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Optical, chemical and biological oceanographic conditions in the Maritimes/Gulf regions in 2005

Conditions océanographiques optiques, chimiques et biologiques dans les régions des Maritimes et du Golfe en 2005

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ABSTRACT

Optical, chemical, and biological oceanographic conditions in the Maritimes/Gulf regions (Georges Bank, eastern Gulf of Maine, Bay of Fundy, Scotian Shelf and Southern Gulf of St. Lawrence) during 2005 are reviewed and related to conditions during the preceding year and over the longer-term where applicable. In addition to descriptions of AZMP core data collections (fixed stations, seasonal sections, groundfish surveys, CPR, remote-sensing), some data from outside the Maritimes/Gulf regions are discussed also to provide the larger, zonal perspective.

Optical properties at the Maritimes/Gulf fixed stations in 2005 differed by site but were, for the most part, comparable to conditions observed in previous years. Mixed-layer depths at the Prince-5 station in 2005 were shallower and stratification stronger than observed previously. At the Halifax-2 station, the onset of stratification was later, by ~months, than typically observed at this station.

Nitrate concentrations in surface waters in 2005 were lower in winter at the Halifax-2 and Prince-5 fixed stations and lower in summer at the Shediac station than seen in previous years. The depth of the nitrate depletion zone at Halifax-2 was the deepest observed since systematic measurements began in 1999. In addition, deep (>50 m) nitrate concentrations were the lowest on record at Halifax-2 and considerably lower than the climatological mean.

The most prominent feature of the phytoplankton in the Maritimes/Gulf regions in 2005 was the strong but short-lived spring bloom; peak chlorophyll concentrations at the Halifax-2 station were close to the record high levels observed in 2003 but the bloom's duration was the shortest on record (half the long term average duration). High springtime chlorophyll concentrations were also evident along the shelf section surveys; record high levels were observed along the Halifax line. At the Prince-5 fixed station, in contrast, chlorophyll concentrations were the lowest since observations began in 1999 and the peak growth season started later than usual. 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 *C. finmarchicus* abundance were geographically and seasonally highly variable in 2005. Record high *C. finmarchicus* numbers were observed in Cabot Strait in spring but numbers were at record lows in fall. Higher than usual *C. finmarchicus* numbers were also seen on the central Scotian Shelf in fall. Zooplankton biomass from the spring and summer Scotian Shelf groundfish surveys was the lowest seen since observations began in 1999. At all fixed stations, but most prominent at Prince-5, the contribution of *Calanus* to the copepod community has steadily increased over the past several years. CPR data continue to show that contemporary zooplankton levels are at or below those observed during the decade of the 1960s/1970s, however, some species (e.g. *C. finmarchicus*) appear to be recovering.

RÉSUMÉ

Nous passons en revue les conditions océanographiques optiques, chimiques et biologiques dans les régions des Maritimes et du Golfe (banc Georges, est du golfe du Maine, baie de Fundy, plateau néo-écossais et sud du golfe du Saint-Laurent) en 2005, puis nous les comparons aux conditions de l'année précédente et à long terme, s'il y a lieu. En plus des descriptions des séries de données de base du PMZA (stations fixes, transects saisonniers, relevés du poisson de fond, enregistreurs de plancton en continu [EPC], télédétection), nous examinons un certain nombre de données provenant de l'extérieur de ces régions afin de donner une vue d'ensemble de la zone.

Les propriétés optiques aux stations fixes des régions des Maritimes et du Golfe en 2005 différaient de l'une à l'autre, mais étaient pour la plupart comparables aux conditions observées au cours des années précédentes. En 2005, la profondeur de la couche de mélange à la station Prince-5 était moins grande et la stratification plus importante que ce que nous avons observé précédemment. À la station Halifax 2, le début de la stratification a été plus tardif (~mois) qu'à l'habitude.

En 2005, les concentrations de nitrates dans les eaux de surface étaient moins élevées en hiver aux stations fixes Halifax 2 et Prince 5 et en été à la station Shediac que celles observées les années précédentes. La profondeur de la zone d'épuisement des nitrates à la station Halifax 2 était la plus grande jamais observée depuis le début des mesures systématiques en 1999. De plus, les concentrations en nitrates sous la surface (>50 m) étaient les plus faibles enregistrées à cette même station et étaient considérablement inférieures à la moyenne climatologique.

La caractéristique dominante du phytoplancton dans les régions des Maritimes et du Golfe en 2005 a été la prolifération printanière intense, mais de courte durée; les concentrations maximales en chlorophylle à la station Halifax 2 ont presque atteint les niveaux record enregistrés en 2003, mais la durée de la prolifération a été la plus courte jamais observée (la moitié de la durée moyenne à long terme). Les concentrations élevées en chlorophylle au printemps étaient également évidentes le long des sections de plateau couvertes par les relevés; nous avons observé des niveaux exceptionnellement élevés le long du transect d'Halifax. En revanche, à la station fixe Prince 5, les concentrations en chlorophylle étaient les plus faibles enregistrées depuis le début des observations en 1999, et la saison de croissance maximale a commencé plus tard qu'à l'habitude. Les données des EPC continuent à indiquer que les niveaux d'abondance récents (des années 1990 à 2000) du phytoplancton sont équivalents ou supérieurs à la moyenne à long terme et que le cycle de croissance saisonnière commence plus tôt pendant l'année comparativement à la première décennie d'observations (des années 1960 à 1970).

La biomasse de zooplancton et l'abondance de *C. finmarchicus* étaient très variables en 2005 sur les plans géographique et saisonnier. Nous avons observé des concentrations exceptionnellement élevées de *C. finmarchicus* dans le détroit de Cabot au printemps et des concentrations exceptionnellement faibles à l'automne. Une concentration inhabituellement élevée de *C. finmarchicus* a également été enregistrée au centre du plateau néo-écossais à l'automne. La biomasse de zooplancton dérivée des relevés du poisson de fond effectués au printemps et à l'été sur le plateau néo-écossais était la plus faible observée depuis le commencement des observations en 1999. À toutes les stations fixes, mais de façon plus marquée à la station Prince 5, la contribution de *Calanus* à la communauté des copépodes a augmenté de façon régulière au cours des dernières années. Les données des EPC continuent de montrer que les niveaux d'abondance récents du zooplancton sont égaux ou inférieurs à ceux qui ont été observés au cours de la décennie des années 1960 à 1970. Toutefois, certaines espèces (p. ex., *C. finmarchicus*) semblent être en voie de rétablissement.

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. 2005a) but are limited in their seasonal coverage. Critically placed fixed stations complement the geography-based sampling by providing more detailed information on temporal (seasonal) changes in ecosystem properties.

We review here the optical, chemical, and biological oceanographic conditions in the Maritimes/Gulf regions, including the Georges Bank/Gulf of Maine/Bay of Fundy system, the Scotian Shelf and the Southern Gulf of St. Lawrence, during 2005. 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 2004 will be compared with those observed during recent years (Harrison et al. 2005b) 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 2005 calendar year in addition to repeat day-trips to the 3 fixed stations; 535 station occupations were the total sampled all together (Table 1).

Fixed Stations. In 2005 the Maritimes/Gulf regions' three fixed stations, Shediac Valley, Halifax-2 and Prince-5 (Fig. 1), were sampled on a minimum monthly basis (Prince-5) with attempted semi-monthly sampling during the spring bloom period. Due, mostly in 2005, to the availability of resources (platforms) and to some extent, difficulties with weather and ice, this sampling frequency was not always achieved. In 2005, Halifax-2 and Prince-5 were sampled on 16 and 12 occasions, respectively. Shediac was sampled only 5 times. By definition the Shediac station has an ice-truncated open water season but, as well, changes in Coast Guard operations in 2005 (as in 2004) adversely affected the availability of platforms in that area. Fixed station occupations were, again, further reduced from our high in 2002. As in 2004 the combined effects of ice coverage, difficulty obtaining suitable platforms and the decision to reduce effort were the major factors controlling sampling in 2005.

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

- CTD (SBE25) profile including electronic sensing of pressure, temperature, conductivity, dissolved oxygen, fluorescence, and PAR (photosynthetically active radiation) as the common suite.
- Niskin water bottle samples at standard depths for nutrient, calibration salinity, calibration oxygen, and chlorophyll analyses as the minimum common suite of measurements.
- Niskin water bottle sample for phytoplankton enumeration.
- Vertical ring net tows for zooplankton biomass and enumeration,
- Secchi depth reading when possible.

Shelf Sections. Four primary transects (Browns Bank Line, Halifax Line, Louisbourg Line, Cabot Strait Line; Fig. 1) and a number of additional lines/stations (Fig. 2) are sampled seasonally in spring (April/May) and fall (October/November). An additional occupation of the Halifax Line is also attempted in May/July period as part of the Labrador Sea program in the Maritimes Region. In 2005, the spring mission was carried out from the 'Alfred Needler'; so only a minimal sampling campaign was possible. The fall section survey was carried out normally onboard Hudson with usual sampling activities. The four core transects were occupied in the both seasons in spite of minimum sea-time allocated to these missions. There was no opportunity to sample the Halifax Line in summer 2005 as the field-time allotted to the Labrador Sea mission did not allow sufficient time to occupy the section.

The standard sampling suite when occupying section stations consisted of:

- CTD (SBE25 – PED Rosette in spring, SBE911 OSD Rosette in fall) 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 2005.

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 on in the northwest Atlantic. The indices are measures of biomass or numbers of plankton collected in CPR samples and represent relative changes in concentrations from year to year. The sampling methods from the first surveys in the northwest Atlantic (1961) to the present are exactly the same so that valid comparisons can be made between years. Data are available approximately one year after collection, i.e. 2004 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).

RESULTS

Fixed Stations

Mixing and Optics. Mixing and optical properties of the upper water column varied by season and location at the Maritimes/Gulf fixed stations (Figs. 6 & 7). Seasonal development of the mixed-layer and upper water-column stratification was most evident at the Shediac Valley and Halifax-2 stations (Fig. 6); shallow mixed layers (~10 m) and maximum stratification (~0.1 kg m^{-4}) were evident throughout the summer and early fall months (May-October). Limited sampling 2005 at the Shediac station did not permit a complete seasonal analysis of mixing properties, however, the observations that were made (June-October) were consistent with those made in previous years. Mixed-layer depths were somewhat more variable and maximum summer stratification less intense at Halifax-2 than at Shediac. Mixed-layers at Halifax-2 in 2005 were consistent with the long-term mean conditions in contrast to 2004 when winter/spring mixing was notably deeper than normal. There was also some indication that springtime development of stratification was delayed in 2005 (as in 2004) compared with the long-term mean, i.e. the seasonal increase in stratification normally occurs in April but was not apparent in 2005 until two months later, in June. In marked contrast to the other fixed stations, stratification was extremely low (<0.01 kg m^{-4}) at Prince-5, due principally to strong tidal mixing. Mixed-layer depths are highly variable and difficult to determine at this station due to the very small vertical density differences, although estimates ranged from <20 m in spring and later in summer to almost full depth in winter; on a number of occasions (summer-late fall), mixed layer depths appeared to be shallower in 2005 (~20 m after May) than usual (~60m). Averaged over the year, mixed layer depths were somewhat shallower and stratification somewhat higher than the norm at Shediac and Prince-5.

Maximum vertical light attenuation at all stations coincided with the maximum in integrated chlorophyll in late spring and was minimum following the decline of the seasonal bloom (not shown). Generally, attenuance estimates derived from Secchi disc readings and direct downwelling irradiance (PAR) measurements were comparable and exceeded those derived empirically from chlorophyll concentrations (except during peak bloom conditions). The discrepancy is most notable at Prince-5 where water properties (dissolved and particulate substances) other than phytoplankton dominate the attenuation of light. At the Shediac Valley station, despite limited sampling in 2005, euphotic depths were relatively invariant during the spring-fall period (~30 m) and comparable to observations from previous years (Fig. 7). At Halifax-2, euphotic depths were generally deeper (40-60 m) and somewhat more variable than at Shediac. No clear seasonal cycle was discernible. At Prince-5, euphotic depths in 2005 were remarkably constant at (~15-30 m), showed little variability and no seasonality. In general, seasonal patterns and magnitudes of optical properties in 2005 at Shediac, Halifax-2 and Prince-5 were similar to those observed in previous years.

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

Rapid spring/early summer reduction in near surface nitrate concentrations was seen at all Maritimes/Gulf fixed stations in 2005 (Fig. 8). Low surface values persisted throughout the summer/fall at Shediac Valley (evident despite limited sampling) and Halifax-2; concentrations did not increase at the surface again until late fall (only observable at Halifax-2). The zone of nitrate depletion (i.e. defined as depths where concentrations were ≤1 μM) in summer is greater at Halifax-2 (~30 m) than at Shediac Valley (~15 m). Summer nitrate depletion depths in 2005 at Halifax-2 were the deepest on record (>40 m) since observations began in 1999. Near surface nitrate concentrations at Prince-5 were never reduced below ~4 μM. Limited sampling in 2005 precluded an evaluation of the seasonal nutrient cycle at the Shediac Valley station, however, the few observations made during summer/fall suggested that surface concentrations may have been somewhat lower than in previous years. The seasonal evolution of the vertical nitrate structure at Halifax-2 in 2005 was similar to that observed in previous years except that concentrations at depth (50-140 m) were the lowest on record. Of particular note were the low concentrations at depth in late spring/early summer. Nitrate anomaly plots for Halifax-2 showed that near surface concentrations in 2005 were comparable to the climatological mean but concentrations at depth were substantially below the long-term average (-6 to –8 μM) and lower than concentrations observed since systematic observations began in 1999.

Strong seasonal variability in nitrate inventories of the upper 50 m (depth zone over which nutrient dynamics are strongly influenced by biological processes) is evident at all of the Maritimes/Gulf fixed stations (Fig. 9). Nitrate levels at the Shediac Valley Station in 2005 were somewhat lower than levels observed previously, despite limited sampling. Although the seasonal pattern of variability in nitrate at Halifax-2 in 2005 was similar to that observed in previous years, wintertime inventories in 2005 were lower than the previous two years (<300 mmol m^{-2}) and continued a trend of declining concentrations. Summer/fall inventories were among the lowest observed over the past seven years (<10 mmol m^{-2}). Winter maximum nitrate inventories (~400 mmol m^{-2}) at Prince-5 in 2005 were significantly lower than the previous two years but similar to the long term average; summer levels were only slightly lower than the long term average (~200 mmol m^{-2}). Overall, annual nitrate inventories continue to be greatest at Prince-5 and lowest at Halifax-2. Except for the anomalously low spring nitrate concentrations at Halifax-2, no discernible trend has been observed in the annual deep (>50 m) nitrate inventories at any of the fixed stations over the seven years of systematic observations.

Phytoplankton. Distinctly different seasonal phytoplankton growth cycles are evident at the three Maritimes/Gulf fixed stations (Fig. 10). Because of the presence of ice in the Southern Gulf in the spring, only the latter phase of the spring bloom can be observed at the Shediac Valley station. This in addition to limited sampling during the ice-free period meant that little could be said about the magnitude and variability of phytoplankton biomass (chlorophyll), vertical distribution and community composition in 2005. Chlorophyll inventories of the upper 100 m at Shediac during the limited sampling in 2005 were lower than levels observed previously (Fig. 11). Similarly, evolution of the phytoplankton community composition at Shediac in 2005 was consistent with observations from earlier years, i.e. a shift from diatom to flagellate back to diatom dominated populations as the year progressed (Fig. 12). The strong spring bloom observed at Halifax-2 in 2003 and 2004 was again evident in 2005. Anomaly plots (Fig. 10) suggested that the 2005 spring bloom, as was the case in 2003 and 2004, was higher than historical levels, however, its termination came sooner than seen previously. A more detailed analysis of the timing of the start and end of the bloom confirmed this, revealing that the 2005 bloom was the shortest on record, lasting 25 days compared to 36-67 in previous years (Fig. 13a). In addition to changes in spring bloom dynamics the "background" chlorophyll inventories (outside the bloom period) have apparently been declining over the past seven years, from ~40 mg m^{-2} in 1999 to ~30 mg m^{-2} in 2005 (Fig. 13b). Winter dominance of the phytoplankton community by flagellates seen at this station in 2004 was evident again in 2005 and differed from previous years when a more typical seasonal evolution of community composition was observed, i.e. winter, spring and late fall dominance by diatoms and post-bloom and summer dominance by flagellates. The phytoplankton growth cycle at Prince-5 in 2005, in contrast to Shediac and Halifax-2; was characterized, after a late start, by a relatively sustained burst of growth beginning in early summer and lasting until fall and characterize by two peaks. Annual chlorophyll inventories at this station were the lowest on record and the biomass maxima were later than usual. As has been noted previously, the phytoplankton community at Prince-5 are consistently almost exclusively comprised of diatoms (>90%), year-round. On an annual basis, Prince-5 sustains the largest chlorophyll inventories of the three Maritimes/Gulf fixed stations.

Zooplankton. Zooplankton biomass at all of the Maritimes/Gulf fixed stations was comparable or lower in 2005 than levels observed in previous years (Fig. 14). The record high biomass observed at the Shediac Valley station in 2003 was not observed in 2005, although sampling in 2005 was limited. Biomass at Halifax-2 in 2005 was significantly lower than high levels seen in 2004 and somewhat lower than the long term average, exhibiting a broad peak of ~30 g wet wt m^{-2} during spring/summer. Similarly, zooplankton biomass at Prince-5 in 2005 was lower than in 2004 and lower than the historical levels, <10 g wet wt m^{-2}. There was, however, a dramatic increase in biomass in late fall, to almost 40 g wet wt m^{-2}. Zooplankton biomass at Prince-5 is typically only a small fraction (10-20%) of the biomass at the other fixed stations and peak levels occur later in the year than at the other stations.

As was the case for zooplankton biomass, *Calanus finmarchicus* abundance at all the fixed stations in 2005 was comparable to or lower than levels seen previously (Fig. 15). *C. finmarchicus* abundance at the Shediac Valley station in 2005 reverted from the record peak abundance observed in 2003 (>500,000 Ind m^{-2}) to levels more typical of the region (~25,000 Ind m^{-2}). At Halifax-2, *C. finmarchicus* abundance in 2005 was comparable to levels seen the previous two years; levels in late summer/fall were somewhat lower than the long term average, however. *C. finmarchicus* abundance at Prince-5 was lower than levels seen in 2004 and lower than the long term average for most of the year, however, as seen for zooplankton biomass, *C. finmarchicus* numbers increased dramatically during late fall, from <5,000 Ind m^{-2} to almost 60,000 Ind m^{-2}. *C. finmarchicus* abundance at Prince-5 continues to be only a small fraction of the counts of that species at the other fixed stations.

Hierarchical community analysis revealed that copepods continued to numerically dominated the zooplankton year-round at all of the Maritimes/Gulf fixed stations in 2005 (Fig. 16). Despite limited sampling, the appearance of euphauiids and decapod larvae was more prominent at the Shediac station than seen previously. The recurring pulse of echinoderm and barnacle larvae and euphausiids observed during the spring and summer at Prince-5 was observed again in 2005, however, the pulse of jellies and appendicularia seen in 2004 was absent. The copepods were dominated (>50% much of the year) at all the fixed stations by small species (*Oithona*, *Pseudocalanus*, *Paracalanus*, *Clausocalanus*, *Centropoges* and *Temora* sp.) in 2005 as in previous years (Fig. 17). The relative importance of the larger *Calanus sp* was lower than normal at Halifax-2 in 2005 while increasing at Prince-5 since AZMP sampling began in 1999. Also at Prince-5, “other” copepod species (e.g. *Acartia sp*., harpacticoids) comprise a significant fraction (up to >60%) of the copepods in summer whereas they play a minor role (<10%) at Shediac and Halifax-2. Stage distribution of *C. finmarchicus* in 2005 revealed that reproduction (indicated by presence of early developmental stages, I-III) was generally confined to the spring/early summer period at Shediac and Halifax-2 but was spread more broadly over the year at Prince-5 with peaks in summer and late fall (Fig. 18). However, the major reproductive activity appeared to occur in spring/summer at all stations as in previous years. The timing of reproduction at Halifax-2 (as judged by maximum abundance of Stage-Is) started earlier in 2005 (late April) than in previous two years but was later than the first three years of AZMP observations, 1999-2001 (Fig. 19). The abundance of Stage-VI females, peaking early in April, was at an all time high in 2005.

Shelf Sections

Nutrients. Vertical distributions of nitrate in spring and fall were generally similar along the Scotian Shelf sections in 2005, i.e. concentrations were low (<1 μM) 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 (>12 μM) and in slope waters off the edge of the shelf. As in the previous year, nitrate levels in surface waters were already depleted at the time of the spring survey in early April (1 μM depth horizon: 20-40 m). Likewise, surface nitrate concentrations were still low during the fall survey in late October (1 μM 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 2005 were comparable to levels observed in previous years except during spring along the Cabot Strait line where levels were higher (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 during the spring 2005 survey were relatively high (>6 mg m^{-3} or ~200-300 mg m^{-2}) (Fig. 22, Table 2). In previous years, chlorophyll inventories were generally higher on the eastern shelf than on the western shelf in spring but levels where high along all lines in 2005. Levels along the Halifax line were the highest seen (>350 mg m^{-2}) since the surveys began in 1999 but low relative to levels previously seen along the Cabot Strait, Lousibourg or Brown’s Bank sections. Concentrations during the fall 2005 survey, in contrast, were an order of magnitude lower (<1 mg m^{-3} or ~30-37 mg m^{-2}) and typical for that time of year (Fig. 23, Table 2). Generally, a pronounced subsurface chlorophyll maximum layer is observed at stations along the Scotian Shelf sections in fall, however, highest concentrations in 2005 survey appeared to be confined to surface waters, as observed in 2004. Chlorophyll inventories in fall 2005 were comparable along all sections except the Louisbourg line where levels were somewhat lower than seen previously.

