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**Maritimes Region**

**Optical, chemical, and biological oceanographic conditions on the Scotian Shelf  
and in the eastern Gulf of Maine in 2013**

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## Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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## ABSTRACT

Ocean conditions were unusually warm and stratified on the Scotian Shelf in 2012, and the plankton response to the physical environment in 2012 set the initial conditions for the plankton in 2013. In particular, zooplankton biomass and the abundance of the two dominant herbivorous copepod species, *Calanus finmarchicus* and *Pseudocalanus* spp., were low, and there appeared to be a shift to a smaller-size phytoplankton community on the Scotian Shelf. In 2013, annual average temperature anomalies were still positive in the Maritimes Region, but less so than in 2012, and temperature and stratification anomalies were marked by strong sub-annual and mesoscale variability. Variability in the physical environment was reflected in nutrient and plankton conditions. Annual average deep-water and winter surface nitrate inventories were similar to average overall, but surface nitrate was higher than average. The magnitude of the spring bloom chlorophyll peak was above average on the Eastern Scotian Shelf (ESS) and below average on the Western Scotian Shelf (WSS) and in the eastern Gulf of Maine, but summer-fall blooms were above average in all areas. Zooplankton biomass and abundance were lower than average on the eastern transects, but anomalies were mixed on the Central Scotian Shelf, ESS and Bay of Fundy. The abundance of *Pseudocalanus* spp. was higher than average in the central and western part of the region. Although *C. finmarchicus* abundance was variable and lower than average overall, it was high on the WSS and in the eastern Gulf of Maine during the summer ecosystem trawl survey and higher than average at the Halifax-2 station and in Emerald Basin in autumn, suggesting a return to more typical abundances in the western part of the region at the end of 2013. Similar to the broader Scotian Shelf, the 2013 Bedford Basin annual average temperature was warmer than normal but not as warm as 2012. Small phytoplankton were more abundant than average in Bedford Basin and large phytoplankton less abundant. An initial evaluation of relationships among annual anomalies of physical variables, nitrate, spring bloom metrics and zooplankton at Halifax-2 from 1999 to 2013 identified bloom duration and enhanced upwelling as important correlates of zooplankton biomass and dominant copepod abundance at an annual scale. Continuous Plankton Recorder sampling showed that observations of phytoplankton bloom dynamics and abundance of *C. finmarchicus* at Halifax-2 in 2012 were representative of shelf-wide patterns.

## Conditions océanographiques optiques, chimiques et biologiques sur le plateau néo-écossais et dans l'est du golfe du Maine en 2013

### RÉSUMÉ

Les conditions océanographiques exceptionnellement chaudes et stratifiées observées sur le plateau néo-écossais en 2012 et la réponse du plancton à l'environnement physique de 2012 ont fixé les conditions initiales du plancton en 2013. En particulier, la biomasse de zooplancton et l'abondance des deux espèces dominantes de copépodes herbivores, *Calanus finmarchicus* et *Pseudocalanus* spp., étaient faibles et il a semblé y avoir un changement vers une communauté de phytoplancton de petite taille sur le plateau néo-écossais. En 2013, les anomalies annuelles moyennes de la température étaient toujours positives dans la région des Maritimes, mais moins prononcées qu'en 2012, et les anomalies de la température et de la stratification ont été marquées par une forte variabilité intra-annuelle et à l'échelle moyenne. La variabilité dans l'environnement physique s'est reflétée dans les conditions du nitrate et du plancton. L'inventaire de nitrate en profondeur et du nitrate de surface hivernal étaient similaires à la moyenne globale, mais le nitrate de surface était plus élevé que la moyenne. L'amplitude de la floraison printanière était supérieure à la moyenne dans la région est du plateau néo-écossais (ESS) et inférieure à la moyenne dans la région ouest du plateau néo-écossais (WSS) et dans l'est du golfe du Maine, mais la floraison d'été-automne était supérieure à la moyenne dans toutes les régions. La biomasse et l'abondance de zooplancton étaient inférieures à la moyenne sur les transects de la région est du plateau néo-écossais, mais des anomalies mixtes ont été observées sur les régions du centre et de l'est du plateau néo-écossais ainsi que dans la baie de Fundy. L'abondance de *Pseudocalanus* spp. était plus élevée que la moyenne dans les parties centrale et ouest de la région. Bien que l'abondance du *C. finmarchicus* était en général variable et inférieure à la moyenne, elle était élevée dans la région ouest du plateau néo-écossais et dans l'est du golfe du Maine lors des relevés d'été au chalut de fond et supérieure à la moyenne à la station Halifax-2 et dans le bassin Emerald à l'automne, suggérant un retour à des abondances types dans la partie ouest de la région à la fin de 2013. Similairement à la région du plateau néo-écossais, la température annuelle moyenne observée dans le bassin de Bedford en 2013 était supérieure à la normale, mais moins chaude qu'en 2012. Toujours dans le bassin de Bedford, l'abondance de phytoplancton de petite taille était supérieure à la moyenne tandis que celle du phytoplancton de grande taille y était inférieure. L'évaluation des relations entre les anomalies annuelles des variables physiques, du nitrate, des paramètres de la floraison printanière du phytoplancton et du zooplancton à la station Halifax-2 de 1999 à 2013 a permis d'identifier de fortes corrélations à l'échelle annuelle entre d'une part la durée de la floraison printanière et la remontée accrue d'eau et d'autre part la biomasse de zooplancton et de l'abondance des copépodes dominants. Les données d'échantillonnage à l'aide d'enregistreurs de plancton en continu ont permis de confirmer que les paramètres de la floraison printanière du phytoplancton et l'abondance du *C. finmarchicus* à la station Halifax-2 en 2012 étaient représentatifs des tendances observées à l'échelle du plateau.

## INTRODUCTION

The Atlantic Zone Monitoring Program (AZMP) was implemented in 1998 to enhance Fisheries and Oceans Canada's (DFO's) capacity to understand, describe, and forecast the state of the marine ecosystem (Therriault et al. 1998). 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, ecosystem trawl surveys) in each DFO region (Québec, Gulf, Maritimes, and Newfoundland) sampled at a frequency of twice-monthly to once annually. The sampling design provides basic information on the variability in physical, chemical, and biological properties of the Northwest Atlantic continental shelf on annual and interannual scales. Ecosystem trawl surveys and cross-shelf sections provide more detailed geographic information (Harrison et al. 2005) but are limited in their seasonal coverage. Fixed stations complement the broad-scale sampling by providing more detailed information on annual changes in ecosystem properties.

This report provides an assessment of the distribution and variability of nutrients and plankton on the Scotian Shelf and in the eastern Gulf of Maine, focussing on conditions in 2013. It complements similar assessments for the physical environment of the Maritimes Region (Hebert et al. 2014), for the pelagic environment in the Gulf of St. Lawrence, for the Newfoundland and Labrador shelves and the Grand Banks, and for the Canadian Northwest Atlantic shelf system as a whole (DFO 2014).

The Scotian Shelf is located in a transition zone influenced by both sub-polar waters, mainly flowing into the region from the Gulf of St. Lawrence and the Newfoundland Shelf, and warmer offshore waters. The deep water properties of the Western Scotian Shelf (WSS) are strongly variable, reflecting shifts in the source of deep slope water to the shelf between cold, lower nutrient Labrador Slope Water, and more nutrient rich Warm Slope Water that can be driven by changes in large-scale atmospheric pressure patterns (Petrie 2007). Temperature and salinity on the shelf are also influenced by heat transfer between the atmosphere and ocean, local mixing, precipitation, and runoff from land. Changes in the physical pelagic environment can influence plankton community composition and locations, timing, and magnitude of biological production cycles, with implications for energy transfer to higher trophic level production.

Water temperatures in the Maritimes Region were well above normal in 2012, with historical record warm temperatures across much of the Scotian Shelf, and stratification was high (Hebert et al. 2013). The winter surface layer nitrate inventory, an indicator of nutrient availability for the spring phytoplankton bloom, was low at the Halifax-2 station on the Scotian Shelf, and there was evidence of a shift to a smaller size distribution in the phytoplankton across much of Scotian Shelf, although localized strong late summer-early fall phytoplankton blooms were also observed in the Gulf of Maine (Johnson et al. 2013). The ecologically important copepod species *Calanus finmarchicus* and *Pseudocalanus* spp. were very low in abundance, as were cold water copepods, and warm water copepods were more abundant than usual. In 2013, water temperatures were still higher than normal, but average temperatures were lower than in 2012 (Hebert et al. 2014). Temperature anomalies exhibited substantial variability across the shelf and during the year in 2013, with both positive and negative anomalies observed (Hebert et al. 2014). Surface temperature anomalies were strongly positive across much of the Central and Eastern Scotian Shelf (CSS and ESS) in July 2013, and the annual stratification index, calculated from July survey data, was similar in 2013 to the previous year (Hebert et al. 2014). However, Halifax-2 surface temperature anomalies were closer to normal during the rest of the year. This report focused on evaluating changes in phytoplankton and zooplankton annual production cycles and community composition in light of these changes in their pelagic environment.

## 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 below.

### Missions

Maritimes/Gulf AZMP sea-going staff participated in six missions (seasonal section cruises, ecosystem trawl surveys, and Halifax section sampling on a mission to the Labrador Sea) during the 2013 calendar year, in addition to day-trips to the three fixed stations. In 2013, a total of 671 station occupations were performed by Maritimes Region (Table 1).

### Fixed Stations

The target sampling frequency for the three AZMP fixed stations in the Maritimes Region and western Gulf of St. Lawrence (Halifax-2, Prince-5 and Shediac Valley; Figure 1) is semi-monthly at Halifax-2, monthly at Prince-5, and either semi-monthly (spring bloom period) or monthly at Shediac. 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. In 2013, Halifax-2, Prince-5, and Shediac were sampled on 23, 12, and 10 occasions, respectively, similar to recent years (Table 1).

The standard sampling suite for the fixed stations includes the following:

- A conductivity, temperature, depth (CTD; measured using a Sea-Bird instrument) profile with dissolved oxygen, fluorescence, photosynthetically active radiation (PAR); pH is also measured at selected stations,
- Niskin water bottle samples at standard depths for nutrient analyses, calibration salinity, calibration oxygen, and chlorophyll analysis,
- Niskin water bottle samples for phytoplankton enumeration,
- Vertical ring net tows (202 and 76  $\mu\text{m}$  mesh net) for zooplankton biomass (wet weight) and abundance, and
- Secchi depth measurement for light extinction when possible.

Chlorophyll values were lost at Prince-5 due to data quality issues in 2013.

### Shelf Sections

The four primary sections (Browns Bank, Halifax, Louisbourg, Cabot Strait sections; Figure 1), and a number of additional sections/stations (Figure 2) were sampled in spring and fall (Table 1). An additional occupation of the Halifax section was performed in May as part of the Labrador Sea sampling mission (results not reported here).

The standard sampling suite for the section stations includes the following:

- Sampling listed above for the fixed stations,
- In addition to the Niskin water bottle sampling for nutrient analyses, calibration salinity, calibration oxygen, and chlorophyll analysis, particulate organic carbon (POC), flow cytometry, and plant pigment analyses (High Pressure Liquid Chromatography and absorbance) are performed at standard depths. Results of these ancillary measurements are not reported here.

## Ecosystem Trawl Surveys

AZMP-Maritimes/Gulf participates in four primary ecosystem trawl surveys, including the late winter (February) Georges Bank survey, the spring (March) 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 2013 by DFO's Population Ecology Division with AZMP participation.

The standard sampling suite for the ecosystem trawl survey stations includes the following:

- Sampling listed above for the fixed stations,
- Vertical ring net tows (202  $\mu\text{m}$  mesh net) for zooplankton biomass (wet weight) and enumeration only at a subset of stations (see Figure 3), and
- Sea-surface temperature recorder, trawl-mounted depth/temperature recorders.

