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Optical, chemical and biological oceanographic conditions in the Maritimes region in 2006

Propriétés optiques, chimiques et biologiques de l'océan dans la région des Maritimes, en 2006

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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 2006 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 to provide the larger, zonal perspective.

Optical properties at the Maritimes fixed stations in 2006 differed by site but were, for the most part, comparable to conditions observed in previous years. Stratification, however, was slightly stronger than usual at both stations during the latter half of the year.

Winter maximum nitrate concentrations in surface waters at Halifax-2 continued to decline in 2006 and in summer, the depth of the summer nitrate depletion zone was among the deepest observed since systematic measurements began in 1999. Nitrate concentrations at Prince-5, in contrast, continued to increase in 2006.

One of the most prominent features of phytoplankton in the Maritimes region in 2006 was the weakened and short-lived spring bloom at Halifax 2 compared with the strong blooms of the previous three years. Over the observation period of AZMP, the spring blooms at this station have been starting later and ending earlier and background chlorophyll levels have been decreasing. At Prince-5, chlorophyll concentrations were higher than usual in 2006 and the summer maximum occurred two months later than normally seen. 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.

Zooplankton biomass and *Calanus finmarchicus* abundance were highly variable (geographically and seasonally) in 2006. Zooplankton biomass, overall, was lower in 2006 than seen previously; record low levels were seen during the March groundfish survey. *Calanus finmarchicus* abundance was also low at the Halifax-2 fixed station, especially the younger developmental stages, and was at record low levels on the central Scotian Shelf during the spring section survey. On the other hand, *C. finmarchicus* numbers were higher than usual in 2006 at the Prince-5 fixed station and on the western Scotian shelf in spring, central shelf in fall and was at record high levels shelf-wide during the summer groundfish survey. Smaller copepod species (*Pseudocalanus sp., Oithona sp*.) at Halifax-2 have been decreasing over the past few years in relative abundance and biomass compared with the larger species (*C. finmarchicus, Metridia sp*.). CPR data continue to show that contemporary zooplankton levels are at or below those observed during the decade of the 1960s/1970s, however, several species (e.g. *C. finmarchicus, Paracalanus/Pseudocalanus sp.,* euphausiids) are recovering, particularly on the Scotian Shelf.

RÉSUMÉ

On passe en revue les propriétés optiques, chimiques et biologiques de l'océan dans la région des Maritimes (banc Georges, est du golfe du Maine, baie de Fundy et, plate-forme Néo-Écossaise) en 2006, puis on les compare aux conditions durant l'année précédente et à long terme s'il y a lieu. En plus de descriptions des séries de données de base du PMZA [stations fixes, transects saisonniers, relevés au chalut de l'écosystème (ou du poisson de fond), enregistreurs de plancton en continu (EPC), télédétection], on examine un certain nombre de données provenant de l'extérieur de ces régions afin de donner une vue d'ensemble de la zone.

Les propriétés optiques aux stations fixes de la région des Maritimes en 2006 différaient d'un endroit à l'autre, mais en général, étaient comparables aux conditions observées les années précédentes. La stratification était toutefois légèrement plus prononcée que d'habitude aux deux stations, pendant la seconde moitié de l'année.

Les concentrations maximales de nitrates près de la surface, au cours de l'hiver, à Halifax-2, ont continué de diminuer en 2006 et, au cours de l'été, la profondeur de la zone de raréfaction des nitrates était la plus grande observée depuis le début des mesures systématiques, soit en 1999. Les concentrations de nitrates à Prince-5, par contre, ont continué à augmenter en 2006.

L'une des caractéristiques dominantes du phytoplancton dans la région des Maritimes en 2006 a été la faible étendue et la courte durée de l'efflorescence printanière à Halifax-2, comparativement à l'ampleur de celles des trois années précédentes. Depuis le début de la période d'observation du PMZA, l'efflorescence printanière à cette station commence plus tard et se termine plus tôt et les concentrations de chlorophylle diminuent. À Prince-5, les concentrations de chlorophylle étaient plus élevées que d'habitude en 2006, et le maximum pour l'été a été atteint deux mois plus tard que la normale. Les données EPC continuent à indiquer que les niveaux d'abondance récents (1990-2000) 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.

La biomasse du zooplancton et l'abondance de *Calanus finmarchicus* étaient très variables (sur les plans géographique et saisonnier) en 2006. La biomasse du zooplancton, dans l'ensemble, était inférieure en 2006 à ce qui avait été observé précédemment; des creux record ont été constatés pendant le relevé du poisson de fond de mars. L'abondance de *Calanus finmarchicus* était aussi faible à la station fixe Halifax-2, notamment aux premiers stades de développement, tandis qu'elle a atteint des creux record dans la partie centrale de la plate-forme Néo-Écossaise pendant les transects printaniers. Par ailleurs, l'abondance de *C. finmarchicus* était plus grande que d'habitude en 2006 à la station fixe Prince-5 et dans l'ouest de la plate-forme Néo-Écossaise au printemps, ainsi que dans la partie centrale de la plate-forme à l'automne et a atteint un record à l'échelle de la plate-forme pendant le relevé du poisson de fond, en été. L'abondance et la biomasse des petites espèces de copépodes (*Pseudocalanus sp., Oithona sp*.) à Halifax-2 diminuent depuis quelques années, comparativement à celles des grandes espèces (*C. finmarchicus, Metridia sp*.). Les données EPC continuent d'indiquer que l'abondance récente du zooplancton se situe aux niveaux observés au cours de la décennie de 1960 à 1970 ou en-dessous; toutefois, plusieurs espèces (p. ex. *C. finmarchicus, Paracalanus/Pseudocalanus sp.,* euphausiacés) se rétablissent, particulièrement sur la plate-forme Néo-Écossaise.

INTRODUCTION

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

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

The AZMP derives its information on the state of the marine ecosystem from data collected at a network of sampling locations (fixed point stations, cross-shelf sections, groundfish surveys) in each region (Quebec, Maritimes/Gulf, Newfoundland) sampled at a frequency of bi-weekly to once annually. The sampling design provides for basic information on the natural variability in physical, chemical and biological properties of the Northwest Atlantic continental shelf. Groundfish surveys and cross-shelf sections provide detailed geographic information (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 2006. For some data (CPR, MODIS/SeaWiFS ocean colour), descriptions will include observations outside the Maritimes/Gulf, i.e. the central and western North Atlantic. Conditions in 2006 will be compared with those observed during recent years (Harrison et al. 2006) and over the longer-term where historical information is available.

METHODS

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

Sample Collection

Maritimes/Gulf AZMP sea-going staff participated in 7 missions (seasonal section cruises and groundfish surveys) during the 2006 calendar year in addition to repeat day-trips to the 3 fixed stations; 693 station occupations were the total sampled all together (Table 1).

Fixed Stations. In 2006 the Maritimes/Gulf regions' three fixed stations, Shediac Valley, Halifax-2 and Prince-5 (Fig. 1), were sampled at least monthly (Prince-5) with attempted semi-monthly sampling during the spring bloom period. Mostly because of the availability of resources (platforms) and to some extent, difficulties with weather and ice, this sampling frequency was not always achieved. In 2006, Halifax-2 and Prince-5 were sampled on 19 and 12 occasions, respectively. Shediac was sampled only 9 times. By definition; the Shediac station has an ice-truncated open water season. Difficulties encountered with Coast Guard operations and platform availability in the two previous years were somewhat resolved and Shediac station occupations increased in 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 reading when possible.

Shelf Sections. Four primary transects (Browns Bank Line, Halifax Line, Louisbourg Line, Cabot Strait Line; Fig. 1) and a number of additional lines/stations (Fig. 2) are sampled seasonally in spring (April/May) and fall (October/November). An additional occupation of the Halifax Line is also attempted in May/July period as part of the Labrador Sea program in the Maritimes Region. In 2006, 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; unlike 2005. The four core transects were occupied in the both seasons. There was an opportunity to sample the Halifax Line in summer 2006 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.

Groundfish Surveys. There are four primary groundfish surveys for 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 2006.

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

- CTD (SBE25 – PED rosette) 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)
- Groundfish 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. 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. 2005 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). Free-access SeaWiFS data ended at the end of December 2004. A new data product from the Moderate Resolution Imaging Spectroradiometer (MODIS) "Aqua" sensor is used now (http://modis.gsfc.nasa.gov/). The MODIS data stream began in July, 2002. The composites and statistics from MODIS used in this report are only provisional since they have not yet been intercalibrated with the SeaWiFS imagery. Satellite data do not provide information on the vertical structure of phytoplankton in the water column but do provide highly resolved (~1.5 km) data on their geographical distribution in surface waters at the large scale. Bi-weekly composite images of surface chlorophyll for the entire NW Atlantic (39-62.5 N Lat., 42-71 W Lon.) are routinely produced from SeaWiFS data (http://www.mar.dfo-mpo.gc.ca/science/ocean/ias/seawifs/seawifs_1.html). Basic statistics (mean, range, standard deviation, etc.) are extracted from the composites for selected sub-regions (Fig. 5), for the fixed stations (defined as a ~5x5 km box centered on the station location) and for the seasonal sections (defined by the inner and outer-most stations and ~5 km in width).

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

RESULTS

Fixed Stations

Mixing and Optics. Mixing and optical properties of the upper water column varied by season and location at the Maritimes fixed stations (Fig. 6, 7). Seasonal development of the mixed-layer and upper water-column stratification was 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 2006 was consistent with the long-term average conditions, as seen in 2005, except for a relatively deep mixing (70-100 m) event in late March and early April; mixed-layers were slightly shallower (<10 m) than the norm in summer. The development of stratification at Halifax-2 was also consistent with the long term average, differing from conditions in 2005 when the seasonal increase in stratification appeared to be later (by 2 months) than usual. There was some evidence of slightly higher stratification in late fall (October-December) in 2006 compared with normal conditions. 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 higher than normal stratification was evident throughout summer and fall (June-November) in 2006. Mixed-layer depths are highly variable and difficult to determine at this station due to the very small vertical density differences; estimates ranged from <20 m in spring and early summer to almost full depth in winter in 2006. Averaged over the year, mixed layer depths were similar to and stratification somewhat higher than the norm 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) coincided with the spring bloom and euphotic depths were deepest following the decline of the bloom at the Halifax-2 station; this was most evident from the Secchi readings (Fig. 7). Euphotic depths at this station fell within the 40-60 m range in 2006, consistent with the long-term average. At the Prince-5 station, in contrast, euphotic depths in 2006 were significantly shallower (~15-30 m) than seen at Halifax-2, remarkably constant through the year and consistent with the long-term average at that station. Overall, seasonal patterns and magnitudes of optical properties in 2006 at Halifax-2 and Prince-5 were similar to those observed in previous years.

<u>Nutrients</u>. 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 2006 (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 2006 at Halifax-2 was shallower (33 m) than the record depth seen in 2005 (40 m) but similar to the long-term average. The seasonal evolution of the vertical nitrate structure at Halifax-2 in 2006 was similar to that observed in previous years. However, anomaly plots showed that nitrate concentrations in deep waters (>50 m) in 2006 were lower (-2 to -4 mmol m^{-3}) in summer and higher (+4 mmol m^{-3}) in fall than the climatological average. Near surface nitrate concentrations at Prince-5 in 2006 were never reduced below ~3 mmol m^{-3}. Anomaly plots for this station indicated that nitrate concentrations were higher (+1 to 2 mmol m^{-3}) than usual throughout the year, but most markedly in late summer/fall.

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 2006 was similar to that observed in previous years, wintertime maximum inventories in 2006 (~260 mmol m^{-2}) were lower than seen in the previous years and continued a trend of declining concentrations following the record high inventories in 2003 (~400 mmol m^{-2}). Inventories in fall, in contrast, were slightly higher than seen previously. Winter maximum nitrate inventories in the upper 50 m at Prince-5 in 2006 (~520 mmol m^{-2}) were significantly higher than seen in 2005 (~440 mmol m^{-2}) but similar to the long term average. In addition, summer levels (~240 mmol m^{-2}) were higher than the long term average (~210 mmol m^{-2}). Nitrate inventories in deep waters (>50 m) at Halifax-2 in 2006 were generally comparable with the long-term average (~800 mmol m^{-2}) although concentrations were slightly higher than the norm late in the year, October-December (Fig. 9B). At Prince-5, however, nitrate inventories in deep waters in 2006 were greater than average conditions (in all seasons) and continued a trend of increasing concentrations over time.

<u>Phytoplankton</u>. Distinctly different seasonal phytoplankton growth cycles are evident at the two Maritimes fixed stations (Fig. 10, 11). The strong spring bloom observed at Halifax-2 between 2003 and 2005 (~650-700 mg m^{-2}) was absent in 2006 and levels (~250 mg m^{-2}) were the lowest seen since 1999. Anomaly plots (Fig. 10) suggested that the 2006 spring bloom started somewhat later and ended somewhat earlier than the norm. A more detailed analysis of the timing of the bloom at this station revealed that the 2006 bloom continued a trend of later initiation, earlier termination and shorter duration

(29 days) than seen previously (Fig. 12a). In addition to changes in bloom dynamics, the “background” chlorophyll levels (outside the bloom period) have been declining over the past eight years, from ~40 mg m^{-2} in 1999 to ~30 mg m^{-2} in 2006 (Fig. 12b). The evolution of the phytoplankton community composition at Halifax-2 in 2006 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. 13). In 2006, total microplankton counts (~50,000 Ind L^{-1}) were the lowest seen since AZMP observations began in 1999 and consistent with the low chlorophyll levels at this station. The phytoplankton growth cycle at Prince-5 in 2006, in contrast to Halifax-2; was characterized by a burst of growth in late summer (August) with a peak concentration (~450 mg m^{-2}) higher than seen since the record high in 2000 (~780 mg m^{-2}). In previous years, multiple growth events were evident at this station, the dominant one occurring much earlier (June) than in 2006. This was clearly evident in the anomaly plot which shows the absence (-2 mg m^{-3} negative anomaly) of the normal June chlorophyll peak and appearance (+5 mg m^{-3} positive anomaly) of a two month later (August) peak. As has been noted previously, the phytoplankton community at Prince-5 are comprised almost exclusively of diatoms (>95%), year-round. On an annual basis, Prince-5 sustains the larger chlorophyll inventories of the two Maritimes fixed stations.

Zooplankton. Average zooplankton biomass over the year at both of the Maritimes fixed stations in 2006 was comparable to or somewhat higher than levels observed previously (Fig. 14). Biomass at Halifax-2 in 2006 was lower, however, than the long-term average late in the year (October-December). In contrast, zooplankton biomass at Prince-5 in 2006 was notably higher early in the year (January-April) than the long-term average. This was likely a carry-over from the high biomass levels observed late in 2005. Zooplankton biomass at Prince-5 is typically only a small fraction (10-20%) of the biomass observed at Halifax-2 and maximum levels are generally broader and occur much later in the year.

Calanus finmarchicus abundance at both of the fixed stations followed the same trends as seen in total zooplankton biomass in 2006 (Fig. 15). At Halifax-2, *C. finmarchicus* abundance was somewhat lower early in the year (March-May) and thus peak abundance occurred later than the long-term average (April-May). *Calanus finmarchicus* abundance at Prince-5 in 2006 (avg: ~14,000 Ind m^{-2}) was the highest seen since the record abundance of 2001 (~15,000 Ind m^{-2}). As was the case with zooplankton biomass, *C. finmarchicus* abundance at Prince-5 was significantly higher than the norm early in the year (January-April) and was likely a carry-over from the high levels seen late in 2005. Prince-5 continues to exhibit only a small fraction of the *C. finmarchicus* counts seen at Halifax-2.

Copepods continued to numerically dominate (~70-90%) the mesozooplankton year-round at both of the Maritimes fixed stations in 2006 (Fig. 16). The recurring pulse of echinoderm and barnacle larvae and euphausiids observed during the spring and summer at Prince-5 was observed again in 2006 as well as a pulse of bivalve larvae in late summer. The copepods were dominated (>50% much of the year) at both fixed stations by small species (*Oithona*, *Pseudocalanus*, *Paracalanus*, *Clausocalanus*, *Centropoges* and *Temora* sp.) in 2006 as in previous years although counts were lower than usual (Fig. 17). *Oithona sp.* abundance was the lowest on record at Prince-5 and *Pseudo/Paracalanus* sp. were lowest since 2002 at both fixed stations. The relative importance of the larger species (*Calanus sp., Metridia),* on the other hand, increased at both stations. At Prince-5, “other” copepod species (e.g. *Acartia sp*., harpacticoids) comprise a significant fraction (~40-60%) of the copepods in summer whereas they play a minor role (<10%) at Halifax-2. Overall, total copepod abundance at Halifax-2 was the lowest seen since the 2002 record low. An analysis of the biomass (as opposed to numerical abundance) distribution of the dominant copepods at Halifax-2 showed that the contribution of the smaller forms (*Pseudocalanus, Oithona sp*.) was the least (~1-2%) seen in 2006 since observations began in 1999. In addition, biomass of the cold-water calanoid, *C. glacialis,* was the lowest on record at this station in 2006. Stage distribution of *C. finmarchicus* in 2006 revealed that reproduction (indicated by presence of early developmental stages, I-III) was generally confined to the single spring/early summer peak at Halifax-2 and a bi-modal peak (summer months) at Prince-5 (Fig. 18). Reproduction at both stations appeared to be of shorter duration than seen previously. The production potential of *C. finmarchicus* at Halifax-2 in 2006 (as judged by abundance of the developmental stages) would be assessed as “poor” because of the low counts of CFIs-CFIIIs (Fig. 19), almost as low as the record low counts seen in 2002. The abundance of CFIV-VIs, however, was comparable to the long-term average.

Shelf Sections

Nutrients. Vertical distributions of nitrate in spring and fall were generally similar along the Scotian Shelf sections in 2006, 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. 20, 21). Deep-water 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 late 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 2006 were comparable to levels observed in previous years except during spring along the Cabot Strait line where levels were lower than usual (~50 mmol m^{-3} versus the long-term average of ~100 mmol m^{-3}) and during fall along the Louisbourg line where levels were higher than the norm, ~90 mmol m^{-3} versus the long-term average of ~60 mmol m^{-3} (Table 2). Generally speaking, spring and fall surface nutrient inventories along the Cabot Strait and Brown's Bank lines are almost twice those found along the Louisbourg and Halifax lines.

Phytoplankton. Chlorophyll levels along all the shelf sections are always considerably higher in spring than in fall. Despite this, chlorophyll levels during the spring 2006 survey were lower than normal (Fig. 22, Table 2), particularly along the Browns Bank and Halifax lines. Indeed, chlorophyll inventories on the Halifax and Louisbourg lines were the lowest on record, i.e. ~40-150 mg m^{-2} in 2006 versus the long-term average of ~200-400 mg m^{-2}. Furthermore, a clear trend of decreasing spring inventories over the last four years of observations was evident along the Brown's Bank and Louisbourg lines. Chlorophyll levels were also below normal along all lines during the fall 2006 survey (Fig. 23, Table 2). Fall chlorophyll inventories, as in spring, were lowest on record but in this case, along the Cabot Strait as well as Halifax and Louisbourg lines, i.e. ~10-30 mg m^{-2} in 2006 versus the long-term average of ~30-40 mg m^{-2}. A clear trend of decreasing fall chlorophyll inventories was evident along all lines for the eight years of AZMP observations.