Zooplankton. Zooplankton biomass and *C. finmarchicus* abundance were generally higher in spring 2005 than during the fall shelf sections survey, except along the Cabot Strait line where the levels were higher in fall than in spring, as observed in previous years (Table 2). Biomass levels increased from west (~30 g wet wt m^{-2} along Browns Bank line) to east (~70 g wet wt m^{-2} along Cabot Strait line) in spring while *C. finmarchicus* was generally more abundant on the western shelf; 26,000-56,000 Ind m^{-2} along the Brown’s/Halifax lines compared with 18,000-21,000 Ind m^{-2} along the Louisbourg/Cabot lines. *C. finmarchicus* abundance was notably lower along the Brown’s Bank line while considerably higher along the Cabot Strait line in spring 2005 than seen in previous years. In fall 2005, zooplankton biomass (17-28 g wet wt m^{-2}) and *C. finmarchicus* abundance (5,000-11,000 Ind m^{-2}) were fairly similar along the Brown’s Bank, Halifax and Louisbourg lines, however, both biomass (47 g wet wt m^{-2}) and species abundance (22,000 Ind m^{-2}) were considerably higher along the Cabot Strait line. In spring 2005, *C. finmarchicus* abundance was lower on the Browns Bank line than seen previously. In contrast, record high levels were seen in along the Cabot Strait line (~18,000 Ind m^{-2}) compared with the long term average in spring

(~9,000 Ind m^{-2}). In fall 2005, zooplankton biomass was lower along the Brown's Bank line and record low *C. finmarchicus* abundances were observed along the Cabot Strait line (22,000 Ind m^{-2} compared with the long term average of 34,000 Ind m^{-2}). On the other hand, record high *C. finmarchicus* abundances were seen along the Halifax line in fall (11,000 Ind m^{-2} compared with the long term average of 8,000 Ind m^{-2}).

Groundfish Surveys

Nutrients. Bottom water nitrate concentrations on the Scotian Shelf in the July, 2005 (Avg: 10.98 μM) were similar to levels observed in 2004 (Avg: 10.35 μM) and not statistically different from the longer term levels (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 nitrate concentrations in the Southern Gulf in September were lower in 2005 (Avg: 8.90 μM) than in 2004 (Avg: 9.73 μM). Highest concentrations were found in the western basin and in deep waters of the Laurentian Channel. Bottom water oxygen saturation on the Scotian Shelf in summer 2005 (Avg: 78% sat) was slightly lower than saturation levels observed in 2004 (Avg: 81% sat) but not statistically different from the previous year nor the long-term mean, however, the area of the bottom covered by waters with <60% saturation was the lowest on record (9,900 km^2 or ~7% of the shelf area, compared with the long term average of 17.7 km^2 or ~12% of the shelf area). Lowest saturations were found in deep basins and deep waters off the shelf edge where nutrients are highest. Bottom water oxygen saturation in the Southern Gulf was virtually the same on average as levels observed in 2004 (Avg: 72% sat). Saturation levels in the Southern Gulf were minimal in the western basin and in the Laurentian Channel where nutrients were highest.

Phytoplankton. Near-surface chlorophyll levels during the 2005 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 2005 summer Scotian Shelf survey, on the other hand, were uniformly low (<1 mg m^{-3}) over most of the central and eastern shelf. Elevated concentrations (>2 mg m^{-3}) were observed near the coast off SW Nova Scotia and approaches to the Bay of Fundy, as observed in previous years. These areas are generally characterized by strong vertical mixing. Overall, summer surface chlorophyll concentrations on the Scotian Shelf in 2005 (Avg: 0.56 mg m^{-3}) were the same as concentrations observed in 2004 (Table 3). Surface chlorophyll concentrations observed during the fall 2005 groundfish survey in the Southern Gulf (Avg: 1.17 mg m^{-3}) were lower than values observed in 2004 (Avg: 1.89 mg m^{-3}) but not statistically different from the long term average. Concentrations tended to be highest in the western basin as has been observed in previous years.

Zooplankton. Zooplankton biomass distribution observed during the major winter/spring and summer/fall groundfish surveys can be characterized as highly variable in space and time (Figs. 26 & 27). Generally, however, biomass is highest in deep basins and deep waters off the edge of the shelf or in channels (e.g. Northeast Channel off Georges Bank, Laurentian Channel bounding the Southern Gulf). Additionally, during the summer surveys, biomass has consistently been higher on the western Scotian Shelf than on the eastern shelf. This is in contrast to the east-west uniformity in biomass observed during the spring and fall surveys (Table 2). In 2005, survey mean zooplankton biomass in February on Georges Bank (~10 g wet wt m^{-2}) was lower than the mean biomass in 2004 (~27 g wet wt m^{-2}) but not statistically different from the long term average. Zooplankton biomass during the eastern Scotian Shelf March survey, however, was the lowest on record (16 g wet wt m^{-2} compared with the long term average of 56 g wet wt m^{-2}). Similarly, zooplankton biomass, as well as *C. finmarchicus* abundance, were at record low levels during the July Scotian Shelf survey; biomass was ~18 g wet wt m^{-2} in 2005 compared with the long term average of ~36 g wet wt m^{-2} and *C. finmarchicus* abundance was ~19,000 Ind m^{-2} compared with the long term average of ~31,000 Ind m^{-2}). Zooplankton biomass was lower in 2005 than in 2004 during the September Southern Gulf of St Lawrence survey but not significantly different from the long term average. Zooplankton species data for most of the groundfish surveys have been processed but not yet interpreted.

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/Gulf Regions covering the major periods of the shelf section surveys (Fig. 28) and groundfish surveys (Fig. 29) 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 for the July and September groundfish surveys show the overall low surface chlorophyll levels shelf-wide for the former and the high surface chlorophyll levels in the Southern Gulf for the latter. Note also from these images that chlorophyll levels were high even in July in the Southern Gulf.

An equally informative application of the satellite-based chlorophyll fields is to generate graphical representations of the seasonal chlorophyll dynamics along the shelf sections. It is evident from the satellite-data, for example, that surface chlorophyll concentrations are generally higher on the eastern Scotian Shelf (e.g. Louisbourg line) than on the central and western shelf (e.g. Halifax line) (Fig. 30). Note that the chlorophyll levels depicted in the SeaWiFS images are much higher than in the MODIS images. Algorithms for the latter will require some adjustment to bring them in line with the earlier SeaWiFS data and are currently interpreted in only a relative sense. 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. 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. This graphical representation also shows, for example, that the spring blooms along the Louisbourg and Halifax lines were weaker in 2005 than in 2004 and that the bloom along the Halifax line was shorter-lived in 2005 than in 2004, consistent with the Halifax-2 fixed station observations.

At the larger scale (i.e. statistical sub-regions in the Maritimes/Gulf, see Fig. 5), the magnitude of the spring bloom in 2005 was noticeably lower in all Maritimes/Gulf locations than in 2004, this was particularly evident for the Scotian Shelf and Georges Bank (Fig 31). However, chlorophyll observations from the Halifax-2 fixed station (Fig. 11) revealed a much stronger spring bloom in 2005 than suggested by the MODIS data for the Central Scotian Shelf. This argues for a number of independent measures of phytoplankton biomass (conventional and remote-sensing), for example, in order to get a more complete and accurate evaluate of the state of the ecosystem.

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 2004 are currently available. Nonetheless, the phytoplankton colour index and abundance of large diatoms and dinoflagellates on the Scotian Shelf (57º-66ºW) have been dramatically higher, starting in the early 1990s and continuing into the 2000s, than levels observed in the 1960s/1970s (Fig. 32). 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 dramatic as on the Scotian Shelf. On the shorter time scale, the phytoplankton colour index on the Scotian Shelf has been relatively stable (and above the long-term mean) over the past few years. Diatoms increased slightly in 2004 and dinoflagellate abundances, in contrast, continued to decline with levels in 2003 and 2004 below the long term average. Further east in the Northwest Atlantic, phytoplankton colour index and diatoms continued a 3-4 year decline while dinoflagellates increased, reversing a 3-year decline. 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 2004, the magnitude and seasonal cycle of phytoplankton abundances aligned more closely with the pattern observed in the

1990s/2000s than in the 1960s/1970s (Fig.33). There appeared to be a shift in phytoplankton abundance in more recent years to earlier months compared with the 1960s/1970s. Although the timing of peak abundance (April) did not change, much higher levels, particularly of diatoms, were observed in January-March in 2004 compared to levels 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 the 1990s/2000s than in the 1960s/1970s), particularly during the early to mid-1990s (Fig. 34). During the last several years, zooplankton numbers have recovered from the mid-1990s lows for some species on the Scotian Shelf, however, counts for other species are still down. Of particular note was the dramatic increase in *C. finmarchicus*, particularly the elevated numbers of stages 1-4, in 2004; for the first time in a decade abundances of stages 1-4 were above the long term average. *Paracalanus/Pseudocalanus spp.* were also on the increase but levels still remained below the long term average. Euphausiid numbers in 2004 were down from the increase seen in 2003 and back below the long term average. In the Northwest Atlantic, the decadal variability in *C. finmarchicus* has not been nearly as dramatic as on the Scotian Shelf; levels in the 1990s/2000s have been similar to those seen in the 1960s/1970s. *Paracalanus/Pseudocalanus spp* numbers, on the other hand, increased significantly in the 1990s compared with the 1960s/1970s, similar to the pattern seen in phytoplankton. Euphausiid numbers have been lower in the 1990s/2000s in the Northwest Atlantic than in the 1960s/1970s, similar to the pattern seen on the Scotian Shelf. The seasonal abundance cycles for zooplankton species in 2004 could not as easily be aligned with the patterns of the 1960s/1970s and 1990s as was the case for phytoplankton (Fig. 35).

DISCUSSION

Sufficient data now exists from AZMP (7-years) to document recurring spatial and temporal patterns in optical, chemical and biological properties of the Maritimes/Gulf regions and to describe changes (trends) in oceanographic properties. Although many of the oceanographic features in the Maritimes/Gulf regions in 2005 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 remarkably recurrent features at the Maritimes/Gulf fixed stations and distinctly different for each station. The annual reproducibility of the hydrographic properties (mixed-layer depths, stratification indices) is particularly evident at the Shediac Valley and Halifax-2 stations and the optical properties (euphotic depths) at Prince-5. The most notable features in these physical properties in 2005 were the shallower mixed layers and somewhat stronger stratification at Prince-5 and the delayed onset of stratification at Halifax-2, the latter seen as well in 2004.

The shallower mixed layers and stronger stratification at the Prince-5 could be linked to the record low chlorophyll levels and perhaps the delay in the appearance of the maximum chlorophyll levels, however, there was no evidence of lower than normal nutrients during the main growing season. Keep in mind also that Prince-5 is never nutrient-limited and located in a region characterized by overall strong tidal mixing and any stratification and mixed layers seen there are weak at best and likely do not pose a significant barrier to nutrient supply to surface waters. Any influence of water column stability on phytoplankton growth, therefore, would have to be through influence on their light environment and there was no evidence that optical properties were different in 2005 from previous years at this station. The delayed development of stratification at Halifax-2 might influence the timing of the spring phytoplankton bloom but there was no evidence that the bloom in 2005 was later than usual. Furthermore, there is evidence from previous observations in this region that blooms may start before the apparent onset of stratification. Optical properties at all of the Maritimes/Gulf fixed stations in 2005 were indistinguishable from properties observed in previous years.

Nutrients. Winter maxima in surface nutrients and summer-time reduction in concentrations is a common feature in the Maritimes/Gulf regions. For the most part, the seasonal cycles of nutrients, vertical structure and regional variations were similar in 2005 to previous years; there were some differences, however.

Winter nitrate inventories in near surface waters were lower in 2005 at Halifax-2 and Prince-5 and summer inventories lower at Shediac than seen previously; no winter data were available for Shediac. In addition, the depth of the nitrate depleted surface layer at Halifax-2 was the deepest on record in 2005. Deep nitrate inventories (>50 m) were also at record low levels at Halifax-2.

Lower winter nitrate inventories in near surface waters (<50 m) suggest less vigorous winter mixing. Certainly, the winter mixed layer depths at Halifax-2 were shallower in 2005 than the record deep mixed layers seen in 2004 but not significantly different from the long term average. Nor was there any evidence of less winter mixing at the Prince-5 station. The trend of decreasing wintertime nitrate levels over the past three years at Halifax-2, if not easily linked to mixing, may mean that the nitrate content of source waters has been changing (decreasing). At Halifax-2, deep (>50 m) nitrate inventories have, in fact, been decreasing with record lows observed in 2005 and anomalies of –8 μM.

In addition to the lower winter nitrate inventories in 2005, summertime nitrate depletion depths at Halifax-2 were 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. Since the chlorophyll concentrations were not unusually high in summer 2005 at Halifax-2 (levels have, in fact, been generally decreasing since 1999), reduced vertical mixing must have accounted for the low surface nutrients although mixed layer depths and stratification data did not show evidence of this.

Phytoplankton. Despite the fact that phytoplankton variability (both temporal and spatial) is characteristically high in coastal waters, the development of a pronounced spring/summer (and less conspicuous fall) phytoplankton blooms are evident from observations at the Maritimes/Gulf 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 and the western Southern Gulf of St. Lawrence in fall, are also observed yearly. There were, however, some features of the phytoplankton growth cycle in the Maritimes/Gulf regions distinctive for 2005, the most prominent of which was the third consecutive strong (but short-lived) spring bloom at Halifax-2 and the lower than normal summer chlorophyll levels at Shediac and Prince-5. The strong 2005 bloom was also evident during the spring groundfish survey and shelf section surveys where record high chlorophyll levels were observed.

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 Shediac Valley station, the presence of ice in winter strongly influences bloom dynamics in this region. At Prince-5, on the other hand, tidal mixing strongly influences the timing of the bloom which generally starts later in the year (May/June) than at the other two fixed stations. Bloom magnitude and duration are thought to be regulated largely by nutrient supply. Since, generally speaking, the timing of initiation of the 2005 spring bloom in the Maritimes/Gulf region was not an issue but the magnitude and duration were, one should be looking for changes in nutrient inventories (principally in the winter preceding) to explain the strong spring bloom of short duration observed at Halifax-2 and the lower than normal summer levels at Shediac and Prince-5. Winter nitrate inventories at both Halifax-2 and Prince-5 were lower than observed previously. The lower winter nutrient reserves at Halifax-2 did not apparently influence the magnitude of the bloom, which was on par with levels seen in 2003 and 2004, but may have contributed to the record low duration of only ~25 days in 2005 (compared with a norm of ~50 days). Abrupt changes in water masses, as inferred from the anomalously low deep nitrate concentrations at about the time of the bloom's termination might also have contributed to its short duration by eliminating or at least reducing the deep source of nutrients needed to sustain the bloom. Greenan et al. (2004), investigating the influence of high-frequency physical processes on bloom dynamics in the same region in 2000 noted that the termination of the bloom that year coincided with a downwelling event, suggesting that it played a role in determining the duration of the bloom.

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

C. finmarchicus occurred close to the time of the bloom termination so grazing might also have been a factor. However, this reproductive pattern was not out of the norm for this station nor were overall zooplankton abundances higher in spring 2005 than usually seen. Some progress in answering these important questions on bloom dynamics could be addressed through modelling (scenario-testing).

Low summer chlorophyll levels at Shediac could be linked to the lower than normal nitrate levels seen there in 2005 (although sampling was limited). In a similar way, the declining background chlorophyll levels at Halifax-2 (outside of bloom periods) could be reasonably linked to declining near surface nutrient reserves in recent years as evidenced by the deepening nitracline, especially in 2005. The lower than normal summer chlorophyll levels at Prince-5 (and delayed growth), however, could not be explained by nutrients since levels are never depleted there, even in summer. Changes in the phytoplankton growth cycle at Prince-5 in 2005 are hard to explain since the obvious control factors, e.g the shallower mixing and stronger stratification, would provide more favorable light conditions conducive to more chlorophyll production rather than less. The delay in growth is puzzling as well. Zooplankton grazing would not have been an issue until late in the year when numbers (particularly *C. finmarchicus*) increased dramatically.
On a broader geographic scale, differences seen in chlorophyll concentrations along on the Scotain Shelf during in the spring section survey could be attributed to regional differences in the timing of the bloom. The survey in 2005 was conducted the earliest (first week of April) since systematic observations began in 1999. Most occupations have been mid-April to early May. The record low chlorophyll concentrations seen in Cabot Strait can be attributed to occupation of the stations before the bloom was fully developed. The record high chlorophyll concentrations along the Halifax line, on the other hand, could be attributed to sampling when the bloom was at its peak. Ocean colour data from SeaWiFS and MODIS corroborate this conclusion, i.e. Scotian Shelf blooms generally start earlier (late March-early April) on the central shelf than on the eastern shelf (late April-early May).

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. 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/Gulf fixed stations also occur. At the Shediac and Halifax-2 stations, a clear transition from diatom-dominated communities in winter/spring to flagellate-dominated communities in summer/fall is evident. At the Prince-5 station, in contrast, diatoms dominate year-round. No noteworthy changes in phytoplankton community structure were observed at any of the fixed stations in 2005.

<u>Zooplankton</u>. Like phytoplankton, zooplankton in the Maritimes/Gulf regions are characterized by high spatial and temporal variability. Despite that, recurring patterns in distribution and growth cycles are emerging from AZMP Maritimes/Gulf data. Both biomass and numerical abundance of zooplankton are: (1) generally higher in spring than in fall, (2) higher (summer and fall) on the western Scotian Shelf/eastern Gulf of Maine and Southern Gulf than on the eastern shelf and (3) higher in the deep basins and off the edge of the shelves than in shallow waters and on banks. At the Maritimes/Gulf fixed stations, lowest levels of zooplankton (and the important copepod, *C. finmarchicus*) have been observed at Prince-5 and highest at Halifax-2 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 very regular and predictable seasonal emergence of barnacle/echinoderm larvae in the late spring at Prince-5 is another example.

Some features of the zooplankton community were notable in 2005, however. During the March eastern Scotian Shelf groundfish survey, the lowest zooplankton biomass levels were seen since sampling began in 1999. On the other hand, during the spring shelf section survey, record high *C. finmarchicus* abundances were seen in Cabot Strait. During the summer groundfish survey, zooplankton biomass was again at record low levels on the Scotian Shelf. During the fall shelf section survey, record low numbers of of *C. finmarchicus* were seen in Cabot Strait while record high numbers were seen on the central shelf. Causes for these large geographic and temporal swings in zooplankton biomass/abundance are unclear at this point. However, the record highs (central shelf) and lows (Cabot Strait) in *C. finmarchicus* abundances in fall could have been linked to the corresponding highs and lows in chlorophyll observed in those regions in spring. The timing of *C. finmarchicus* reproduction at Halifax-2 appeared to start later than in 2004 and closer to the long term average timing based on the appearance of young developmental stages. At all fixed stations, the contribution of *Calanus* to the complement of copepod species has continued to increase since AZMP sampling began in 1999 with the increase has been most striking at Prince-5. The causes of these changes in species composition are unknown at present.

At the larger scale and over the long-term, the CPR data record shows that contemporary zooplankton abundance, in general, has been considerably lower over the past decade than it was during the decade following the initiation of the CPR surveys in the 1960s. However, over the past few years, abundances have been on the increase for some species (*C.* finmarchicus, *Paracalanus/Pseudocalanus spp*) but continue to be down for others (euphausiids). The explanation for the fundamental shift (decrease) in zooplankton during the recent decade in the presence of an abundant food supply (CPR phytoplankton abundances well above levels observed in the 1960s/1970s) is still a major unknown.

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Table 1. AZMP Sampling Missions in the Maritimes/Gulf regions, 2005.

Group	Location	Mission ID	Dates	# Hydro Stns	# Net Stns
Groundfish Surveys	Georges Bank	TEL2005545	Feb 18 – Mar 04	37	13
	Eastern Shelf	TEL2005546	March 5 - 16	38	7
	Scotian Shelf	NED2005027	June 27 – Jul 13	22	-
	Scotian Shelf	TEL2005605	Jul 05 – 13	78	15
	Scotian Shelf	TEL2005633	Jul 13 – 27	116	21
	SGSL	TEL2005607	Sep 06 – 27	139	14
Special Missions	Gulf of Maine	HUD2005021	June 11 - 17	7	7
Seasonal Sections	Scotian Shelf	NED2005004	Apr 01 – 10	39	38
	Scotian Shelf	No summer Section	June	-	-
	Scotian Shelf	HUD2005055	Oct 17 – 31	39	32
Fixed Stations	Shediac	BCD2005668	May 16 – Oct 05	4	5
	Halifax-2	BCD2005666	Feb 18 – Oct 28	16	15
	Prince-5	BCD2005669	Jan 25 – Dec 15	12	10
			Total:	**547**	**178**

Table 2. Chemical and biological properties of the 1999-2005 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
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
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
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

Table 3. Chemical and biological properties of the 1999-2005 summer Scotian and fall Southern Gulf of St. Lawrence groundfish surveys. Statistics: means, (ranges), #obs. Numbers in brackets in oxygen column represent percent area of shelf covered by bottom waters with <60% oxygen saturation.