The sum of nitrate and nitrite is reported here as "nitrate." Bottom nitrate concentrations were interpolated on a three minute latitude-longitude grid using optimal estimation (Petrie et al. 1996) to generate maps of bottom properties within the ecosystem trawl survey strata. The interpolation method uses the three nearest neighbours, with a horizontal length scale of 30 km and a vertical length scale of 15 m when the sounding depth is shallower than 50 m, 25 m for sounding depths between 50 and 500 m, and 50 m for sounding depths deeper than 500 m. Data near the interpolation grid point were weighted proportionately more than those farther away. Anomalies of 2013 bottom oxygen were not presented, while the quality of past oxygen data is under review.

## Gear Deployment

### Conductivity, Temperature, Depth (CTD)

The CTD is lowered to a target depth within 2 m of the bottom.

Standard depths for water samples include:

- 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, near-bottom (depths sampled are limited by bottom depth).
- Ecosystem trawl surveys: 5, 25, 50 m, and near bottom when possible.

### Net Tows

Ring nets of a standard 202  $\mu\text{m}$  mesh are towed vertically from near bottom to surface at approximately 1 m/sec. In deep offshore waters, maximum tow depth is 1000 m. Samples are preserved in buffered formalin and samples are analyzed according to the protocol outlined in Mitchell et al. 2002.

### Mixed-Layer and Stratification Indices

Two simple indices of the vertical physical structure of the water column were computed:

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

- The stratification index ( $Strat_{Ind}$ ) was calculated as:

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

where  $\sigma_{t-50}$  and  $\sigma_{t-z_{min}}$  are interpolated values of density ( $\sigma_t$ ) at 50 m and  $z_{min}$ , the minimum depth of reliable CTD data, which is typically around 5 m and always less than 9 m.

## Optical Properties

The optical properties of seawater (attenuation coefficient, photic depth) were derived using (1) *in-situ* light extinction measurements using a rosette-mounted PAR meter, and (2) Secchi depth, according to the following procedures:

- The downward vertical attenuation coefficient for PAR ( $K_{d-PAR}$ ) was estimated as the slope of the linear regression of  $\ln(E_d(z))$  versus depth  $z$  (where  $E_d(z)$  is the value of downward irradiance at depth  $z$ ) in the depth interval from minimum depth to 50 m. The minimum depth is typically around 2 m although the calculation is sometimes forced below that target when near-surface PAR measurements appear unreliable.
- The value of the light attenuation coefficient  $K_d$  from Secchi disc observations was found using:

$$K_{d\_secchi} = 1.44 / Z_{sd} \text{ (m}^{-1}\text{)}$$

where  $Z_{sd}$  = depth in m at which the Secchi disc disappears from view (Holmes 1970). The estimate of euphotic depth ( $Z_{eu}$ ) was made using the following expression:

$$Z_{eu} \text{ (m)} = 4.6 / K_d$$

## Vertically Integrated Variables

Integrated chlorophyll and nutrients were calculated over various depth intervals (e.g., 0-100 m for chlorophyll, and 0-50 m or 50-150 m for nutrients) using trapezoidal numerical integration. The lower integration limit was set according to the maximum depth at a given station (e.g., 150 m for Halifax-2 and 95 m for Prince-5). Data at the surface (0 m) was taken as the closest near-surface sampled value. Data at the lower depth was taken as:

- the interpolated value when sampling was below the lower integration limit, or
- the closest deep water sampled value when sampling was shallower than the lower integration limit.

## Satellite Remote-Sensing of Ocean Colour

Near-surface phytoplankton biomass was also estimated from ocean colour data collected by the Sea-viewing Wide Field-of-view (SeaWiFS) satellite sensor<sup>1</sup> launched by NASA in late summer 1997 and the Moderate Resolution Imaging Spectroradiometer (MODIS) "Aqua" sensor<sup>2</sup> launched by NASA in July 2002. Basic statistics (mean, standard deviation, etc.) were extracted from semi-monthly composites for selected sub-regions (Figure 4) for both SeaWiFS 4 km spatial resolution data and MODIS 1.5 km spatial resolution data.

<sup>1</sup> While the SeaWiFS mission ended in December 2010, information about SeaWiFS is archived at the [NASA Ocean Color Biology Group](http://ocecolor.gsfc.nasa.gov/) website (accessed 21 July 2014).

<sup>2</sup> Additional information about the MODIS sensor can be found on the [NASA MODIS](http://modis.gsfc.nasa.gov/) website (accessed 21 July 2014).

## 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 anomalies of nutrient availability, phytoplankton biomass and bloom dynamics, and the abundance of dominant copepod species and groups (*C. finmarchicus*, *Pseudocalanus* spp., total copepods, and total non-copepods) are produced in each of the AZMP regions, including the Maritimes. To visualize Northwest Atlantic shelf scale patterns of environmental variation, a zonal scorecard was prepared in addition to the regional scorecards presented here (DFO 2014).

## Data Products

Data products presented in figures 6, 7, 9, 10, 13, 14, 16–24, and 27-28 are available at the [Atlantic Zone Monitoring Program \(AZMP\)](#) website in the “Research Document Data” link under the “Data and Products” Heading. To access the compressed files containing the data, click on the “Scotian Shelf and Eastern Gulf of Maine” link and then click on the document citation to reveal a drop-down menu containing data downloads. Each compressed file contains a text file with the data required to reproduce the figure, a meta-data text file describing the terms of use and field heading descriptions, and a PDF file of the figure. Chlorophyll bi-weekly estimates and climatologies presented in Figure 15 are available at the DFO Maritimes [SeaWIFS FTP website](#) and [MODIS FTP website](#).

## Continuous Plankton Recorder (CPR)

The Continuous Plankton Recorder (CPR) is an instrument that is towed by commercial ships and that collects plankton at a depth of approximately 7 m on a long continuous ribbon of silk (approximately 260 µm mesh). The position on the silk corresponds to location of the different sampling stations. CPR data are analysed to detect differences in the indices of phytoplankton (colour and relative numerical abundance) and zooplankton relative abundance for different months, years or decades in the Northwest Atlantic. The indices indicate relative changes in concentration (Richardson et al. 2006). The sampling methods from the first surveys in the Northwest Atlantic (1960 for the continental shelf) to the present are exactly the same so that valid comparisons can be made between years and decades. CPR sample analysis lags AZMP by one year, and thus CPR observations from 2012 are presented following discussion of the conditions in 2013.

The tow routes between Reykjavik, Iceland, and the Gulf of Maine are divided into eight regions: the WSS, the ESS, the South Newfoundland Shelf (SNL), the Newfoundland Shelf (NS) and four regions in the Northwest Atlantic sub-polar gyre, divided into 5 degree of longitude bins (Figure 5). Only CPR data collected on the Scotian Shelf since 1992 are reported here, since these are comparable to AZMP survey results, which date back to 1999. CPR data collected on the Newfoundland Shelf (SNL and NS regions) are presented in annual AZMP reports of the Newfoundland region, while data collected in all regions and all decades (i.e., including the four regions in the sub-polar gyre east of 45°W) are presented in annual AZOMP reports.

Continuous Plankton Recorder (CPR) data collected from January to December 2012 were received in January 2014 and added to the DFO data archive. In 2012, there was CPR sampling on the WSS in 10 months and on the ESS in nine months.

Monthly abundances of 14 taxa ( $\log_{10}(N+1)$  transformed) and phytoplankton colour index (PCI), a semi-quantitative measure of total phytoplankton abundance were calculated by averaging values for all individual samples collected within either the WSS or ESS region for each month and year sampled. Climatological seasonal cycles were obtained by averaging these monthly averages for 1992-2011, and these are compared with values in 2012. Annual abundance

anomalies were also calculated for years where there was sampling in 8 or more months, and where there were no sampling gaps of three or more consecutive months. For years with gaps of one or two months, linear interpolation was used to fill in values for the missing months. Seasonal cycles in 2012 and the 1992-2011 climatological average seasonal cycles are shown for three indices of phytoplankton concentration and for the two zooplankton CPR taxa that correspond to young and late stages of the biomass dominant zooplankton species, the copepod *C. finmarchicus*.

## ATLANTIC ZONE MONITORING PROGRAM (AZMP) OBSERVATIONS

### Mixing and Optical Properties

Mixing and optical properties of the upper water column vary both seasonally and spatially at the Maritimes fixed stations. At Halifax-2, stratification is lowest and MLD deepest during the winter months when surface heating is weak and wind-driven mixing is strong (Figure 6). Stratification increases in the spring to maximum values in August and September and then declines during the fall months. Similarly, MLD shoals in the spring to minimum values from June to August and deepens in the last four months of the year. At Prince-5, MLDs are more variable and stratification lower than at the Halifax-2 station due to strong tidal mixing. The stratification index normally remains below  $0.01 \text{ kg m}^{-4}$  for most of the year, and MLD varies from full depth (90 m) in winter to approximately 40 m in summer.

Stratification and MLD followed similar patterns of annual variation at Halifax-2 as have been observed in the past, with minor deviations from the climatological pattern (Figure 6). Stratification was mostly lower than average at Halifax-2 in winter-early spring 2013, but it increased rapidly to values typical of the seasonal maximum in June, earlier than usual. Following an abrupt dip in August, stratification was higher than average again in the fall. MLD was deeper than average in the winter, variable in spring, and most often shallower than average in the summer and fall.

At Prince-5, the stratification index was lower than average in winter, spring, and fall 2013 but above average in the late spring and early summer (Figure 6). MLD was deeper than average during much of winter, spring, and fall 2013, but shallower than average in much of the summer months.

The maximum light attenuation and shallowest euphotic zone depths normally coincide with the spring phytoplankton bloom, and euphotic depths are generally deepest after the decline of the bloom and in winter months. Attenuation and euphotic depths were not measured at Halifax-2 during the 2013 bloom period due to nighttime occupation of the station (Figure 7). Outside of the bloom time, euphotic depths estimated using PAR data were shallower than average, but Secchi-disc based euphotic depth estimates were more variable and deeper than average on many dates.

At Prince-5, photic depths are relatively constant year round, since the primary attenuator is non-living suspended matter due to tidal action and continental freshwater input. In 2013, PAR-based and Secchi-based euphotic depths were shallower than usual in the early winter and late fall (Secchi only), but otherwise similar to the average (Figure 7).

### Nutrients

The primary dissolved inorganic nutrients (nitrate, silicate, phosphate) measured by the 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 coastal waters of the Maritimes Region (DFO 2000), only variability patterns for nitrate are presented in this report.

### **Fixed Stations**

At Halifax-2, the highest surface nitrate concentrations are observed in the winter when the water column is well mixed and primary production is low (Figure 8). Surface nitrate declines with the onset of the spring phytoplankton bloom, and the lowest surface nitrate concentrations are observed in the late spring through early fall. Deep-water nitrate concentrations are lowest in the late fall and early winter, and they increase from February to August, perhaps reflecting sinking and decomposition of the spring phytoplankton bloom (Petrie and Yeats 2000).

The overall annual variability in nitrate at the Halifax-2 stations in 2013 had general similarity to climatological annual variability patterns, with substantial higher frequency variability superimposed on the climatological variability pattern, especially in deep water (Figure 8). Transient low deep-water nitrate concentrations in February and high deep-water concentrations in March were associated with pulses of anomalously cold, fresh (February) and warm, salty water (March), likely driven by advective water mass changes at the Halifax-2 station (Figure 8; Hebert et al. 2014). Lower than average deep-water nitrate in the summer and higher than average deep-water nitrate in the fall were also associated with cooler, fresher water and warmer, saltier water, respectively. There was a shift from mostly negative anomalies in deep-water nitrate inventories in the late spring and early summer to positive deep nitrate anomalies in the fall (Figure 9). Early winter surface nitrate concentrations were a bit lower than normal at Halifax-2 in 2013, but maximum winter surface nitrate concentrations were similar to climatological maximum concentrations (Figures 8, 9), and winter surface nitrate was similar to average overall (Figure 10). Following the spring bloom, the depth of the nitricline was variable and shallower than normal (Figure 8), resulting in higher than average nitrate inventories in the upper 50 m in the spring and summer (Figure 9) and a positive annual anomaly (Figure 10).

