Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

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Research Document 2012/071 | **Document de recherche 2012/071**

Maritimes Region | **Région des Martimes**

Optical, chemical, and biological oceanographic conditions in the Maritimes Region in 2011

Propriétés optiques, chimiques et biologiques de l'océan dans la région des Maritimes, en 2011

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ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

Canada

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Correct citation for this publication:

Johnson, C., Harrison, G., Head, E., Casault, B., Spry, J., Porter, C., and Yashayaeva, I. 2012. Optical, chemical, and biological oceanographic conditions in the Maritimes Region in 2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/071. iv + 57 p.

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 2011 are reviewed and related to conditions during the preceding year and over the longer-term, where applicable. In addition to descriptions of Atlantic Zone Monitoring Program (AZMP) core data collections (fixed stations, seasonal sections, ecosystem trawl or groundfish surveys, Continuous Plankton Recorder), some data from outside the Region are also discussed to provide the larger, zonal perspective.

Optical properties at both Maritimes fixed stations (Halifax-2 and Prince-5) indicated shallower than normal photic depths in 2011. Seasonal stratification and mixed-layer development, however, were similar to conditions seen previously.

Seasonal nutrient inventories at the fixed stations were below normal in 2011, and summertime nutricline depths were the deepest on record. Shallow (<50 m) nutrient inventories were higher than normal along the seasonal sections and possibly linked to a later spring bloom; however, deep (>50 m) nutrients were generally below normal. The exception was the Halifax section, where deep nutrients were higher than usual, coincident with low oxygen saturation, and suggesting the influence of warm slope water on the central shelf at the time of sampling. Overall, nutrient conditions were near normal in the Maritimes Region in 2011.

The spring phytoplankton bloom at both fixed stations was later, smaller in magnitude, and of shorter duration than typically seen; however, chlorophyll levels outside the bloom period at Halifax-2 were higher than normal. Microplankton (diatoms, dinoflagellates, flagellates, ciliates) abundance at the fixed stations was also lower than normal although the relative abundance of diatoms was up. In contrast to observations at the fixed stations, a strong spring bloom was evident from the seasonal sections, particularly on the eastern shelf. Overall, phytoplankton conditions were near normal in the Maritimes Region in 2011.

Zooplankton biomass and *Calanus finmarchicus* abundance were lower than average overall in 2011 at the fixed stations and on shelf sections and trawl surveys. Copepod community composition was similar to normal at Halifax-2, but the spring—summer period of higher abundance started about a month later and ended about a month sooner than average; warm-water copepods were more abundant than usual in the fall. At Prince-5, total copepod abundance was lower than average throughout the year, particularly in the late summer to early fall, and shelf species dominated more than usual while nearshore species were low in abundance.

Continuous Plankton Recorder data reported for 2010 indicate an increase in abundance of arctic zooplankton species on the eastern Scotian Shelf, Southern Newfoundland Shelf, and east of Flemish Cap since the 1980s. There is no evidence of a decline in calcifying (acid-sensitive) plankton since the 1980s.

RÉSUMÉ

Les conditions océanographiques optiques, chimiques et biologiques dans la région des Maritimes (banc Georges, est du golfe du Maine, baie de Fundy et plateau néo-écossais) en 2011 sont examinées puis comparées aux conditions observées au cours de l'année précédente et à long terme, s'il y a lieu. En plus des descriptions des séries de données de base du Programme de surveillance de la zone atlantique (PMZA) [stations fixes, transects saisonniers, relevés au chalut de l'écosystème ou du poisson de fond, enregistreur continu de plancton], certaines données de l'extérieur de la région sont également examinées afin de donner une vue d'ensemble de la zone.

Les propriétés optiques des deux stations fixes des Maritimes (Halifax 2 et Prince 5) indiquent une profondeur de la zone euphotique moins élevée que les normales en 2011. La stratification saisonnière et le développement de la couche de mélange sont cependant similaires aux conditions observées antérieurement.

Les inventaires saisonniers des nutriments réalisés dans les stations fixes indiquent des niveaux inférieurs aux normales en 2011 et la profondeur de la nutricline en été est la plus élevée jamais enregistrée. Les inventaires des nutriments peu profonds (<50 m) affichent des résultats supérieurs aux normales dans les transects saisonniers, possiblement en raison d'une prolifération printanière tardive, alors que les nutriments profonds (>50 m) sont généralement au-dessous des normales. La section d'Halifax fait exception. En effet, les concentrations de nutriments profonds y sont plus élevées qu'en temps normal et coïncident avec une faible saturation en oxygène, ce qui suggère une influence de l'eau plus chaude du talus continental sur la plate-forme centrale au moment de l'échantillonnage. Globalement, les conditions des nutriments étaient près des normales dans la région des Maritimes en 2011.

Dans les deux stations fixes, la prolifération printanière du phytoplancton était plus tardive, moins importante et plus brève que la prolifération généralement observée. En revanche, les teneurs en chlorophylle en dehors de la période de prolifération à Halifax 2 étaient supérieures aux normales. L'abondance du microplancton (diatomées, dinoflagellés, flagellés, ciliés) constatée dans les stations fixes était aussi inférieure aux normales, bien que l'abondance relative des diatomées ait connu une hausse. À l'inverse de la situation observée dans les stations fixes, une forte prolifération printanière a été mesurée dans les transects saisonniers, particulièrement dans l'est du plateau. Globalement, les conditions du phytoplancton étaient près des normales dans la région des Maritimes en 2011.

Globalement, la biomasse du zooplancton et l'abondance du *Calanus finmarchicus* étaient inférieures à la moyenne pour les stations fixes, les transects du plateau et les relevés au chalut en 2011. La composition de la communauté de copépodes affichait des niveaux normaux à Halifax 2, mais la période de plus grande abondance, du printemps et de l'été, a commencé environ un mois plus tard et s'est terminée un mois plus tôt que la moyenne. Les copépodes d'eau chaude étaient plus abondants qu'à la normale en automne. À Prince 5, l'abondance totale des copépodes était inférieure à la moyenne tout au long de l'année, particulièrement à la fin de l'été et au début de l'automne. Les espèces du plateau continental étaient plus dominantes que d'habitude tandis que l'abondance des espèces côtières était faible.

Les données de l'enregistreur continu de plancton de 2010 indiquent une augmentation de l'abondance des espèces arctiques de zooplancton dans l'est du plateau néo-écossais, le sud de la plate-forme de Terre-Neuve et l'est du Bonnet Flamand depuis les années 1980. Rien ne démontre un déclin du plancton calcifiant (sensible aux acides) depuis les années 1980.

INTRODUCTION

The Atlantic Zone Monitoring Program (AZMP) was implemented in 1998 (Therriault et al. 1998) with the aim of: (1) increasing Fisheries and Oceans Canda's (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 (nitrate, silicate, phosphate) and oxygen dissolved in seawater provides important information on the water-mass movements and on the locations, timing, and magnitude of biological production cycles. A description of the distribution of phytoplankton and zooplankton provides important information on the organisms forming the base of the marine foodweb. An understanding of the production cycles of plankton is an essential part of an ecosystem approach to fisheries management.

The AZMP derives its information on the state of the marine ecosystem from data collected at a network of sampling locations (fixed point stations, cross-shelf sections, trawl surveys) in each DFO region (Québec, Gulf, Maritimes, Newfoundland) sampled at a frequency of twice-monthly to once annually. The sampling design provides for basic information on the natural variability in physical, chemical, and biological properties of the Northwest Atlantic continental shelf. Trawl (groundfish) surveys and cross-shelf sections provide detailed geographic information (Harrison et al. 2005), but are limited in their seasonal coverage. Critically placed fixed stations complement the geography-based sampling by providing more detailed information on temporal (seasonal) changes in ecosystem properties.

Reviewed here are the optical, chemical, and biological oceanographic (lower trophic levels) conditions in the Maritimes Region, including the Georges Bank/Gulf of Maine/Bay of Fundy system and the Scotian Shelf, during 2011. Conditions will be compared with those observed during recent years and over the longer term where historical information is available.

METHODS

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

SAMPLE COLLECTION

Maritimes/Gulf AZMP sea-going staff participated in six missions (seasonal section cruises and trawl surveys) during the 2011 calendar year, in addition to repeat day-trips to the three fixed stations. In 2011, a total of 648 station occupations were performed by Maritimes Region (Table 1).

Fixed Stations

The aim of the AZMP program is to sample Maritimes/Gulf regions' three fixed stations, Shediac Valley, Halifax-2, and Prince-5 (Figure 1), on a minimum monthly basis with attempted semi-monthly sampling during the spring bloom period. The responsibility for sampling the Shediac Valley station is shared between the Maritimes and Québec regions, and variability patterns at Shediac Valley are reported by the Québec Region. As always, the availability of sampling platforms and, to some extent, difficulties with weather and ice, make achieving this sampling frequency a challenge. In 2011, Halifax-2 and Prince-5 were sampled on 21 and 12 occasions, respectively. Shediac was sampled only five times by Maritimes Region, with three additional occupations by the Québec Region through the year. The Halifax-2 fixed station occupations were close to the best frequency, while the Shediac fixed station occupations were, once again, below the desired frequency. In general, the Shediac station has an ice-truncated open-water season. While difficulties encountered with Coast Guard operations and platform availability in previous years had been resolved somewhat, the number of Shediac station occupations in 2011 was amongst the lowest ever achieved.

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

- A CTD (conductivity, temperature, depth) (Sea-Bird instrument) profile consisting of the electronic sensing of pressure, temperature, conductivity, dissolved oxygen, fluorescence, PAR (photosynthetically active radiation), and possibly pH as the common suite of measurements,
- Niskin water bottle samples at standard depths for nutrient, calibration salinity, calibration oxygen, and chlorophyll analyses,
- Niskin water bottle sample for phytoplankton enumeration,
- Vertical ring net tows (202 and 76 µm mesh net) for zooplankton biomass (wet weight) and enumeration, and
- Secchi depth measurement for light extinction when possible.

Shelf Sections

Four primary transects (Browns Bank, Halifax, Louisbourg, Cabot Strait sections; Figure 1), and a number of additional sections/stations (Figure 2) are sampled seasonally in spring (April/May) and fall (October/November). An additional occupation of the Halifax section is also attempted in the May—July period as part of the Labrador Sea program in the Maritimes Region. In 2011, the normal/full sampling campaigns for the spring and fall missions were carried out from the CCGS *Hudson*. The four core transects were occupied in both seasons. There was an opportunity to sample the Halifax section in May 2011, as the time allotted to the Labrador Sea mission allowed sufficient time to occupy the section. While seven new deep-water stations added to the Halifax section (HL8-HL14) were sampled at that time, one of the shelf stations was not occupied.

The standard sampling suite when occupying section stations consists of:

- As above for the fixed stations, and
- Niskin water bottle sampling is extended to include POC (particulate organic carbon), flow cytometry, and plant pigment analyses (HPLC [High Pressure Liquid Chromatography], absorbance) at standard depths.

Trawl (Groundfish) Surveys

There are four primary trawl surveys in which AZMP—Maritimes/Gulf participates: the late winter (February) Georges Bank survey, the spring (March) western Scotian Shelf (WSS) survey, the summer (July) Scotian Shelf/eastern Gulf of Maine survey, and the fall (September) Southern Gulf of St. Lawrence survey (Figure 3). These surveys were carried out in 2011 by DFO's Population Ecology Division (PED) with AZMP participation. Sampling was seriously curtailed on the March 2011 survey for the WSS (4X NAFO, Northwest Atlantic Fisheries

Organization, area) by extreme weather and vessel problems with CCGS *Needler*. In addition, the Southern Gulf survey was reduced by one week when the CCGS *Teleost* was removed from service for special testing.

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

- As above for fixed stations,
- Vertical ring net tows (202 µm mesh net) for zooplankton biomass (wet weight) and enumeration at a subset of stations **only** (see Figure 3), and
- Sea-surface temperature recorder, trawl-mounted depth/temperature recorders.

DEPLOYMENT

Conductivity, Temperature, Depth (CTD)

The CTD is suspended from a hydrographic wire (or electromechanical conducting cable for the rosette system) and lowered at approximately 0.3 m s^{-1} for the portable SBE25 (approximately 0.83 m s^{-1} for the higher-resolution SBEf911 rosette system) to within 2 m 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, and
  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 depending on bottom).
- Trawl surveys: 5, 25, 50 m; near bottom when possible.

Net Tows

Ring nets of a standard 202 µm mesh are towed vertically from near bottom to surface at approximately 1 m/sec. In deep offshore waters, maximum tow depth is 1000 m. The net is hosed carefully, and the sample is collected from the cod-end and 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, thereby giving a light extinction estimate.

MIXED-LAYER AND STRATIFICATION INDICES

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

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

2. The stratification index ($\text{Strat}_{\text{Ind}}$) was calculated as:

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

where $\sigma_{t\text{-}50}$ and $\sigma_{t\text{-}zmin}$ are interpolated values of σ_t for depths of 50 m and z_{min} (the minimum depth of reliable CTD data); typically z_{min} is around 5 m and always less than 9 m.

OPTICAL PROPERTIES

Optical properties of the seawater (attenuation coefficient, photic depth) were derived using one or more data source including (a) in-water light extinction measurements using a rosette-mounted PAR 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 the light attenuation coefficient 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 (Holmes 1970). 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 the 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 0–100 m (0–95 m for the Prince-5 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: $dd_i = 0.5{*}(z_{i+1} - z_{i-1})$.

SATELLITE REMOTE-SENSING OF OCEAN COLOUR

Satellite ocean colour (SeaWiFS in the past, MODIS, and most recently MERIS) 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;

Figure 4), and have proven useful in providing temporal and synoptic spatial context for interpreting the conventional AZMP phytoplankton observations. Unfortunately, technical problems with the Moderate Resolution Imaging Spectroradiometer (MODIS) "Aqua" sensor (http://modis.gsfc.nasa.gov/) developed in 2011 and corrective action and reliable data products were not available for inclusion in this research document.

CONTINUOUS PLANKTON RECORDER (CPR)

The Continuous Plankton Recorder (CPR) is an instrument that collects phytoplankton and zooplankton at a depth of approximately 7 m on a long continuous ribbon of silk (approximately 260 μm mesh) deployed from commercial ships (Figure 5). The position on the silk corresponds to location of the different sampling stations. Historical CPR data are analyzed to detect differences in the indices of phytoplankton (colour and relative numerical abundance) and zooplankton relative abundance for different years in the northwest Atlantic. The indices are measures of biomass or numbers of plankton collected in CPR samples and represent relative changes in concentrations from year to year (Richardson et al. 2006). The sampling methods from the first surveys in the northwest Atlantic (1961) to the present are exactly the same, so valid comparisons can be made among years.

CPR data up to 2010 were made available in February 2012. In 2010, CPRs were towed during most months of the year, but from June to October the route was through the Strait of Belle Isle and into the Gulf of St. Lawrence, rather than across the Newfoundland Shelf to St. John's (Figure 5). Nevertheless, there was CPR sampling from St. John's to Halifax and into the Gulf of Maine during these summer months, from an alternative vessel.

Monthly decadal $\log_{10}(N+1)$ transformed CPR abundances of 15 taxa and phytoplankton colour index (PCI), a semi-quantitative measure of total phytoplankton abundance, were averaged over eight northwest Atlantic shelf and deep ocean regions. The regions, divided by longitude, correspond to the WSS, the eastern Scotian Shelf (ESS), the South Newfoundland Shelf (SNL), the Newfoundland Shelf (NLSh), and a series of four regions between Flemish Cap and Iceland, divided into bins of five degrees longitude (Figure 5). The decadal monthly averages were then used to calculate decadal annual averages, which were compared with the annual average values for 2010. Data gaps of one to two months in 2010 were filled by linear interpolation, but interpolation could not be used to fill a longer gap of five consecutive months (June—October) in the NLS region, so annual averages were not calculated for NLS in 2010.

RESULTS

MIXING AND OPTICAL PROPERTIES

Mixing and optical properties of the upper water column varied by season and location at the Maritimes fixed stations (figures 6 and 7). Seasonal development of the mixed layer and upper water-column stratification were most evident at the Halifax-2 station (Figure 6); shallow mixed layers (<10 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 general, was consistent with the long-term average conditions. However, mixed layers in early winter (January—February) were on occasion deeper (approximately 70 m) than normal (40—60 m) but shallower (20—40 m) than normal in late winter / early spring. Atypically shallow (<5 m) mixed layers were also seen in late summer (August—September). The development of stratification at Halifax-2 in 2011 was consistent with the long-term average. In marked contrast to Halifax-2, stratification was extremely low (<0.01 kg m^{-4}) at Prince-5 throughout the year, due principally to strong tidal mixing; this is a recurring feature of that station. Mixed-layer depths are highly variable and are difficult to determine at Prince-5 due to the very small vertical density differences (see Methods section); they normally range from 30—40 m in spring and early summer to almost full depth (90 m) in winter. In 2011, mixed layer depths at Prince-5 were similar to seasonal patterns seen previously.

Photic depth estimates derived from Secchi disc readings and direct downwelling irradiance (PAR) measurements were generally comparable; PAR estimates were slightly shallower but not statistically different (Figure 7). Maximum vertical light attenuation (and shallowest photic zone depths) normally coincides with the spring bloom, and photic depths are generally deepest during the decline of the bloom; this was evident at Halifax-2. Overall, photic depths in 2011 were slightly shallower than normal (by approximately 5—10 m) throughout the year at both fixed stations. The reason for this difference is not clear.

NUTRIENTS

Fixed Stations

Distributions of the primary dissolved inorganic nutrients (nitrate, silicate, phosphate) included in the observational program of AZMP strongly co-vary in space and time (Petrie et al. 1999). For that reason, and because the availability of nitrogen is most often associated with phytoplankton growth limitation in the Maritimes Region's coastal waters (DFO 2000), emphasis in this document will be placed on variabilities in nitrate concentrations and inventories.

A clear spring/early summer biologically mediated reduction in near surface nitrate concentrations was seen at both Maritimes fixed stations in 2011 (Figure 8). The seasonal evolution of the vertical nitrate structure at Halifax-2 was similar to that observed in previous years. Low surface values persisted throughout the summer/fall, and concentrations did not increase at the surface again until late fall. The onset of spring nutrient draw-down, however, appeared later than usual in 2011. In addition, the zone of nitrate depletion (i.e., defined as depths where concentrations were $\leq$1 mmol m^{-3}) in summer 2011 was the deepest on record: 42 m compared to the long-term average of 34 m. Near surface nitrate concentrations at Prince-5 in 2011 were never reduced below 2 mmol m^{-3}. As seen for Halifax-2, the onset of nutrient draw-down at Prince-5 was also later than usual, but the extent of draw-down, i.e., nutrient depletion, was less than normal.

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 (figures 9a, b). Seasonal patterns of nitrate variability at Halifax-2 in 2011 were generally similar to those observed in previous years. However, shallow (<50 m) inventories in winter were lower (220 mmol m^{-2}) than usual (250 mmol m^{-2}). Shallow inventories in summer were also lower (40 mmol m^{-2}) than the norm (60 mmol m^{-2}). A similar pattern was seen for deep (>50 m) inventories: in winter, levels in 2011 were low (520 mmol m^{-2}) compared to the long-term average (700 mmol m^{-2}). Likewise, deep inventories in summer were lower (830 mmol m^{-2}) than usual (910 mmol m^{-2}). Shallow and deep nutrient inventories are generally similar at Prince-5 because it is well mixed. As seen at Halifax-2, winter nitrate inventories in 2011 at Prince-5 were lower (380—420 mmol m^{-2}) than normal (430—470 mmol m^{-2}). However, summer inventories were similar to (220—260 mmol m^{-2}) the long-term average (200—260 mmol m^{-2}). The anomaly plots showed that, in general, the lower than usual nutrient conditions at the fixed stations were more evident at Halifax-2 (largely negative anomalies) than at Prince-5 (mix of negative and positive anomalies). Because of the relatively strong interannual variability in nutrient concentrations at both fixed stations, it is difficult to discern a clear long-term trend in shallow and deep water nitrate inventories from the annual anomalies.

Shelf Sections

Vertical distributions of nitrate in spring were generally similar along the Scotian Shelf sections in 2011, i.e., concentrations were low (<2 mmol m^{-3}) in near-surface waters (<50 m), as a result of phytoplankton consumption, and increased with depth (Figure 10). Deep-water (>50 m) concentrations were highest in basins (>10 mmol m^{-3}) and in slope waters off the shelf edge. As in previous years, nitrate levels in surface waters were already reduced at the time of the spring survey in April but not as low as usually seen in spring, i.e., surface values <2 mmol m^{-3}. Likewise, surface nitrate concentrations were still low during the fall survey in September—October with little evidence of seasonal mixing of nutrients from depth into surface waters (not shown). Nitrate inventories in the upper 50 m in spring were higher (140—210 mmol m^{-2}) than normal (80—140 mmol m^{-2}) on all but the Louisbourg section; inventories on the Louisbourg section were lower (50 mmol m^{-2}) than normal (70 mmol m^{-2}) in spring but higher (90 mmol m^{-2}) than normal (70 mmol m^{-2}) in fall (Table 2). Deep-water (>50 m) inventories were lower (440—700 mmol m^{-2}) than normal (590—780 mmol m^{-2}) along the Louisbourg and Cabot sections in spring but higher (780 mmol m^{-2}) than normal (730 mmol m^{-2}) along the Halifax section in fall. Inter-annual variability in surface nitrate inventories along all sections, some of which could be attributed to differences in annual sampling dates, preclude the detection of any obvious long-term trends, although there is a suggestion of increasing inventories (spring and fall) along the Halifax section since the early 2000s (Figure 11a). Deep-water inventories, on the other hand, appear to have been decreasing over the period of AZMP observations on the eastern shelf (Cabot and Louisbourg sections) with no apparent trends on the central (Halifax section) and western (Browns Bank section) shelf (Figure 11b).

Trawl (Groundfish) Surveys

Bottom water nitrate concentrations on the Scotian Shelf in July 2011 (avg: 11.3 mmol m^{-3}) were not significantly different from the long-term average (11.2 mmol m^{-3}) (Table 3) although concentrations on the central shelf (Emerald Basin and adjoining deep waters) were higher than normal, i.e., >20 mmol m^{-3} (Figure 12). Concentrations increased with water depth, with the highest levels observed in the deep basins and in slope waters off the shelf edge, as have been seen in the past. Bottom water oxygen saturation in 2011 (avg: 72% saturation) was the lowest on record compared with the long-term average (79% saturation). Also notable were the widespread lower (60—80% saturation) than usual (>80% saturation) oxygen saturation levels on the eastern Shelf. Moreover, the area of the bottom covered by waters with <60% saturation was the largest since AZMP observations began in 1999, i.e., 14.6% of the shelf or 17,244 km^2 compared with the long-term average of 10.9% or 12,874 km^2. As usual, the lowest oxygen saturations were found in deep basins and deep waters off the shelf edge where nutrients are highest. There was no discernible long-term trend in bottom water nitrate concentrations or in oxygen content on the Scotian Shelf over the AZMP time series.

PHYTOPLANKTON

Fixed Stations

Distinctly different seasonal phytoplankton growth cycles are evident at the two Maritimes fixed stations (figures 13 and 14). The spring bloom at Halifax-2 was different in 2011 from that typically seen. The bloom started later (day of the year [yearday] 98) than usual (yearday 74), was of much smaller magnitude at its peak (127 mg Chl m^{-2}) than normal (451 mg Chl m^{-2}) and was of shorter duration (16 days) than typical (41 days) (see also Figure 15a). Besides changes in bloom dynamics, the "background" chlorophyll levels (outside the bloom period) were slightly higher (29 mg Chl m^{-2}) than seen in the previous few years but lower than seen in the early AZMP years (Figure 15b). Due to high interannual variability in chlorophyll inventories, no clear long-term trends were seen in the annual chlorophyll anomalies at Halifax-2 (Figure 14).

The evolution of the phytoplankton community composition at Halifax-2 in 2011 was broadly similar to that seen previously, i.e., diatoms dominated in the winter/spring, with >75% of the total count, while flagellates and dinoflagellates dominated (>60% of the total count) the rest of the year (Figure 16). Although community composition was similar to previous years, total microplankton abundance was dramatically reduced in 2011, consistent with chlorophyll levels. For example, average diatom counts were 13,000 cells mL^{-1} versus the normal 53,000 cells mL^{-1}; flagellates were 9,000 cells mL^{-1} compared to 17,000 cells mL^{-1}.

The phytoplankton growth cycle at Prince-5, in contrast to Halifax-2, is usually characterized by a primary burst of growth in early summer (June) with secondary peaks in late summer or fall (August—September). In 2011, there was only a single bloom (figures 13 and 14). Moreover, the bloom started later (yearday 167) than usual (yearday 134), was of smaller magnitude (267 mg Chl m^{-2}) than usual (389 mg Chl m^{-2}) and of shorter duration (60 days) than typical (72 days), similar to the spring bloom characteristics seen at Halifax-2. No long-term trends were evident in the annual chlorophyll anomalies at Prince-5 due to large interannual variability in inventories (Figure 14).