Survey	Year	Chlorophyll ($mg\ m^{-3}$) Surface (5 m)	Nitrate ($mmol\ m^{-3}$) Bottom	Oxygen (% Saturation) Bottom	Zoopl Biomass ($g\ wet\ wt\ m^{-2}$)	*C. finmarchicus* ($Ind\ m^{-2}$)
Scotian Shelf						
	1999	**0.93** (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
Southern Gulf						
	1999	**1.65** (0.03-4.97) 185	**9.87** (0.35-22.92) 178	**84** (38-114) 180	**37.4** (5.1-112.0) 17	**18,101** (0-56,354) 17
	2000	**1.56** (0.16-6.35) 197	**11.45** (0.37-24.57) 192	**79** (33-117) 175	**44.9** (4.5-223.7) 17	**36,840** (221-248,753) 17
	2001	**1.04** (0.04-3.60) 149	**8.93** (0.19-23.94) 155	**98** (68-118) 8	**30.6** (2.9-142.0) 18	**23,946** (35-46,630) 18
	2002	**2.36** (0.75-5.97) 176	**10.91** (0.37-24.94) 175	**68** (28-95) 175	**42.5** (4.5-153.0) 18	**29,475** (129-79,679) 17
	2003	**1.13** (0.07-2.78) 83	**8.19** (0.23-24.53) 79	**71** (27-90) 79	**48.2** (7.6-129.9) 7	**61,452** (3,378-162,075) 7
	2004	**1.89** (0.08-9.65) 170	**9.73** (0.00-24.18) 164	**71** (28-100) 155	**74.3** (2.15-225.8) 16	**56,966** (39-128573) 16
	2005	**1.17** (0.50-3.49) 138	**8.9** (0.05-23.85) 138	**72** (27-96) 139	**42.9** (3.8-135.9) 14	**43,897** (237-117,711) 14

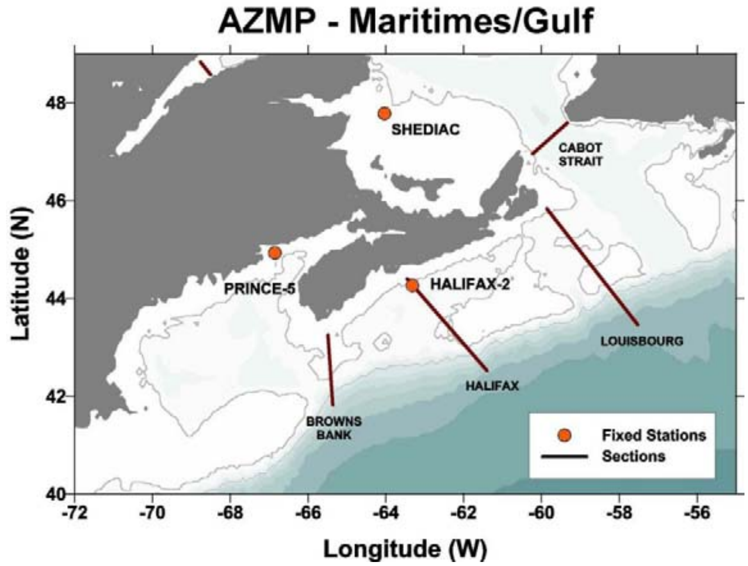

Figure 1. Primary sections and fixed stations sampled in the Maritimes/Gulf regions.

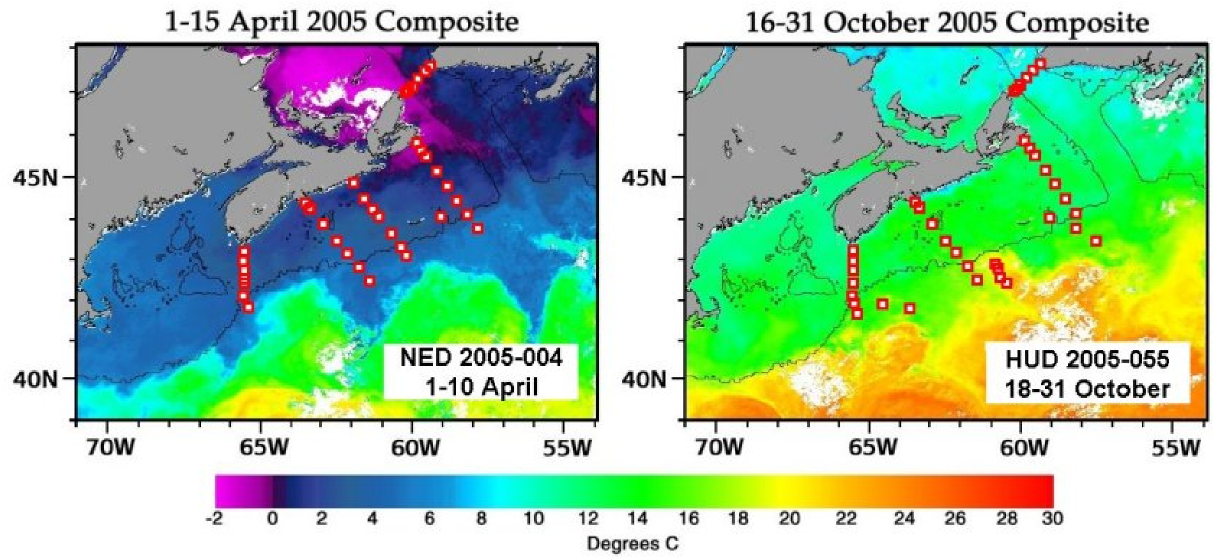

Figure 2. Stations sampled during the 2005 spring, summer and fall section surveys. Station locations superimposed on bi-weekly SST composite images.

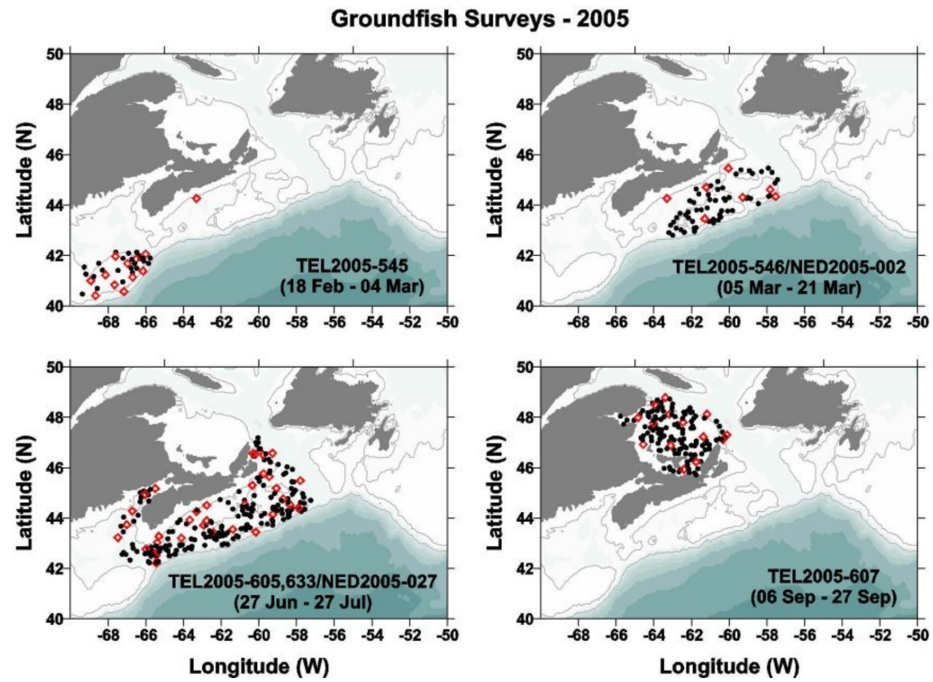

Figure 3. Stations sampled during major groundfish surveys in 2005. Black symbols are hydrographic stations; red symbols are stations where vertical nets hauls were taken in addition to hydrographic measurements.

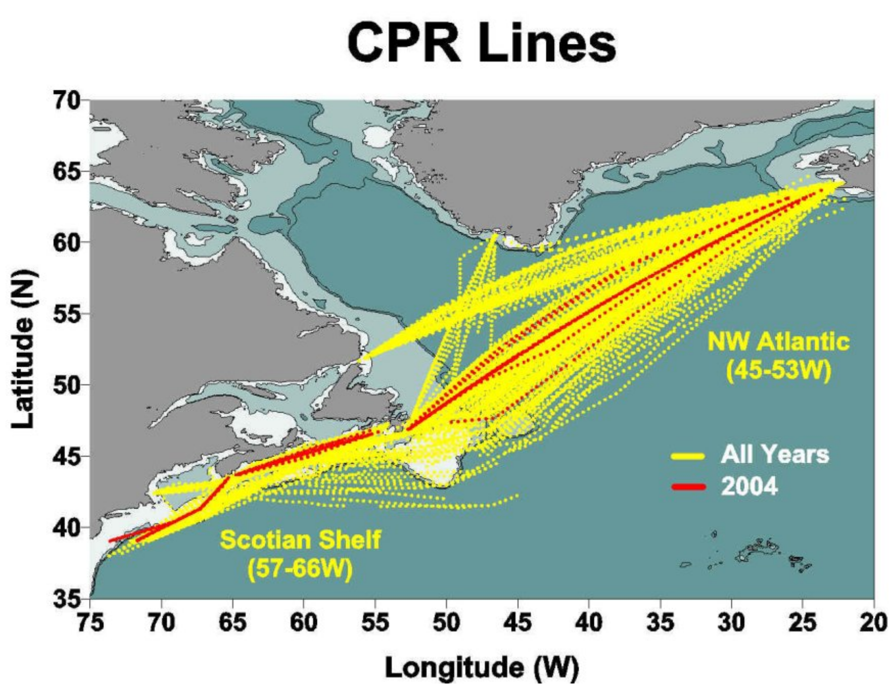

Figure 4. CPR lines and stations, 1961 to 2004 (2004 highlighted).

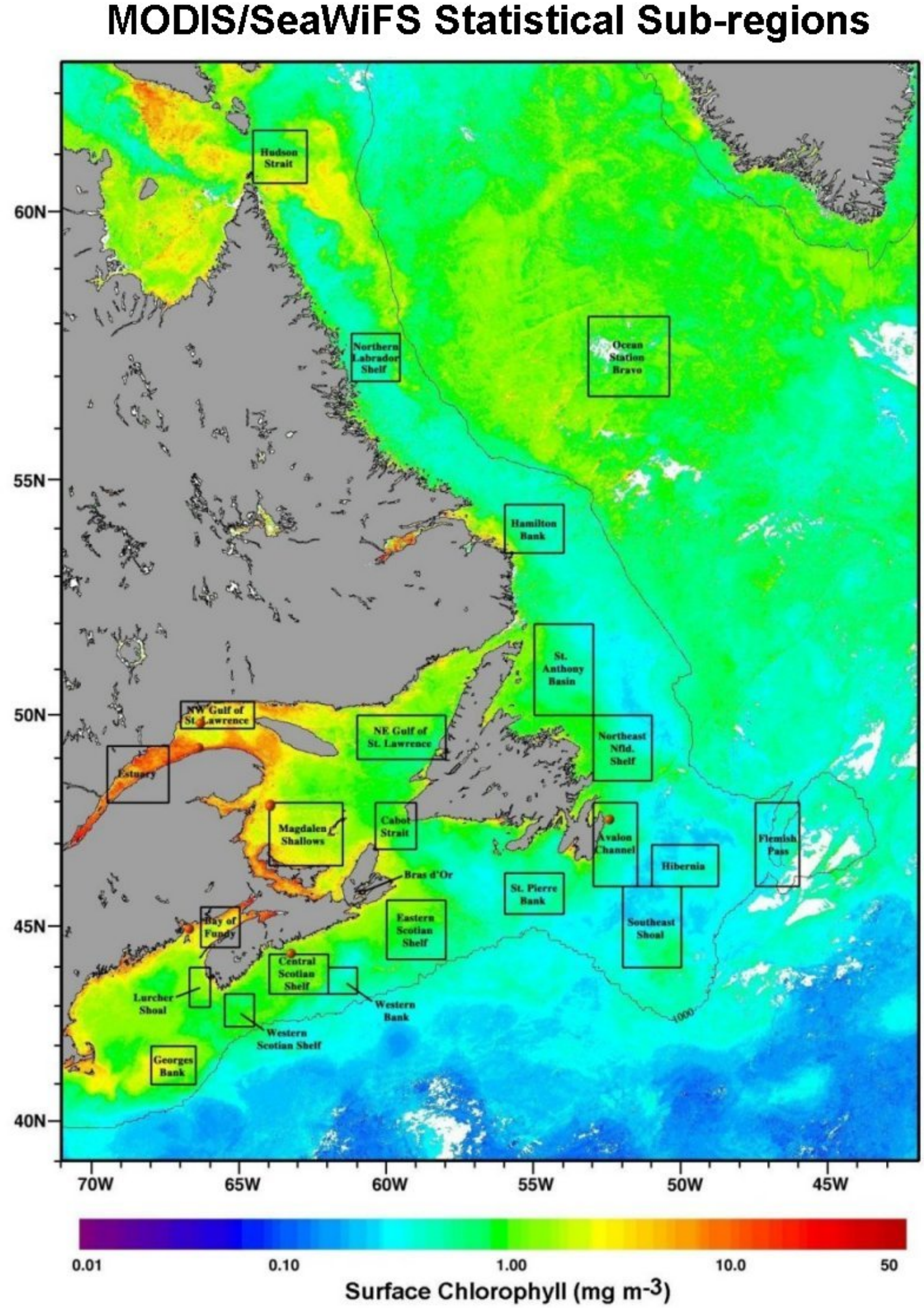

Figure 5. Statistical sub-regions in the Northwest Atlantic identified for spatial/temporal analysis of SeaWiFS/MODIS ocean colour data.

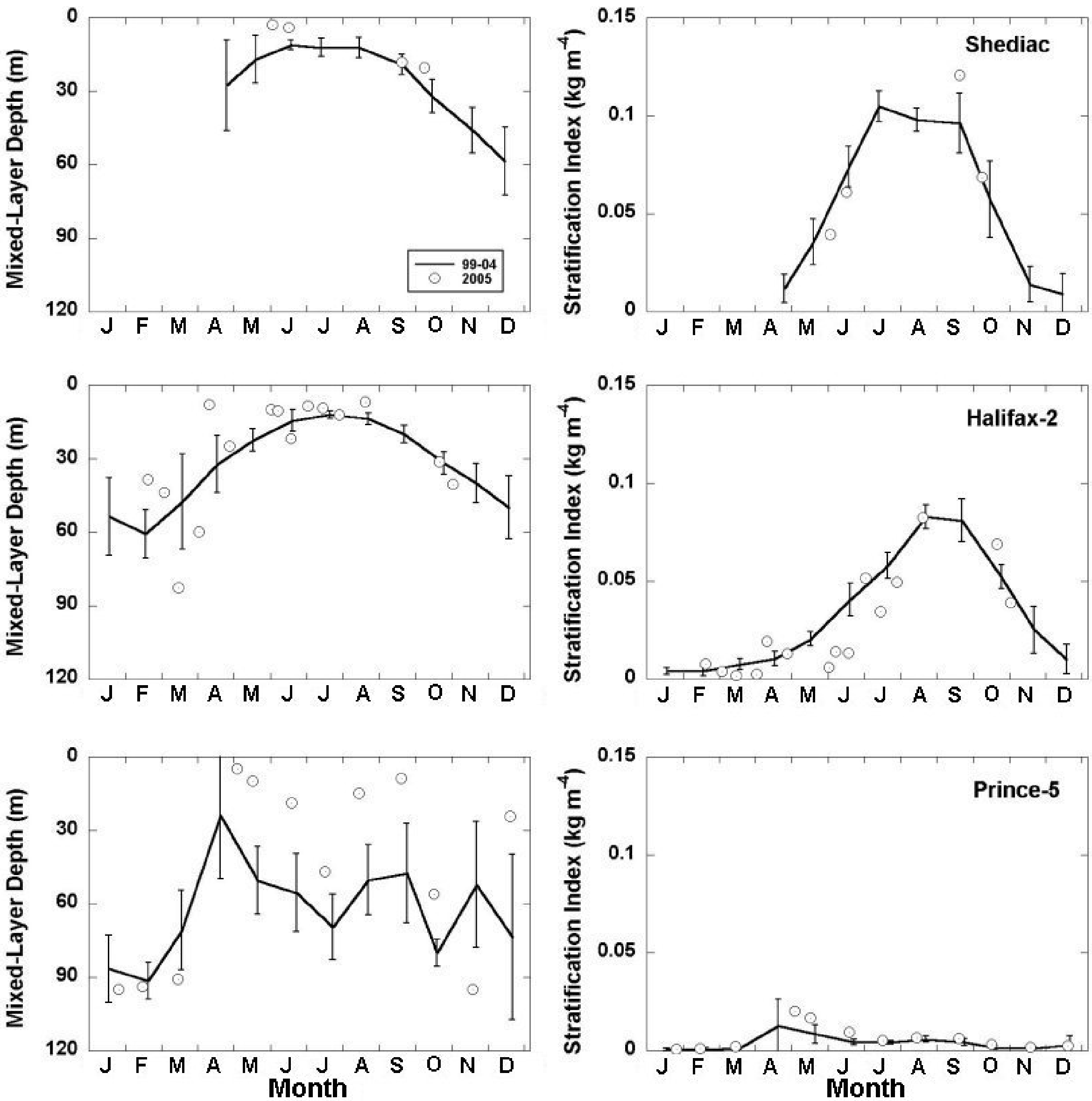

Figure 6. Mixing properties (mixed-layer depth, stratification index) at the Maritimes/Gulf fixed stations. 2005 data (circles) compared with observations from 1999-2004 (solid line). Vertical lines are 95% confidence limits.

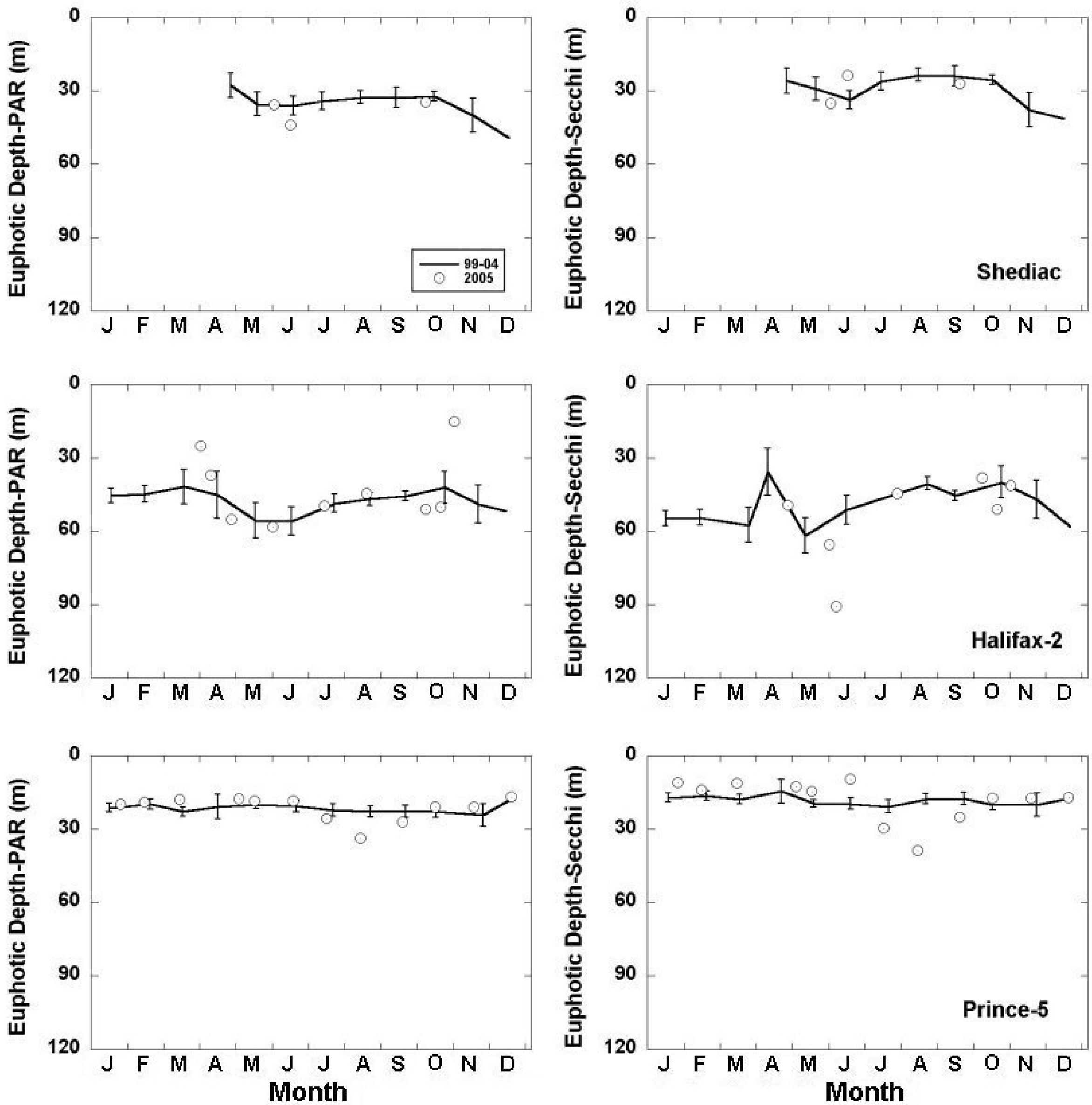

Figure 7. Optical properties (euphotic depth from PAR irradiance meter and Secchi disc) at the Maritimes/Gulf fixed stations. 2005 data (circles) compared with observations from 1999-2004 (solid line). Vertical lines are 95% confidence limits.