At Prince-5, the highest nitrate concentrations are observed in the late fall and winter, when the water column is well mixed from surface to bottom (Figure 8). Nitrate concentrations start to decline in the upper water column when the spring phytoplankton bloom starts in April, and the lowest surface nitrate concentrations are observed in June and July. In 2013, winter and spring nitrate concentrations were lower than average at Prince-5 (Figures 8, 9). Nitrate inventories increased during the summer, possibly associated with input of warmer deep water, but were again lower than average in the fall (Figures 8, 9). Annual average deep-water and surface water nitrate anomalies were negative at Prince-5 in 2013 (Figure 10).

### **Broad-scale Surveys**

There was substantial spatial variability observed in bottom nitrate anomalies during the 2013 July ecosystem trawl survey, with greater prevalence of positive anomalies on the ESS and Bay of Fundy, and more negative anomalies on the WSS and eastern Gulf of Maine (Figure 11). Surface nitrate annual anomalies based on the spring and fall missions were mainly positive, while the deep nitrate anomalies were mixed in sign and slightly low overall (Figure 10).

### **Phytoplankton**

Although phytoplankton temporal and spatial variability is high in coastal and shelf waters, recurrent annual patterns including pronounced spring phytoplankton blooms and smaller fall blooms are observed across the Scotian Shelf. Spring bloom initiation timing is thought to be regulated principally by the phytoplankton's light environment, determined by incident irradiance and upper-ocean mixing. 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 by zooplankton (Johnson et al. 2012).

## Fixed Stations

In 2013, spring bloom initiation timing at Halifax-2 was slightly later than average, and spring bloom duration was similar to the average (Figures 10, 12). However, the spring bloom peak magnitude was lower than average, and integrated chlorophyll values were lower than climatological values throughout the bloom period (Figure 13). There was an unusually strong sub-surface phytoplankton bloom, centered at about 30 m, in August and September (Figure 12).

Phytoplankton abundance estimates at Halifax-2 were lower than average during most of 2013, except during the peak of the spring bloom in April (Figure 14). Abundance was notably low during the early part of the spring bloom. The relative abundance of flagellates was higher than average and relative abundance of diatoms and dinoflagellates lower than average prior to the peak of the spring bloom and in the fall, while diatom relative abundance was higher than average at the peak of the spring bloom in April and during the summer (Figure 14).

Chlorophyll data were not available at Prince-5 in 2013. Seasonal phytoplankton abundance variability deviated from the climatological pattern at Prince-5 during 2013, with much higher abundance observed in May and much lower abundance in August and September (Figure 14). The phytoplankton community at Prince-5 is normally dominated overwhelmingly by diatoms, but in 2013, ciliates made up nearly 20% of community abundance in the winter and early spring. However, diatoms returned to overwhelming dominance in May until the end of the year (Figure 14).

## Broad-scale Surveys and Satellite Remote Sensing

Chlorophyll estimates based on satellite remote sensing data indicated a generally similar pattern of seasonal variability on the CSS as at Halifax-2 (Figure 15). Timing of the spring bloom peak was similar to normal, although satellite data indicated somewhat late spring bloom initiation. Satellite-based chlorophyll estimates were higher than average in the late summer and early fall on the CSS.

Remote sensing data indicated stronger than average spring blooms in the Cabot Strait and ESS boxes, with high spring chlorophyll values observed earlier than average in the Cabot Strait and slightly later than average on the ESS (Figure 15). Higher than average chlorophyll values were observed in the late summer and early fall in both regions, but chlorophyll was low at the end of the year.

Spring bloom initiation was late and peak bloom magnitude lower than average on the WSS and Lurcher Shoal (Figure 15). Higher than average chlorophyll was observed at both sites in summer (WSS) or late summer and fall (Georges Bank), but late fall values were low at both locations. At Lurcher Shoal, where spring blooms are typically small, the bloom was lower than average, but chlorophyll was higher than average in late spring and early summer.

In contrast to chlorophyll status indicated by remote sensing, annual chlorophyll anomalies based on the spring and fall missions were somewhat low on the Cabot Strait and Louisbourg (ESS) sections, higher than average on the Halifax (CSS) section, and about average on the Browns Bank (WSS) section (Figure 10). Deviations in annual chlorophyll status assessments between measurement programs can reflect differences in temporal and vertical spatial coverage of sampling.

## Zooplankton

### Fixed Stations

At Halifax-2, zooplankton biomass and total abundance are typically lowest in January-February and increase to maximum values in April, similar to spring phytoplankton bloom peak timing,

before declining to low levels again in the fall (Figures 16, 17). In 2013, Halifax-2 zooplankton biomass anomalies were variable in sign during the year (Figure 16). Biomass was lower than average at the start of the year but increased to a peak of normal magnitude in April before declining to markedly lower than average levels in the summer (Figure 16). Zooplankton biomass returned to about average levels in the fall. Zooplankton total abundance increased from about average levels in the winter to an early peak of average magnitude in March before declining to lower than average levels during most of the rest of the year (Figure 17). The zooplankton community was dominated by copepods at Halifax-2, as is typical, with lower than average contributions of non-copepod groups in the summer and a large pulse of larvaceans (*Oikopleura* sp.) in the fall (Figure 17). The abundance of *C. finmarchicus* was lower than average at the start of the year and increased to a much higher than average, transient, and slightly early peak in early April, before declining sharply to lower than average conditions in the late spring and summer (Figure 18). *C. finmarchicus* abundance returned to about average levels in the fall. The rapid changes in *C. finmarchicus* developmental stage distributions and abundance during the late winter and spring suggest that water movement past the site may have had a strong influence on observed population dynamics. Unusually high relative abundances of *C. finmarchicus* early copepodite stages in August suggest that population growth, perhaps stimulated by higher than average summer phytoplankton production, may have contributed to the return to average *C. finmarchicus* abundance levels in the fall.

The abundance of total copepods at Halifax-2 was about average in winter, increased to an early spring peak of about average magnitude in late March, and then declined to lower than average abundance in April (Figure 19a). Total copepod abundance was unusually low in the summer, and abundance anomalies were more variable in the fall, ending the year near average. Copepod relative abundances were quite variable at Halifax-2 in 2013. At the start of the year, the relative abundances of *Centropages* spp. and *Metridia lucens*, both warm water species, were both fairly high, while the relative abundance of *C. finmarchicus* was fairly low. However, *C. finmarchicus* relative abundance increased to high levels during its abundance peak in early April. There was an unusually high relative abundance of unidentified copepods, both nauplii and copepodites, during the summer, while the relative abundance of typical summer sub-dominant species was quite low. The copepod community returned to more typical conditions in late summer and fall, although the relative abundances of deep water sub-dominant species *Microcalanus* spp., *Oithona atlantica*, and *M. lucens* were higher than usual.

At Prince-5, zooplankton biomass and total abundance are typically lowest in January-May and increase to maximum values in July-September, lagging increases in phytoplankton by about a month, before declining to low levels again in the late fall (Figures 16, 17). Zooplankton biomass variation was similar to the climatology at Prince-5 in 2013 (Figure 16). Variation in total zooplankton abundance deviated from the climatological pattern in March due to a strong pulse of copepods, mainly *Acartia hudsonica* and *Oithona similis*, and in the summer and early fall when total zooplankton abundance was somewhat lower than average (Figures 17, 19b). The zooplankton community at Prince-5 was dominated by copepods throughout most of 2013, similar to climatological conditions, except in May and June when Cirripedia (barnacles) made up a large proportion of the community (Figure 17). The relative abundance of non-copepods was lower than average in the summer of 2013. The abundance of *C. finmarchicus* was very low in winter 2013, but increased to average or above average levels in the late spring and summer, before returning to very low levels in the late summer and fall (Figure 18). Lower than average relative abundances of early copepodite stages, especially in the late summer and fall, suggest that *C. finmarchicus* production may have been lower than average at Prince-5 in 2013.

Total copepod abundance anomalies at Prince-5 in 2013 (Figure 19b) were similar to those of total zooplankton (Figure 17). The Prince-5 copepod community was characterized by lower than average relative abundance of *C. finmarchicus* and *Microcalanus* spp. and higher than average abundance of *Acartia* spp. in winter, perhaps an indication of greater influence of near-

shore waters at the station. Spring and summer were characterised by higher than average relative abundances of *Pseudocalanus* spp. and *Centropages* spp. and lower than average abundances of *Temora longicornis* and *Eurytemora* spp. In the fall, *Pseudocalanus* spp. and *C. finmarchicus* relative abundance were low, while *Centropages* spp. and *T. longicornis* relative abundance were higher than average.

### Broad-scale Surveys

Zooplankton biomass overall was lower than average on the Scotian Shelf in 2013 (Figure 10). Spring and fall normalized biomass anomalies were negative on all sections in the spring and on the Cabot Strait and Halifax section in the fall (Figure 20). Positive normalized biomass anomalies on the Louisbourg and Browns Bank sections in fall were driven by high abundances of salps (Louisbourg) and larvaceans (Browns Bank) at slope water stations. Zooplankton biomass estimates from winter ecosystem trawl surveys on Georges Bank were among the lowest measured since 1999, while summer zooplankton biomass on the Scotian Shelf and eastern Gulf of Maine was closer to average (Figure 21). The highest zooplankton biomass values observed on the summer ecosystem trawl surveys were on Browns Bank and in the Scotian Gulf, on the CSS, and biomass was also relatively high in the eastern Gulf of Maine. Zooplankton biomass was low on the ESS in summer.

The abundance of *C. finmarchicus* was also lower than average across much of the Scotian Shelf in 2013 (Figure 10). Normalized abundance anomalies of *C. finmarchicus* were lower than average on all of the sections in spring and on the two eastern sections in the fall (Figure 22). *C. finmarchicus* abundance was higher than average on the Halifax section in fall due to very high abundances in Emerald Basin, and *C. finmarchicus* abundance was about average on the Browns Bank section in fall, with the highest abundances observed on the inner shelf (Figure 22). *C. finmarchicus* abundance estimates from the winter ecosystem trawl surveys on Georges Bank were about average, while the average summer *C. finmarchicus* abundances on the Scotian Shelf and in the eastern Gulf of Maine were among the highest observed (Figure 23). Summer *C. finmarchicus* abundance was highest on the WSS and in the eastern Gulf of Maine, and quite low on the ESS.

### Immigrant Species Scorecard

In 2013, the abundance anomalies of Arctic *Calanus* species (*C. hyperboreus* and *C. glacialis*) continued to be negative throughout the region (Figure 24). Warm offshore species (*Clausocalanus* spp., *Mecynocera clausi*, and *Pleuromamma borealis*) abundance anomalies were negative on all of the sections, but positive at Halifax-2 and Prince-5. Warm shelf species (the summer-fall copepods *Paracalanus* sp. and *Centropages typicus*) abundance anomalies were slightly negative on the sections and at Halifax-2, but very positive at Prince-5 due to uncharacteristically high late winter-early spring abundances of *C. typicus*, normally a summer-fall species.

### Relationships Among Variables at Halifax-2

Sufficient data are now available to consider possible drivers of annual-scale variability through examination of relationships among annual environmental and plankton anomalies at Halifax-2. To visualize patterns in relationships among pelagic environment and plankton metrics, matrices of Pearson correlation coefficients were calculated for Halifax-2 *in situ* data products and plotted as corrgrams, ordered by the first principle component (Murdoch and Chow 1996, Friendly 2002), using the R package corrplot (Wei 2013). Over the 15 years of the program, there were strong correlations among many of the physical variables, including strong positive correlations among surface temperature (0-50 m), bottom temperature and air temperature and negative correlations of all three with cold intermediate layer (CIL) volume and winter nitrate inventories (Figure 25). Bottom temperature and deep nitrate inventories were positively correlated,

consistent with higher nutrient concentrations in the Warm Slope Water than in the cold Labrador Slope Water. However, winter surface (0-50 m) nitrate had a non-significant weak negative correlation with deep nitrate, suggesting little influence of deep water nitrate concentrations on the nitrate inventories available for production. On the other hand, winter surface nitrate had a significant negative correlation with surface layer salinity, in addition to the relationships noted above, suggesting the influence of upwelling or vertical mixing on nitrate supply at Halifax-2. Winter surface nitrate had a strong positive correlation with annual surface nitrate inventories (0-50 m).