As has been noted previously, the phytoplankton community at Prince-5 is composed almost exclusively of diatoms (>95%) throughout the year (Figure 16). Diatom abundance levels were normal in 2011; however, dinoflagellate and flagellate cell counts were less than half (120–540 cells mL^{-1}) of normal levels (500–1200 cells mL^{-1}).

Shelf Sections

Chlorophyll levels along all the shelf sections are always considerably higher in spring than in fall. Spring levels are also characterized by a high degree of spatial variability, and such was the case in 2011 (figures 17 and 18). Despite the near absence of a spring bloom at the Halifax fixed station, a strong spring bloom was evident from chlorophyll levels along all of the seasonal sections, especially on the eastern shelf where surface chlorophyll levels exceeded 10 mg Chl m^{-3}. Interestingly, there was apparently a "patch" of low chlorophyll water at Halifax-2 when the Halifax section was sampled (see Figure 17, middle panel), and this certainly contributed to the apparent weak bloom at the fixed station. High interannual variability also characterized spring chlorophyll inventories (0–100 m) along all sections (Figure 18). Spring and fall inventories were higher (500 and 50 mg Chl m^{-2}, respectively) than normal (300 and 40 mg Chl m^{-2}, respectively) on the Louisbourg section but lower (130 and 30 mg Chl m^{-2}, respectively) than normal (250 and 50 mg Chl m^{-2}, respectively) on the Browns Bank section. No clear long-term trends have been discernible for either the spring or fall chlorophyll inventories.

Trawl (Groundfish) Surveys

Average surface chlorophyll levels during the summer Scotian Shelf survey, were lower (0.53 mg Chl m^{-3}) than normal (0.68 mg Chl m^{-3}) (Table 3). Elevated concentrations (>1 mg m^{-3}) were only observed near the coast off southwest Nova Scotia and approaches to the Bay of Fundy, as observed in previous years (not shown). These areas are generally characterized by strong vertical mixing. There is no discernible trend in shelf-wide surface chlorophyll concentrations over the AZMP time series.

ZOOPLANKTON

Fixed Stations

Zooplankton biomass and abundance were lower than average overall in 2011. Seasonal variability patterns in both zooplankton biomass and the abundance of *Calanus finmarchicus,* the biomass-dominant copepod species, differ substantially between the Halifax-2 and Prince-5 fixed stations, and zooplankton interannual variability does not appear to be correlated between the two stations over the AZMP years. In 2011, both zooplankton biomass and *C. finmarchicus* abundance were low or average compared to the climatology in nearly all months of 2011 at both Halifax-2 and Prince-5 (Figure 19). The timing of spring increases in zooplankton biomass and *C. finmarchicus* abundance were similar to normal at Halifax-2 and about a month early at Prince-5 (Figure 19). Annual average abundance anomalies of both zooplankton biomass and *C. finmarchicus* abundance were below average at both Halifax-2 and Prince-5 (figures 20a, b). Annual average abundance anomalies of zooplankton biomass at both stations and *C. finmarchicus* abundance at Halifax-2 were among the lowest observed in the AZMP years.

Seasonal variations in *C. finmarchicus* developmental stage distributions reflect the dominant reproductive pulse of this species in spring (Halifax-2) or summer (Prince-5) and additional reproductive activity in summer or fall. The seasonal variation in *C. finmarchicus* developmental stage proportions in 2011 was similar to past years at both fixed stations (Figure 21). The dominance of early stages during the period of maximum abundance was somewhat lower than usual, but this pattern is not representative of other years of low abundance at the fixed stations.

The zooplankton community is usually dominated by copepods throughout the year at Halifax-2, and 2011 was similar to previous years, except for a very strong pulse of *Limacina helicina*, a pelagic gastropod in the late fall (Figure 22, included in “Others”). The abundance of this species in December 2011 was the highest observed at Halifax-2 during the AZMP years. At Halifax-2, seasonal variation in total copepod abundance is relatively low on average, and the abundance of small copepods such as *Oithona similis* and *Pseudocalanus* spp. is relatively high during the fall and winter (Figure 23a). Cooler-season species such as *C. finmarchicus, Metridia lucens*, *Temora longicornis*, and *Calanus hyperboreus* are relatively abundant in the spring and early summer, while warmer-water taxa such as *Centropages* spp. and *Paracalanus* spp. are more abundant in the late summer and fall. In 2011, the copepod community and its seasonal variability were similar to the climatological pattern, even though total copepod abundance was lower than average (Figure 23a). However, the spring–summer period of higher abundance started about a month later and ended about a month sooner than average, and *Centropages* spp. and *Paracalanus* spp. were more abundant than usual in the fall. Lower than average abundances of small copepods and copepod nauplii and relatively high abundances of warm-water species in fall were also evident in time series of dominant or important species at Halifax-2 (Figure 24a). Abundances of euphausiids (krill), larvaceans (small-particle feeders), and *C. hyperboreus* were average or low at Halifax-2 in 2011.

At Prince-5, the zooplankton community is dominated by copepods for much of the year, particularly in fall and winter, but large transient pulses of other taxa are typical in spring and summer. In 2011, copepods were dominant throughout the year at Prince-5, and pulses of other taxa, including euphausiids, made up a smaller portion of the community than in most previous years (Figure 22). In contrast to Halifax-2, climatological seasonal variability in total copepod abundance is relatively high at Prince-5, and the abundance of all species is low in the late fall through early spring (Figure 23b). The taxa *O. similis*, *Acartia* spp., *T. longicornis*, and *C. finmarchicus* are abundant in late spring through early fall, on average, while *Pseudocalanus* spp. is abundant in late spring and *Centropages* spp., *Eurytemora* spp., and *Paracalanus* spp. are abundant in the early fall. In 2011, total copepod abundance was lower than average throughout the year, and particularly so in the late summer to early fall period (Figure 23b). Dominant species in the spring and summer included *C. finmarchicus* and *Pseudocalanus* spp., which are typical of the central Gulf of Maine and Scotian Shelf community, as well as unidentified copepods (usually young copepodite and naupliar stages, listed as "Others" in Figure 23b; 2011 copepod naupliar abundance shown in Figure 24b). Nearshore species, such as *Acartia* spp. and *Eurytemora* spp., and small shelf copepods, such as *O. similis*, *T. longicornis*, *Centropages* spp., and *Paracalanus* spp., were low in abundance. The low abundances of many small copepod species in 2011 were also evident in time series plots (Figure 24b). Abundances of euphausiids and larvaceans were also low at Prince-5 in 2011 (Figure 24b).

Shelf Sections

Both zooplankton biomass and *C. finmarchicus* abundance were low or average compared to previous years on the shelf sections in spring and fall 2011 (figures 25a, b). Zooplankton biomass was low on the Cabot Strait, Louisbourg, and Halifax sections and closer to average on the Browns Bank section in spring 2011, while in fall 2011, zooplankton abundance was low on the Cabot Strait and Browns Bank sections and about average on the Louisbourg and Halifax sections (Figure 25a). Section-averaged *C. finmarchicus* abundance was low on the Cabot Strait and Browns Bank sections and about average on the Louisbourg and Halifax sections in spring 2011, while it was low on all of the sections in fall 2011 (Figure 25b). On the Cabot Strait section, average zooplankton biomass and *C. finmarchicus* abundance were the lowest observed in both spring and fall 2011.

Trawl (Groundfish) Surveys

Both zooplankton biomass and *C. finmarchicus* abundance were low or average compared to previous years on the trawl surveys on Georges Bank in February and the Scotian Shelf in July 2011 (figures 26a, b); no data on zooplankton biomass and *C. finmarchicus* abundance were collected in March 2011 for the eastern Scotian Shelf. Zooplankton biomass on Georges Bank in February was the lowest recorded during the AZMP years, and *C. finmarchicus* abundance was the second lowest recorded, but these low numbers may be influenced by the limited sampling performed on the bank in 2011. Zooplankton biomass appears to have a declining trend on both the February Georges Bank and July Scotian Shelf surveys. In contrast, the March eastern Scotian Shelf survey was characterized by greater variability from 2000 to 2010.

SCORECARD

Scorecards of key indices, based on normalized, seasonally adjusted annual anomalies, represent physical, chemical, and biological observations in a compact format. A standard set of indices representing nutrient availability, phytoplankton biomass, and growth dynamics, as well as the abundance of dominant copepod species and groups (*C. finmarchicus, Pseudocalanus* spp., total copepods, and total non-copepods) in each year at the fixed stations and on transects are produced in each of the AZMP regions, including the Maritimes (Figure 27).

While variability among indices and years is high in the standard scorecard, there has been considerable coherence among variables, from nutrients to zooplankton (Figure 27). In 2011, the combined scores for both nutrients and phytoplankton were about average, while the combined score for zooplankton was the lowest on record (Figure 27). However, the combined scores for both nutrients and phytoplankton mask important patterns that are illustrated by the individual scores. Lower than average deep-water nutrient concentrations persisted in 2011 on all sections except for the Halifax section, where higher than average nutrient concentrations likely reflected an incursion of nutrient-rich slope water. Wintertime shallow-water nitrate concentration at the fixed stations was similarly lower than average. In contrast, shallow nitrate concentrations on the sections were higher than average in spring, likely reflecting the relative timing of the spring cruise and the spring bloom, which started only after the cruise began, in contrast to previous years. The most notable features of the spring bloom – its late start and short duration – are evident in the fixed station scores. However, high spring and moderate fall chlorophyll concentrations on the eastern and offshore central Scotian Shelf are reflected in positive chlorophyll scores on the Cabot Strait, Louisbourg, and Halifax sections, and high background chlorophyll at Halifax-2 is reflected in the positive chlorophyll score for the Halifax-2 station.

Zooplankton scores were nearly all negative in 2011, with *C. finmarchicus* at Halifax-2 and on the Cabot Strait section exhibiting the lowest scores. Scores for non-copepods were mixed, with positive scores observed at Halifax-2 and on the Cabot Strait and Louisbourg sections. The combined scores for zooplankton suggest a negative trend in zooplankton over the AZMP years, but whether this apparent trend will hold up over time is uncertain.

CONTINUOUS PLANKTON RECORDER (CPR)

Scotian Shelf

Phytoplankton levels in 2010 were similar to those of the most recent two decades and higher than those of the 1960s and 1970s (Figure 28). *C. finmarchicus* (Figure 28) and the two arctic *Calanus* species (not shown) decreased in abundance on the WSS, but they all increased on the ESS, perhaps due to increased influx from the Gulf of St. Lawrence. Copepod nauplii and small copepods were at relatively low levels and euphausiids were at historically low levels. There is no evidence that calcifying (acid-sensitive) organisms, such as coccolithophores, foraminifera, and pteropods, are experiencing deleterious effects due to ocean acidification, and indeed coccolithophores were at historically high levels on the ESS in 2010.

South Newfoundland Shelf

Phytoplankton levels in 2010 were similar to those of the most recent two decades and higher than those of previous decades (Figure 29). There was an increase in abundance of *C. finmarchicus* (young and late stages) and a decrease in abundance of euphausiids that were both consistent with observations upstream at Station 27 on the Newfoundland Shelf (Pepin et al. 2011). Increases in *Calanus glacialis* and hyperiid abundance on the SNL were not seen at Station 27, but suggest an increased influx of arctic water. There is no evidence that calcifying organisms are experiencing deleterious effects due to ocean acidification, and there was a historically high abundance of coccolithophores in 2010, which might be related to the high contribution of freshwater in the near-surface layers, increased stratification, and to the relatively warm temperatures (Colbourne et al. 2011).

East of Flemish Cap (40-45, 35-40)

Changes in plankton abundances in the two most westerly deep-ocean regions suggested that a trend that started in the 1980s, towards an increased abundance of arctic zooplankton species, is continuing. Thus, levels of the arctic *Calanus* species (not shown) and hyperiids (Figure 29) have been higher since the 1980s, although they are generally much lower than levels in the NLSh (not shown), where the arctic influence is greater. In addition, abundances of diatoms, dinoflagellates and coccolithophores have been increasing since the 1980s, likely as the result of increasing stratification (Head and Pepin 2010). Copepod nauplii, small copepod species, and foraminifera all appear to have responded to the increased phytoplankton levels, continuing increasing trends in abundance that started in the 1980s. Meanwhile, the abundances of young and late-stage *C. finmarchicus* were markedly higher in 2010 than in previous decades. In fact, *C. finmarchicus* levels (young and late stages) were at historically high values in 2010 from Flemish Cap to Iceland. Whether this is the beginning of a large-scale response to changes in environmental conditions is as yet unclear.

DISCUSSION

Sufficient data now exist from AZMP observations (13 years) to document recurring spatial and temporal patterns in optical, chemical, and biological properties of the Maritimes Region and form the basis for detecting and quantifying changes (trends) in regional oceanographic and ecosystem properties. Although many of the properties in the Maritimes Region in 2011 were similar to observations from previous years, a number of differences were noteworthy.

MIXING AND OPTICS PROPERTIES

Optical properties and their seasonal variability at both fixed stations in 2011 fell within the general range of conditions that have been seen in previous years. At Halifax-2, photic depths generally follow the seasonal chlorophyll cycle with minimum values (approximately 40 m) at the bloom's peak and maximum values (approximately 60 m) immediately after the bloom's decline. At Prince-5, photic depths are relatively constant year-round (approximately 20 m), with primary attenuators being non-living suspended matter. In 2011, there appears to have been a 5–10 m offset (shallowing) in photic depths at both stations that cannot be easily explained. Increased suspended matter (e.g., as a result of more vigorous mixing than usual) could possibly account for the difference at Prince-5, but the only plausible way to increase attenuation (decrease photic depth) at Halifax-2 would be a rather substantial increase in chlorophyll when, in fact, chlorophyll levels were, overall, the lowest on record at Halifax-2 in 2011. Mixing properties (stratification, mixed layer depth [MLD]) at the fixed stations in 2011 were generally similar to conditions seen previously. Therefore, there is no supporting evidence in the near-normal mixing conditions at either Halifax-2 or Prince-5 that can explain the lower than usual winter surface and year-round deep nutrient concentrations in 2011. Furthermore, local mixing conditions could not explain the later-than-usual blooms at both stations. In fact, shallower than usual MLDs at Halifax-2 in late winter / early spring should have triggered an earlier than usual bloom. Over the longer term, there is accumulating evidence that summer stratification on the Scotian Shelf has been increasing over the past 60 years (Hebert et al. 2012).

NUTRIENTS

Winter maxima in surface nutrients and summer-time reductions in concentrations associated with the phytoplankton growth cycle are common features in the Maritimes Region. For the most part, the seasonal cycles of nutrients, vertical structure, and regional variations were similar in 2011 to previous years, but there were some differences. Most notable was the later-than-usual onset of the spring draw-down of nutrient concentrations at both fixed stations linked to the spring bloom. In addition, the 2011 summer nutricline depth (index of extent of nutrient depletion) at Halifax-2 was the deepest on record. The later than normal draw-down at Halifax-2 and Prince-5 was consistent with the later than normal spring blooms at the fixed stations. The smaller than normal bloom at Prince-5 was also consistent with the lower than usual nutrient draw-down at that station. On the other hand, the record nutrient depletion at Halifax-2 could be associated with elevated chlorophyll levels outside the bloom period. Overall, shallow (<50 m) and deep (>50 m) nutrient inventories at both fixed stations in 2011 were lower than normal. As already mentioned, local mixing conditions could not explain these observations.

Near-surface nutrient inventories along the shelf sections were generally higher than normal, particularly in spring. Evidence of a delayed bloom from the fixed stations could have accounted for the higher than normal residual spring nutrients along the sections. The exception was the Louisbourg section, where inventories were lower than normal. However, the bloom was already well-developed in that region. Deep nutrient inventories, on the other hand, were lower than normal along most sections in spring and in fall. The exception was the Halifax section, where deep nutrients were higher than normal. High bottom water concentrations were also noted on the central shelf during the summer groundfish survey as were low oxygen levels. These nutrient and oxygen conditions, along with temperature/salinity characteristics of the water masses, suggest the influence of warm shelf water on the central shelf in 2011. The observed lower than normal deep nutrient conditions on the eastern and western shelves are consistent with recent analyses by Townsend et al. (2010) and Yeats et al. (2010), who have extended the nutrient time series back to the 1960s; however; trends are difficult to discern on the short time scale of AZMP since interannual fluctuations in nutrient concentrations are large compared to the magnitude of the trend. Townsend concluded that nutrient concentrations have been decreasing over time, largely due to the increasing influence of cold fresh arctic water entering the Maritimes Region via the shelf slope and the Gulf of St. Lawrence. Yeats refined Townsend's explanation by suggesting that, in addition to increased influence of arctic water in the Maritimes Region, the nutrient and oxygen characteristics of arctic source water are also being modified by ice melt and biogeochemistry (e.g., denitrification, remineralization). These changes, in turn, are modifying nutrient and oxygen concentrations that are in transit equatorward. In other words, the nutrient and oxygen trends observed are a balance between advective and internal biogeochemical processes. There is considerable debate currently on the influence of large-scale atmospheric processes, such as the North Atlantic Oscillation (NAO), on the advective processes (i.e., Labrador Slope water versus warm slope water) that influence the nutrient trends observed. Record low NAO conditions were observed in 2010 and again in 2011, and the obvious question is what influence the NAO had on local physical, chemical and biological processes in the Maritimes Region. It is tempting to link the contrasting nutrients conditions seen in 2009 (elevated nutrients) with 2010 and 2011 (reduced nutrients) to the dramatic changes in atmospheric properties over that period, but further analysis is required. Oceanographic and ecosystem impacts may not be apparent in the short-term but may take months to years to manifest, on the time scales of major water-mass circulation and transit. If low NAO conditions persist, then one might expect deep-water oxygen levels to increase and nutrient concentrations to decrease on the eastern and central Scotian Shelf, with the anticipated increased influence of Labrador Slope water under those atmospheric conditions.

Taking all of the nutrient observations together and adjusting for seasonal differences (i.e., scorecard analysis; Figure 27), overall nutrient conditions in the Maritimes Region in 2011 were about normal. Compared over the 13 years of the AZMP program, however, it is clear that this ecosystem property varies considerably year-to-year. Furthermore, it is apparent that the interannual variability in nutrient conditions has been greater in the latter half of the time series than in the earlier years.

PHYTOPLANKTON

Despite the fact that phytoplankton variability (both temporal and spatial) is characteristically high in coastal and shelf waters, the development of pronounced spring/summer (and less conspicuous fall) phytoplankton blooms is evident from observations at the Maritimes fixed stations, seasonal sections, and trawl surveys, as well as 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 ESS in fall, are observed almost every year. There were, however, some features of the phytoplankton growth cycle in the Maritimes Region distinctive for 2011, one of which was the later, smaller, and shorter spring blooms at both fixed stations.

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. In 2011, there were no indications from the seasonal cycle of stratification, mixed-layer development, or optical properties at Halifax-2 that would account for a later spring bloom. Satellite ocean colour data would have provided some indication if late initiation of the bloom extended beyond the fixed stations, but the absence of satellite data for technical reasons precludes answering that question. Evidence of the (vigorous) bloom conditions on all the seasonal sections in early/mid-April did not suggest a later than usual bloom, although higher than normal residual surface nutrients at a number of the stations indicated that the bloom was not as advanced as usual. At this point, there is no clear explanation for the observed late bloom at the fixed stations in 2011.

Bloom magnitude is thought to be regulated largely by nutrient supply, and bloom duration is regulated by both nutrient supply and secondarily by loss processes such as aggregation-sinking and grazing (principally by zooplankton). In north temperate waters, winter stores of nutrients in surface waters are considered the principal fuel for the spring phytoplankton bloom. In 2011, the magnitude of the spring bloom at both fixed stations was below normal and of significantly shorter duration than is usually seen. If changes in winter nutrient reserves accounted for the smaller blooms in 2011, then one would have expected comparable reductions in nutrients. At Halifax-2, the 2011 bloom was about 33% of long-term bloom levels. Although winter nutrients were also lower, they were only 12% lower than long-term average conditions so could not have accounted entirely for the weak 2011 bloom. Similarly, the 2011 bloom at Prince-5 was 66% of the usual bloom magnitude, but winter nutrients were lower by <10%. Clearly other factors came into play to account for the smaller and shorter blooms at both fixed stations in 2011. Zooplankton grazing could have contributed, but the numbers of grazers at the fixed stations were at all-time low levels in 2011. At this point, there are only partial clues to explain the observed small and short blooms at the fixed stations in 2011.

Recurrent patterns in the seasonal succession of phytoplankton communities at both Maritimes fixed stations were evident in 2011. At Halifax-2, a clear transition from diatom-dominated communities in winter/spring to flagellate-dominated communities in summer/fall is evident year after year and appears to be fairly well conserved despite large interannual variations in phytoplankton biomass. There may, however, be more subtle changes in phytoplankton community structure and composition that are unable to be detected with this rather coarse taxonomic categorization (i.e., major functional groups).

Taking all of the phytoplankton observations together and adjusting for seasonal differences (i.e., scorecard analysis, Figure 27), overall phytoplankton conditions in the Maritimes Region in 2011 were close to normal. Compared over the 13 years of the AZMP program, as for nutrients, it is clear that this ecosystem property also varies considerably year-to-year. In contrast to nutrients, however, it is apparent that the interannual variability in phytoplankton conditions has been generally lower in the latter half of the time series than in the earlier years.

ZOOPLANKTON

Seasonal changes in zooplankton biomass and abundance are controlled by interactions among the egg production, growth, and mortality rates of zooplankton populations. Physical transport also influences local biomass and abundance of zooplankton. Growth and egg production rates are influenced by temperature and food availability, while mortality rates are primarily driven by the abundance of predators and the behaviour and life history characteristics of prey species. The dominant pattern for zooplankton across the Maritimes Region in 2011 was one of low biomass and abundance at the fixed stations, sections, and on trawl survey cruises. Higher than average surface temperatures throughout the region in 2011 (Hebert et al. 2012) might be expected to contribute to an early increase in zooplankton biomass and abundance, due to increased egg production and growth rates; in contrast, a late spring phytoplankton bloom could lead to delayed increases in zooplankton biomass and abundance due to food limitation (e.g., Song et al. 2011). In fact, the timing of spring increases in zooplankton biomass and *C. finmarchicus* abundance was about normal at Halifax-2 and about a month early at Prince-5 in 2011. The environmental setting for zooplankton growth, i.e., warm temperatures and a late spring phytoplankton bloom, was unprecedented in the AZMP years, and the mechanisms driving the zooplankton response are unclear. The dominant copepod species in terms of biomass, *C. finmarchicus,* typically emerges from dormancy prior to the spring bloom in this region (Durbin et al. 2003). When food is scarce, this species will consume its own eggs (Ohman and Hirche 2001). This behaviour could sustain the adults until the late start of the phytoplankton bloom, when the presence of adult *C. finmarchicus* could have contributed to the low magnitude of the phytoplankton peak. Although higher chlorophyll concentrations and normal bloom timing were observed on the ESS than at the Halifax-2 station, zooplankton biomass was also anomalously low on the ESS during the spring cruise, similar to Halifax-2. The warm temperatures in the Maritimes in 2011 were reflected in higher abundances of warm-water copepod species at Halifax-2 in the fall.

Although 2011 was a record low year for zooplankton, the responses of zooplankton to its physical, chemical, and biological environment are complex, and it was difficult to discern the dominant processes driving zooplankton seasonal timing, biomass, and community composition. As the length of the AZMP time series increases, greater sample sizes will facilitate identification of relationships through multivariate analyses of zooplankton species and environmental data. Incorporation of information about zooplankton predators and mortality, as well as changes in advection would aid interpretation of AZMP zooplankton variability patterns, and mechanistic modelling would help to test conceptual models of the drivers of variability.

Taking all of the zooplankton observations together and adjusting for seasonal differences (i.e., scorecard analysis, Figure 27), overall zooplankton conditions in the Maritimes Region in 2011 were the lowest observed in the AZMP years.

SCORECARD

The scorecard, based on normalized, seasonally adjusted annual anomalies, provides a tool for visually integrating the suite of chemical and biological observations made in AZMP. By combining these indicators under the broad categories of nutrients, phytoplankton, and zooplankton, it is possible to examine how these “aggregate indices” vary across the region, from year to year, and in relation to one another, providing insight, for example, into “bottom-up” (nutrient-driven) versus “top-down” (grazing-driven) ecological controls. Overall, covariance has been weak among the aggregate indices over the 13 years of AZMP observations, even when large swings in anomalies have been observed, and establishing a clear cause and effect relationship among nutrients, phytoplankton and zooplankton has been elusive.