Zooplankton. Zooplankton biomass and *C. finmarchicus* abundance are generally higher in spring than during fall along the shelf section surveys, except along the Cabot Strait line where the levels are higher in fall. In addition, biomass tends to increase west to east while *C. finmarchicus* abundance is the reverse. These same patterns of zooplankton distribution were generally seen in 2006 as well (Table 2). Biomass levels in spring and fall in 2006 were similar to levels seen in the past along all lines, i.e. ~30-60 g wet wt m^{-2} in spring versus ~20-80 g wet wt m^{-2} in fall. In contrast to zooplankton biomass, *C. finmarchicus* abundance was higher than usual in spring 2006 along the Brown's Bank line (~65,000 Ind m^{-2} versus the long-term average of ~45,000 Ind m^{-2}) while spring abundance was lower along the Halifax line (~25,000 Ind m^{-2} versus the long-term average of ~50,000 Ind m^{-2}). During the fall survey, abundance was the highest on record along the Halifax line (~15,000 Ind m^{-2} versus the long-term average of ~10,000 Ind m^{-2}), the 2nd year of record high counts.

Groundfish Surveys

Nutrients. Bottom water nitrate concentrations on the Scotian Shelf in July 2006 (Avg: 11.5 mmol m^{-3}) were similar to levels observed previously, 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. 24). Bottom water oxygen saturation on the Scotian Shelf in summer 2006 (Avg: 77% sat) was also similar to the long-term average (79% sat). The area of the bottom covered by waters with <60% saturation, however, was lower (14,000 km^2 or ~10% of the shelf area) than usual (16,600 km^2 or ~11% of the shelf area) but not statistically different. Lowest saturations were found in deep basins (e.g. Emerald Basin) and deep waters off the shelf edge where nutrients are highest.

Phytoplankton. Near-surface chlorophyll levels during the 2006 spring survey on the eastern Scotian Shelf showed a distributional pattern seen in previous years, i.e. concentrations were highest off-shelf (>8 mg m^{-3}) indicating that the spring bloom was well underway in that region but had not yet begun on the inner shelf (Fig. 25). 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 2006 (Avg: 0.69 mg m^{-3}) were similar to the long-term average of 0.68 mg m^{-3} (Table 3).

Zooplankton. Zooplankton biomass distribution observed during the major winter/spring and summer groundfish surveys can be characterized as highly variable in space and time (Fig. 26). Generally, however, biomass is highest in deep basins and deep waters off the edge of the shelf or in channels (e.g. Northeast Channel off Georges Bank). Additionally, during the summer survey, biomass has consistently been higher on the western Scotian Shelf than on the eastern shelf. This is in contrast to the west-east increase in biomass observed during the spring and fall section surveys (Table 2), the differences likely being season-related. In 2006, survey average zooplankton biomass in February on Georges Bank (~10 g wet wt m^{-2}) was lower than the long-term average biomass (~20 g wet wt m^{-2}). Zooplankton biomass during the eastern Scotian Shelf March survey was the lowest on record (~10 g wet wt m^{-2} compared with the long term average of ~50 g wet wt m^{-2}). Similarly, zooplankton biomass was below normal levels during the July Scotian Shelf survey, i.e. ~30 g wet wt m^{-2} in 2006 compared with the long term average of ~35 g wet wt m^{-2}. For all three surveys there appears to be a trend of decreasing zooplankton biomass with time and this is particularly evident from the year-by-year decrease (>3 g wet wt m^{-2} y^{-1}) on the July survey (Fig. 26). Zooplankton species data for most of the groundfish surveys have been processed but not yet interpreted, however, *C. finmarchicus* abundance for the July survey have been done and in contrast to zooplankton biomass, counts were at record levels in 2006 (>40,000 Ind m^{-2}).

Remote-sensing of 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 Maritime Region covering the major periods of the shelf section surveys and groundfish surveys (Figs. 27, 28) 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 observed during the March Eastern Scotian Shelf groundfish survey (Fig. 25) was confirmed by MODIS data and the latter indicated the spatial extent of that offshore bloom. In a similar way, the MODIS composites indicated that the major spring bloom event was already in decline when the April/May shelf section survey was done. As well, the composites showed the overall low surface chlorophyll levels, shelf-wide, observed during the July groundfish survey and surface chlorophyll levels during October shelf section survey where highest levels were seen on the eastern shelf.

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 the Cabot Strait line were particularly high in 2006 (Fig. 29). 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, the earlier appearance of the spring bloom off the edge of the central Scotian Shelf (Halifax line) compared to the bloom on the inner shelf is clearly evident. 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 magnitude of the spring bloom in 2006 compared with previous years (Fig 30). The timing of peak spring chlorophyll, for example, was YD (year-day) 94-98 on the eastern shelf and somewhat earlier (YD 82-91) on the central and western shelf. Peak chlorophyll at the Halifax-2 fixed station was at YD 95. Contrary to the Halifax-2 results, the satellite data did not indicate that the magnitude of the spring bloom in 2006 was notably lower than seen in previous years, with the exception of Georges Bank where no spring bloom was evident above the high background chlorophyll concentrations.

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 2005 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 and continuing into the 2000s, than levels observed in the 1960s/1970s (Fig. 31). 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. On the shorter time scale, the phytoplankton colour index on the Scotian Shelf has been declining over the past few years although levels are still above the long-term average. Diatoms remained unchanged in 2005 and dinoflagellates showed a dramatic increase from low levels in 2003 and 2004, returning to levels above the long-term average. Further east in the Northwest Atlantic, phytoplankton colour index continued a 4 year decline in 2005 while diatoms increased, reversing a similar decline. Dinoflagellates were relatively unchanged. All phytoplankton indices in the Northwest Atlantic remained at or above the long-term average in 2005. The somewhat inconsistent patterns seen between the color index and diatom/dinoflagellate counts could be accounted for by the fact that the color index may also include phytoplankton species smaller than are routinely counted, i.e. the CPR retains particles smaller than the nominal 260 μm mesh of the silk gauze (C. Reid, pers. comm.). In 2005, the magnitude and seasonal cycle of phytoplankton abundance aligned more closely with the pattern observed in the 1990s/2000s than in the 1960s/1970s (Fig.32). 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.

While phytoplankton were high on the Scotian Shelf and the Northwest Atlantic in the 1990s/2000s compared with the 1960s/1970s, zooplankton were generally the reverse (i.e. lower in more recent years), particularly during the early to mid-1990s (Fig. 33). During the last several years, zooplankton numbers have been recovering from the mid-1990s lows on the Scotian Shelf, however, counts for some species in the Northwest Atlantic are still down. Of particular note is the dramatic increase in the younger development stages (CF1-4) of *C. finmarchicus* and *Paracalanus/Pseudocalanus sp.* on the Scotian Shelf; levels are now at or above the long-term average. Euphausiid numbers in 2005 also increased and are approaching long-term average levels. In the Northwest Atlantic, in contrast, *C. finmarchicus* and Euphausiid numbers continued to decline in 2005 and were well below the long-term average. *Paracalanus/Pseudocalanus sp* numbers, on the other hand, continued to increase in 2005 and are now well above the long-term average. The seasonal abundance cycles for zooplankton species in 2005 could not as easily be aligned with the patterns of the 1960s/1970s or 1990s, as was the case for phytoplankton, because of the smaller difference in zooplankton abundance between decades and higher seasonal variability (Fig. 34).

DISCUSSION

Sufficient data now exists from AZMP (8-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. The most notable features in these physical properties that deviated from the norm were the stronger stratification at both Halifax-2 and Prince-5 during the latter half of the year but these differences were not substantial.

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 2006 to previous years although there were some differences. Winter maximum and summer minimum nitrate inventories in near surface waters were lower in 2006 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 and deep nitrate inventories at Prince-5, on the other hand, were higher than usual in 2006 and have been increasing since observations began in 1999.

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. However, the trend of decreasing wintertime maximum nitrate levels over the past several years at Halifax-2 cannot easily be explained by physical processes since the indices we monitor (mixed-layer depth and stratification) have been fairly stable and do not indicate any obvious weakening in mixing over time. On the other hand, 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.). Deeper source water (>50 m) inventories have not decreased perceptibly over the past few years.

In addition to the lower winter nitrate inventories in 2006, summertime nitrate depletion depths at Halifax-2 were among the 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 the deep layers of nitrate depletion. Because the chlorophyll concentrations were not unusually high in summer 2006 at Halifax-2 (background levels have, in fact, been decreasing 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 recently, however, these deviations of these properties from the norm have been small and are likely too late in the year to strongly modify the nutrient cycles that influence the biological cycles, but perhaps not. Trends in nutrient inventories are in the opposite direction at the Prince-5 station where levels have been increasing steadily since observations began in 1999. Mixing processes have not been changing in concert with nutrients nor have phytoplankton levels (i.e. nutrient demand) been decreasing. Nutrient changes at this station, therefore, must be driven by some larger scale advection of waters into the area with higher nutrient content. The nature of that mechanism is merely speculation at this point. On a broader geographic scale, observations from the shelf section surveys and from the groundfish surveys over the past several years do not indicate that near surface or deep nutrient inventories are in a general decline on the Scotian Shelf.

Phytoplankton. Despite the fact that phytoplankton variability (both temporal and spatial) is characteristically high in coastal waters, the development of pronounced spring/summer (and less conspicuous fall) phytoplankton blooms are evident from observations at the Maritimes fixed stations, seasonal sections, groundfish 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 also observed yearly. There were, however, some features of the phytoplankton growth cycle in the Maritimes region distinctive for 2006, the most prominent of which was the dramatic decrease in the magnitude (and duration) of the spring bloom at Halifax-2 compared with blooms of the previous three years. Over the observation period of AZMP, the bloom at this station appears to be progressively starting later and ending earlier in the spring. The weaker 2006 bloom was also evident during the spring shelf section survey although there is evidence from satellite (MODIS) data that the spring shelf survey might have missed the peak of the bloom in 2006.

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 Haliax-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. 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 grazing. The delay in the development of the bloom at Prince-5 and observation of a single summer peak in 2006 would suggest some changes in spring mixing conditions occurred, however, no obvious differences from conditions seen previously were observed in 2006. At Halifax-2, bloom initiation was not at issue but magnitude and duration were in which case one should be looking for changes in nutrient inventories (principally in the winter preceding) to explain the weak and short-lived 2006 spring bloom. Winter maximum nitrate inventories at Halifax-2 were lower than observed previously and continued a 4-year decline. The lower winter nutrient reserves could help explain the weak 2006 bloom but did not explain the record high bloom conditions for the three previous years. Perhaps the declining winter nutrients contributed to the progressively shorter bloom duration seen at this station over the AZMP observation period even if the bloom magnitude was not affected. 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).

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. However, the abundance of young developmental stages (CFI-CF III) was at or near record low levels in 2006 so it is unlikely grazing contributed significantly to bloom decline. Interestingly, the duration of *C. finmarchicus* reproduction was short compared to previous years; it is tempting to relate that observation to the short spring bloom duration in 2006. 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 deepening 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 a broader geographic scale, differences seen in chlorophyll concentrations on the Scotian Shelf during in the spring section surveys can be attributed to regional differences in the timing of the bloom. The record low levels of chlorophyll seen along a number of the shelf sections in 2006 were likely due to the fact that the spring mission missed the major peak of the bloom which occurred earlier in April according to satellite imagery. This illustrates the issue of temporal aliasing and the problems posed in looking at long-term (interannual) trends using data with limited temporal coverage. Near-surface chlorophyll concentrations observed during the winter-summer groundfish surveys were, on average, at levels seen in the past.

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 ~12% year^{-1} while at the same time decreasing ~6%year^{-1} in fall over the period of AZMP observations. Observations in 2006 suggest that the spring chlorophyll levels have deviated from that trend but fall levels continue to decline as Li et al suggested. On the decadal scale, it appears from CPR data that the spring phytoplankton bloom on the Scotian Shelf for the last decade has been much larger and started earlier in the year than blooms during the first decade of the CPR measurements beginning some 30 years ago.

Recurrent patterns in the seasonal succession of phytoplankton communities at the Maritimes 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 2006 although total microplankton counts were down at Halifax-2, consistent with the notably low chlorophyll levels.

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

Some features of the zooplankton community were notable in 2006, however. Zooplankton biomass continued to decline on all groundfish surveys (winter-summer) in 2006; during the March eastern Scotian Shelf groundfish survey, the lowest zooplankton biomass levels were seen since sampling began in 1999. On the other hand, record high *C. finmarchicus* abundance was seen shelf-wide during the July groundfish survey. *C. finmarchicus* abundance was also above normal levels on the western shelf in spring and central shelf in fall. At the Prince-5 fixed station *C. finmarchicus* abundance was higher than the norm as well and this likely resulted from carry-over of individuals from the unusually high numbers that appeared during the latter half of the previous year. *Calanus finmarchicus* abundance at Halifax-2, on the other hand, was lower than seen since the record low counts of 2002. The younger developmental stages (CFI-CFIII) were particularly low and the period of reproduction was shorter in 2006 than seen previously. Perhaps the latter could be explained by the weak and short-lived spring bloom at Halifax-2, however, the shelf-wide decline in zooplankton biomass while at the same time *C. finmarchicus* abundance increased in many locations is more difficult to explain by phytoplankton conditions. There is some evidence from Halifax-2, as well, that the smaller copepod species such as *Pseudocalanus sp.* and *Oithona sp.* may be decreasing relative to the larger species (e.g. *C. finmarchicus, Metridia sp*.). More generally, the causes for these large geographic differences and temporal variations in zooplankton biomass/abundance are unclear at this point.

At the larger scale and over the long-term, the CPR data record shows that contemporary zooplankton abundance, in general, has been considerably lower over the past decade than it was during the decade following the initiation of the CPR surveys in the 1960s. However, over the past few years, abundances have been on the increase for many species (*C. finmarchicus*, *Paracalanus/Pseudocalanus sp.,* euphausiids) on the Scotian Shelf and are at or above historical levels. Further east in the Northwest Atlantic, many of these same species continue to decline. The explanation for these temporal swings in abundance and regional differences in the recent decade in the presence of a relatively abundant food supply (CPR phytoplankton abundances well above levels observed in the 1960s/1970s) is still a major unknown. CPR observations, in some cases, appear at odds with AZMP data, however, we continue to explore new analytical approaches that we hope will reconcile these differences.

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Table 1. AZMP Sampling missions in the Maritimes/Gulf regions, 2006.

Group	Location	Mission ID	Dates	# Hydro Stns	# Net Stns
Trawl Surveys	Georges Bank	TEL2006614	Feb 18 – Mar 03	30	7
	Eastern Shelf	TEL2006615	March 05 - 15	84	14
	Eastern Shelf	NED2006002	March 06 – 08	11	-
	Scotian Shelf	NED2006030	Jul 05 – 18	110	22
	Scotian Shelf	NED2006036	Jul 20 – Aug 03	107	19
	SGSL	TEL2006678	Sep 04 – 28	200	17
Seasonal Sections	Scotian Shelf	HUD2006008	Apr 20 – May 7	60	47
	Scotian Shelf	HUD2006019	June 06 - 08	10	8
	Scotian Shelf	HUD2006052	Oct 05 – 20	53	34
Fixed Stations	Shediac	BCD2006668	Apr 28 – Dec 06	8	8
	Halifax-2	BCD2006666	Jan 25 – Dec 13	8	7
	Prince-5	BCD2006669	Jan 13 – Dec 14	12	12
			Total:	**693**	**195**

Table 2. Chemical and biological properties of the 1999-2006 spring and fall Scotian Shelf sections. Statistics: section means (average of all stations).

	Year	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})	
		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	84	260	11	55	87	9.8	30
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	79	151	28	42	16	29	8.4
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	60	39	6.7	50	30	27	15
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	98	44	51	34	26	65	12

Table 3. Chemical and biological properties of the 1999-2006 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

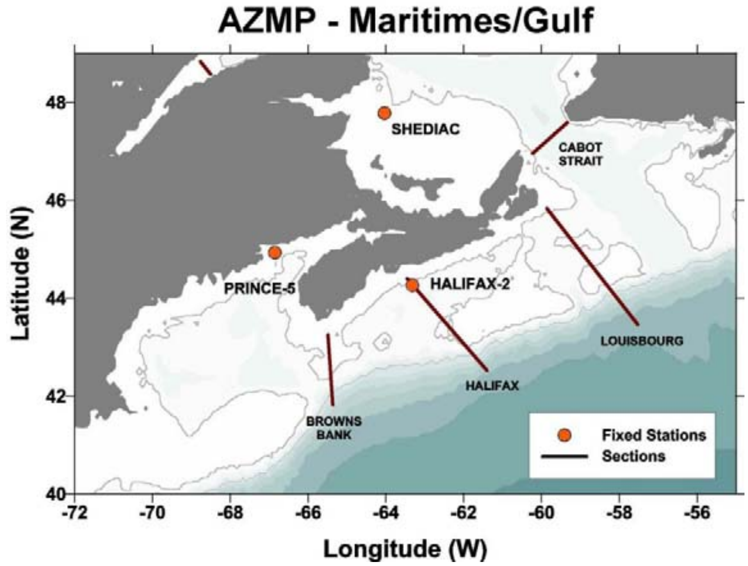

Figure 1. Primary sections and fixed stations sampled in the Maritimes/Gulf regions.

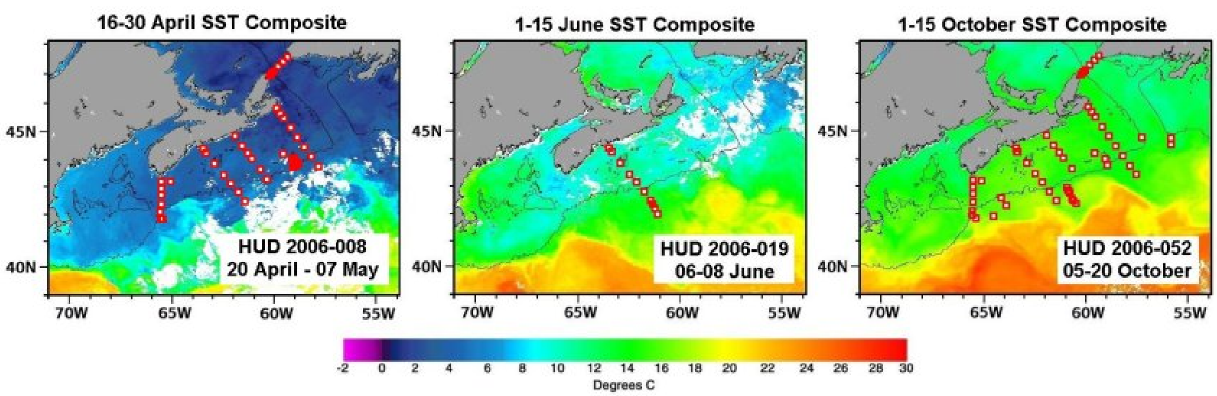

Figure 2. Stations sampled during the 2006 spring, summer and fall section surveys. Station locations superimposed on bi-weekly SST composite images.