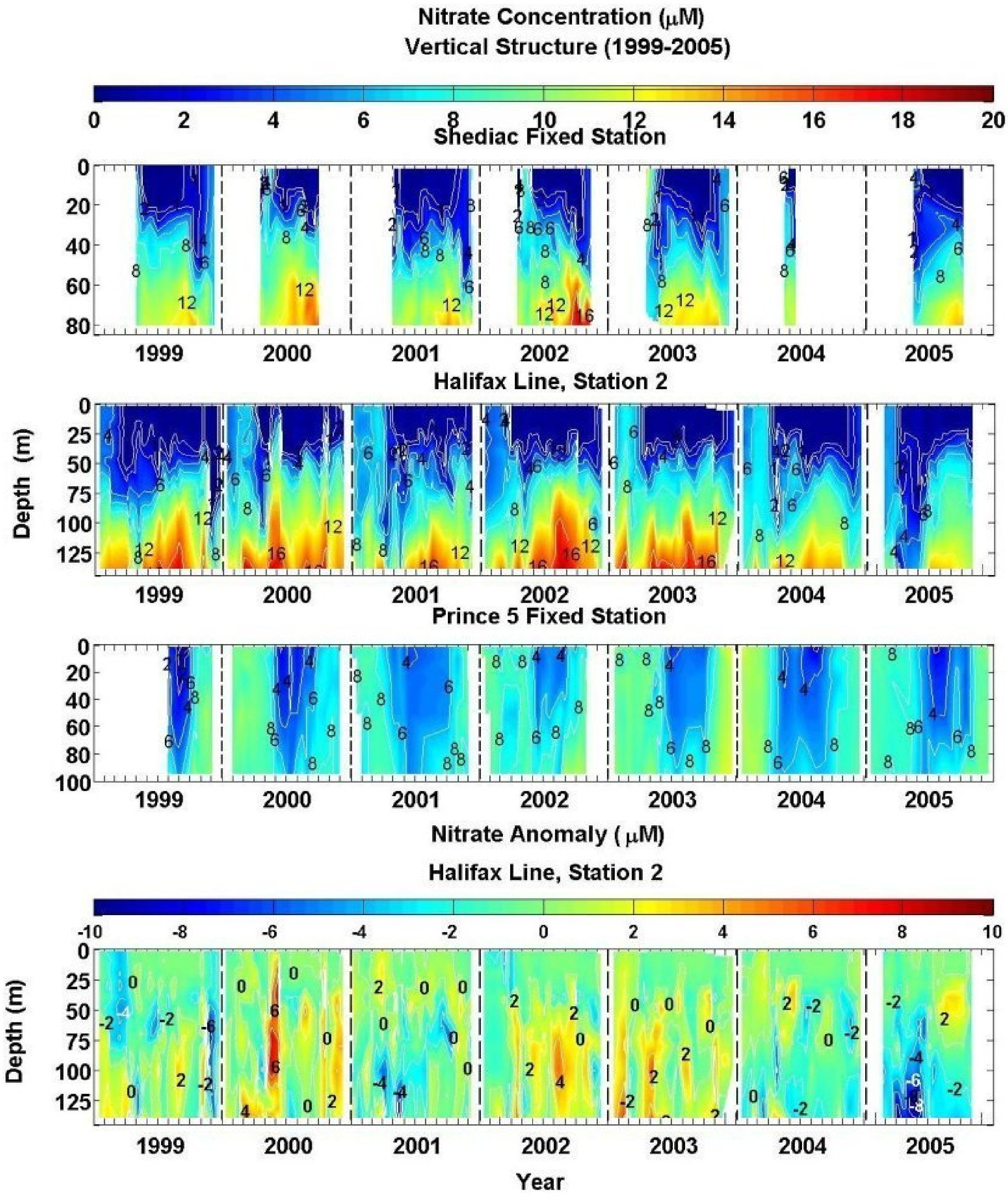

Figure 8. Time-series of vertical nitrate structure at the Maritimes/Gulf fixed stations, 1999-2005. Bottom panel: nitrate anomaly (2005 values minus long-term average).

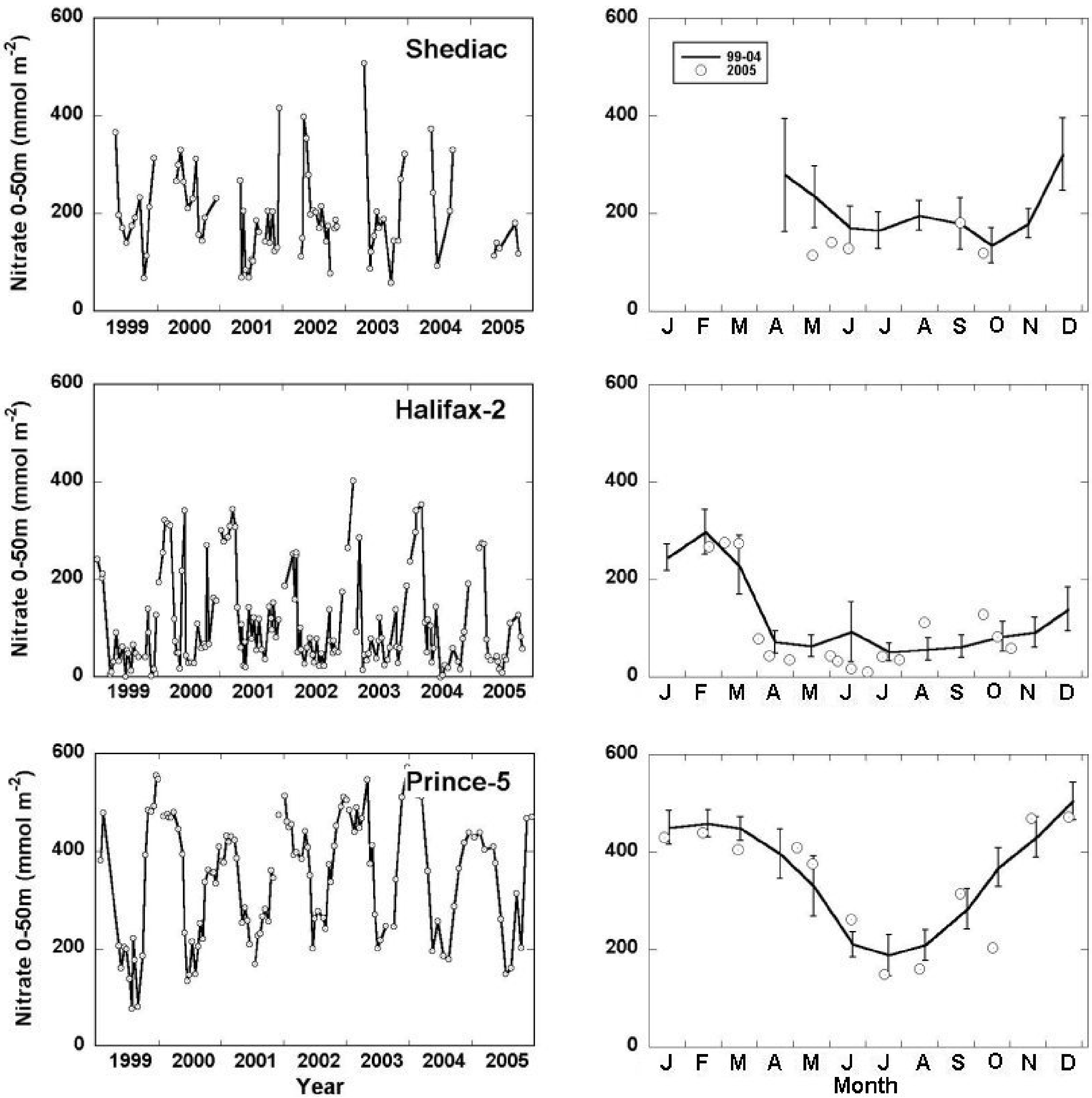

Figure 9. Nitrate inventories (surface-50 m integrals) at the Maritimes/Gulf fixed stations, 1999-2005. Right panels: 2005 data (circles) compared with observations from 1999-2004 (solid line). Vertical lines are 95% confidence limits.

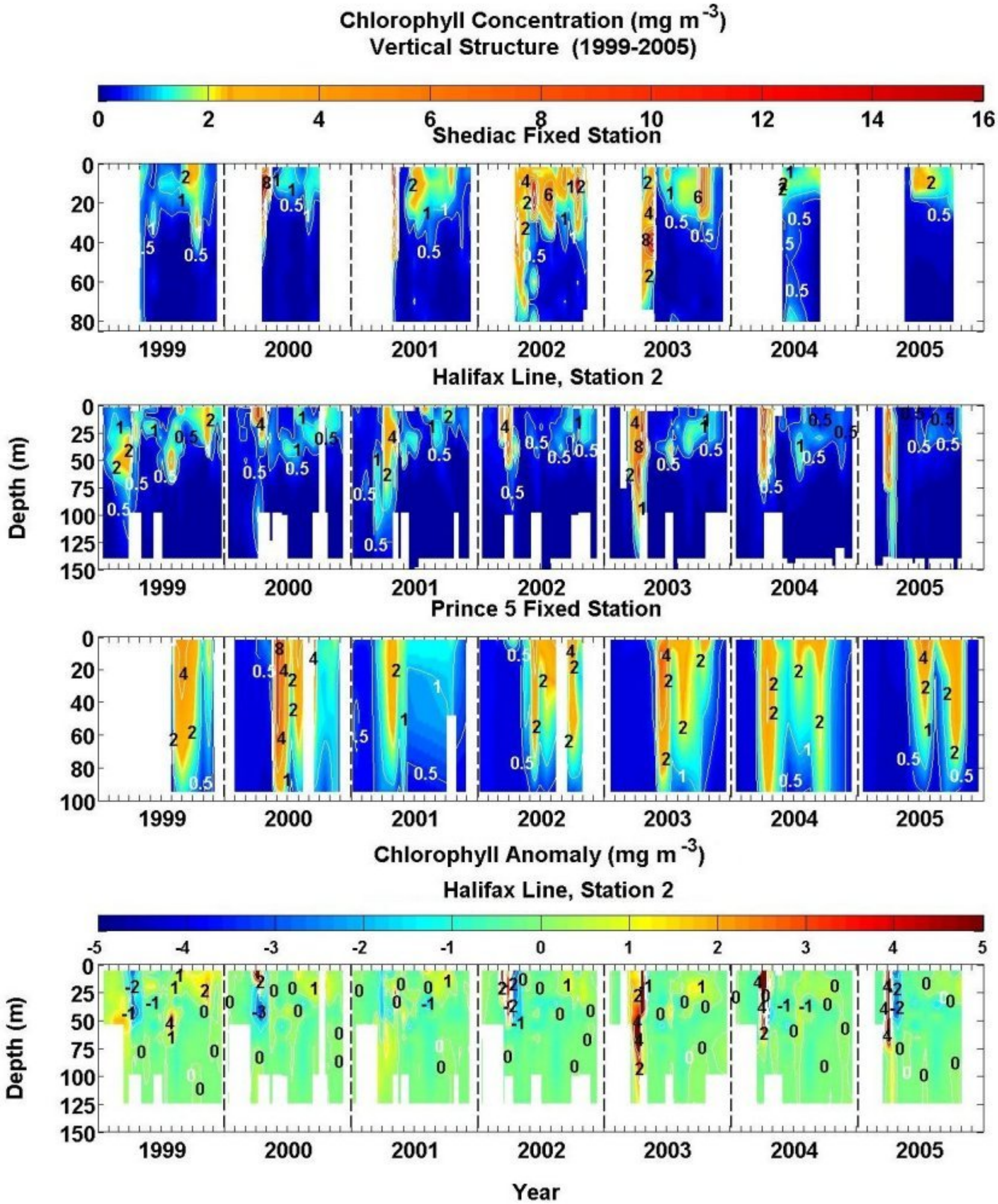

Figure 10. Time-series of vertical chlorophyll structure at the Maritimes/Gulf fixed stations, 1999-2005. Bottom panel: chlorophyll anomaly (2005 values minus long-term average).

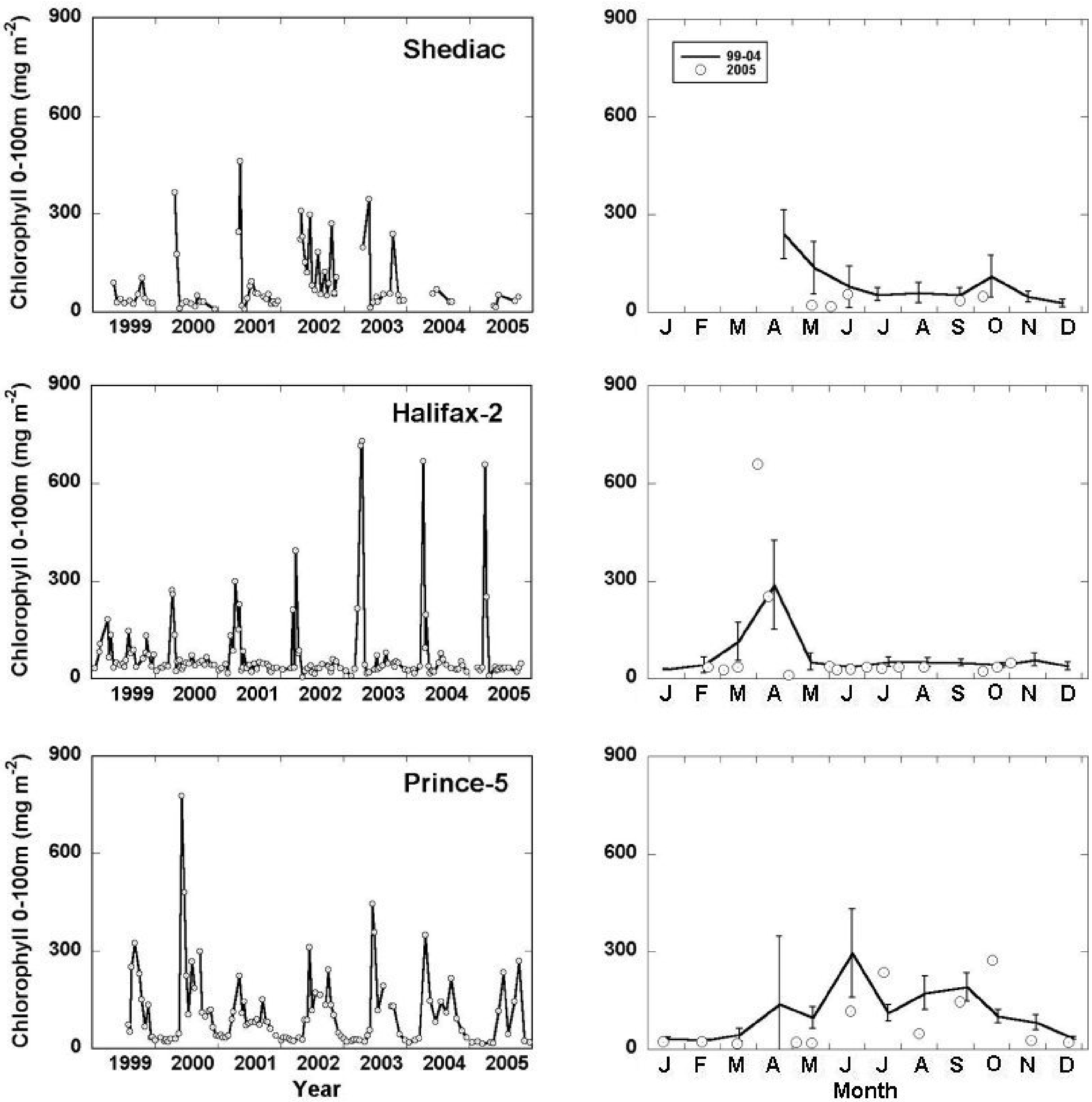

Figure 11. Chlorophyll inventories (surface-100 m integrals) at the Maritimes/Gulf fixed stations, 1999-2004. Right panels: 2005 data (circles) compared with observations from 1999-2004 (solid line). Vertical lines are 95% confidence limits.

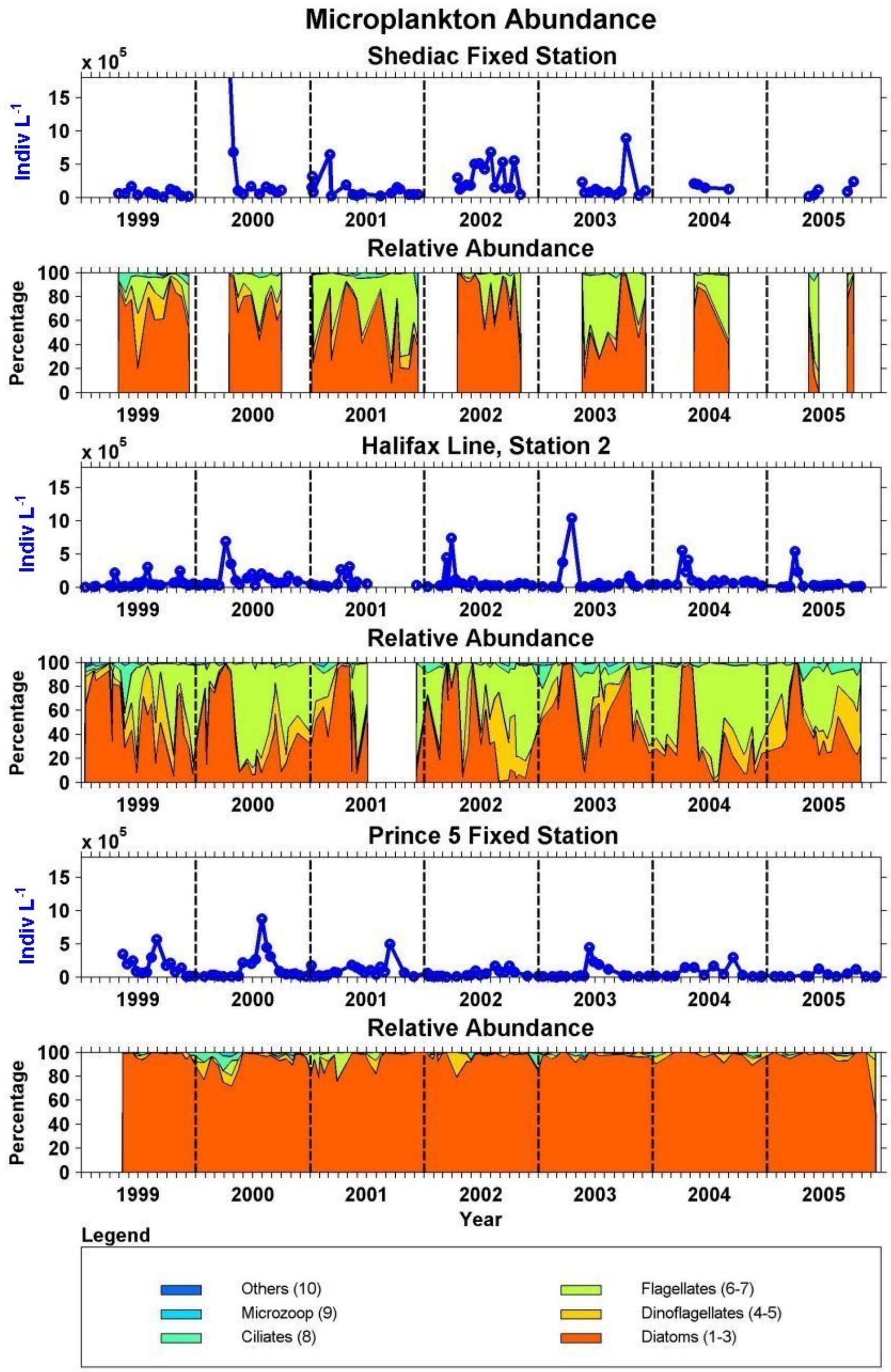

Figure 12. Time-series of microplankton (phytoplankton and protests) abundance and community composition at the Maritimes/Gulf fixed stations, 1999-2005.