The Scotian Shelf and eastern Gulf of Maine are in a region influenced by both sub-polar and sub-tropical waters, and the eastern and western Scotian Shelves can exhibit different responses to large-scale climate variability (Petrie 2007). Deep waters of the central and WSS are particularly sensitive to large-scale forcing signals that propagate down the shelf break (Petrie and Drinkwater 1993). This spatial variability in the environmental response to large-scale forcing within the Maritimes Region may confound interpretation of aggregate indices composed of anomalies from across the region. Currently, AZMP is working to synthesize its observations across the northwest Atlantic. This exercise will provide a large-scale context for environmental and lower trophic level responses to large-scale forcing and help to refine spatial boundaries over which aggregate indices should be calculated to provide the most informative indicators of large-scale environmental variability.

SUMMARY

- Photic depths were shallower than normal at the Maritimes fixed stations in 2011, but seasonal stratification and mixed-layer depths were similar to conditions seen previously.

- Seasonal nutrient inventories at the fixed stations were below normal in 2011. On the transects, shallow nutrient inventories were higher than normal, possibly due to a later spring phytoplankton bloom, but deep-water nutrients were lower than normal, except on the central Scotian Shelf, which may have been influenced by the inflow of warm Slope Water. The annual aggregate nutrient index was close to average.

- The spring phytoplankton bloom was later, smaller in magnitude, and shorter than normal at the fixed stations in 2011, but chlorophyll levels outside of the bloom period at Halifax-2 were higher than normal. However, a strong spring bloom was observed on the spring transects, especially on the ESS. The annual aggregate phytoplankton index was close to average.

- Zooplankton biomass and *C. finmarchicus* abundance were lower than average overall in 2011 at the fixed stations and on shelf sections and trawl surveys. Copepod community composition was similar to normal at Halifax-2, but warm-water copepods were more abundant than usual in the fall. At Prince-5, the copepod community was dominated by shelf / Gulf of Maine species, while nearshore species were low in abundance, suggesting a greater influence of offshore water there. The annual aggregate zooplankton index was the lowest on record.

- Continuous Plankton Recorder data reported for 2010 indicate an increase in abundance of arctic zooplankton species on the ESS, Southern Newfoundland Shelf, and east of Flemish Cap since the 1980s. There is no evidence of a decline in calcifying (acid-sensitive) plankton since the 1980s.

ACKNOWLEDGEMENTS

The authors wish to thank the sea-going staff of the Ocean Research and Monitoring Section at the Bedford Institute of Oceanography (BIO) and staff at the St. Andrews Biological Station (SABS), as well as the officers and crew of the CCGS *Opilio, Hudson, Needler, Teleost* and search and rescue vessels for their able assistance in successfully completing the

Maritimes/Gulf regions' 2011 field program. Carol Anstey, Carla Caverhill, Mary Kennedy, Heidi Maass, Kevin Pauley, Tim Perry, Marc Ringuette, and Jackie Spry contributed to sample analysis, data analysis, and data management. Pierre Pepin and Laure Devine provided helpful comments to improve the document.

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Table 1. Atlantic Zone Monitoring Program (AZMP) sampling missions in the Maritimes/Gulf regions, 2011.

Group	Location	Mission ID	Dates	# Hydro Stations	# Net Stations
Trawl Surveys	Georges Bank / Western Scotian Shelf	NED2011-002	Feb 05 – Mar 14	50	10
	Scotian Shelf	NED2011-025	Jul 05 – Aug 08	264	37
	Southern Gulf of St. Lawrence	TEL2011-094	Sept 12 - Oct 02	138	16
Seasonal Sections	Scotian Shelf	HUD2011-004	Apr 07 – Apr 23	84	67
	Scotian Shelf	HUD2011-009	May 25 – 28	22	10
	Scotian Shelf	HUD2011-043	Sep 24– Oct 14	66	48
Fixed Stations	Shediac Valley	BCD2011-668	May 01 – Nov 30	5	5
	Halifax-2	BCD2011-666	Jan 01 – Dec 31	21(7)[1]	20 (7)[1]
	Prince-5	BCD2011-669	Jan 01 – Dec 31	12	12
			Total:	648	212

[1]Total station occupations, including occupations during trawl surveys and seasonal sections (dedicated occupations with mission ID as listed at left).

Table 2. Chemical and biological properties of the 1999–2011 spring and fall Scotian Shelf sections. Statistics: Section means (average of all stations).

		Nitrate 0–50 m (mmol m^{-2})		CHL 0–100 m (mg m^{-2})		Zoopl Biomass (g wet wt m^{-2})		*C. finmarchicus* (Ind*10^{3} m^{-2})	
Section	**Year**	**Spring**	**Fall**	**Spring**	**Fall**	**Spring**	**Fall**	**Spring**	**Fall**
Cabot	**1999**	133	140	423	47	23	40	17	38
	2000	92	31	549	38	29	33	5.3	29
	2001	31	120	137	35	90	86	6.2	28
	2002	-	238	-	69	-	-	-	-
	2003	-	76	-	38	-	85	-	39
	2004	98	81	326	26	79	271	8.3	34
	2005	137	84	157	34	67	47	18	22
	2006	48	144	260	11	55	87	9.8	30
	2007	140	110	291	37	37	64	11	41
	2008	140	122	168	41	60	52	12	24
	2009	100	107	320	38	62	88	7	25
	2010	59	119	150	36	65	-	13	-
	2011	180	93	297	37	30	42	4.2	13
Louisbourg	**1999**	99	91	177	53	17	8.8	68	10
	2000	94	24	378	38	13	8.4	23	3.0
	2001	29	72	152	39	95	34	13	13
	2002	-	37	-	41	-	43	-	27
	2003	81	71	710	39	90	16	15	6.7
	2004	48	77	405	29	47	30	10	23
	2005	48	79	397	30	56	17	21	9.8
	2006	62	94	151	28	42	16	29	8.4
	2007	72	92	597	24	29	12	12	15
	2008	115	41	195	39	45	31	14	38
	2009	82	56	162	47	80	25	20	12
	2010	72	-	96	-	51	-	38	-
	2011	53	94	504	46	40	24	17	5.8
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
	2006	80	64	39	6.7	50	30	27	15
	2007	52	63	720	35	29	25	19	10
	2008	119	100	267	44	41	37	25	15
	2009	110	27	254	39	59	41	5	14
	2010	94	60	89	58	40	15	69	4.7
	2011	139	52	168	48	35	28	37	7.5
Browns	**1999**	124	143	58	83	12	28	75	2.8
	2000	239	26	154	45	-	17	25	5.4
	2001	30	175	116	59	89	26	59	16
	2002	-	109	-	36	-	34	-	15
	2003	157	145	545	58	74	42	49	31
	2004	133	118	219	26	34	26	28	4.5
	2005	187	98	165	37	28	17	26	5.4
	2006	152	130	44	51	34	26	65	12
	2007	53	115	680	29	40	14	15	8.3
	2008	195	174	102	59	61	29	81	12
	2009	121	194	452	40	29	18	74	12
	2010	142	-	220	-	45	-	26	-
	2011	206	110	130	34	41	17	11	4.1

Table 3. Chemical and biological properties of the 1999–2011 summer Scotian Shelf ecosystem trawl (groundfish) survey. Statistics: means, ranges (in parentheses), and number of observations. Numbers in square brackets in the oxygen column represent the 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 (percent saturation) Bottom	Zoopl Biomass (g wet wt m^{-2})	*C. finmarchicus* (Individuals m^{-2})
1999	**0.93** (0.10-7.07) 137	**13.22** (2.12-24.06) 163	**77 [7.3]** (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 [12.4]** (43-121) 203	**34.0** (2.7-158.6) 38	**37,625** (2.7-238.1) 38
2001	**0.78** (0.03-4.08) 206	**11.75** (1.72-21.76) 155	**82 [9.9]** (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 [6.2]** (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 [9.7]** (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 [12.8]** (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 [8.2]** (43-103) 191	**19.5** (0.32-46.6) 34	**19,181** (24-143,063) 34
2006	**0.69** (0.05-4.74) 201	**11.48** (0.01-22.82) 207	**77 [5.2]** (41.62-110.58) 207	**31.4** (1.81-135.76) 41	**42,837** (431-109,560) 41
2007	**0.68** (0.18-3.19) 163	**9.56** (0.12-19.96) 161	**77 [10.9]** (43.32-113.55) 163	**26.9** (0.69-115.88) 34	**29,703** (830-138,987) 35
2008	**0.64** (0.06-4.43) 165	**10.47** (0.72-22.79) 167	**79 [7.8]** (41.2-112.4) 165	**31.8** (1.56-121) 31	**33,889** (144-114,991) 31
2009	**0.55** (0.02-5.06) 200	**11.32** (0.65-22.97) 188	**77 [9.95]** (44.8-103.1) 188	**23.9** (2.54-100) 31	**16,198** (151-44971) 31
2010	**0.89** (0.09-5.19) 192	**10.86** (0.44-23.02) 186	**79 [13.25]** (32.6-108.0) 186	**17.5** (0.88-86.7) 29	**20,470** (28-82,848) 29
2011	**0.53** (0.05-2.57) 257	**11.27** (0.43-22.67) 256	**72 [14.6]** (34.38-104.1) 254	**25.4** (0.35-151) 37	**18,424** (91-89,639) 37

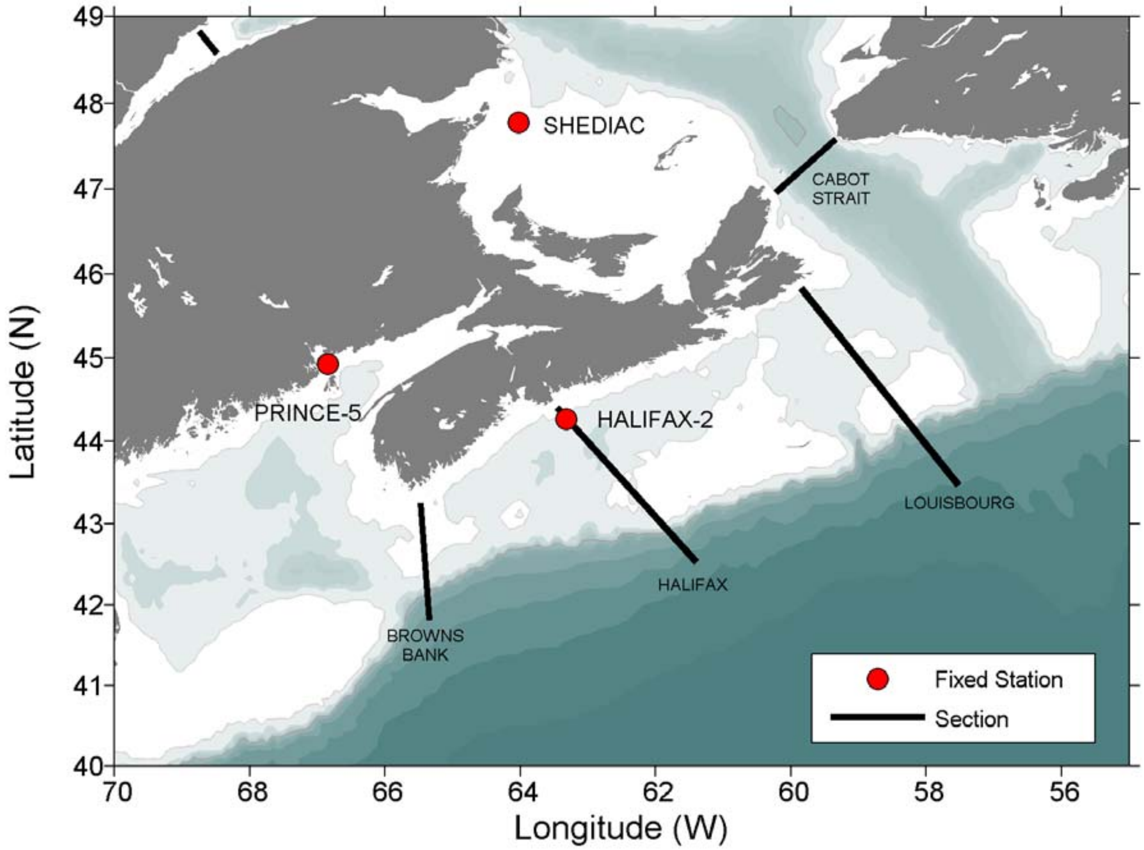

Figure 1. Primary sections and fixed stations sampled in the DFO Maritimes and Gulf regions.

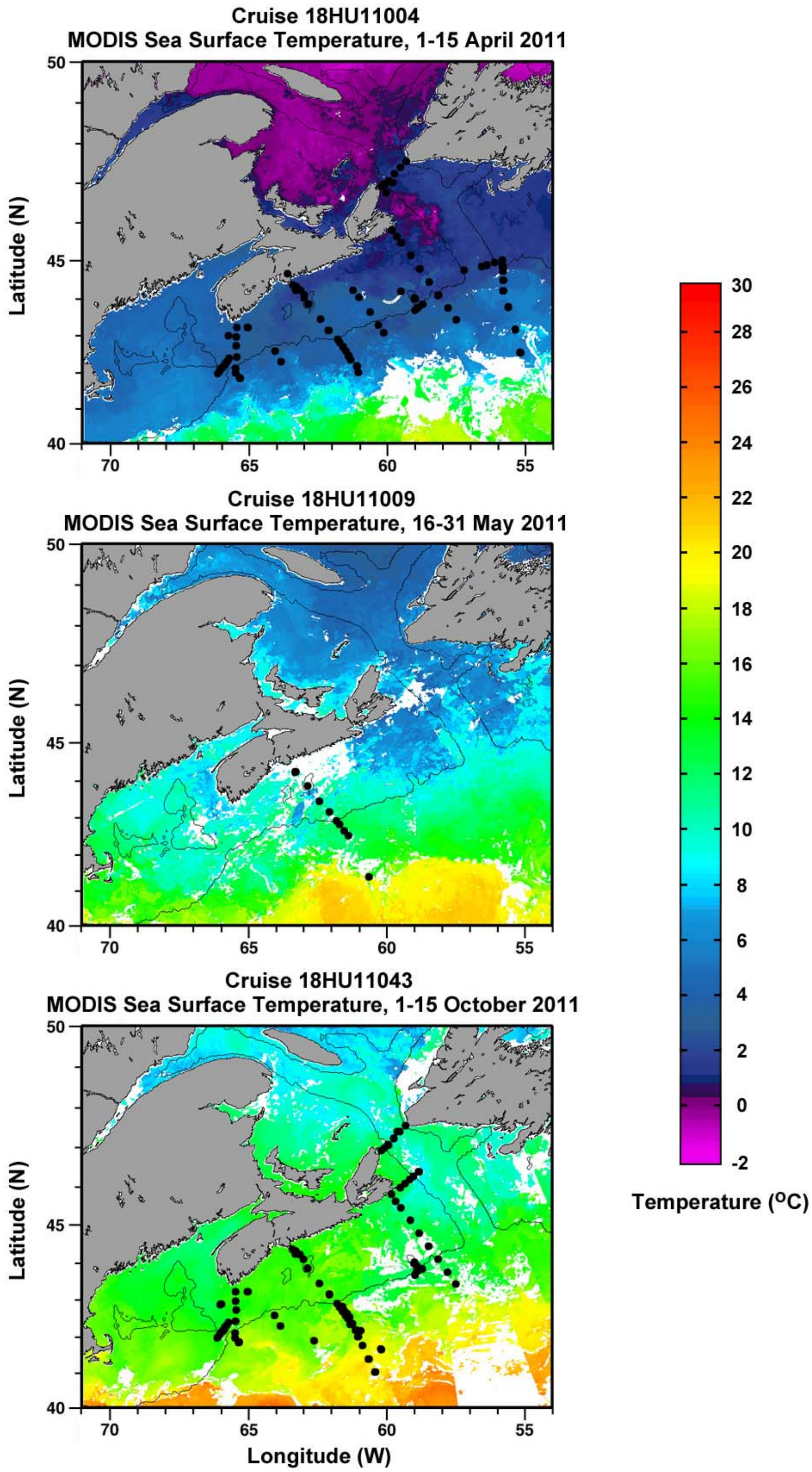

Figure 2. Stations sampled during the 2011 spring, summer, and fall section surveys. Station locations superimposed on twice-monthly sea-surface temperature composite images.

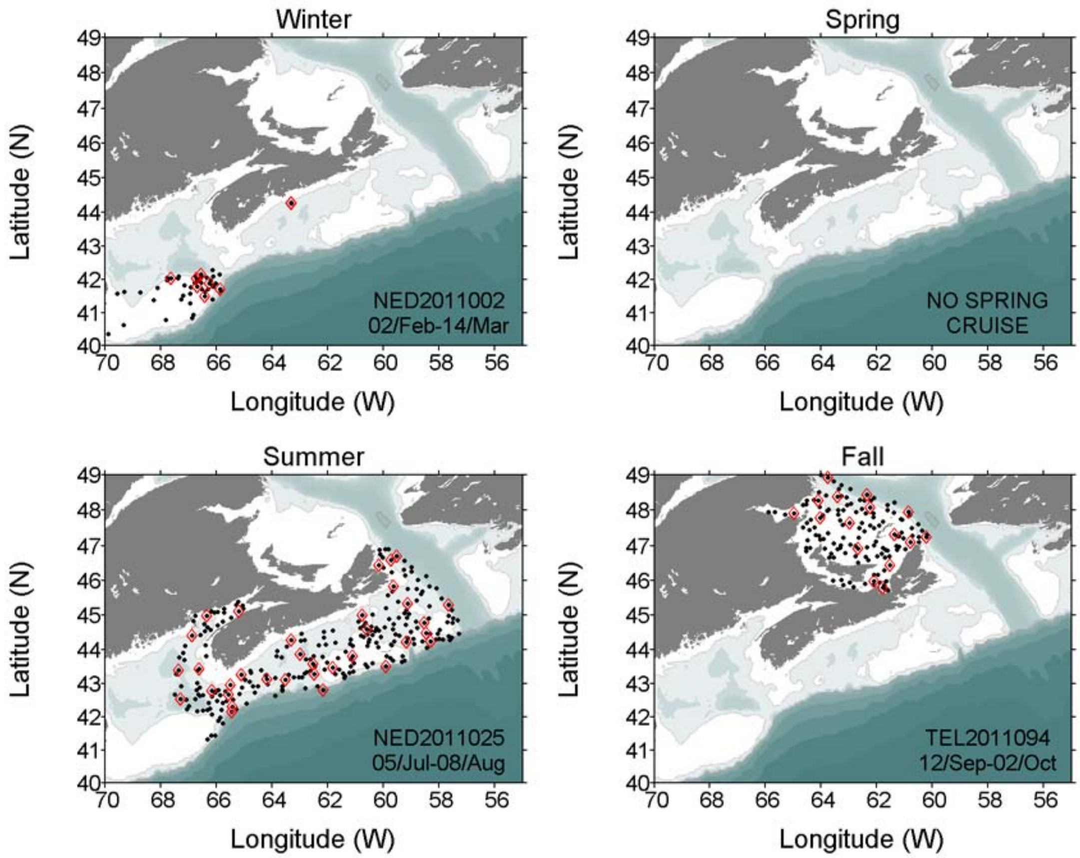

Figure 3. Stations sampled during major Maritimes/Gulf trawl (groundfish) surveys in 2011. Black symbols are hydrographic stations; red symbols are stations where vertical nets hauls were taken in addition to hydrographic measurements.

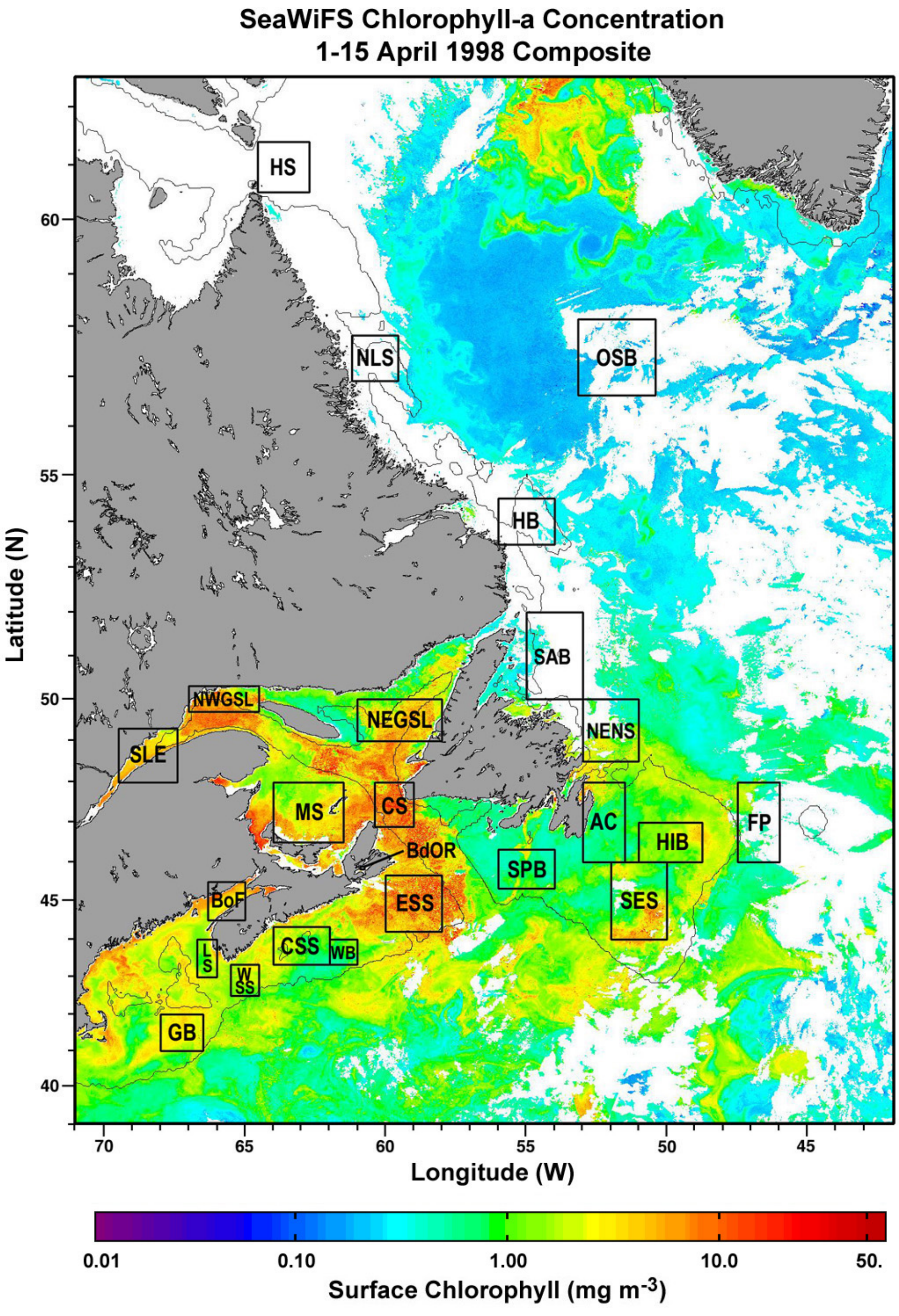

Figure 4. Statistical sub-regions in the Northwest Atlantic identified for spatial/temporal analysis of satellite ocean colour data. AC – Avalon Channel; BdOR – Bras d'Or; BoF – Bay of Fundy; CS – Cabot Strait; CSS – central Scotian Shelf; ESS – eastern Scotian Shelf; FP – Flemish Pass; GB – Georges Bank; HB – Hamilton Bank; HIB - Hibernia; HS – Hudson Strait; LS – Lurcher Shoal; MS – Magdalen Shallows; NEGSL – northeast Gulf of St. Lawrence; NENS – northeast Newfoundland Shelf; NLS – northern Labrador Shelf; NWGSL – northwest Gulf of St. Lawrence; OSB – Ocean Station Bravo; SAB – St. Anthony Basin; SES – southeast Shoal; SLE – St. Lawrence Estuary; SPB – St. Pierre Bank; WB – Western Bank; WSS – western Scotian Shelf.