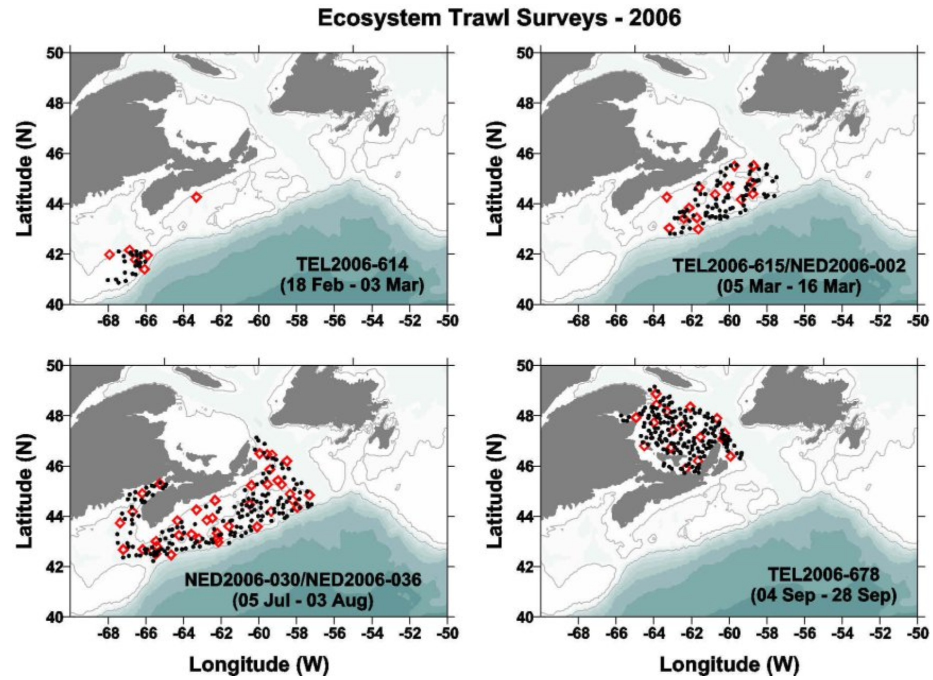

Figure 3. Stations sampled during major Maritimes/Gulf ecosystem trawl (groundfish) surveys in 2006. Black symbols are hydrographic stations; red symbols are stations where vertical nets hauls were taken in addition to hydrographic measurements.

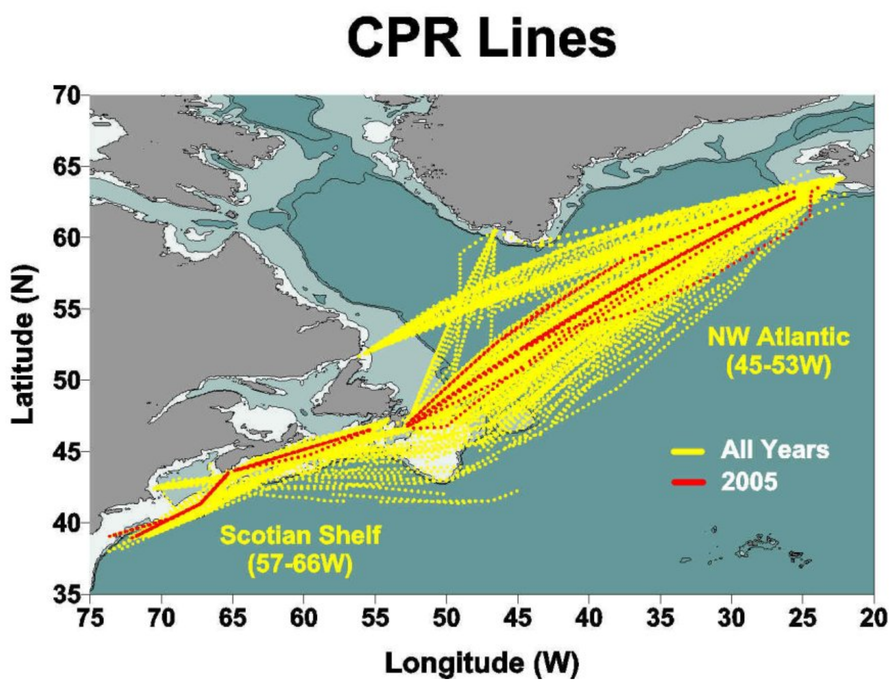

Figure 4. CPR lines and stations, 1961 to 2005 (2005 highlighted).

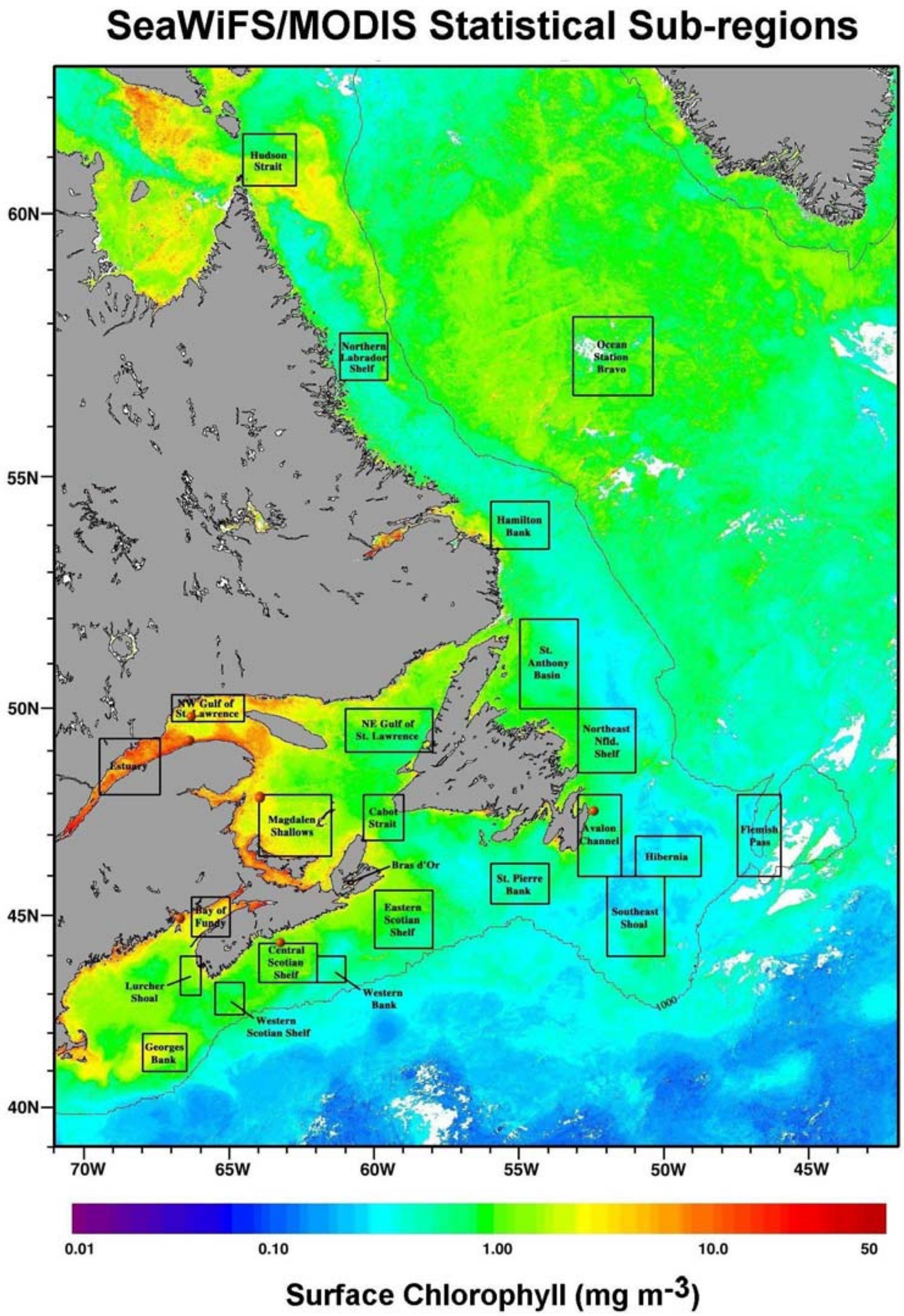

Figure 5. Statistical sub-regions in the Northwest Atlantic identified for spatial/temporal analysis of SeaWiFS/MODIS ocean colour data.

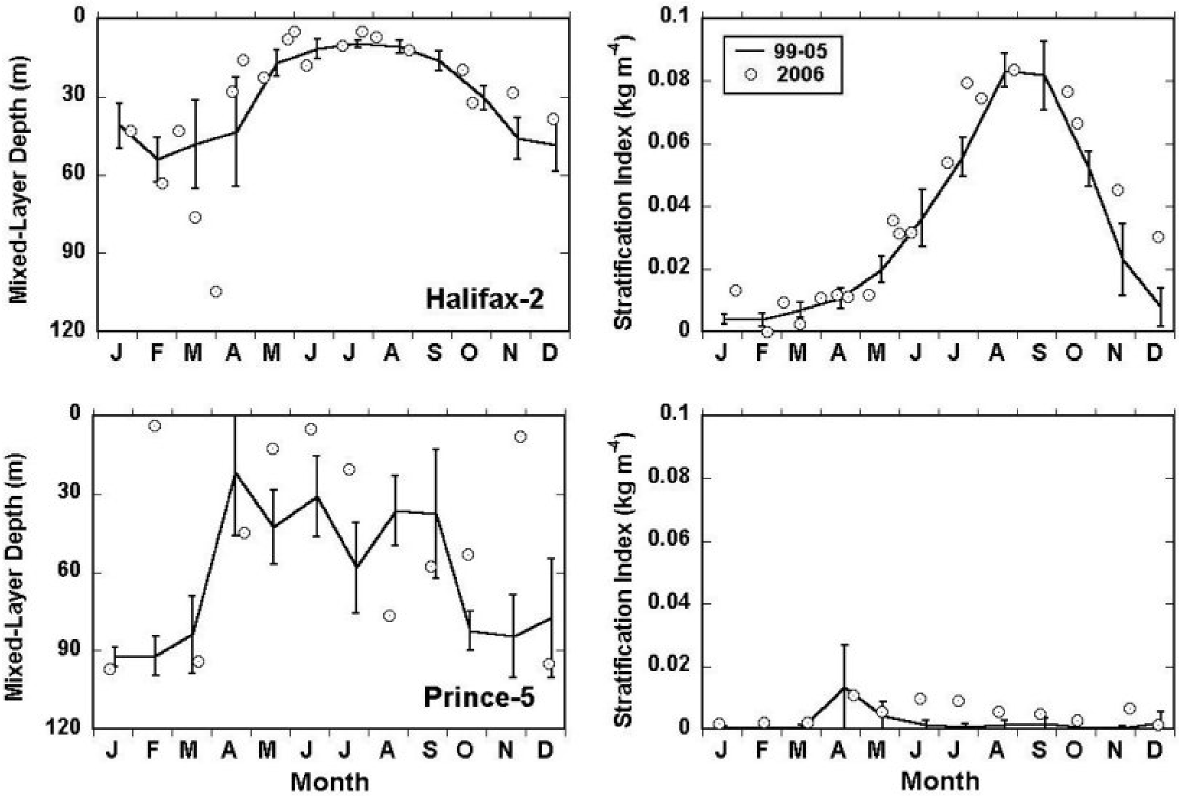

Figure 6. Mixing properties (mixed-layer depth, stratification index) at the Maritimes fixed stations. 2006 data (circles) compared with observations from 1999-2005 (solid line). Vertical lines are 95% confidence limits.

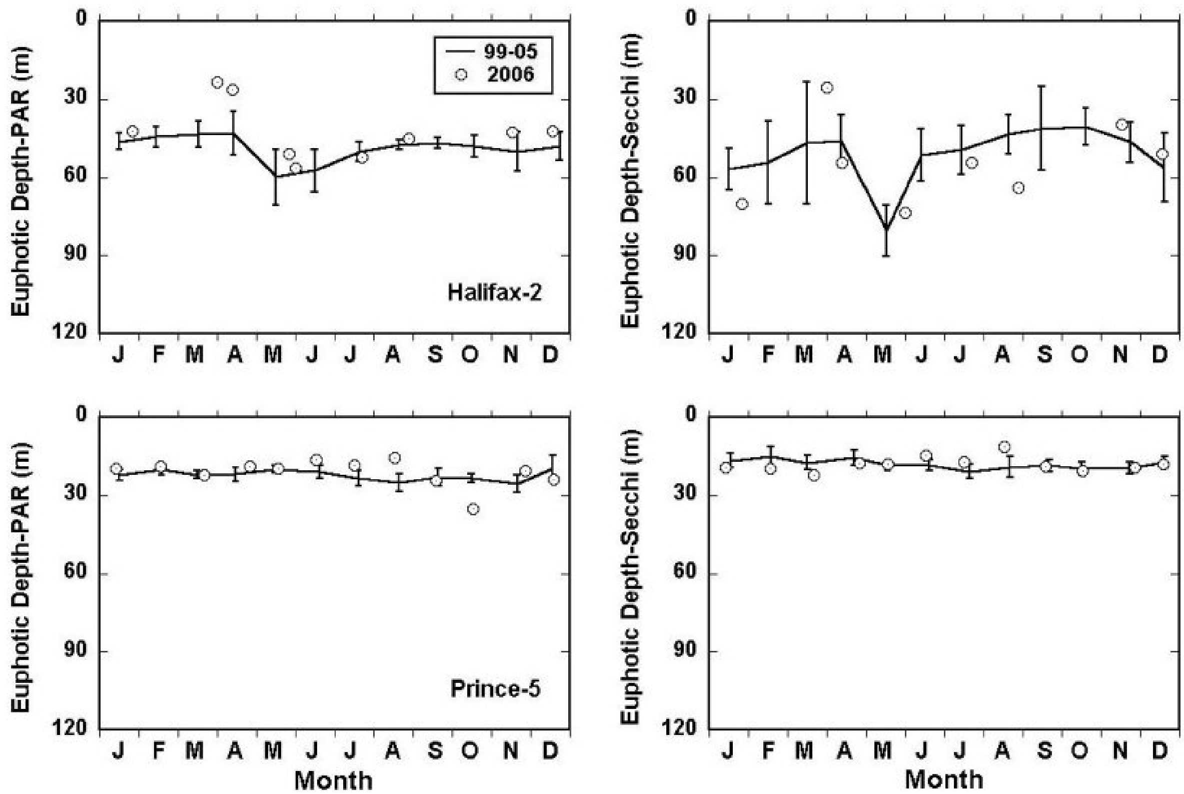

Figure 7. Optical properties (euphotic depth from PAR irradiance meter and Secchi disc) at the Maritimes fixed stations. 2006 data (circles) compared with observations from 1999-2005 (solid line). Vertical lines are 95% confidence limits.

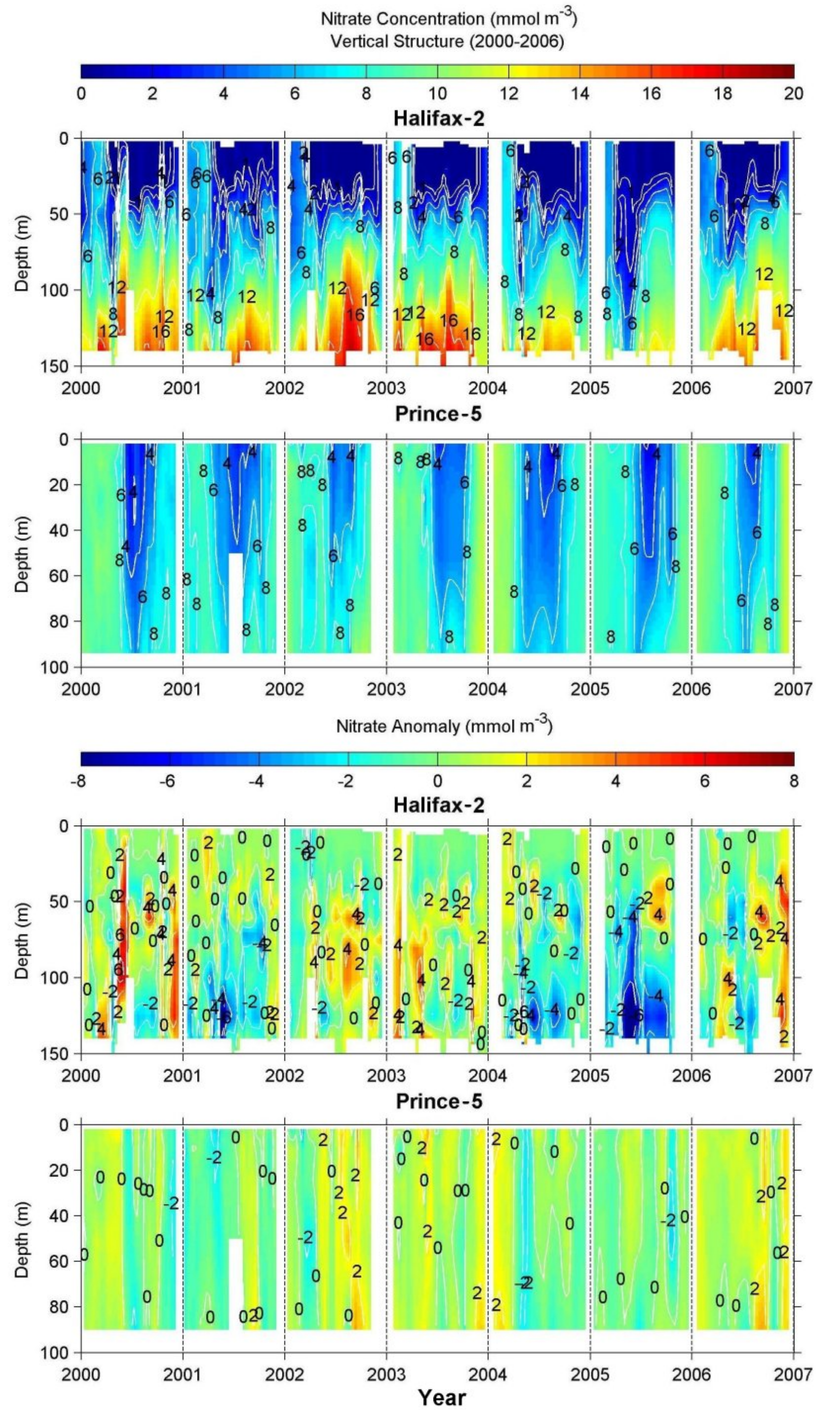

Figure 8. Time-series of vertical nitrate structure at the Maritimes fixed stations, 2000-2006. Bottom panels: nitrate anomaly (2006 values minus long-term average).