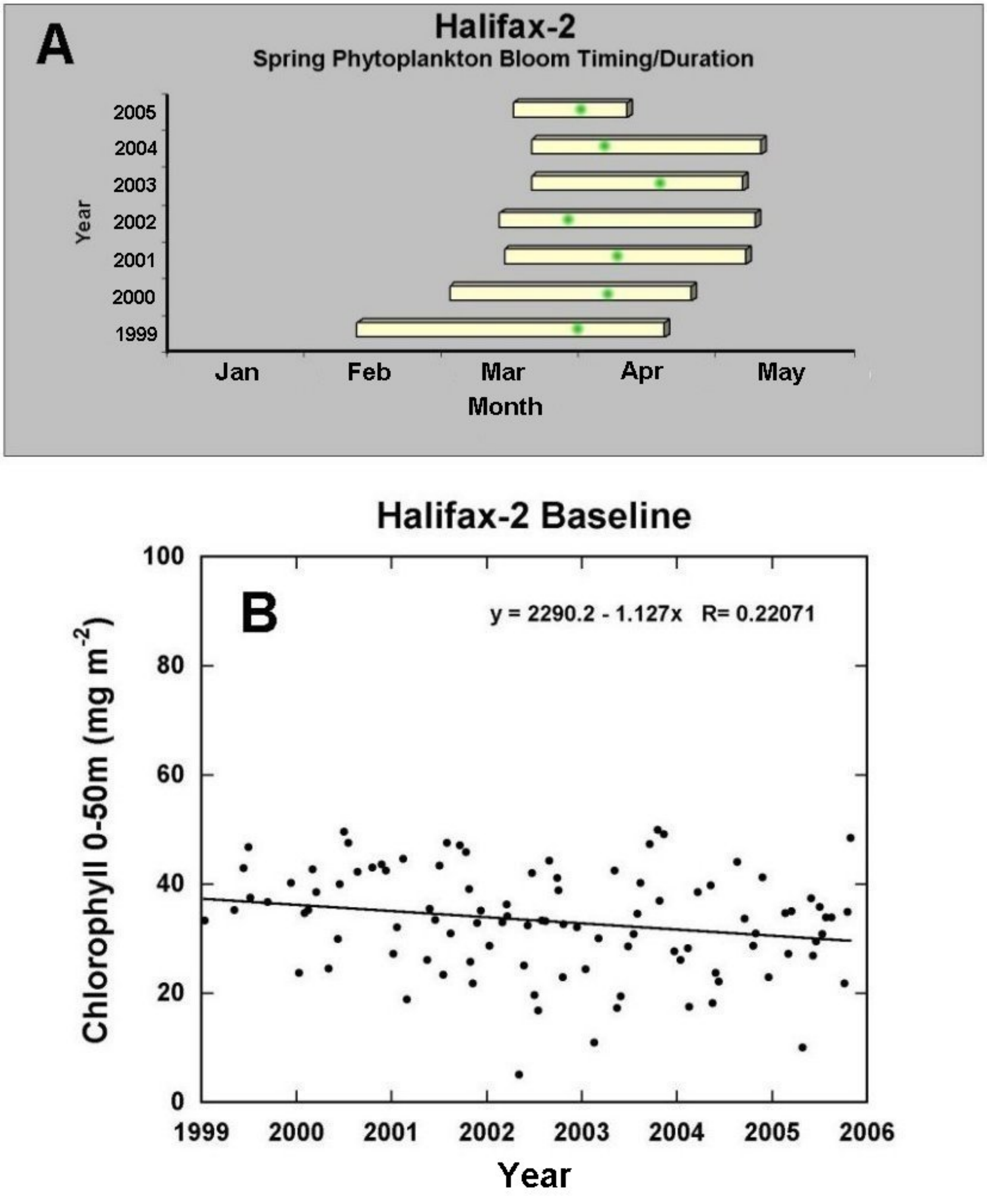

Figure 13. Dynamics of the spring phytoplankton bloom, Halifax-2 fixed station 1999-2005: (A) start-end times (duration) and time of peak chlorophyll levels (green circles inside horizontal bars), (B) baseline chlorophyll levels, outside of spring bloom periods (line = least squares linear regression).

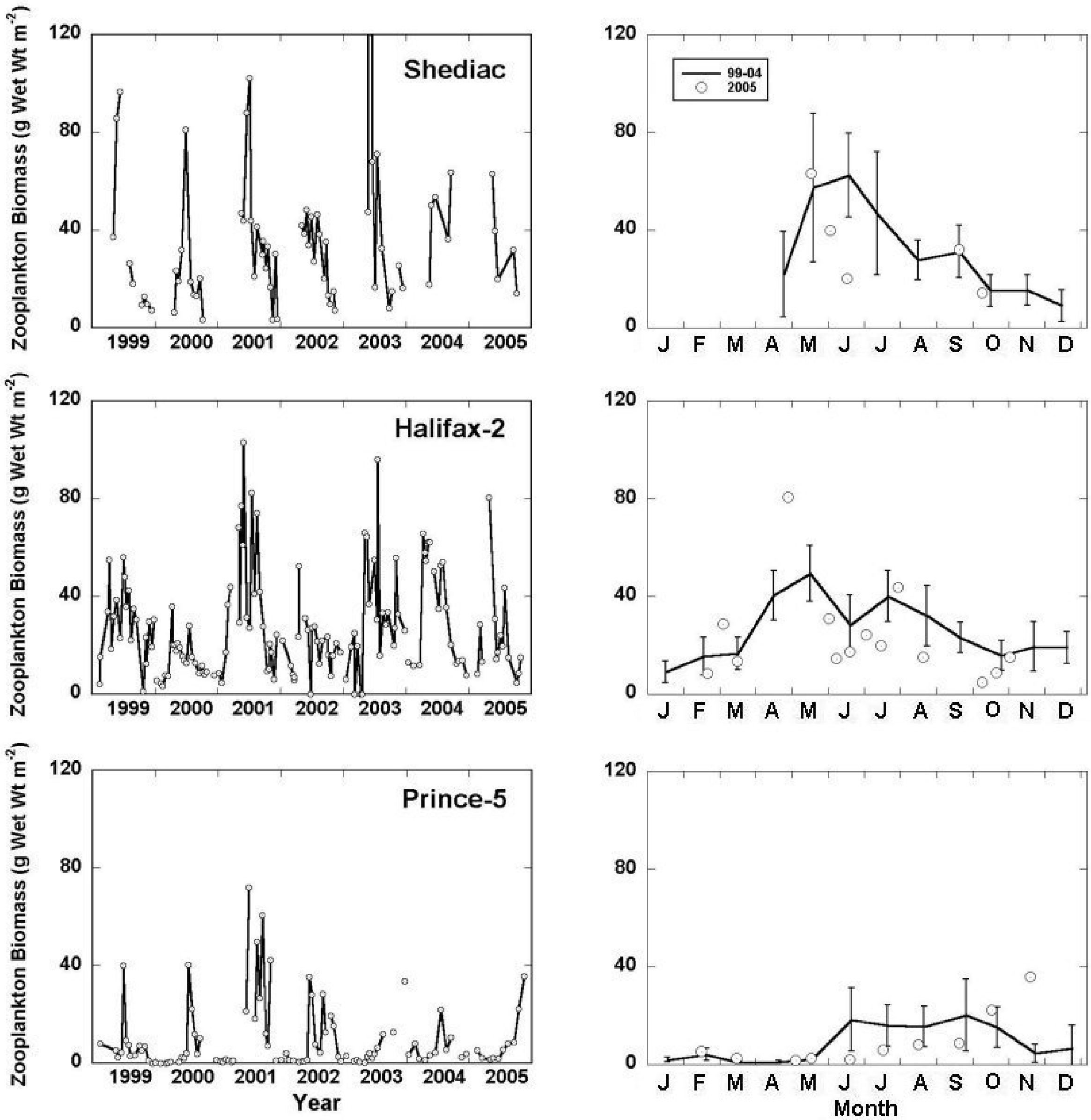

Figure 14. Time-series of zooplankton biomass (surface-bottom) at the Maritimes/Gulf fixed stations, 1999-2005. Right panels: 2005 data (circles) compared with observations from 1999-2004 (solid line). Vertical lines are 95% confidence limits.

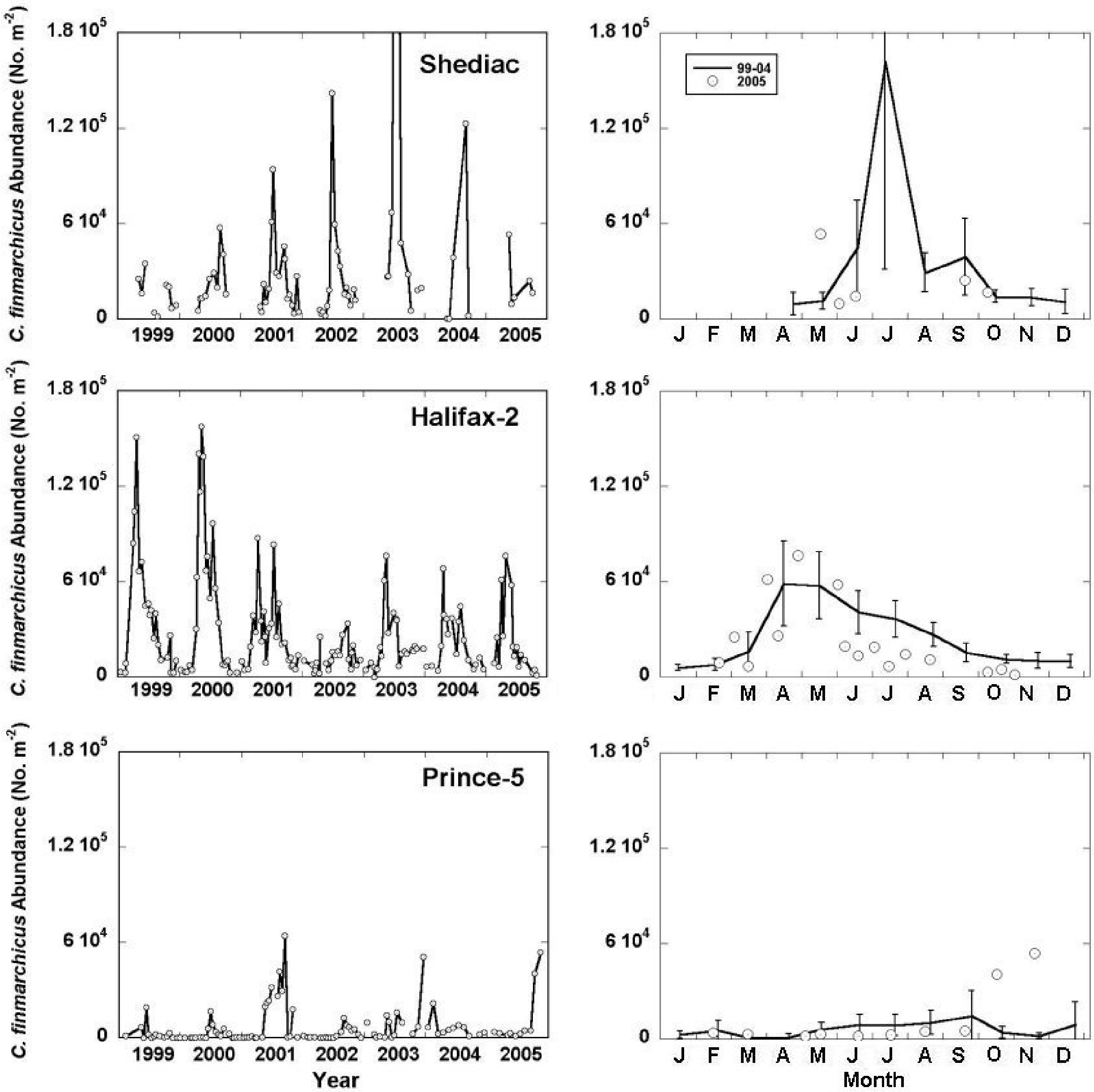

Figure 15. Time-series of *C. finmarchicus* abundance (surface-bottom) at the Maritimes/Gulf fixed stations, 1999-2005. Right panels: 2005 data (circles) compared with observations from 1999-2004 (solid line). Vertical lines are 95% confidence limits.

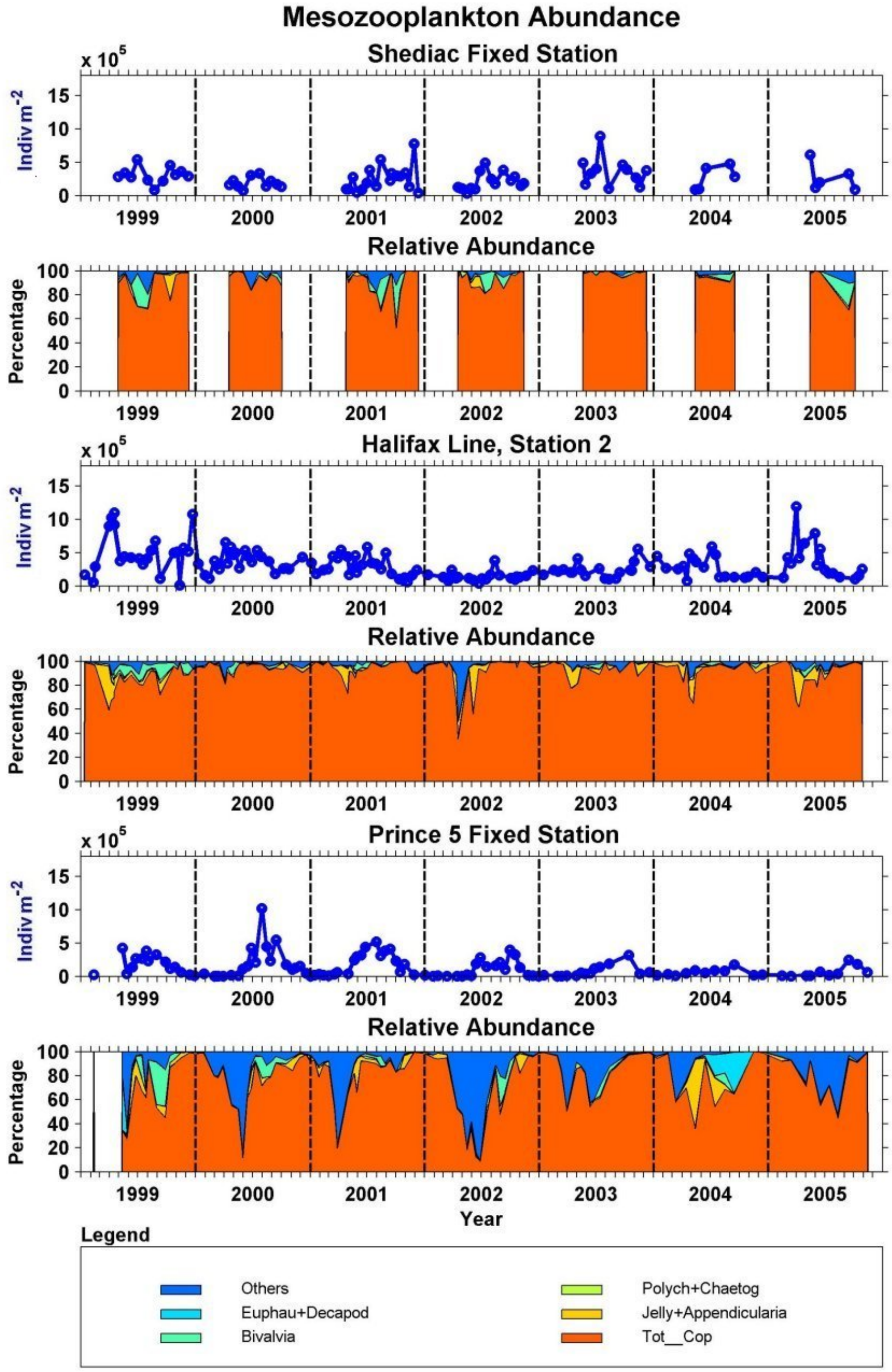

Figure 16. Time-series of mesozooplankton abundance and community composition at the Maritimes/Gulf fixed stations, 1999-2005.

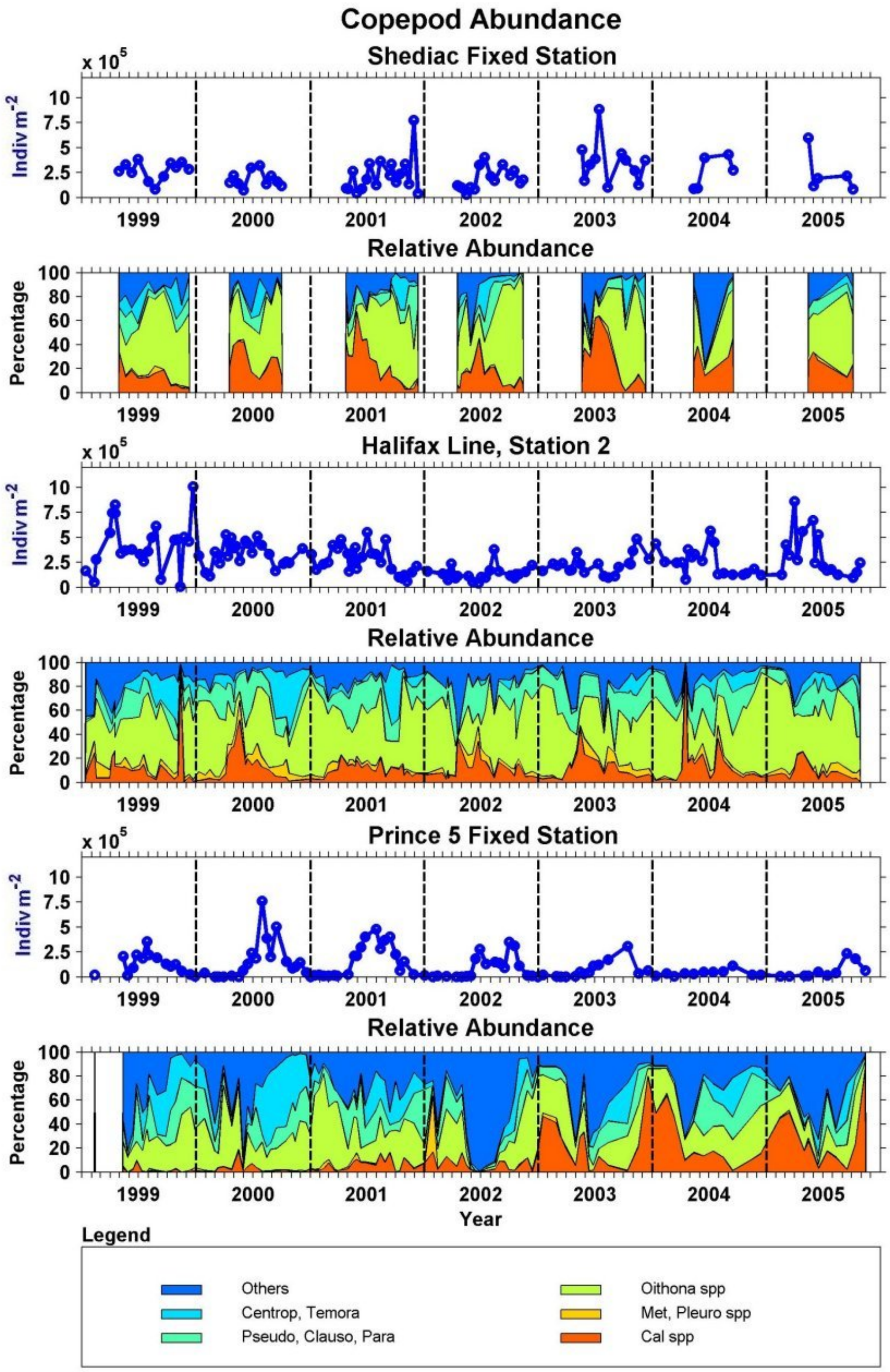

Figure 17. Time-series of copepod abundance and community composition at the Maritimes/Gulf fixed stations, 1999-2005.

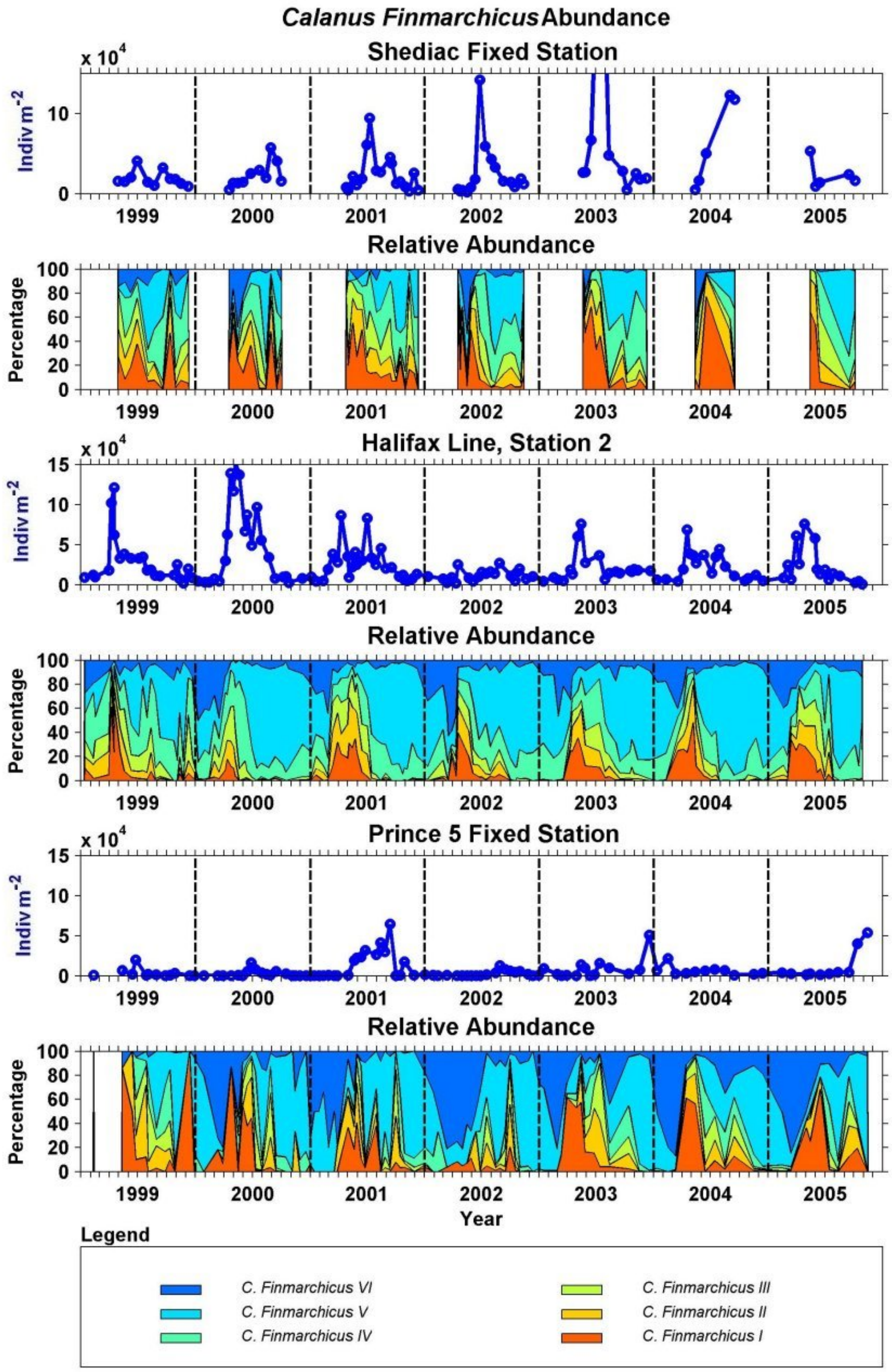

Figure 18. Time-series of *C. finmarchicus* abundance and developmental stages at the Maritimes/Gulf fixed stations, 1999-2005.