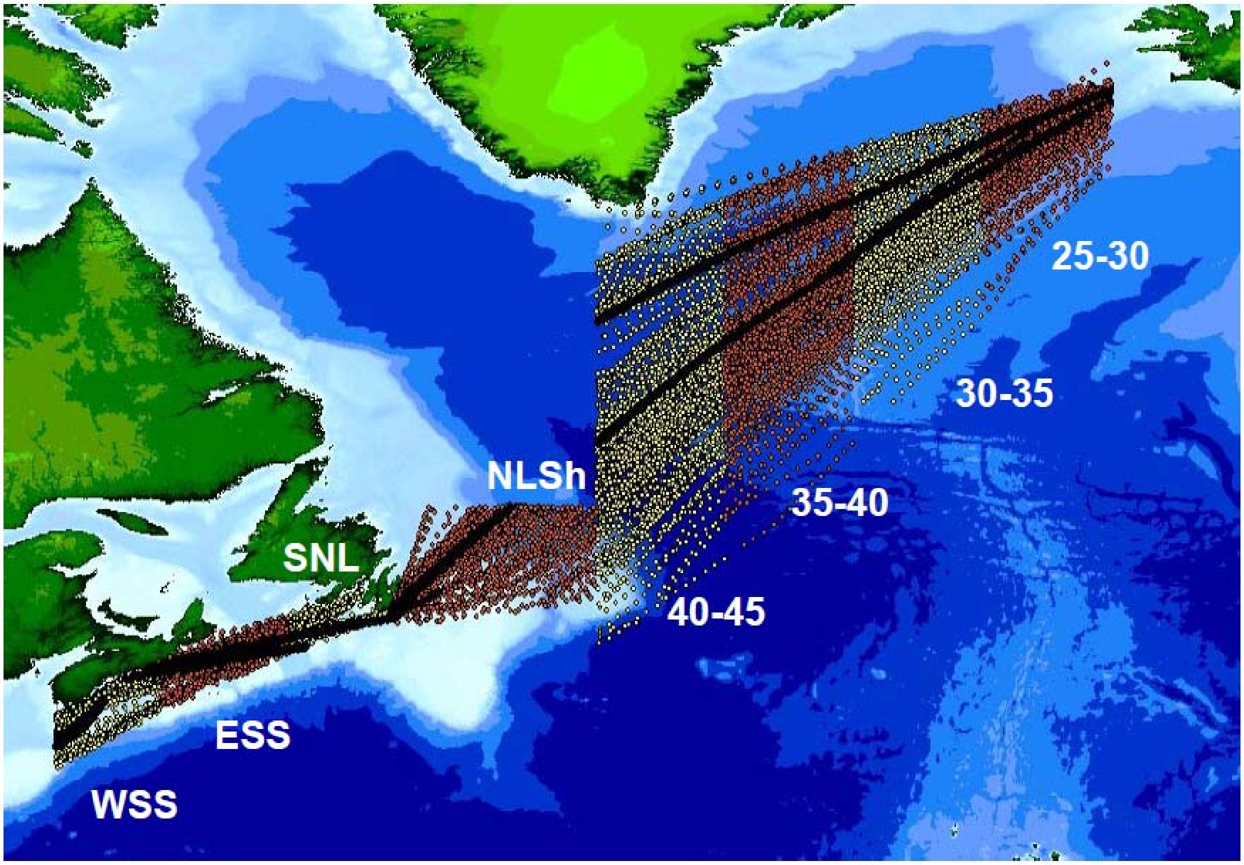

Figure 5. Continuous Plankton Recorder lines and stations 1961–2010. Only stations that are included in the analysis are shown, with adjacent regions delineated alternately by colour (yellow and orange) in the years preceding 2010. Stations sampled in 2010 are shown in black. Western Scotian Shelf – WSS, eastern Scotian Shelf – ESS, South Newfoundland Shelf – SNL, Newfoundland Shelf – NLSh, and between longitudes 40–45°W, 35–40°W, 30–35°W, 25–30°W.

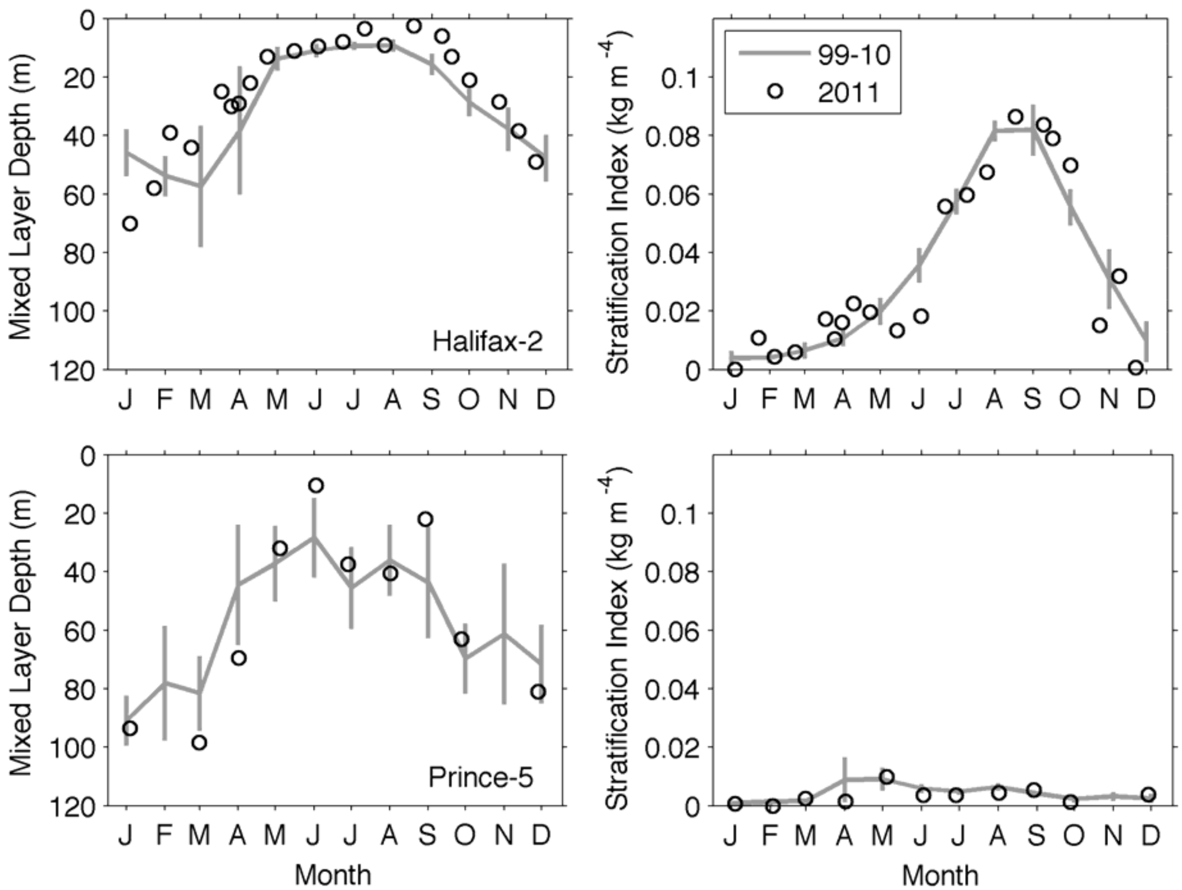

Figure 6. Mixing properties (mixed-layer depth, stratification index) at the Maritimes fixed stations comparing 2011 data (open circle) with mean conditions from 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the observations.

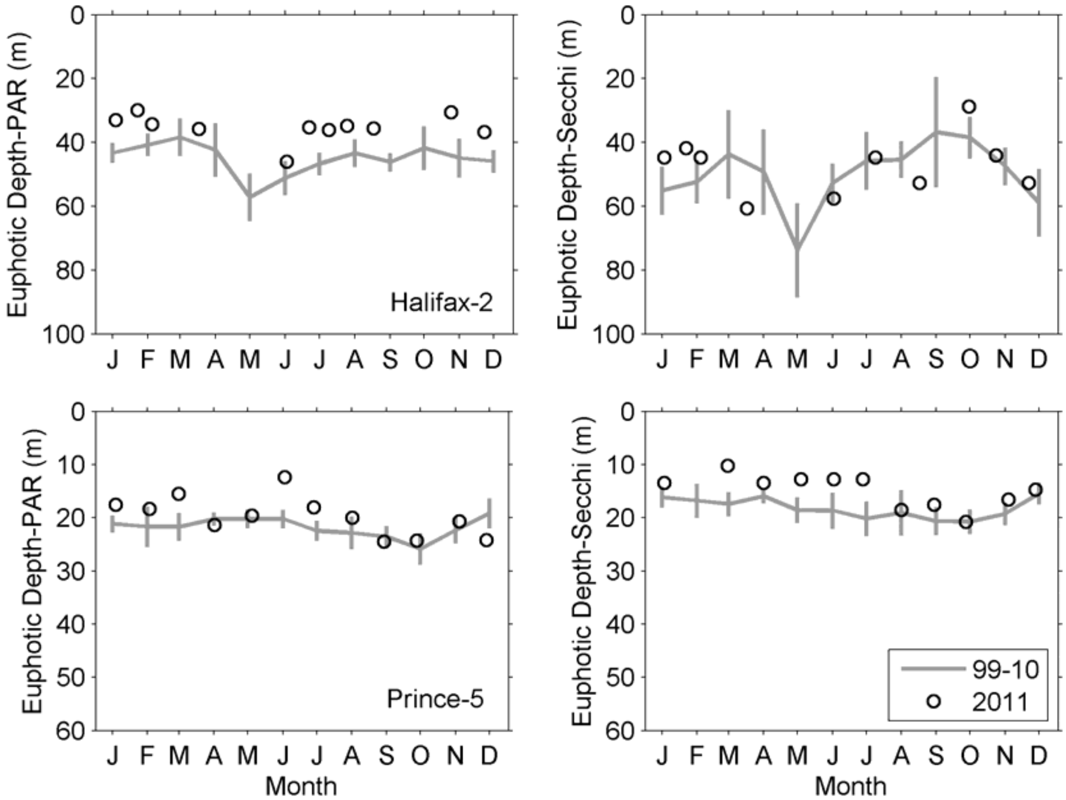

Figure 7. Optical properties (euphotic depth from PAR irradiance meter and Secchi disc) at the Maritimes fixed stations. Year 2011 data (circles) compared with mean conditions from 1999–2010 (solid line), except 2001–2010 for euphotic depth from PAR at Prince-5. Vertical lines are 95% confidence intervals of the observations.

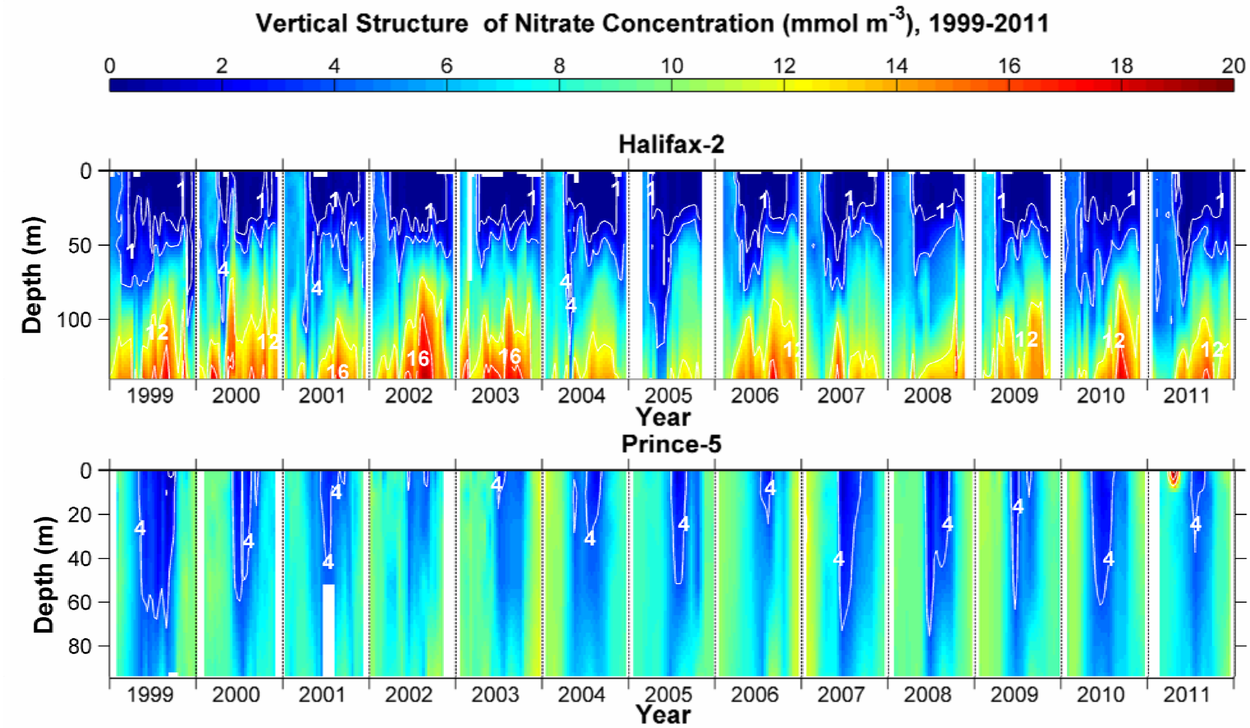

Figure 8. Time series of vertical nitrate structure at the Maritimes fixed stations, 1999–2011.

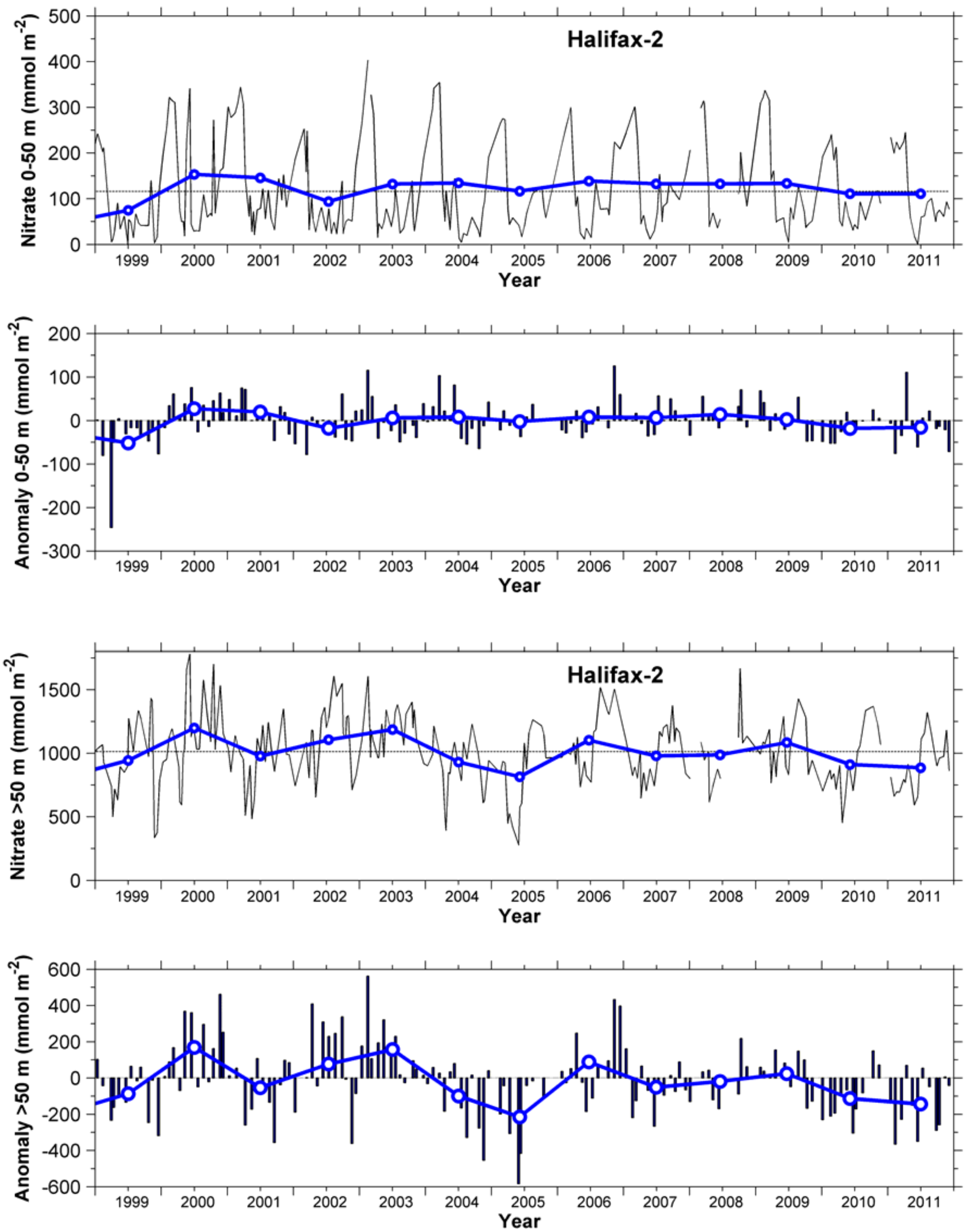

Figure 9a. Nitrate inventories at the Halifax-2 fixed station, 1999–2011. Top two panels: surface (0–50 m) time series with annual averages (solid line); monthly (vertical bars) and annual (solid line) anomalies. Bottom two panels: deep (>50 m) time series with annual averages (solid line); monthly (vertical bars) and annual (solid line) anomalies (reference period: 1999–2010). The overall mean is shown as a horizontal line in the first and third panels.

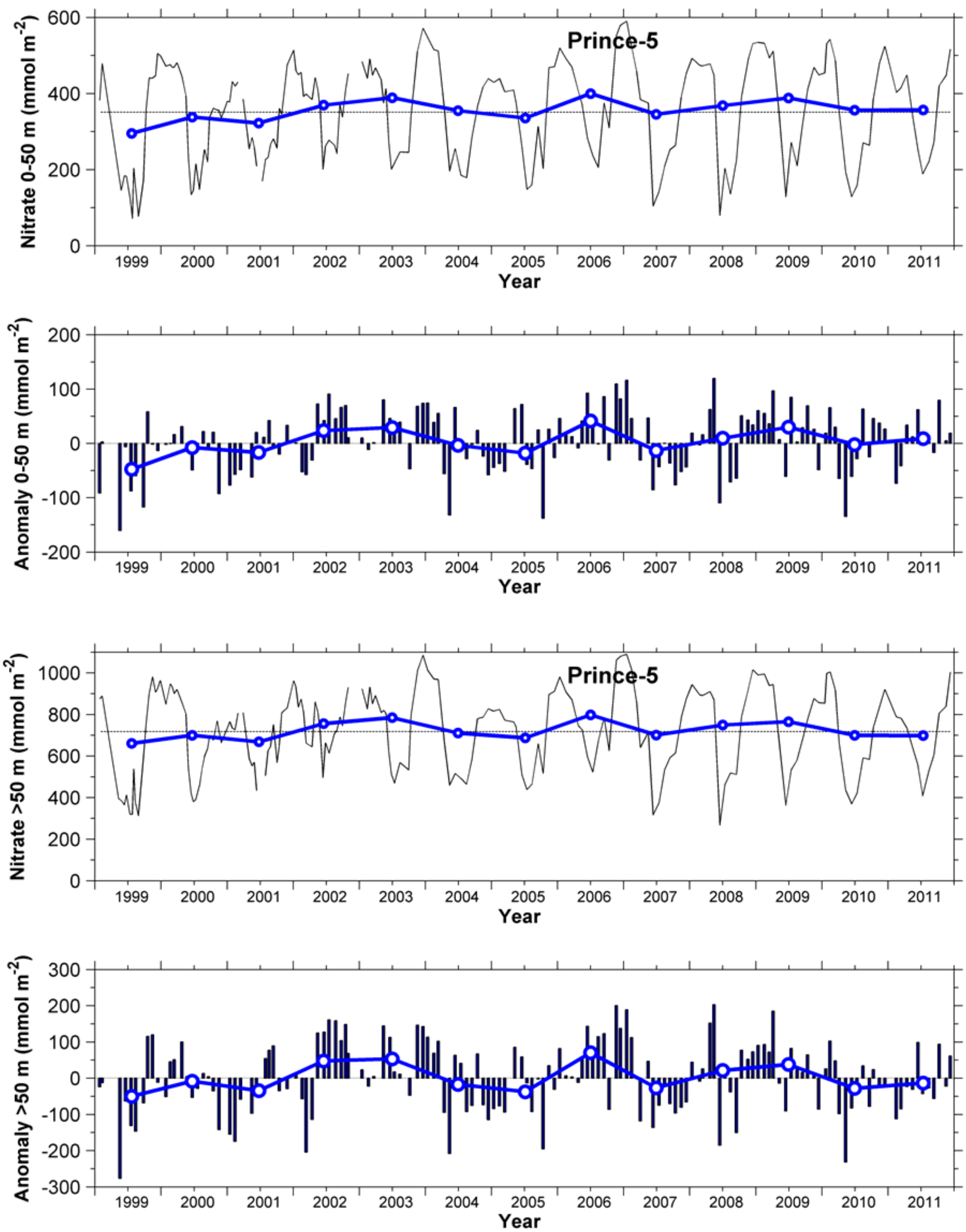

Figure 9b. Nitrate inventories at the Prince-5 fixed station, 1999–2011. Top two panels: surface (0–50 m) time series with annual averages (solid line); monthly (vertical bars) and annual (solid line) anomalies. Bottom two panels: deep (>50 m) time series with annual averages (solid line); monthly (vertical bars) and annual (solid line) anomalies (reference period: 1999–2010). The overall mean is shown as a horizontal line in the first and third panels.

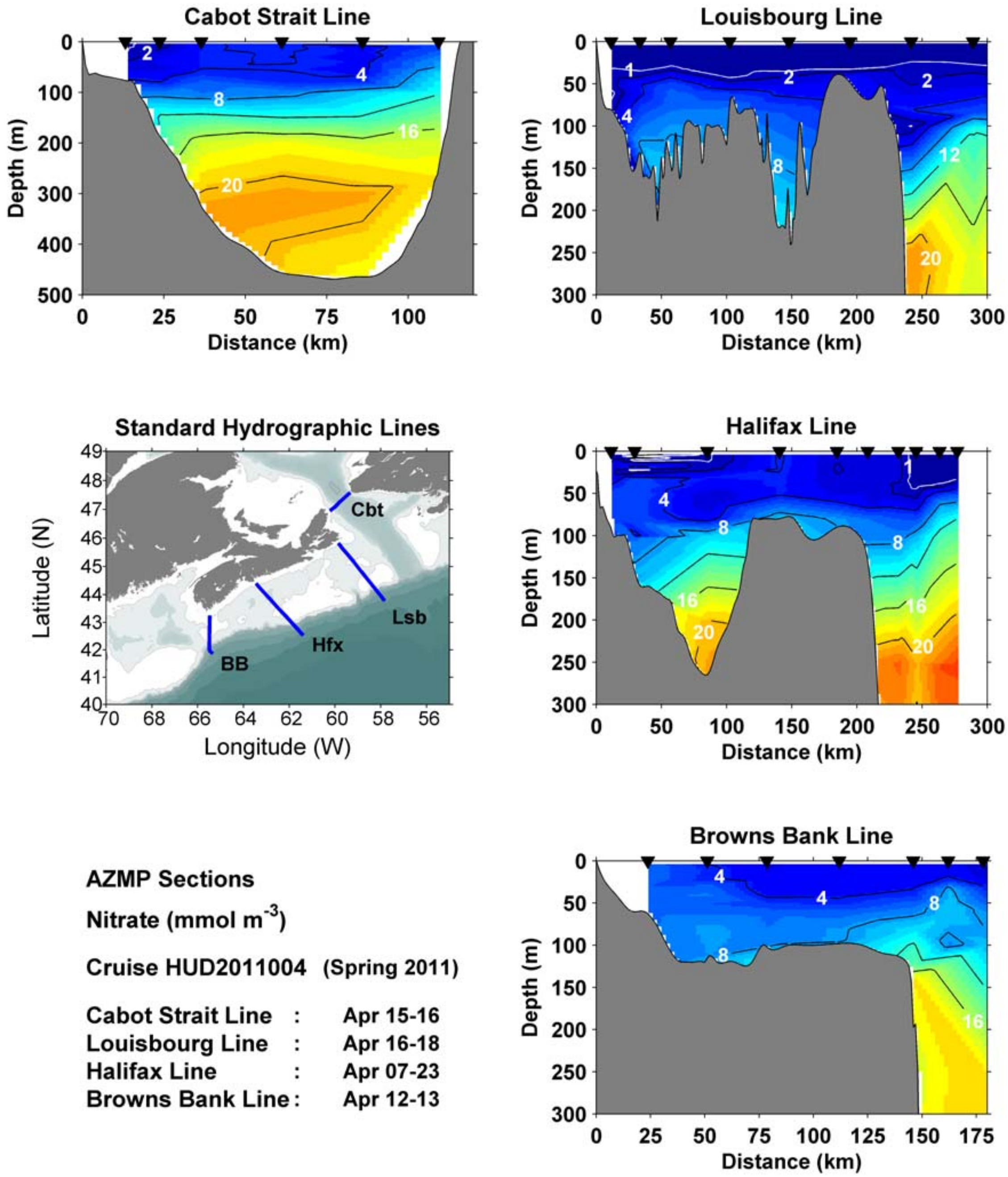

Figure 10. Vertical nitrate structure along the Scotian Shelf sections during the spring survey in 2011.

