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Optical, chemical and biological oceanographic conditions in the Maritimes region in 2007

Propriétés optiques, chimiques et biologiques de l'océan dans la région des Maritimes, en 2007

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ABSTRACT

Optical, chemical, and biological oceanographic conditions in the Maritimes region (Georges Bank, eastern Gulf of Maine, Bay of Fundy and the Scotian Shelf) during 2007 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, ecosystem trawl (or groundfish) surveys, CPR, remote-sensing), some data from outside the region are discussed also to provide the larger, zonal perspective.

Optical properties at the Maritimes fixed stations in 2007 differed by site but were, for the most part, comparable to conditions observed in previous years. The most notable features in physical structure of the water column in 2007 were the slightly stronger stratification and shallower summer mixed layers at Halifax-2 and the record shallow summer-fall mixed layers at Prince-5.

Wintertime maximum nitrate concentrations in surface waters at Halifax-2 were at normal levels in 2007 while they were above normal at P-5. Deep (50-150 m) nutrient inventories in spring were lower than normal, shelf-wide. Summer levels and the depth of nitrate depletion were among the lowest (deepest) observed since systematic measurements began in 1999. Concentrations in deep waters were near normal at both stations.

The most prominent feature of phytoplankton in the Maritimes region in 2007 was the record high and shelf-wide spring bloom in April, with concentrations >8 mg m^{-2} penetrating to depths of 100 m and inventories approaching 1,000 mg m^{-2}. Phytoplankton community structure at the two fixed stations in 2007 was similar to that seen in previous years with diatoms dominating during the spring bloom (~90%) and flagellates dominating (~50-80%) in summer-fall at Halifax-2 and diatoms dominating (~95%) the community at Prince-5 year-round. CPR data continue to show that contemporary (1990s/2000s) 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.

In 2007, zooplankton biomass and abundance were highly variable in space and time, as in past years. Zooplankton biomass and abundance, overall, were low in 2007, although near-record peaks in zooplankton biomass and *C. finmarchicus* abundance were observed at Halifax-2. Low zooplankton biomass was observed during the February, March, and July trawl surveys, at Halifax-2 during non-peak periods, and at Prince-5 throughout the year. Zooplankton seasonal zooplankton peak timing tended to be later than normal in 2007. Warm-water zooplankton taxa that are usually abundant during summer and fall were less abundant than normal on the Scotian Shelf, and some warm-water and off-shelf species were nearly absent. Arctic species were more abundant than normal on the eastern Scotian Shelf. At Prince-5, there was a major shift in community composition in the summer and fall, with low abundances of most of the normally dominant species, and a high abundance of two cladoceran species. The 2006 CPR data generally continued the trends of 2005. The abundance of *C. finmarchicus* early copepodid stages was close to normal on the Scotian Shelf and in the northwest Atlantic region. The abundance of *C. finmarchicus* late stages and euphausiids were higher than normal, and *Para-* and *Pseudocalanus* abundance was lower than normal on the Scotian Shelf, while the opposite was true in the northwest Atlantic region.

RÉSUMÉ

On examine les conditions océanographiques optiques, chimiques et biologiques dans la région des Maritimes (banc Georges, est du golfe du Maine, baie de Fundy et plate-forme néo-écossaise) au cours de 2007, puis on les compare aux conditions observées au cours de l'année précédente et à long terme, s'il y a lieu. En plus des descriptions des séries de données de base du Programme de monitorage de la zone atlantique (PMZA) [stations fixes, transects saisonners, relevés au chalut de l'écosystème (ou du poisson de fond), enregistreurs de plancton en continu (EPC), télédétection], on examine un certain nombre de données de l'extérieur de la région afin de donner une perspective une vue d'ensemble de la zone.

Les propriétés optiques aux stations fixes de la région des Maritimes en 2007 différaient d'un endroit à l'autre, mais en général, étaient comparables aux conditions observées les années précédentes. Les caractéristiques les plus remarquables de la structure physique de la colonne d'eau en 2007 étaient la stratification légèrement plus prononcée et les couches de mélange d'été moins profondes à Halifax 2, et l'eau peu profonde record des couches de mélange d'été et d'automne à Prince 5.

Les concentrations maximales de nitrates des eaux de surface, au cours de l'hiver, à Halifax 2, se situaient à des niveaux habituels en 2007, alors qu'elles se situaient en haut de la moyenne à Prince 5. Les concentrations d'éléments nutritifs en profondeur (de 50 à 150 m) au printemps étaient plus faibles que la moyenne, à l'échelle de la plate-forme. Les niveaux au cours de l'été et la profondeur de la zone de raréfaction des nitrates étaient parmi les plus bas (les plus profonds) de ceux observés depuis le début des mesures systématiques, soit en 1999. Les concentrations dans les eaux profondes étaient presque normales aux deux stations.

La caractéristique la plus dominante du phytoplancton dans la région des Maritimes en 2007 a été le maximum record de l'efflorescence printanière à l'échelle de la plate-forme en avril, avec des concentrations de plus de 8 mg m^{-2} pénétrant jusqu'à des profondeurs de 100 m où les concentrations approchent 1 000 mg m^{-2}. La structure de la communauté du phytoplancton aux deux stations fixes en 2007 était semblable à celle observée au cours d'années précédentes avec la domination de diatomées au cours de l'efflorescence printanière (~90 %), de flagellés (~50 à 80 %) au cours de l'été et de l'automne à Halifax 2 et de diatomées (~95 %) dans la communauté à Prince 5 toute l'année. Les données EPC continuent à indiquer que les niveaux d'abondance récents (années 1990 et 2000) du phytoplancton se situent bien au-dessus de la moyenne à long terme et que le cycle de croissance saisonnière a débuté plus tôt dans l'année que durant la première décennie d'observations des années 1960 à 1970.

En 2007, la biomasse et l'abondance du zooplancton étaient très variables sur les plans géographique et saisonnier, tout comme au cours des dernières années. La biomasse et l'abondance du zooplancton, dans l'ensemble, étaient faibles en 2007, quoique des sommets presque records de biomasse de zooplancton et d'abondance de *Calanus finmarchicus* aient été observés à Halifax 2. Une faible biomasse de zooplancton a été observée au cours des relevés au chalut de février, de mars et de juillet à Halifax 2, hors des périodes de pointe, ainsi qu'à Prince 5, tout au long de l'année. La période de pointe du zooplancton saisonnier a eu tendance à survenir plus tard que la moyenne, en 2007. Les taxons de zooplancton d'eau chaude qui sont habituellement abondants au

cours de l'été et de l'automne ont été moins abondants que la moyenne sur la plate-forme néo-écossaise, et certaines espèces d'eau chaude et océaniques étaient presque absentes. Les espèces arctiques étaient plus abondantes que la moyenne dans l’est de la plate-forme néo-écossaise. À Prince 5, il y a eu un important changement dans la composition de la communauté au cours de l'été et de l'automne, avec de faibles abondances de la majorité des espèces habituellement dominantes, ainsi qu'une forte abondance de deux espèces de cladocères. Les données EPC de 2006 ont généralement maintenu les tendances de 2005. L'abondance des premiers stades copépodites de *C. finmarchicus* était près de la moyenne sur la plate-forme néo-écossaise et dans la région de l'Atlantique nord-ouest. L'abondance des derniers stades de *C. finmarchicus* et d'euphausiacés était plus forte que la moyenne et l'abondance de *Paracalanus* et de *Pseudocalanus* était plus faible que la moyenne sur la plate-forme néo-écossaise, alors que le contraire était vrai dans la région de l'Atlantique nord-ouest.

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, trawl 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. Trawl (groundfish) surveys and cross-shelf sections provide detailed geographic information (Harrison et al. 2005) 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 Georges Bank/Gulf of Maine/Bay of Fundy system and the Scotian Shelf, during 2007. For some data (CPR), descriptions will include observations outside the Maritimes/Gulf, i.e. the central and western North Atlantic. Conditions in 2007 will be compared with those observed during recent years (Harrison et al. 2007) 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 trawl surveys) during the 2007 calendar year in addition to repeat day-trips to the 3 fixed stations; 682 station occupations were the total sampled all together (Table 1).

Fixed Stations. In 2007 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. As always, the availability of resources (platforms) and to some extent, difficulties with weather and ice, make achieving this sampling frequency a challenge. In 2007, Halifax-2 and Prince-5 were sampled on 22 and 12 occasions, respectively. Shediac was sampled only 9 times. By definition; the Shediac station has an icetruncated open water season. Difficulties encountered with Coast Guard operations and platform availability in the previous years were somewhat resolved and Shediac station occupations were consistent with those of 2006. Fixed station occupations were, once again, below our highest frequency in 2002.

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 suite of measurements.
- Niskin water bottle sample for phytoplankton enumeration.
- Vertical ring net tows for zooplankton biomass and enumeration,
- Secchi depth measurement 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 2007, the spring and fall missions were carried out from the 'CCGS Hudson'; so were once again able to carry out our normal/full sampling campaign. The four core transects were occupied in the both seasons. There was an opportunity to sample the Halifax Line in May 2007 as the field-time allotted to the Labrador Sea mission allowed sufficient time to occupy the section.

The standard sampling suite when occupying section stations consisted of:

- CTD (SBE911 OSD 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.

Trawl (Groundfish) Surveys. There are four primary trawl surveys in which AZMP-Maritimes/Gulf participates: 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). These surveys were all carried-out in 2007 by the Population Ecology Division with AZMP participation.

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

- CTD (SBE25 – standalone CTD in 2007) 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 taken 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 ~0.3 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)
- Trawl surveys - 5m, 25m, 50m, near bottom (when possible)

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 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 (Richardson et al. 2006). 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. 2006 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) and the Moderate Resolution Imaging Spectroradiometer (MODIS) "Aqua" sensor (http://modis.gsfc.nasa.gov/). The MODIS data stream began in July, 2002. Satellite data do not provide information on the vertical structure of phytoplankton in the water column but do provide synoptic information on their geographical distribution in surface waters at the large scale. Bi-weekly composite images (based on MODIS 1.5 km spatial resolution data) of surface chlorophyll for the entire NW Atlantic (39-62.5 N Lat., 42-71 W Lon.) are routinely produced and posted (http://www.mar.dfo-mpo.gc.ca/science/ocean/ias/seawifs/seawifs_3.html). Basic statistics (mean, range, standard deviation, etc.) are extracted from weekly composites (based on SeaWiFS 4 km spatial resolution data) for selected sub-regions (Fig. 5), for the fixed stations and for the seasonal sections.

As in 2006, oceanographic conditions at the Shediac fixed station and conditions observed during the September Southern Gulf of St. Lawrence trawl survey will be reported by the Quebec Region in order to better consolidate regional (i.e. entire Gulf of St. Lawrence) observations and interpretation.

RESULTS

Mixing and Optical Properties

Mixing and optical properties of the upper water column varied by season and location at the Maritimes fixed stations (Figs. 6, 7). Seasonal development of the mixed-layer and upper water-column stratification were most evident at the Halifax-2 station (Fig. 6); shallow mixed layers (<20 m) and maximum stratification (>0.08 kg m^{-4}) were evident in late summer and early fall months (August-October). Mixed-layer development at Halifax-2 in 2007 was consistent with the long-term average conditions. Winter mixed layers depths were slightly deeper than the long-term mean (48 m) while mixed layers in summer and fall were significantly shallower (<10-20 m) than the norm (>10-30 m). The development of stratification at Halifax-2 was also consistent with the long term average, however, conditions in the summer and fall of 2007 were higher than usual. In marked contrast to the Halifax-2 station, stratification was extremely low (<0.01 kg m^{-4}) at the Prince-5 station throughout the year, due principally to strong tidal mixing. Slightly lower than normal stratification was evident in spring, 2007. Mixed-layer depths are highly variable and difficult to determine at this station due to the very small vertical density differences; estimates normally range from ~30-40 m in spring and early summer to almost full depth in winter. In 2007, mixed layer depths in summer and fall were the shallowest on record (10-20 m) at Prince-5.

Euphotic zone depth estimates derived from Secchi disc readings and direct downwelling irradiance (PAR) measurements were comparable. Maximum vertical light attenuation (and shallowest euphotic zone depths) normally coincide with the spring bloom and euphotic depths are generally deepest immediately following the decline of the bloom (Fig. 7). Unfortunately, light measurements were not made at the time of the strong bloom at Halifax-2 in 2007. Overall, however, euphotic depths fell within the 45-50 m range, consistent with the long-term average. At the Prince-5 station in contrast, euphotic depths were significantly shallower (~20 m), remarkably constant through the year and consistent with the long-term average at that station. Overall, seasonal patterns and magnitudes of optical properties in 2007 at Halifax-2 and Prince-5 were similar to those observed in previous years.

Nutrients

Fixed stations. 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 both Maritimes fixed stations in 2007 (Fig. 8). Low surface values persisted throughout the summer/fall at Halifax-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 mmol m^{-3}) in summer 2007 at Halifax-2 (38 m) was close the record depths seen in 2004 and 2005 (>40 m) and deeper than the long-term average (34 m). The seasonal evolution of the vertical nitrate structure at Halifax-2 in 2007 was similar to that observed in previous years. Anomaly plots showed that nitrate concentrations in surface waters were near normal and in deep waters (>50 m) somewhat lower (-2 to -4 mmol m^{-3}) than the long term average. Near surface nitrate concentrations at Prince-5 in 2007 were never reduced below 2 mmol m^{-3}. Anomaly plots for this station indicated that nitrate concentrations were higher (>2 mmol m^{-3}) than usual in winter, and variable (±2 mmol m^{-3}) in surface and deep waters the rest of the year.

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 both of the Maritimes fixed stations (Fig. 9A). Although the seasonal pattern of variability in nitrate at Halifax-2 in 2007 was similar to that observed in previous years, inventories immediately following the spring bloom were lower (~20 mmol m^{-2}) than the norm. Winter maximum nitrate inventories in the upper 50 m at Prince-5 in 2007 (~560 mmol m^{-2}) were significantly higher than the long term average (~470 mmol m^{-2}) but, like Halifax-2, summer levels (~100 mmol m^{-2}) were lower than the norm (~210 mmol m^{-2}). Nitrate inventories in deep waters (>50 m) at Halifax-2 in 2007 were generally comparable with the long-term average (~700-900 mmol m^{-2}) (Fig. 9B). At Prince-5 nitrate inventories in deep waters were higher in winter (~500 mmol m^{-2}) and lower in summer (~180 mmol m^{-2}) than the long-term mean (winter: ~420 mmol m^{-2}, summer: ~270 mmol m^{-2}).

Shelf sections. Vertical distributions of nitrate in spring were generally similar along the Scotian Shelf sections in 2007, 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. 10); the exception was along the Cabot Strait line where surface concentrations generally exceeded 2 mmol m^{-3}. Deep-water (>50 m) concentrations were highest in basins (>20 mmol m^{-3}) and in slope waters off the edge of the shelf. As in previous years, nitrate levels in surface waters were already reduced at the time of the spring survey in April (1 mmol m^{-3} depth horizon: ~20-50 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 2007 were comparable to levels observed in previous years in fall, however, record high levels (Avg: ~140 mmol m^{-2}) were seen along the Cabot Strait line and record low levels (Avg: ~50 mmol m^{-2}) along the Browns Bank line in spring (Fig. 11A, Table 2). On both the Louisbourg and Halifax lines, there is a trend of increasing inventories over time in both spring and fall whereas there is a decreasing trend on the Browns Bank line. Deep nitrate inventories (50-150 m) were lower (480-600 mmol m^{-3}) than normal (570-740 mmol m^{-3}) in spring but comparable to levels seen in previous years in fall, 2007 (Fig. 11B); there is a suggestion of a small but general decline in deep inventories over time, particularly in spring.

Trawl (groundfish) surveys. Bottom water nitrate concentrations on the Scotian Shelf in July 2007 (Avg: 9.6 mmol m^{-3}) were the lowest on record, long-term average = 11.6 mmol m^{-3-} (Table 3). 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. 12). Bottom water oxygen saturation on the Scotian Shelf in summer 2007 (Avg: 77% sat), in contrast, was close to the long-term average (79% sat). Similarly, the area of the bottom covered by waters with

<60% saturation was the same as the long term average (16,600 km^2 or ~11% of the shelf area. As usual, lowest saturations were found in deep basins (e.g. Emerald Basin) and deep waters off the shelf edge where nutrients are highest.

Phytoplankton

Fixed stations. Distinctly different seasonal phytoplankton growth cycles are evident at the two Maritimes fixed stations (Figs. 13, 14). The strongest (magnitude) spring bloom on record (976 mg m^{-2}) was observed at Halifax-2 in 2007, considerably higher than the long term average (436 mg m^{-2}) and in marked contrast to the record low seen in 2006 (256 mg m^{-2}). Anomaly plots (Fig. 13) suggested that the timing of the 2007 spring bloom was consistent with the long term mean (peak at YD 97) but was >5 mg m^{-3} above the norm. A more detailed analysis of the timing of the bloom at this station revealed that the 2007 bloom started earlier (YD 77) than in 2006 (YD 90) and closer to the long term average, YD 71 (Fig. 15a). The duration of the bloom was longer (35 days) than in the previous two years but shorter than the long-term average (46 days). In addition to changes in bloom dynamics, the "background" chlorophyll levels (outside the bloom period) have been declining over the past 9 years, from ~40 mg m^{-2} in 1999 to <30 mg m^{-2} in 2007 (Fig. 15b). The evolution of the phytoplankton community composition at Halifax-2 in 2007 was similar to that seen previously, i.e. diatoms dominated in the winter/spring, i.e. >75% of the total count, and flagellates and dinoflagellates dominated (>60% of the total count) the rest of the year (Fig. 16). In 2007, the contribution of diatoms to the microplankton community immediately following the spring bloom was lower (~10%) and the contribution of flagellates higher (~80%) than normally seen. Overall, diatoms account for ~45% of the total community counts, flagellates account for another ~40% and dinoflagellates for ~10%.

The phytoplankton growth cycle at Prince-5, in contrast to Halifax-2; is characterized by a primary burst of growth in summer (June) with secondary peaks in late summer or fall (August-September). In 2007, the peak concentration (600 mg m^{-2}), occurring on YD 164, was significantly higher than the long term average (400 mg m^{-2}) but normal in timing relative to the long term mean. However, the duration of the primary bloom (96 days) was longer than the average (73 days). The anomaly plot confirms the timing of the primary peak was normal and the magnitude was >5 mg m^{-3} above average. A negative anomaly (-2 mg m^{-2}) in September indicated a diminished secondary fall peak. As has been noted previously, the phytoplankton community at Prince-5 is comprised almost exclusively of diatoms (>95%) year-round. Total microplankton counts during the blooms at both fixed stations did not increase to the extent that chlorophyll levels would have suggested. On an annual basis, Prince-5 sustains the larger chlorophyll inventories of the two Maritimes fixed stations (P-5: >100 mg m^{-2}, Halifax-2: 75 mg m^{-2}).

Shelf sections. Chlorophyll levels along all the shelf sections are always considerably higher in spring than in fall. Chlorophyll levels during spring of the 2007 survey were no exception and were, in fact, the highest observed since AZMP observations began in 1999 (Fig. 17, Table 2), particularly along the Louisbourg, Halifax and Browns Bank lines. Concentrations exceeding 8 mg m^{-3} were seen as deep as 100 m. Indeed, chlorophyll inventories were at record high levels in spring, i.e. ~600-700 mg m^{-2} in 2007 versus the long-term average of ~150-300 mg m^{-2} (Fig. 18). In contrast, chlorophyll levels during the fall surveys were at or slightly below (~30-40 mg m^{-2}) average levels (~30-50 mg m^{-2}).

Trawl (groundfish) surveys. Near-surface chlorophyll levels during the 2007 spring survey on the eastern Scotian Shelf showed a distributional pattern somewhat different from previous years, i.e. the high concentrations seen off-shelf (usually >8 mg m^{-3}) and distributed along the eastern sector (see Harrison et al. 2007) were distributed more in the western sector and lower in concentration, mostly in the 2-6 mg m^{-3} range (Fig. 19). Surface chlorophyll levels during the summer Scotian Shelf survey, on the other hand, were uniformly low (<1 mg m^{-3}) over the central and eastern shelf. Elevated concentrations (>1 mg m^{-3}) were only observed near the coast off SW Nova Scotia and approaches to the Bay of Fundy, as observed in previous years. These areas are generally characterized by strong vertical mixing. Overall, summer surface chlorophyll concentrations on the Scotian Shelf in 2007 were the same as the long-term average of 0.68 mg m^{-3} (Table 3).

Satellite ocean colour. Satellite ocean colour (SeaWiFS and MODIS) 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) and have the potential to provide temporal data and synoptic spatial coverage not possible from conventional sampling. Two-week composite images of the Maritimes region covering the major periods of the shelf section surveys and trawl surveys (Figs. 20, 21) put those operations into a larger geographic context and reveal features that supplement/corroborate ship-based observations or provide information not otherwise attainable. For example, the off-shelf maximum in surface chlorophyll generally observed during the early March Eastern Scotian Shelf trawl survey was absent for the most part in 2007 (Fig. 20) based on MODIS imagery. In a similar way, the MODIS imagery indicated clearly the intense, wide-spread and persistent, longer duration (eastern shelf) spring bloom that occurred on the Scotian Shelf in April, 2007. As well, the images show the overall low surface chlorophyll levels observed during the July trawl survey and elevated eastern shelf surface chlorophyll levels seen during the October shelf section survey (Fig. 21).

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 than on the central and western shelf; spring levels along all lines were particularly high in 2007 (Fig. 22). The dynamics of the onset, duration and termination of the spring and fall blooms are also revealed in this type of graphical presentation as well as spatial (across-shelf) relationships. For example, it is apparent that the duration of the spring bloom in 2007 was longer on the Eastern Shelf and in Cabot Strait than seen previously. The bloom duration was also longer in 2006 in the east, however, its magnitude was not nearly as high as seen in 2007. Generally speaking, spring blooms on the Scotian Shelf can be viewed as discrete, intense and short-lived events whereas the fall blooms appear to be much weaker in magnitude, more diffuse and time-varying.

At the larger scale (i.e. statistical sub-regions in the Maritimes region, see Fig. 5), the timing and duration of the spring bloom in 2007 compared with previous years in most regions (Fig 23). The exceptions were Cabot Strait where the bloom was approximately a week later than usual and the Cabot and Louisbourg lines where high concentrations lasted longer than usual. Most notable, however, was the fact that the magnitude of the 2007 bloom was at record high levels at all locations on the Scotian Shelf; peak surface chlorophyll concentrations 2-6x higher than average conditions (over previous 9 years) were observed. In the western Gulf of Maine (Lurcher Shoal and Georges Bank) and Bay of Fundy (Prince-5 station), however, levels in 2007 were comparable to the long term mean.

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 2006 are currently available. Nonetheless, the phytoplankton colour index and abundance of large diatoms and dinoflagellates on the Scotian Shelf (57º-66ºW) have been notably higher, starting in the early 1990s, peaking in the mid 1990s and continuing into the 2000s, than levels observed in the 1960s/1970s (Fig. 24). A similar decadal pattern has been observed in the Northwest Atlantic (45º-53ºW) although the difference between levels in the 1960s/1970s compared with the 1990s/2000s has not been as large as on the Scotian Shelf, particularly for diatoms. On the shorter time scale, the phytoplankton colour index on the Scotian Shelf has been declining over the past few years with levels approaching the long-term average. Diatoms and dinoflagellates declined as well in 2006 but remain close to the long-term average. Further east in the Northwest Atlantic, phytoplankton colour index, diatoms and particularly dinoflagellates increased in 2006. In contrast to conditions on the Scotian Shelf, all phytoplankton indices in the Northwest Atlantic are now well above the long-term average. In 2006, the magnitude and seasonal cycle of phytoplankton abundance aligned more closely with the pattern observed in the 1990s/2000s than in the 1960s/1970s for the colour index and diatoms but more closely with the early period for dinoflagellates (Fig.25). Although the timing of peak abundance (April) has not changed, much higher levels, particularly of diatoms, are now observed in January-March than observed during the 1960s/1970s.

Zooplankton

Fixed stations. Average zooplankton biomass over the year was close to normal in 2007 at Halifax-2, but the biomass peak in April and May was higher than normal (Fig. 26). Biomass at Halifax-2 was low prior to the bloom in February and March, and it was on the low side of normal in the summer and fall. At Prince-5, the zooplankton biomass was lower than normal overall, especially in the late summer and fall.

Calanus finmarchicus abundance followed a similar trend as total abundance at both Halifax-2 and Prince-5 (Fig. 27). However, the pre-bloom period of low abundance at Halifax-2 lasted longer for *C. finmarchicus* than for zooplankton abundance overall, remaining low into April. The abundance peak for *C. finmarchicus* was later and shorter than normal (Fig. 27), and it was the second highest since the time series began in 1999 (Fig. 28). The seasonal development of the *C. finmarchicus* population structure was similar to past years. The proportion of adults in the CI – CVI population began to increase in December, 2006, and continued to increase until the end of February, 2007 when the proportion of early copepodid stages had begun to increase. Early copepodid stages dominated before the abundance peak, and later copepodid stages dominated after the peak, with a subsequent shift to dominance of CV stages indicating that the population began to go into dormancy by late July, about a month later than normal. A second peak of early copepodid stages in September indicates that part of the population remained active into the fall.

At Prince-5, the average *C. finmarchicus* biomass over the year was lower than normal, especially in the late summer to early fall (Fig. 27). Despite their low abundance, the *C. finmarchicus* population structure at Prince-5 was similar to previous years, as well as to that at Halifax-2 during the first part of the year (Fig. 28). Emergence from dormancy began in December, and early stage contribution to the population increased at the end of March, slightly later than at Halifax-2. By July, the population began to be dominated by CVs, but this trend was reversed during the fall when the proportion of CI to CIII stages increased and dominated the population.

Zooplankton biomass and abundance are lower at Prince-5 than at Halifax-2, on average, and biomass and abundance peaks are later (Figs. 26 and 29). At Halifax-2, zooplankton is most abundant in April, on average, while at Prince-5, zooplankton abundance peaks occur in July and September (Fig. 29). The zooplankton communities of both stations are numerically dominated by copepods, but copepods are more dominant at the Halifax-2 stations throughout the year, while other taxa are sometimes more abundant than copepods at Prince-5 in the summer (Fig. 30).