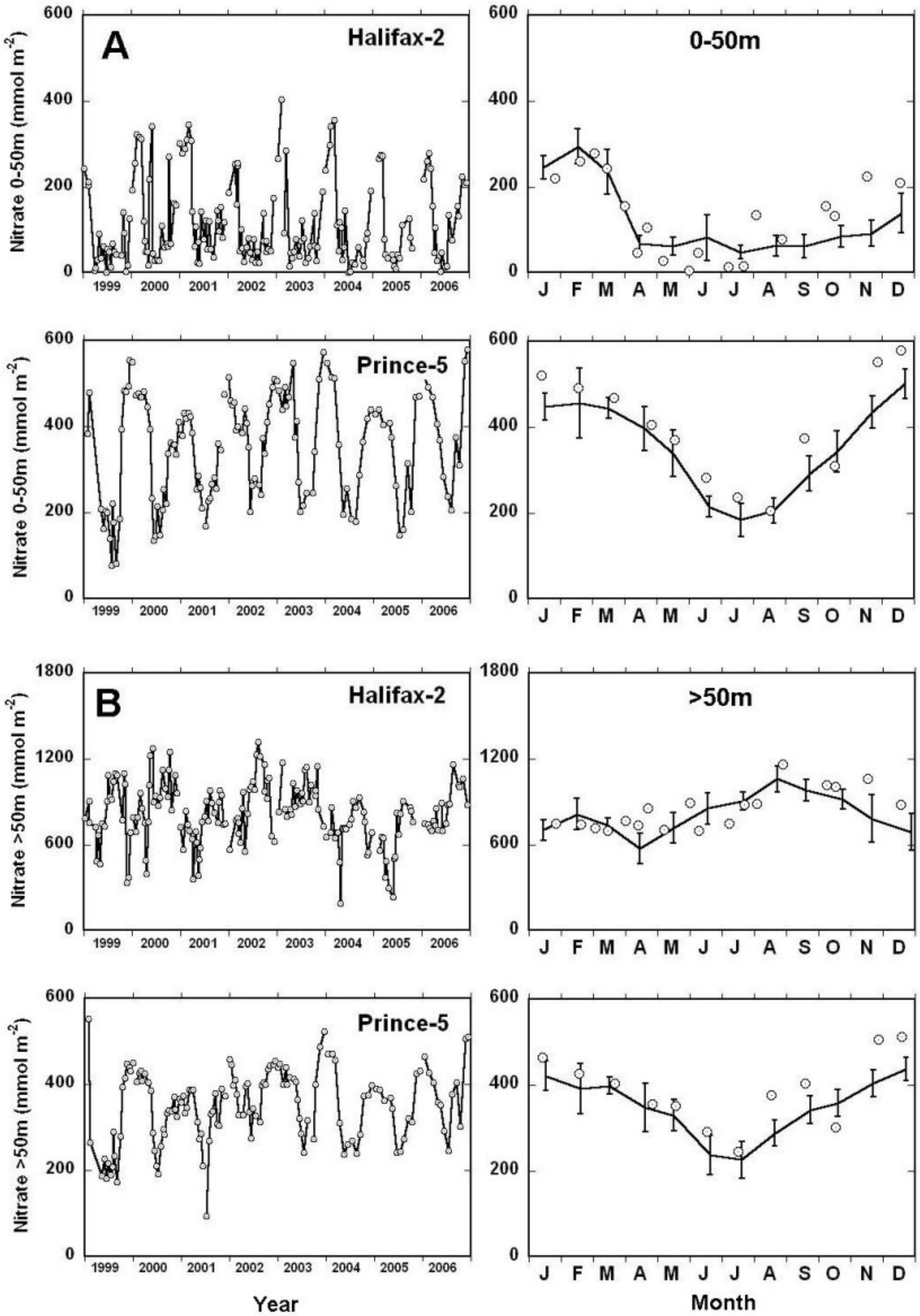

Figure 9. Nitrate inventories at the Maritimes fixed stations, 1999-2006. (A) surface (0-50 m) integrals, (B)deep (>50 m) integrals. Right panels: 2006 data (circles) compared with observations from 1999-2005 (solid line). Vertical lines are 95% confidence limits.

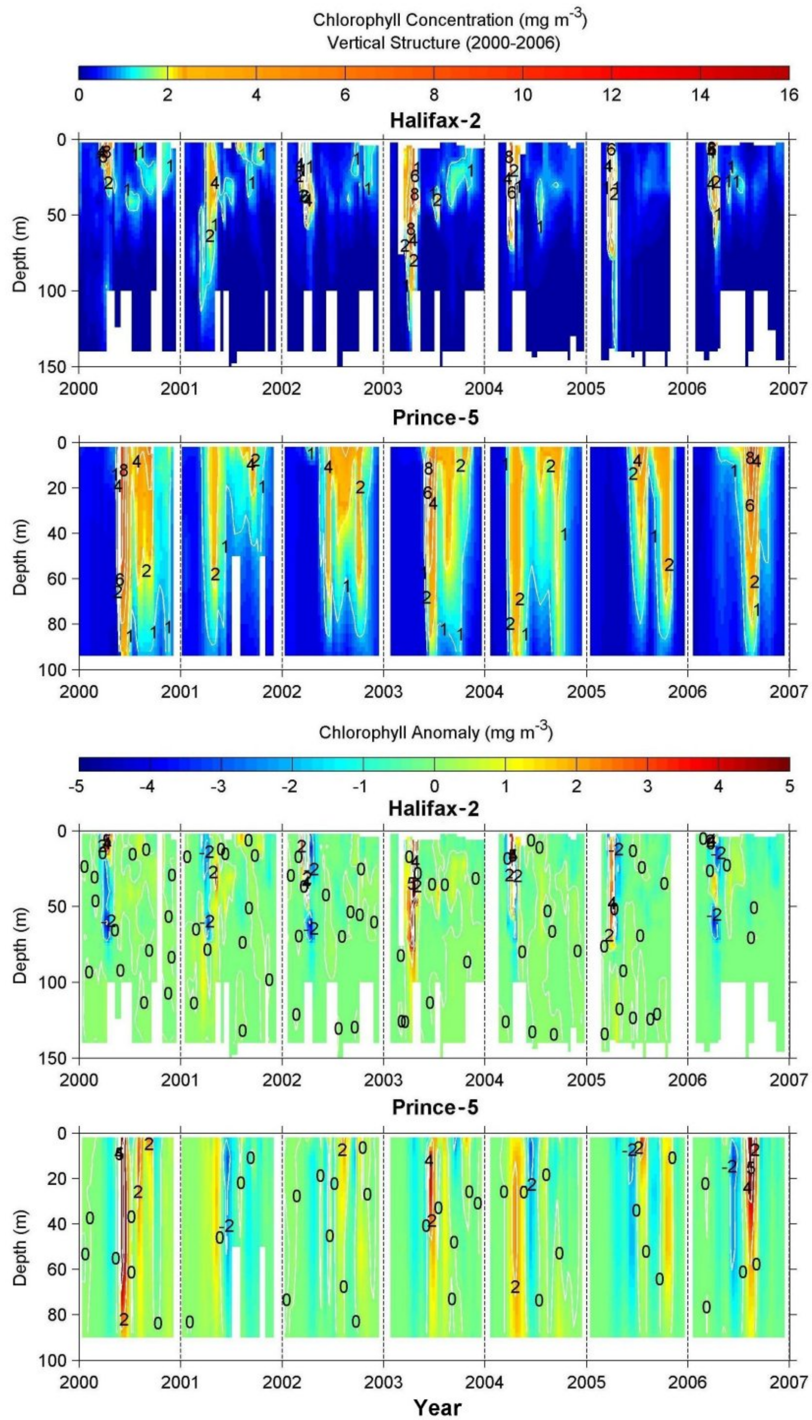

Figure 10. Time-series of vertical chlorophyll structure at the Maritimes fixed stations, 2000-2006. Bottom panels: chlorophyll anomaly (2006 values minus long-term average).

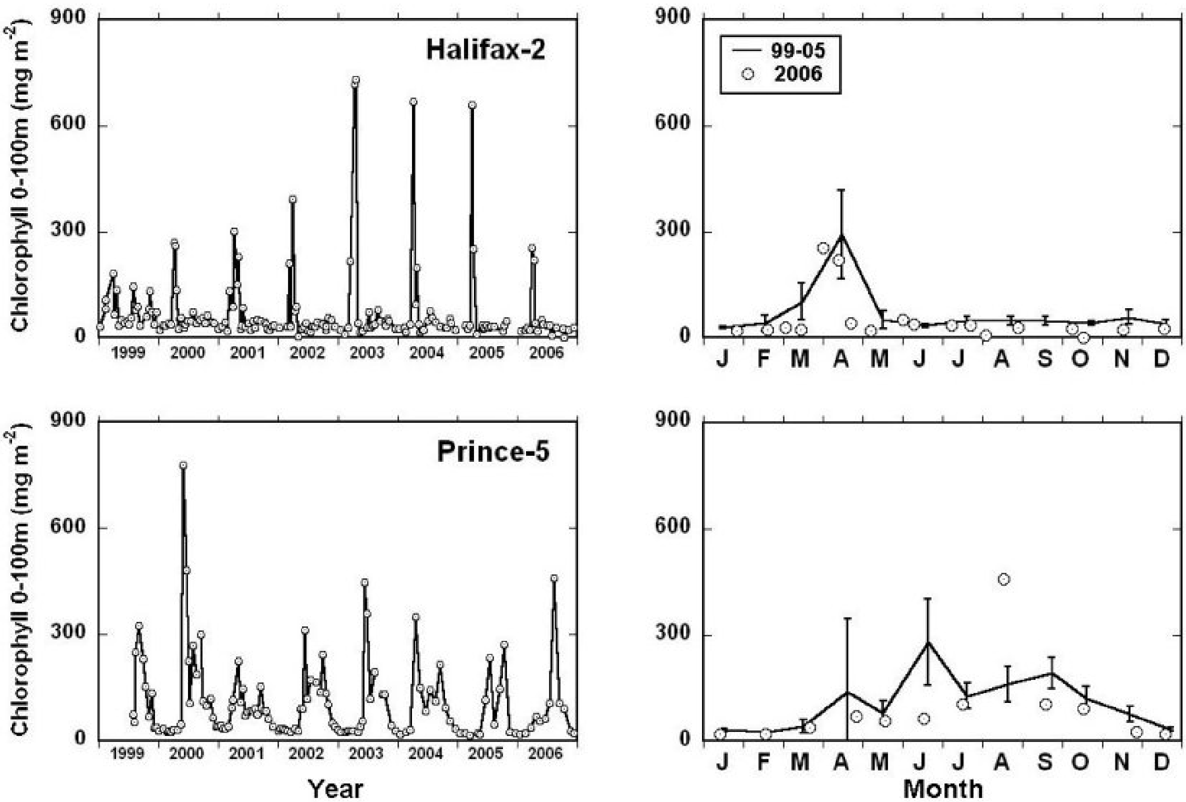

Figure 11. Chlorophyll inventories (surface-100 m integrals) at the Maritimes fixed stations, 1999-2006. Right panels: 2006 data (circles) compared with observations from 1999-2005 (solid line). Vertical lines are 95% confidence limits.

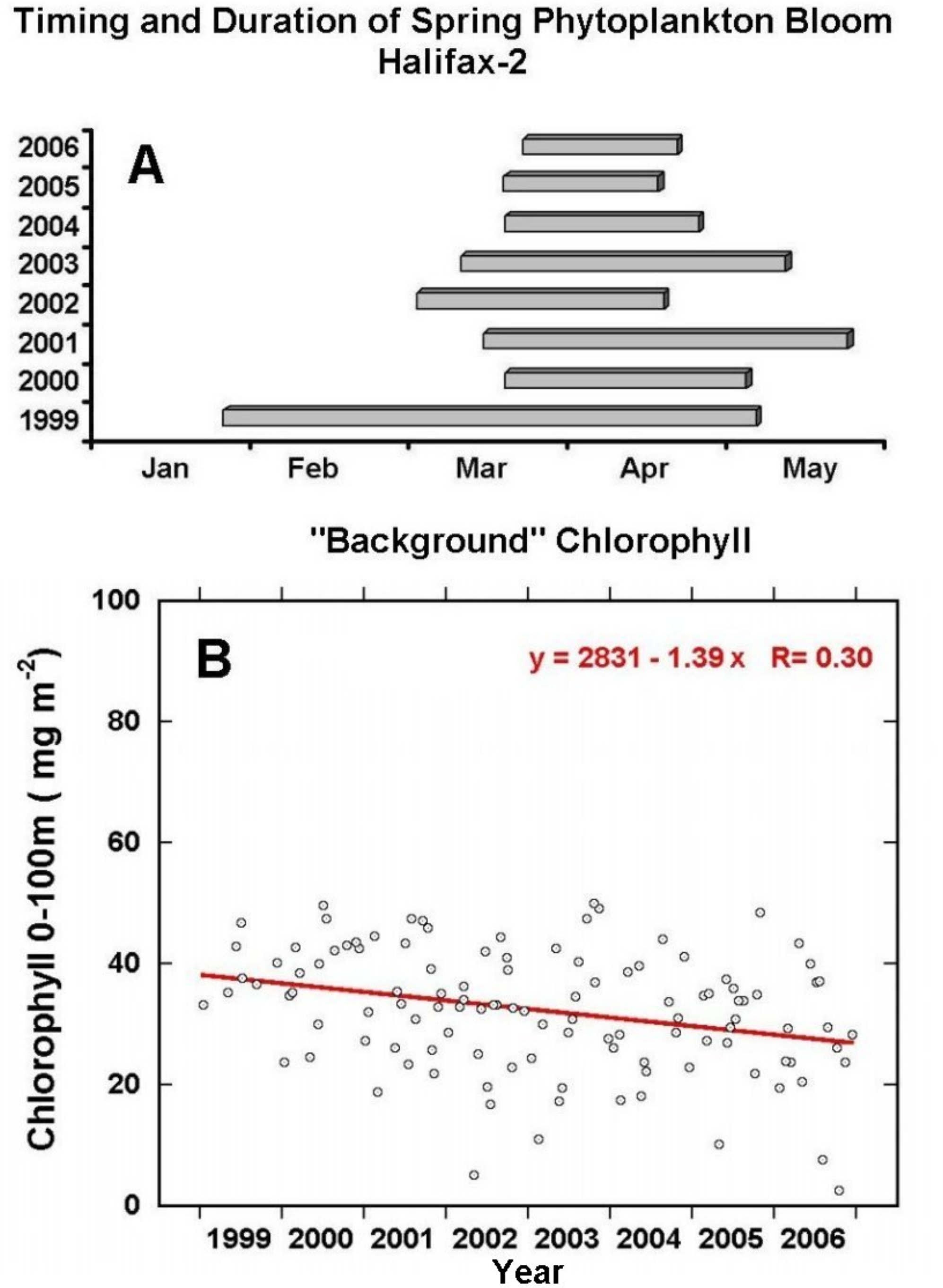

Figure 12. Dynamics of the spring phytoplankton bloom, Halifax-2 fixed station 1999-2006: (A) timing and duration based on 50 mg CHL m^{-2} threshold for determining start and end of the bloom (B) baseline chlorophyll levels, outside of spring bloom periods (line = least squares linear regression).

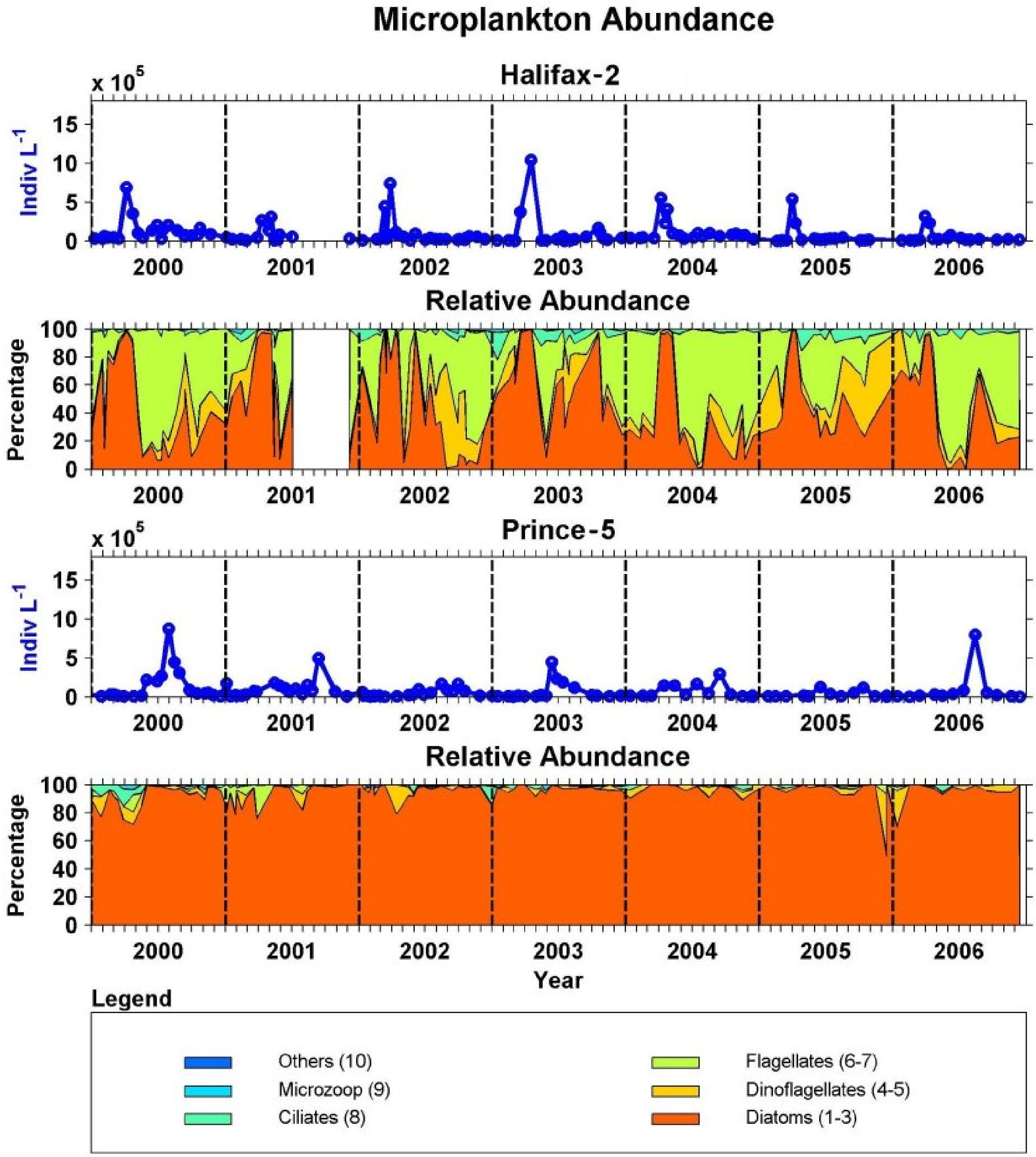

Figure 13. Time-series of microplankton (phytoplankton and protists) abundance and community composition at the Maritimes fixed stations, 2000-2006.