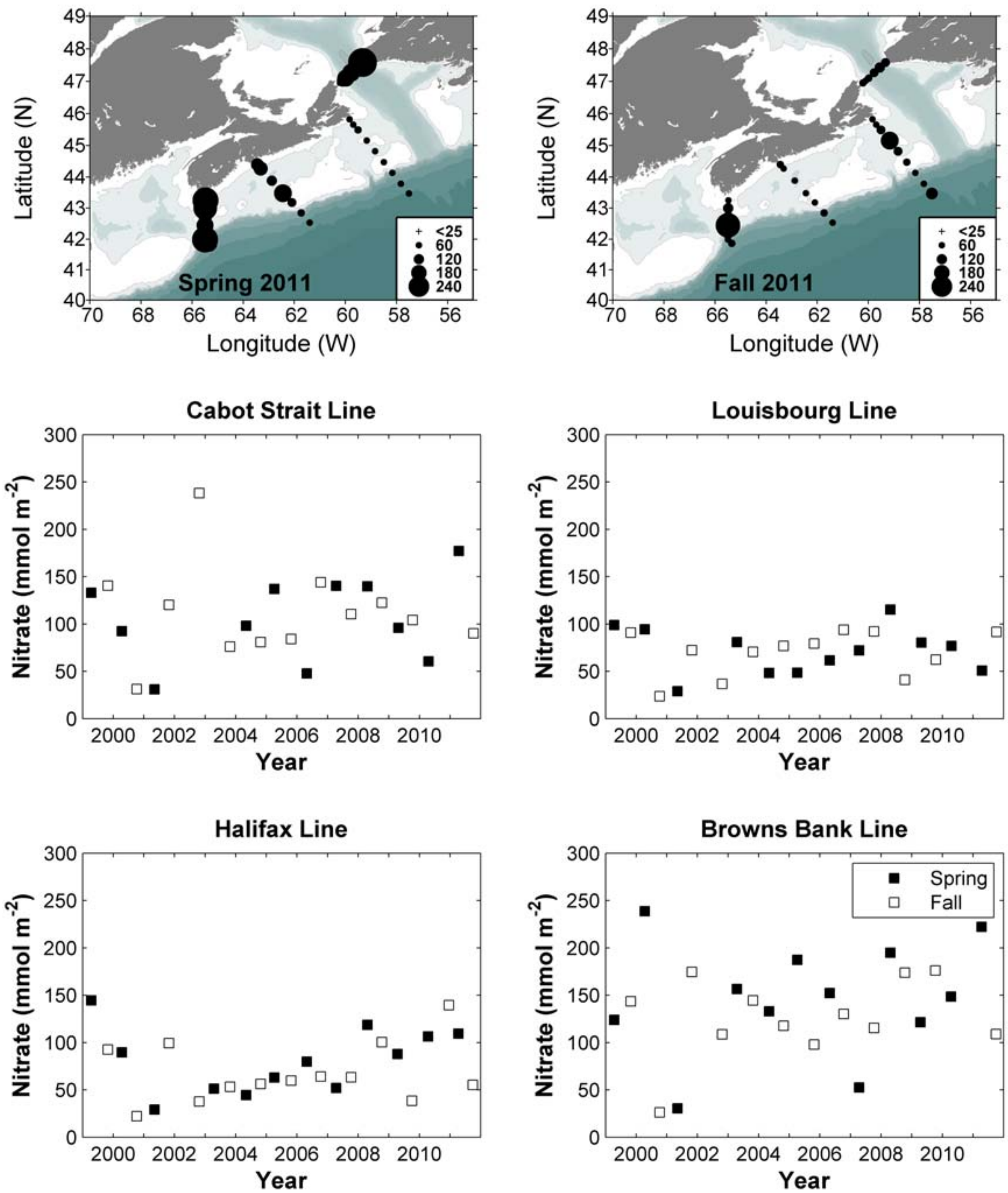

Figure 11a. Spatial distribution of upper water column nitrate (0–50 m) for spring and fall 2011 (upper panels) and time series of average upper water column nitrate on the Scotian Shelf sections in spring (filled squares) and fall (open squares), 1999–2011 (lower panels).

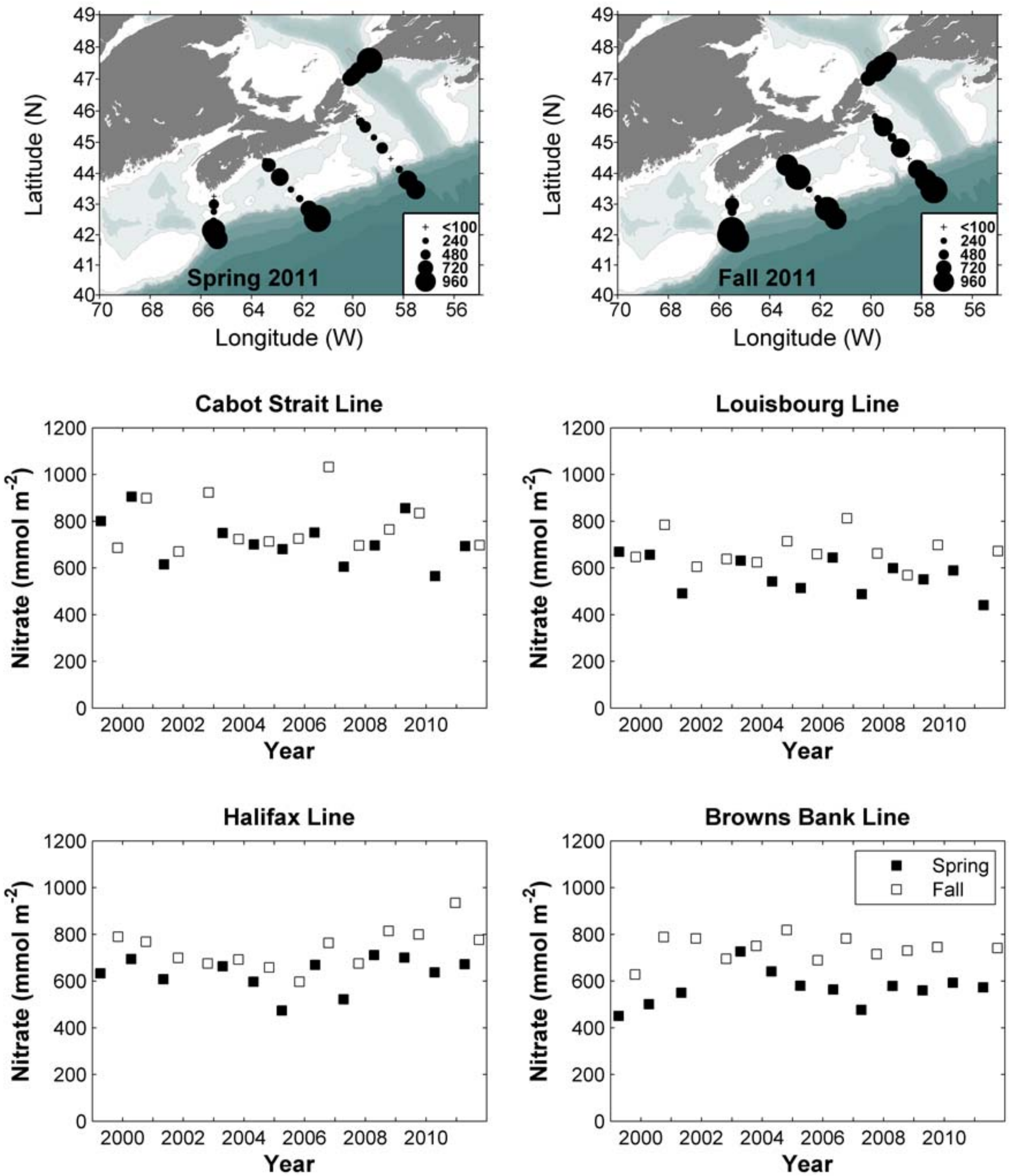

Figure 11b. Spatial distribution of deep water nitrate (>50 m) for spring and fall 2011 (upper panels) and time series of average deep water nitrate on the Scotian Shelf sections in spring (filled squares) and fall (open squares), 1999–2011 (lower panels).

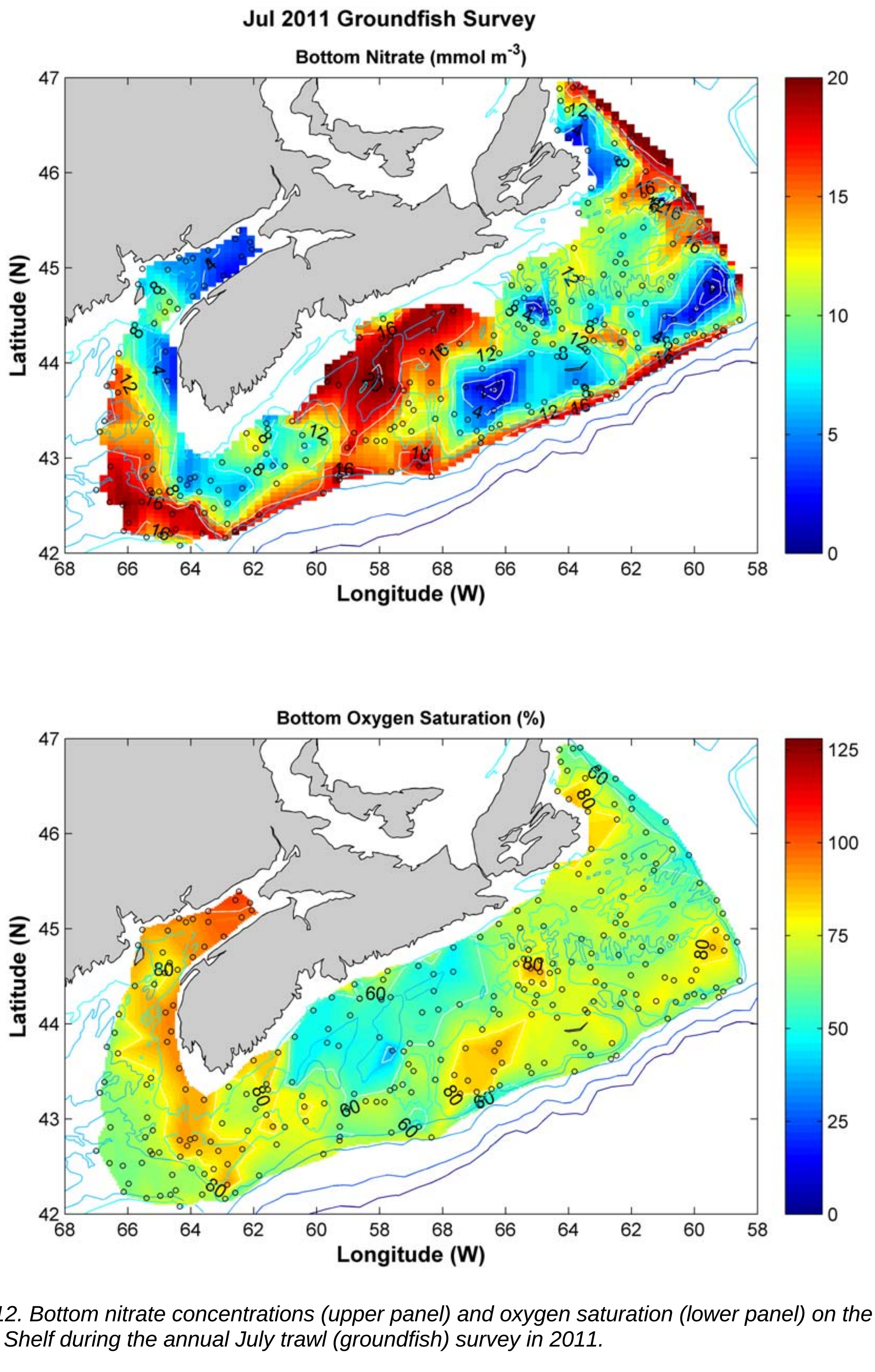

Figure 12. Bottom nitrate concentrations (upper panel) and oxygen saturation (lower panel) on the Scotian Shelf during the annual July trawl (groundfish) survey in 2011.

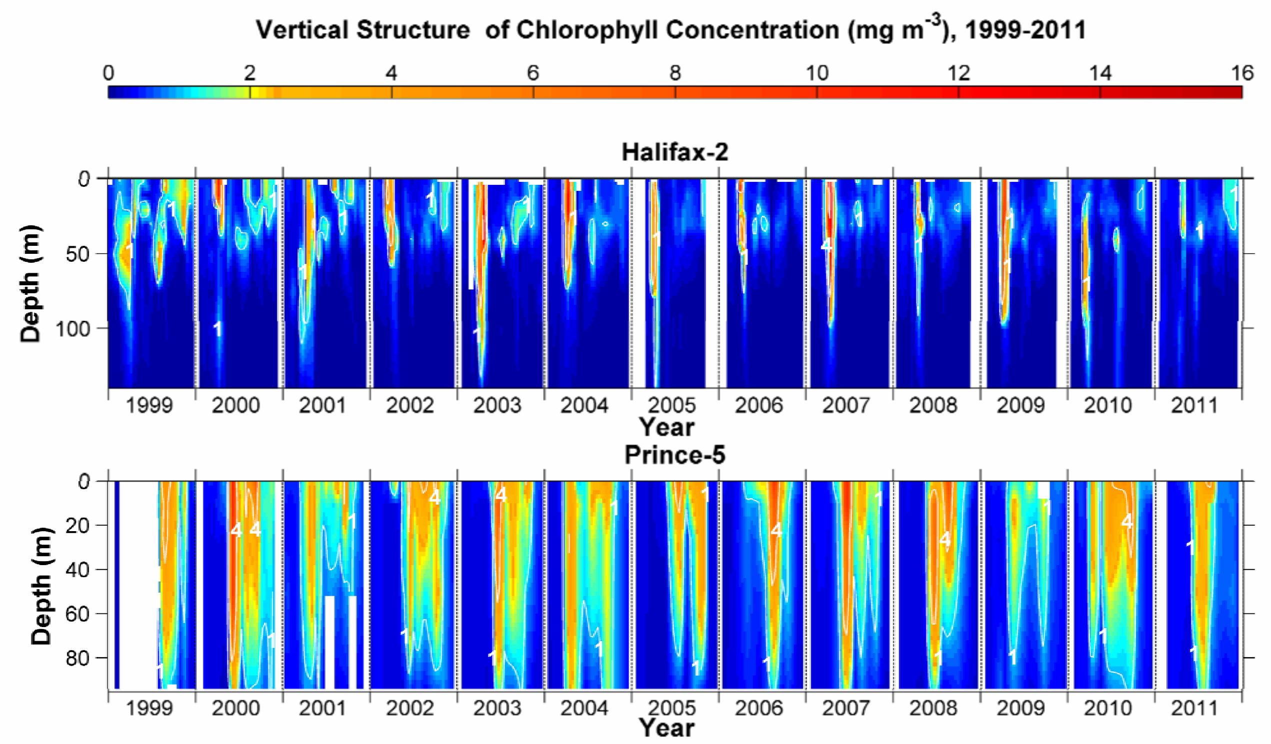

Figure 13. Time series of vertical chlorophyll structure at the Maritimes fixed stations, 1999–2011. Colour scale chosen to emphasize change near estimated food saturation levels for large copepods.

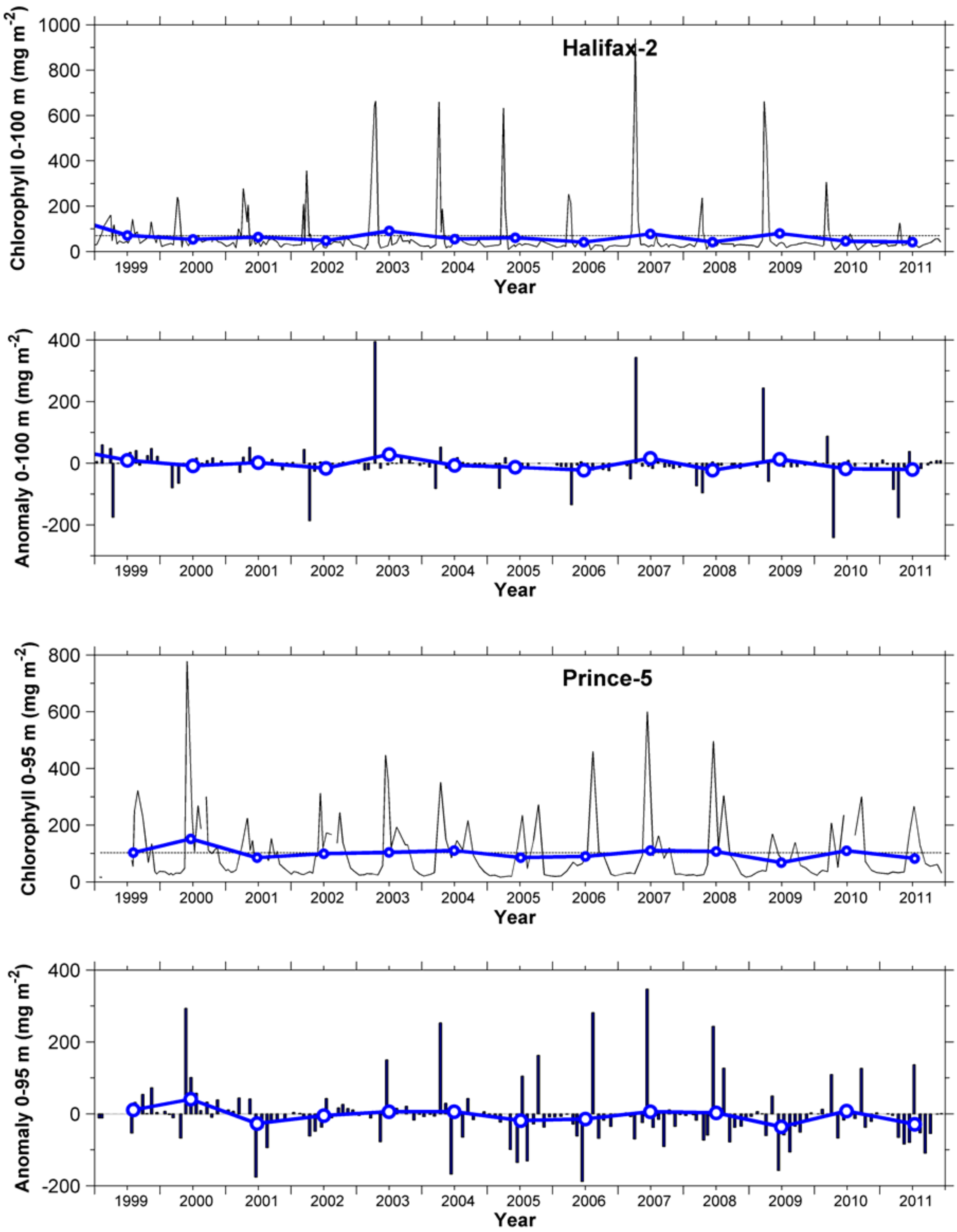

Figure 14. Chlorophyll inventories at the Maritimes fixed stations, 1999–2011. Top two panels: Halifax-2 time series with annual averages (solid line); monthly (vertical bars) and annual (solid line) anomalies. Bottom two panels: Prince-5 time series with annual averages (solid line); monthly (vertical bars) and annual (solid line) anomalies (reference period: 1999–2010). The overall mean is shown as a horizontal line in the first and third panels.

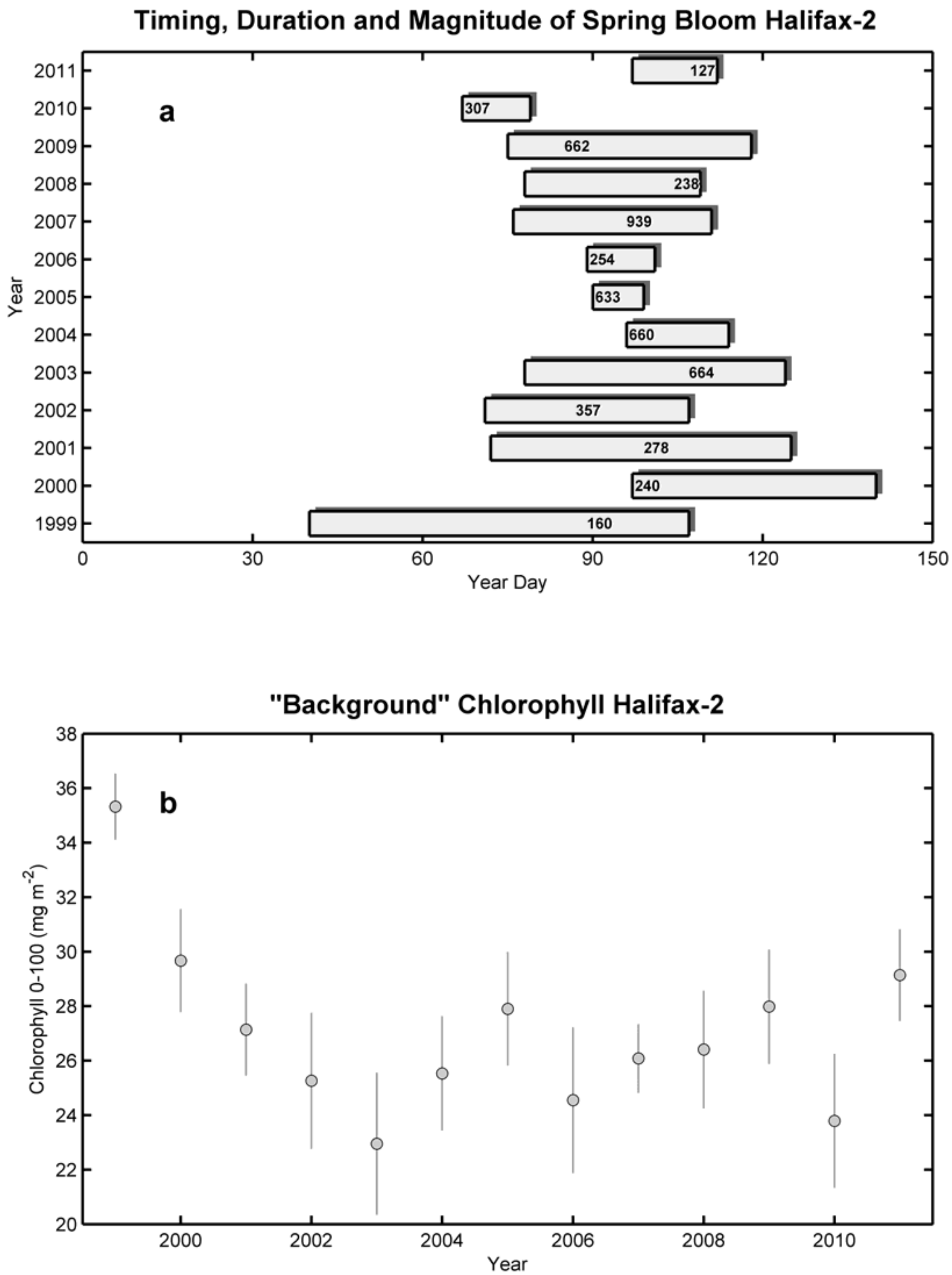

Figure 15. Dynamics of the spring phytoplankton bloom at the Halifax-2 fixed station, 1999–2011: (upper panel) timing, duration (based on 40 mg Chl m^{-2} threshold for determining start and end of the bloom), and magnitude (numbers inside horizontal bars); and (lower panel) "background" chlorophyll levels, i.e., outside of spring bloom periods based on the 0–100 m integral (annual averages ± SE, line = least squares linear regression).

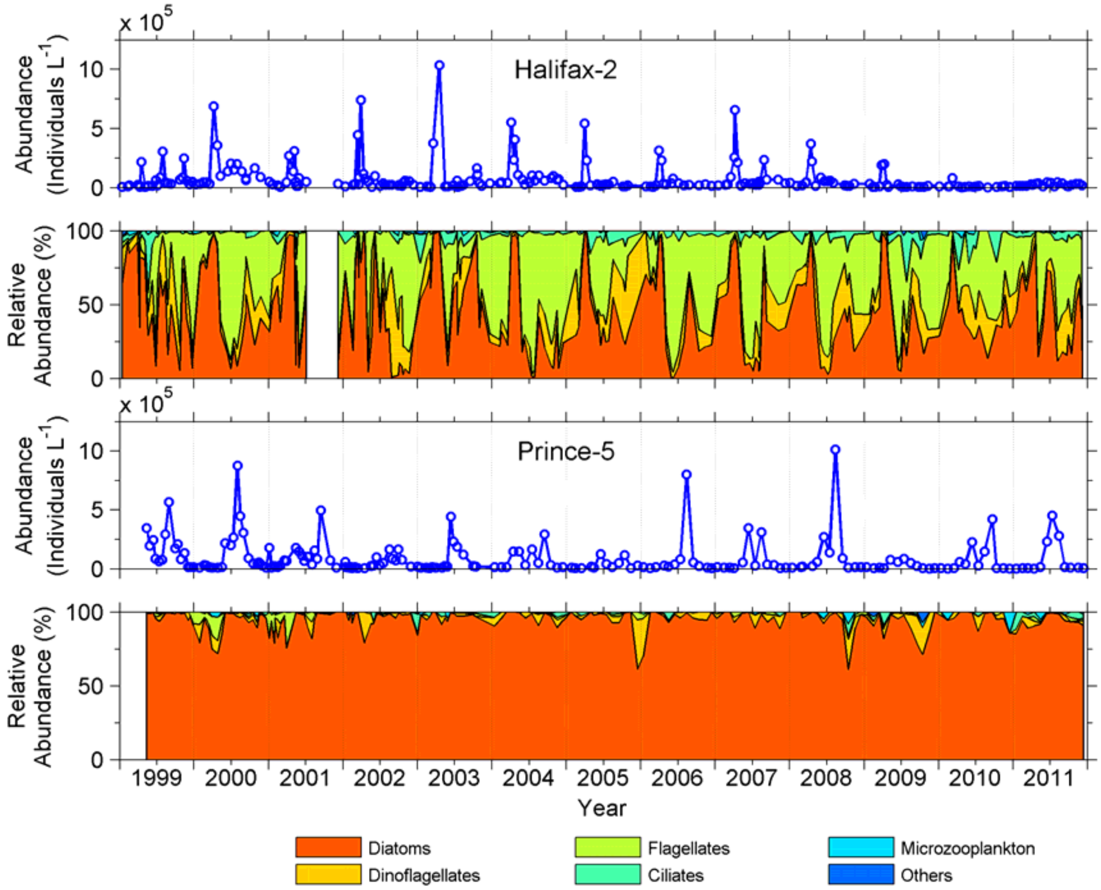

Figure 16. Time series of microplankton (phytoplankton and protists) abundance and community composition at the Maritimes fixed stations, 1999–2011.