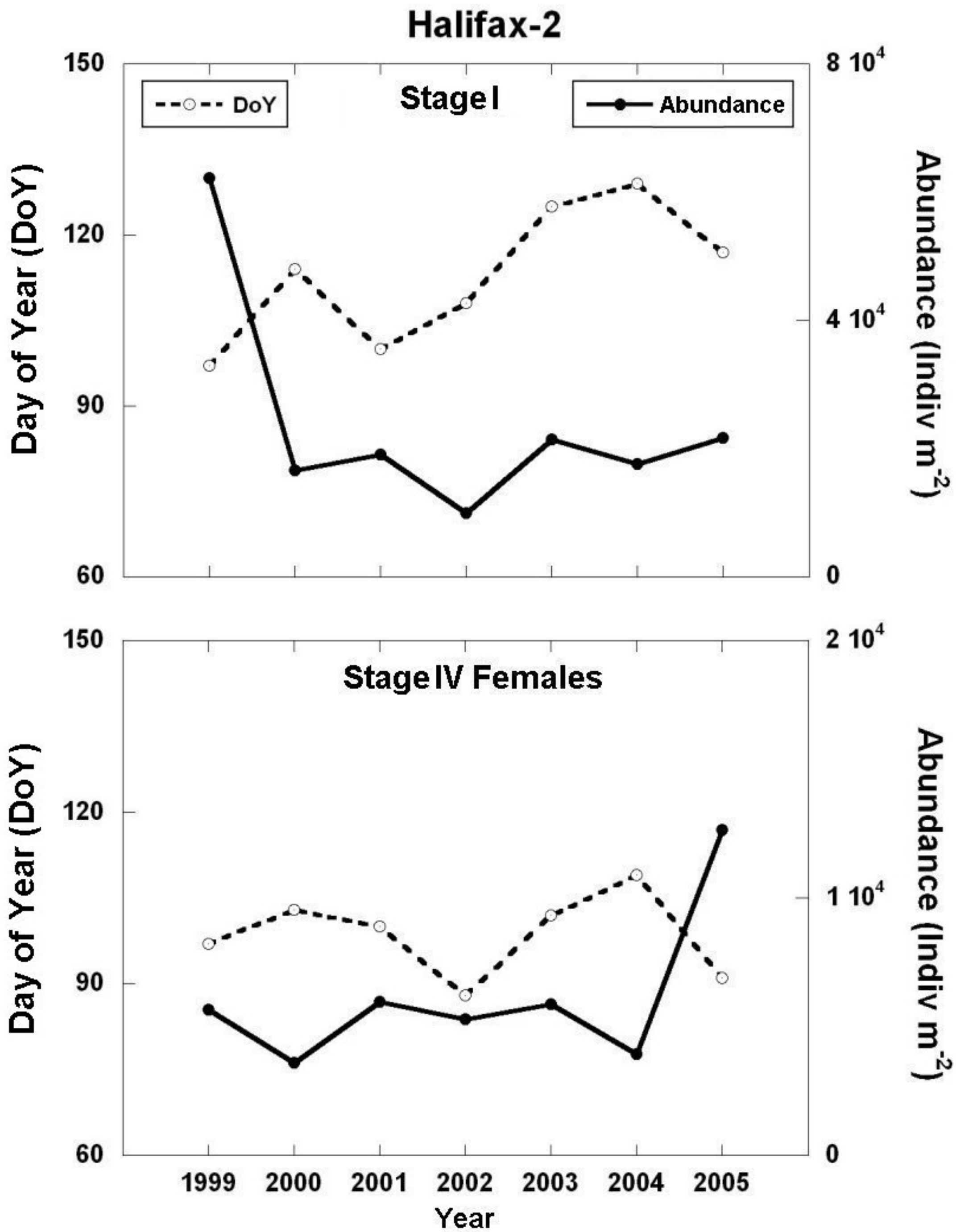

Figure 19. Time-series (1999-2005) of maximum abundance and timing of *C. finmarchicus* Stage-1s and Stage-4 females, Halifax-2 fixed station.

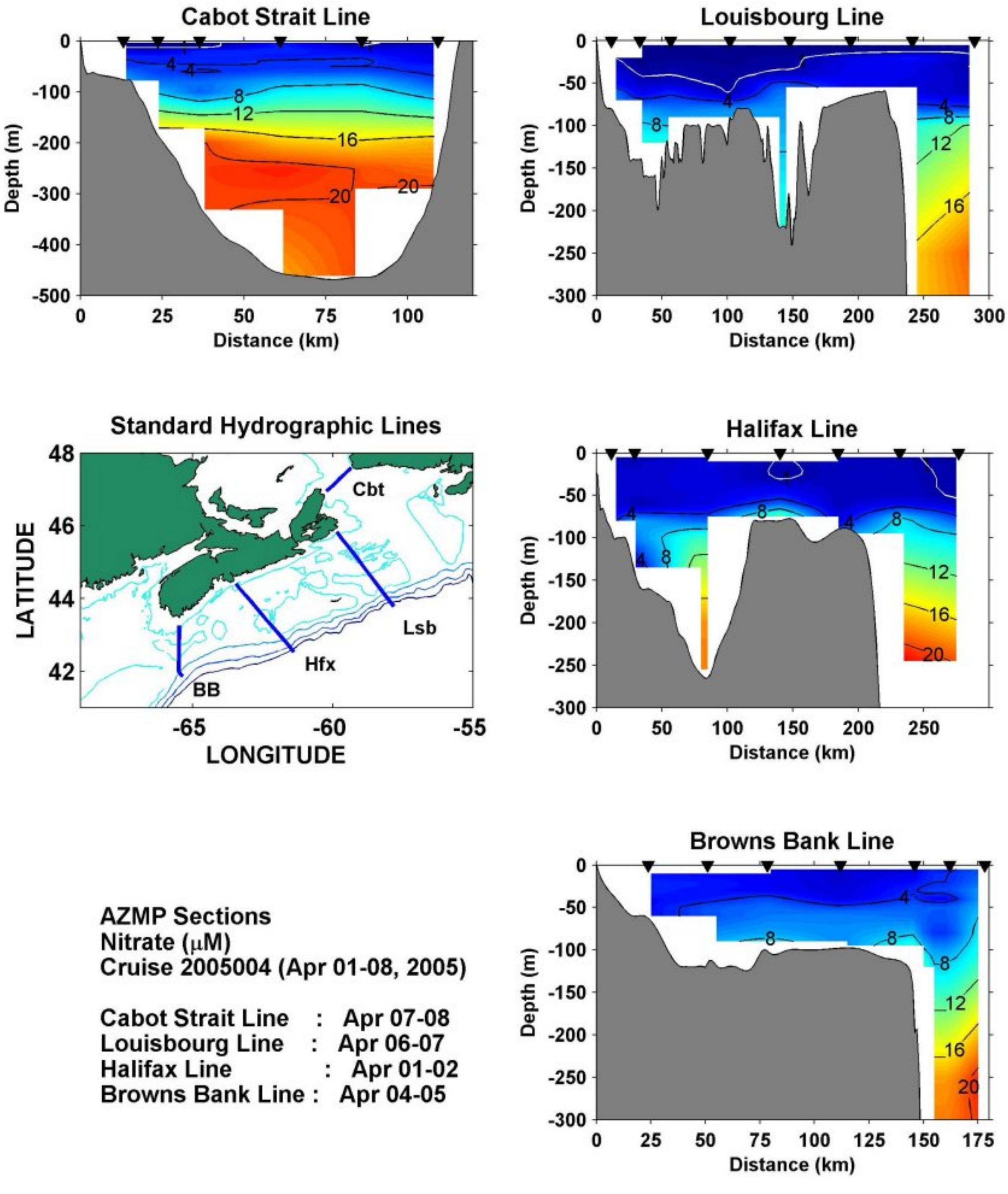

Figure 20. Vertical nitrate structure along the Scotian Shelf sections during the spring survey in 2005.

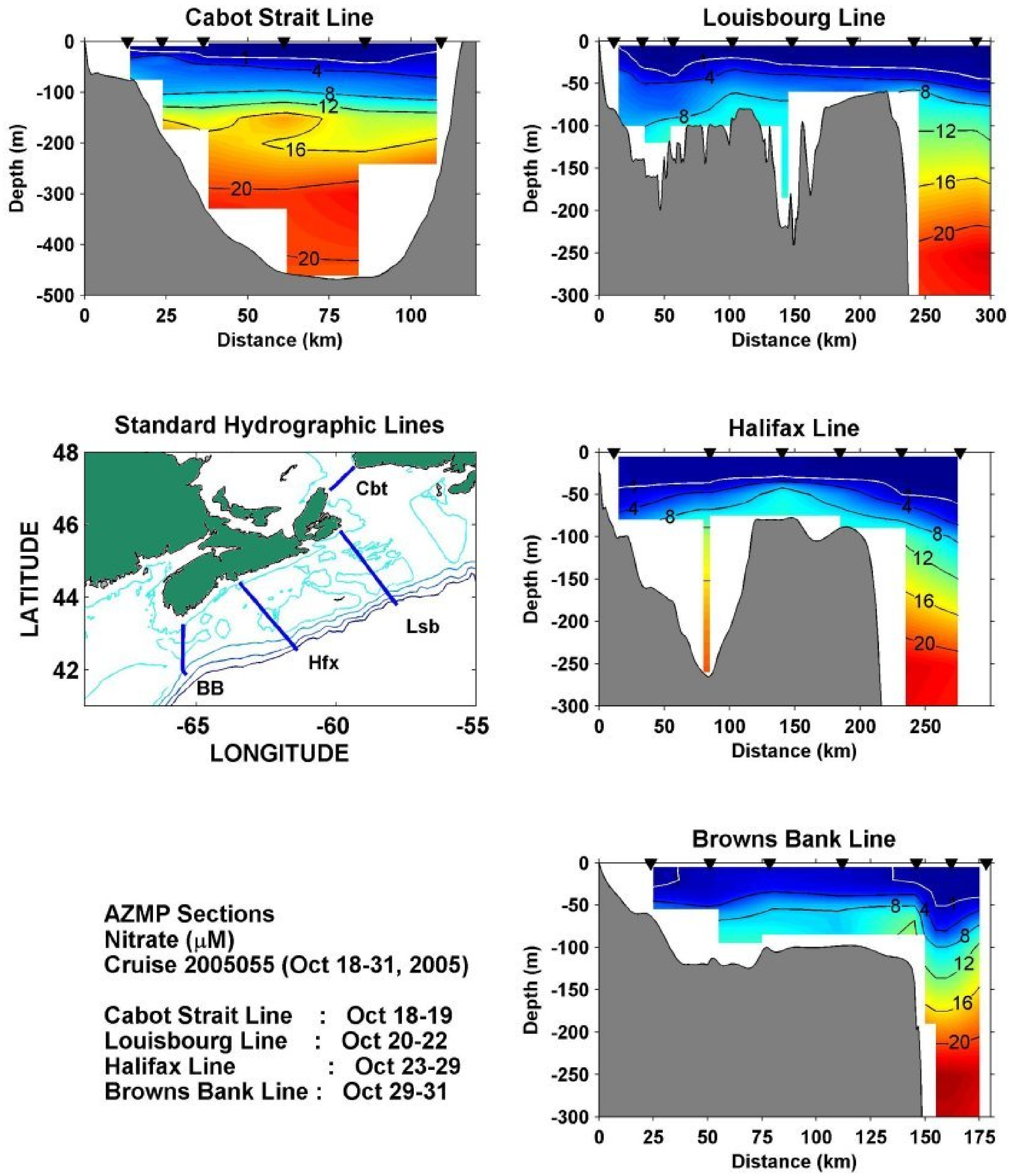

Figure 21. Vertical nitrate structure along the Scotian Shelf sections during the fall survey in 2005.

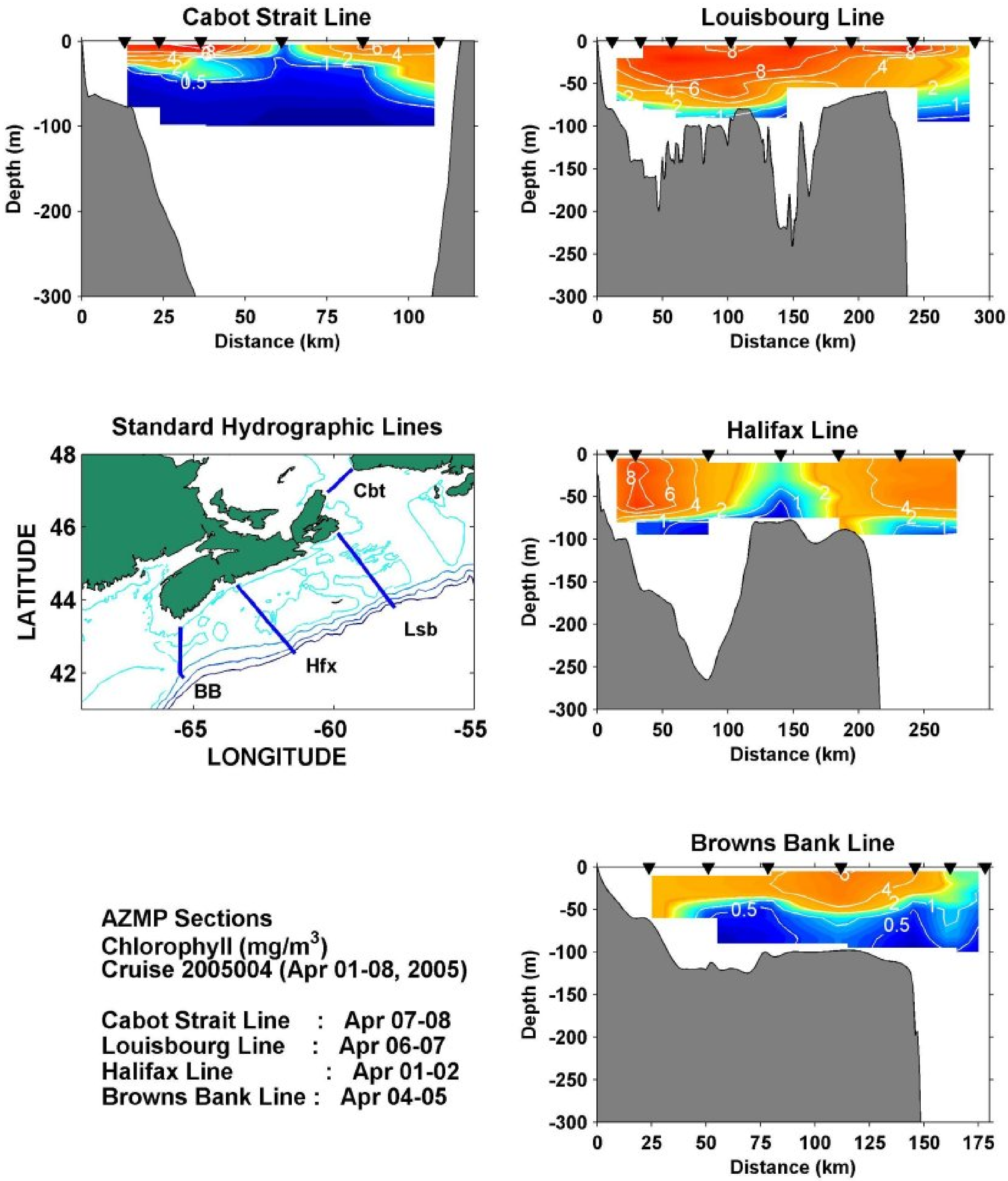

Figure 22. Vertical chlorophyll structure along the Scotian Shelf sections during the spring survey in 2005.

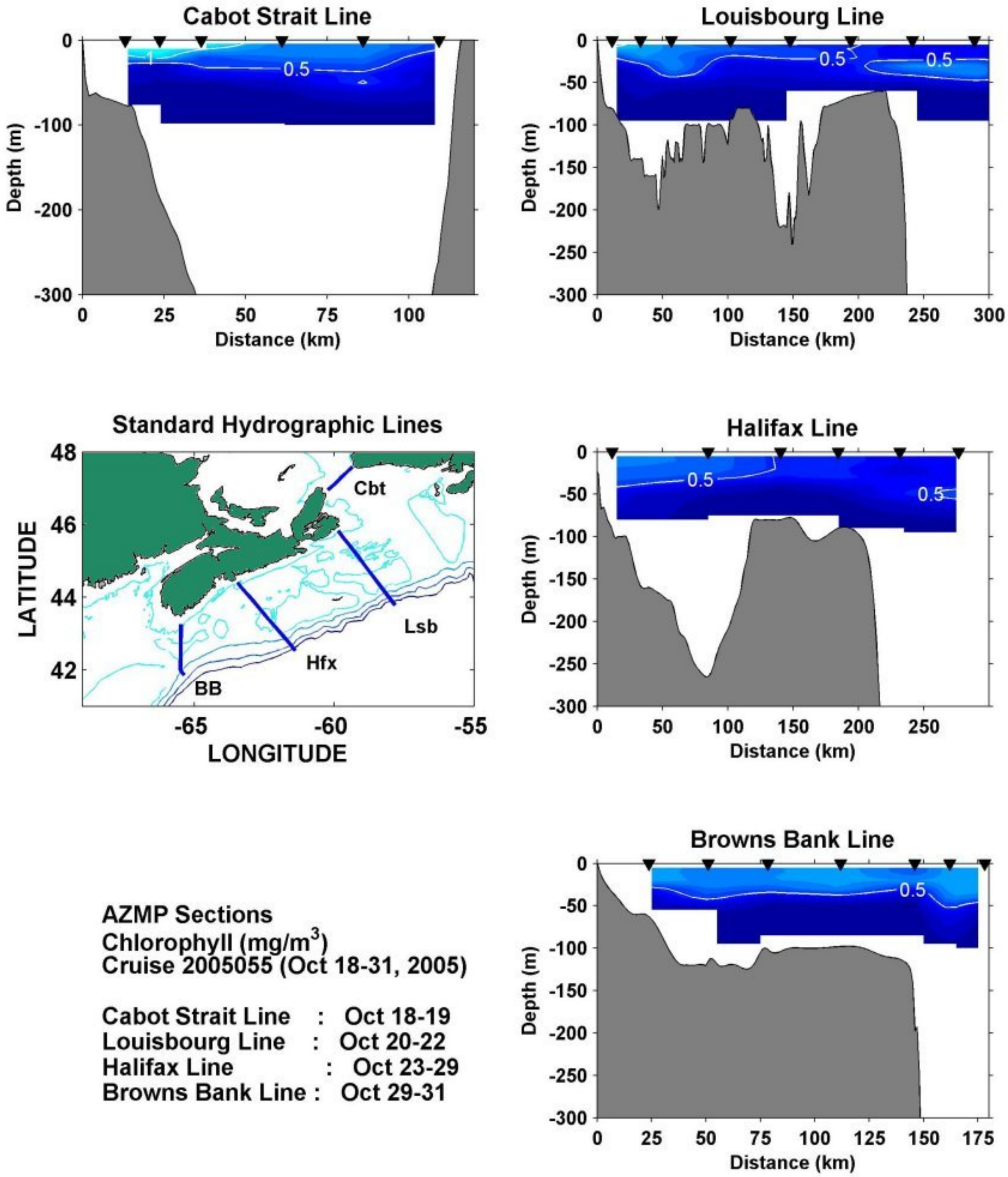

Figure 23. Vertical chlorophyll structure along the Scotian Shelf sections during the fall survey in 2005.

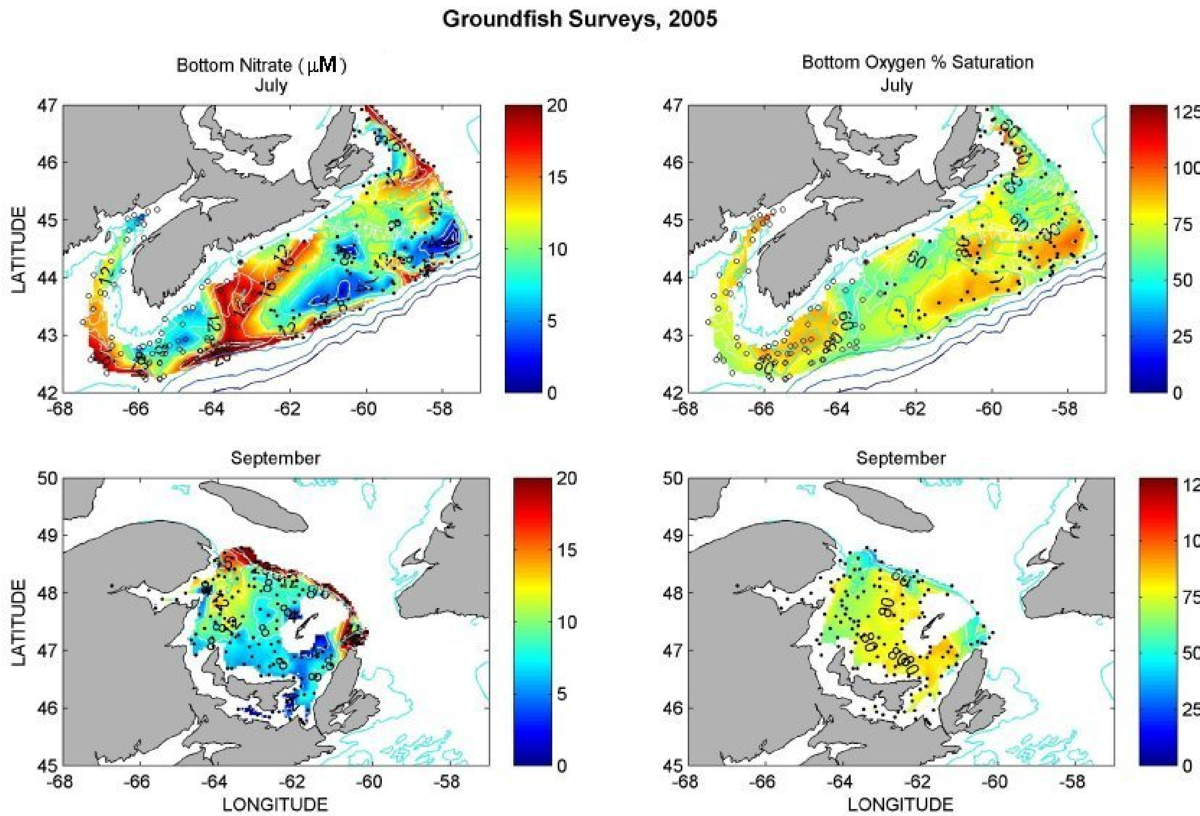

Figure 24. Bottom nitrate concentrations and oxygen saturation on the Scotian Shelf and in the Southern Gulf of St. Lawrence during the annual July and September groundfish surveys in 2005.