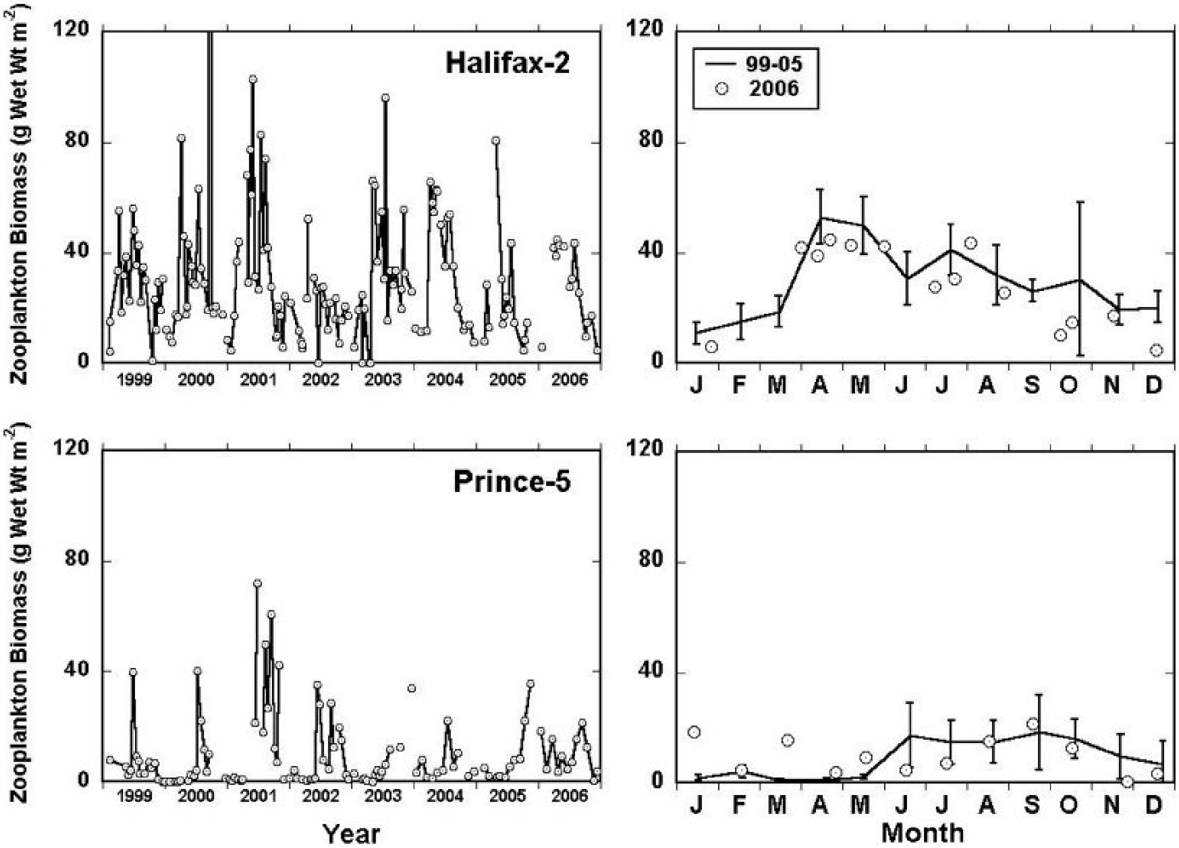

Figure 14. Time-series of zooplankton biomass (surface-bottom) at the Maritimes fixed stations, 1999-2006. Right panels: 2006 data (circles) compared with observations from 1999-2005 (solid line). Vertical lines are 95% confidence limits.

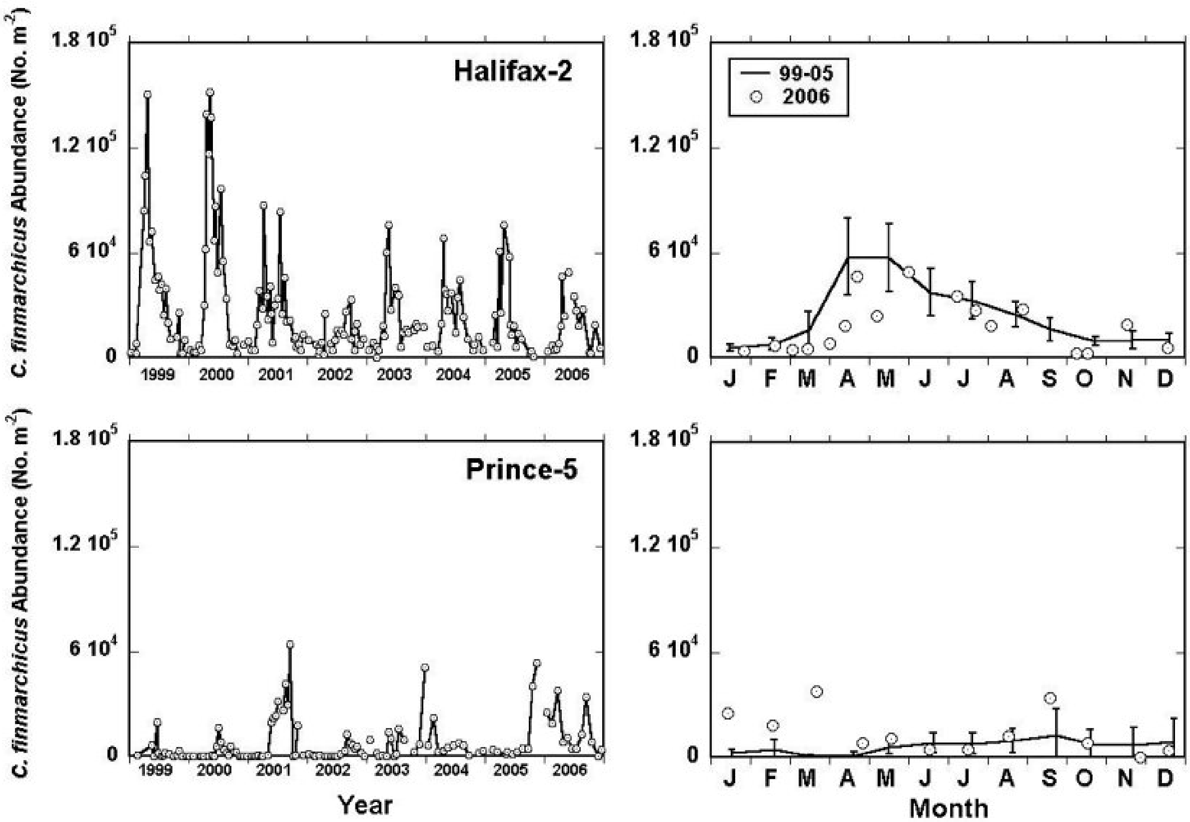

Figure 15. Time-series of *C. finmarchicus* abundance (surface-bottom) at the Maritimes fixed stations, 1999-2006. Right panels: 2006 data (circles) compared with observations from 1999-2005 (solid line). Vertical lines are 95% confidence limits.

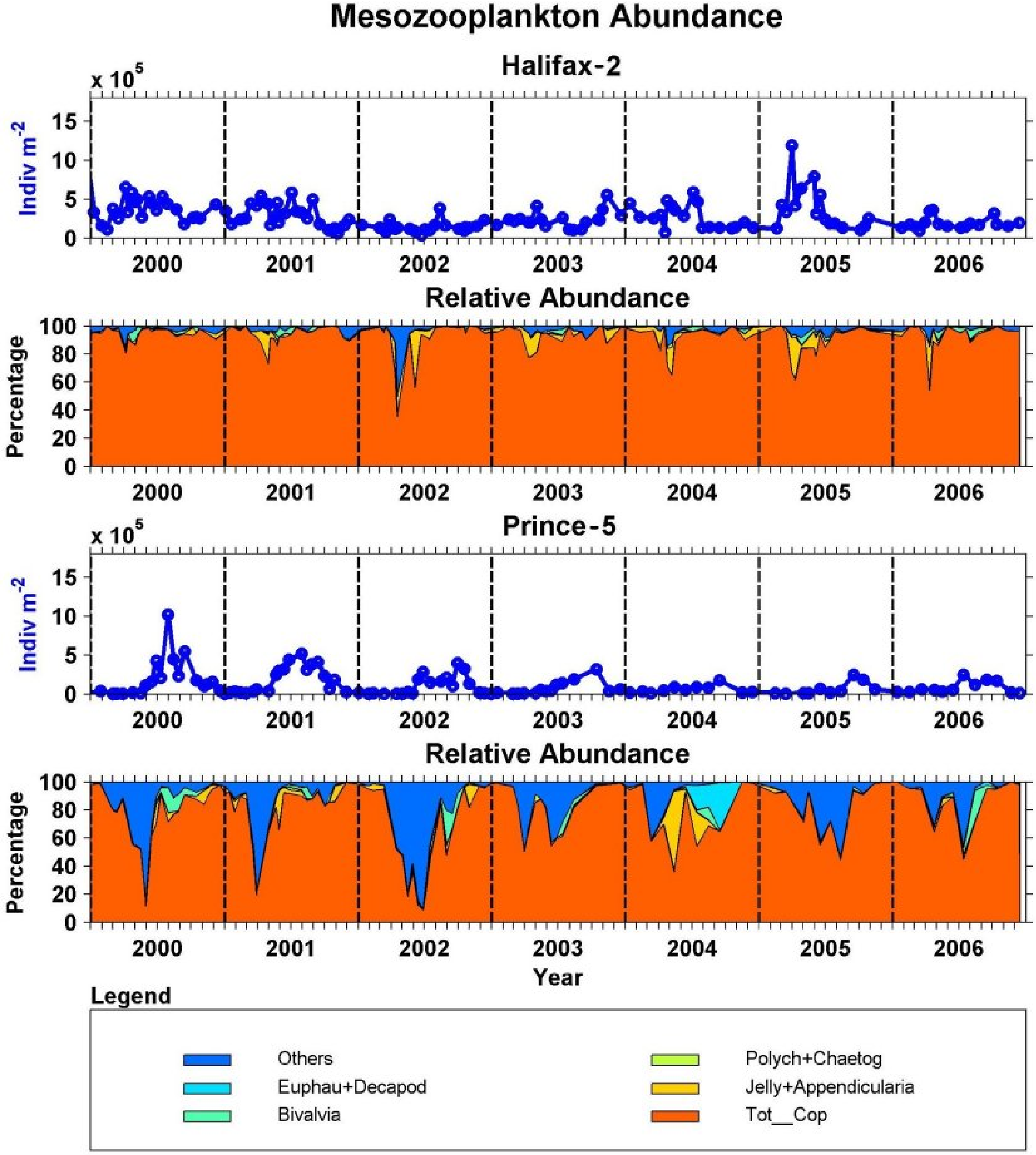

Figure 16. Time-series of mesozooplankton abundance and community composition at the Maritimes fixed stations, 2000-2006.

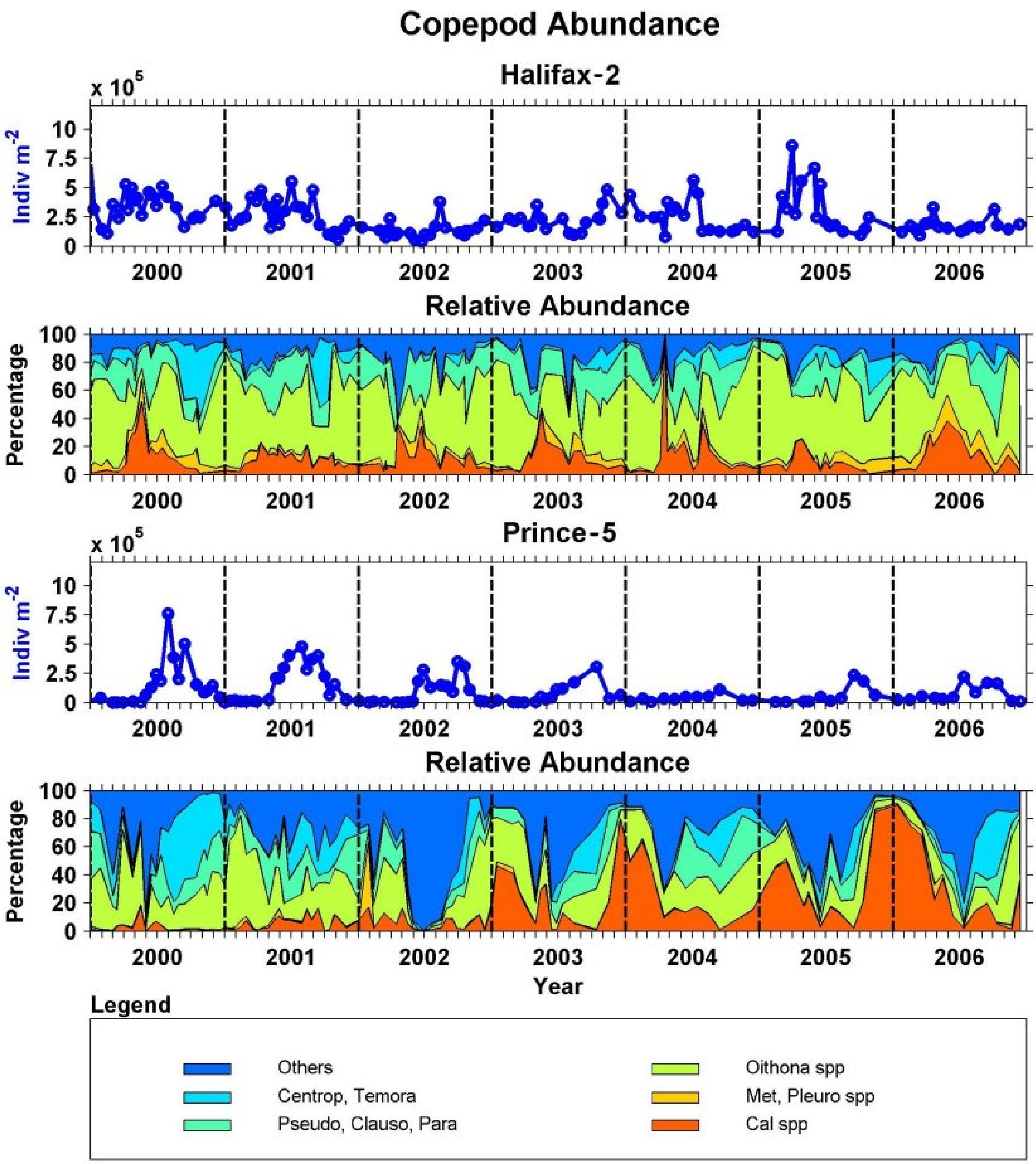

Figure 17. Time-series of copepod abundance and community composition at the Maritimes fixed stations, 2000-2006.

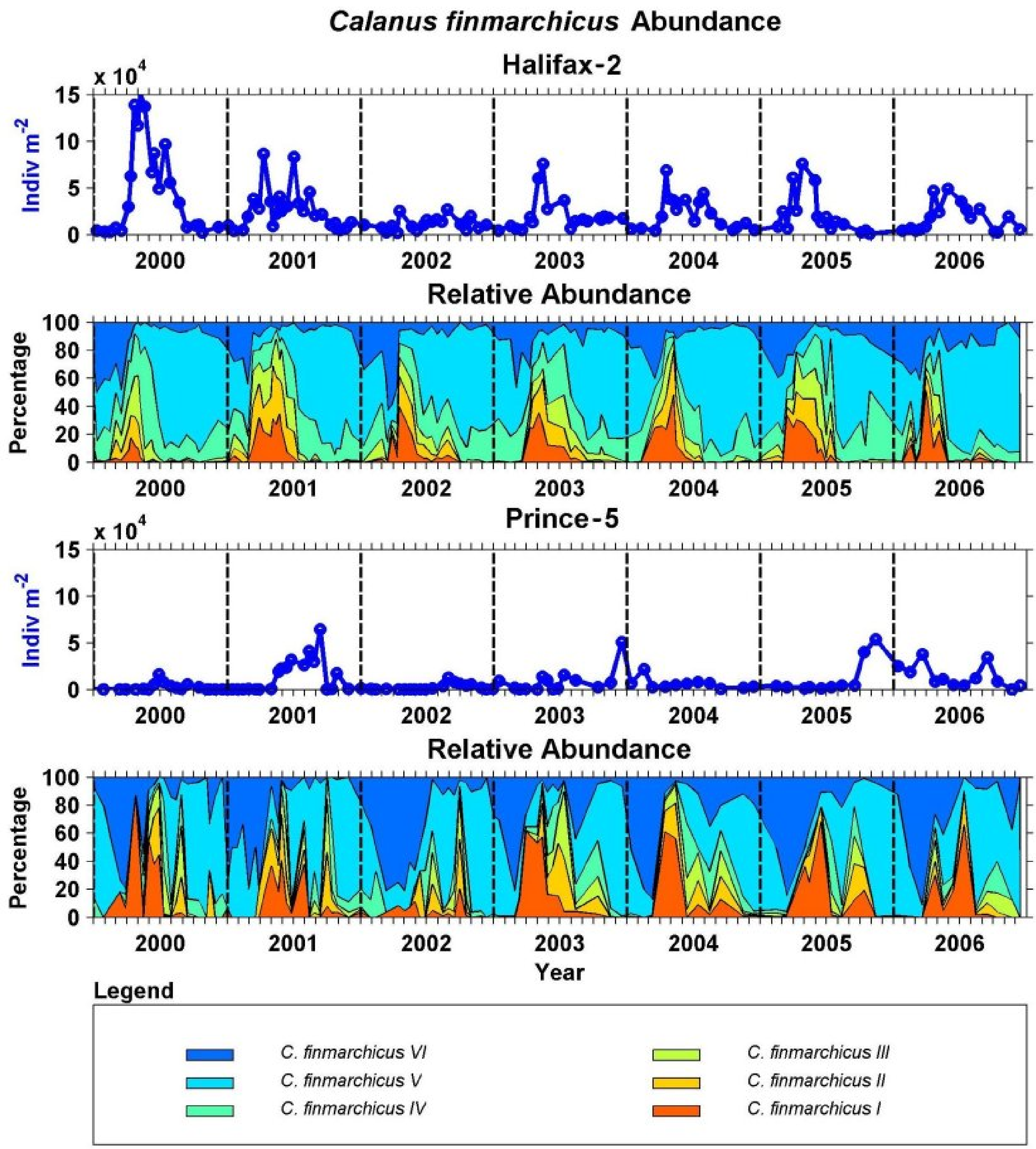

Figure 18. Time-series of *C. finmarchicus* abundance and developmental stages at the Maritimes fixed stations, 2000-2006.

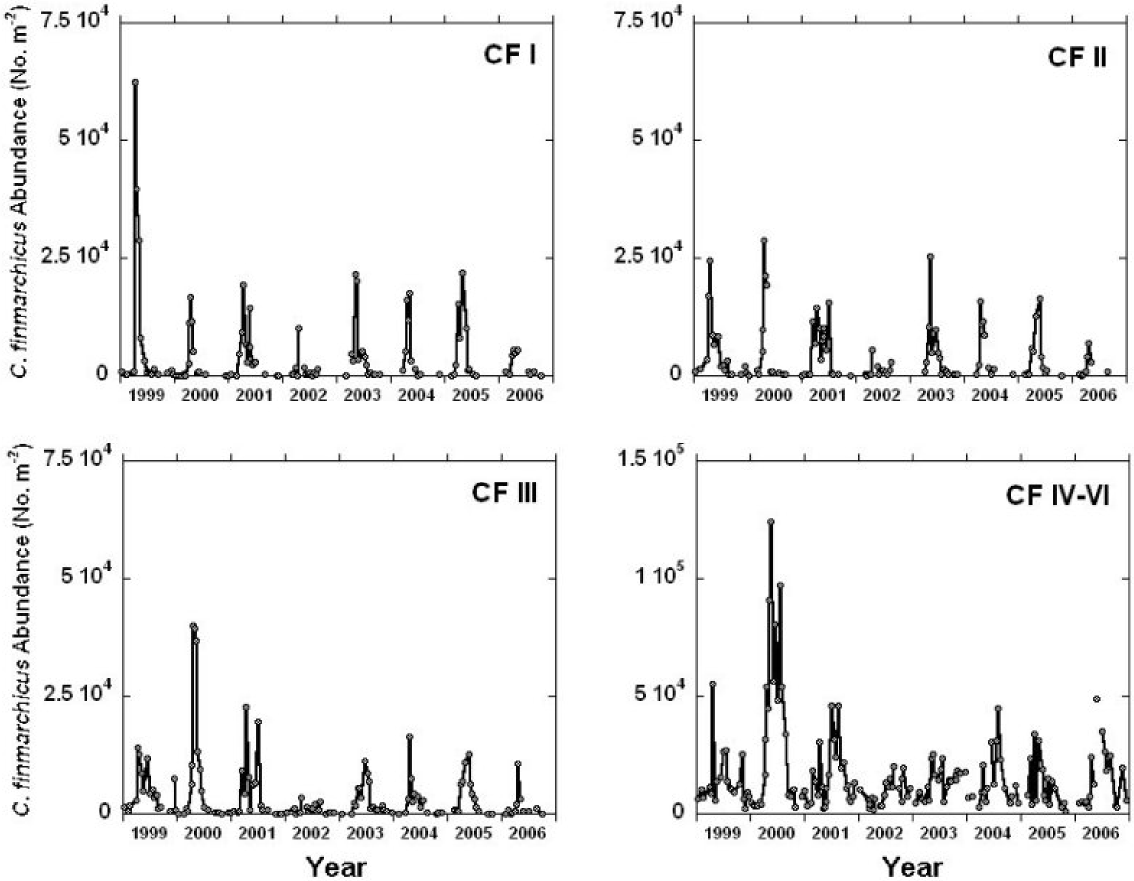

Figure 19. Time-series (1999-2006) of abundance of developmental stages of *C. finmarchicus* , Halifax-2 fixed station.