The timing of spring bloom initiation at Halifax-2 was negatively correlated with annual average surface temperature, i.e., the bloom started earlier in warmer years (Figure 25). The relationship between spring bloom initiation timing and annual average stratification was positive but not significant ( $r = 0.38$ ; not shown in Figure 25, as stratification had no significant correlations to the other variables presented). Neither bloom magnitude nor duration was significantly related to winter surface nitrate inventories, annual surface or deep nitrate inventories, or to surface temperature or stratification. Bloom magnitude had significant correlations with only air temperature and bottom temperature, both negative. Bloom duration had a positive correlation to surface salinity, suggesting that annual-scale levels of upwelling or vertical mixing may prolong the spring bloom.

Zooplankton biomass and *C. finmarchicus* and *Pseudocalanus* spp. abundance were all positively correlated with bloom duration (Figure 25). In addition, zooplankton biomass was positively correlated with CIL volume and winter surface nitrate inventories, *C. finmarchicus* abundance had a positive correlation with surface nitrate inventories, and *Pseudocalanus* spp. had a positive correlation with surface salinity. The abundance of warm shelf species were also positively correlated with bloom duration, as well as with annual surface chlorophyll inventories (Figure 26). The abundances of two immigrant groups, Arctic *Calanus* and warm offshore species were negatively correlated to one another. Arctic *Calanus* abundance had strong negative correlations to surface and bottom temperature and a strong positive correlation to CIL volume, while warm offshore species abundance had strong positive correlations to surface and bottom temperature and deep nitrate inventories and a negative correlation to CIL volume.

## BEDFORD BASIN

The 21-year environmental scorecard for Bedford Basin is presented in Figure 27. For the year 2013 as a whole, the upper 10 m of the water column in Bedford Basin was slightly warmer, fresher, and less dense than normal. Surface layer temperature cooled in 2013 from the 20-year record high observed in Bedford Basin in 2012 but was still warmer than average in 2013, similar to the broader Scotian Shelf. Bedford Basin surface layer conditions in 2013 were associated with higher than normal values for measurements associated with small phytoplankton (picoeukaryotes, *Synechococcus*, picophytoplankton, zeaxanthin). For *Synechococcus*, a time series plot shows that abundance has been increasing on an annual basis for the past 10 years, since the lowest recorded values in 2003 (Figure 28). Conversely, the warmer, fresher, less dense conditions of 2013 were associated with lower than normal values for measurements associated with large phytoplankton (diadinoxanthin, microplankton pigments, fucoxanthin). Of particular note is that both phosphate and heterotrophic bacteria have remained at below normal conditions for the past three years, which is coincident with the period since the Halifax Wastewater Treatment Facility was restored to full operation in June 2010 following the system malfunction in 2009. No direct scientific examination has been made on putative causes for the current low levels of phosphate and bacteria.

## DISCUSSION

The strong sub-annual and mesoscale variability in physical conditions observed in the region during 2013 (Hebert et al. 2014) was reflected in variability in nutrient and plankton anomalies. Abrupt changes in stratification observed at Halifax-2 in summer suggest the influence of upwelling or advection, while shifts in deep water nitrate concentrations at Halifax-2 were consistent with changes in the deep water source at the station, with higher nutrients associated with the warm slope water and lower levels with cool Labrador slope waters (Hebert et al. 2014). Unusually strong shifts between negative and positive zooplankton biomass and *C. finmarchicus* abundance anomalies at Halifax-2 in the winter, spring and summer suggest that advection across horizontal zooplankton gradients may have contributed to observed sub-annual variability, in addition to changes associated with the annual production cycle. The mesoscale spatial structure observed in nutrient anomalies and chlorophyll concentrations and the strong contrast between low zooplankton biomass and *C. finmarchicus* abundance on the ESS and high values on the WSS observed in July are consistent with this interpretation. Overall, the strong sub-annual and mesoscale variability means that annual anomaly values reported in 2013 may not be representative of the chemical and biological conditions in a particular season or area within the region.

Despite the strong variability observed in 2013, winter nitrate, zooplankton biomass and dominant copepod abundance, which had very low anomalies in 2012, were closer to average in 2013, suggesting a return to more typical conditions. Although *C. finmarchicus* abundance was low on the ESS in 2013, high production in some areas in early spring or summer may have helped to restock areas like Emerald Basin, where abundance was high in the fall. Phytoplankton community composition was variable at the fixed stations, but large phytoplankton made up a greater part of the community in 2013 than in 2012 at the Halifax-2 station, particularly during the late summer-early fall bloom. At Bedford Basin, small taxa were more abundant than average and large taxa less abundant, consistent with the warmer temperatures in 2013 (Li and Harrison 2008). The persistence of lower than average Arctic *Calanus* abundance in 2013 was also consistent with continued warm average temperatures.

Correlation analysis of annual anomalies at Halifax-2 provides an initial assessment of lower trophic level responses to environmental change at an annual scale. Correlations were generally strongest among the physical and chemical variables, reflecting water mass relationships (e.g., deep nitrate inventories and bottom temperature) or other non-independent variables (e.g., surface layer temperature and CIL volume; winter surface nitrate and annual surface nitrate). The positive correlation between deep water nitrate concentration and bottom temperature at Halifax-2 was consistent with differences in nitrate in the Warm Slope Water and Labrador Slope Water, sources of deep water on the CSS and WSS (Petrie and Yeats 2000), but deep water nitrate concentration did not appear to have a strong influence on winter nitrate inventories. Rather, the association of winter nitrate inventories with colder, saltier water suggests that upwelling or vertical mixing of sub-surface waters may have a greater role in driving winter nitrate inventories than changes in sub-surface nitrate concentration.

Spring bloom initiation is thought to be controlled by the light environment of phytoplankton, starting when the water column stabilizes or with adequate light penetration in the absence of wind-driven vertical mixing (Sverdrup, 1953, Townsend et al. 1992). The annual-scale metrics examined here, including stratification, likely do not capture the seasonal and event-scale processes controlling development of the light environment for phytoplankton growth in late winter, and only surface temperature had a significant relationship to bloom initiation time. Warmer annual average temperatures may indicate years in which the water column stabilized earlier due to earlier onset of positive ocean-atmosphere heat fluxes or mixed layer depth shoaling (Brody et al. 2013). Although spring bloom magnitude is thought to be controlled largely by nutrient supply, the positive correlation between bloom magnitude and winter surface

nutrient supply at Halifax-2 was not significant. This weak relationship may in part reflect uncertainty in estimating bloom magnitude, due to the low sampling frequency at Halifax-2, relative to time-scales of bloom dynamics, and the influence of advection at the station. The significant positive correlation of spring bloom duration and near-surface salinity anomalies suggest that the bloom could be prolonged in years of greater upwelling and vertical mixing (Greenan et al. 2008). Positive correlations between bloom duration, zooplankton biomass and abundance of dominant copepods suggest that zooplankton grazing did not play a major role in bloom termination, and indeed that longer blooms may enhance zooplankton production. In contrast to the relationships between zooplankton biomass and abundance of core shelf copepods with phytoplankton metrics, strong relationships between the abundance of immigrant copepod groups, Arctic *Calanus* and warm offshore copepods, and temperature and CIL volume suggests that they are water mass indicators. Although analysis of annual metrics cannot capture high frequency or event-scale processes that drive variability, the analysis identified bloom duration and possibly enhanced upwelling as important correlates of zooplankton biomass and the abundance of dominant copepod species at an annual scale.

Strong water mass variability, such as was observed in 2013, is a typical property of Maritimes waters, particularly on the CSS and WSS, due to their location near the boundary between sub-polar and Gulf Stream waters. This implies a variable pelagic habitat for upper trophic levels in the region and highlights the need to incorporate numerical modeling approaches including ocean circulation to understand the drivers of plankton variability in the region.

## CONTINUOUS PLANKTON RECORDER (CPR)

### Phytoplankton

The PCI and diatom abundance have similar climatological seasonal cycles on the WSS and ESS, with high values in March and April (Figure 29). Dinoflagellate abundance shows no clear seasonal cycle in either region. In 2012, the PCI was lower than normal in March and April in both regions and normal for much of the year, except for one very low value in June and one high value in July on the WSS. Diatom abundance was normal in March, somewhat lower (WSS) or much lower (ESS) than normal in April and generally higher than normal on the WSS in summer and fall and lower than normal on the ESS in summer. Dinoflagellate abundance was highly variable in 2012. The 2012 annual average anomaly of PCI was close to normal (WSS) or much lower (ESS) than the 1992-2011 average, while the diatom and dinoflagellate annual average abundances for 2012 were slightly higher (WSS) or much lower (ESS) than the 1992-2011 averages (Figure 30).

### Zooplankton

*Calanus I-IV* (mostly *C. finmarchicus*) abundances show similar climatological seasonal cycles on the WSS and ESS, each having a peak between April and June (Figure 31). The seasonal cycles for the late stages are different, with a peak in abundance that follows the one for *Calanus I-IV* by a month on the WSS, and with a broad peak between November and April on the ESS. As the CPR samples only near-surface waters, the broader peak in late stages on the ESS may perhaps reflect earlier emergence from dormancy and return to the surface, on average, on the ESS than on the WSS. In 2012, the springtime peak for *Calanus I-IV* appeared to be of shorter duration than normal in both regions and in other months values were near average (WSS) or well below average (ESS). Monthly abundances for *C. finmarchicus V-VI* were near (6 months) or below (4 months) average values on the WSS and generally below average values on the ESS. Annual average abundance anomalies for *Calanus I-IV* and *C. finmarchicus V-VI* in 2012 were below the 1992-2011 averages (Figure 30). The annual average abundances of the Arctic species *C. glacialis* and *C. hyperboreus* are generally about

50 times lower than those of *C. finmarchicus* V-VI in CPR tows, and annual average abundance anomalies of both species were lower than normal in 2012, especially on the ESS. Annual average abundance anomalies of the small zooplankton taxa (copepod nauplii, *Paracalanus/Pseudocalanus*, *Oithona* spp.) were near normal levels on the WSS in 2012 and below normal levels on the ESS. Euphausiid annual average abundance anomalies were much lower than normal in 2012 on both the WSS and ESS, while levels of hyperiids (amphipods) were much higher than normal on the WSS in 2012 and slightly lower than normal on the ESS.

### Acid Sensitive Organisms

Annual average abundance anomalies of coccolithophores (phytoplankton) and foraminifera (microzooplankton) were slightly higher (coccolithophores, ESS) or substantially higher than the 1992-2011 average values in 2012, whereas the abundance anomaly for pteropods (*Limacina* spp.) was higher (WSS) or slightly lower (ESS) (Figure 30).

### CPR Results *versus in situ* Observations

CPR results in 2012 were generally consistent with *in situ* observations resulting from DFO sampling at Halifax-2 and on sections across the WSS and ESS. At Halifax-2 the spring bloom was of average magnitude, but of short duration (Johnson et al. 2013): the same pattern was seen for CPR diatom abundance levels (Figure 29), although not for the other CPR phytoplankton taxa. Zooplankton biomass was low throughout the year at Halifax-2 and elsewhere, with *C. finmarchicus* and two Arctic *Calanus* species showing especially low abundances: CPR abundances were lower than normal for most zooplankton taxa, including all three *Calanus* species (Figure 30). The water column was anomalously warm in 2012, which apparently led to a high degree of stratification, which may have been linked to the higher than normal abundance of coccolithophores (Raitos et al. 2006).