Zooplankton abundance at Halifax-2 was lower than normal throughout 2007, especially in late winter and in the summer and fall (Fig. 29). The 2007 zooplankton abundance peak at Halifax-2 was a few weeks later than normal, similar to the biomass peak. The contrast between the above-average biomass peak and below-average abundance peak is probably due to the high peak abundance of *Calanus finmarchicus*, a large-bodied copepod that is a biomass-dominant species on the Scotian Shelf and in the Gulf of Maine. Among the copepods, *Calanus* species were somewhat more dominant during 2007 than in previous years (Fig. 31). Lower-than-normal abundances of two numerically dominant copepods, *Oithona similis* and *Pseudocalanus* spp., contributed to the low overall zooplankton abundance at Halifax-2 in 2007, and several species that are normally-abundant in the summer-fall period, including *Temora longicornis*, *Paracalanus* spp., and *Centropages typicus*, were nearly absent in 2007 (Figs. 29, 31, and 32). *Oithona atlantica*, bivalve larvae, and euphausiids, normally present during the spring-summer period, were also rare in 2007 at Halifax-2, but three Arctic copepods, *Calanus hyperboreus*, *C. glacialis*, and *Microcalanus* spp., and the deep-water copepod *Metridia lucens* were present at near-normal abundance levels (Figs. 29 and 32).

At Prince-5, the abundance peaks in 2007 were later than normal, in August and October, and the second peak was much lower than normal (Fig. 29). The community changes at Prince 5 in 2007 were more extreme than the changes observed at Halifax-2. Like *Calanus finmarchicus*, the abundance of the taxa that are normally dominant, *Oithona similis*, *Pseudocalanus* spp., and euphausiids, were low, and *Temora longicornis*, *Paracalanus* spp., and bivalve larvae were nearly absent (Figs. 29 and 33). The abundance of the summer-fall copepod *Centropages typicus* was also low, but *Centropages* spp., representing younger stages that are not identified to species, was more abundant than normal (Fig. 29). Despite the low abundances of many taxa, the overall zooplankton abundance peak in 2007 was similar to previous years, due to high abundance levels of the cladocerans *Evadne* and *Podon* (Figs. 29 and 30). The dominance of these cladocerans have not previously been observed at Prince-5 (Fig. 30).

<u>*Shelf sections*</u>. Springtime zooplankton biomass was relatively low on the Cabot Strait and Louisbourg lines in 2007 compared to previous years (Fig. 34 and Table 2). Only the years 1999 and 2000 had lower zooplankton biomass in spring on those two lines. Fall zooplankton biomass was the lowest observed on the Brown's Bank line and the lowest since 1999-2000 on the Louisbourg line, but it was similar to other years on the Cabot Strait and Halifax lines.

On all sections, *Calanus finmarchicus* populations are dominated by CV and some CIV stages in the fall and by young copepodid stages in the spring (data not shown). Seasonal biomass variability of *C. finmarchicus* was out of phase between the Cabot Strait line in the east and the Halifax and Brown's Bank lines in the west (Fig. 35). This difference in seasonal biomass variability may be due to the suitability of habitat in the two areas for different life history phases, i.e. dormancy v. active development, of *C. finmarchicus*. The Louisbourg line, where *C. finmarchicus* does not exhibit clear seasonal cycles, may be influenced to varying degrees by both of these environments. Springtime *C. finmarchicus* biomass in 2007 was the lowest yet observed on both the Halifax and Brown's Bank lines, and it was also low on the Louisbourg and Cabot Strait lines (Fig. 35 and Table 2). Fall *C. finmarchicus* biomass in 2007 was the highest yet observed on the Cabot Strait line.

The abundance of zooplankton was slightly lower than normal in spring 2007 at most of the transect stations (Fig. 36). A core group of three numerically dominant copepod species, including *Oithona similis, Calanus finmarchicus*, *Pseudocalanus* spp., was found at nearly all transect stations, similar to normal conditions, and the larvacean *Fritillaria* spp. was found at nearly all of the stations on the shelf lines, also similar to normal conditions. The off-shore shelf stations exhibited slightly elevated proportions of rare species ('others,' i.e. taxa that are not included in the top 90% by cumulative abundance) and of the copepod *Oithona atlantica* in spring, reflecting the influence of the high-diversity, warm water, offshore zooplankton community at these stations. In spring of 2007, the proportions of 'others' and *Oithona atlantica* were lower than normal on the two western lines. The proportions of the arctic species *Calanus hyperboreus* and *C. glacialis* were higher than normal in spring of 2007, especially on the Louisbourg and Cabot Strait lines. *Centropages* spp. made up a slightly higher than normal proportion of the zooplankton community on the Browns Bank and Halifax lines in spring 2007.

Fall zooplankton abundance in 2007 was lower than normal across the central and eastern Cabot Strait stations and at the inshore and mid-shelf stations on the Scotian Shelf, especially on the Browns Bank line (Fig. 37). Zooplankton abundance was closer to normal at the offshore stations on the Louisbourg, Halifax, and Brown's Bank lines. In the fall, *Oithona similis*, *Paracalanus*, *Centropages typicus*, and *Calanus finmarchicus* are numerically dominant species on the mid-shelf, while *O. similis*, *C. finmarchicus,* and *Temora longicornis* are dominant in Cabot Strait (Fig. 37). In fall 2007, however, the proportion of *C. typicus* was much lower than normal on all the lines, and *Paracalanus* spp. also represented a lower than normal proportion of the community on the Louisbourg and Cabot Strait lines. On the Cabot Strait line in fall 2007, *C. hyperboreus* and *Metridia lucens* exhibited higher relative abundances than normal. In the fall, the offshore community becomes more prominent at the off-shore shelf stations than in the spring, represented by the copepods *Mecynocera clausi*, *Clausocalanus* spp., the ostracod *Conchoecia* spp., and 'others,' here taxa that are not included in the top 85% by cumulative abundance. In fall 2007, the offshore community on the Halifax line was less prominent on the mid-shelf, and *Mecynocera clausi* was a smaller proportion of the offshore community. On the Louisbourg line, encroachment of the offshore community onto the shelf was about normal, while on the Brown's Bank line, it was greater than normal (Fig. 37).

Trawl (groundfish) surveys. The zooplankton biomass distribution observed during the winter/spring and summer trawl surveys is highly variable in space and time (Fig. 38). Generally, biomass is highest in deep waters, including deep basins, channels, and the shelf edge. In addition, biomass has usually been higher on the western Scotian Shelf than on the eastern Scotian Shelf during the summer survey, in contrast to the west-to-east increase in biomass during the spring and fall surveys. In 2007, the survey-wide average zooplankton biomass in February was the lowest yet observed since the beginning of the survey in 1999 (Fig. 38). Zooplankton biomass on the eastern Scotian Shelf in March continued the trend of low abundance started in 2005, but it was not as low as in 2006. Zooplankton biomass was also below average during the July Scotian Shelf survey, but *Calanus finmarchicus* abundance was close to normal (Table 3).

Continuous Plankton Recorder (CPR). On the Scotian Shelf CPR section, the annual average abundance of *Calanus finmarchicus* early copepodid stages (1-4) in 2006 was close to the long-term average abundance (Fig. 39). *C. finmarchicus* stage C5-6 abundance was above average, continuing a recent trend. *Paracalanus / Pseudocalanus* spp. annual average abundance was below the long-term average in 2006, down from average values in 2005, and total euphausiids returned to above average abundance after two years of below-average abundance. The peak abundance of *C. finmarchicus* C1-4 stages was higher and later, on average, during the 1990s period than during the 1963-1973 period (abbreviated as ‘1960s’ here; Fig. 40). The peak abundance of this group in 2006 was similar to peak abundance in the 1990s period, but its winter-time abundance in 2006 was higher than both the 1960s and 1990s and its late-summer and fall abundance was lower than the 1990s. The abundance of *C. finmarchicus* C5-6 stages was higher in 2006 than both the 1960s and 1990s averages, except in August to October. *Pseudo*- and *Paracalanus* exhibited a later abundance peak in the 1990s than in the 1960s. The 2006 *Pseudo*- and *Paracalanus* seasonal abundance cycle was quite variable, but higher abundances occurred early in the year, while abundances in the second half of the year were mostly lower than both the 1960s and 1990s monthly averages. Euphausiid seasonal abundance variability in the first half of 2006 was similar to the 1990s with an early peak in March and a second peak in the summer; however, it was quite variable in the second half of the year and did not follow the seasonal patterns observed in either the 1960s or 1990s.

On the northwest Atlantic CPR section, the annual average abundance of *Calanus finmarchicus* early copepodid stages (1-4) abundance in 2006 was close to the long-term average abundance (Fig. 39). *C. finmarchicus* stages C5-6 abundance below average, similar to the previous three years. *Paracalanus* / *Pseudocalanus* spp. were above average in 2006, similar to 2005. Total euphausiid abundance was the second lowest of the time series, and continued a decade-long trend of below-average abundance.

DISCUSSION

Sufficient data now exists from AZMP (9-years) to document recurring spatial and temporal patterns in optical, chemical and biological properties of the Maritimes region and to describe changes (trends) in oceanographic properties with some confidence. Although many of the oceanographic features in the Maritimes region in 2006 were similar to observations from previous years a number of differences were noteworthy.

Mixing and optics. The seasonal development of the mixed-layer, stratification and optical properties of the upper water-column are recurrent features at the Maritimes fixed stations and distinctly different for each location. These physical properties are known to influence nutrients distributions and phytoplankton growth cycles. Halifax-2 is notable for its strong seasonally varying hydrographic properties (mixed-layer depths and stratification) whereas Prince-5 is notable for its lack of variability in these properties, due largely to the influence of strong tidal mixing. Prince-5 is also notable for its shallow and invariant euphotic depths where optical properties are dominated by suspended non-living (detrital) particulates in contrast to Halifax-2 where phytoplankton dominate optical properties. Optical properties appear to be an attribute of both fixed stations that is remarkably invariant or predictable both seasonally and interannually. The most notable features in these physical properties that deviated from the norm in 2007 were the slightly stronger stratification and shallower summer mixed layers at Halifax-2 and the record shallow summer-fall mixed layers at Prince-5.

Nutrients. Winter maxima in surface nutrients and summer-time reduction in concentrations is a common feature in the Maritimes region. For the most part, the seasonal cycles of nutrients, vertical structure and regional variations were similar in 2007 to previous years; there were some differences, however. Post spring bloom and summer surface nitrate inventories in near surface waters were lower in 2007 at Halifax-2 than seen previously. In addition, the depth of the nitrate depleted surface layer in summer was among the deepest on record. Surface nitrate inventories in winter at Prince-5, on the other hand, were higher than usual in 2007 and, like Halifax-2, summer inventories were lower than the norm.

Winter nitrate inventories in near surface waters (<50 m), when biological activity is at an ebb, should be determined largely by physical processes, principally vertical mixing. Recent analysis of wind patterns on the central Scotian Shelf have shown a strong correlation between late fall wind stress and surface nutrient inventories in winter (B. Petrie, pers. comm.). Normal wintertime nitrate levels observed at Halifax-2 in 2007, therefore, suggest preceding fall-winter wind conditions were also normal; this has to be verified, however. Mixing and winter nutrient inventories at Prince-5, on the other hand, are determined largely by tidal processes. Since tidal energy will not change significantly from year to year, the increase in winter nitrate levels observed at this station in 2007 was likely due to changes in source waters linked to larger scale circulation and advection, however, this also needs to be verified.

Summertime nitrate inventories and depletion depths at Halifax-2 were among the lowest (deepest) observed since systematic observations began in 1999. Either greater demand (i.e. more phytoplankton) or less mixing of nitrate into surface waters from depth, or both, would be needed to explain this observation. Since the chlorophyll concentrations were not unusually high in summer 2007 at Halifax-2 (indeed, background levels have been decreasing systematically since 1999), reduced vertical mixing must have accounted for the low surface nutrients. Shallower mixed layer depths and stronger stratification have been observed, particularly late in the year at this station in recent years, however, deviations of these properties from the norm have been relatively small. An obvious place to look may be trends in summer meteorological conditions – have summer wind conditions changed over the past few years? Summer nutrient inventories have also been declining at Prince-5 but the mechanisms may be fundamentally different than at Halifax-2 as described above. On a broader geographic scale, observations from the shelf section surveys over the past several years suggest that deep nutrient inventories may be in a general but small decline on the Scotian Shelf. We did note, in addition, that bottom water nitrates on the Scotian Shelf in July, 2007 were the lowest on record and possibly linked to incursion of low-nutrient Labrador Slope water. Indeed, large scale meteorological conditions (e.g. NAO) since ~2000 have been favorable for increased influence of Labrador Slope Water on the Scotian Shelf (B. Petrie pers. comm.). On the other hand, observations along the Flemish Cap line in the Newfoundland region indicated enhanced levels of nutrients throughout the year and depths in slope waters compared to levels observed near the adjacent GB Shelf waters (http://journal.nafo.int/37/maillet/3-maillet.html).

Phytoplankton. Despite the fact that phytoplankton variability (both temporal and spatial) is characteristically high in coastal and shelf waters, the development of pronounced spring/summer (and less conspicuous fall) phytoplankton blooms are evident from observations at the Maritimes fixed stations, seasonal sections, trawl surveys, CPR and remote-sensing data. Recurring spatial patterns such as the off-shelf bloom that develops in spring, elevated chlorophyll concentrations in summer off southwest Nova Scotia, Georges Bank, the eastern Gulf of Maine/Bay of Fundy, and the elevated concentrations on the eastern Scotian Shelf in fall, are observed almost every year. There were, however, some features of the phytoplankton growth cycle in the Maritimes region distinctive for 2007, the most prominent of which was the record high and geographically wide-spread spring bloom. Not only was the bloom at unprecedented levels, but its duration, particularly on the eastern shelf, persisted much longer than usual.

Spring bloom timing (initiation) is thought to be regulated principally by the phytoplankton's light environment that is, in turn, determined by incident irradiance and upper-ocean mixing. At the Halifax-2 fixed station, bloom initiation is driven by the solar cycle, local heating of surface waters, shallowing of the mixed-layer and development of stratification in early spring (March/April). At Prince-5, tidal mixing strongly influences the timing of the bloom which generally starts later in the year (May/June) than at the Halifax-2 (March/April). Bloom magnitude is thought to be regulated largely by nutrient supply and bloom duration regulated by both nutrient supply and secondarily by loss processes such as aggregation and sinking and grazing (principally by zooplankton). The timing of bloom development at both the Halifax-2 and Prince-5 stations was similar to the long-term mean in 2007. At both stations as well, the magnitude of the bloom was significantly higher than the long term mean; at Halifax-2 bloom duration was shorter than usual and longer than usual at Prince-5. At Prince-5, elevated winter nutrients in 2007 (~100 mmol N m^{-2} above the norm) could explain (assuming 1 mmol N = 1 mg Chl), half of the stronger than usual bloom (~200 mg Chl m^{-2} above the norm). However, wintertime nutrient inventories at Halifax-2 (~250 mmol N m^{-2}) were at normal levels and therefore could account for only about 25% of the unprecedented (almost 1,000 mg Chl m^{-2}) bloom at that station. An additional source of nutrients would be necessary to fuel the 2007 bloom. Between mid-March and early April, there was evidence of a strong (~50m) vertical upward displacement of isolines at Halifax-2 which would bring more nutrients into the euphotic zone. Upwelling could have played a role but it would have been confined largely to the inner shelf. The nutrient source required to fuel the shelf-wide 2007 bloom, therefore, would have to be large-scale. Indirect evidence, based on a >40 km northward movement of the shelf-slope front between mid-March and mid-April suggests that a major intrusion of Labrador Slope Water onto the shelf likely provided the additional nutrients needed to fuel the record bloom of 2007 (Petrie et al. 2008).

Another factor that could determine bloom duration would be on the biological loss side, i.e. "top-down" control from zooplankton grazing. Interestingly enough, the emergence of young development stages of the principal copepod at Halifax-2, *C. finmarchicus*, occurred close to the time of the bloom termination so grazing might also have been a factor. Indeed, the maximum abundance of young developmental stages (CFI-CFIII) was at or near record high levels in 2007 so it is plausible that grazing contributed to bloom decline. The dynamics of the spring bloom, indeed, is influenced by a complex interaction of physical, chemical and biological processes operating on timescale from days to weeks (Greenan et al. 2004; Smetacek and Cloern 2008). Outside of the bloom period, the declining background chlorophyll levels at Halifax-2 could be reasonably linked to declining near surface nutrient reserves in recent years as evidenced by the deeper nitracline, especially during the last few years. Some progress in answering these important questions on bloom dynamics could be addressed through modelling (scenario-testing).

On the longer term, Li et al. (2006) have investigated trends in the abundance of phytoplankton on the Scotian Shelf and have concluded that, generally speaking, phytoplankton have been increasing in spring by more than 10% $year^{-1}$ while at the same time decreasing by more than 5%$year^{-1}$ in fall over the period of AZMP observations. Observations from our 2007 spring and fall section surveys reinforce this general "spring up - fall down" trend. On the decadal scale, it appears from CPR data that the spring phytoplankton bloom on the Scotian Shelf for the last decade has been larger and has 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 fixed stations also occur. At the Halifax-2 station, 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. No noteworthy changes in phytoplankton community structure were observed at either of the fixed stations in

2007. Interestingly enough, total microplankton counts did not parallel the elevated chlorophyll levels seen in the 2007 blooms at either fixed station.

Zooplankton. Like phytoplankton, zooplankton biomass, abundance, and community composition in the Maritimes region are characterized by high spatial and temporal variability. Nevertheless, clear seasonal variability patterns are evident at the fixed stations and also in the spring and fall AZMP transect data. Zooplankton biomass and abundance both peak in April at Halifax-2, while at Prince-5, there are biomass and abundance peaks later in the season, in July and September. The differences in the zooplankton seasonal cycle at these stations likely reflect the differences in the seasonal timing of phytoplankton blooms at these two stations.

There are also consistent seasonal patterns in zooplankton community composition at the fixed stations. The small copepod *Oithona similis* is a numerically dominant member of the zooplankton community throughout the year at both fixed stations and throughout the study region. *Calanus finmarchicus* is a dominant species in the springtime at both Halifax-2 and Prince-5, although its abundance at Prince-5 is low. At Halifax-2, the larvacean *Fritillaria* spp. is often abundant in the springtime as well. *Pseudocalanus* spp., *Centropages typicus*, and *Temora longicornis* are summer and fall dominants at both fixed stations, as is *Paracalanus* spp. at Halifax-2 and *Acartia clausi* at Prince-5. Invertebrate larvae form part of the zooplankton community at both fixed stations; barnacle larvae (Cirripedia) are a spring dominant at the Prince-5 station. These seasonal changes in zooplankton community composition are also evident in the inshore and mid-shelf sections of the AZMP transects. In addition, the offshore transect stations show greater influence of the warm-water offshore community in the fall than in spring.

Zooplankton biomass and abundance are generally higher in the deep basins and off the edge of the shelves than in shallow waters and on banks. Both onshore-offshore and along-shore gradients in community composition are evident on the AZMP transects. These gradients are influenced by water circulation patterns of the Scotian Shelf. Outflow from the Gulf of St. Lawrence onto the eastern, inshore Scotian Shelf influences the water properties and the zooplankton community of this region. This region is generally the coldest part of the shelf, and Arctic species like *Calanus hyperboreus*, *Calanus glacialis*, *Metridia longa,* and *Microcalanus* spp. are abundant in this area and on the Cabot Strait line. The offshore zooplankton community is more diverse than the inshore and mid-shelf community. Dominant offshore taxa include *Clausocalanus* species and *Mecynocera clausi,* copepods, and the ostracod *Conchoecia* spp. The copepod *Microcalanus* spp. is a cold-water, offshore form. The onshore-offshore gradient in the zooplankton community is most distinct on the eastern Scotian shelf at the Louisbourg line, particularly during the fall survey. The onshore-offshore zooplankton community gradient becomes less distinct on the Halifax and Brown's Bank lines, where the mid-shelf community includes more offshore species due to on-shelf and southwestward advection of shelf water onto the central Scotian Shelf.

The anomalously high zooplankton peak in May 2007 was driven primarily by the high abundance of *Calanus finmarchicus* copepodid stages. The abundances of other species were lower than normal, and *C. finmarchicus* abundance was lower than normal for much of the year. The *C. finmarchicus* abundance peak was captured only at Halifax-2 because of its timing in May; the 2007 AZMP Scotian Shelf transects were completed by the third week of April. The unusually high *C. finmarchicus* abundance peak may have been driven by high egg production rates during the large phytoplankton bloom in April. The time lag between the phytoplankton bloom and the appearance of large numbers of early copepodid stages is consistent with development of eggs produced during the bloom at the low temperatures typical of the Scotian

Shelf in April. The high peak abundance of *C. finmarchicus* did not result in persistently high abundance in the fall. Anomalously high phytoplankton concentrations were spatially widespread in 2007, so this decline in *C. finmarchicus* is more likely due to high mortality, rather than advection of less productive sub-populations of *C. finmarchicus* past Halifax-2 later in the summer and fall.

In 2007, Arctic species were more prevalent on the eastern, inshore Scotian Shelf, and warm-water species were less abundant over much of the region, with the exception of the western Scotian Shelf in the fall. These shifts in zooplankton community composition were consistent with the overall cooler conditions that were present on the Scotian Shelf in 2007, including cooler annual average sea surface temperature on the western Scotian Shelf, cooler 0-100 m average temperature at Halifax-2, and a larger volume of cold intermediate layer water on the Scotian Shelf in July 2007 (Petrie et al., 2008). The reasons for the major zooplankton community shift at Prince-5 are unclear. This station is near shore in a region dominated by tidal currents, and the zooplankton community is normally a mixture of near-shore, off-shore, and ubiquitous species, probably reflecting complex mixing patterns in the vicinity of the station. The dominance of marine cladocerans in the summer and fall of 2007 may reflect a greater influence of near-shore waters and high stratification during this period, as these conditions are favorable for marine cladocerans.

The CPR data record continue to show 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. However, over the past few years, abundances of some species (*C. finmarchicus*, euphausiids) on the Scotian Shelf have been at or above historical levels. Anomalies of some of the more abundant taxa sampled by the CPR (*C. finmarchicus*, *Paracalanus/Pseudocalanus spp,* euphausiids) were out of phase between the Scotian Shelf and the region further east in the Northwest Atlantic in 2006, perhaps due to the larger proportion of offshore Slope water sampled in the Northwest Atlantic section compared to the Scotian Shelf section. When one looks at the Grand Banks Shelf and near-slope waters, the relative abundance looks more in phase with the Scotian Shelf values. Because of temporal, spatial, and analytic differences between the CPR observations and net samples, interannual patterns observed in the CPR samples have sometimes been at odds with the AZMP data; however, we continue to explore new analytical approaches that we hope will reconcile these differences.

SCORECARD

Another approach being explored for integrating the suite of chemical and biological observations made in AZMP is a scorecard of key indices, based on normalized, seasonally-adjusted annual anomalies. This is similar to the approach adopted for summarizing AZMP's physical variables (AZMP Bulletin, 2008). For the chemical-biological observations, the key variables selected were: [1] near surface (0-50 m) and deep (50-150m) nitrate inventories, [2] chlorophyll inventories (0-100m), the magnitude, timing and duration of the spring bloom, and zooplankton abundances (*C finmarchicus, Pseudocalanus spp*., total copepods, total non-copepods) for the fixed stations and seasonal section surveys.

Despite considerable variability among variables and years, there are some clear patterns emerging from the Maritimes regions scorecard (Fig. 41). The first is that for years where there were overall high (or low) scores (e.g. positive: 1999 and to a lesser extent 2003, negative: 2002), there was considerable coherence among variables, from nutrients to zooplankton. Within groups, there was strong coherence among the zooplankton indices over individual years; less so for nutrients and phytoplankton indices. Secondly, the range in scores is generally greater for zooplankton than for nutrients or phytoplankton. Finally, there are more years with positive scores than negative scores (although small) for phytoplankton while there are more years with negative scores than positive ones for zooplankton, particularly in the most recent years. Indeed, there appears to be a general trend of declining scores for zooplankton over the entire time period of AZMP observations, however, this is strongly influenced by the high zooplankton scores in the first year of AZMP observations, 1999. Overall, 2007 would be assessed as a normal year but this is due primary to the compensatory effects of a neutral or normal year for nutrients, a good year for phytoplankton and poor year for zooplankton.

ACKNOWLEDGEMENTS

The authors wish to thank the sea-going staff of the Ocean Research and Monitoring Section (BIO) and staff at the St. Andrews Biological Stations (SABS), and the officers and crew of the CCGS Opilio, Hudson, Needler, Templeman, Teleost and SAR vessels for their able assistance in successfully completing the Maritimes/Gulf regions' 2006 field program. Jackie Spry (contractor – Sprytech Biological) provided expert identification and enumeration of zooplankton. AZMP core members provided helpful comments to improve the manuscript. A special acknowledgement this year goes to Doug Sameoto who retired in 2007 and who was one of the key players in the development and implementation of the AZMP. As well, he was writing DFO status reports on plankton well before AZMP got off the ground and set the standard for our current Research Documents and Science Advisory Reports. To Doug, thank you for all your years of service!

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Table 1. AZMP Sampling missions in the Maritimes/Gulf regions, 2007.