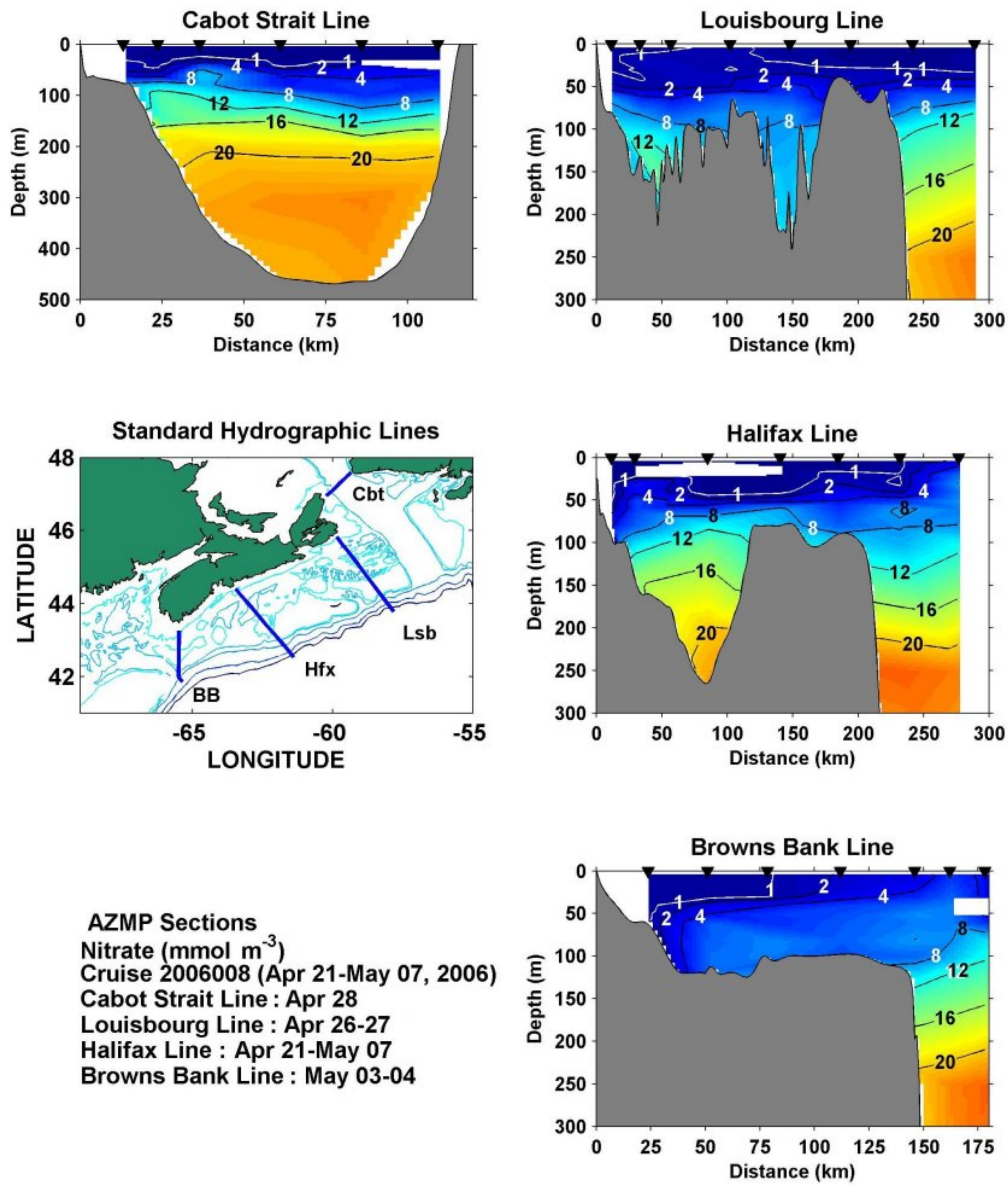

Figure 20. Vertical nitrate structure along the Scotian Shelf sections during the spring survey in 2006.

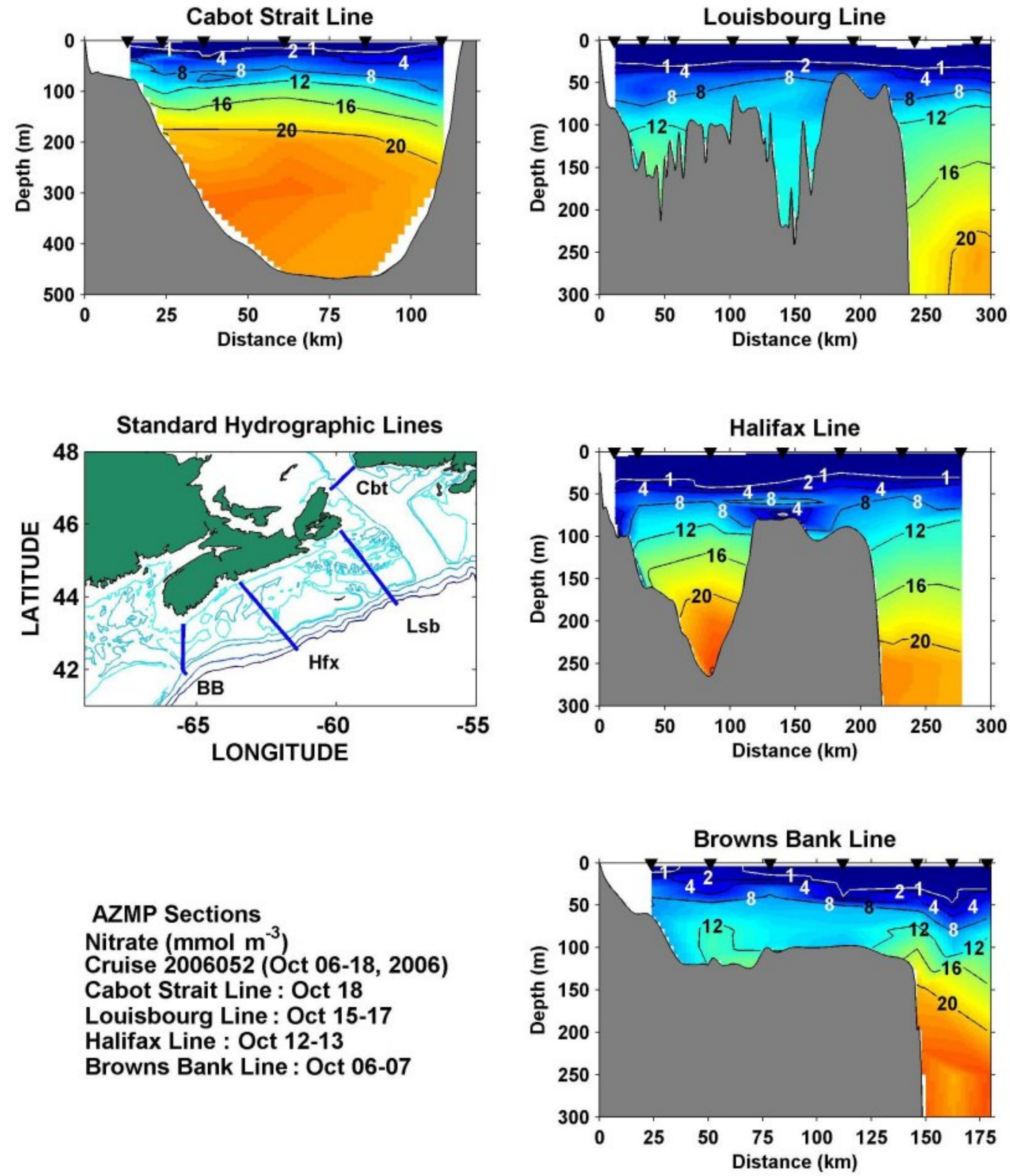

Figure 21. Vertical nitrate structure along the Scotian Shelf sections during the fall survey in 2006.

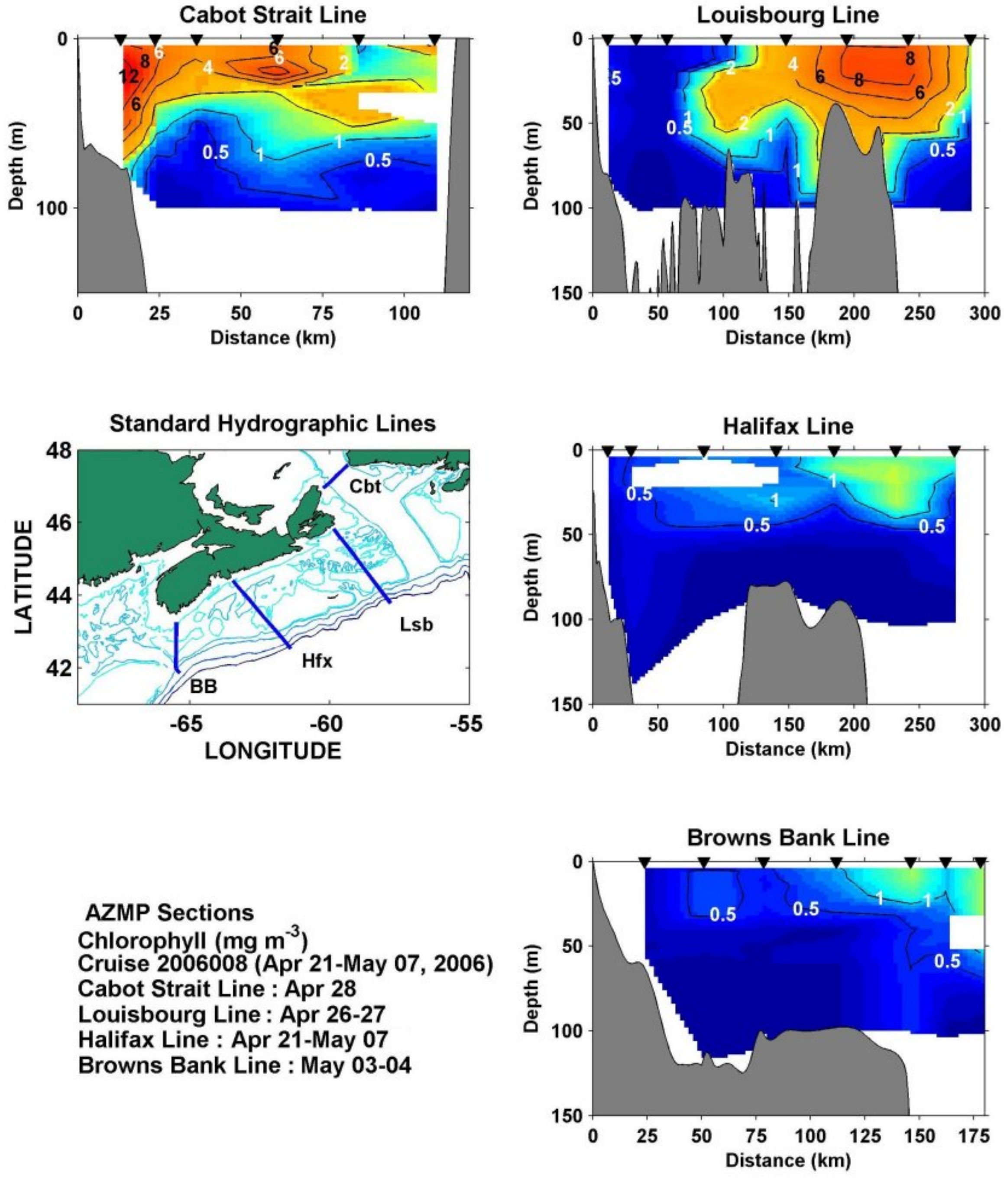

Figure 22. Vertical chlorophyll structure along the Scotian Shelf sections during the spring survey in 2006.

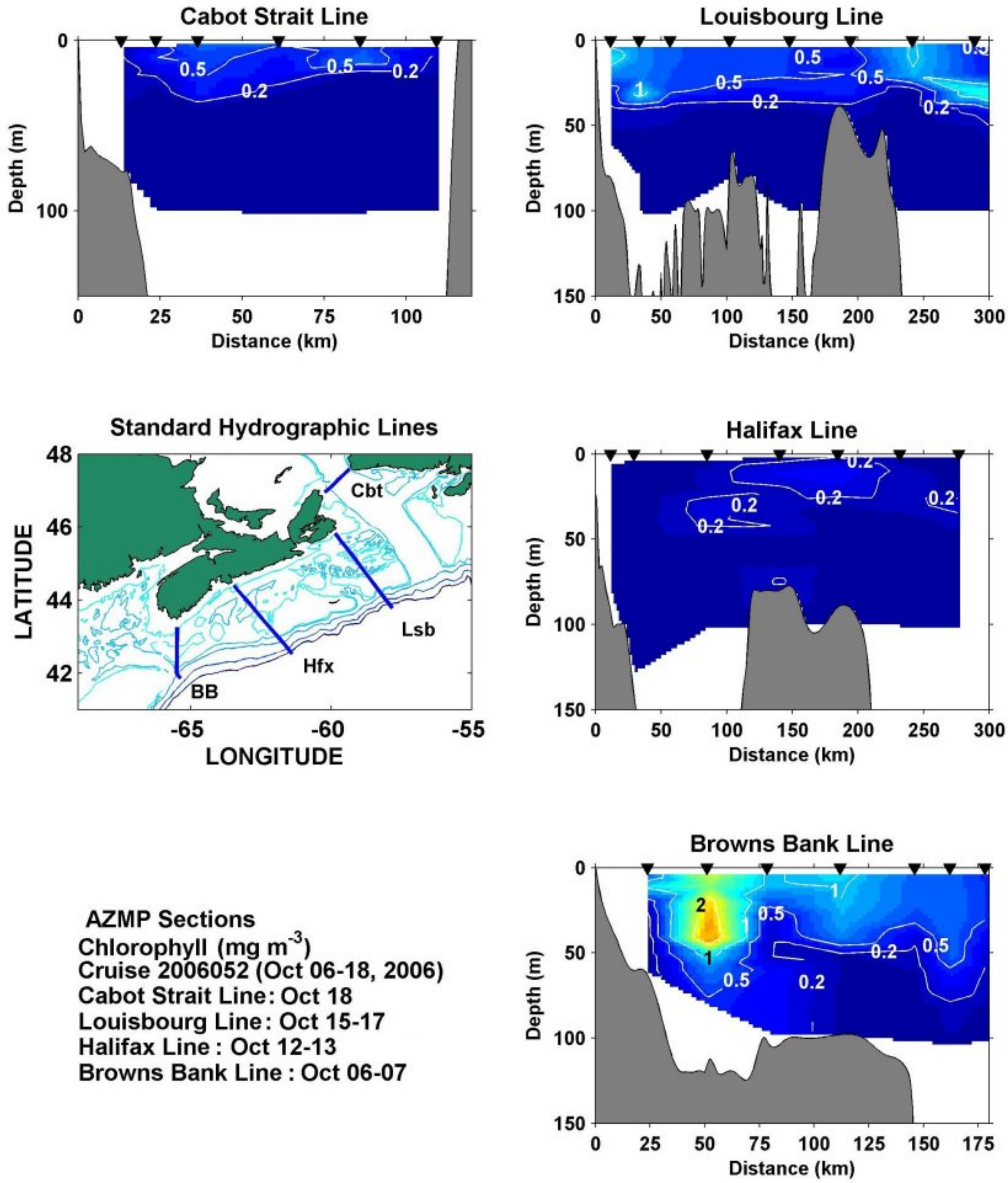

Figure 23. Vertical chlorophyll structure along the Scotian Shelf sections during the fall survey in 2006.

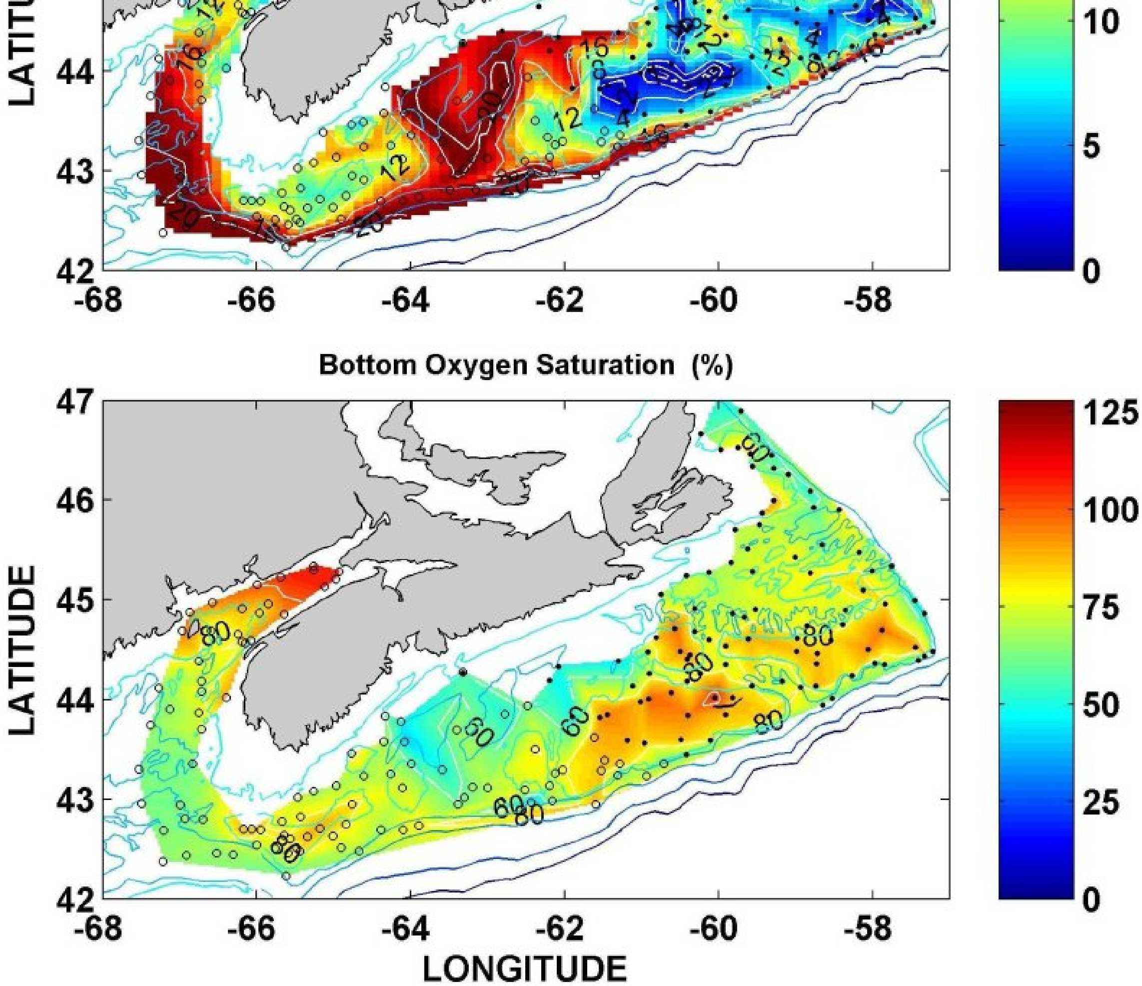

Figure 24. Bottom nitrate concentrations and oxygen saturation on the Scotian Shelf during the annual July groundfish survey in 2006.