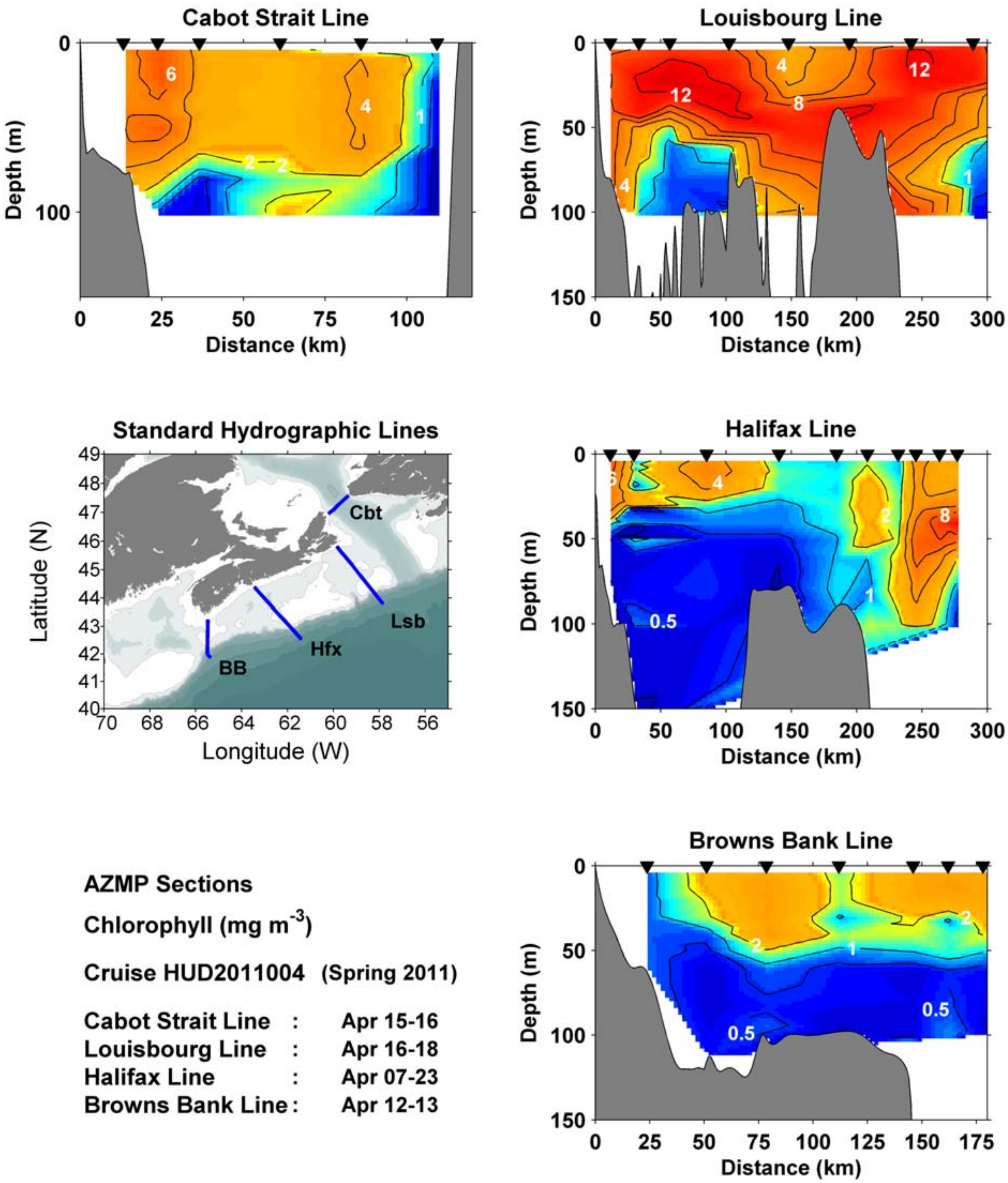

Figure 17. Vertical chlorophyll structure along the Scotian Shelf sections during the spring survey in 2011.

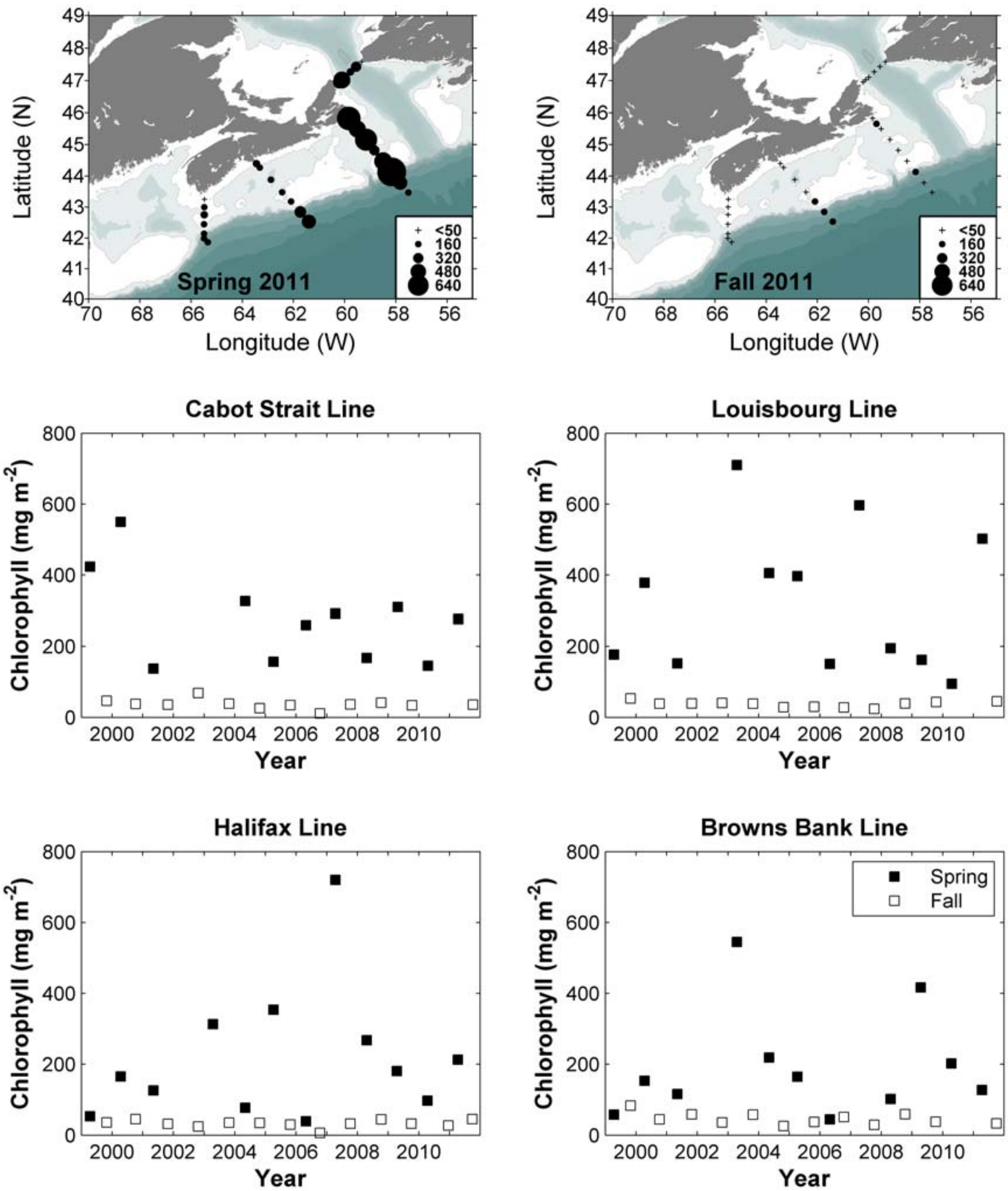

Figure 18. Spatial distribution of upper water column chlorophyll (0—100 m) for spring and fall 2011 (upper panels) and time series of average upper water column chlorophyll on the Scotian Shelf sections in spring (filled squares) and fall (open squares), 1999–2011 (lower panels).

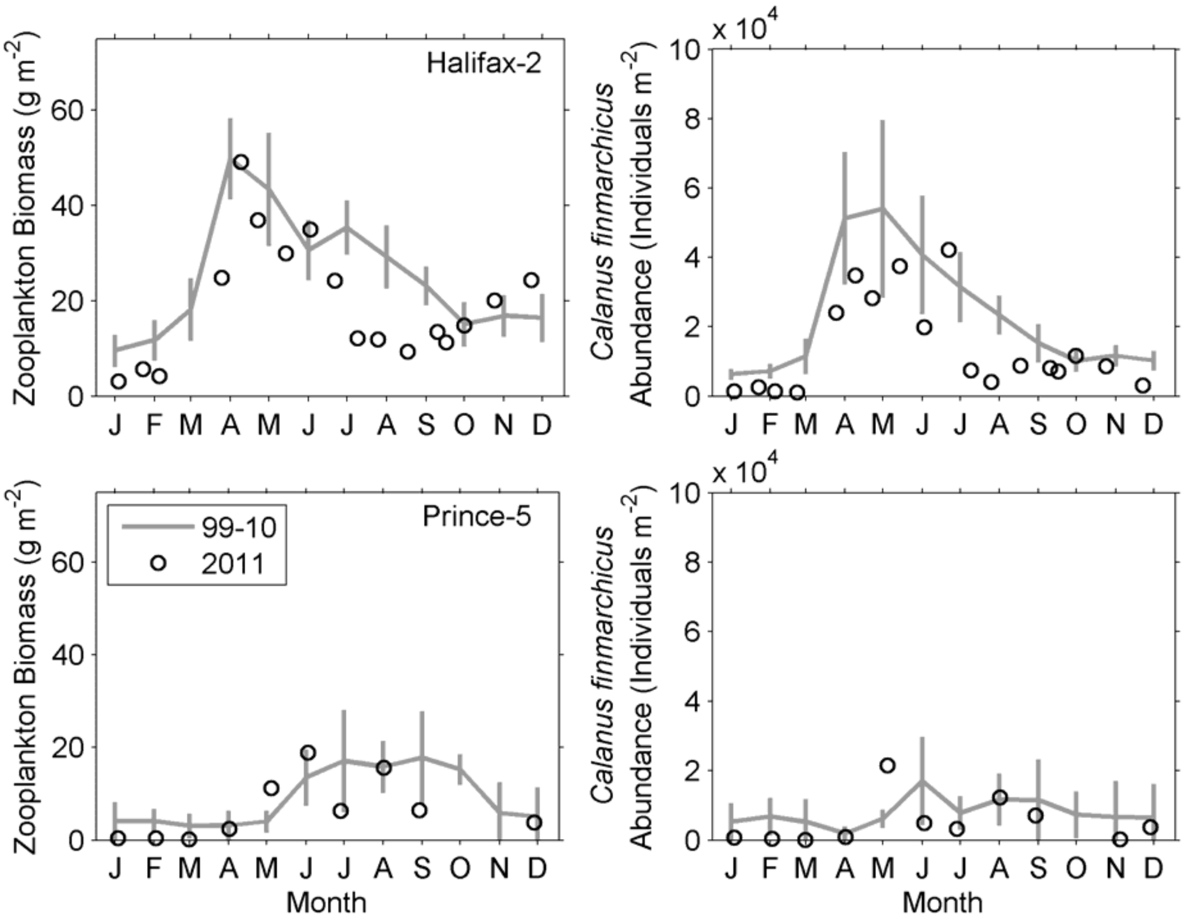

Figure 19. Comparison of 2011 (open circle) data with mean conditions from 1999–2010 (solid line) at the Maritimes fixed stations. Left panels: zooplankton biomass (surface to bottom). Right panels: C. finmarchicus abundance (all copepodite and adult stages, surface to bottom). Vertical lines are 95% confidence intervals of the annual averages.

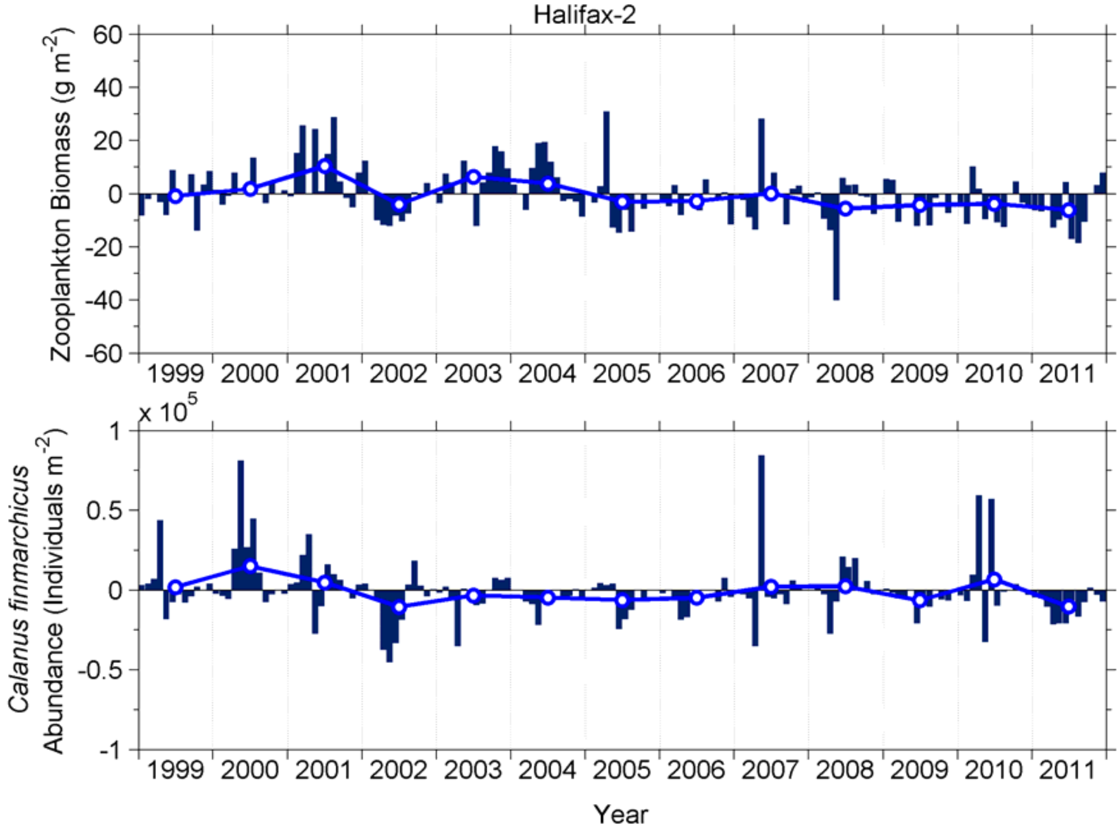

Figure 20a. Zooplankton biomass and C. finmarchicus abundance anomalies at Halifax-2, with monthly anomalies (vertical bars) and annual anomalies (open circle) (reference period: 1999–2010).

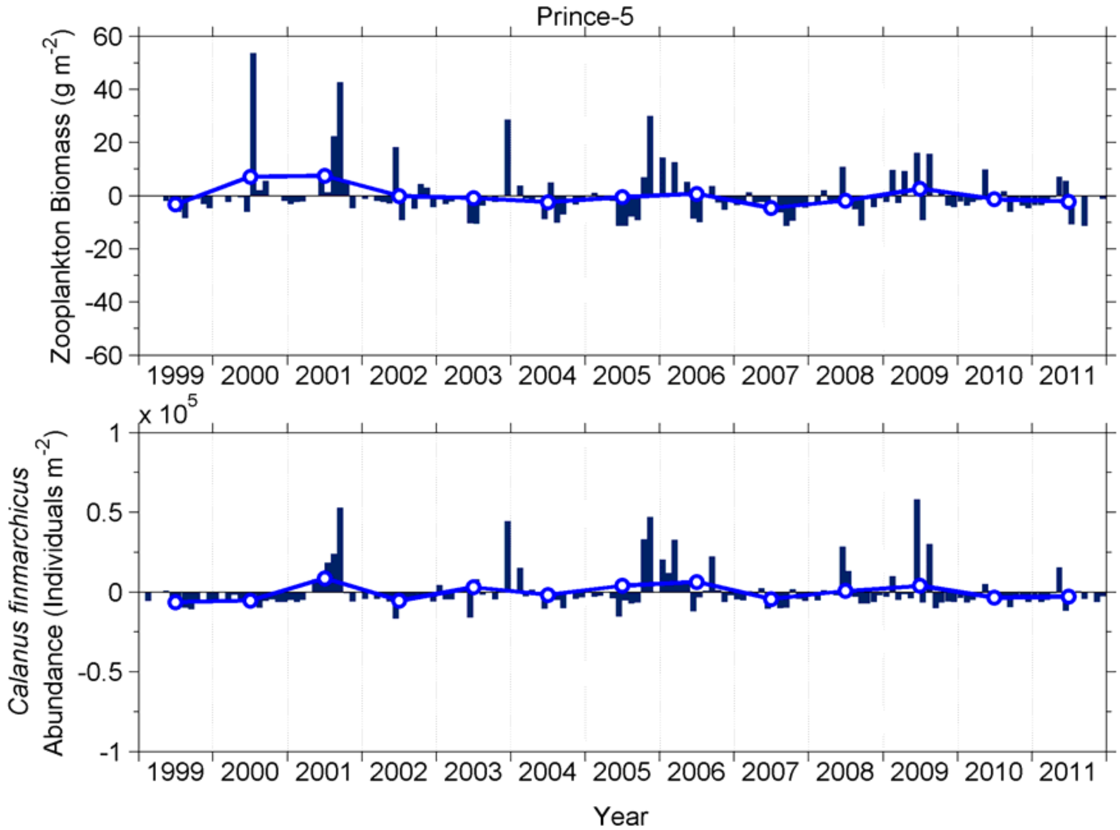

Figure 20b. Zooplankton biomass and C. finmarchicus abundance anomalies at Prince-5, with monthly anomalies (vertical bars) and annual anomalies (open circle) (reference period: 1999–2010).

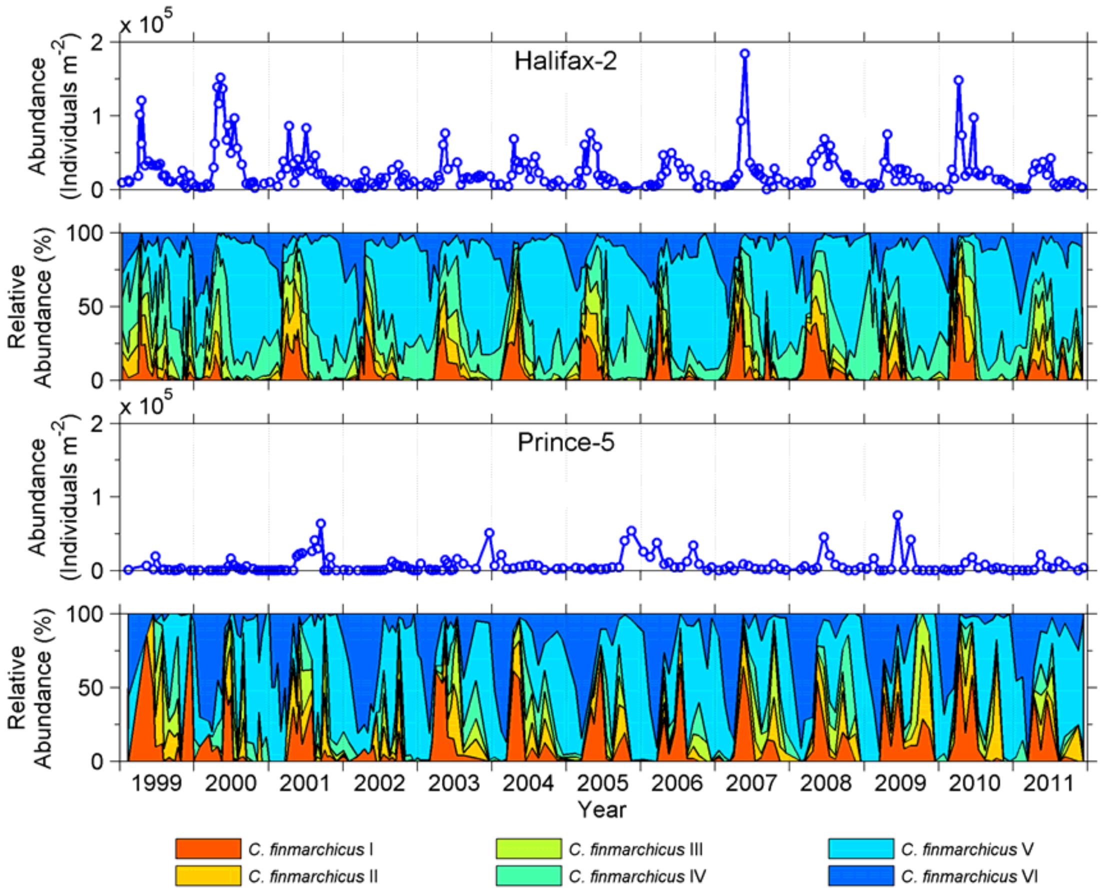

Figure 21. Time series of C. finmarchicus abundance and developmental stages at the Maritimes fixed stations, 1999–2011.

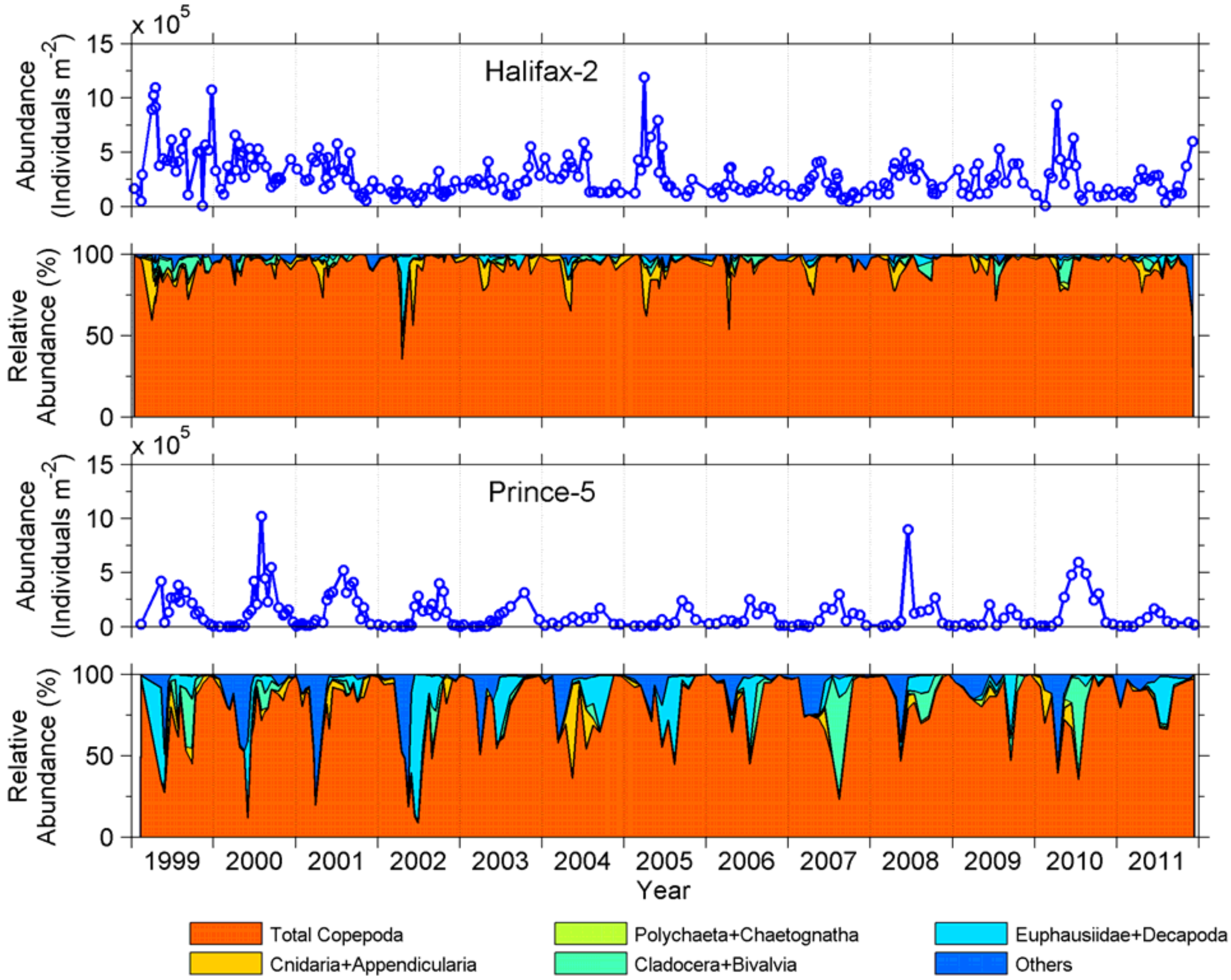

Figure 22. Time series of zooplankton (>200 µm) abundance and community composition at the Maritimes fixed stations, 1999–2011.