Group	Location	Mission ID	Dates	# Hydro Stns	# Net Stns
Trawl Surveys	Georges Bank	TEM2007685	Feb 20 – Mar 04	40	12
	Eastern Shelf	TEM2007686	March 05 - 24	92	14
	Scotian Shelf	TEL2007745	Jul 07 – Aug 02	197	35
	SGSL	TEL2007749	Sep 04 – 30	189	17
Seasonal Sections	Scotian Shelf	HUD2007001	Apr 04 – Apr 22	80	61
	Scotian Shelf	HUD2007011	May 25 – 27	9	9
	Scotian Shelf	HUD2007045	Sept 28– Oct 18	48	33
Fixed Stations	Shediac	BCD2007668	Apr 26 – Nov 20	8	8
	Halifax-2	BCD2006666	Jan 15 – Dec 11	21	21
	Prince-5	BCD2006669	Jan 18 – Dec 15	12	12
			Total:	**696**	**222**

Table 2. Chemical and biological properties of the 1999-2007 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
2005	137	84	157	34	67	47	18	22
2006	48	144	260	11	55	87	9.8	30
2007	140	110	291	37	37	64	11	41
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
2005	48	79	397	30	56	17	21	9.8
2006	62	94	151	28	42	16	29	8.4
2007	72	92	597	24	29	12	12	15
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
2005	63	60	354	30	41	28	56	11
2006	80	64	39	6.7	50	30	27	15
2007	52	63	720	35	29	25	19	10
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
2005	187	98	165	37	28	17	26	5.4
2006	152	130	44	51	34	26	65	12
2007	53	115	680	29	37	14	15	8.3

Table 3. Chemical and biological properties of the 1999-2007 summer Scotian Shelf ecosystem trawl (groundfish) survey. Statistics: means, (ranges), #obs. Numbers in brackets in oxygen column represent percent area of shelf covered by bottom waters with <60% oxygen saturation.

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})
1999	**0.93** (0.10-7.07) 137	**13.22** (2.12-24.06) 163	**77 [14]** (41.9-106.7) 197	**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 [12]** (43-121) 203	**34.0** 2.7-158.6 38	**-**
2001	**0.78** (0.03-4.08) 206	**11.75** (1.72-21.76) 155	**82 [8]** (40-107) 206	**34.4** (1.2-144.8) 38	**32,598** (43-185,472) **37**
2002	**0.51** (0.08-4.17) 303	**10.96** (0.32-22.66) 215	**74 [11]** (28-109) 215	**27.0** (1.0-120.1) 38	**25,906** (9-171,131) **38**
2003	**0.72** (0.03-6.65) 214	**11.01** (0.14-23.27) 213	**78 [16]** (34-109) 217	**34.9** (1.07-252.5) 34	**33,224** (1154-233,326) 34
2004	**0.56** (0.12-5.25) 185	**10.35** (0.14-24.28) 193	**81 [10]** (36-110) 191	**36.9** (2.51-182.2) 38	**37,036** (151-219,398) 38
2005	**0.56** (0.001-3.83) 192	**10.98** (0.44-23.10) 191	**78 [7]** (43-103) 191	**19.5** (0.32-46.6) 34	**19,181** (24-143,063) 34
2006	**0.69** (0.045-4.74) 201	**11.48** (0.014-22.82) 207	**77 [10]** (41.62-110.58) 207	**31.44** (1.81-135.76) 41	**42,837** (431-109560) 41
2007	**0.682** (0.179-3.192) 163	**9.558** (0.116-19.96) 161	**77 [11]** (43.32-113.55) 163	**26.90** (0.69-115.88) 34	**29703** (830-138987) 35

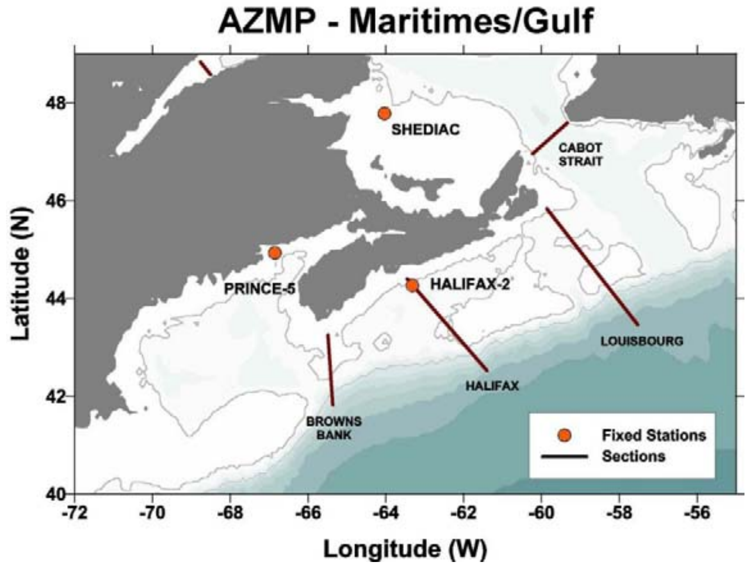

Figure 1. Primary sections and fixed stations sampled in the Maritimes/Gulf regions.

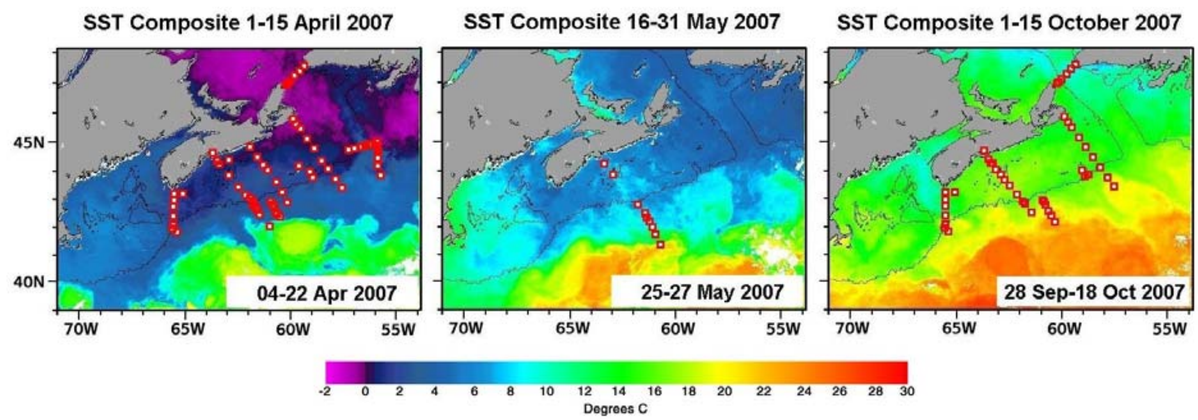

Figure 2. Stations sampled during the 2007 spring, summer and fall section surveys. Station locations superimposed on bi-weekly SST composite images.

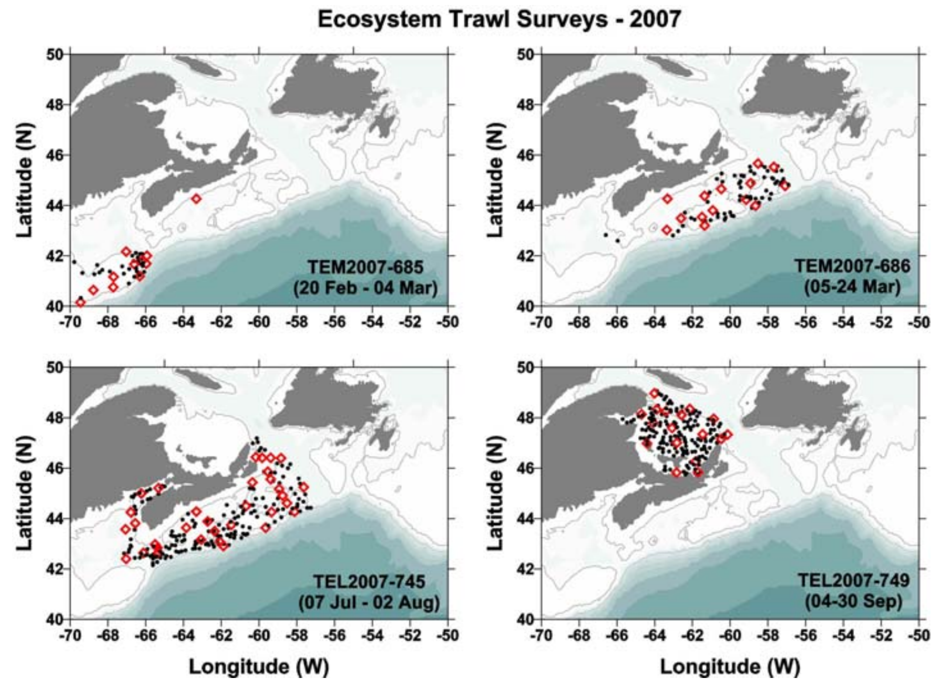

Figure 3. Stations sampled during major Maritimes/Gulf trawl (groundfish) surveys in 2007. Black symbols are hydrographic stations; red symbols are stations where vertical nets hauls were taken in addition to hydrographic measurements.

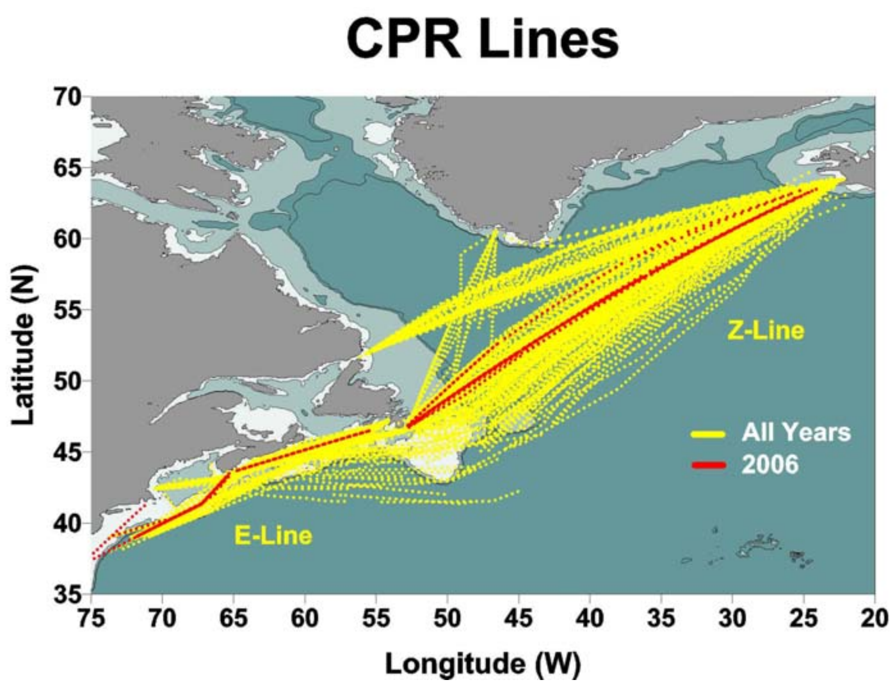

Figure 4. CPR lines and stations, 1961 to 2006 (2006 highlighted).

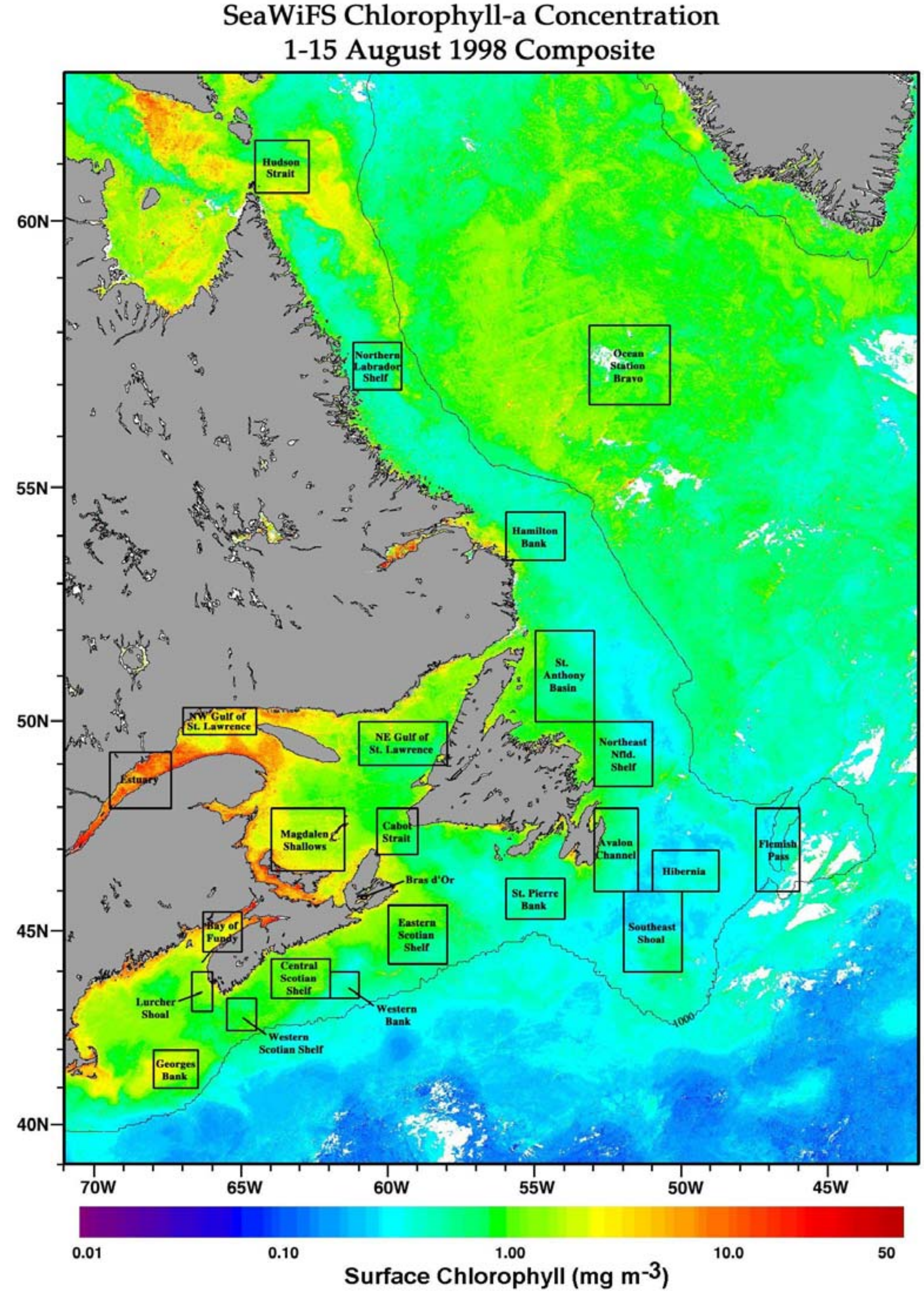

Figure 5. Statistical sub-regions in the Northwest Atlantic identified for spatial/temporal analysis of SeaWiFS/MODIS ocean colour data.

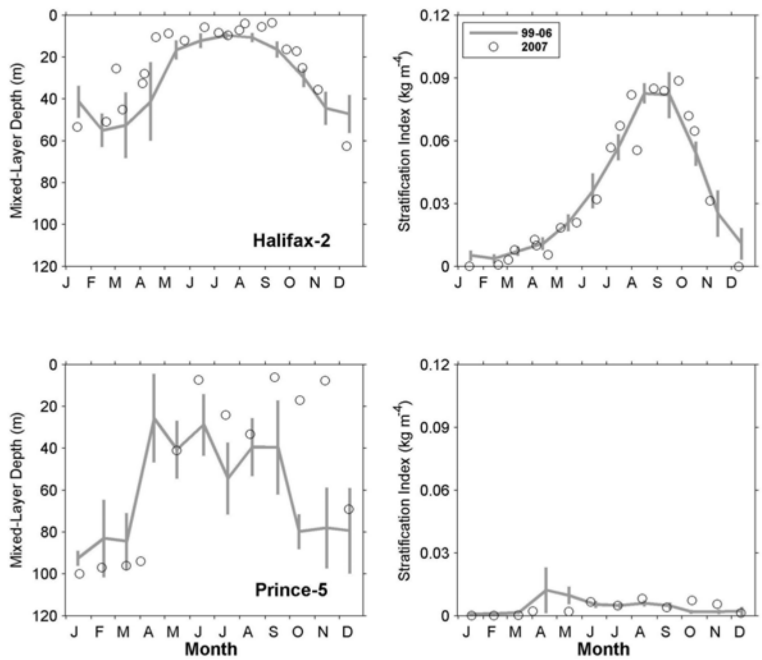

Figure 6. Mixing properties (mixed-layer depth, stratification index) at the Maritimes fixed stations. 2007 data (circles) compared with mean conditions from 1999-2006 (solid line). Vertical lines are 95% confidence limits.

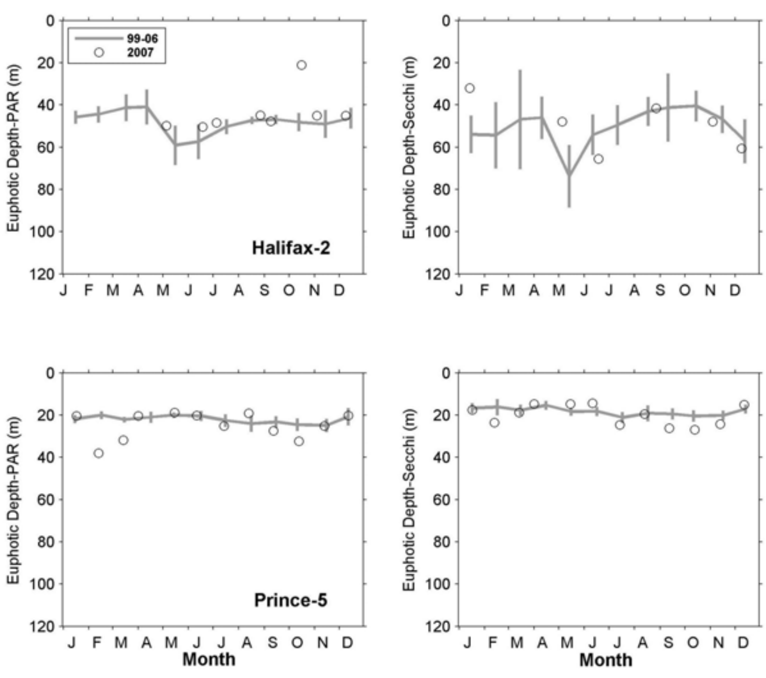

Figure 7. Optical properties (euphotic depth from PAR irradiance meter and Secchi disc) at the Maritimes fixed stations. 2007 data (circles) compared with mean conditions from 1999-2006 (solid line). Vertical lines are 95% confidence limits.

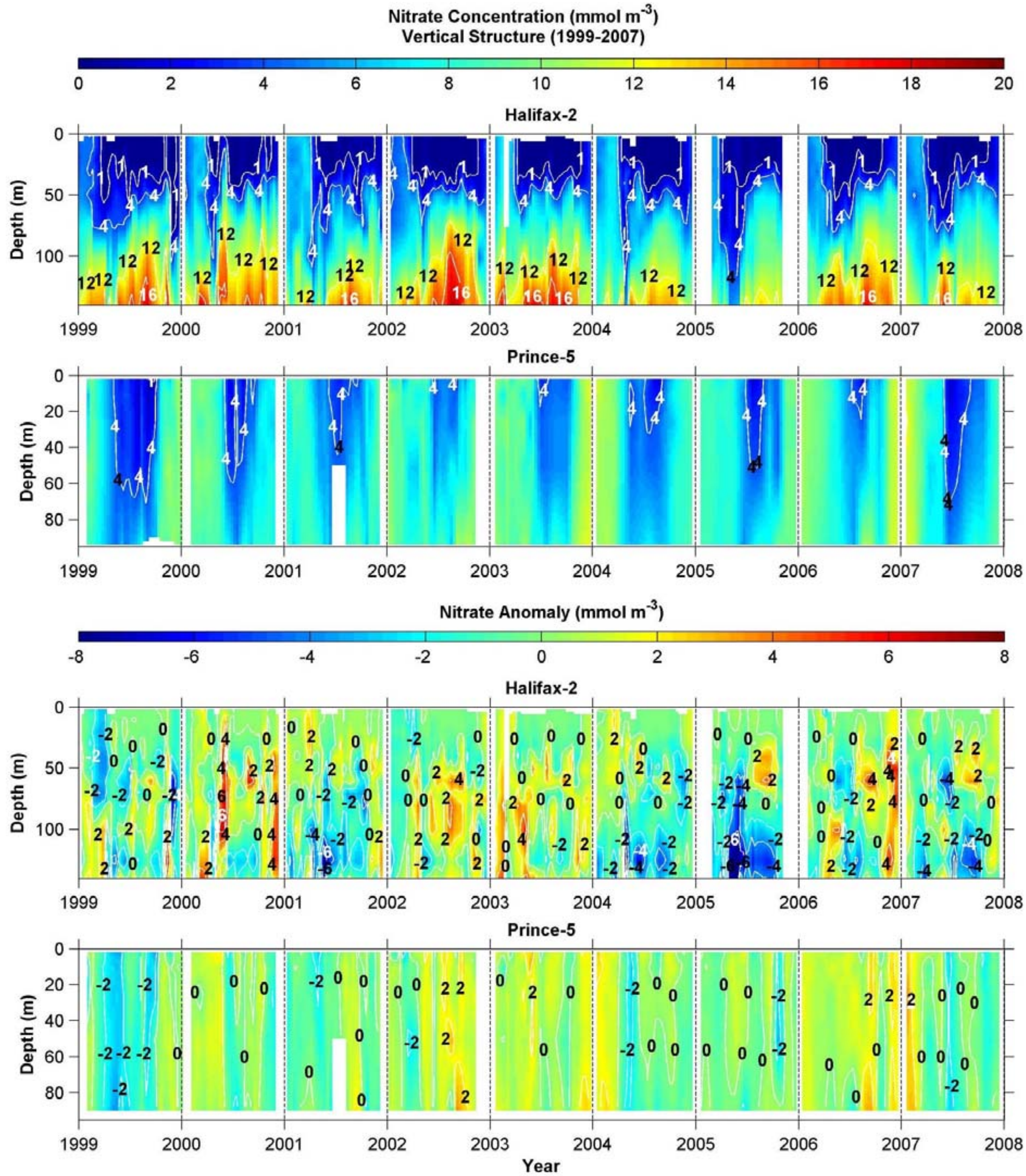

Figure 8. Time-series of vertical nitrate structure at the Maritimes fixed stations, 1999-2007. Bottom panels: nitrate anomaly (value minus long-term average).

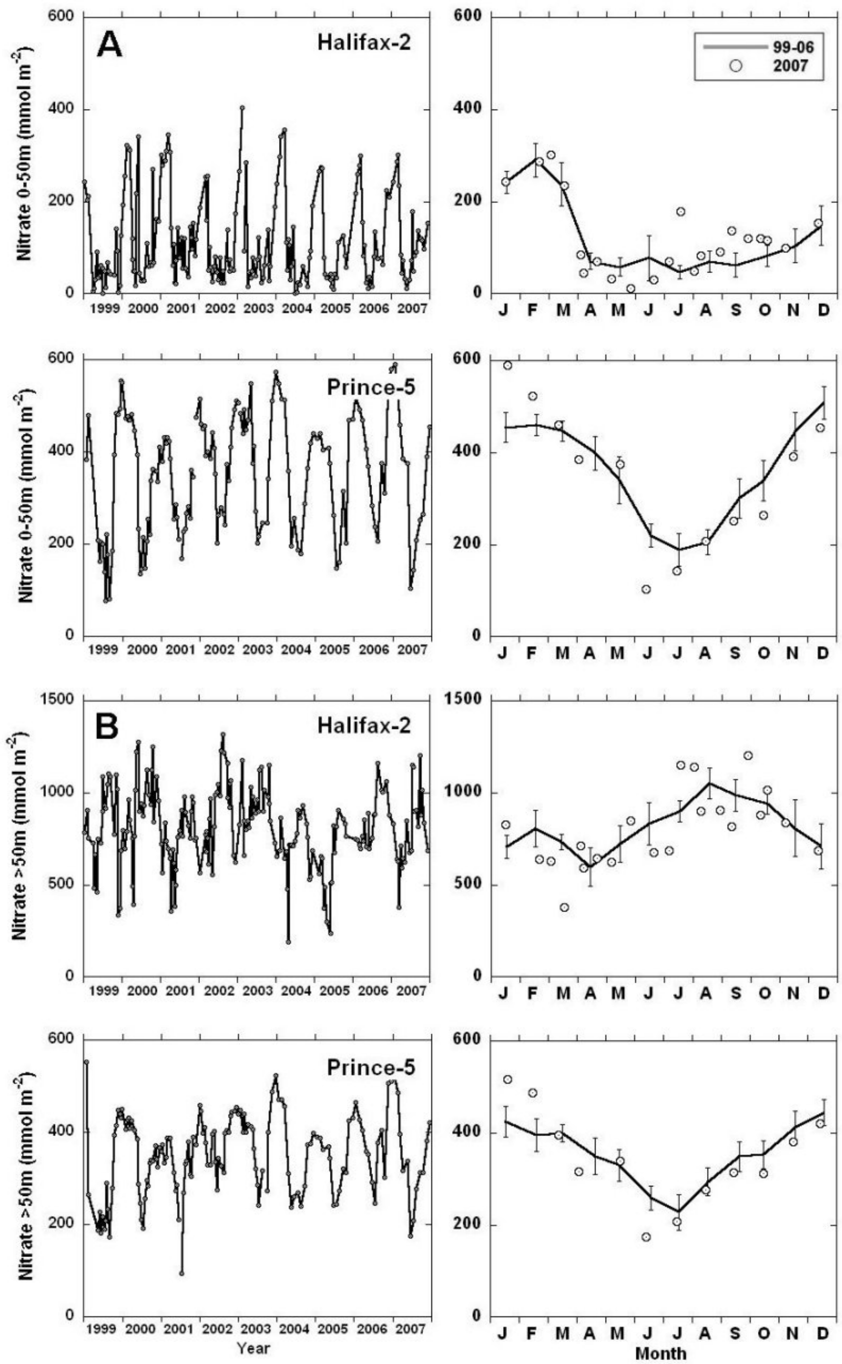

Figure 9. Nitrate inventories at the Maritimes fixed stations, 1999-2007. (A) surface (0-50 m) integrals, (B)deep (>50 m) integrals. Right panels: 2007 data (circles) compared with mean conditions from 1999-2006 (solid line). Vertical lines are 95% confidence limits.