## SUMMARY

- In 2013, strong sub-annual and mesoscale variability in physical conditions was reflected in variability in nutrient and plankton anomalies.
- Spring phytoplankton bloom magnitudes were overall higher than average on the ESS and lower than average on the WSS and in the Gulf of Maine.
- Summer-fall chlorophyll levels were above average throughout the region.
- Zooplankton biomass and abundance were lower than average overall.
- *C. finmarchicus* abundance was lower than average overall but ended the year about average on the CSS.
- Arctic *Calanus* abundance, an indicator of cold water on the Scotian Shelf, was lower than average in 2013, while abundance anomalies of warm offshore species were mixed.
- Bedford Basin annual temperature anomalies were positive in 2013 but lower than in 2012, and small phytoplankton continued to be more abundant than normal and large phytoplankton less abundant.
- CPR sampling showed that observations at Halifax-2 in 2012 were representative of shelf-wide patterns: CPR-derived diatom abundance indicated an early bloom, of short duration, and the abundance of the dominant zooplankton species, *C. finmarchicus*, was markedly lower than normal.

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## TABLES

Table 1. Atlantic Zone Monitoring Program (AZMP) sampling missions in the Maritimes/Gulf regions, 2013.

Group	Location	Mission ID	Dates	# Hydro Stns	# Net Stns
Trawl Surveys	Georges Bank / Western Scotian Shelf	NED2013-002	Feb 26 – Mar 19	56	12
	Scotian Shelf	NED2013-022	Jul 02 – Aug 04	230	33
	Southern Gulf of St. Lawrence	TEL2013-118	Sept 04 - 28	132	15
Seasonal Sections	Scotian Shelf	HUD2013-004	Apr 04 - 26	96	84
	Scotian Shelf	HUD2013-008	May 24 - 28	16	7
	Scotian Shelf	HUD2013-037	Sep 21 – Oct 09	96	86
Fixed Stations	Shediac Valley	BCD2013-668	Mar 11 – Nov 31	10	8
	Halifax-2	BCD2013-666	Jan 01 – Dec 31	23(8) <sup>1</sup>	22(8) <sup>1</sup>
	Prince-5	BCD2013-669	Jan 01 – Dec 31	12	12
Total:				671	279

Note: <sup>1</sup>Total station occupations, including occupations during trawl surveys and seasonal sections (dedicated occupations with mission ID as listed at left are in parentheses).

## FIGURES

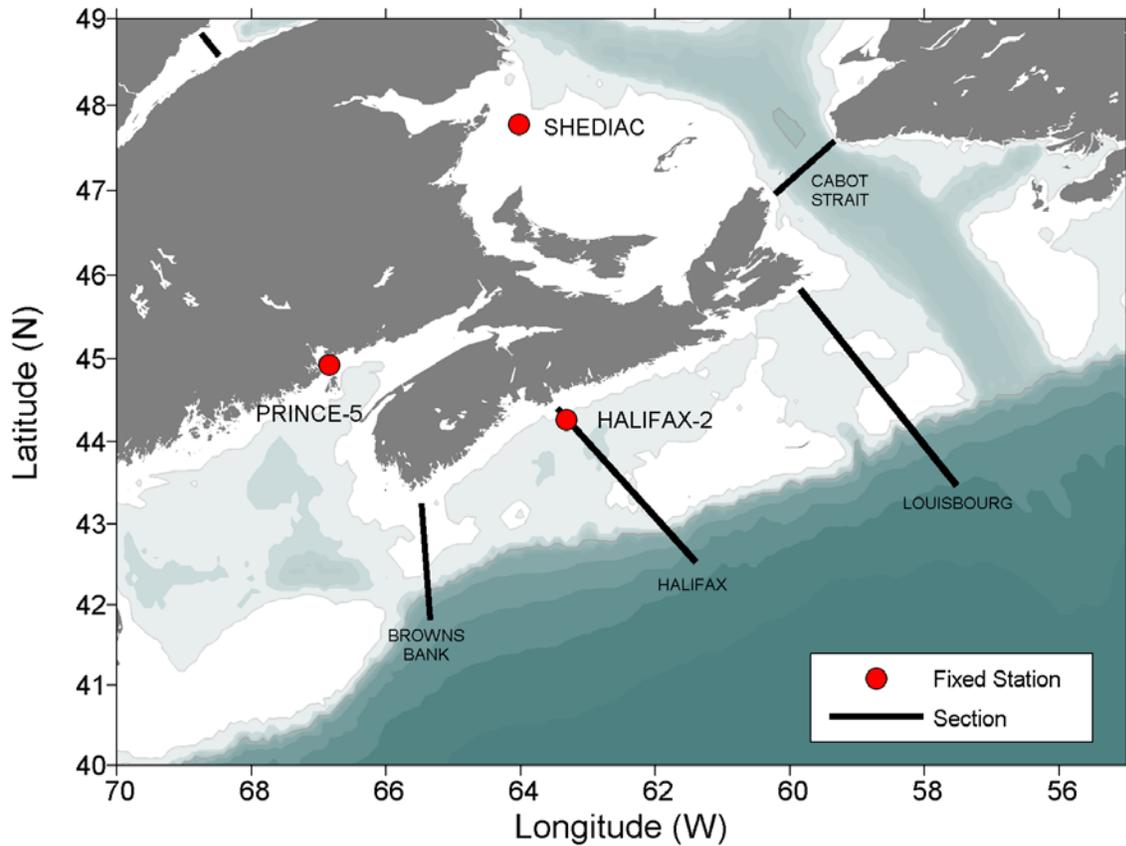


Figure 1. Map of primary sections (Cabot Strait, Louisbourg, Halifax, and Browns Bank) and fixed stations (Shediac, Halifax-2, and Prince-5) sampled in the DFO Maritimes and Gulf regions.

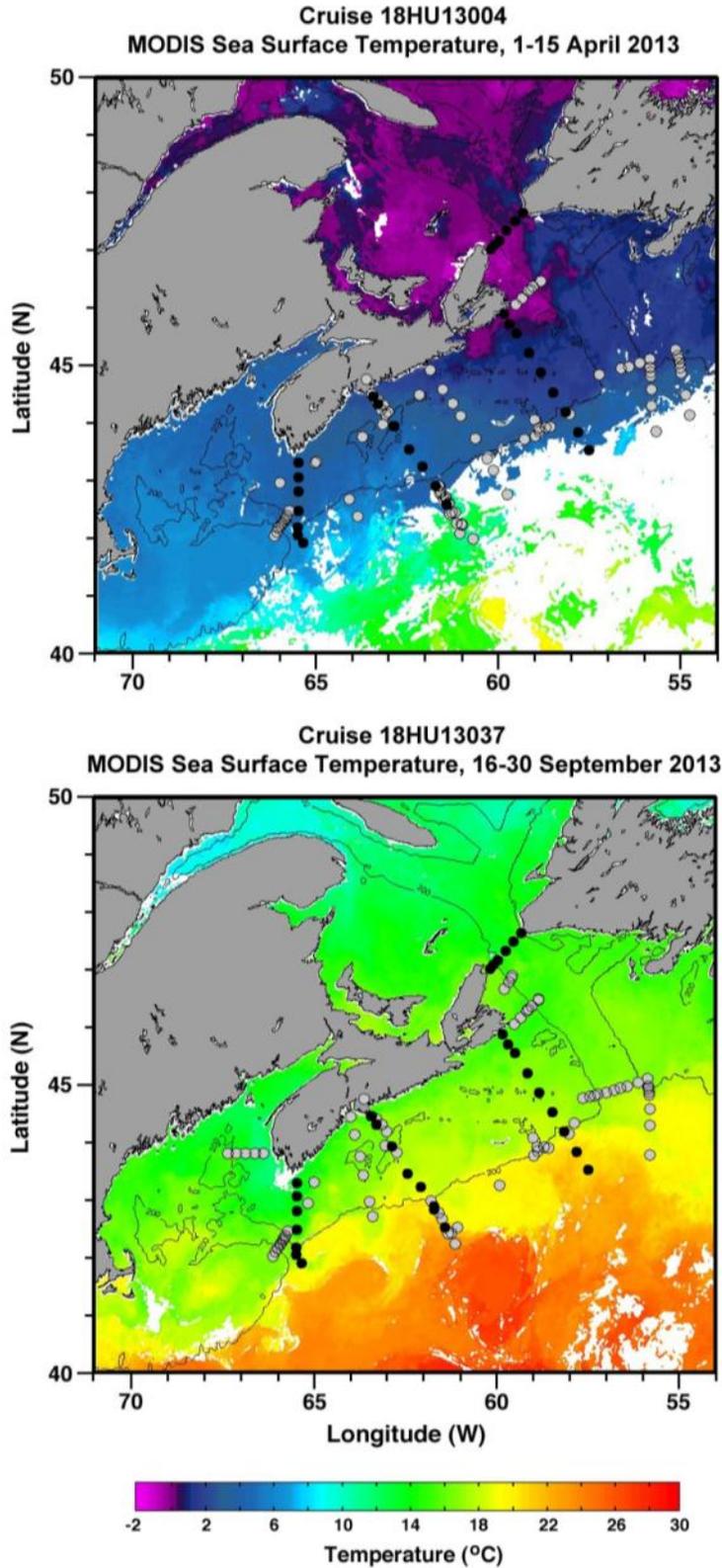


Figure 2. Stations sampled during the 2013 spring and fall surveys. Station locations are superimposed on a sea-surface temperature composite image for dates close to the mission dates. Black markers indicate core stations, and gray markers indicate stations sampled for ancillary programs.

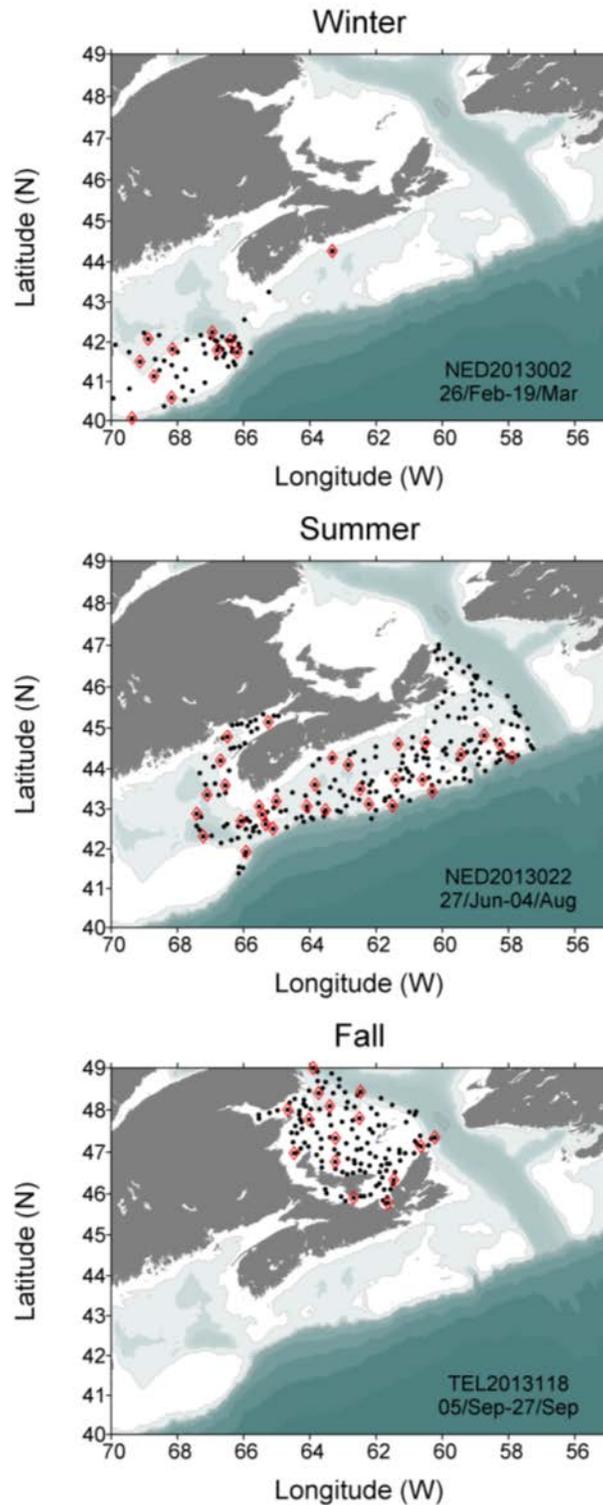


Figure 3. Stations sampled during major Maritimes/Gulf ecosystem trawl surveys in 2013. Black solid markers are hydrographic stations; red open diamonds are stations where vertical nets hauls were taken in addition to hydrographic measurements.