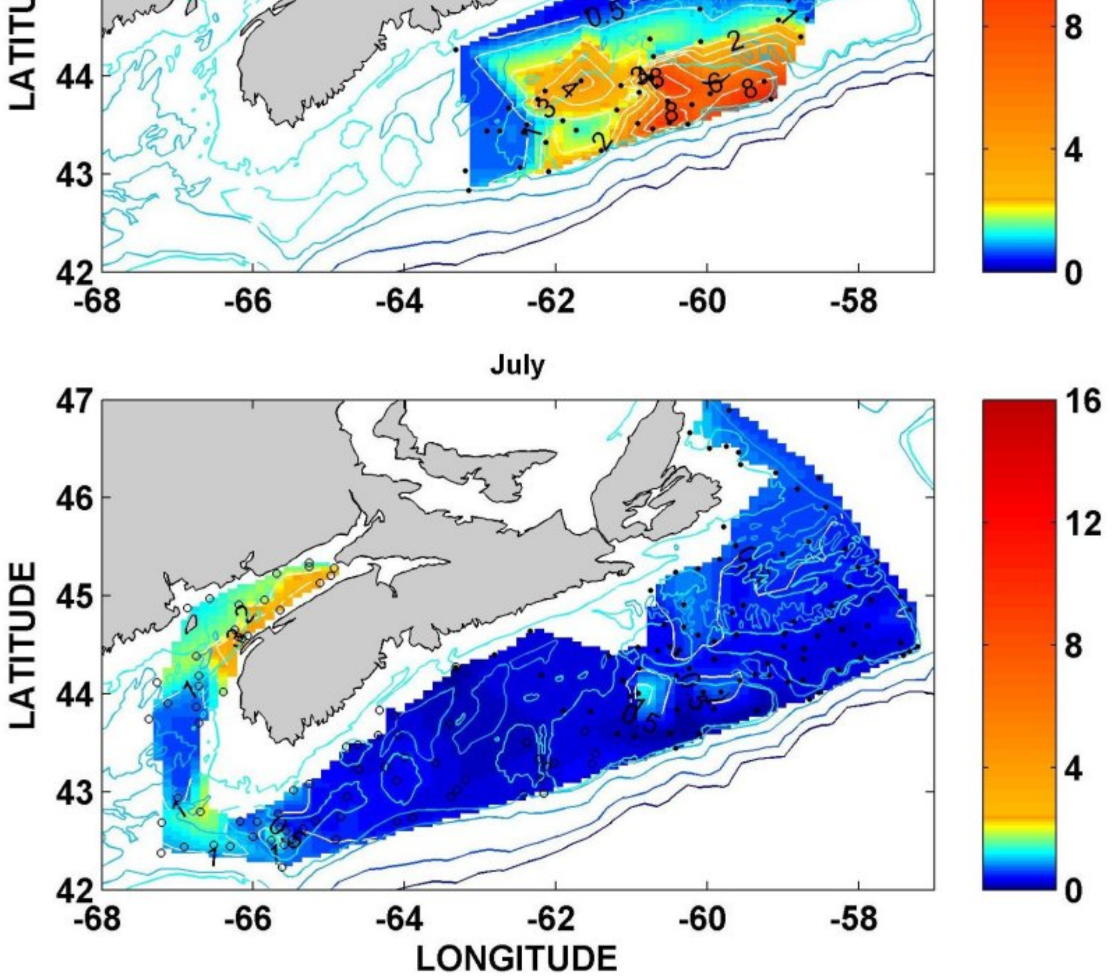

Figure 25. Surface chlorophyll concentrations on the Scotian Shelf during the annual March and July groundfish surveys in 2006.

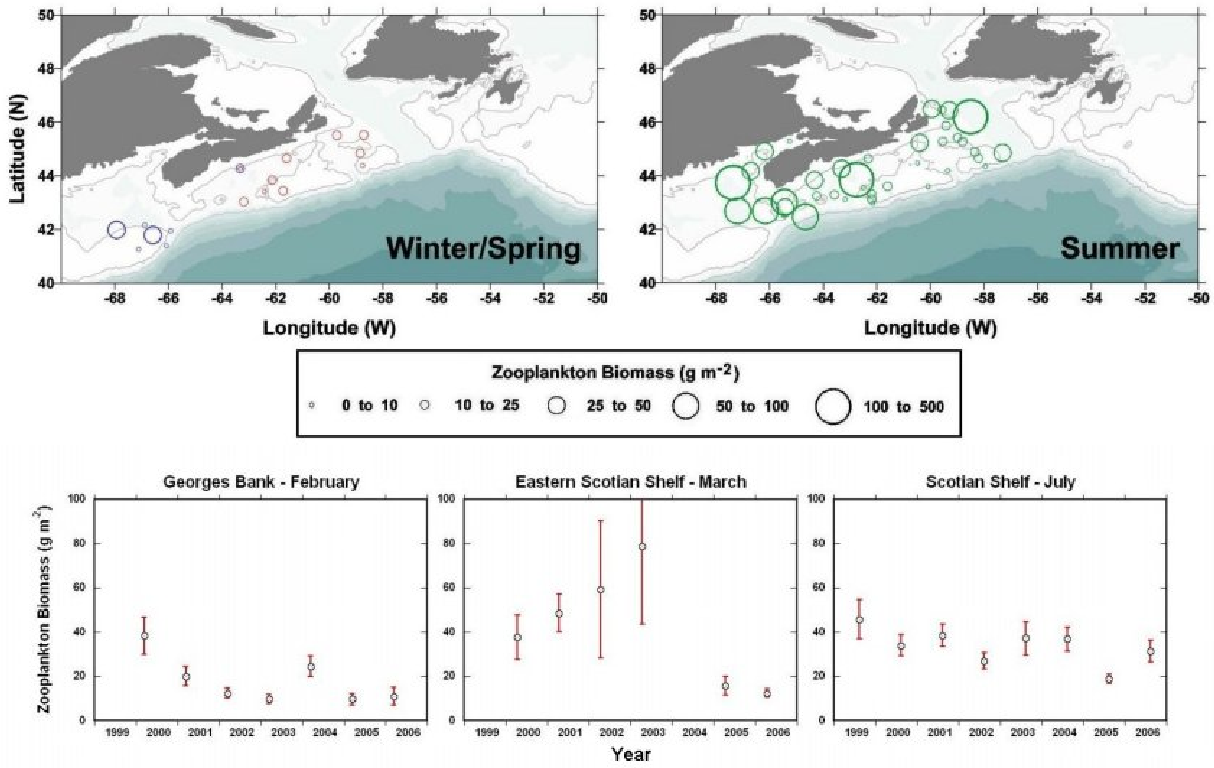

Figure 26. Zooplankton biomass (g wet wt m^{-2}) from ecosystem trawl (groundfish) surveys on Georges Bank (February) the eastern Scotian Shelf (March) and the Scotian Shelf and eastern Gulf of Maine (summer): upper panels show 2006 conditions, lower panels show survey mean biomass, 1999-2006 (vertical bars are standard errors).

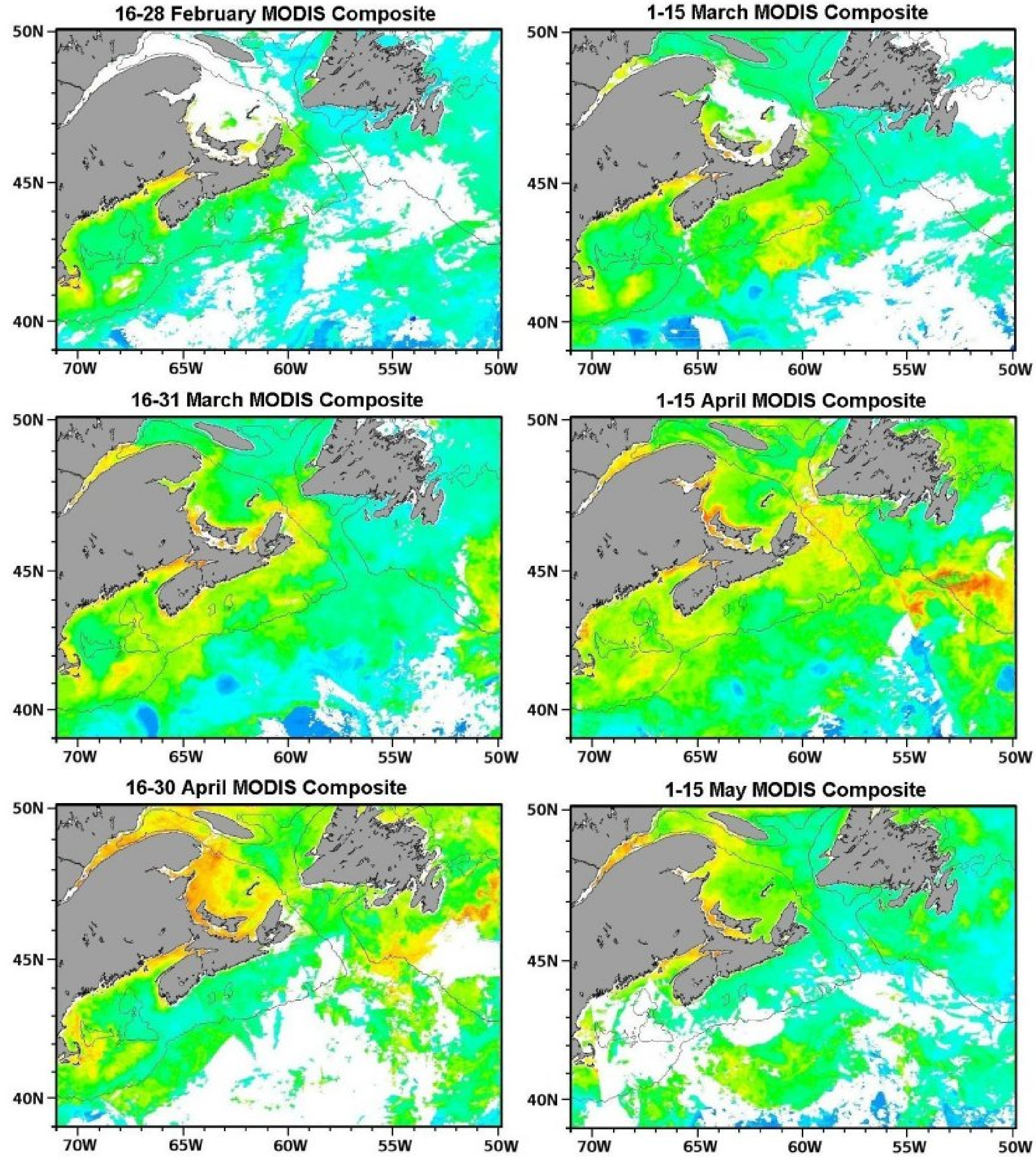

Figure 27. MODIS bi-weekly composite images of surface chlorophyll in the Maritimes/Gulf regions: late February through early May, 2006, covering the periods before, during and after the phytoplankton bloom and including the winter ecosystem trawl (groundfish) survey (see Fig. 3) and spring shelf section survey (see Fig. 2).

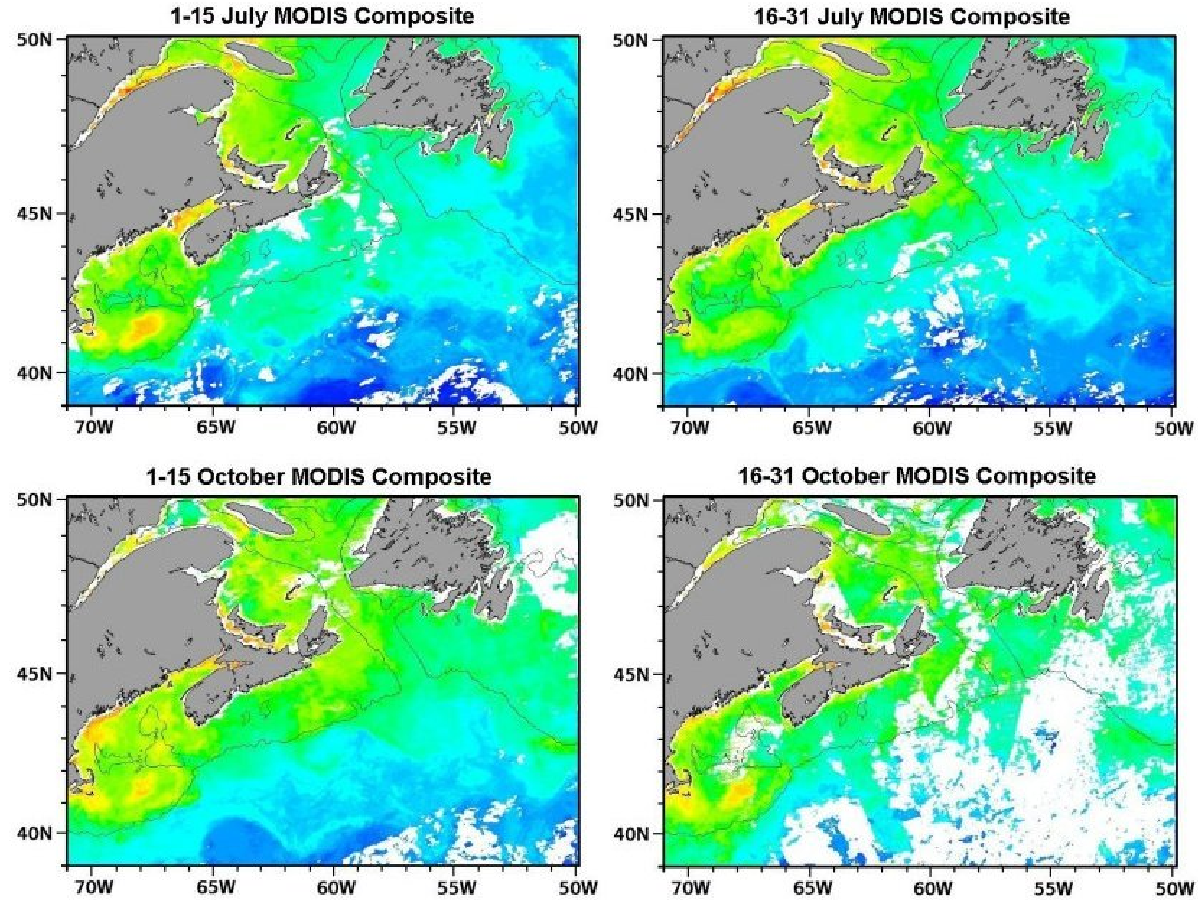

Figure 28. MODIS bi-weekly composite images of surface chlorophyll in the Maritimes/Gulf regions: July, and October, 2006, covering the periods of the summer ecosystem trawl (groundfish) survey (see Fig. 3) and the fall shelf section survey (see Fig. 2).

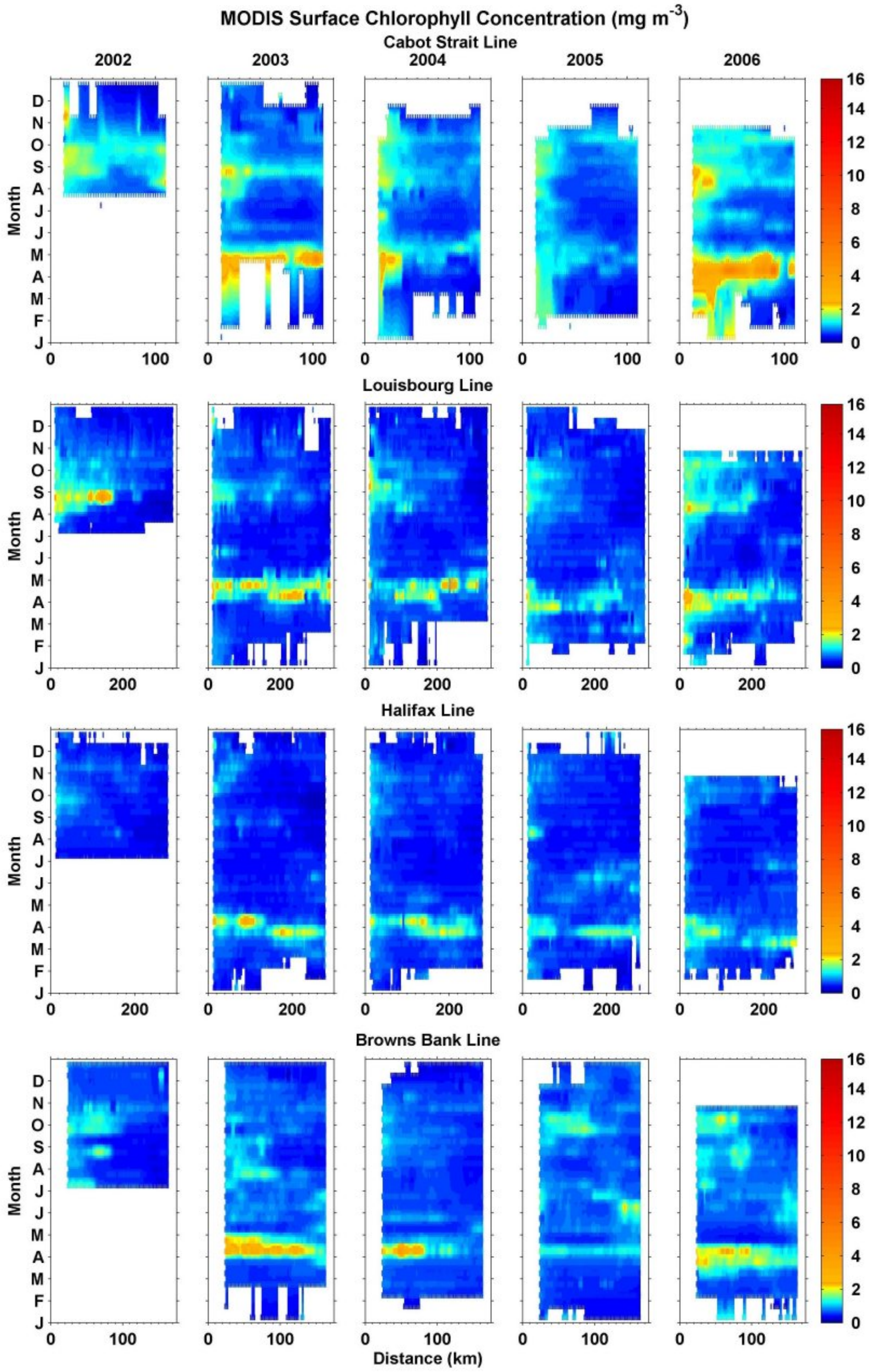

Figure 29. Time-series of surface chlorophyll concentrations (mg m^{-3}), from MODIS bi-weekly ocean colour composites, along the Maritimes sections (see Fig. 1), 2002-2006. Horizontal axes running south to north (Cabot line) or west to east (Louisbourg, Halifax, Browns Bank lines).

