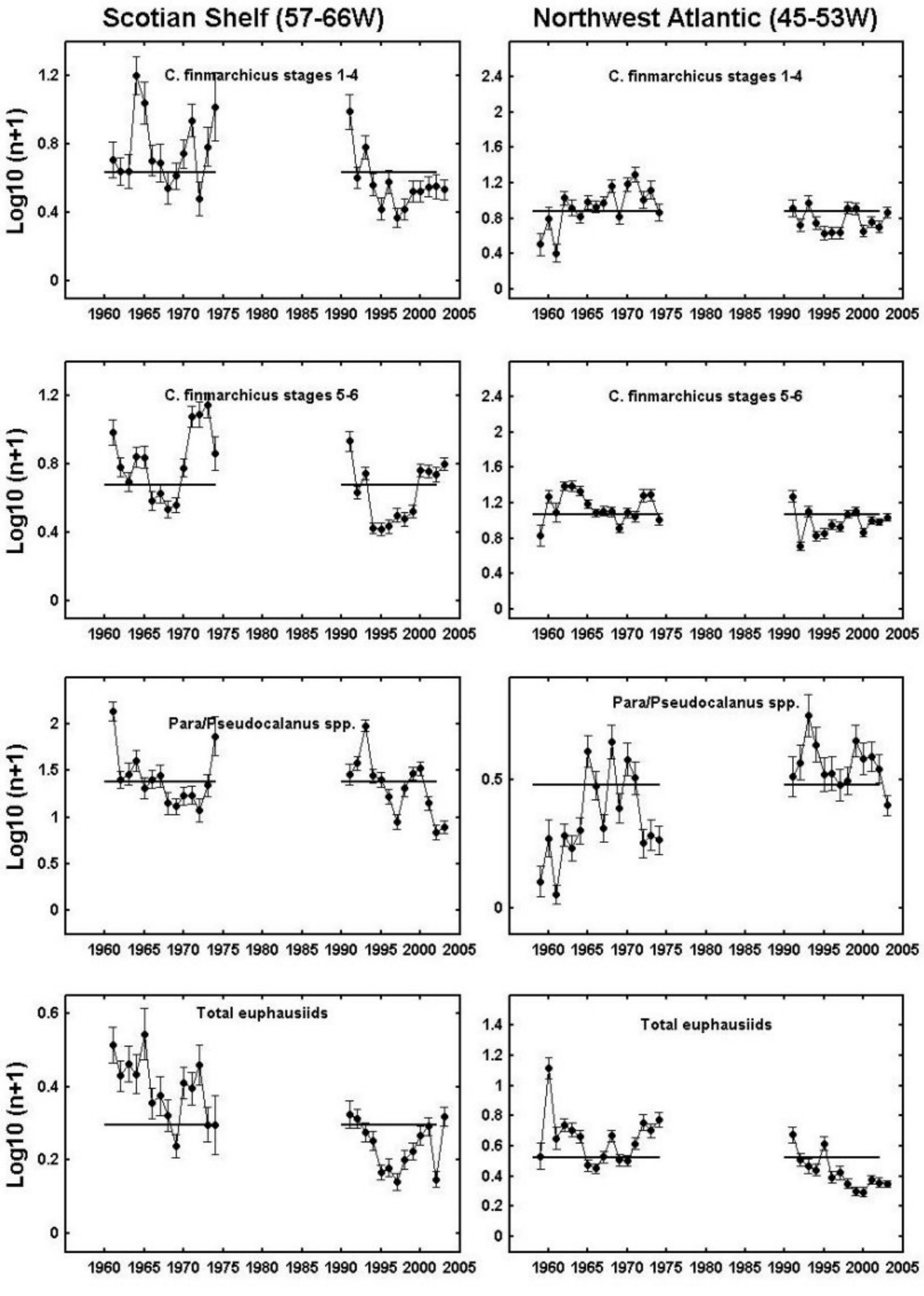


Figure 33. Time-series of relative abundances of selected zooplankton species (annual means) on the Scotian Shelf (57-66º W) and the Northwest Atlantic (45-53º W) from CPR surveys, 1961-2003 (see Fig. 4 for area coverage). Vertical bars are standard errors.

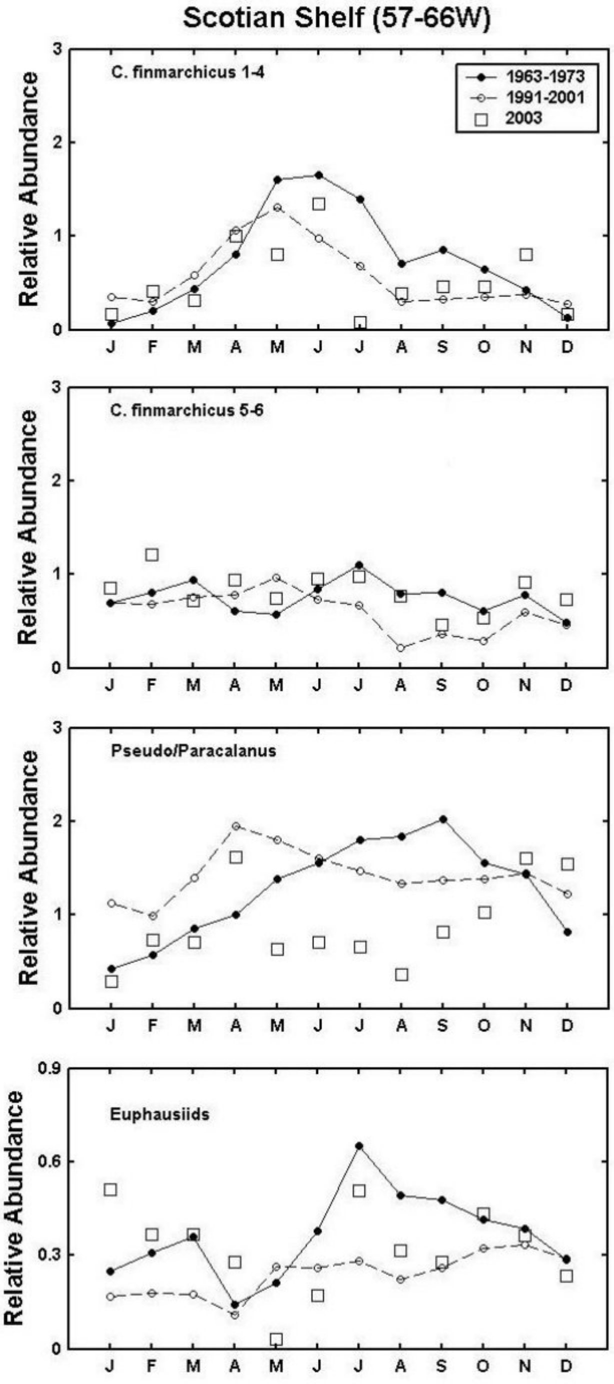


Figure 34. Monthly means of zooplankton abundance on the Scotian Shelf in 2003 from CPR surveys. Means for the decades of the 1960s and 1990s shown for comparison.