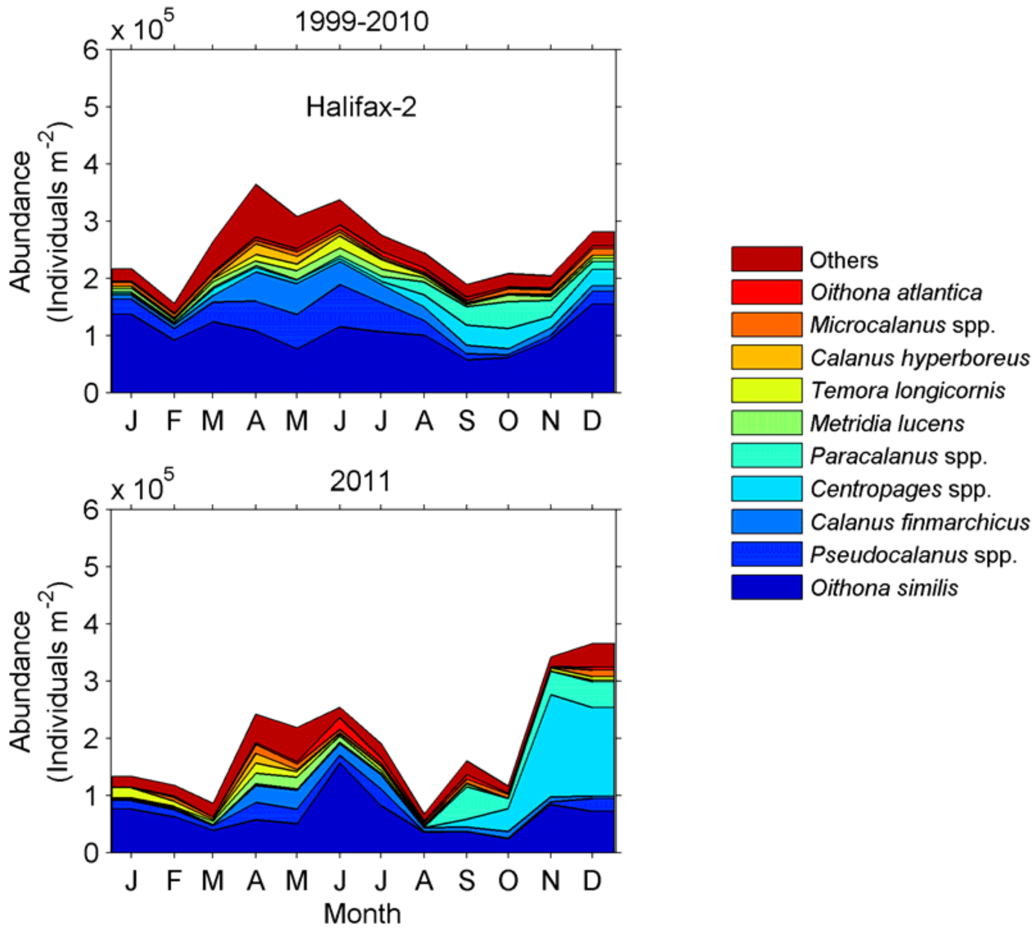

Figure 23a. Seasonal variability of dominant copepods at Halifax-2. The top 95% of copepods by abundance are shown individually; others are grouped as 'others.' The top panel is based on monthly mean abundances from 1999–2010; the bottom panel is monthly mean abundances in 2011.

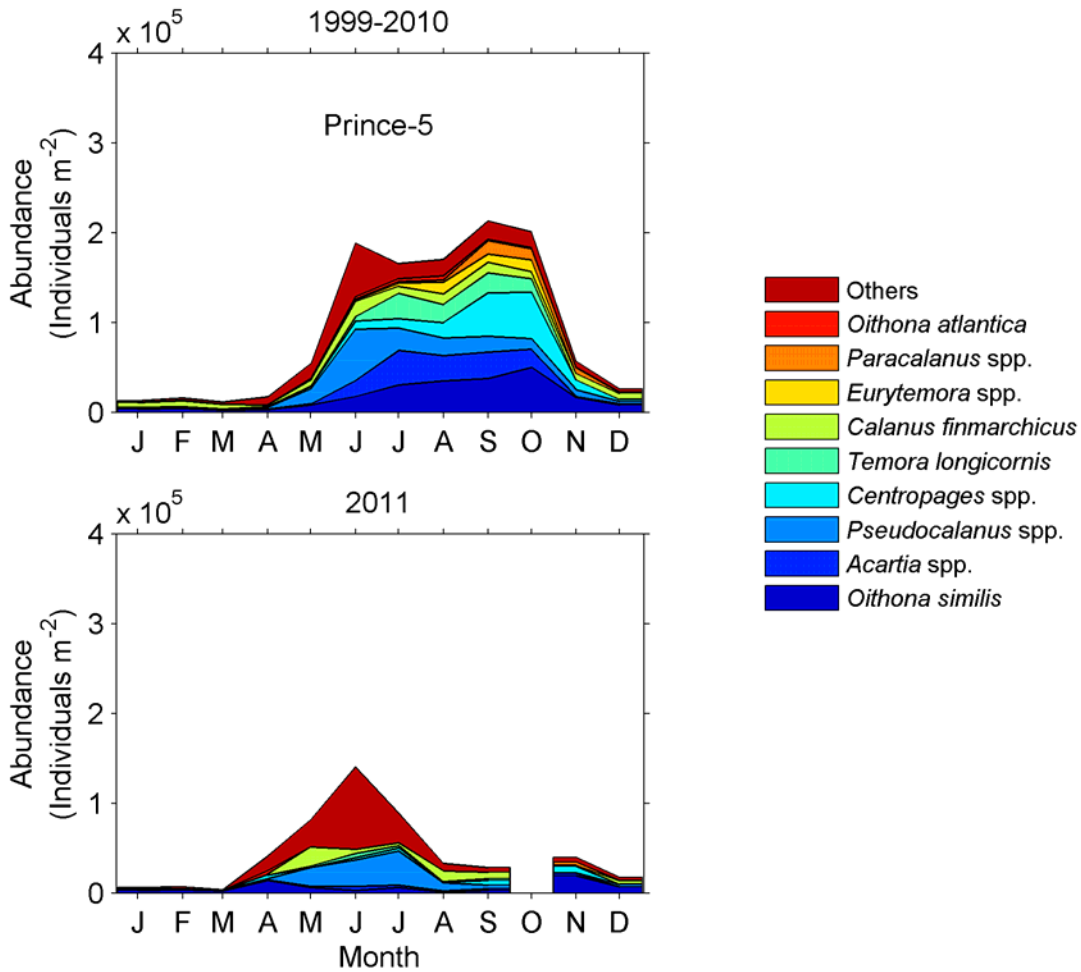

Figure 23b. Seasonal variability of dominant copepods at Prince-5. The top 95% of copepods by abundance are shown individually; others are grouped as 'others.' The top panel is based on monthly mean abundances from 1999–2010. Bottom panels are monthly mean abundances in 2011.

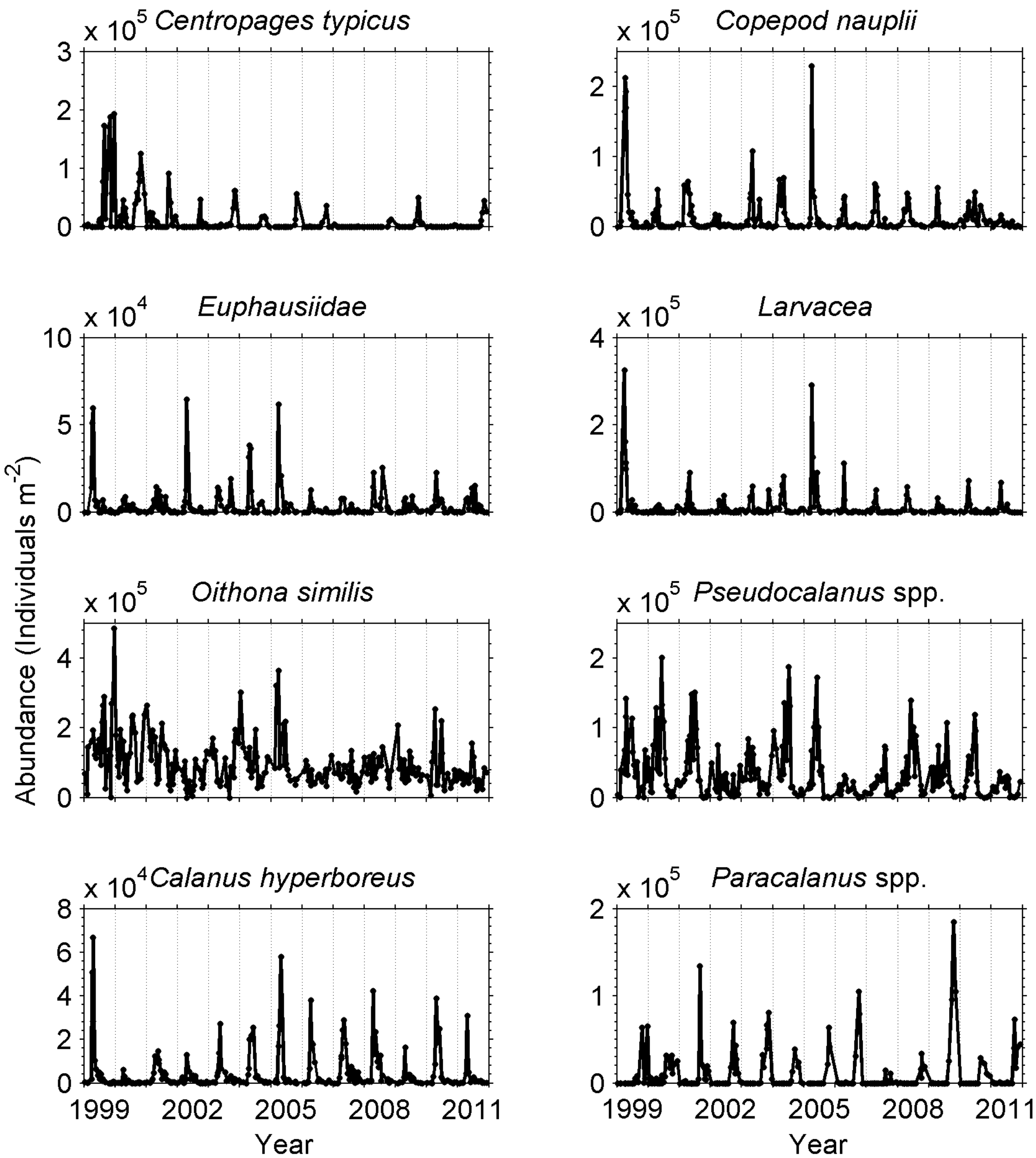

Figure 24a. Time series of eight dominant or important zooplankton taxa from Halifax-2 for the period 1999–2011.

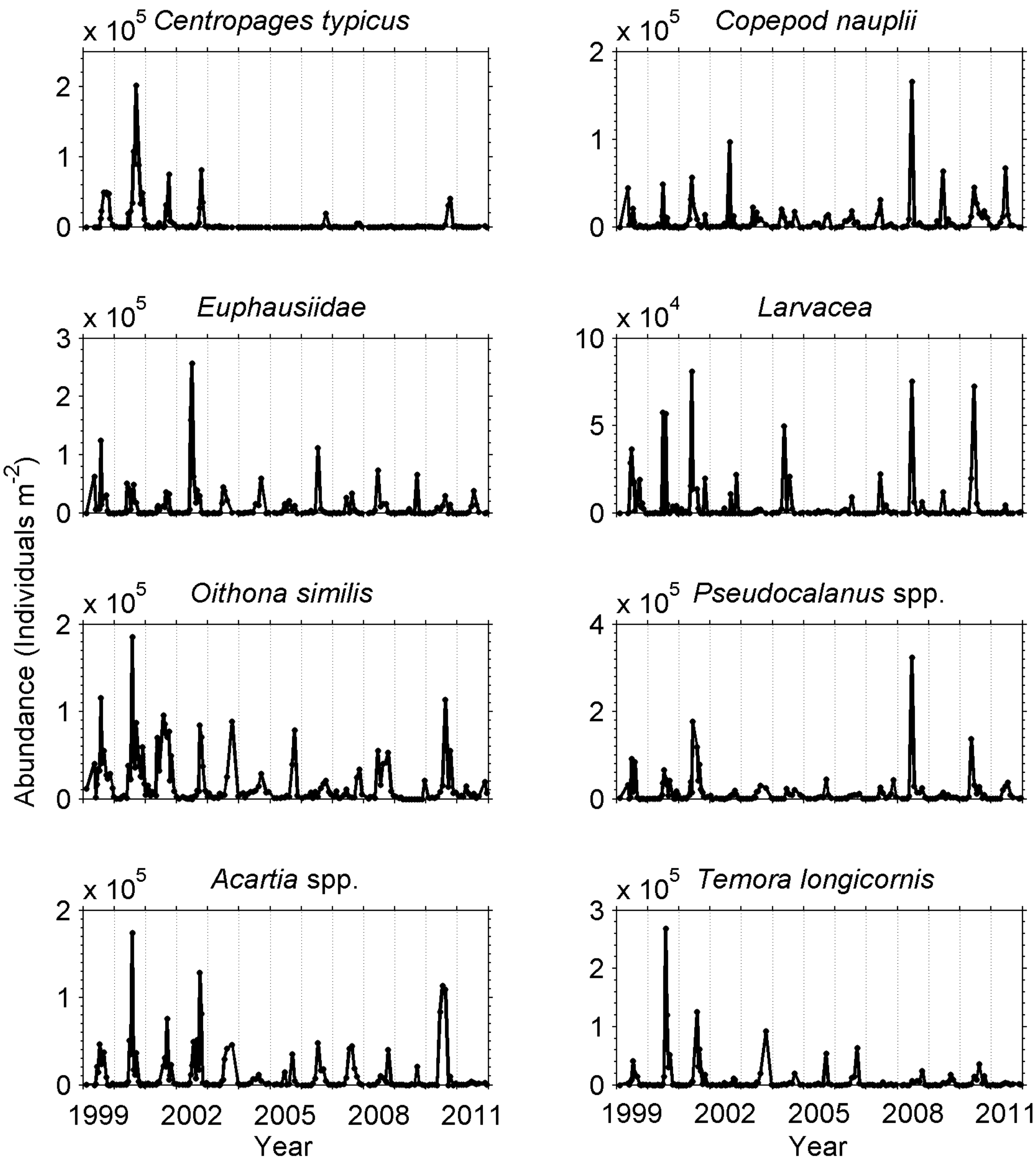

Figure 24b. Time series of eight dominant or important zooplankton taxa from Prince-5 for the period 1999–2011.

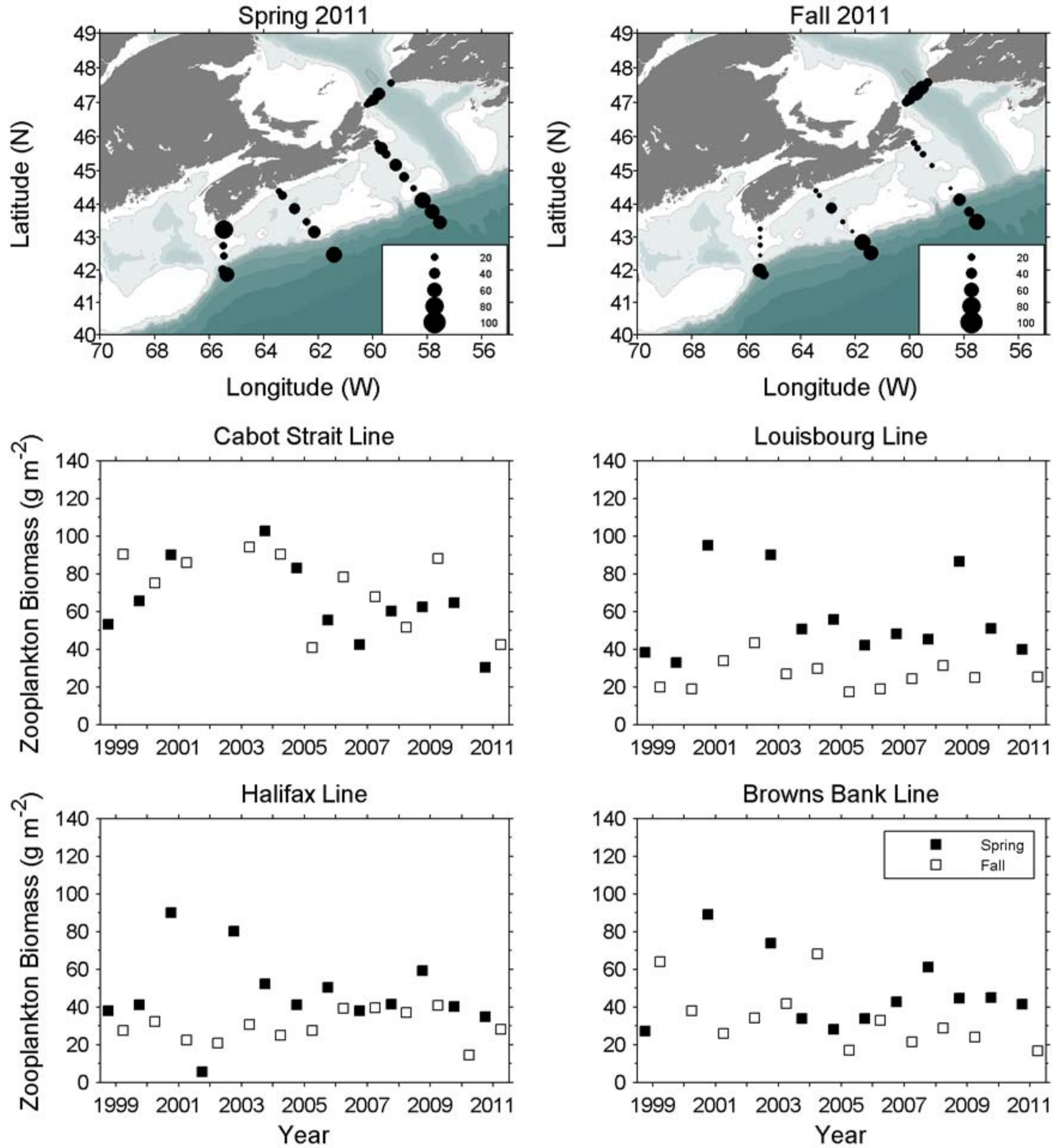

Figure 25a. Spatial distribution of zooplankton biomass (upper panels) and average zooplankton biomass on Scotian Shelf sections (lower panels) in spring and fall, 1999–2011.

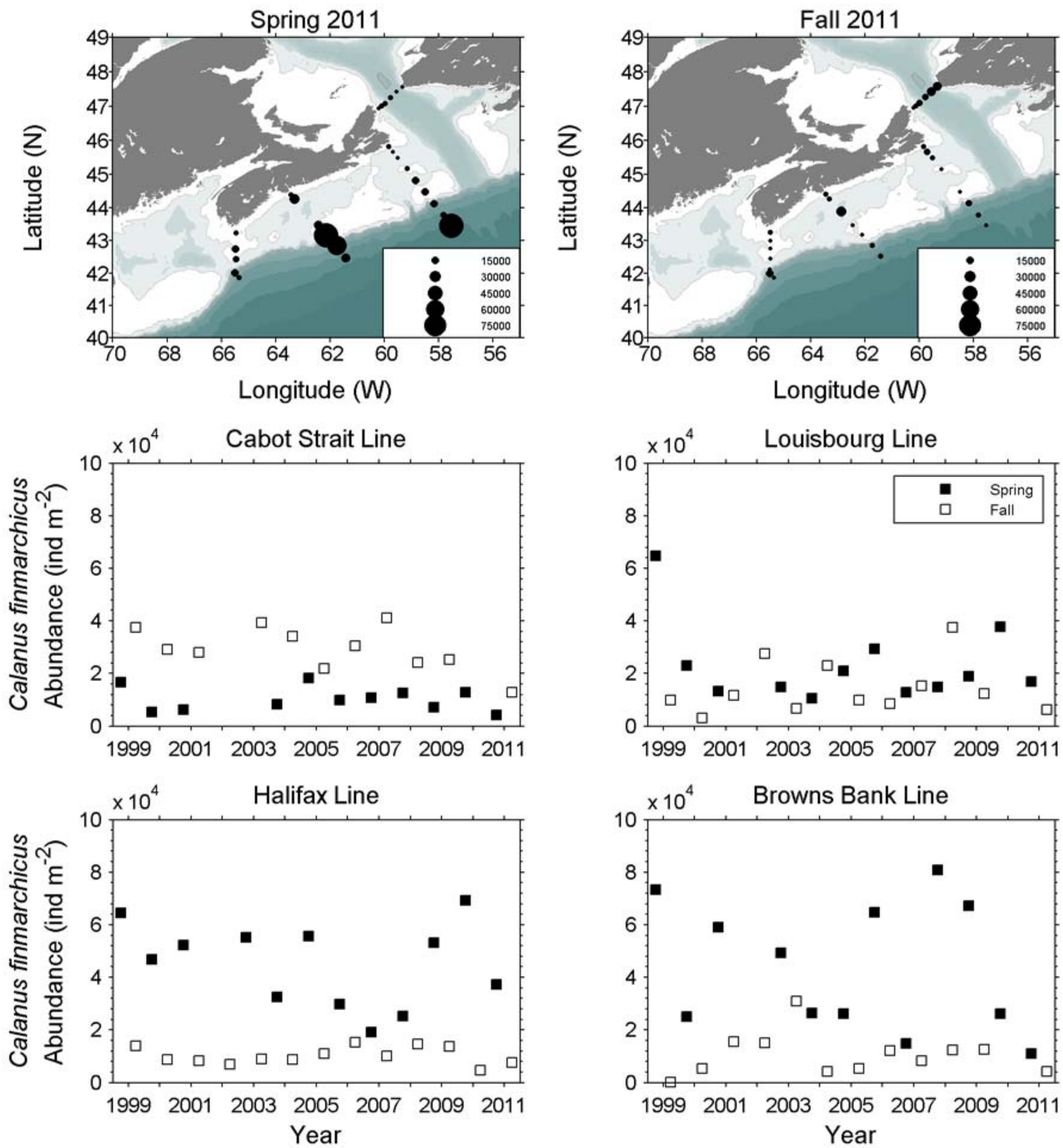

Figure 25b. Spatial distribution of C. finmarchicus abundance (upper panels) and average C. finmarchicus abundance on Scotian Shelf sections (lower panels) in spring and fall, 1999–2011.