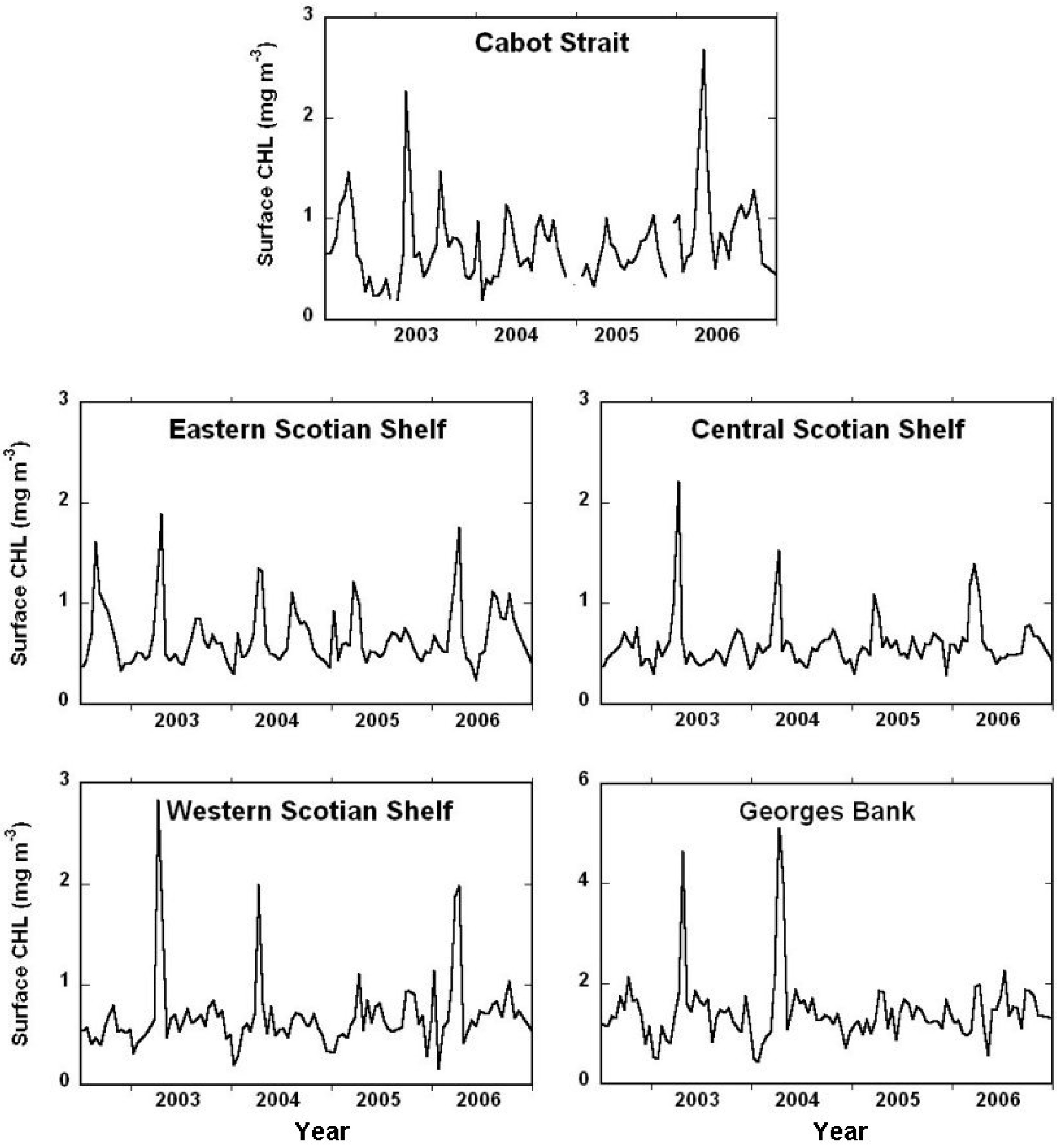

Figure 30. Time-series of surface chlorophyll concentrations (from MODIS bi-weekly ocean colour composites) for statistical sub-regions of the Maritimes region (see Fig. 5), 2002-2006.

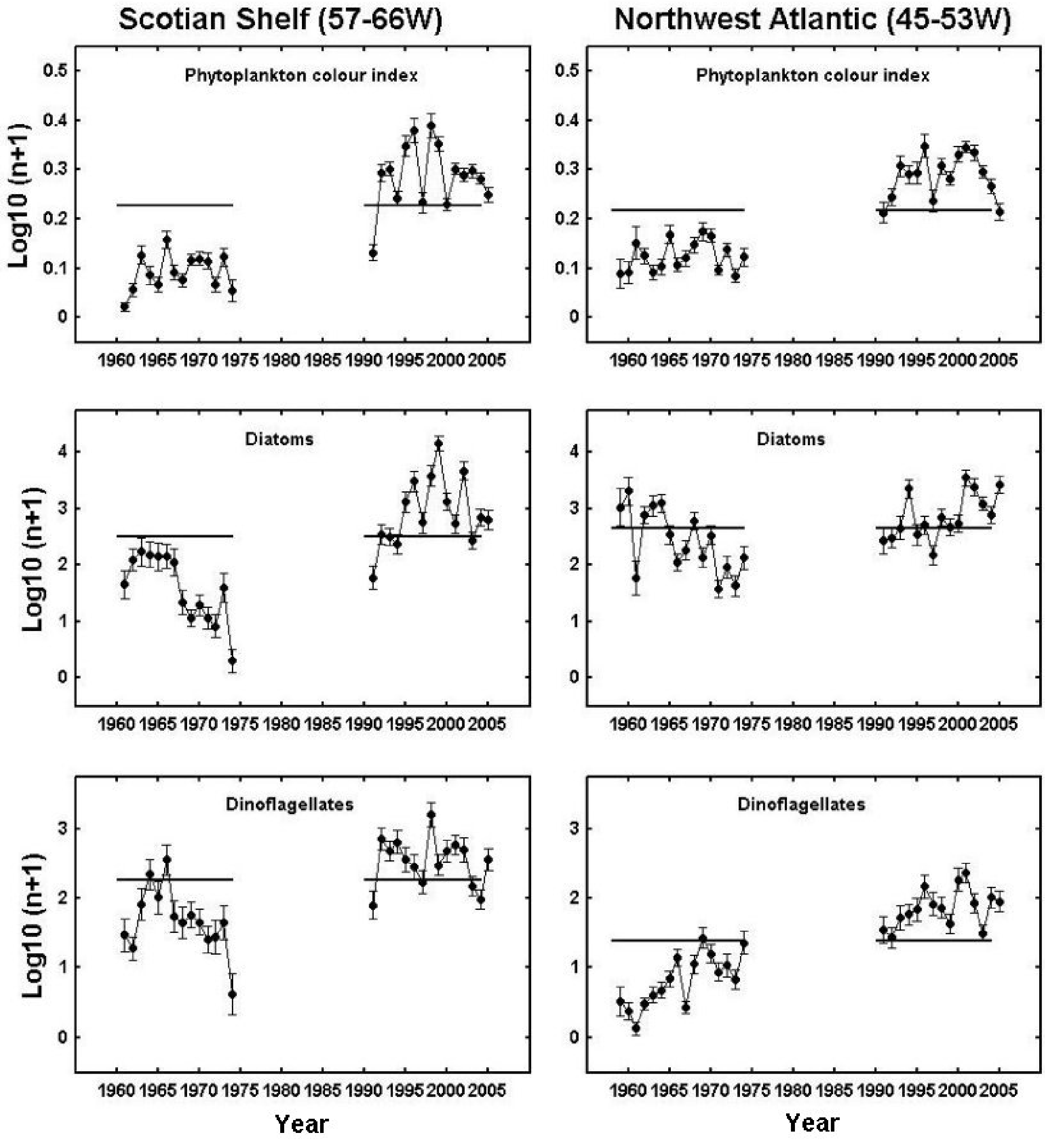

Figure 31. Time-series of phytoplankton biomass (colour index), diatom and dinoflagellate relative abundances (annual means) on the Scotian Shelf (57-66º W) and the Northwest Atlantic (45-53º W) from CPR surveys, 1961-2005 (see Fig. 4 for area coverage). Vertical bars are standard errors.

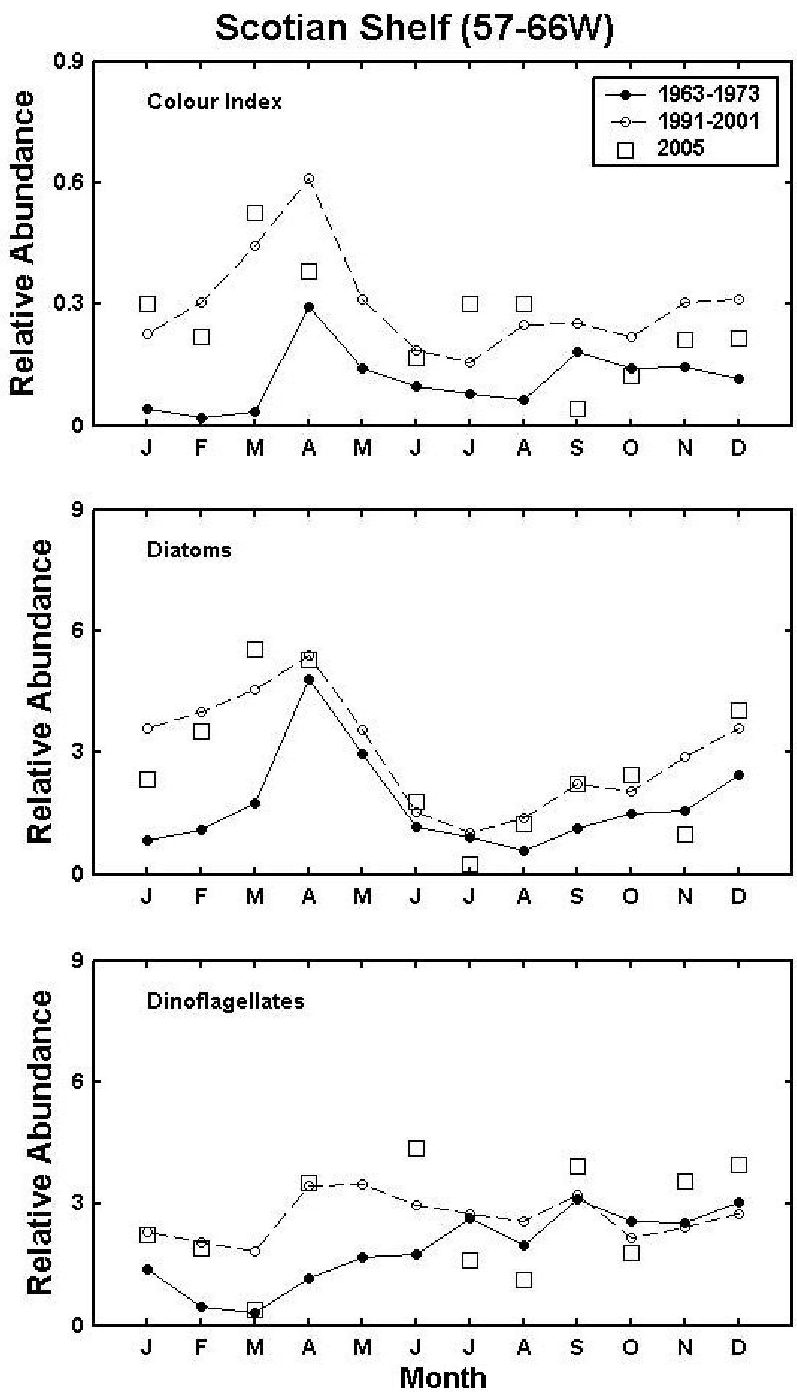

Figure 32. Monthly means of phytoplankton abundance on the Scotian Shelf in 2005 from CPR surveys. Means for the decades of the 1960s and 1990s shown for comparison.

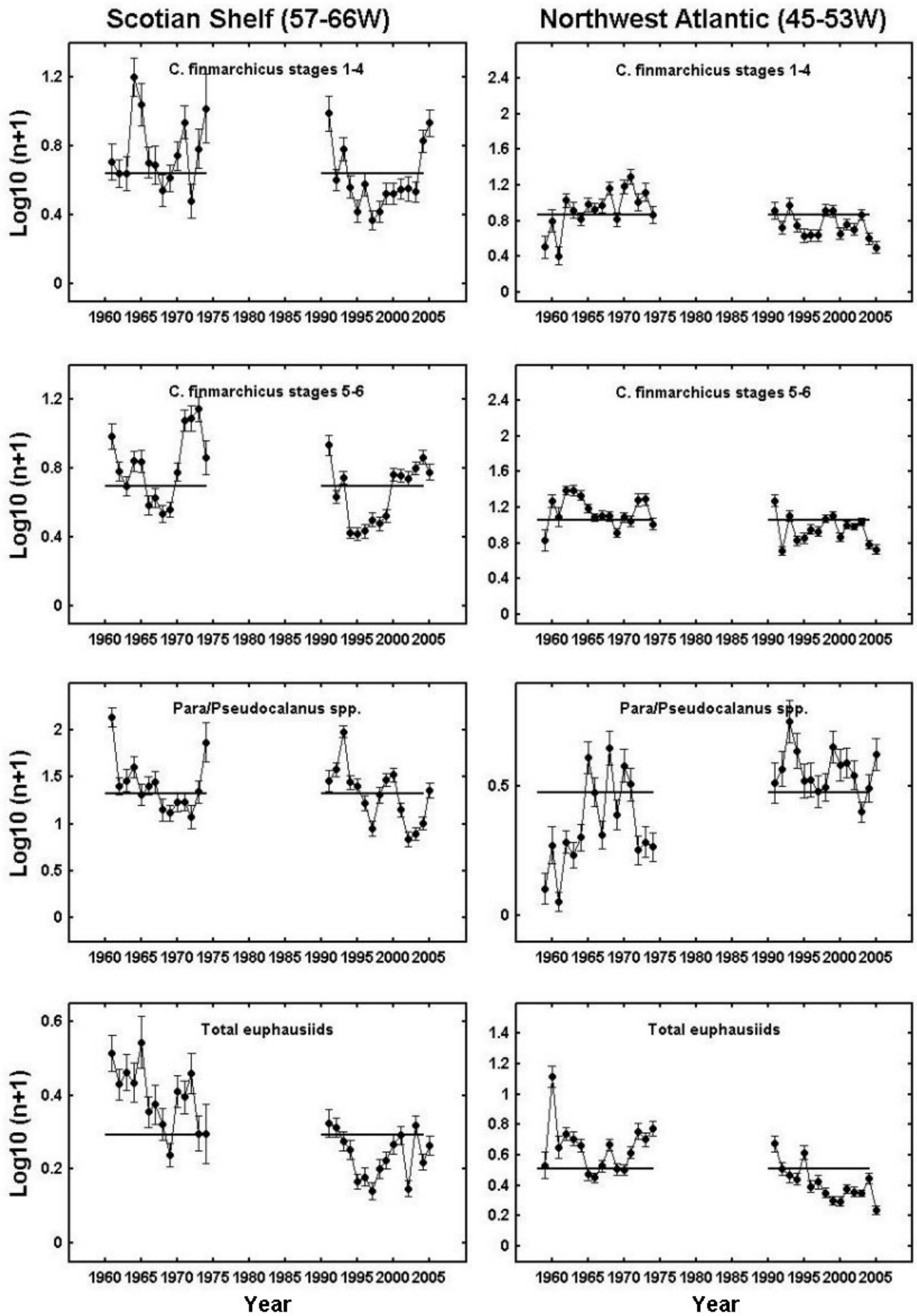

Figure 33. Time-series of relative abundances of selected zooplankton species (annual means) on the Scotian Shelf (57-66° W) and the Northwest Atlantic (45-53° W) from CPR surveys, 1961-2005 (see Fig. 4 for area coverage). Vertical bars are standard errors.

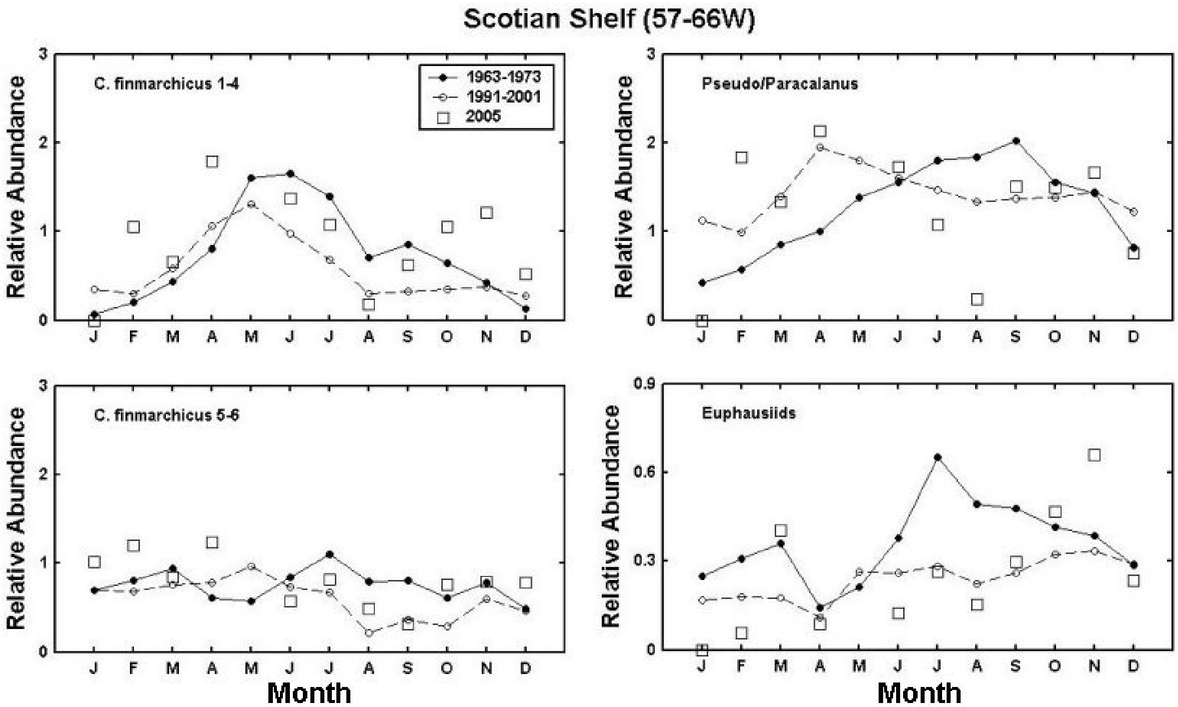

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Figure 34. Monthly means of zooplankton abundance on the Scotian Shelf in 2005 from CPR surveys. Means for the decades of the 1960s and 1990s shown for comparison.