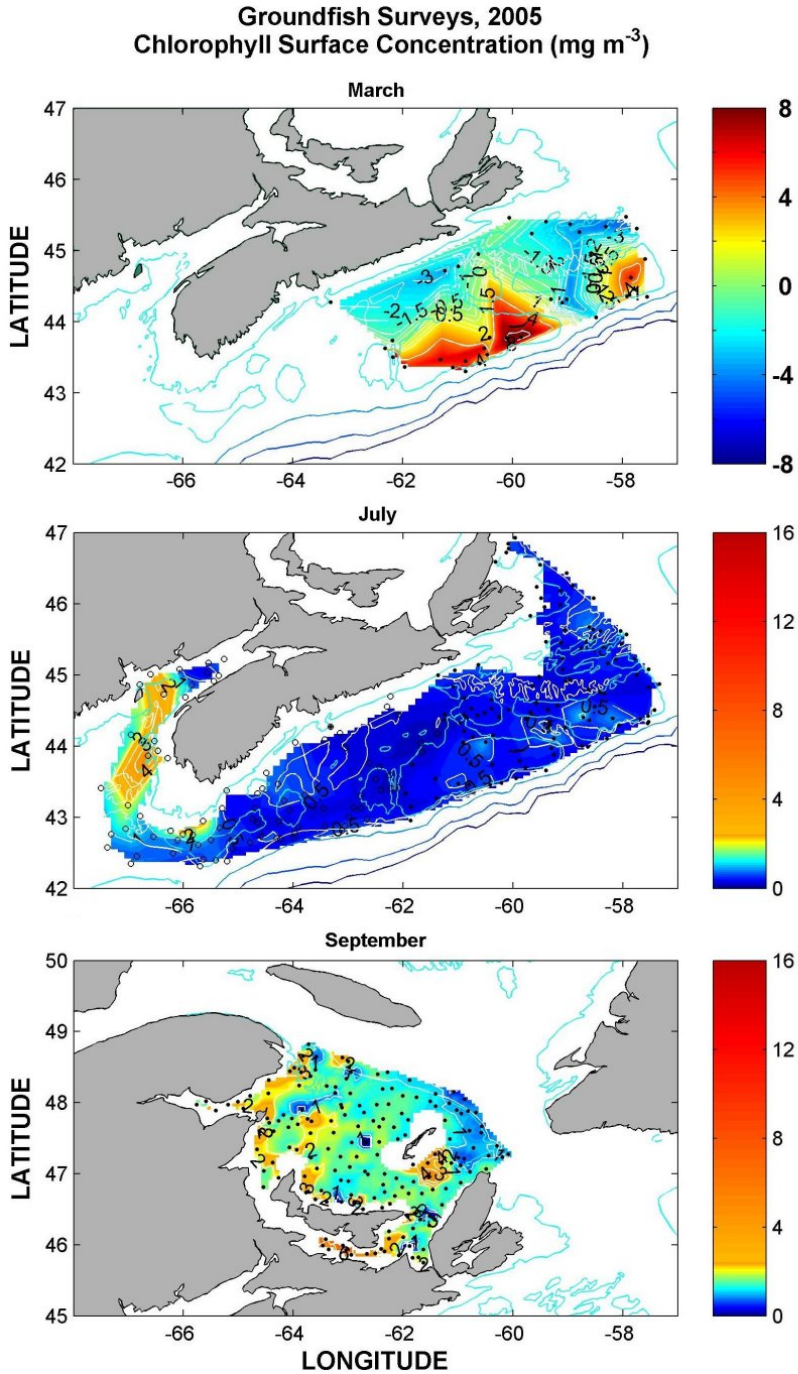

Figure 25. Surface chlorophyll concentrations on the Scotian Shelf and in the Southern Gulf of St. Lawrence during the annual March, July and September groundfish surveys in 2005.

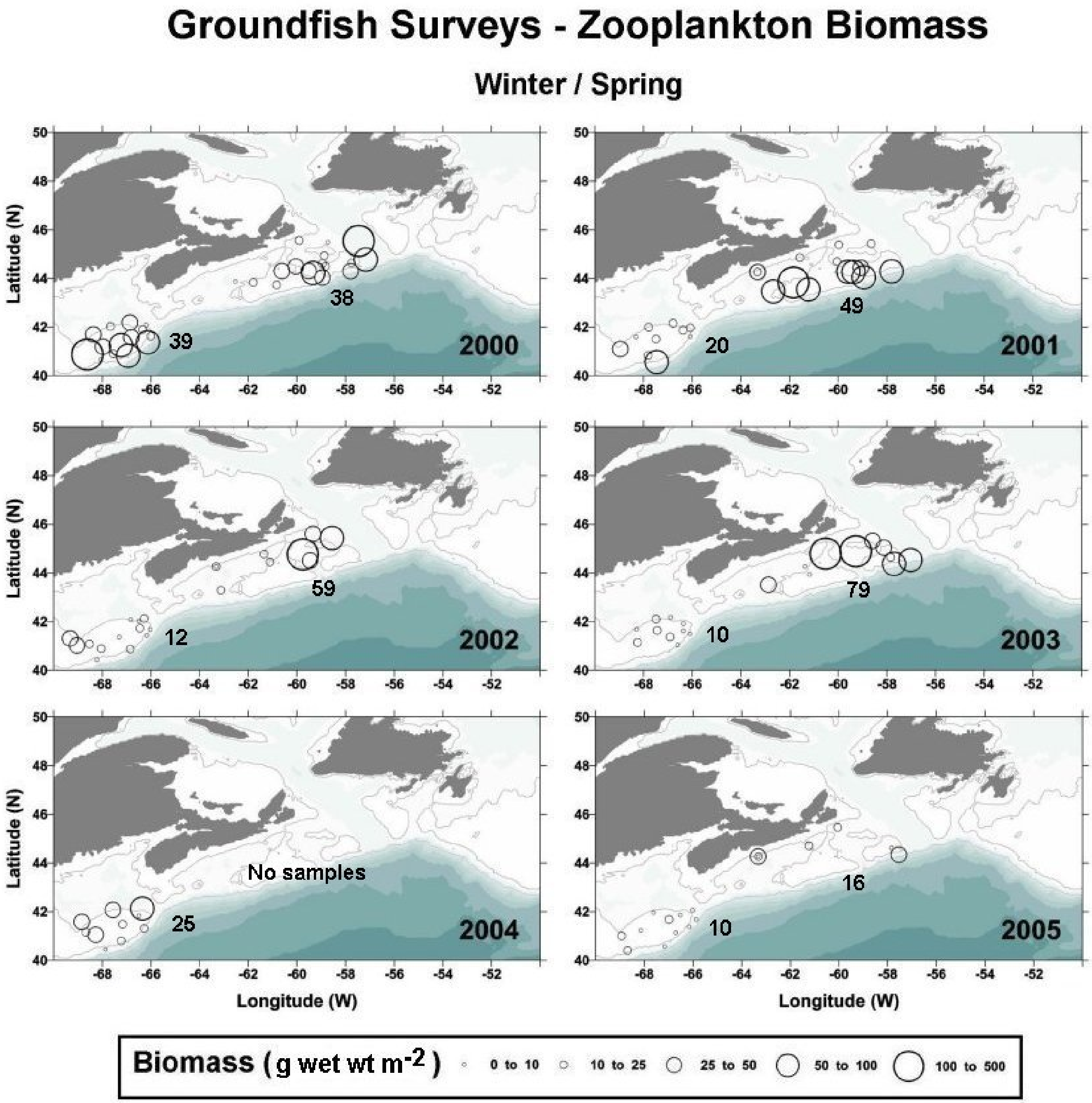

Figure 26. Zooplankton biomass on Georges Bank (February) and the eastern Scotian Shelf (March) during the annual groundfish surveys, 2000-2005. Numbers are survey average biomass (g wet wt m^{-2}).

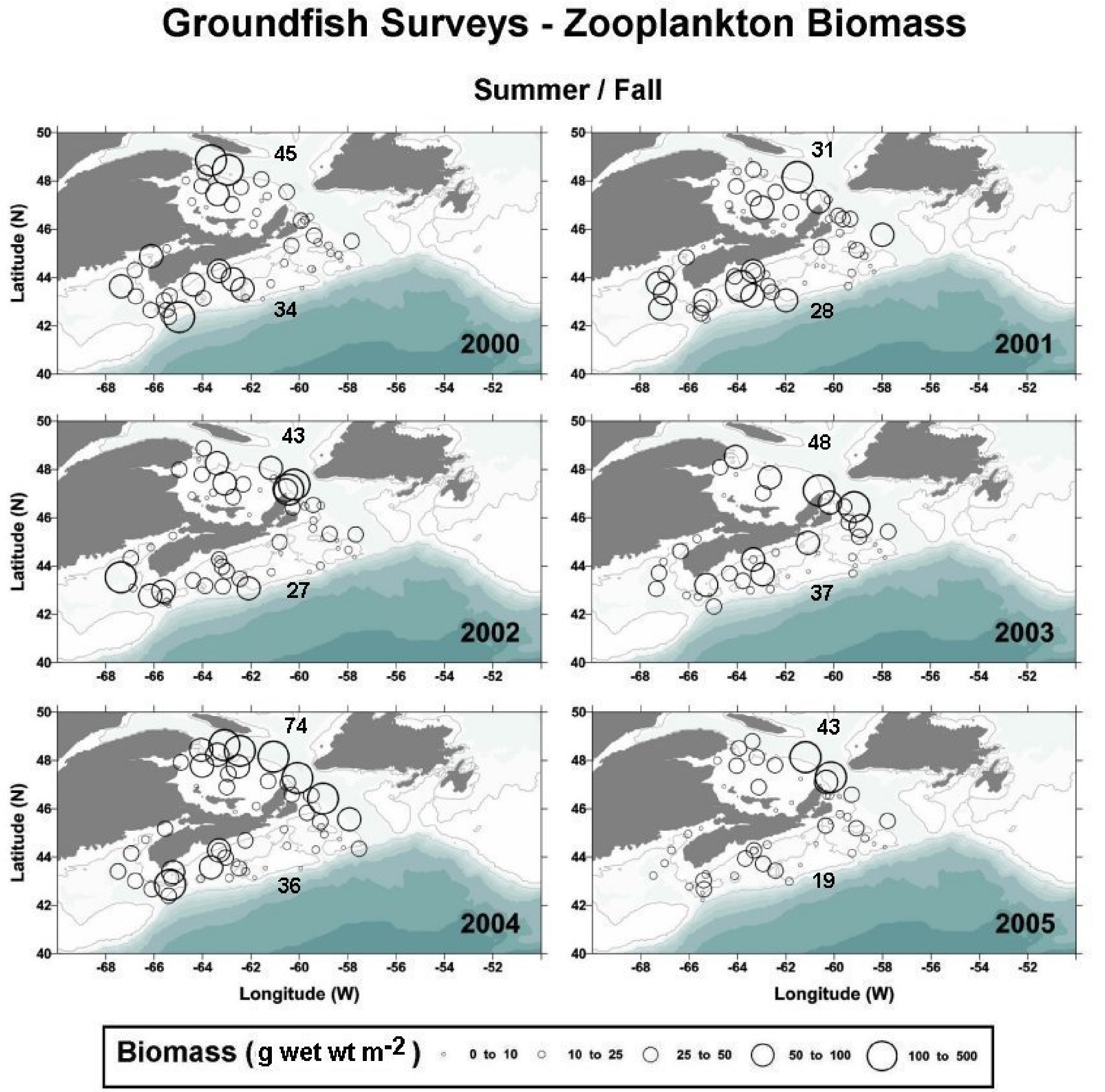

Figure 27. Zooplankton biomass on the Scotian Shelf (July) and the southern Gulf of St. Lawrence (September) during the annual groundfish surveys, 2000-2005. Numbers are survey average biomass (g wet wt m^{-2}).

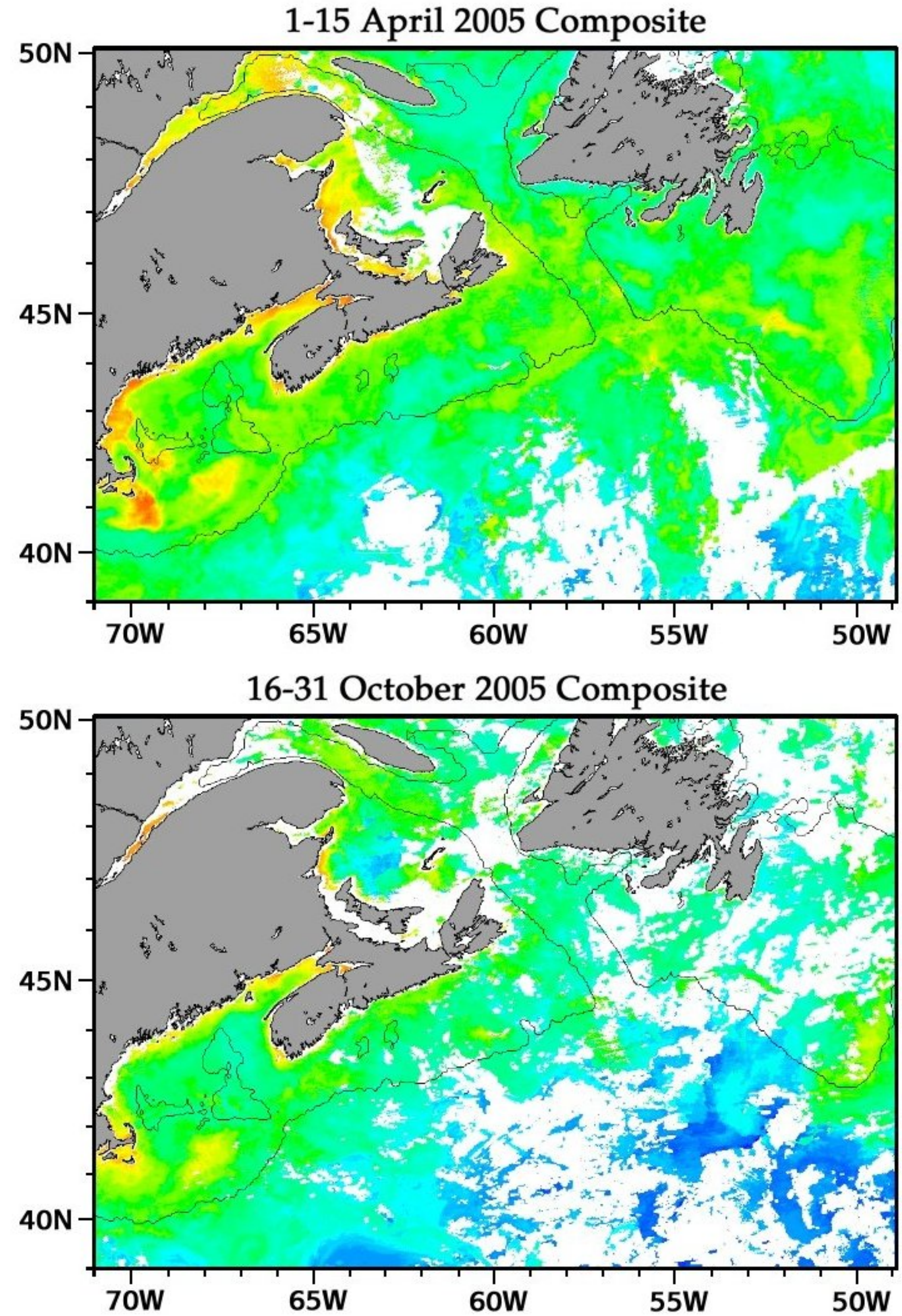

Figure 28. MODIS bi-weekly composite images of surface chlorophyll in the Maritimes/Gulf region: early April and late October, 2005, covering the periods of the spring and fall Scotian Shelf section surveys.

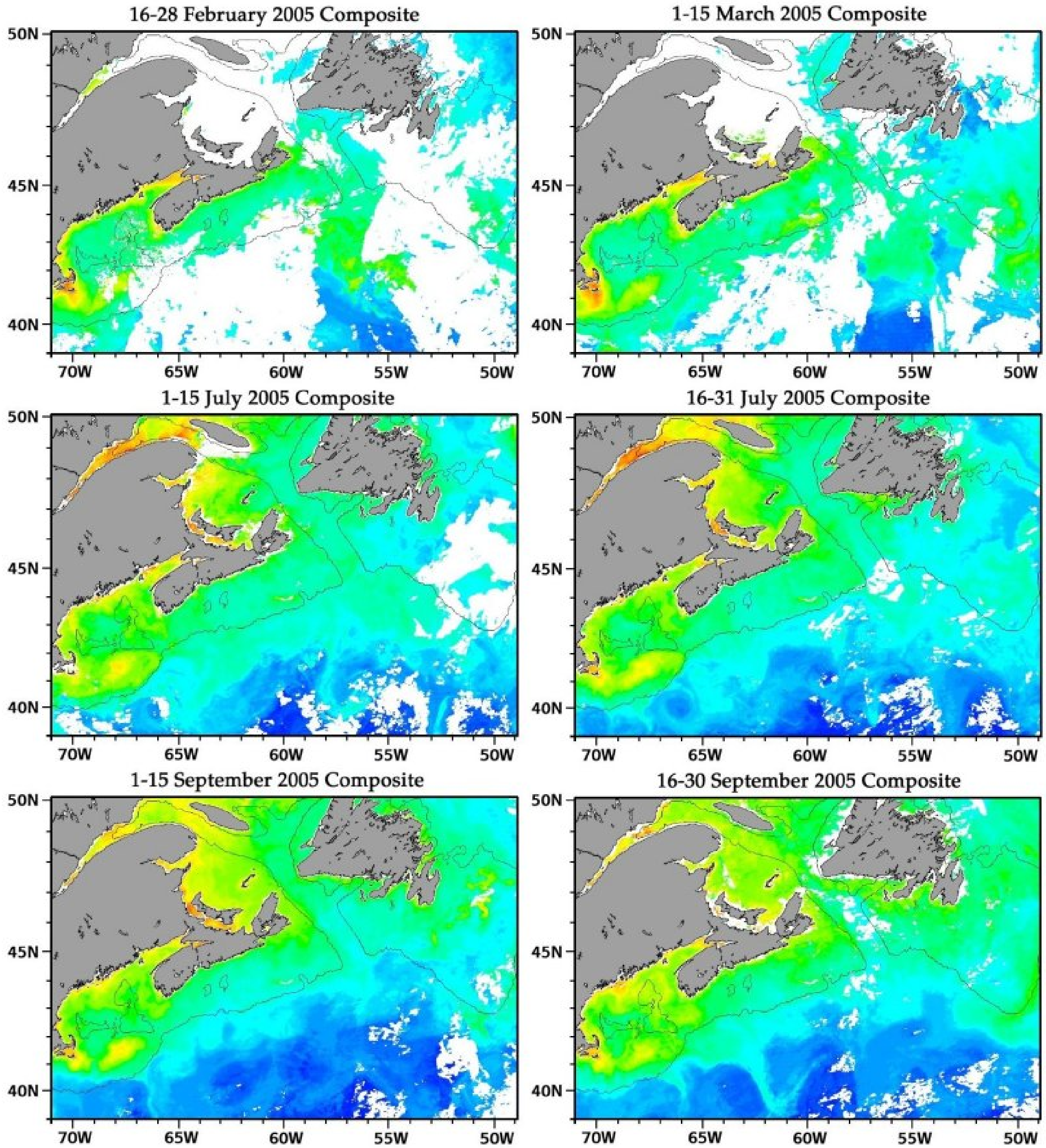

Figure 29. MODIS bi-weekly composite images of surface chlorophyll in the Maritimes/Gulf region: late February, early March, July and September, 2005, covering the periods of the four major groundfish surveys.