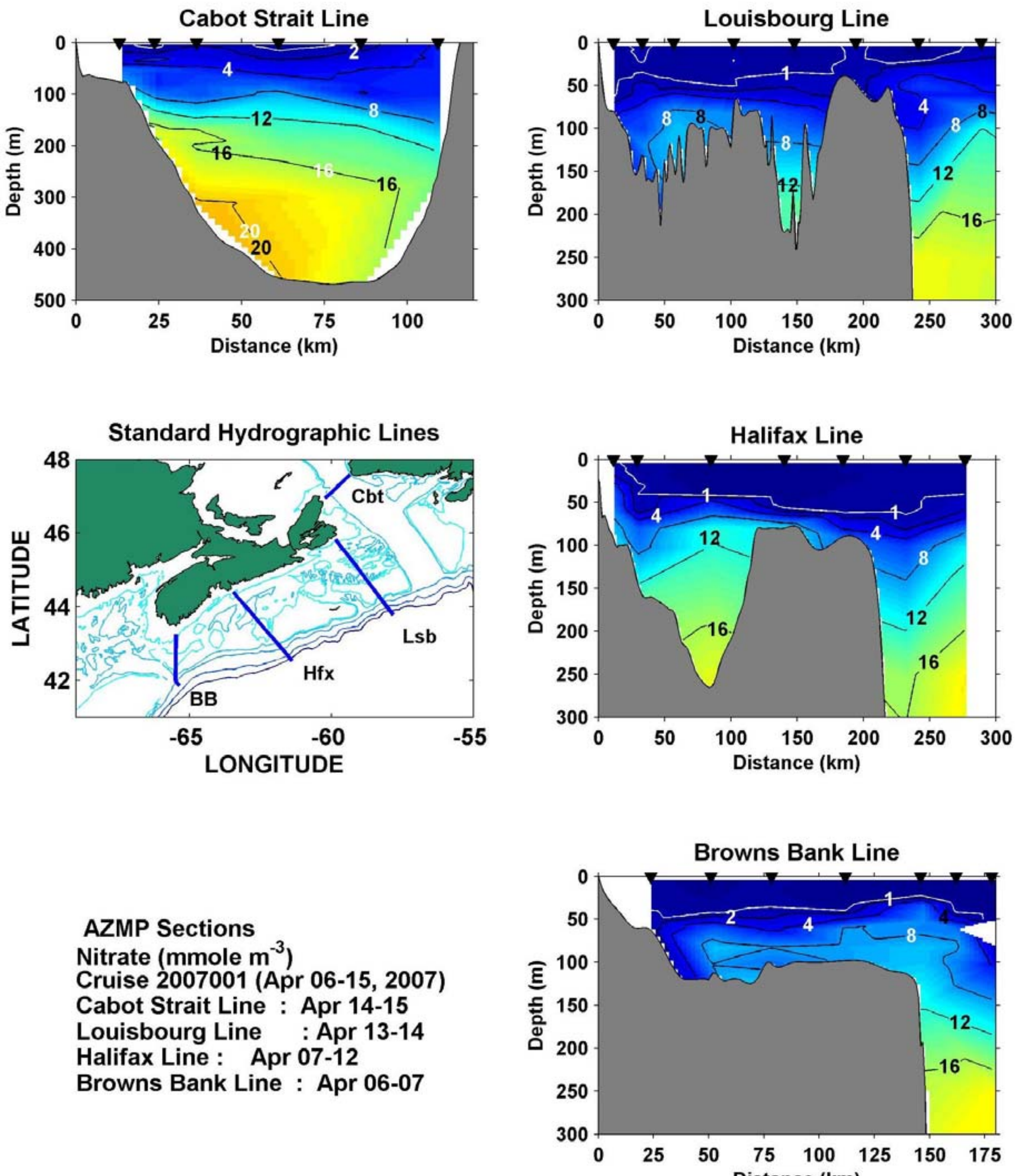

Figure 10. Vertical nitrate structure along the Scotian Shelf sections during the spring survey in 2007.

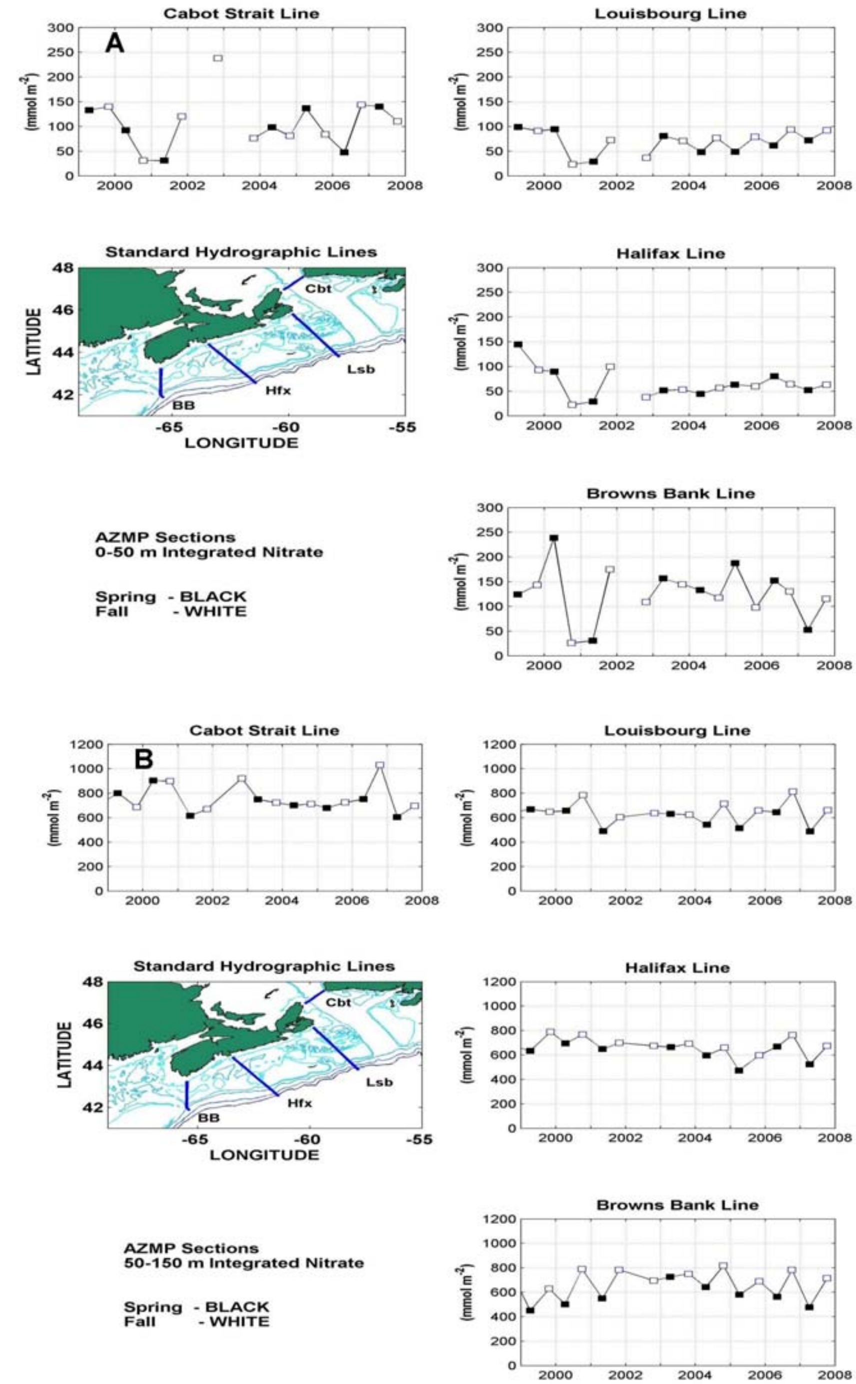

Figure 11. Time-series of average inventories of nitrate (A) in the upper water column (0-50 m) and (B) in deep waters (50-150 m) for the spring and fall Scotian Shelf sections, 1999-2007.

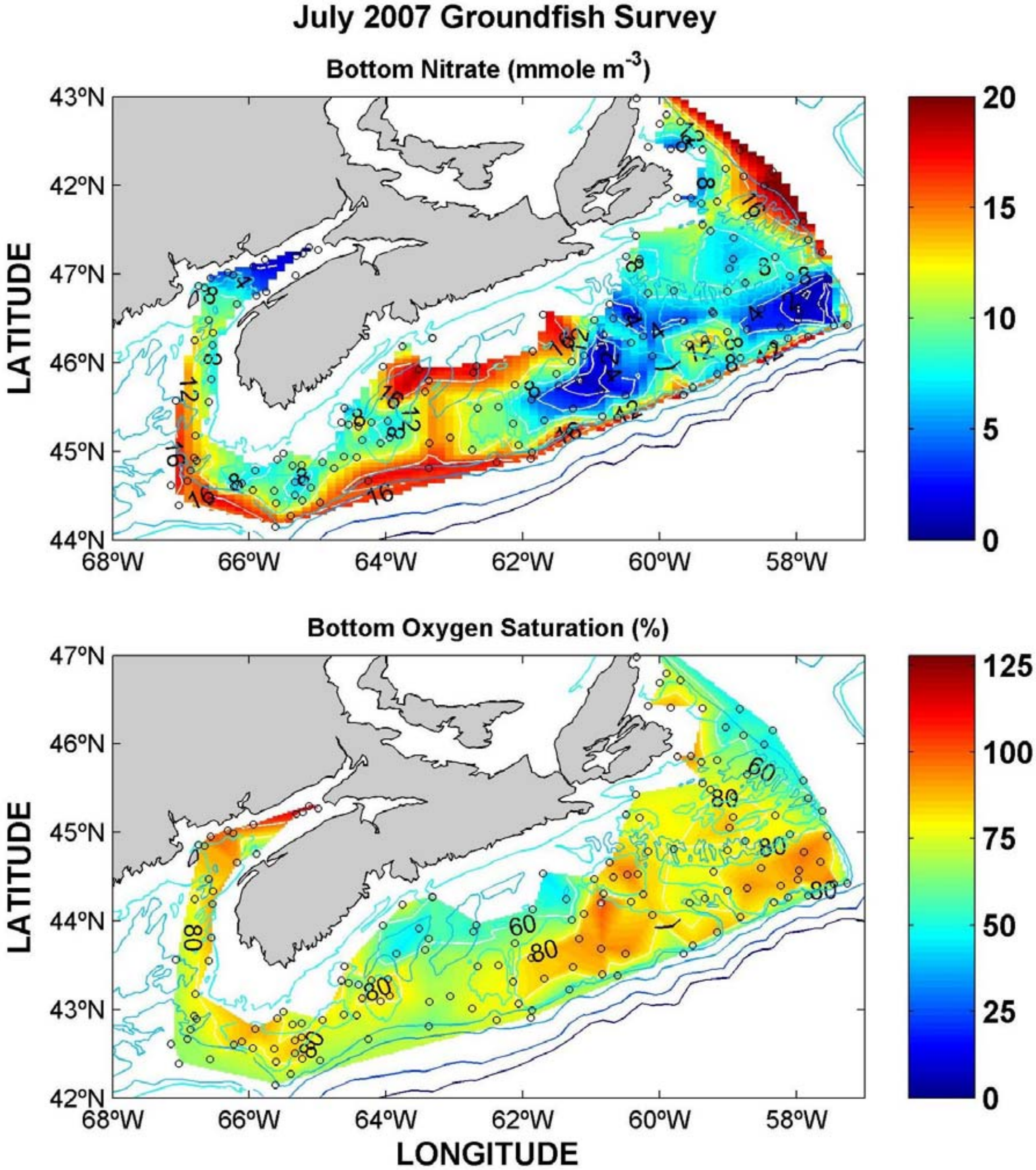

Figure 12. Bottom nitrate concentrations and oxygen saturation on the Scotian Shelf during the annual July trawl (groundfish) survey in 2007.

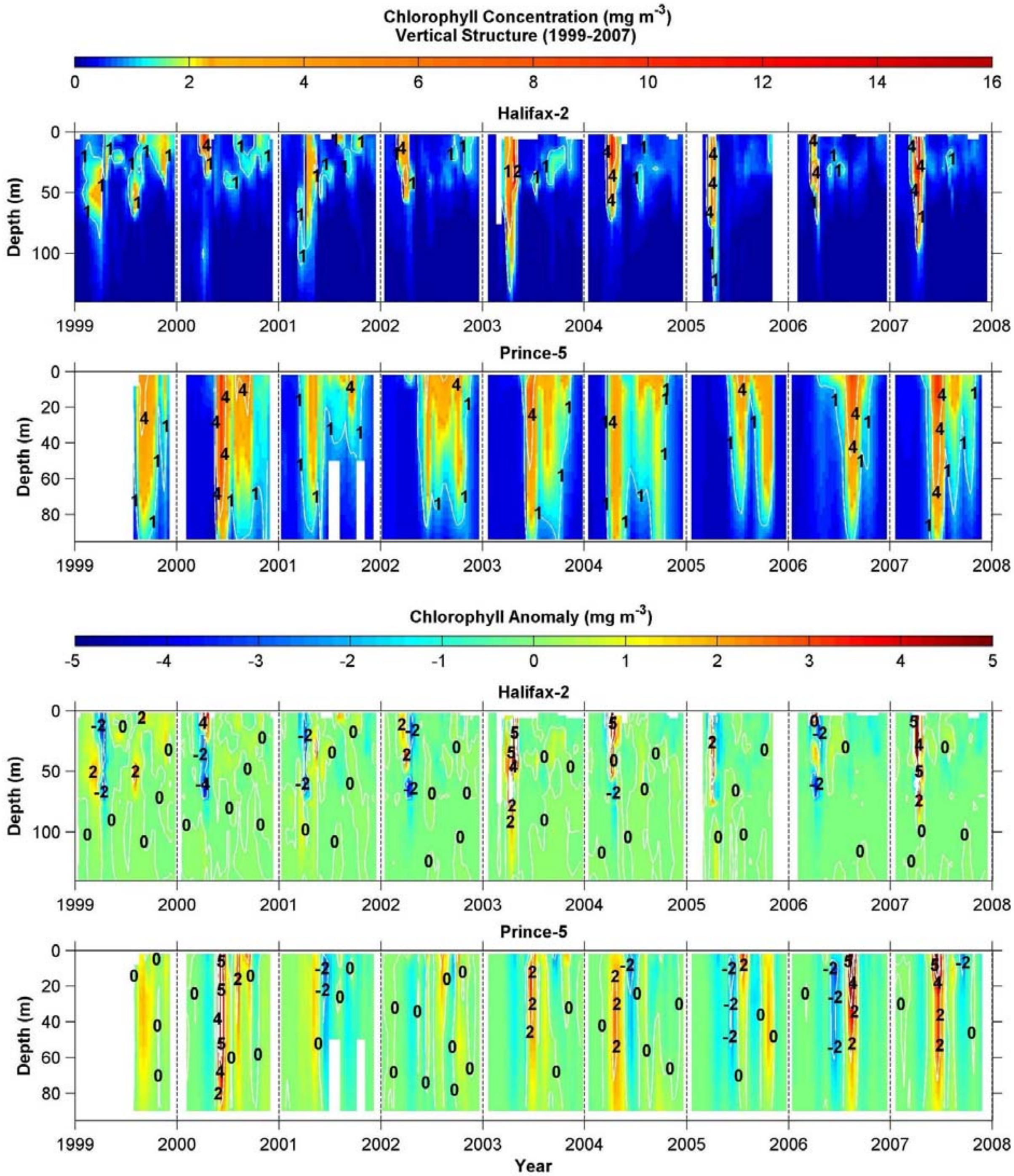

Figure 13. Time-series of vertical chlorophyll structure at the Maritimes fixed stations, 1999-2007. Bottom panels: chlorophyll anomaly (value minus long-term average).

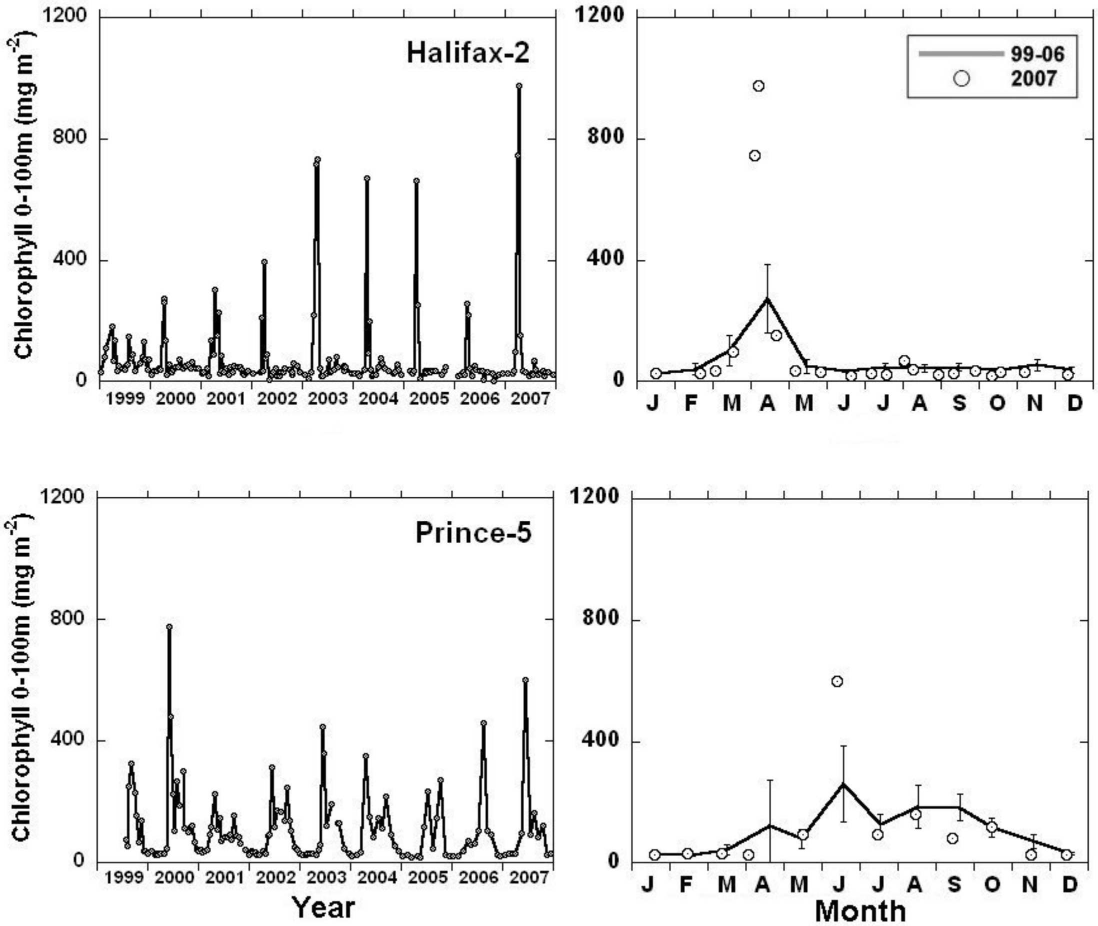

Figure 14. Chlorophyll inventories (surface-100 m integrals) at the Maritimes fixed stations, 1999-2007. Right panels: 2007 data (circles) compared with mean conditions from 1999-2006 (solid line). Vertical lines are 95% confidence limits.

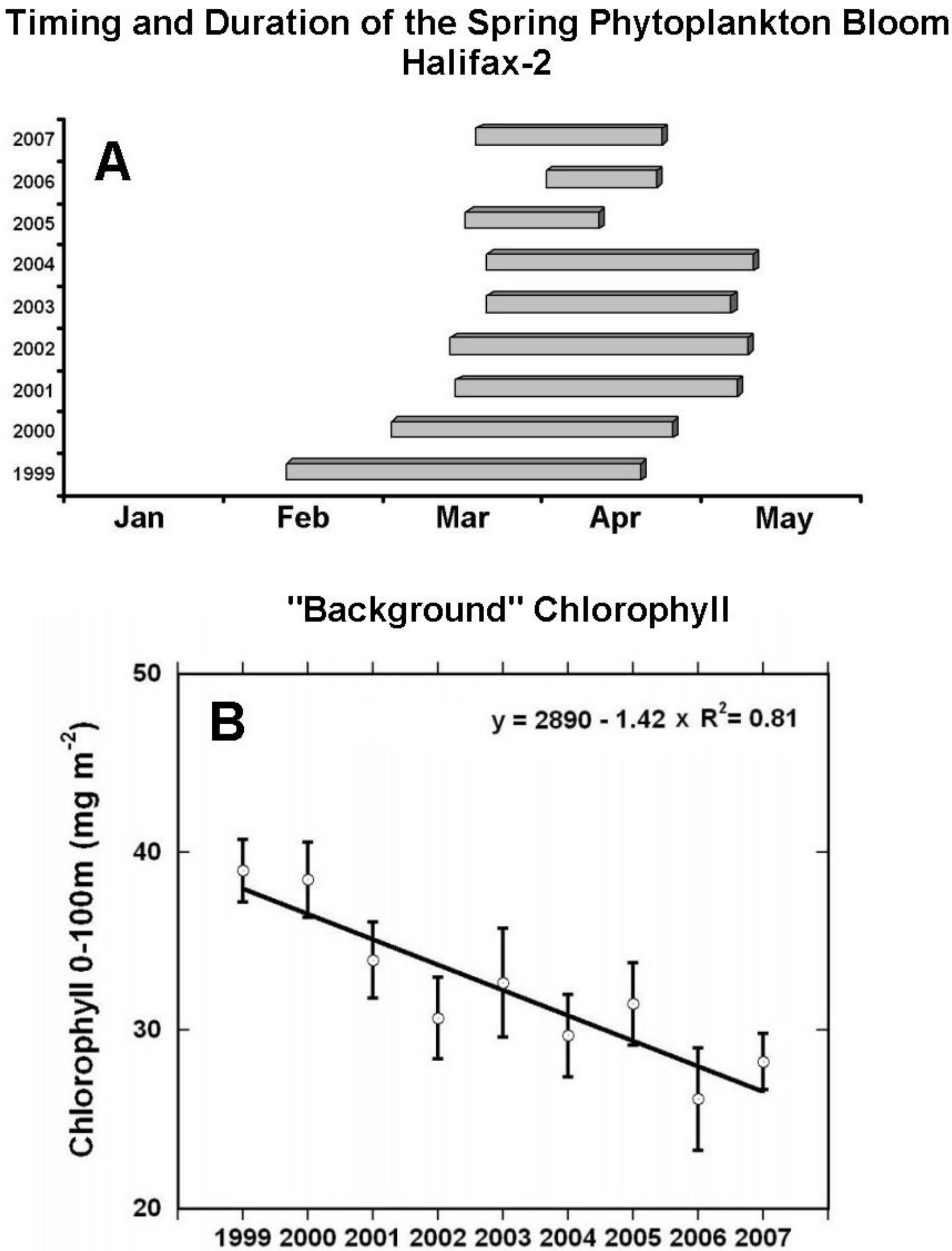

Figure 15. Dynamics of the spring phytoplankton bloom, Halifax-2 fixed station 1999-2007: (A) timing and duration based on 40 mg CHL m^{-2} threshold for determining start and end of the bloom (B) “background” chlorophyll levels, outside of spring bloom periods; annual average +/- SE, line = least squares linear regression.

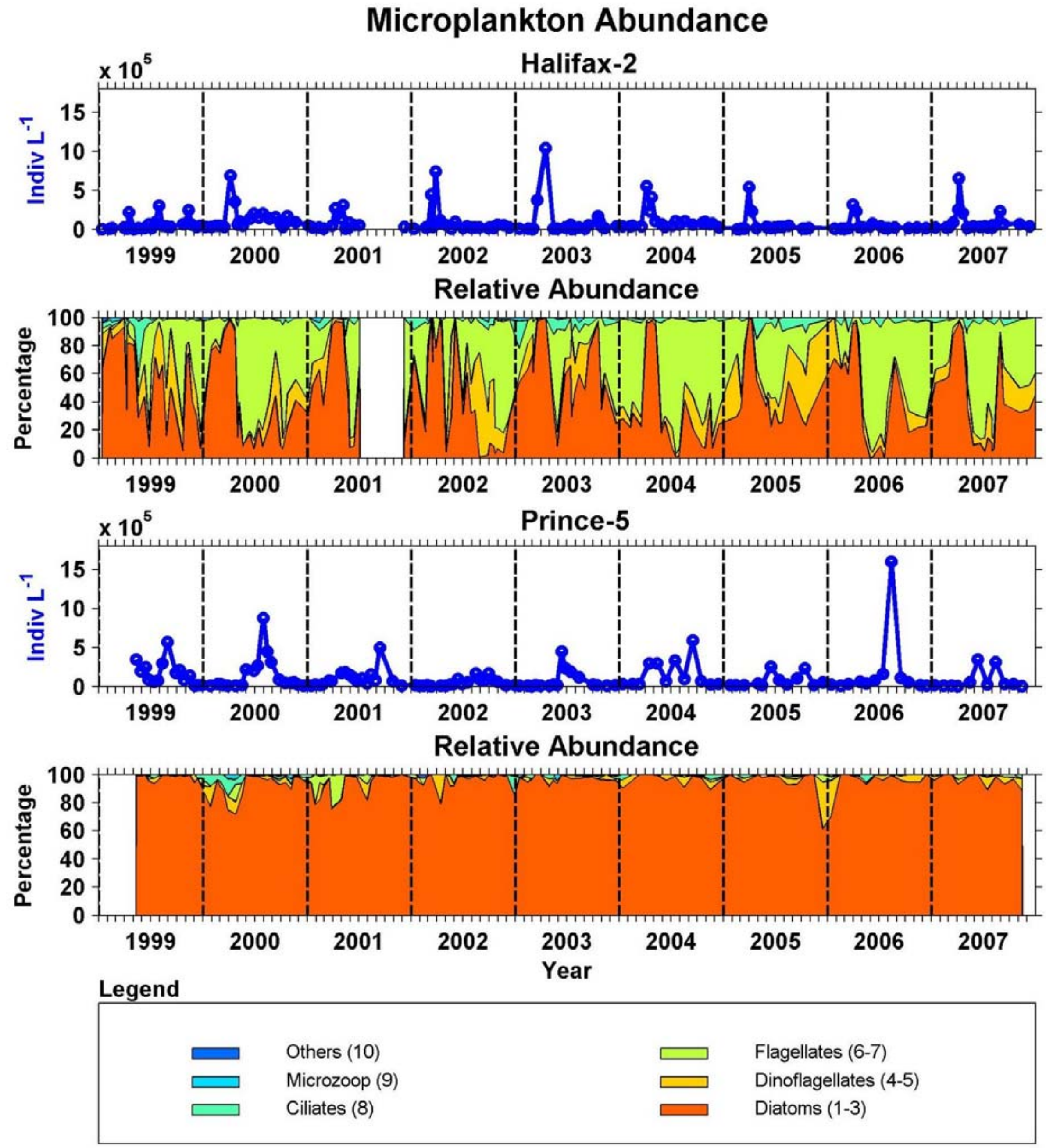

Figure 16. Time-series of microplankton (phytoplankton and protists) abundance and community composition at the Maritimes fixed stations, 1999-2007.