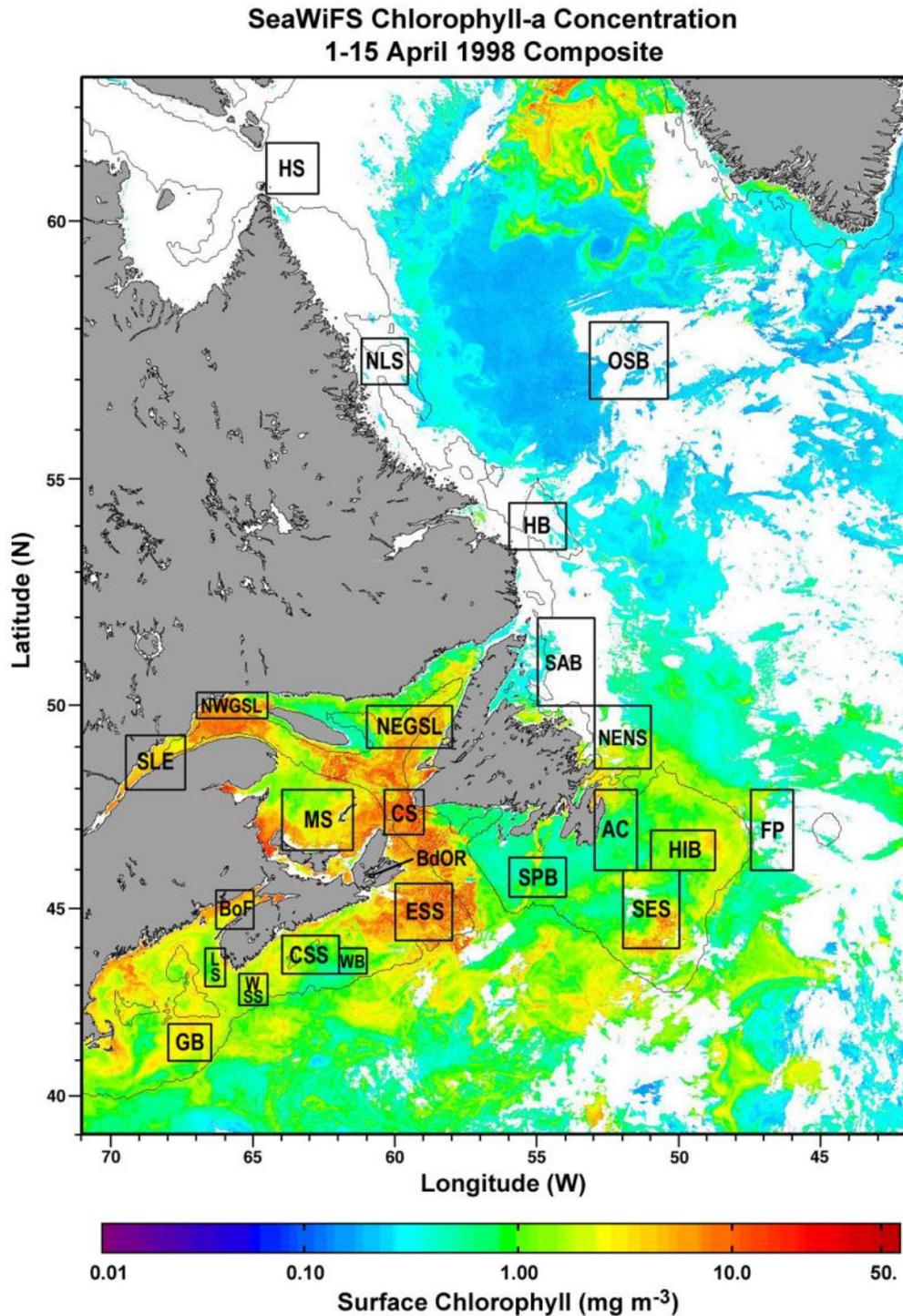


Figure 4. Statistical sub-regions in the Northwest Atlantic identified for spatial/temporal analysis of satellite ocean colour data. AC – Avalon Channel; BdOR – Bras d’Or; BoF – Bay of Fundy; CS – Cabot Strait; CSS – central Scotian Shelf; ESS – eastern Scotian Shelf; FP – Flemish Pass; GB – Georges 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.

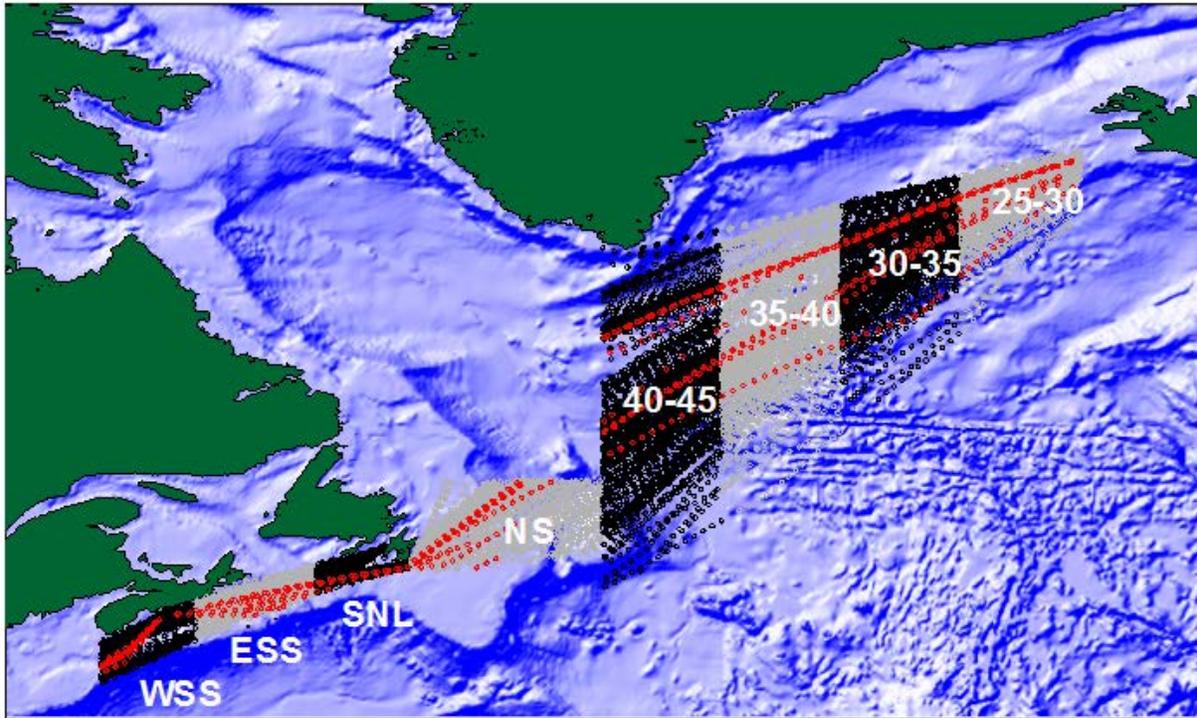


Figure 5. Continuous Plankton recorder (CPR) lines and stations 1957 to 2012. Stations sampled in 2012 are shown in red. Data are analysed by region. Regions are: Western Scotian Shelf (WSS), Eastern Scotian Shelf (ESS), South Newfoundland Shelf (SNL), Newfoundland Shelf (NS), and between longitudes  $40-45^{\circ}$ W,  $35-40^{\circ}$ W,  $30-35^{\circ}$ W,  $25-30^{\circ}$ W.

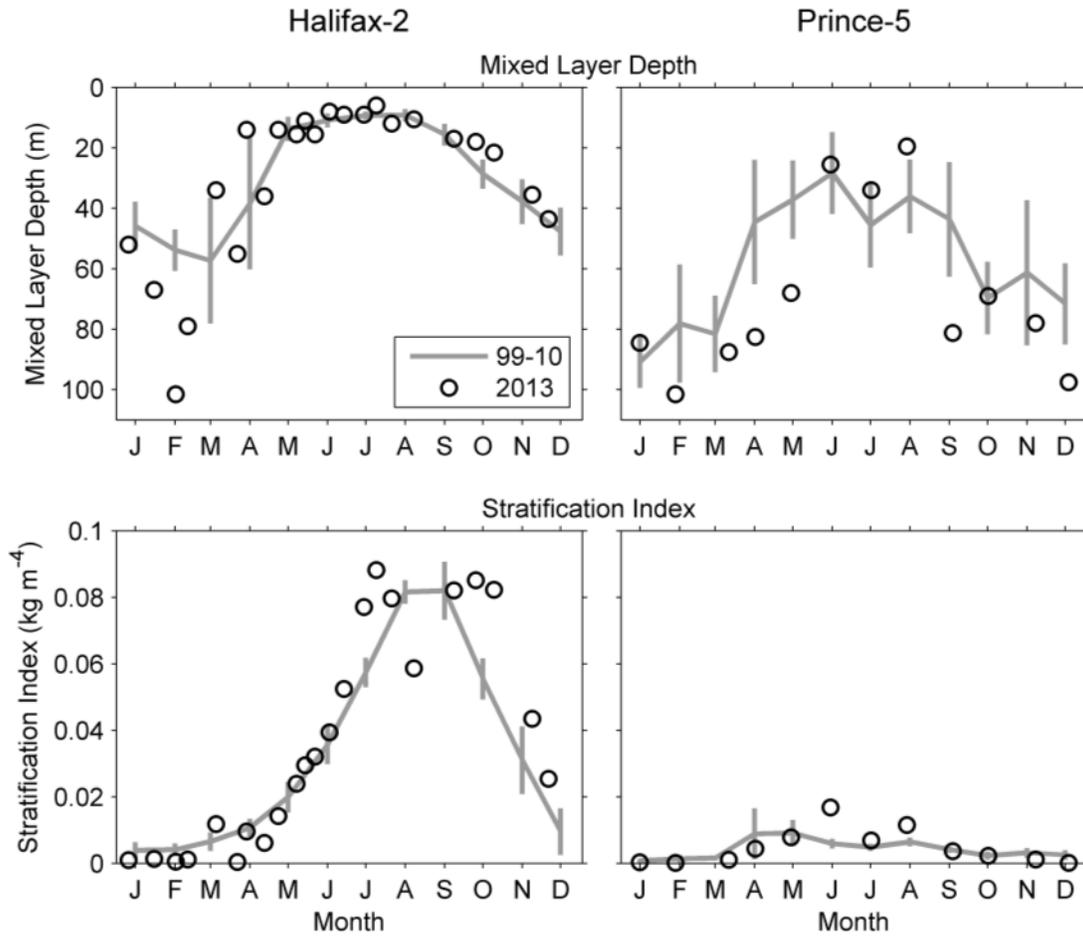


Figure 6. Mixing properties (MLD, stratification index) at the Maritimes fixed stations comparing 2013 data (open circle) with mean conditions from 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the observations.