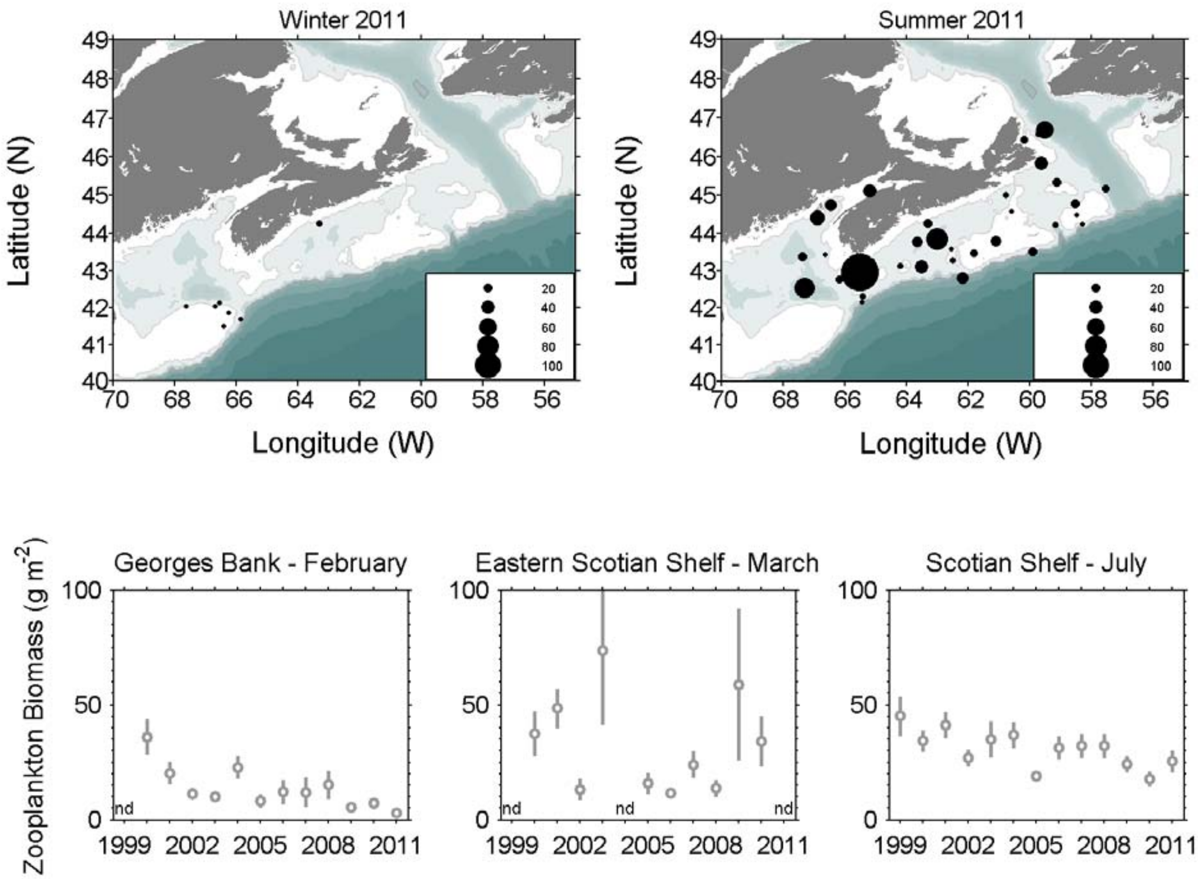

Figure 26a. Zooplankton biomass from trawl (groundfish) surveys on Georges Bank (February), the eastern Scotian Shelf (March) and the Scotian Shelf and eastern Gulf of Maine (summer): upper panels show 2011 spatial distributions, lower panels show survey mean biomass, 1999–2010 (vertical bars are standard errors; nd = no survey in that year).

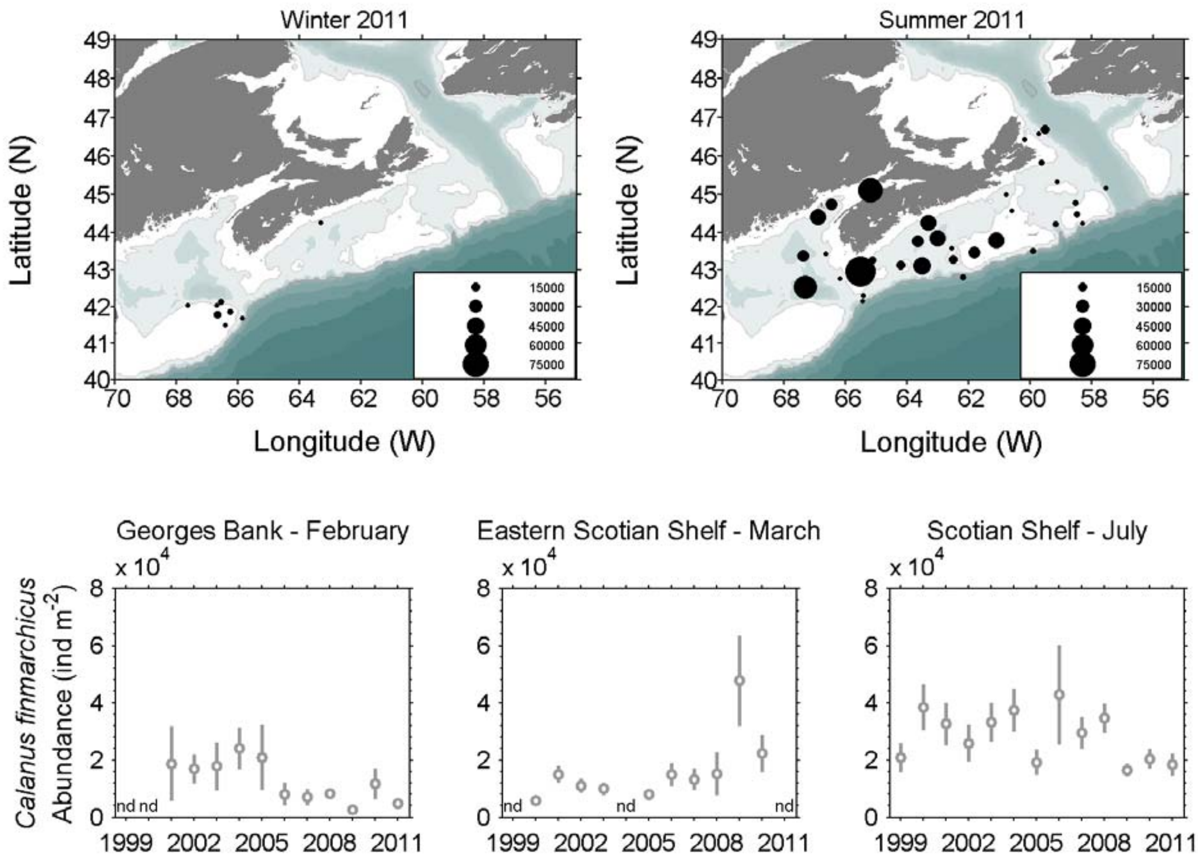

Figure 26b. Calanus finmarchicus abundance from trawl (groundfish) surveys on Georges Bank (February), the eastern Scotian Shelf (March) and the Scotian Shelf and eastern Gulf of Maine (summer): upper panels show 2011 spatial distributions, lower panels show survey mean abundance, 1999–2010 (vertical bars are standard errors; nd = no survey in that year).

SCORECARD-Maritimes 2011

Variable	Station	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
NO3_0-50m (mmol m^{-2})	Hfx-2	-2.18	1.16	1.25	-0.74	-0.19	0.09	-0.58	0.28	0.19	1.19	0.39	-0.87	-0.19
	P-5	-1.01	-0.49	-0.59	0.72	1.13	0.06	-0.88	1.44	-0.40	0.09	1.49	-1.54	-0.04
	CSL	1.52	-1.57	-0.91		-1.09	-0.41	0.42	-0.07	1.04	1.27	0.16	-0.36	1.51
	LBL	1.78	-0.69	-1.17		0.48	-0.37	-0.28	0.65	0.93	0.59	0.02		0.38
	HL	2.03	-0.82	0.14		-0.68	-0.73	-0.30	0.11	-0.40	1.77	-0.31	0.41	0.94
	BBL	0.08	-0.58	-0.84		0.67	-0.34	0.15	0.27	-1.78	1.98	1.17		0.74
NO3_50-150m (mmol m^{-2})	Hfx-2	-0.66	0.80	-0.83	0.15	1.49	-0.76	-1.06	1.71	-0.68	-0.30	1.03	-0.88	-1.14
	P-5	-0.84	-0.45	-1.26	0.88	1.07	-0.31	-0.60	1.12	-0.43	0.42	1.69	-1.28	-0.48
	CSL	-0.02	1.73	-0.92		-0.12	1.24	-0.68	0.11	-1.27	0.62	1.16	-1.13	-0.60
	LBL	0.48	1.55	-1.28		0.70	-0.61	0.45	0.37	-1.91	-0.11	0.39		-1.46
	HL	0.42	0.65	-0.14		-0.10	-0.77	-1.98	0.46	-1.11	1.09	1.48	0.73	1.14
	BBL	-1.96	-0.21	0.12		1.21	1.13	-0.45	0.23	-1.02	-0.09	0.91		-0.06
NO3-Win(J-M)_0-50m (mmol m^{-2})	Hfx-2	-1.81	0.49	1.15	-1.24	1.06	0.84	-0.04	-0.45	0.21	-0.03	1.05	-1.21	-0.80
	P-5	-0.88	0.12	-1.44	-1.06	-0.05	1.32	-1.14	0.51	1.12	0.22	1.53	-0.24	-1.21
CHL_0-100m (mg m^{-2})	Hfx-2	2.58	0.75	0.48	-0.23	0.37	-0.56	-0.54	-1.15	-0.82	-0.86	-0.10	0.07	1.20
	P-5	1.38	1.68	0.56	0.19	-0.58	0.21	-0.82	-1.23	-0.47	-1.07	-0.90	1.07	-0.50
	CSL	0.85	0.99	-0.75		-0.04	-0.39	-0.72	-1.25	-0.09	-0.40	0.07	-0.68	1.05
	LBL	1.05	0.45	-0.43		1.85	-0.35	-0.29	-1.47	-0.03	-0.21	0.40		1.69
	HL	-0.49	0.44	-0.47		0.37	-0.49	0.23	-2.14	1.65	0.73	0.38	0.86	0.59
	BBL	1.20	-0.52	0.10		1.93	-1.28	-0.87	-0.63	0.92	0.07	0.54		-1.21
Bloom-Timing (Year-Day)	Hfx-2	-0.31	0.45	0.64	-0.50	1.40	0.36	-0.21	-0.31	0.36	1.21	-0.69	-2.40	1.88
	P-5		-0.37	-1.02	-0.09	-0.11	-1.37	0.59	1.25	-0.11	-0.02	-0.83	2.08	0.53
Bloom-Magnitude (mg m^{-2})	Hfx-2	-1.15	-0.80	-0.69	-0.33	1.00	0.84	0.72	-0.86	1.96	-0.82	0.75	-0.62	-1.28
	P-5		2.10	-0.97	-0.49	0.26	-0.27	-0.92	0.33	1.11	0.53	-1.29	-0.38	-0.74
Bloom-Duration (Days)	Hfx-2	1.25	0.50	0.50	0.66	0.13	0.34	-0.99	-1.21	-0.46	-0.62	1.57	-1.69	-1.47
	P-5		-1.01	1.66	-1.07	-0.52	1.12	0.52	-0.41	-0.68	-0.63	-0.41	1.44	-0.69
C. finmarchicus (Indiv m^{-2} * 10^3)	Hfx-2	0.86	0.73	1.76	-0.25	0.38	-0.89	-1.15	-0.83	-0.26	1.04	-1.56	0.17	-2.56
	P-5	-1.06	-1.16	1.44	-1.16	0.62	0.02	0.53	1.88	-0.73	-0.02	0.20	-0.57	-0.11
	CSL	1.45	-1.15	-1.11		1.52	-0.18	0.10	-0.33	0.90	-0.50	-1.24	0.53	-2.95
	LBL	1.38	-1.00	-0.84		-1.11	-0.17	-0.61	-0.33	-0.59	1.04	-0.53		-1.08
	HL	1.83	-0.28	-0.16		0.17	-0.96	0.70	0.49	-1.33	0.06	1.24	-0.17	-1.05
	BBL	-0.10	-1.01	0.71		1.64	-1.07	-0.98	0.59	-1.06	1.05	0.70		-1.49
Pseudocalanus (Indiv m^{-2} * 10^3)	Hfx-2	1.54	0.45	0.05	-0.26	1.00	1.02	0.28	-1.79	-1.30	0.47	-0.56	-0.89	-1.67
	P-5	0.31	0.51	2.16	0.21	-0.05	-0.69	-0.87	-1.13	-0.35	0.75	-1.52	0.67	-0.88
	CSL	0.94	-1.41	-0.52		2.07	-0.20	-0.40	-0.61	-0.11	0.61	-1.08	0.69	-1.33
	LBL	2.35	-1.17	0.61		0.11	-0.62	-0.83	0.04	-0.45	0.27	-0.84		-0.98
	HL	1.27	0.81	0.85		0.82	-0.32	0.26	-2.01	-1.20	-0.04	-0.32	-0.94	-1.21
	BBL	1.21	-0.02	2.04		1.47	-0.71	-0.69	-0.52	-0.86	-0.23	-0.97		-1.16
Copepods (Indiv m^{-2} * 10^3)	Hfx-2	1.87	0.94	0.69	-1.43	0.03	0.14	0.65	-1.00	-1.40	-0.25	0.46	-0.69	-0.90
	P-5	-0.11	1.21	1.56	-0.78	0.50	-0.25	-1.28	0.72	-1.06	-0.38	-1.24	1.10	-0.82
	CSL	1.32	-1.33	-1.03		1.18	0.29	0.22	-1.00	-0.38	-0.02	-0.75	1.49	-1.72
	LBL	2.68	-0.78	0.19		0.32	-0.64	0.03	0.21	-0.83	0.62	-0.82		-0.97
	HL	2.13	0.92	0.13		-0.37	-1.32	1.19	-0.60	-0.44	-0.64	0.48	-0.65	-1.03
	BBL	1.28	1.37	0.45		1.29	-1.30	-0.53	-0.24	-1.07	0.52	-0.55		-1.52
Non-copepods (Indiv m^{-2} * 10^3)	Hfx-2	2.77	0.30	-0.09	-0.93	-0.26	0.22	0.59	-0.57	-0.94	-0.01	-0.31	-0.77	1.19
	P-5	0.96	1.06	1.09	0.24	-1.09	-0.41	-1.29	-0.54	-0.56	-0.38	-0.87	1.78	-0.95
	CSL	1.14	-0.98	-0.77		0.48	1.46	-0.64	0.21	-1.28	-0.54	-0.53	1.46	0.65
	LBL	0.73	-0.99	1.72		-0.98	-0.28	0.00	1.42	-0.97	0.60	-0.90		0.25
	HL	2.53	0.61	-0.68		0.25	-0.44	0.87	-0.91	-0.81	0.25	-0.64	-0.89	-0.33
	BBL	1.97	0.74	-0.54		1.42	-1.03	0.66	-0.97	-0.96	0.16	-0.82		-1.28
Nutrients		-0.22	0.12	-0.48	-0.22	0.40	0.03	-0.50	0.48	-0.39	0.62	0.87	-0.64	-0.09
Phytoplankton		0.83	0.46	0.00	-0.21	0.48	-0.08	-0.37	-1.00	0.31	-0.33	0.10	0.01	-0.14
Zooplankton		1.30	-0.07	0.40	-0.54	0.48	-0.35	-0.13	-0.33	-0.75	0.18	-0.54	0.15	-1.00
OVERALL		0.73	0.09	0.05	-0.34	0.46	-0.20	-0.27	-0.20	-0.40	0.22	-0.03	-0.12	-0.48

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

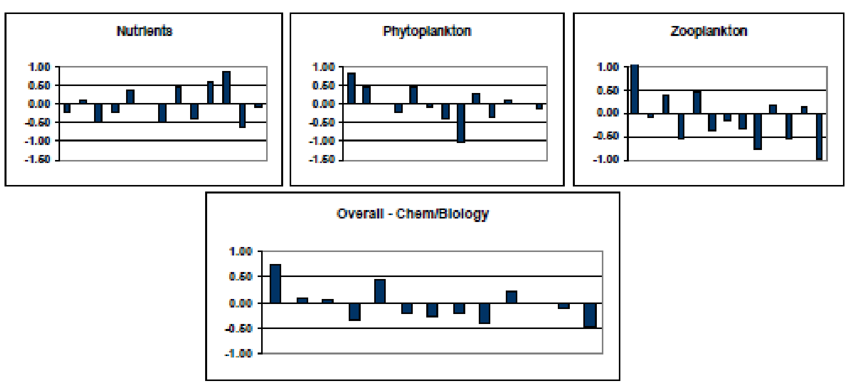

Figure 27. Maritimes Region scorecard: time series of chemical and biological variables, 1999–2011. A white cell indicates missing data. Red (blue) cells indicate higher (lower) than normal nutrient, phytoplankton, zooplankton levels or later and longer (earlier or shorter) than normal duration of phytoplankton blooms. Reference period is 1999–2010. The numbers in the cells are the anomaly values. CSL: Cabot Strait Line; LBL: Louisbourg Line; HL: Halifax Line; BBL: Browns Bank Line.

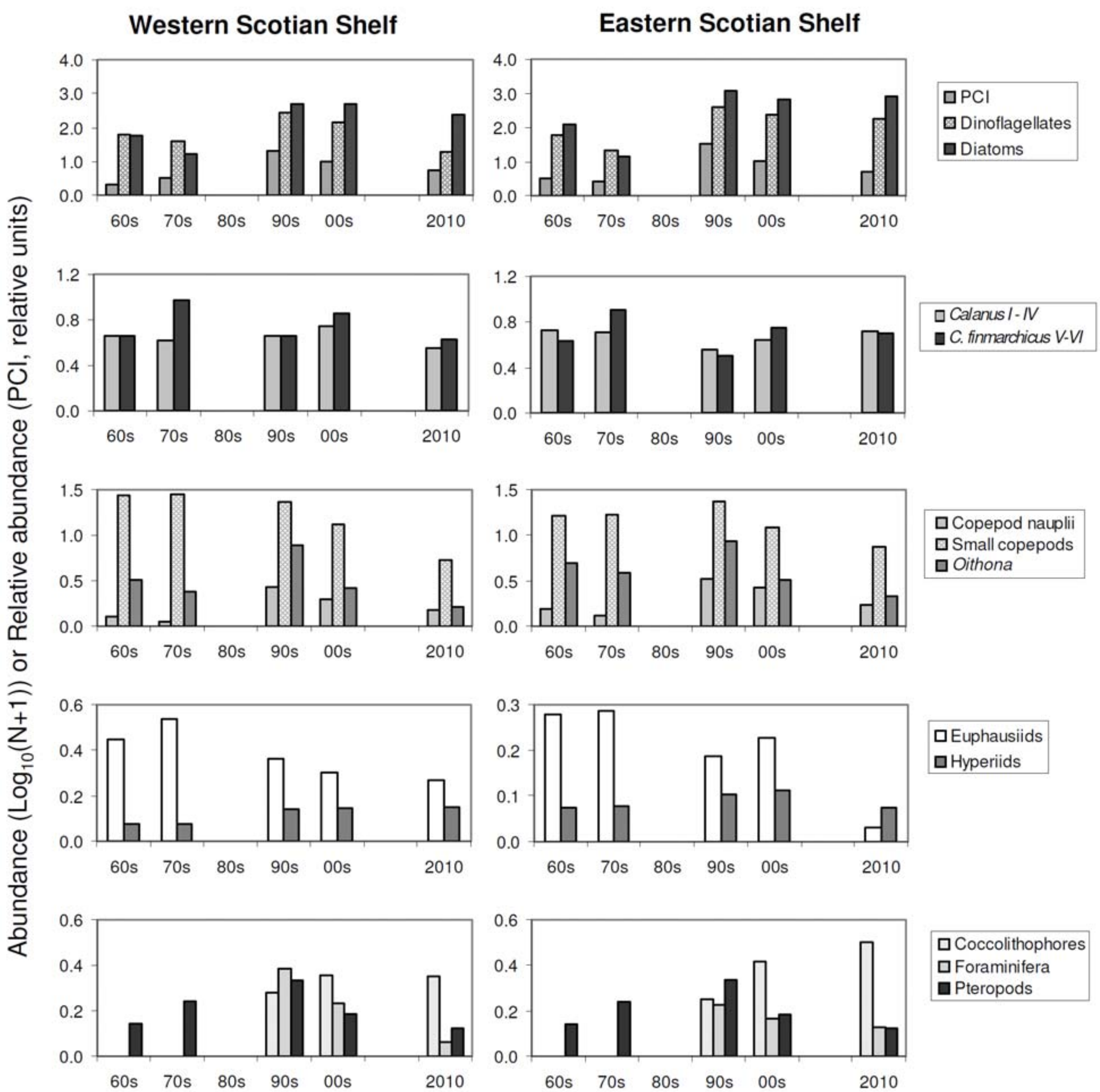

Figure 28. Annual average abundances by decade of phytoplankton and zooplankton indices on the western and eastern Scotian Shelf for the 1960s (1961–1969), the 1970s (1970–1976), the 1980s (1980–1986), the 1990s (1991–1999), and the 2000s (2000–2009) and for 2010.

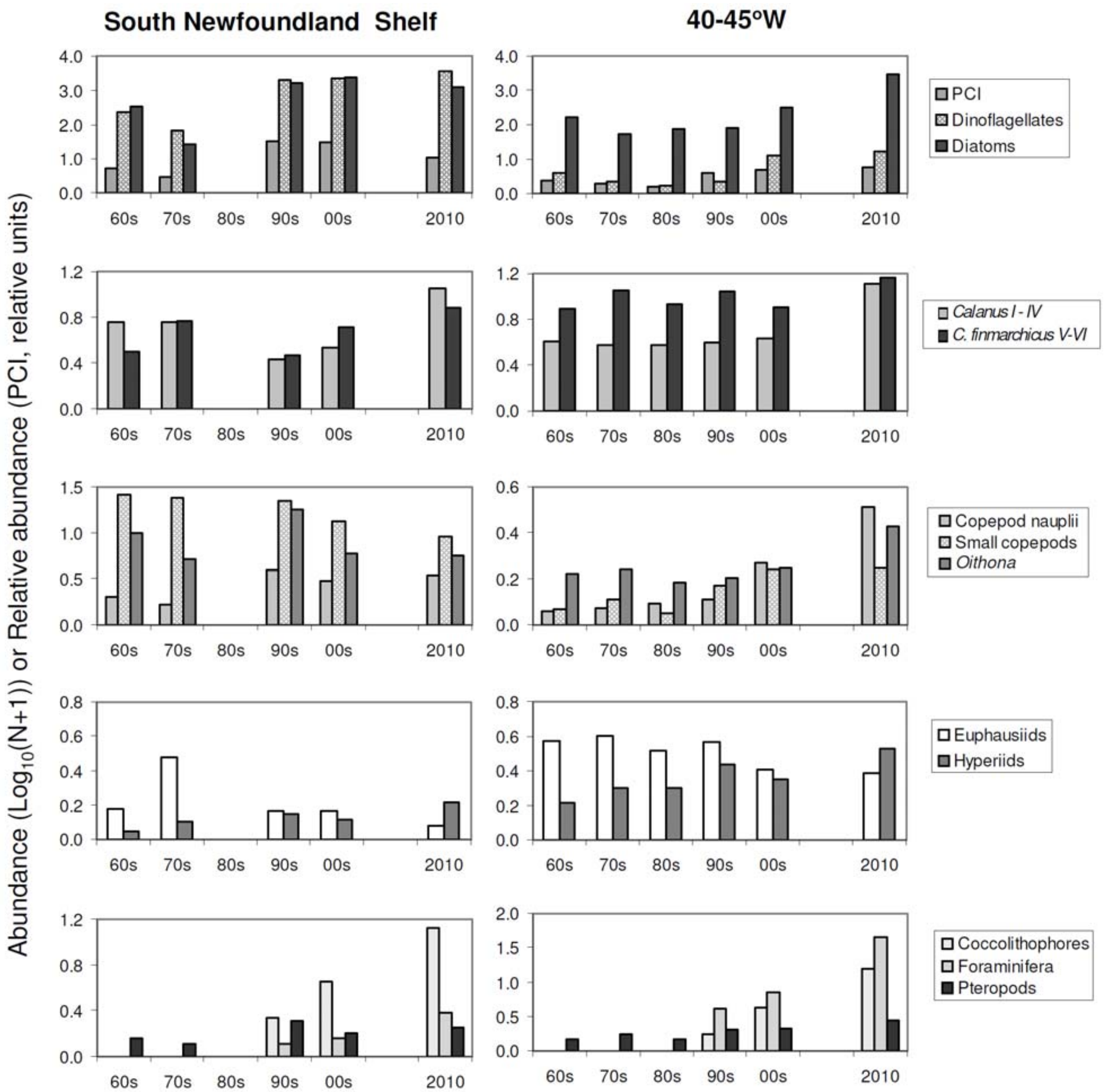

Figure 29. Annual average abundances by decade of phytoplankton and zooplankton indices on the South Newfoundland Shelf and the deep ocean east of Flemish Cap between 40 and 45ºW for the 1960s (1961–1969), the 1970s (1970–1976), the 1980s (1980–1986), the 1990s (1991–1999), and the 2000s (2000–2009) and for 2010.