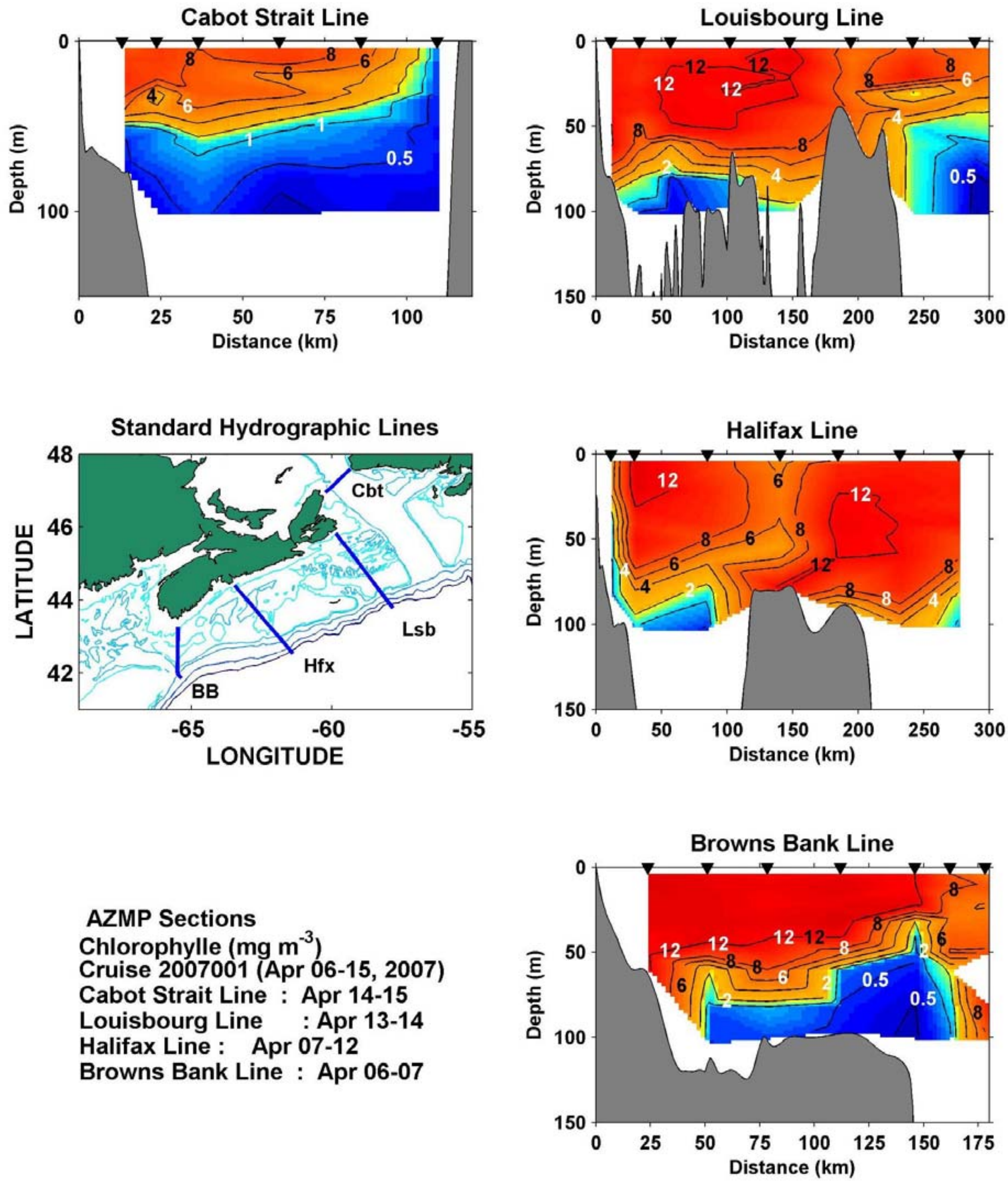

Figure 17. Vertical chlorophyll structure along the Scotian Shelf sections during the spring survey in 2007.

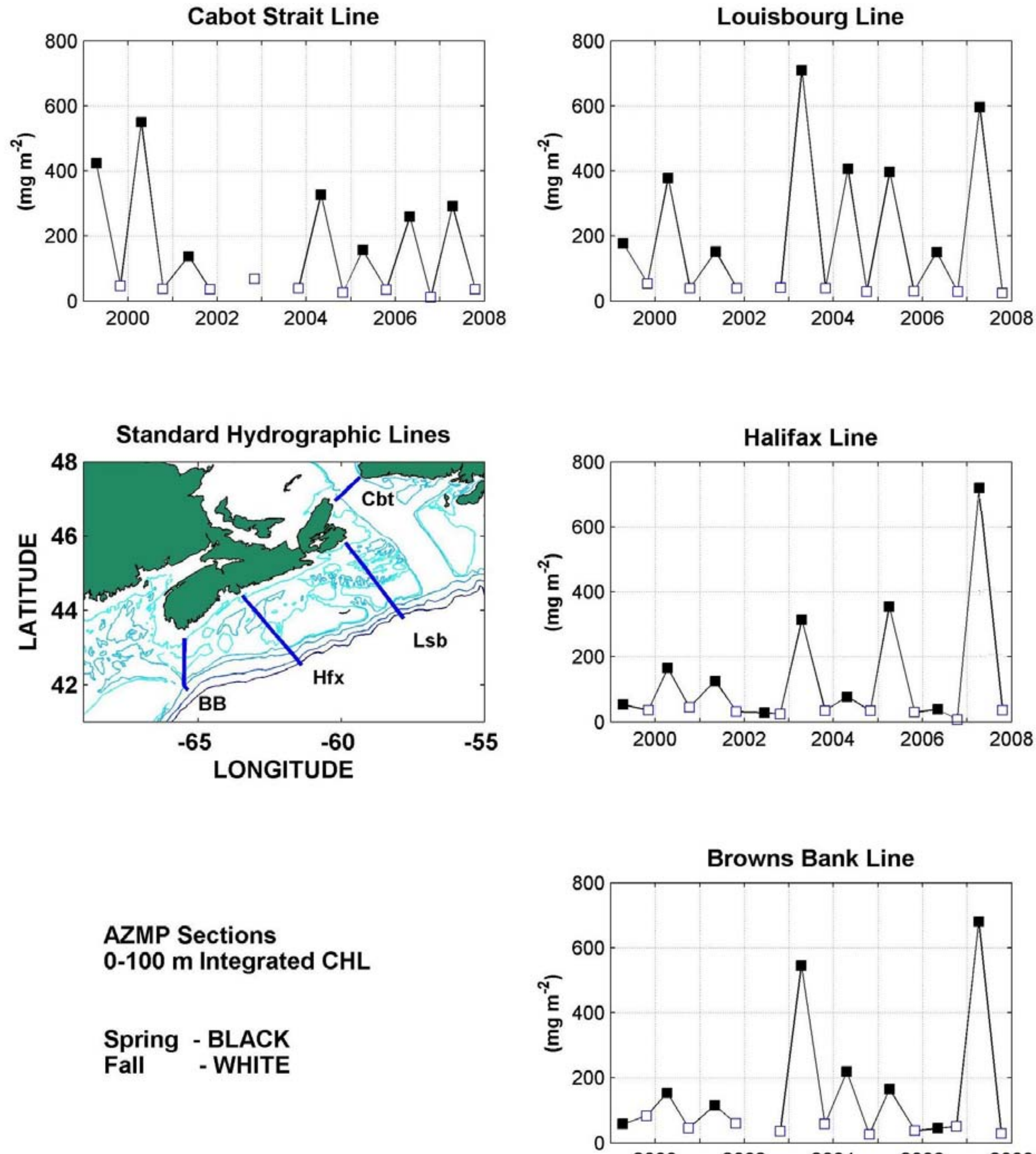

Figure 18. Time-series of average inventories of chlorophyll in the upper water column (0-100 m) for the spring and fall Scotian Shelf sections, 1999-2007.

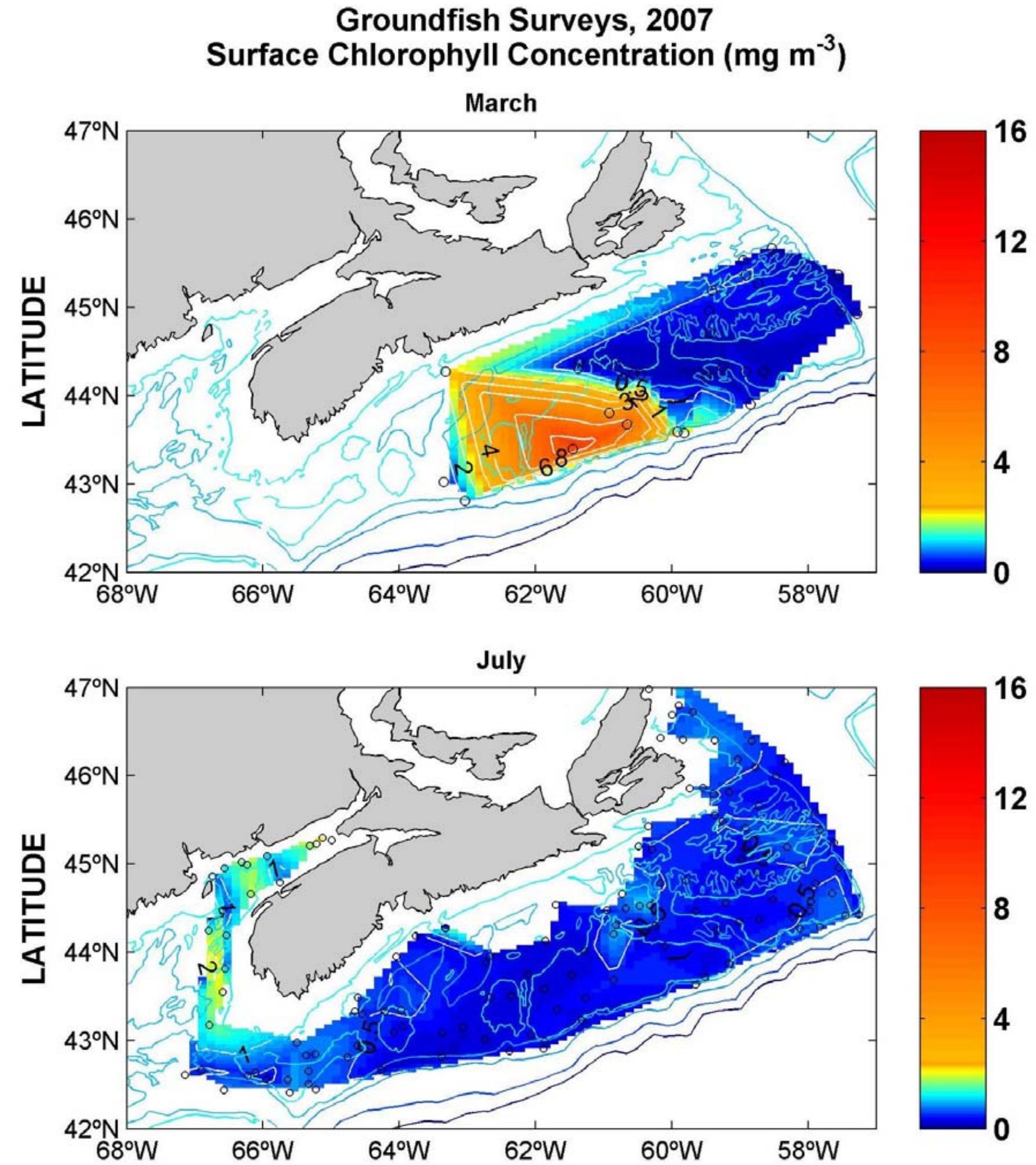

Figure 19. Surface chlorophyll concentrations on the Scotian Shelf during the annual March and July trawl (groundfish) surveys in 2007.

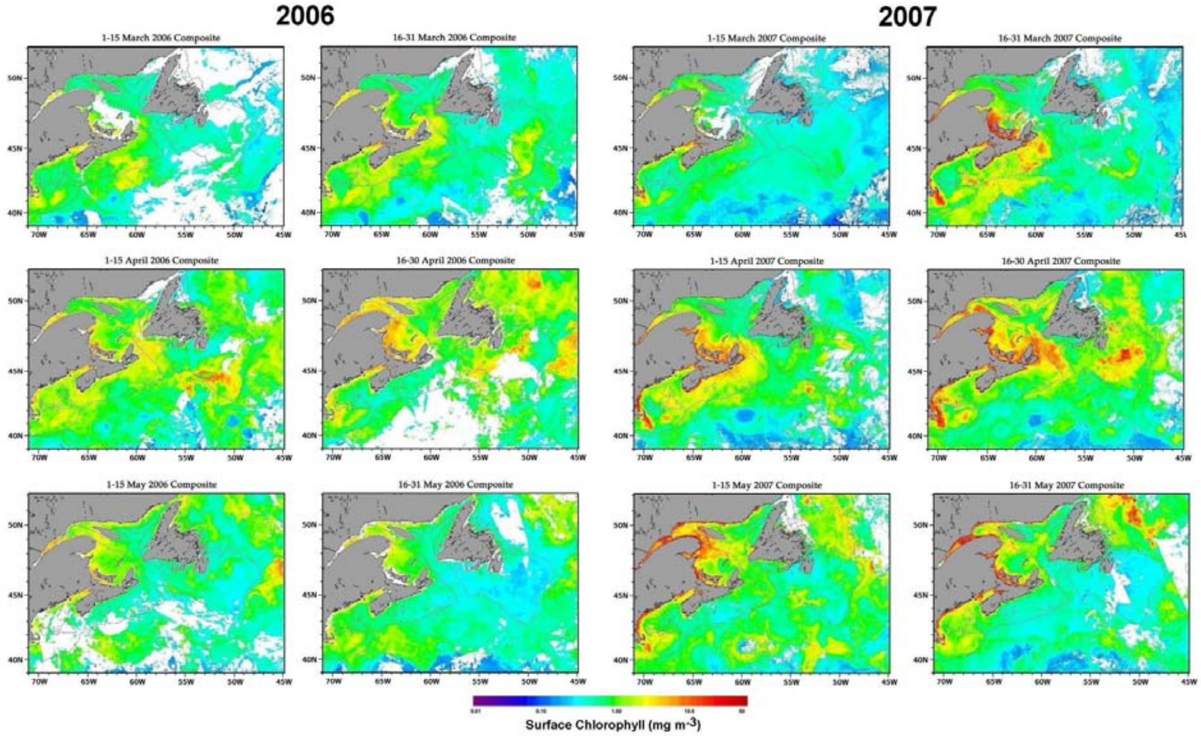

Figure 20. MODIS bi-weekly composite images of surface chlorophyll in the Maritimes/Gulf regions: early March through late May, 2006 and 2007, covering the periods before, during and after the spring phytoplankton bloom.

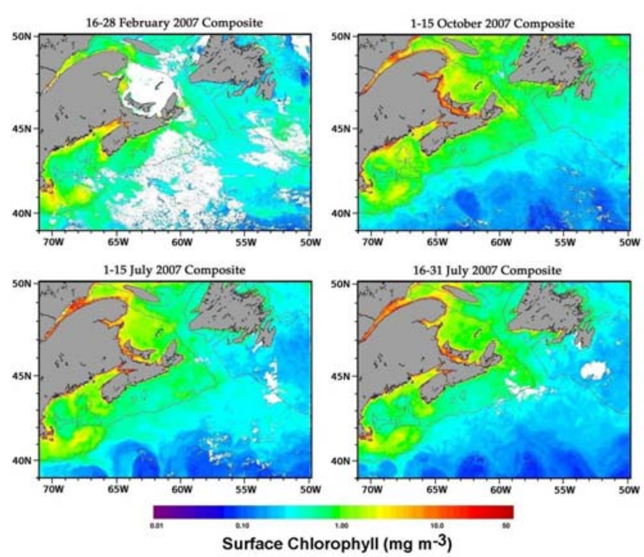

Figure 21. MODIS bi-weekly composite images of surface chlorophyll in the Maritimes/Gulf regions: February, July and October, 2007, covering the periods of the winter and summer ecosystem trawl (groundfish) survey (see Fig. 3) and the fall shelf section survey (see Fig. 2).

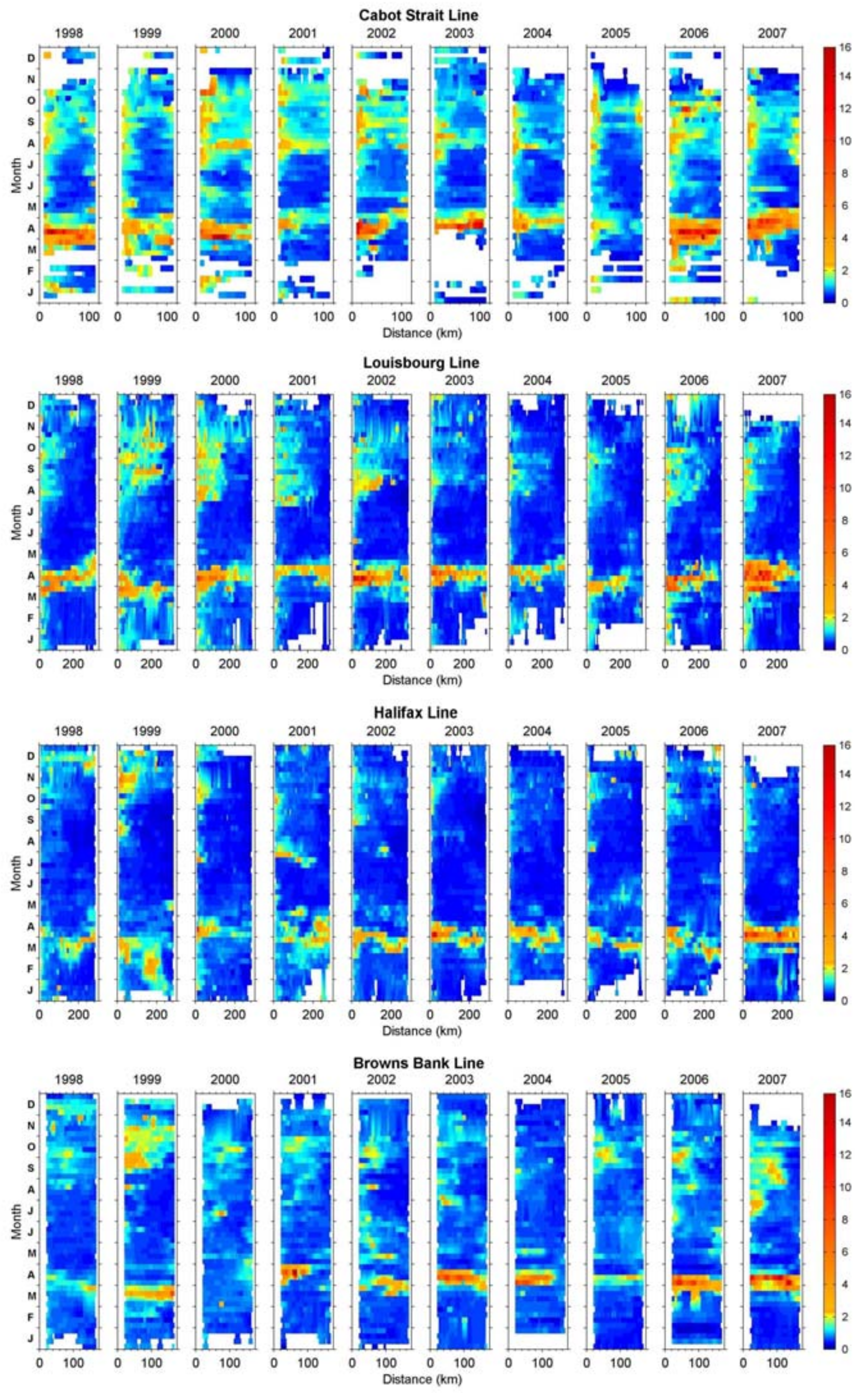

Figure 22. Time-series of surface chlorophyll concentrations (mg m^{-3}), from SeaWiFS 4 km weekly ocean colour data, along the Maritimes sections (see Fig. 1), 1999-2007. Horizontal axes running south to north (Cabot line) or west to east (Louisbourg, Halifax, Browns Bank lines).

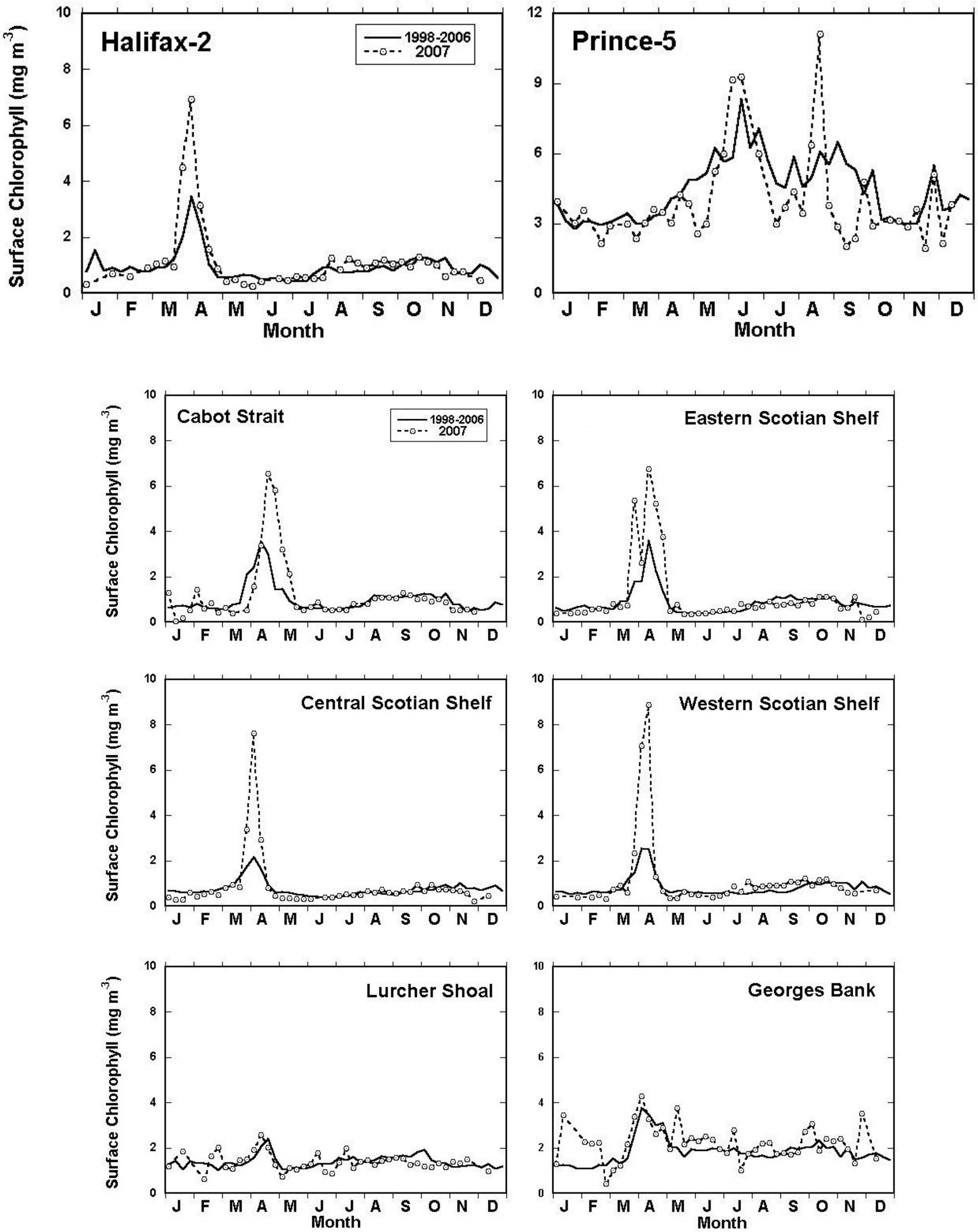

Figure 23. Seasonal variability in surface chlorophyll concentrations (from MODIS bi-weekly ocean colour composites) for the fixed stations and statistical sub-regions of the Maritimes region (see Fig. 5). Solid lines represent mean (1998-2006) levels, dashed lines represent 2007 levels.