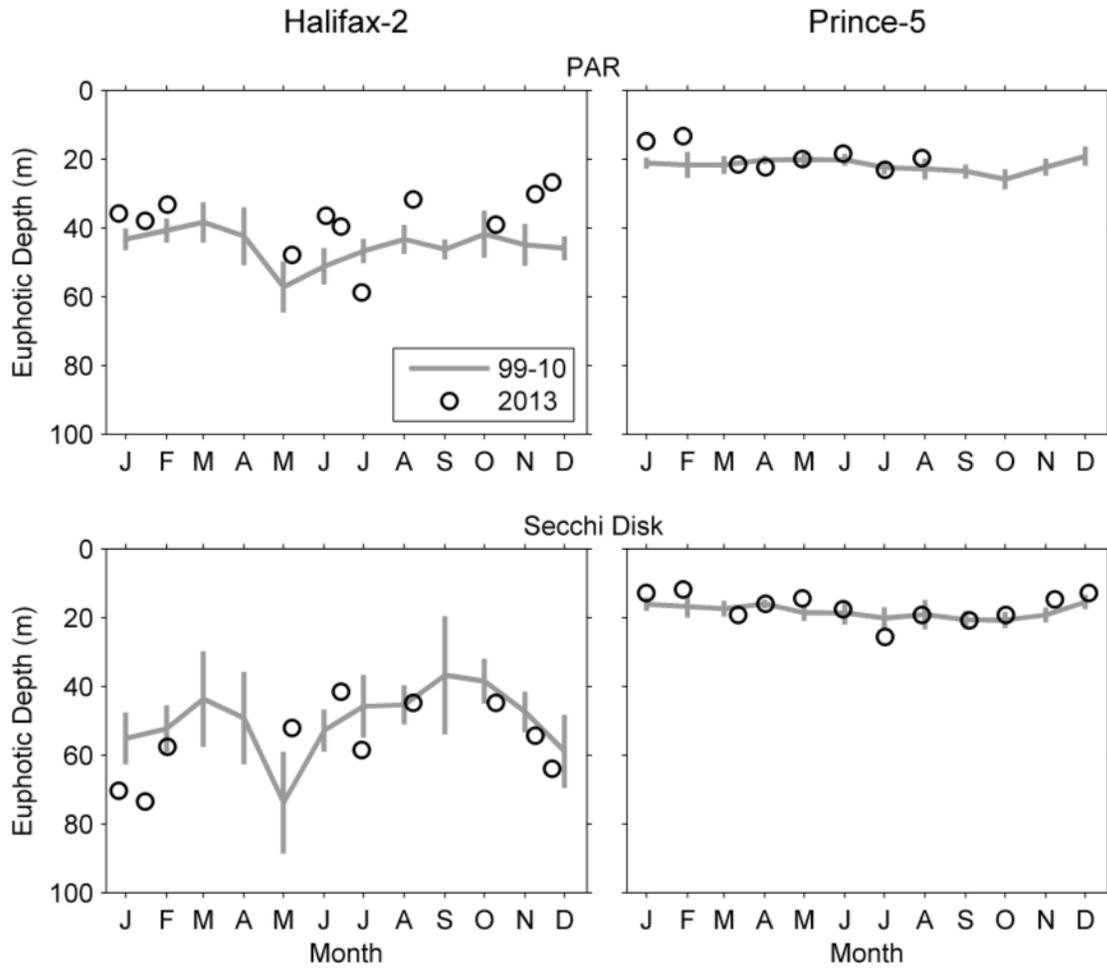


Figure 7. Optical properties (euphotic depth from PAR irradiance meter and Secchi disc) at the Maritimes fixed stations. Year 2013 data (circles) compared with mean conditions from 1999–2010 (solid line), except 2001–2010 for euphotic depth from PAR at Prince-5. Vertical lines are 95% confidence intervals of the observations.

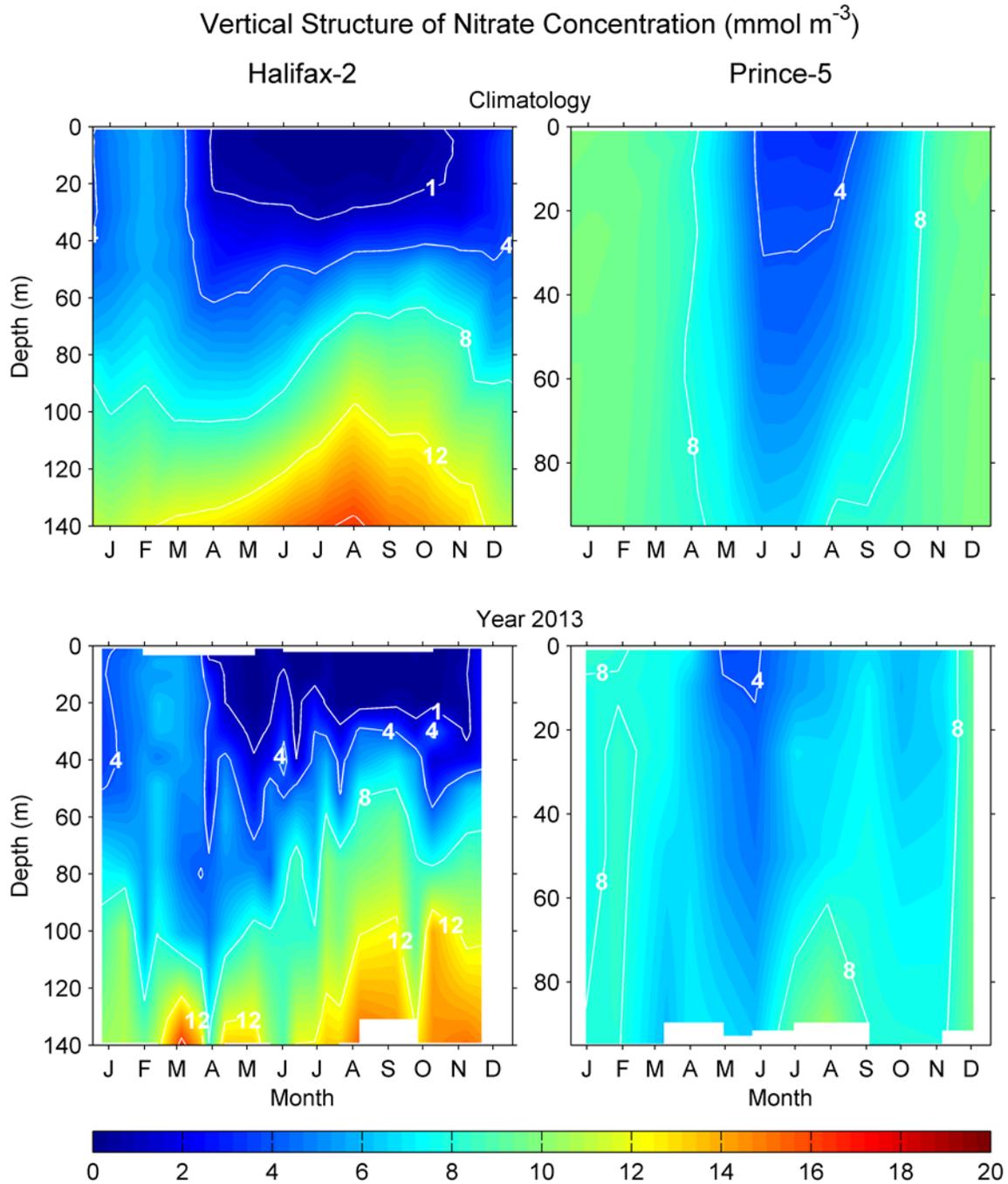


Figure 8. Comparison of vertical structure of nitrate concentrations ( $\text{mmol m}^{-3}$ ) in 2013 (bottom panels) with climatological mean conditions from 1999–2010 (upper panels) at the Maritimes fixed stations.

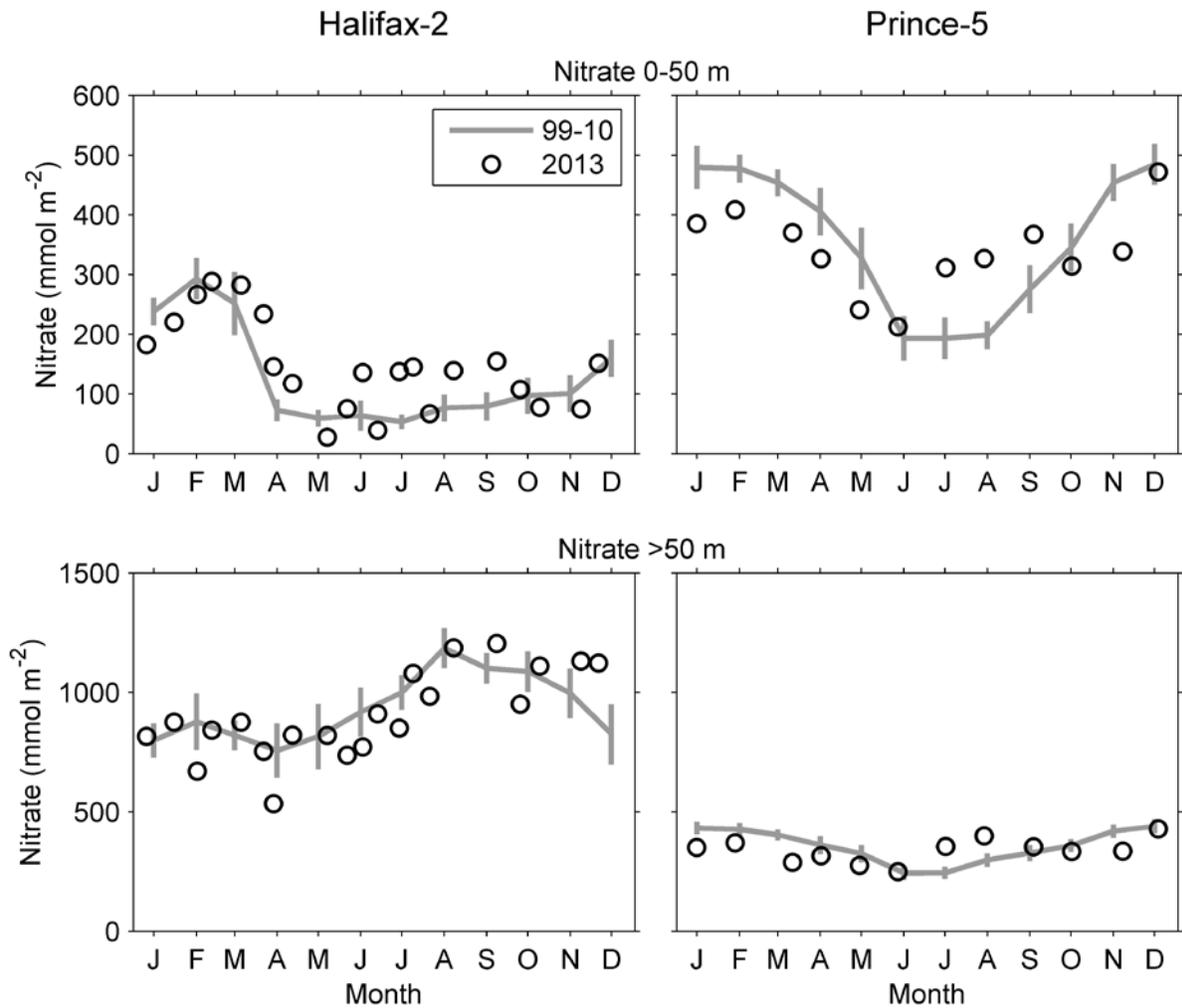


Figure 9. Comparison of 2013 (open circle) data with mean conditions from 1999–2010 (solid line) at the Maritimes fixed stations. Upper panels: surface (0–50 m) nitrate inventory. Lower panels: deep (>50 m) nitrate inventory. Vertical lines are 95% confidence intervals of the annual averages.