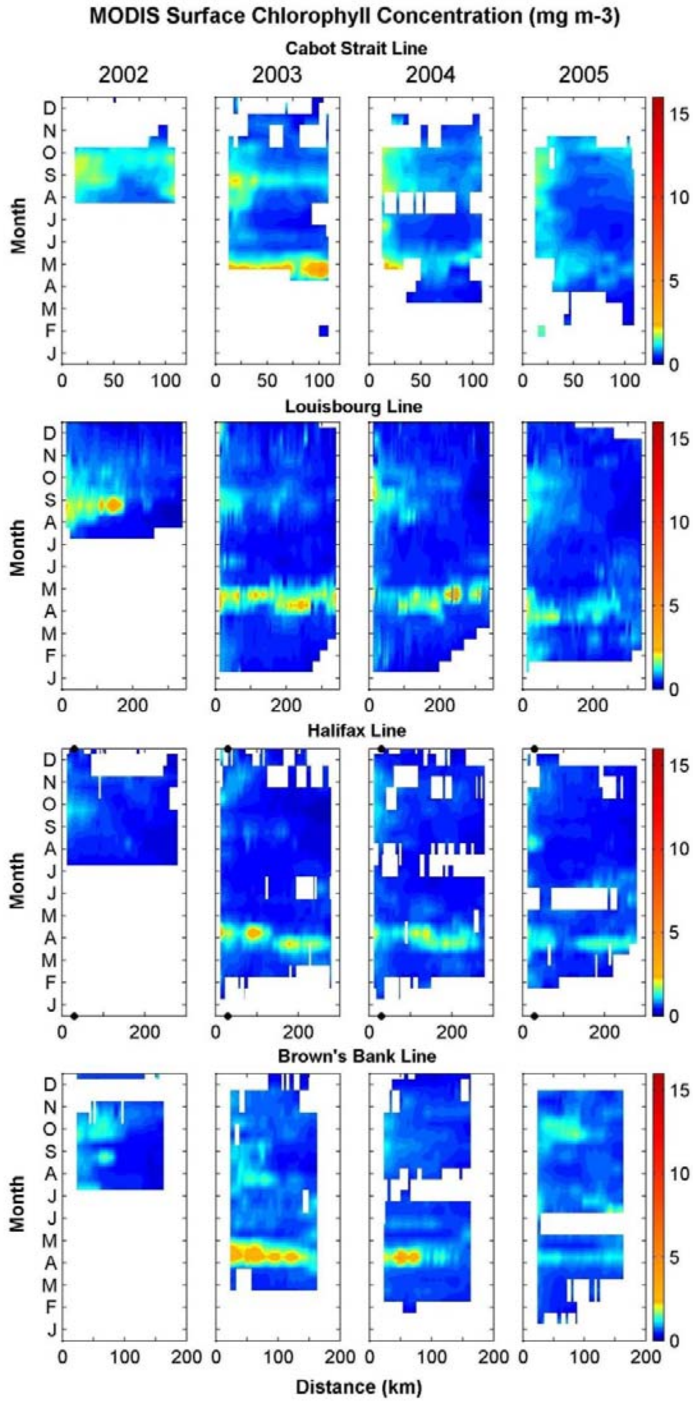

Figure 30. Time-series of surface chlorophyll concentrations (mg m^{-3}), from MODIS bi-weekly ocean colour composites, along the Maritimes/Gulf sections (see Fig. 1), 2002-2005. Horizontal axes running south to north (Cabot line) or west to east (Louisbourg, Halifax, Browns Bank lines).

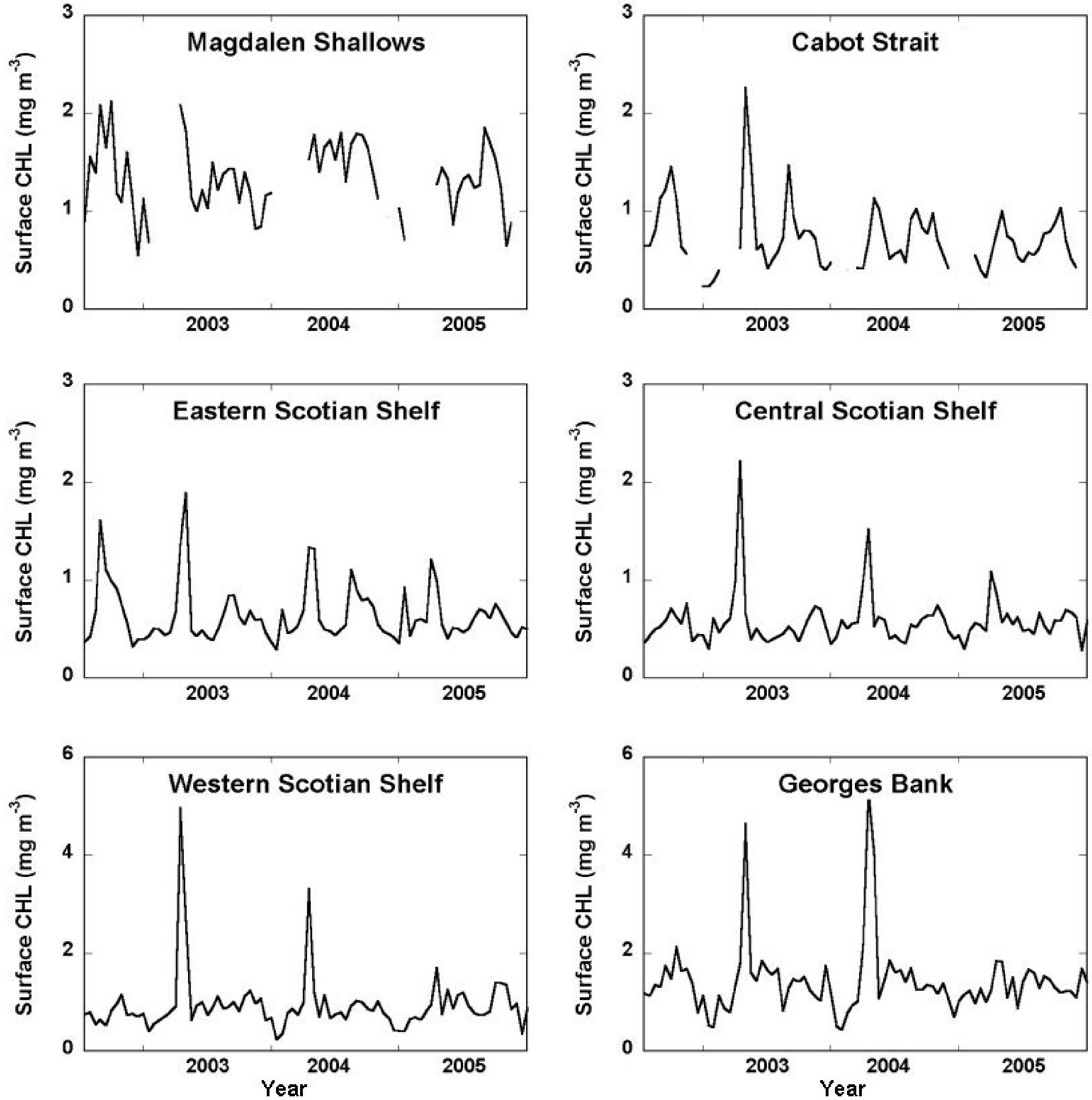

Figure 31. Time-series of surface chlorophyll concentrations (from MODIS bi-weekly ocean colour composites) for statistical sub-regions of the Maritimes/Gulf regions (see Fig. 5), 2002-2005.

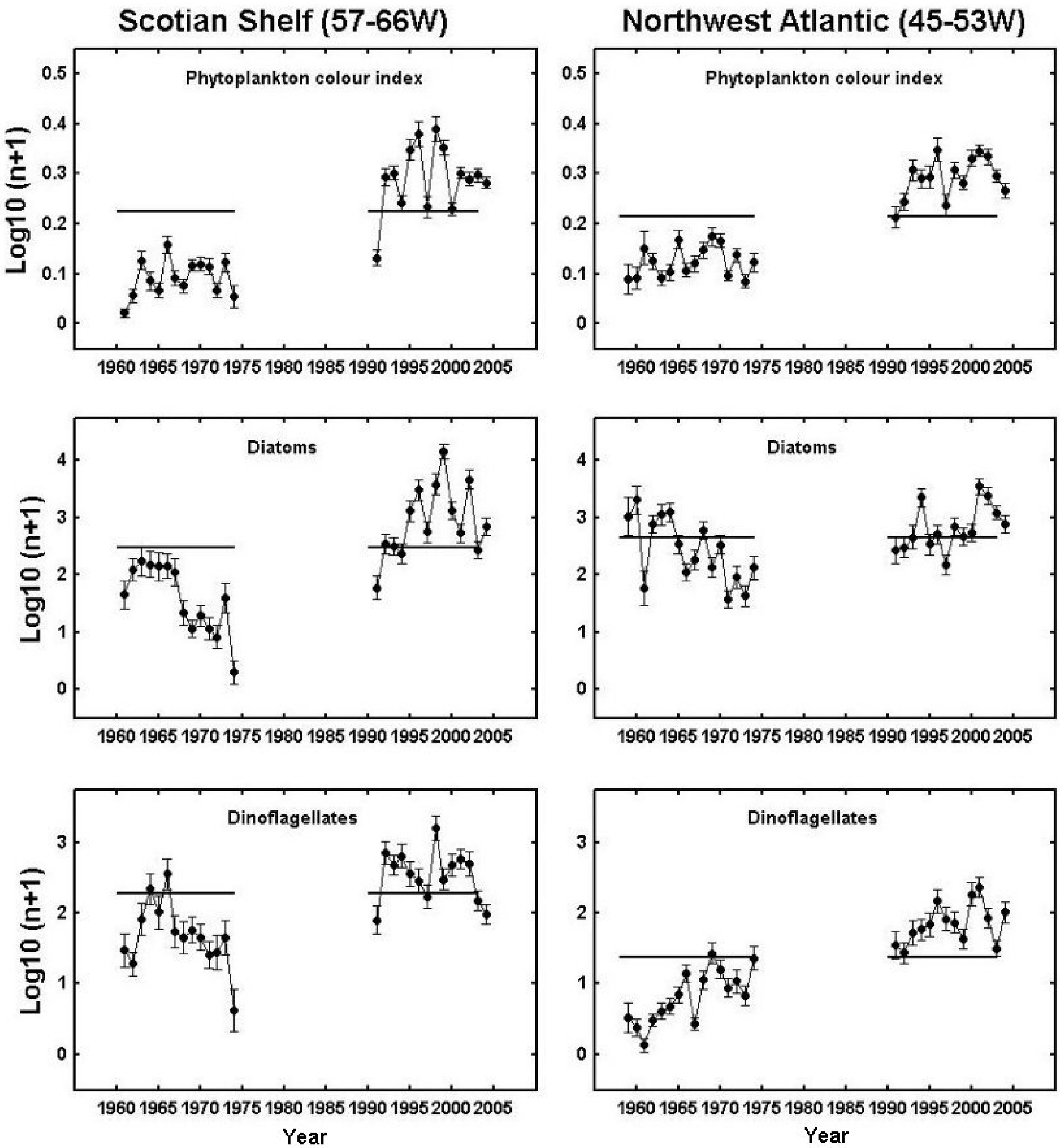

Figure 32. Time-series of phytoplankton biomass (colour index), diatom and dinoflagellate relative abundances (annual means) on the Scotian Shelf (57-66º W) and the Northwest Atlantic (45-53º W) from CPR surveys, 1961-2004 (see Fig. 4 for area coverage). Vertical bars are standard errors.

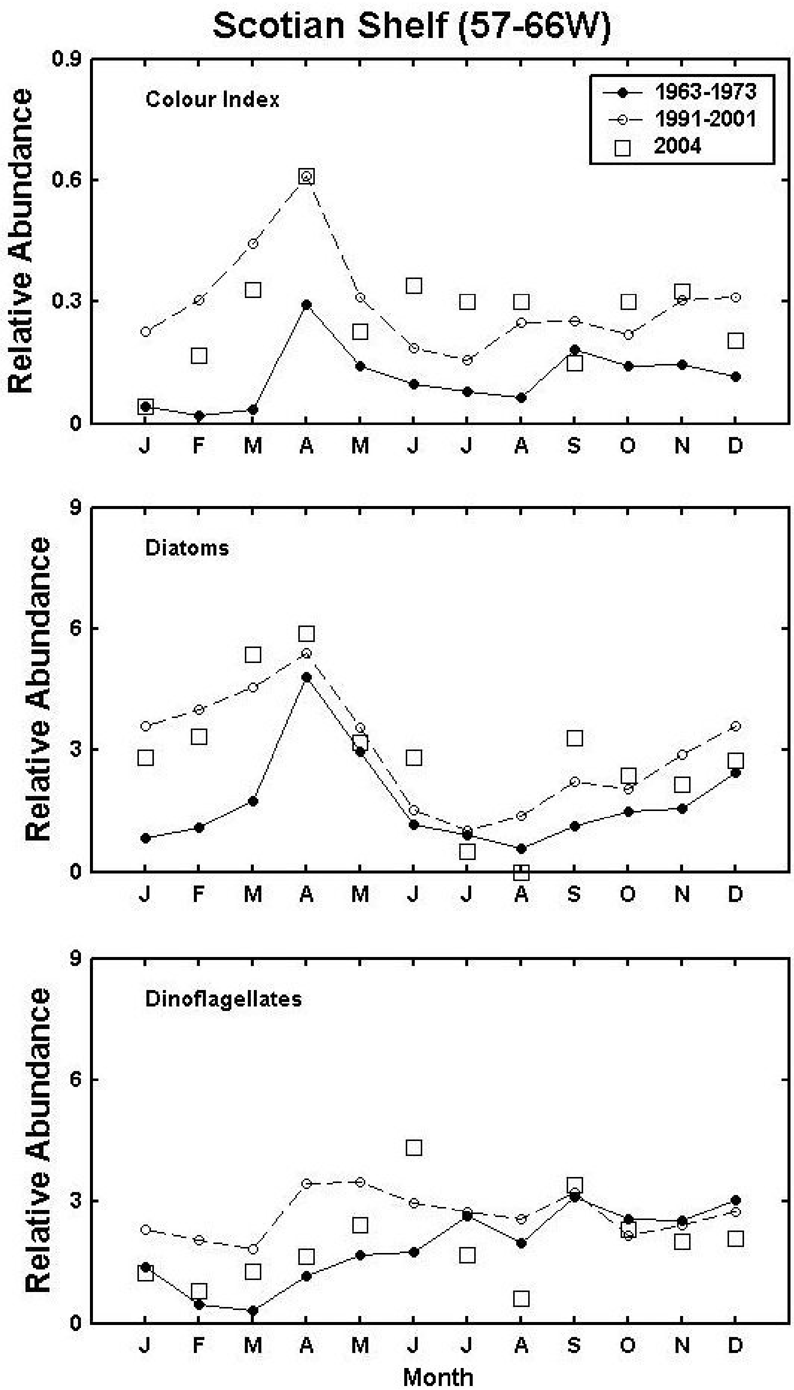

Figure 33. Monthly means of phytoplankton adundance on the Scotian Shelf in 2004 from CPR surveys. Means for the decades of the 1960s and 1990s shown for comparison.

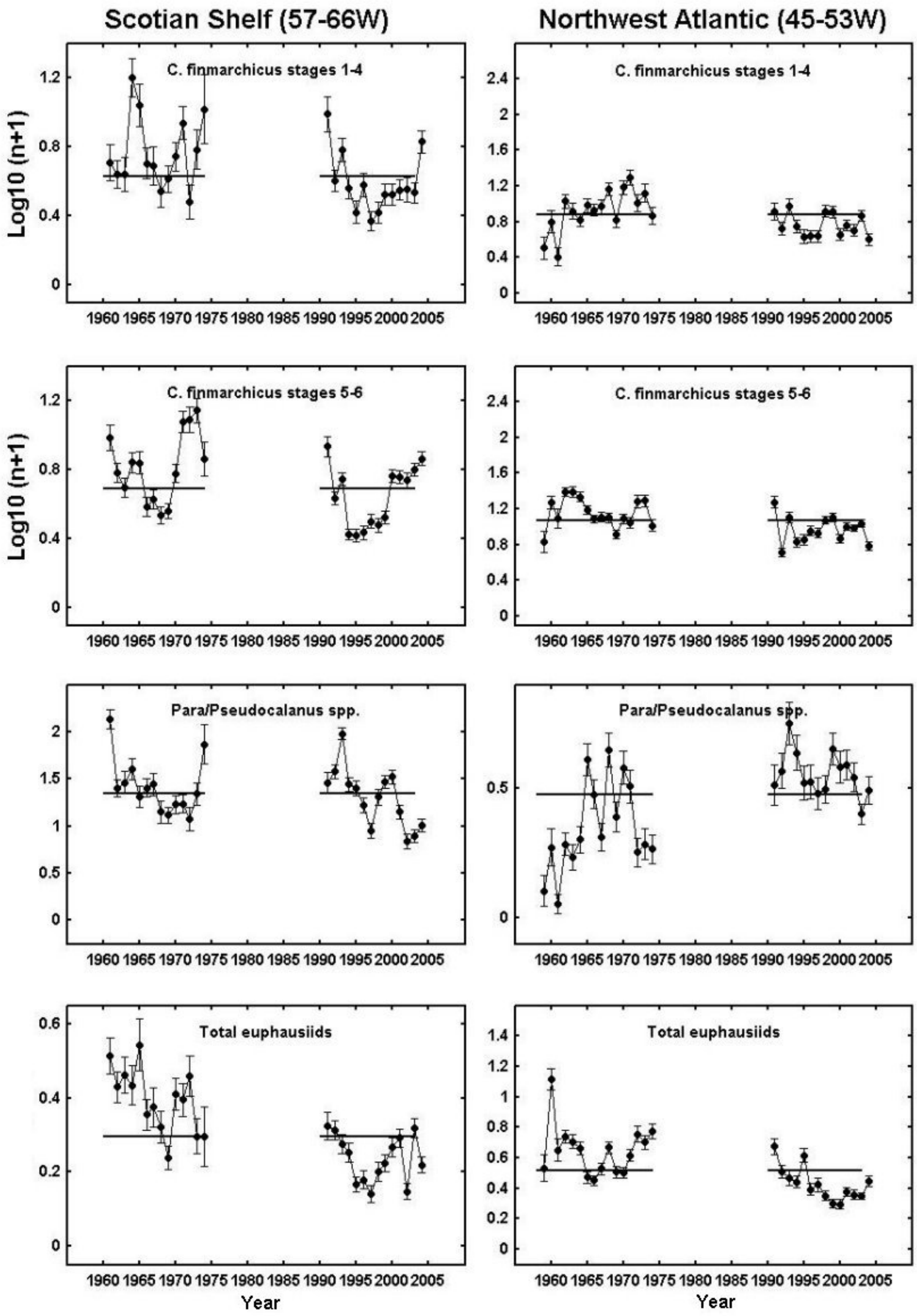

Figure 34. Time-series of relative abundances of selected zooplankton species (annual means) on the Scotian Shelf (57-66º W) and the Northwest Atlantic (45-53º W) from CPR surveys, 1961-2004 (see Fig. 4 for area coverage). Vertical bars are standard errors.

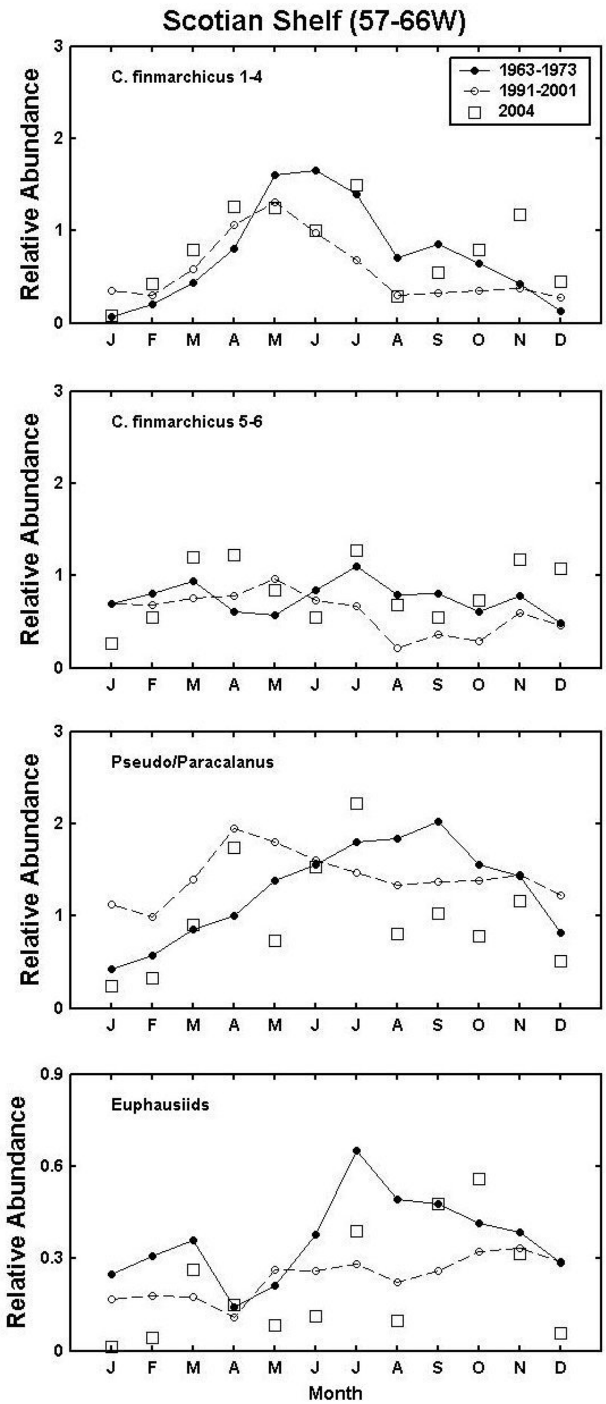

Figure 35. Monthly means of zooplankton abundance on the Scotian Shelf in 2004 from CPR surveys. Means for the decades of the 1960s and 1990s shown for comparison.