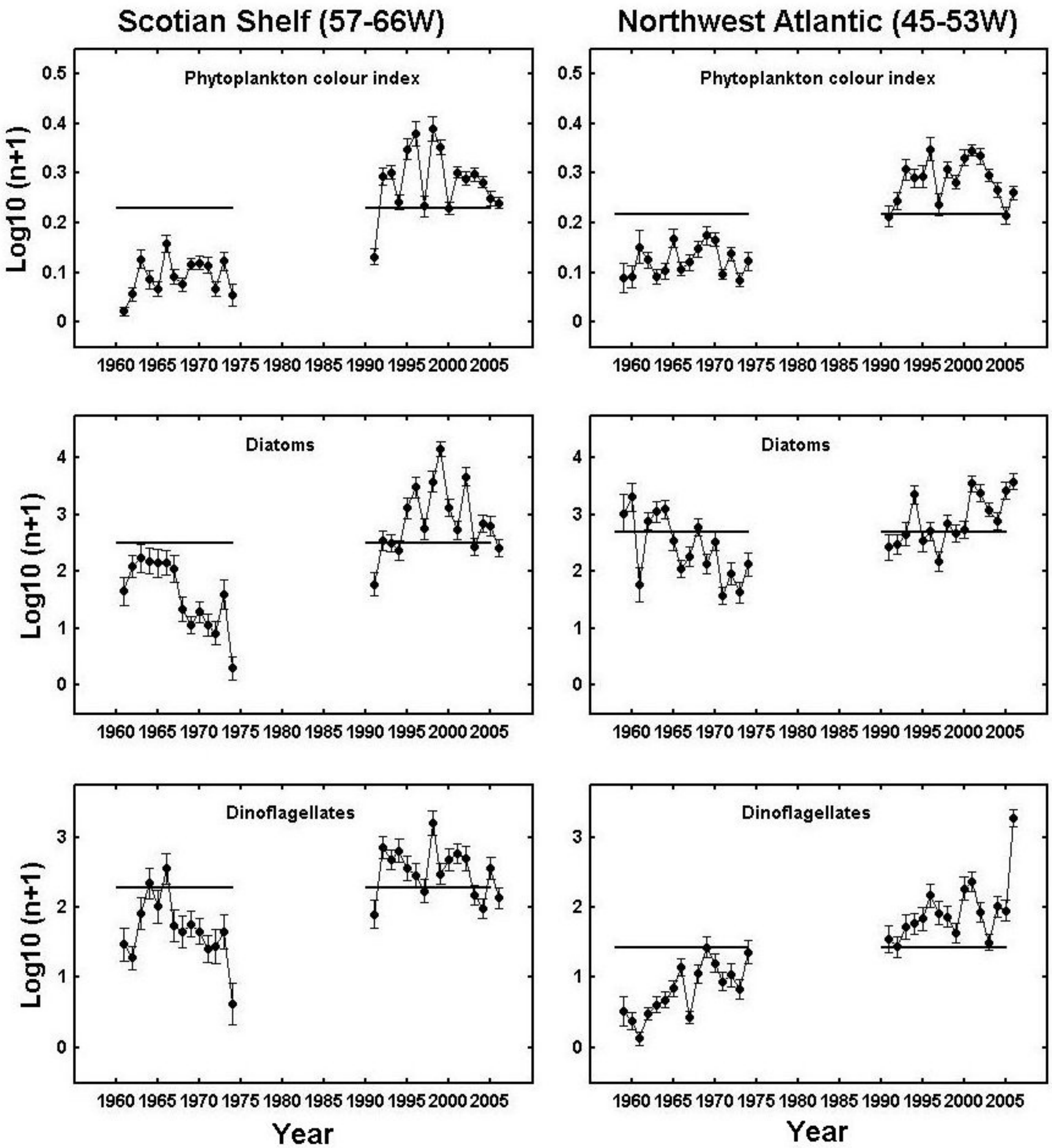

Figure 24. Time-series of phytoplankton biomass (colour index), diatom and dinoflagellate relative abundances (annual means) on the Scotian Shelf (57-66º W) and the Northwest Atlantic (45-53º W) from CPR surveys, 1961-2006 (see Fig. 4 for area coverage). Vertical bars are standard errors.

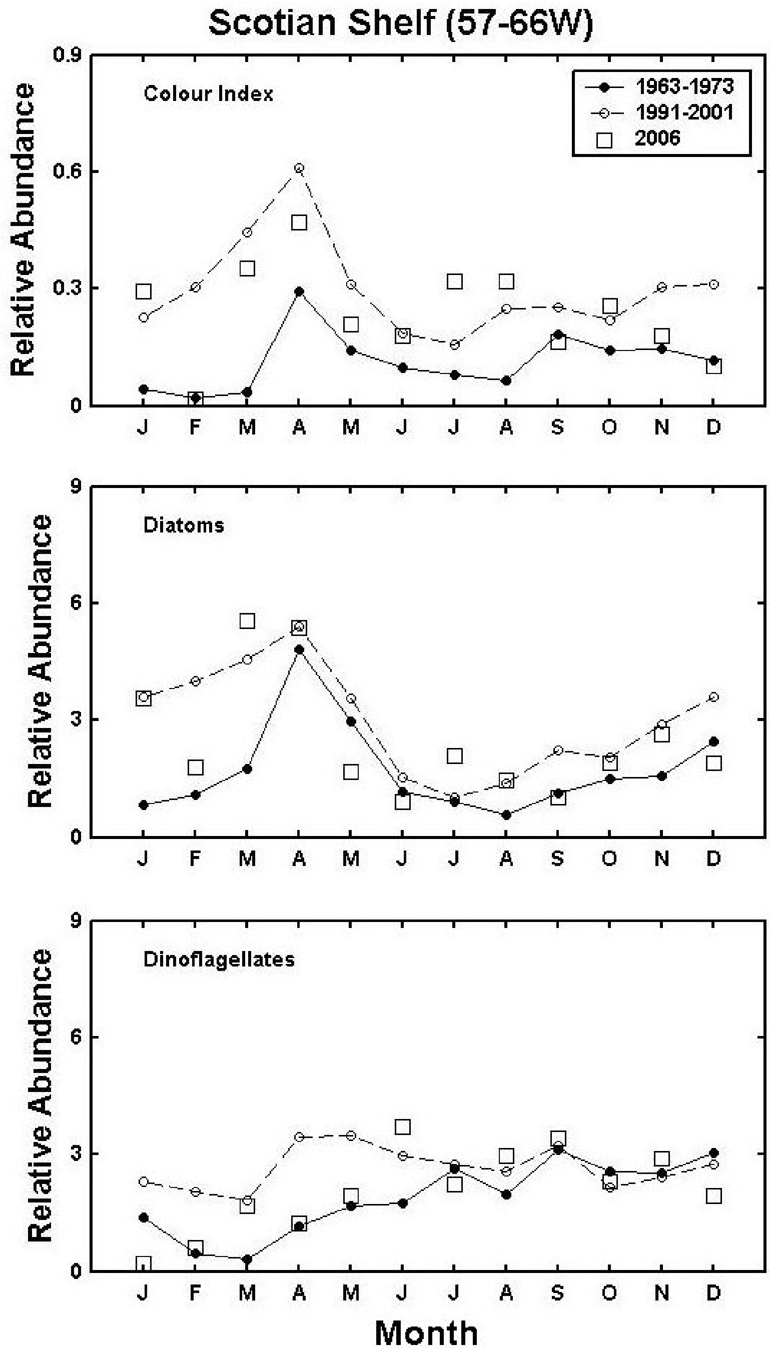

Figure 25. Monthly means of phytoplankton abundance on the Scotian Shelf in 2006 from CPR surveys. Means for the decades of the 1960s and 1990s shown for comparison.

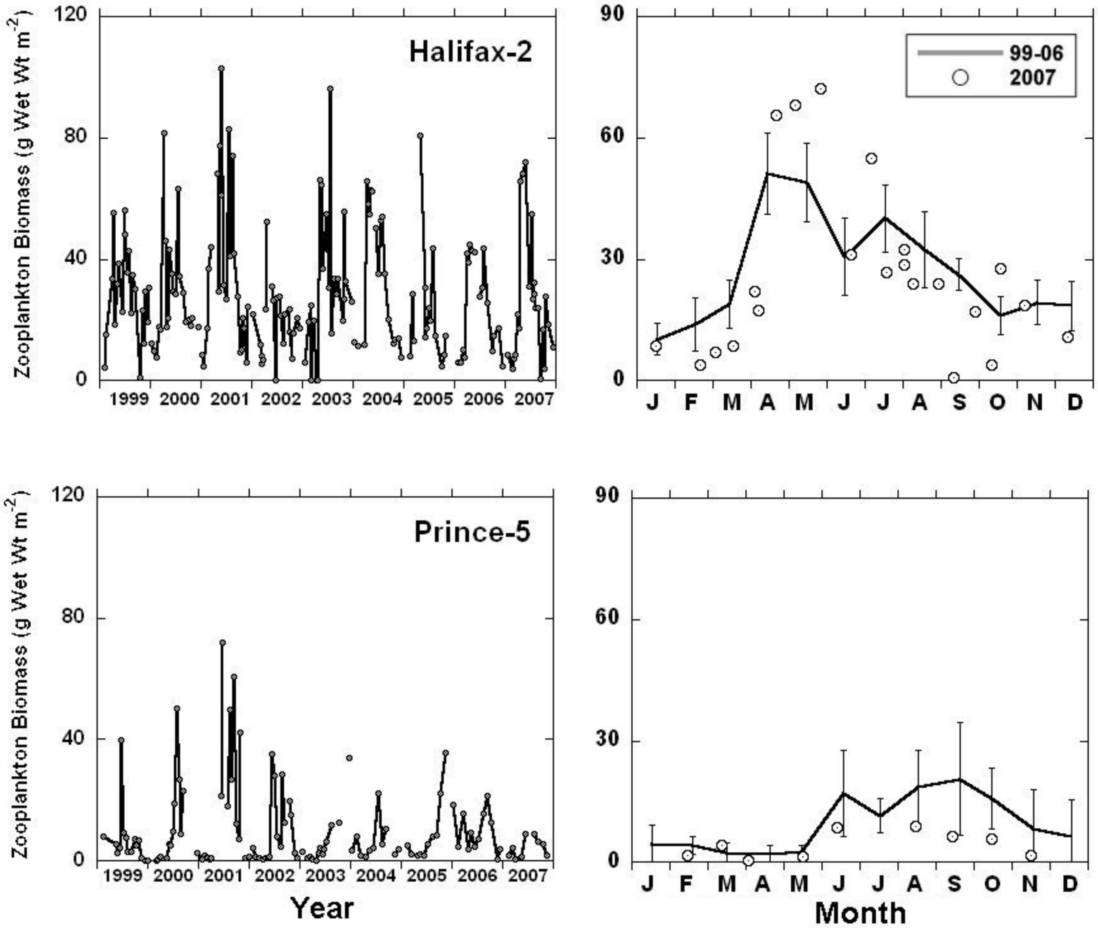

Figure 26. Time-series of zooplankton biomass (surface-bottom) at the Maritimes fixed stations, 1999-2007. Right panels: 2007 data (circles) compared with mean conditions from 1999-2006 (solid line). Vertical lines are 95% confidence limits.

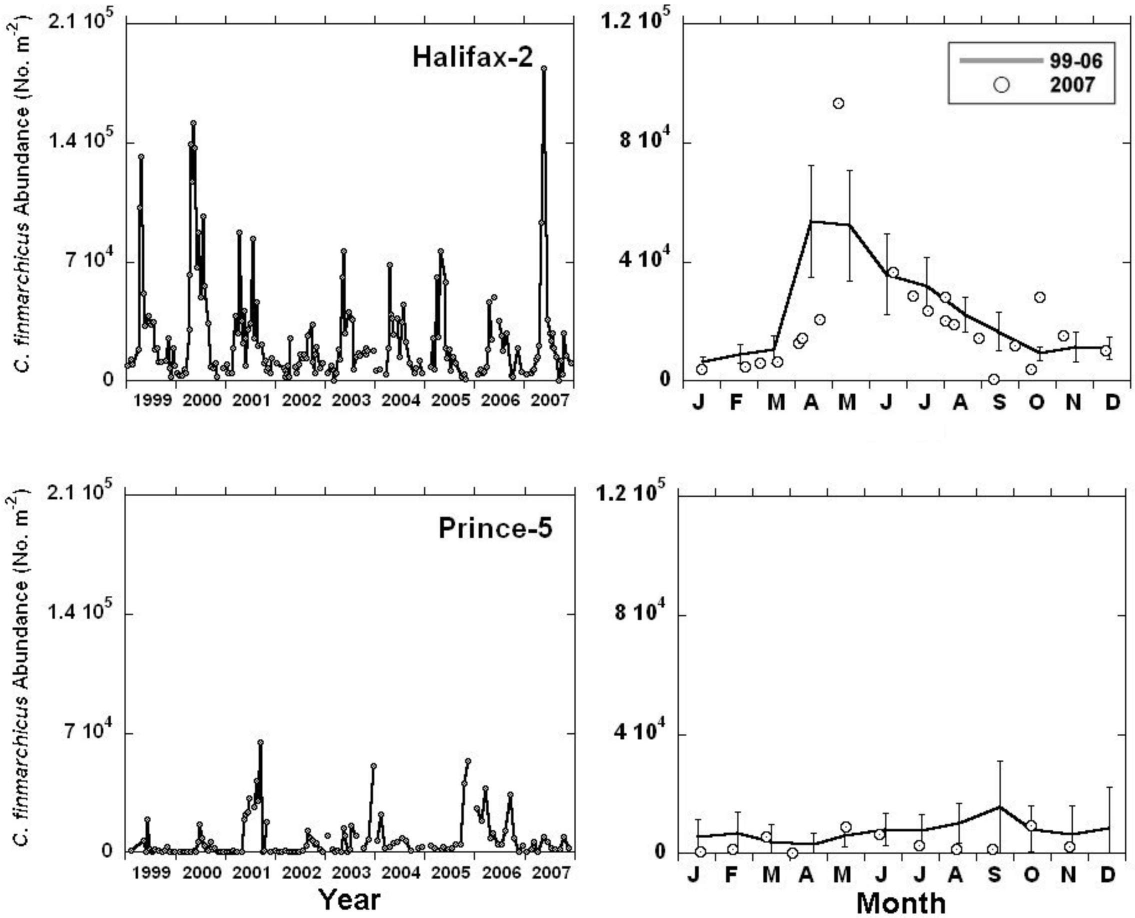

Figure 27. Time-series of *C. finmarchicus* (all stages) abundance (surface-bottom) at the Maritimes fixed stations, 1999-2007. Right panels: 2007 data (circles) compared with mean conditions from 1999-2006 (solid line). Vertical lines are 95% confidence limits.

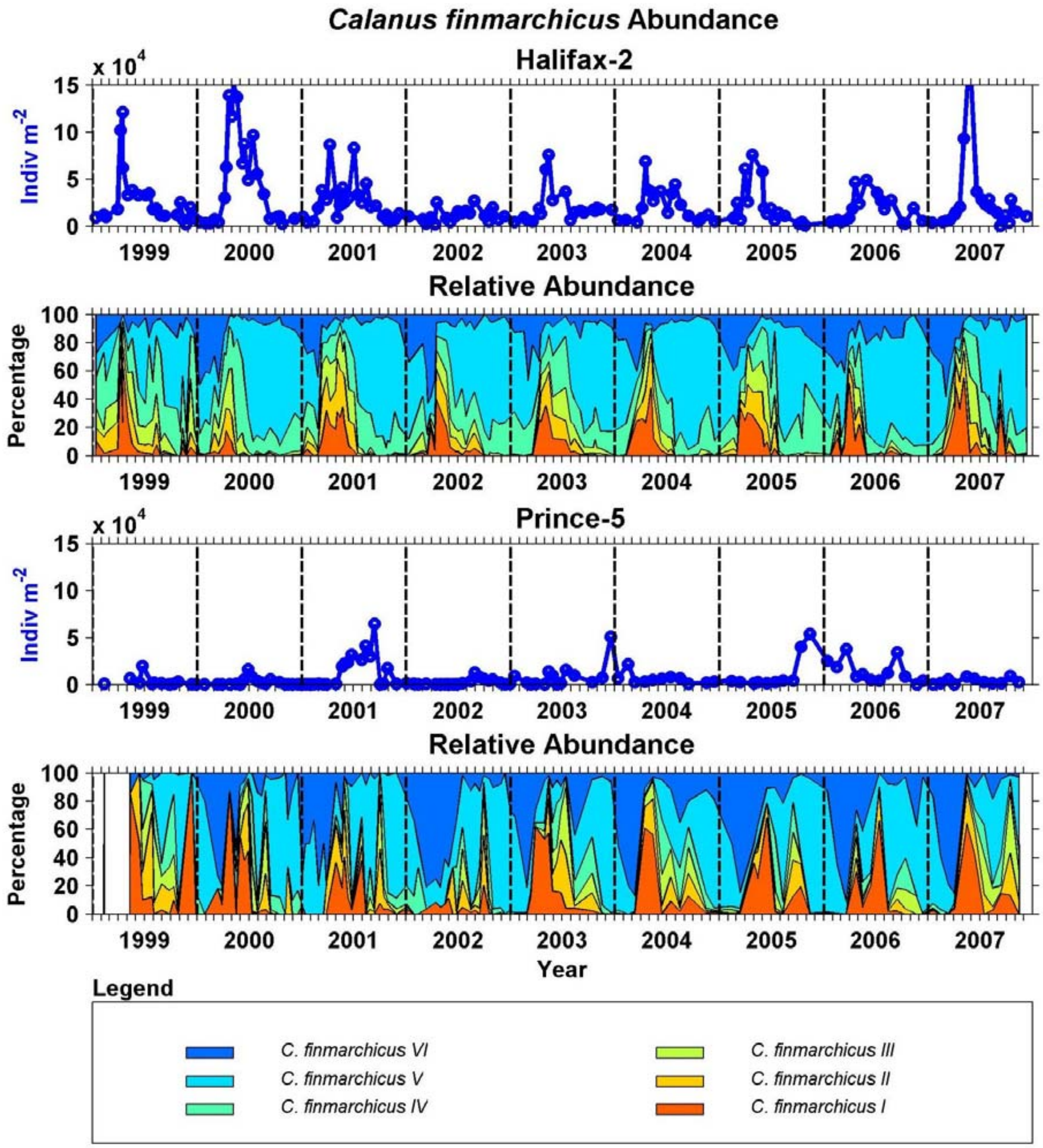

Figure 28. Time-series of *C. finmarchicus* abundance and developmental stages at the Maritimes fixed stations, 1999-2007.

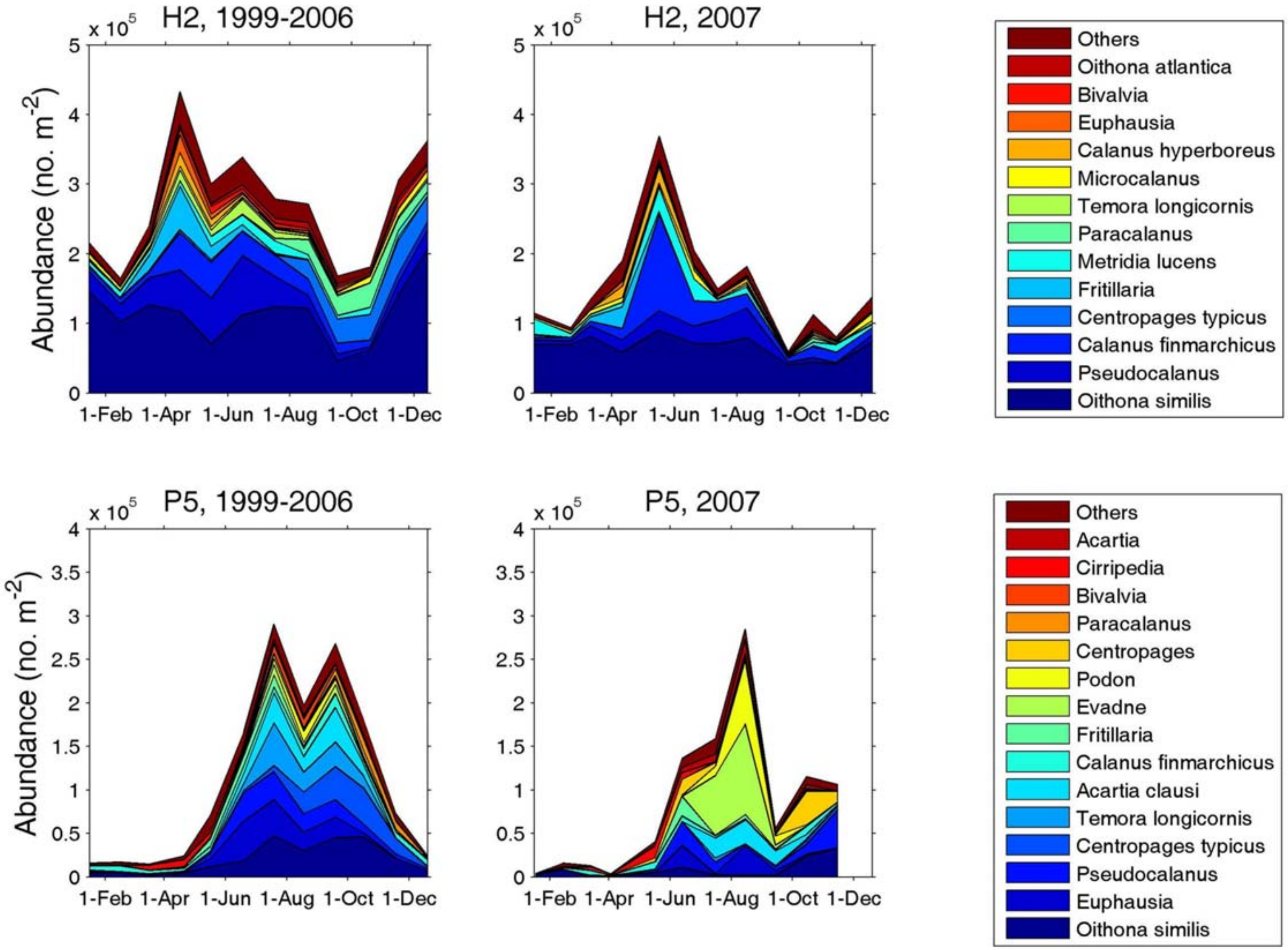

Figure 29. Seasonal variability of dominant taxa at Halifax-2 and Prince-5. The top 90% of taxa by abundance are shown individually; other taxa are grouped as 'others.' Left-hand panels are based on average abundance of monthly mean abundance from 1999-2006. Right-hand panels are monthly mean abundance in 2007.

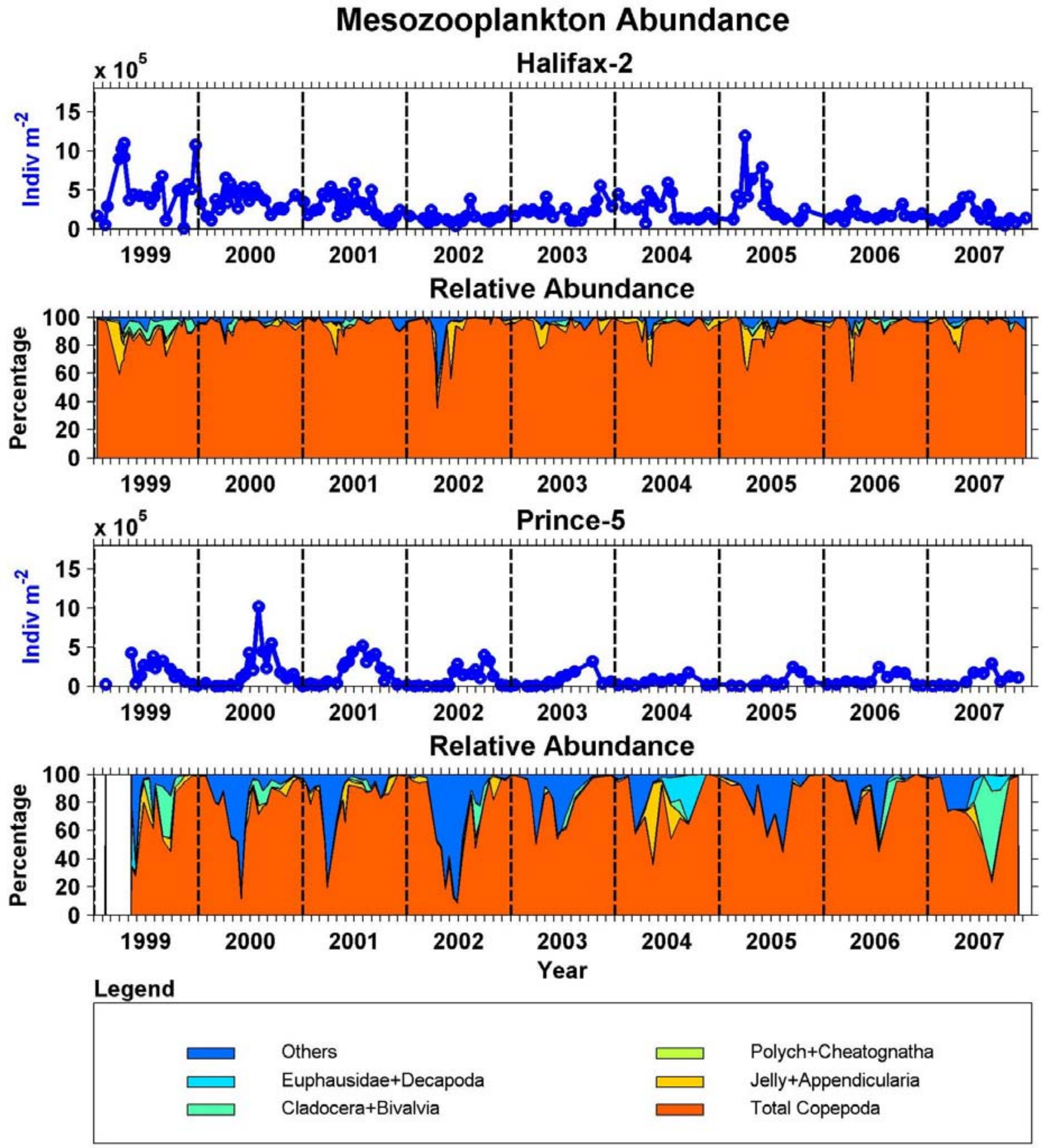

Figure 30. Time-series of mesozooplankton (<200 μm) abundance and community composition at the Maritimes fixed stations, 1999-2007.

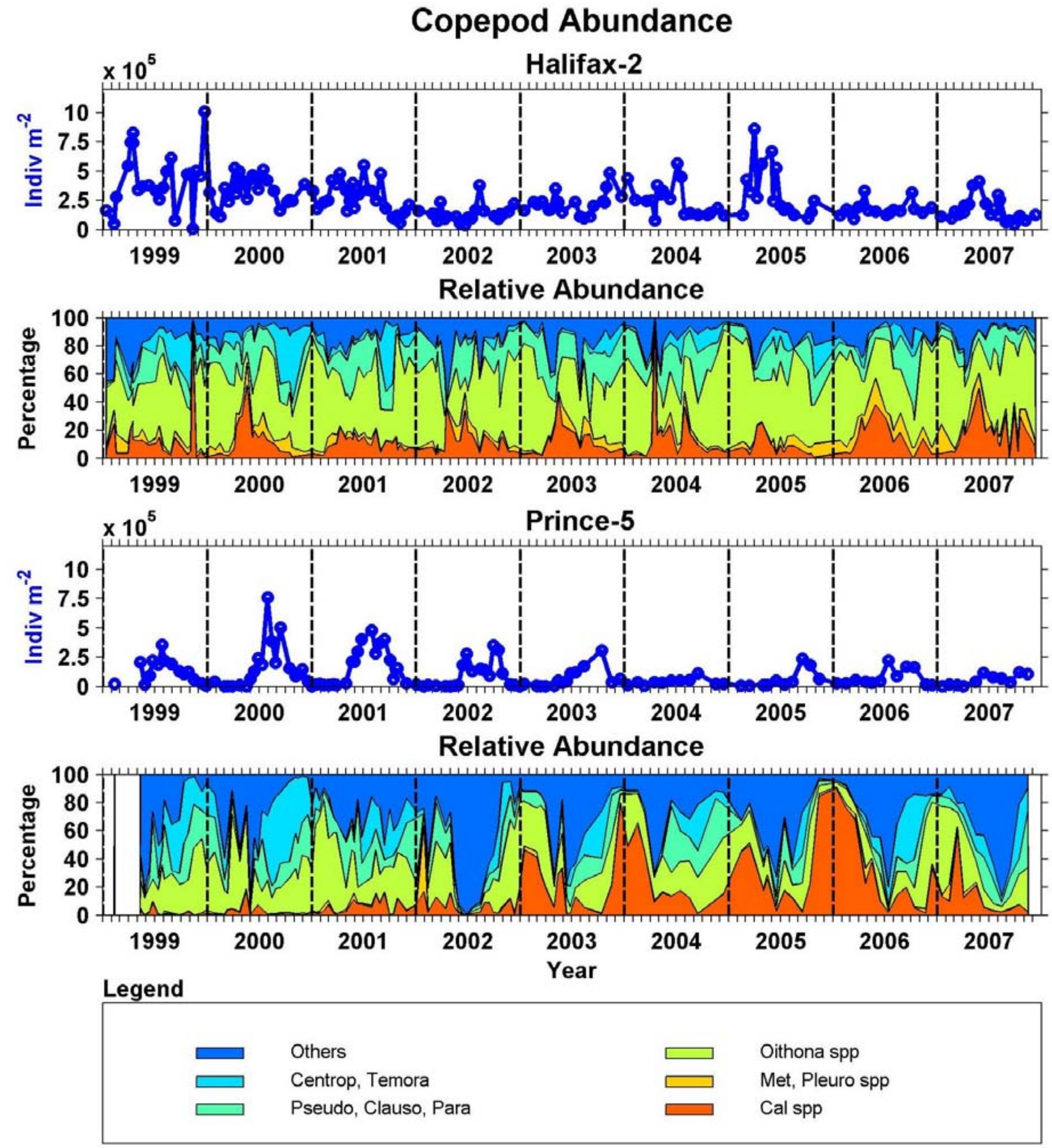

Figure 31. Time-series of copepod abundance and community composition at the Maritimes fixed stations, 1999-2007.

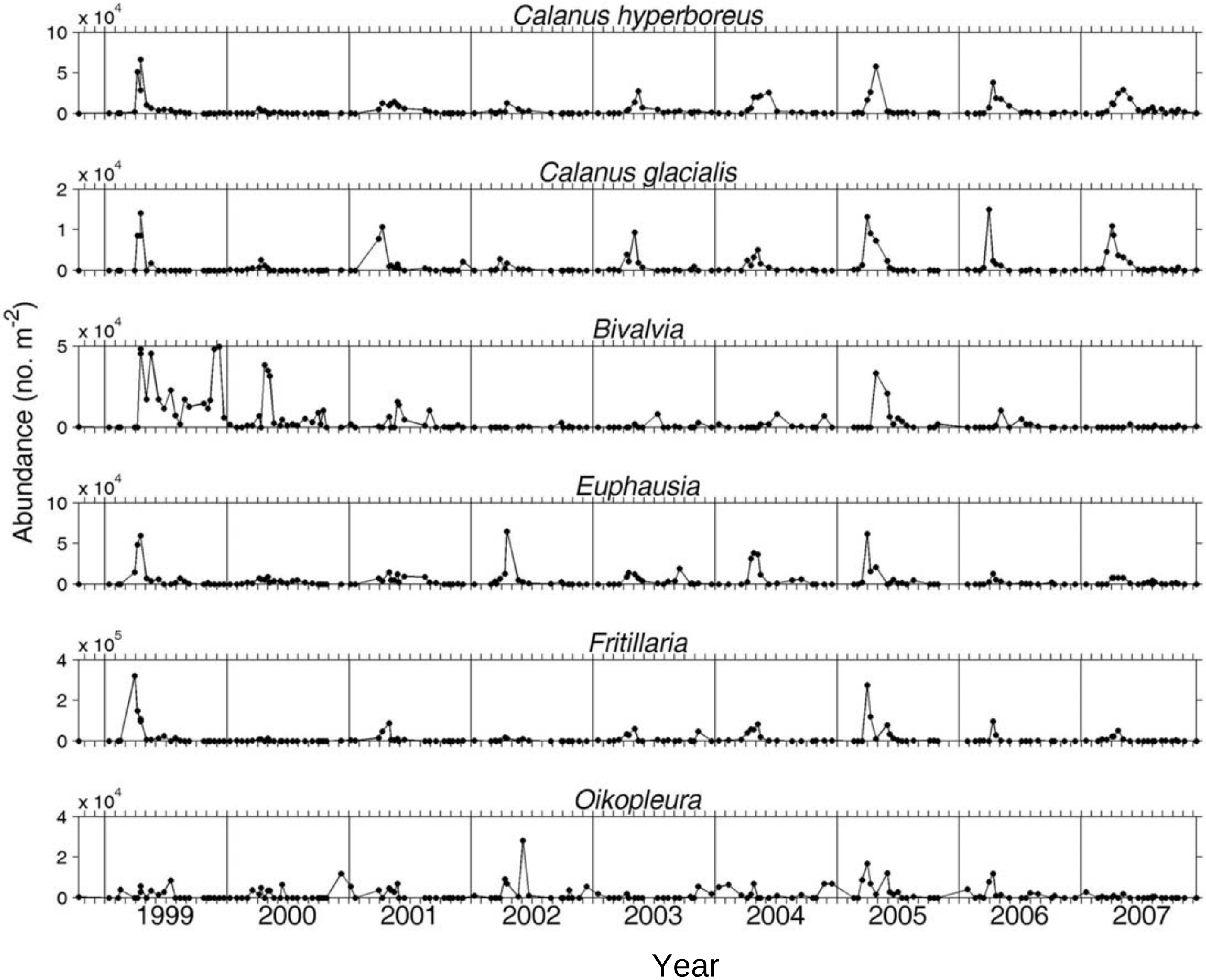

Figure 32. Time series of twelve dominant zooplankton taxa from Halifax-2 for the period 1999-2007.

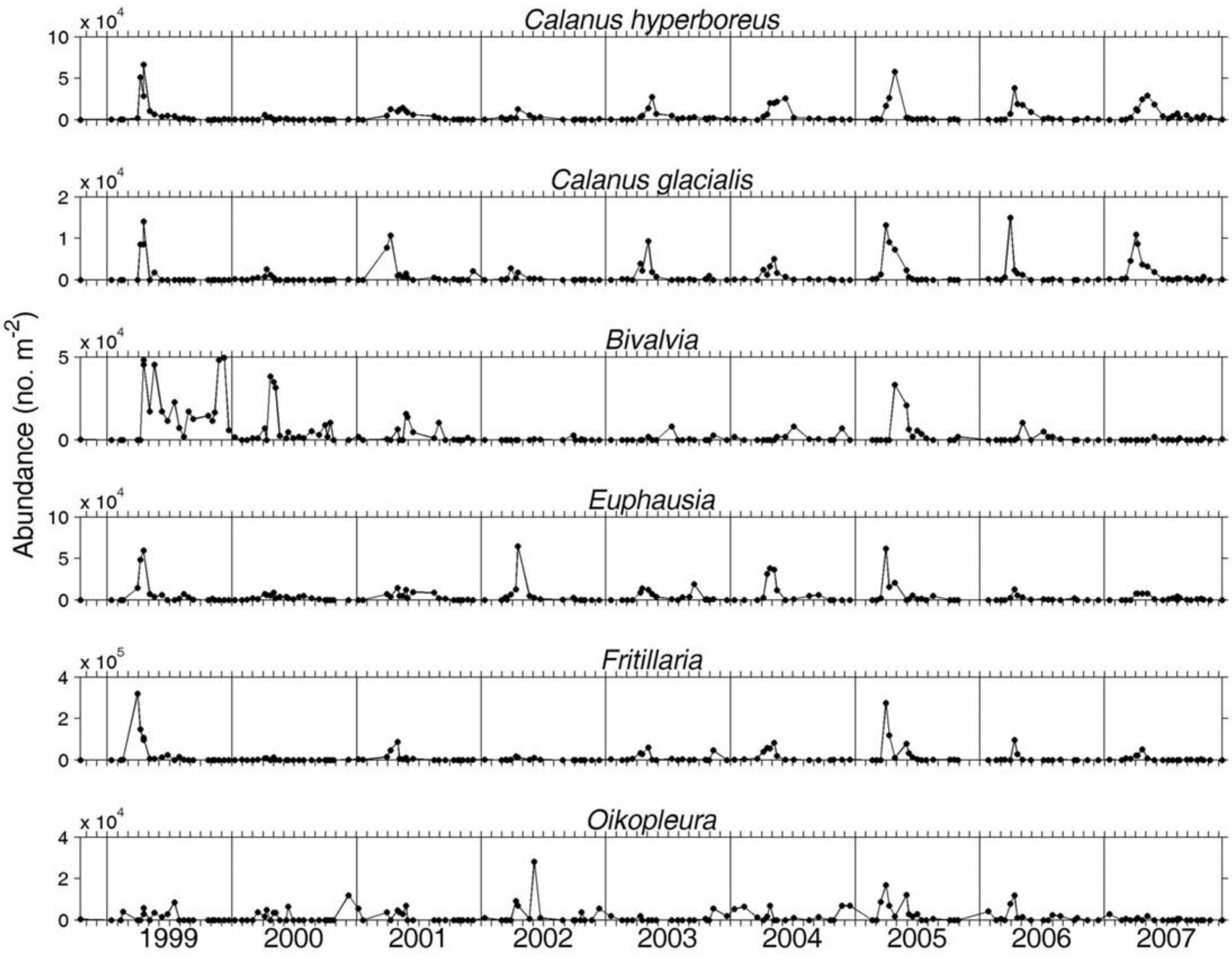

Figure 32 (Cont'd).

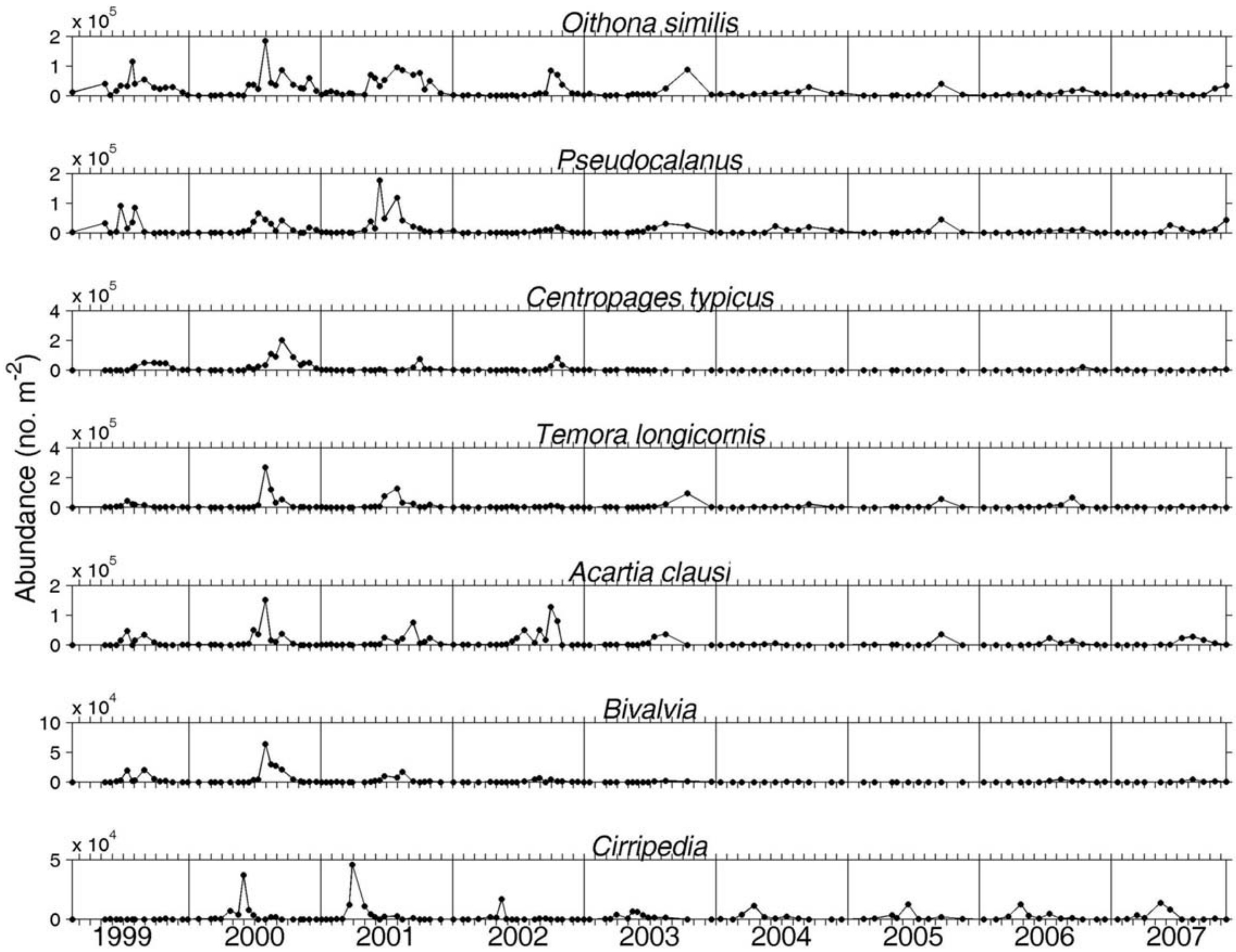

Figure 33. Time series of thirteen dominant zooplankton taxa from Prince-2 for the period 1999-2007.

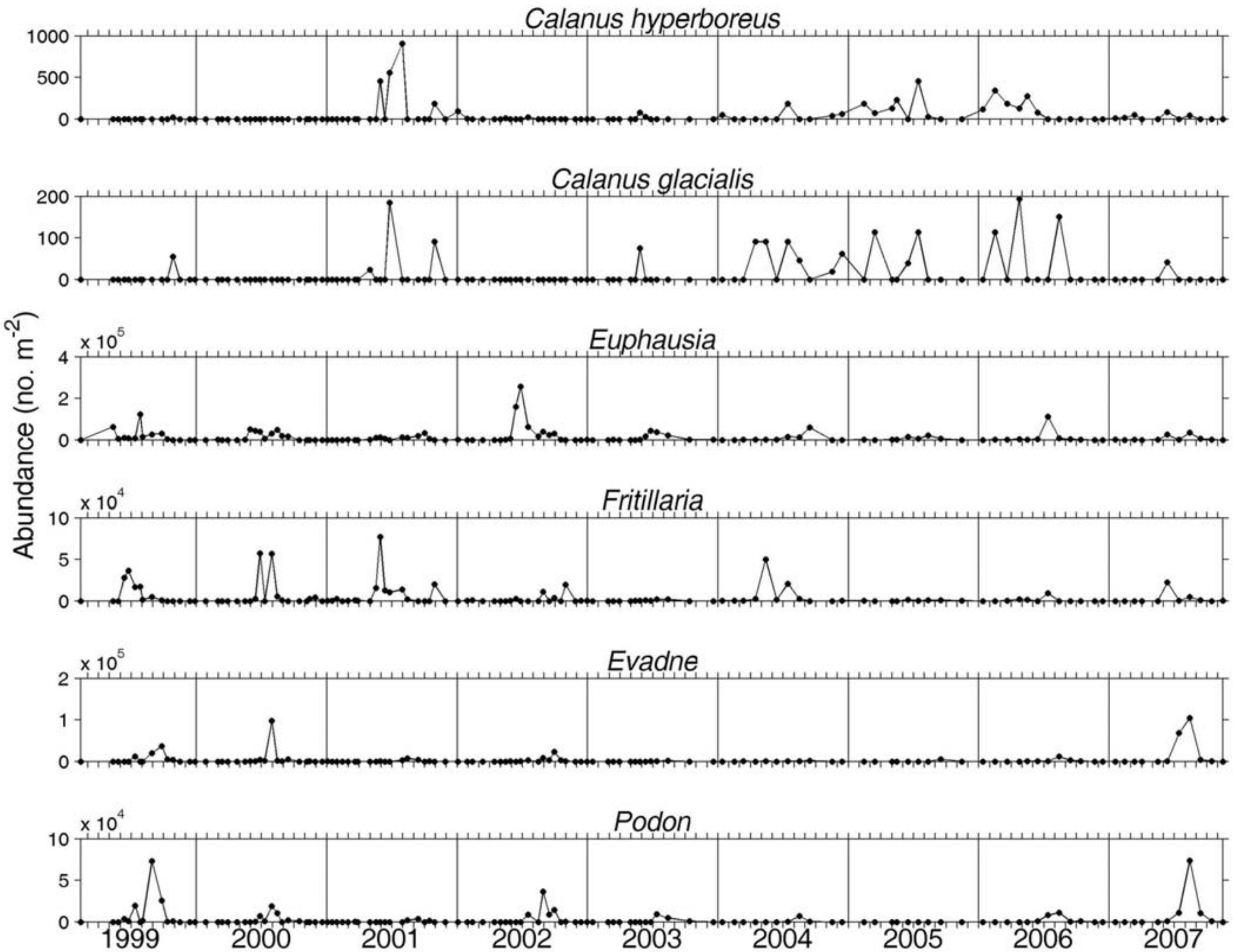

Figure 33 (cont'd).

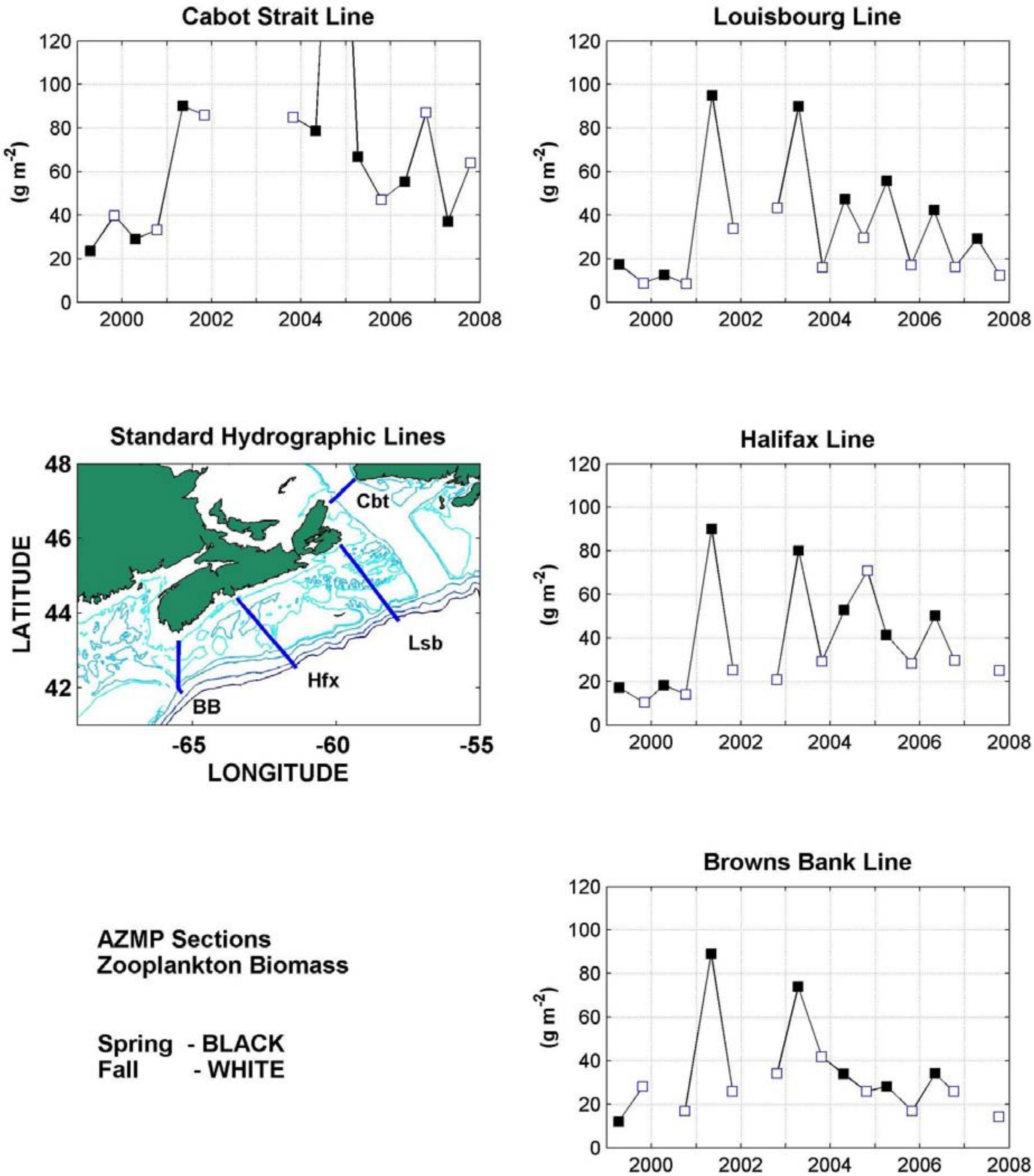

Figure 34. Time-series of average zooplankton biomass for the spring and fall Scotian Shelf sections, 1999-2007.

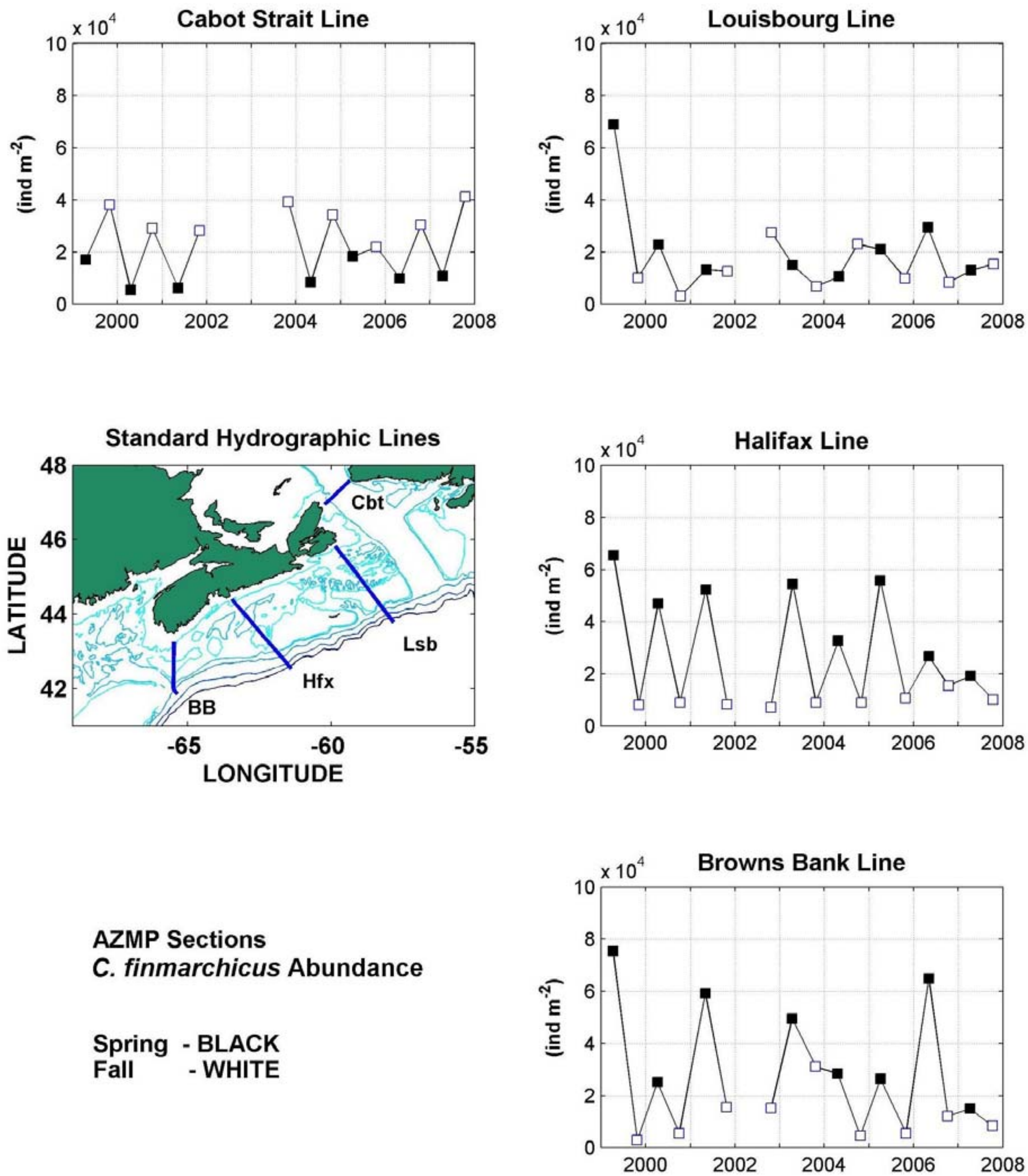

Figure 35. Time-series of average *C. finmarchicus* abundance for the spring and fall Scotian Shelf sections, 1999-2007.

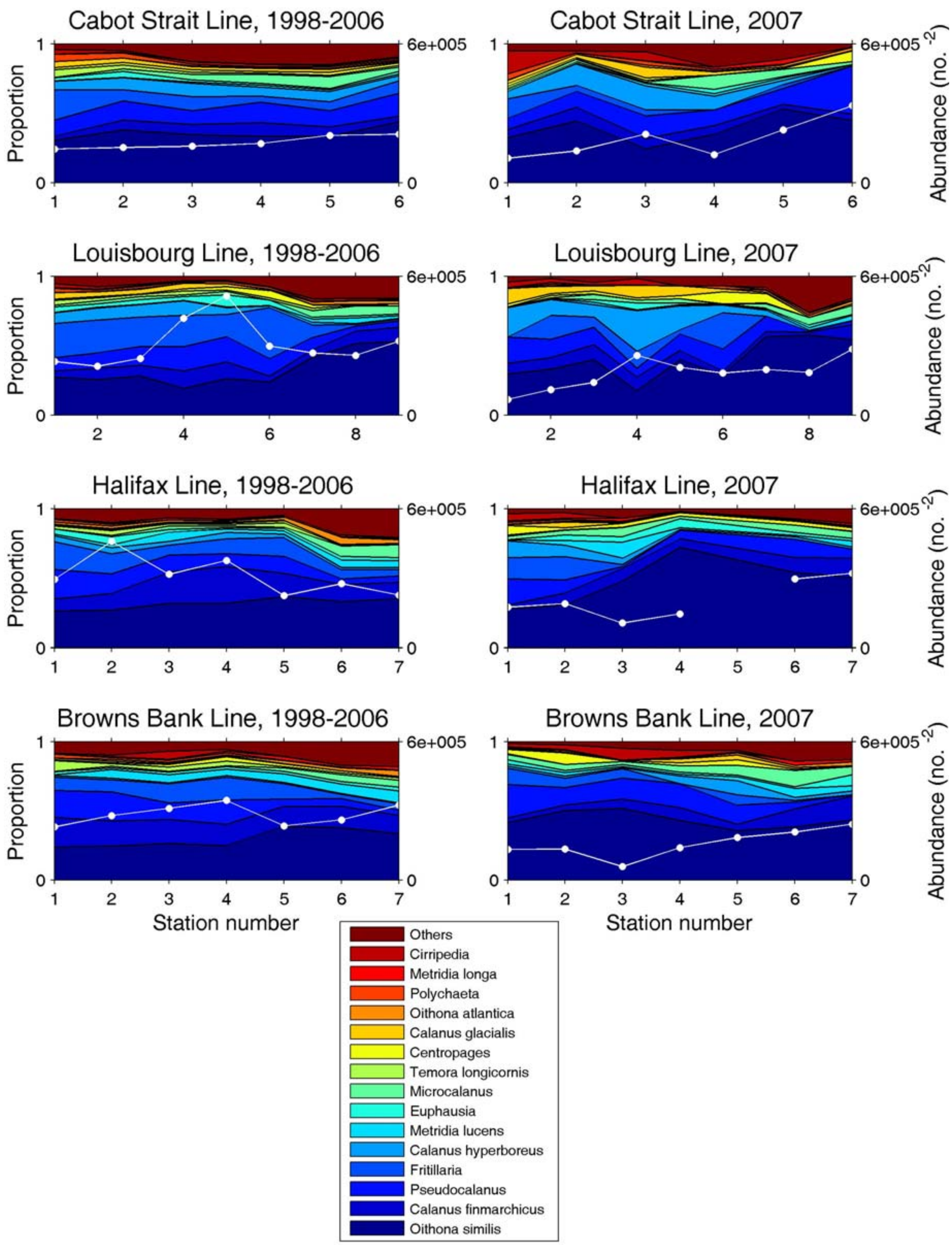

Figure 36. Spatial distribution of total zooplankton abundance (white lines and markers) and relative abundance of the most abundant taxa (top 85% by abundance) along transects sampled in the spring surveys. The left-hand panels show the average distribution for 1999-2006, while the right-hand panels show the observations for 2007.

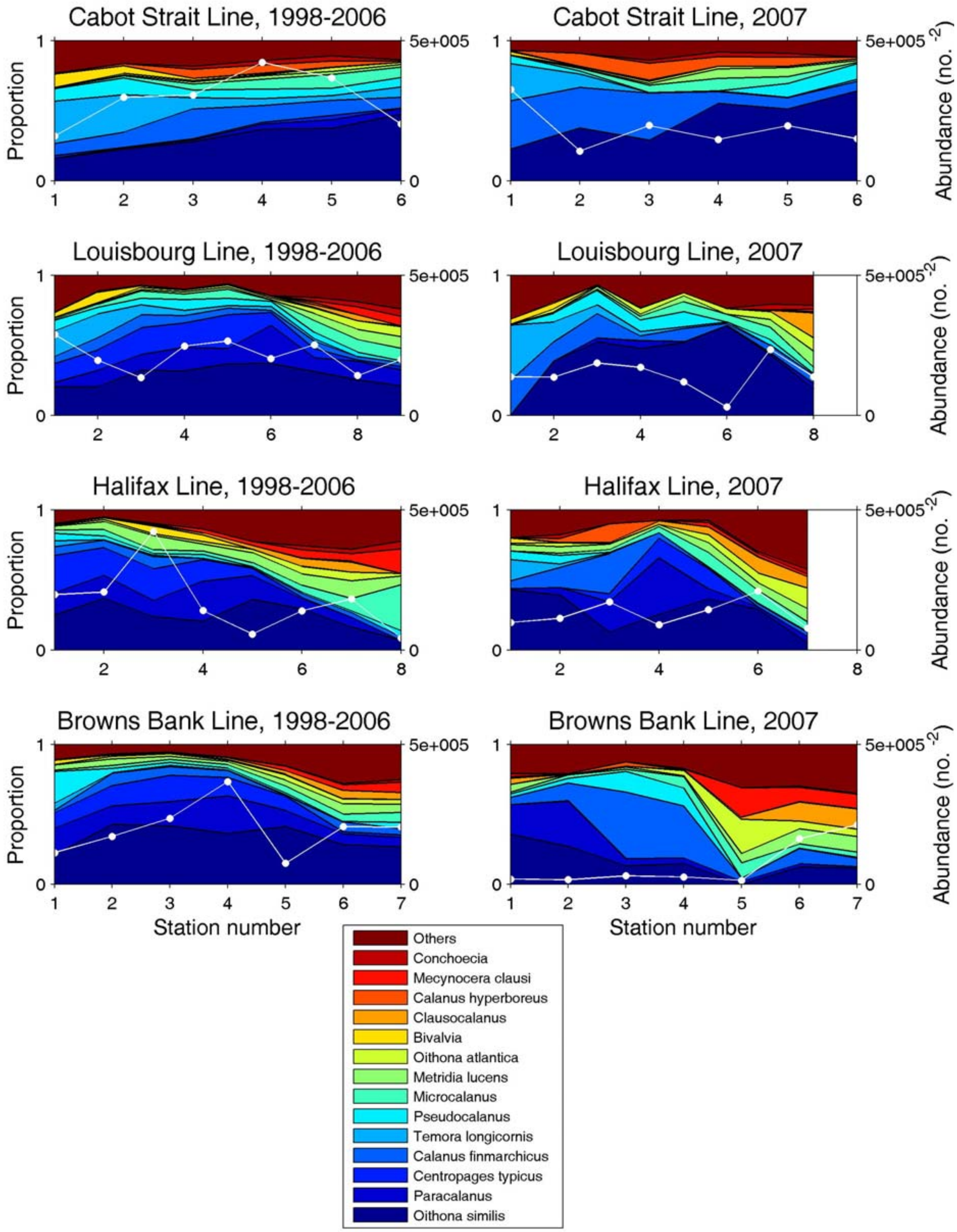

Figure 37. Spatial distribution of total zooplankton abundance (white lines and markers) and relative abundance of the most abundant taxa (top 85% by abundance) along transects sampled in the fall surveys. The left-hand panels show the average distribution for 1999-2006, while the right-hand panels show the observations for 2007.

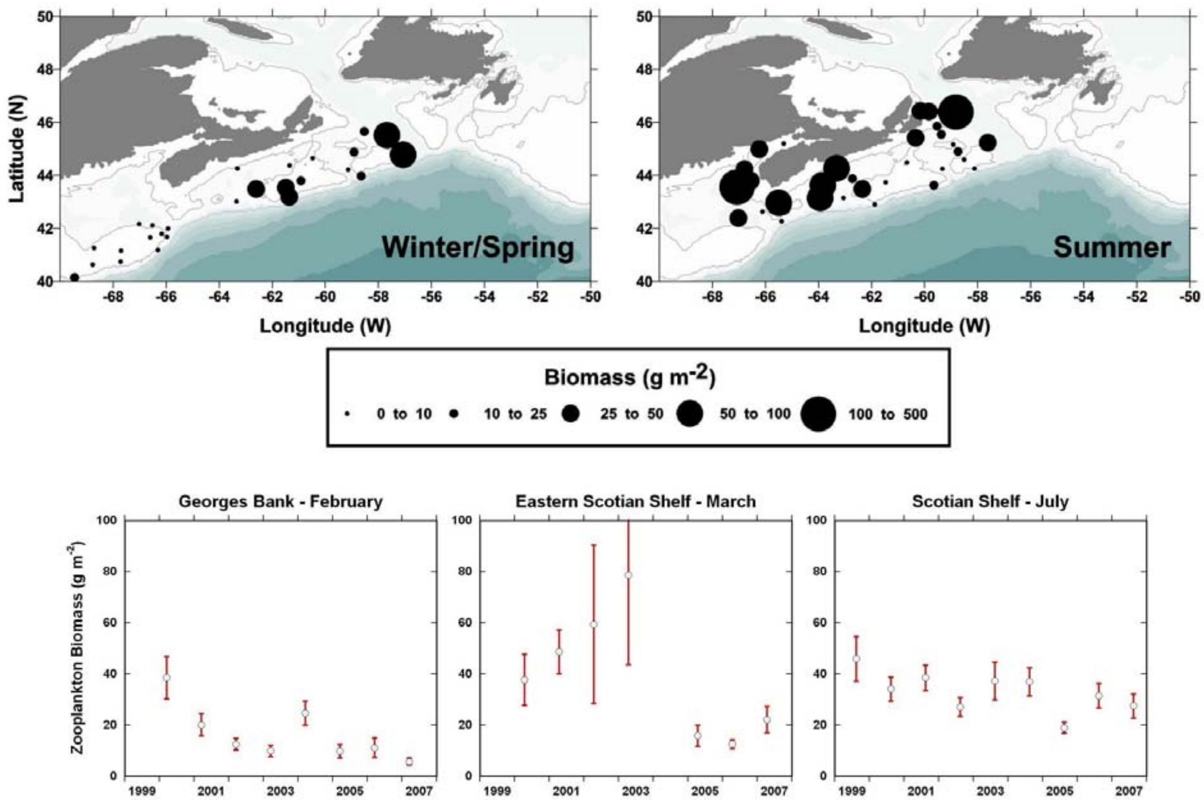

Figure 38. Zooplankton biomass (g wet wt m^{-2}) from trawl (groundfish) surveys on Georges Bank (February) the eastern Scotian Shelf (March) and the Scotian Shelf and eastern Gulf of Maine (summer): upper panels show 2007 conditions, lower panels show survey mean biomass, 1999-2007 (vertical bars are standard errors).

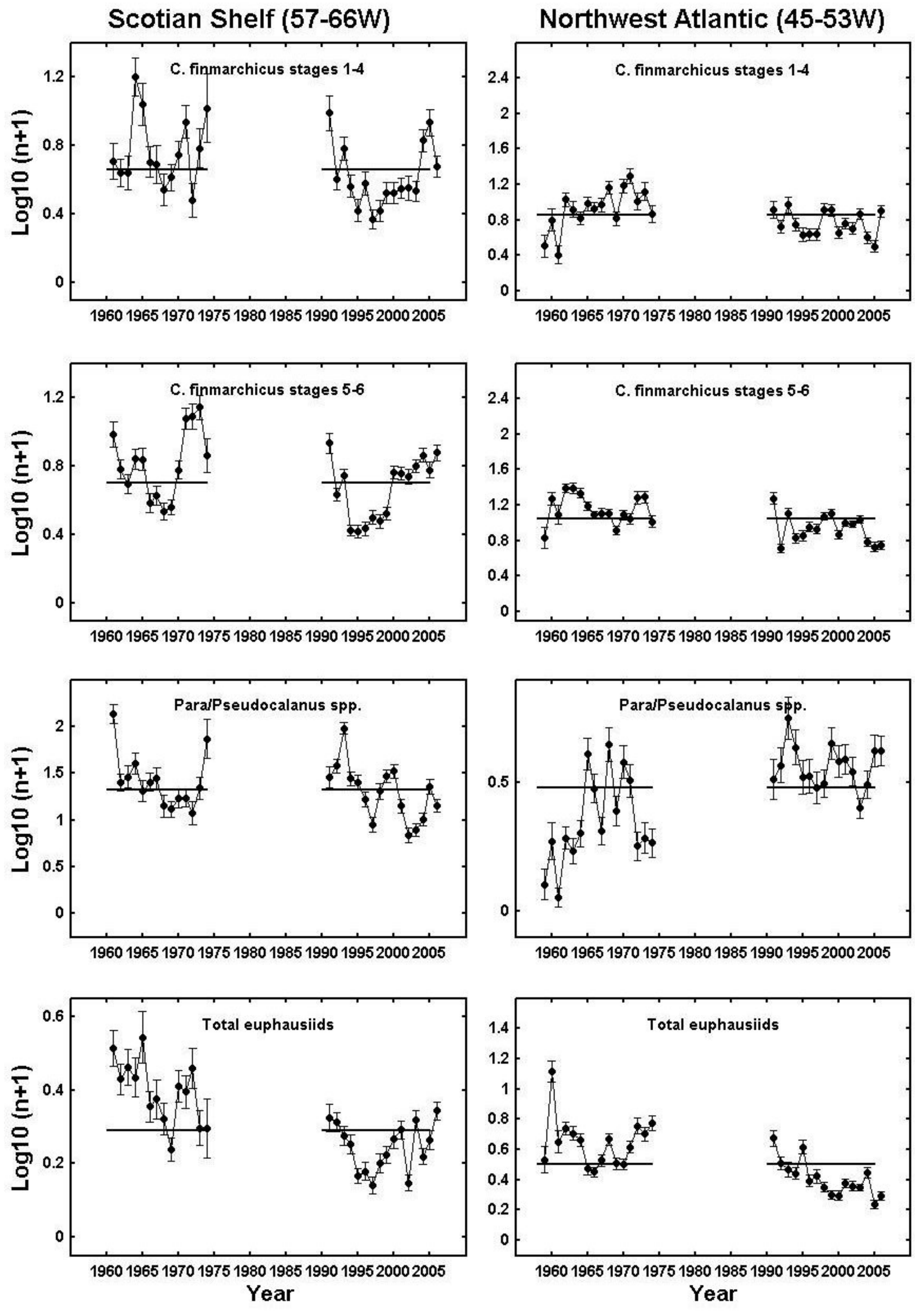

Figure 39. Time-series of relative abundances of selected zooplankton species (annual means) on the Scotian Shelf (57-66º W) and the Northwest Atlantic (45-53º W) from CPR surveys, 1961-2006 (see Fig. 4 for area coverage). Vertical bars are standard errors. Horizontal lines are overall mean values for all years sampled.

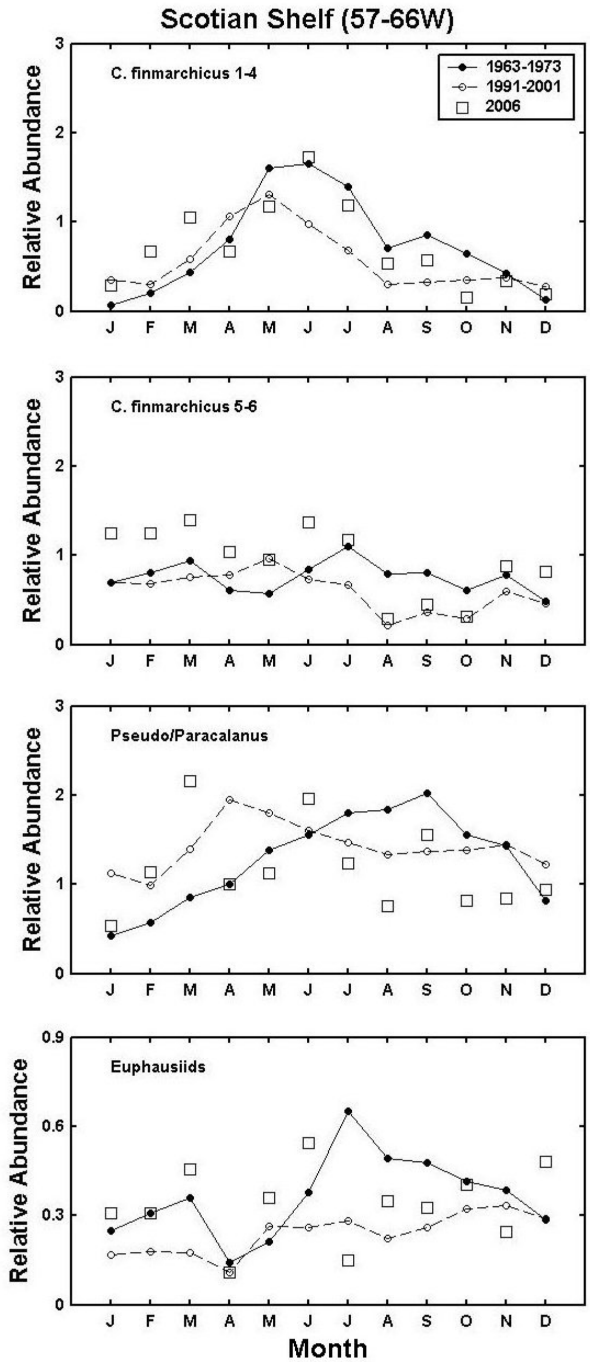

Figure 40. Monthly means of zooplankton abundance on the Scotian Shelf in 2006 from CPR surveys. Means for the decades of the 1960s and 1990s shown for comparison.

SCORECARD-Maririmes 2007		1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean +/- SD
NO3_0-50m	Hfx-2	-1.82	1.18	1.37	-0.50	0.04	-0.05	-0.36	0.16	-0.39	113 +/- 96
(mmol m-2)	P-5	-1.23	-0.27	-0.79	0.59	1.00	0.09	-0.96	1.58	0.29	352 +/- 124
	BBL	0.24	0.17	-1.62	-1.25	1.25	-0.25	0.78	0.69	-2.73	131 +/- 88
	CSL	0.46	-0.86	-0.62	2.26	-0.61	-0.37	0.00	-0.26	0.26	104 +/- 73
	HL	2.25	-0.34	0.01	-1.08	-0.48	-0.56	-0.11	0.32	-0.26	66 +/- 61
	LBL	1.67	-0.35	-0.82	-1.59	0.59	-0.15	-0.07	0.71	0.95	72 +/- 42
NO3_50-150m	Hfx-2	0.00	1.13	-0.71	0.64	1.07	-0.92	-1.63	0.42	-0.09	812 +/- 212
(mmol m-2)	P-5	-1.07	-0.33	-1.09	1.08	1.16	-0.28	-0.68	1.23	0.12	351 +/- 84
	BBL	-2.00	-0.33	0.02	0.48	1.16	1.03	-0.49	0.13	-1.11	666 +/- 437
	CSL	-0.35	1.12	-1.28	1.31	-0.42	-0.69	-0.73	1.03	-1.21	772 +/- 325
	HL	0.68	1.00	0.09	0.10	0.15	-0.65	-2.12	0.76	-1.11	664 +/- 429
	LBL	0.27	1.29	-1.54	-0.07	-0.24	-0.23	-0.90	1.41	-1.10	642 +/- 354
NO3-Win(J-M)_0-50m	Hfx-2	-0.94	0.56	1.01	-1.78	0.54	1.00	0.16	-0.55	0.07	253 +/- 81
(mmol m-2)	P-5	-0.67	0.41	-1.20	-0.62	0.30	1.71	-0.84	0.92	1.67	453 +/- 45
CHL_0-100m	Hfx-2	2.06	0.43	0.25	-0.32	0.20	-0.75	-0.75	-1.11	-0.93	74 +/- 114
(mg m-2)	P-5	1.24	0.72	0.65	0.44	-0.58	0.27	-1.11	-1.64	-0.57	107 +/- 114
	BBL	-0.45	-0.11	-0.25	-0.87	2.32	0.17	-0.08	-0.73	2.97	113 +/- 165
	CSL	1.07	1.73	-0.62	-0.82	-1.17	0.40	-0.52	-0.06	0.26	154 +/- 197
	HL	-0.66	0.28	-0.13	-0.96	1.33	-0.48	1.60	-0.99	4.43	91 +/- 126
	LBL	-0.51	0.37	-0.69	-1.21	1.93	0.45	0.41	-0.75	1.33	186 +/- 230
Bloom-Timing	Hfx-2	-0.77	0.41	0.70	-1.07	1.88	0.26	-0.63	-0.77	0.26	95 +/- 7
(Year-Day)	P-5		-0.23	-0.96	0.08	0.06	-1.35	0.84	1.57	0.06	162 +/- 41
Bloom-Magnitude	Hfx-2	-1.14	-0.74	-0.61	-0.19	1.33	1.14	1.01	-0.81	2.43	436 +/- 222
(mg m-2)	P-5		2.00	-0.92	-0.46	0.25	-0.26	-0.87	0.27	1.06	400 +/- 190
Bloom-Duration	Hfx-2	1.32	0.42	0.42	0.61	-0.02	0.23	-1.36	-1.62	-0.73	46 +/- 16
(Days)	P-5		-0.98	1.52	-1.03	-0.52	1.01	0.44	-0.42	1.16	73 +/- 20
C. finmarchicus	Hfx-2	0.86	0.85	1.48	-0.33	0.22	-0.89	-1.18	-1.01	-0.26	25.5 +/- 28.2
(Indiv m-2 * 10^3)	P-5	-0.87	-1.01	1.53	-1.15	0.28	-0.11	0.11	1.20	-0.66	7.7 +/- 12.2
	BBL	0.82	-0.88	0.86	-0.89	1.09	-1.11	-0.83	0.95	-1.17	28.1 +/- 32.9
	CSL	0.51	-0.76	-0.77	-2.95	2.05	-0.25	-0.40	-0.39	0.36	21.9 +/- 18.0
	HL	1.25	0.16	0.40	-1.96	0.55	-0.56	0.70	-0.53	-1.19	27.0 +/- 34.7
	LBL	2.02	-0.65	-0.70	1.01	-0.85	-0.30	-0.42	-0.10	-0.54	18.6 +/- 28.3
Pseudocalanus	Hfx-2	1.45	0.20	-0.21	-0.63	0.54	0.57	0.02	-1.85	-1.25	40.7 +/- 41.8
(Indiv m-2 * 10^3)	P-5	0.32	0.36	1.97	0.11	0.05	-0.54	-1.18	-1.10	1.25	13.2 +/- 25.4
	BBL	1.11	-0.01	1.58	-1.05	0.53	-1.16	-0.57	-0.44	-0.75	22.3 +/- 32.9
	CSL	1.15	-1.36	-0.36	-2.32	1.51	-0.18	-0.18	-0.58	0.12	22.4 +/- 17.1
	HL	0.94	0.27	1.14	-1.60	-0.22	0.05	0.70	-1.28	-0.79	20.3 +/- 23.6
	LBL	2.11	-0.99	0.51	-0.02	-0.25	-0.74	-0.80	0.19	-0.78	24.9 +/- 43.4
Copepods	Hfx-2	1.61	0.72	0.37	-1.43	-0.30	-0.04	0.30	-1.23	-1.65	272.7 +/- 167.4
(Indiv m-2 * 10^3)	P-5	-0.11	0.94	1.69	-0.92	0.19	-0.57	-1.42	0.21	-1.03	96.1 +/- 123.8
	BBL	1.16	0.98	0.17	-0.54	0.97	-1.68	-0.68	-0.39	-1.20	253.8 +/- 198.1
	CSL	1.28	-1.08	-0.92	-3.19	1.23	0.19	0.18	-0.89	-0.35	224.1 +/- 147.7
	HL	1.91	0.42	-0.04	-1.17	-0.33	-0.87	0.72	-0.63	-0.39	250.7 +/- 244.0
	LBL	2.31	-0.66	-0.03	-0.88	0.16	-0.61	-0.18	-0.12	-0.79	247.9 +/- 175.1
Non-copepods	Hfx-2	2.14	0.09	-0.58	-0.98	-0.54	0.01	0.56	-0.70	-1.12	37.1 +/- 62.1
(Indiv m-2 * 10^3)	P-5	1.51	0.97	0.38	0.17	-1.21	-0.43	-1.40	0.01	0.47	33.8 +/- 62.9
	BBL	1.49	0.48	-0.37	-1.04	0.24	-1.04	1.15	-0.92	-0.87	32.3 +/- 45.1
	CSL	1.00	-1.17	-0.81	-2.51	0.20	1.53	-0.78	0.03	-1.44	39.5 +/- 41.3
	HL	1.59	0.10	-0.70	-1.04	0.22	-0.33	1.24	-1.08	-0.91	39.5 +/- 66.8
	LBL	0.91	-1.04	0.65	-0.50	-1.26	-0.21	-0.20	1.65	-1.27	60.4 +/- 93.6
Nutrients		**-0.18**	**0.31**	**-0.51**	**-0.03**	**0.39**	**-0.02**	**-0.57**	**0.61**	**-0.33**	
Phytoplankton		**0.24**	**0.36**	**-0.05**	**-0.48**	**0.58**	**0.09**	**-0.08**	**-0.59**	**0.98**	
Zooplankton		**1.19**	**-0.13**	**0.30**	**-1.08**	**0.21**	**-0.39**	**-0.19**	**-0.38**	**-0.67**	
OVERALL		**0.60**	**0.11**	**-0.01**	**-0.64**	**0.35**	**-0.17**	**-0.27**	**-0.15**	**-0.18**	

Anom	Scale
>3	
2.5 to 3	
2 to 2.5	
1.5 to 2	
1 to 1.5	
0.5 to 1	
0 to 0.5	
-0.5 to 0	
-1 to -0.5	
-1.5 to -1	
-2 to -1.5	
-2.5 to -2	
-3 to -2.5	
<-3	

Figure 41. Maritimes region scorecard (1999-2007). Time series of chemical and biological variables, 1999-2007. White cells represent values within ± 0.5 standard deviations of the long term average based on a 1999-2006 reference period. Red cells indicate higher nutrient, phytoplankton, zooplankton levels than normal or later and longer duration phytoplankton blooms. Blue cells indicate lower nutrient, phytoplankton, zooplankton levels, or earlier and shorter duration blooms.