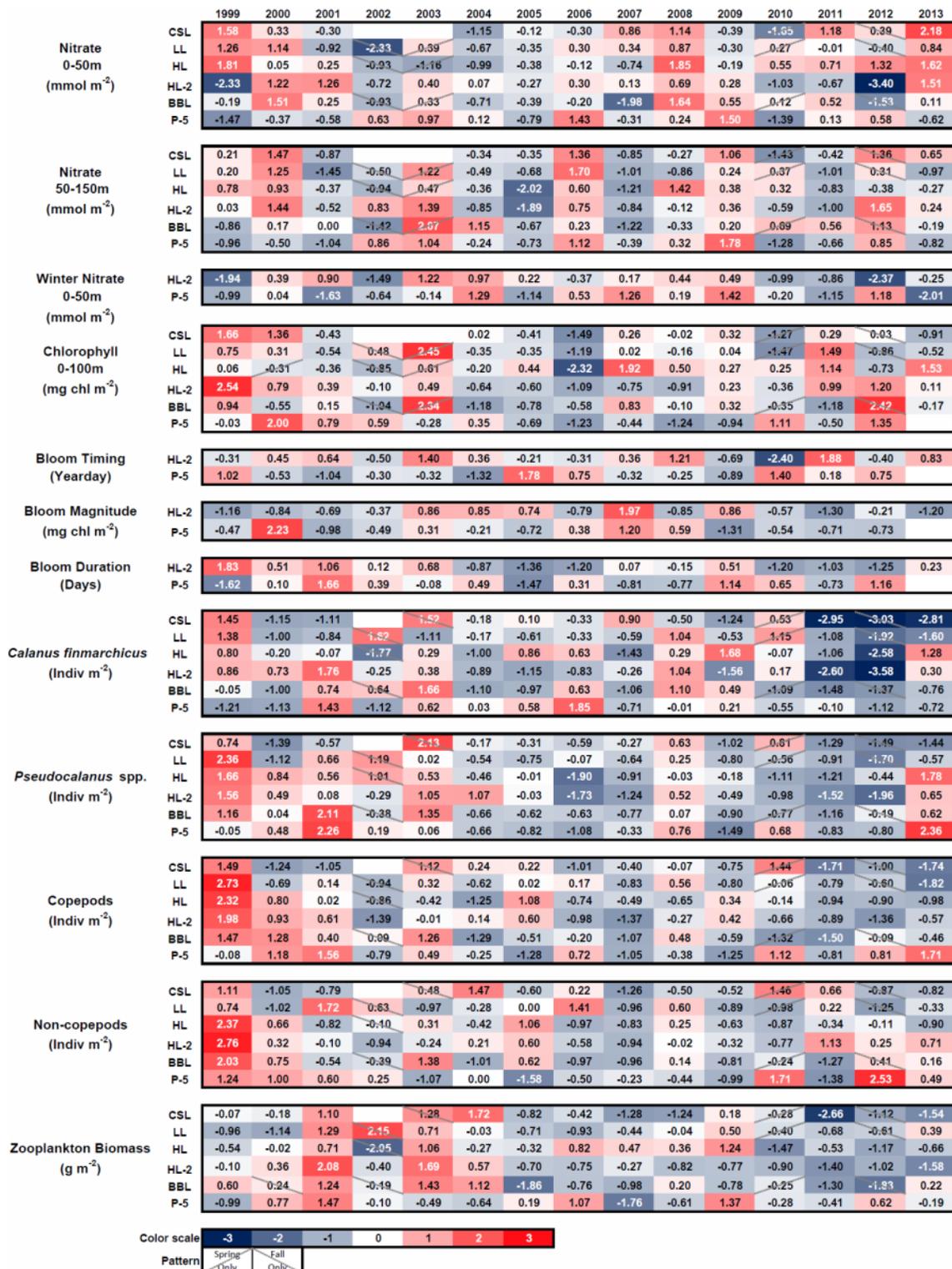


Figure 10. Maritimes Region scorecard: time series of chemical and biological variables, 1999–2013. A blank cell indicates missing data. Red (blue) cells indicate higher (lower) than normal nutrient, phytoplankton, zooplankton levels or later and longer (earlier or shorter) than normal duration of phytoplankton blooms. Reference period is 1999–2010. The numbers in the cells are the anomaly values. CSL: Cabot Strait section; LL: Louisbourg section; HL: Halifax section; HL2: Halifax-2; BBL: Browns Bank section; P5: Prince-5.

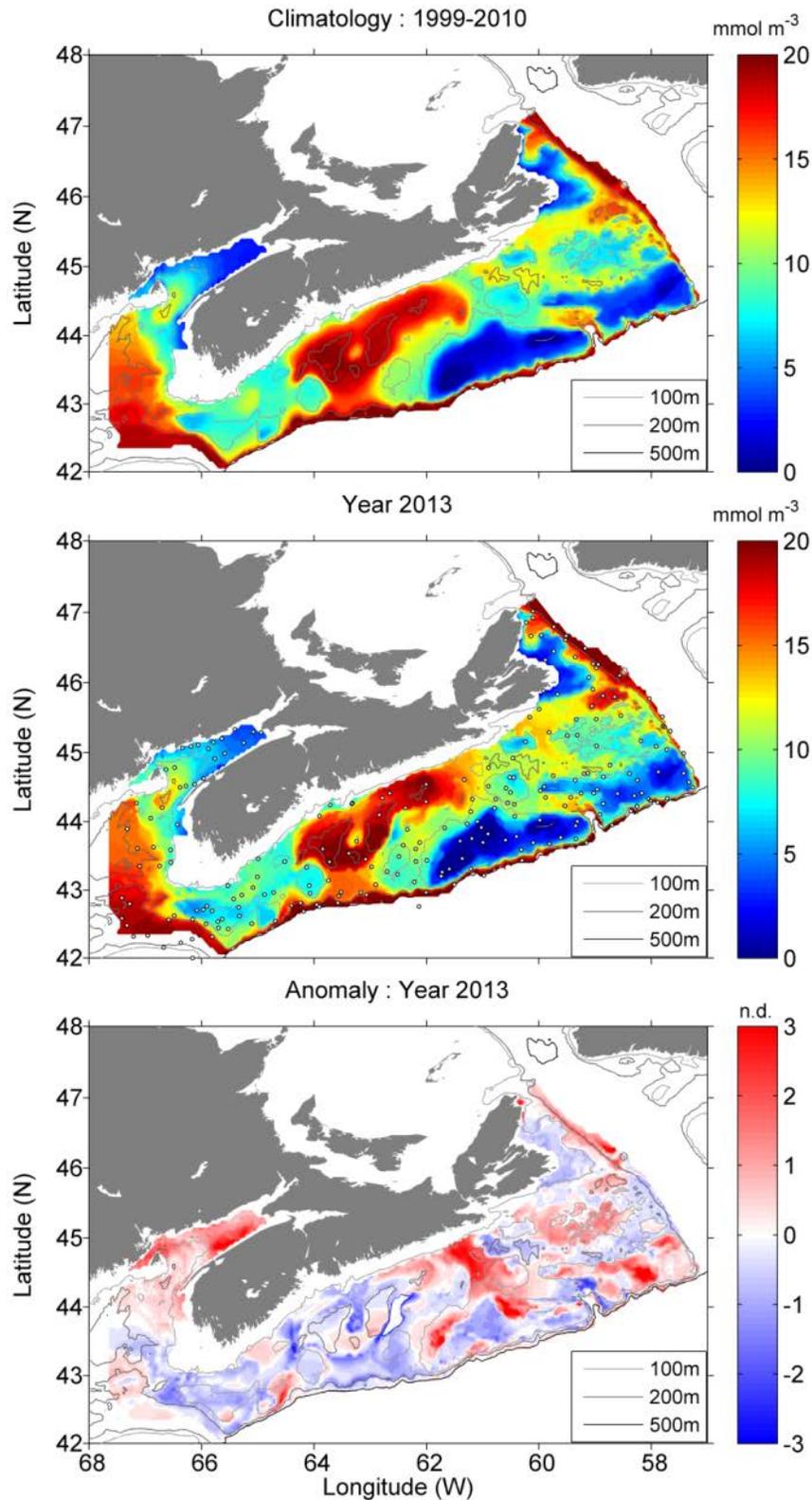


Figure 11. Bottom nitrate concentration on the Scotian Shelf during the annual July ecosystem trawl survey: 1999-2010 climatology (upper panel), 2013 conditions (middle panel), and anomalies of 2013 from climatology (lower panel). Markers in middle panel represent the 2013 sampling locations. nd = no dimensions.

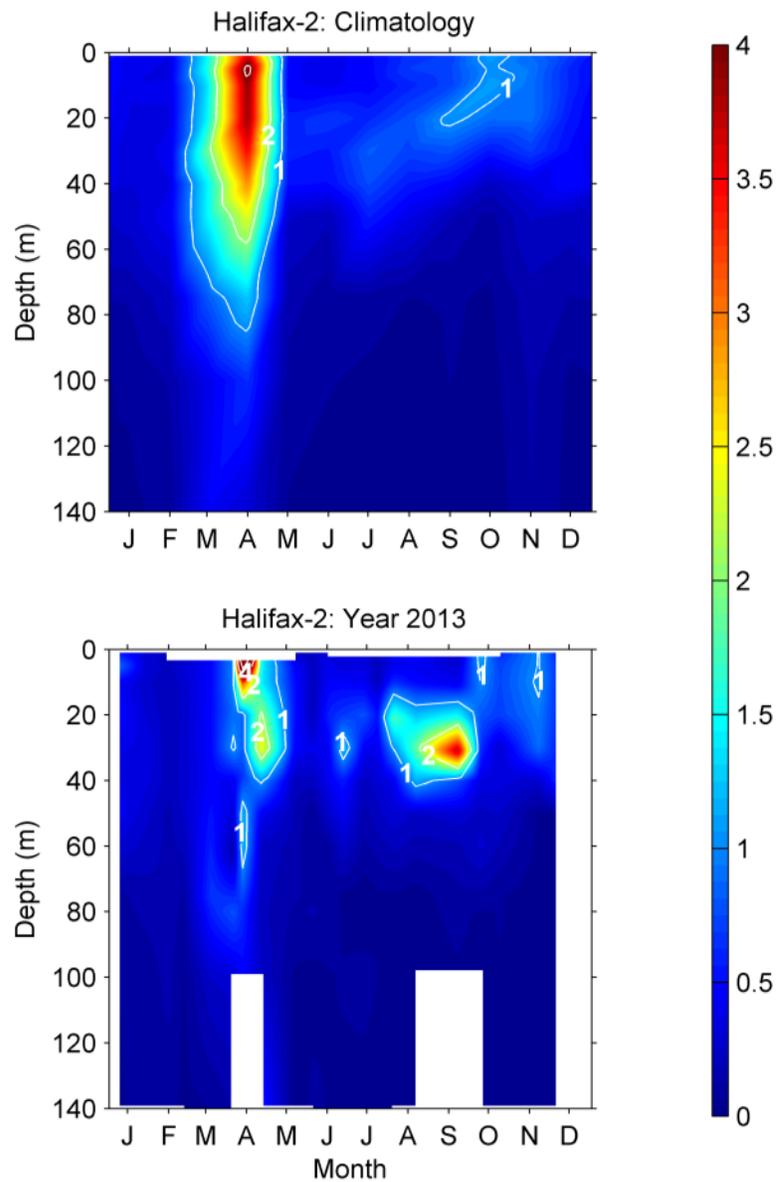
Vertical Structure of Chlorophyll Concentration ( $\text{mg m}^{-3}$ )

Figure 12. Comparison of vertical structure of chlorophyll concentrations ( $\text{mg m}^{-3}$ ) in 2013 (bottom panels) with mean conditions from 1999–2010 (upper panels) at the Halifax-2 station. Colour scale chosen to emphasize change near estimated food saturation levels for large copepods.

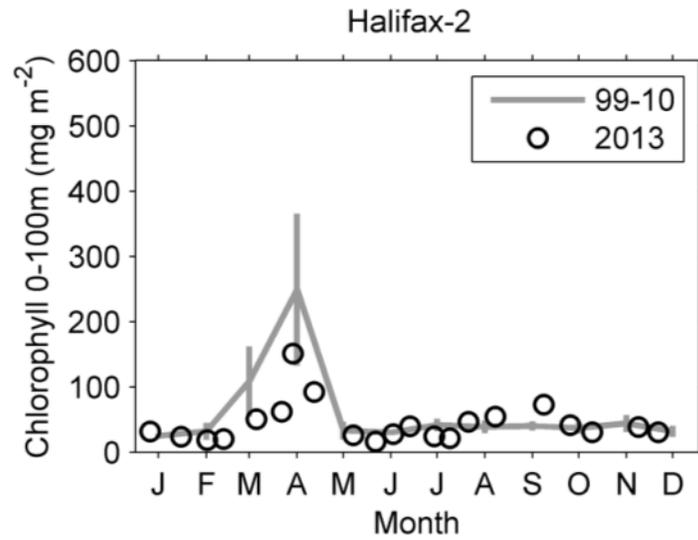


Figure 13. Comparison of 2013 (open circle) chlorophyll inventories with mean conditions from 1999–2010 (solid line) at the Halifax-2 station. Vertical lines are 95% confidence intervals of the annual averages.

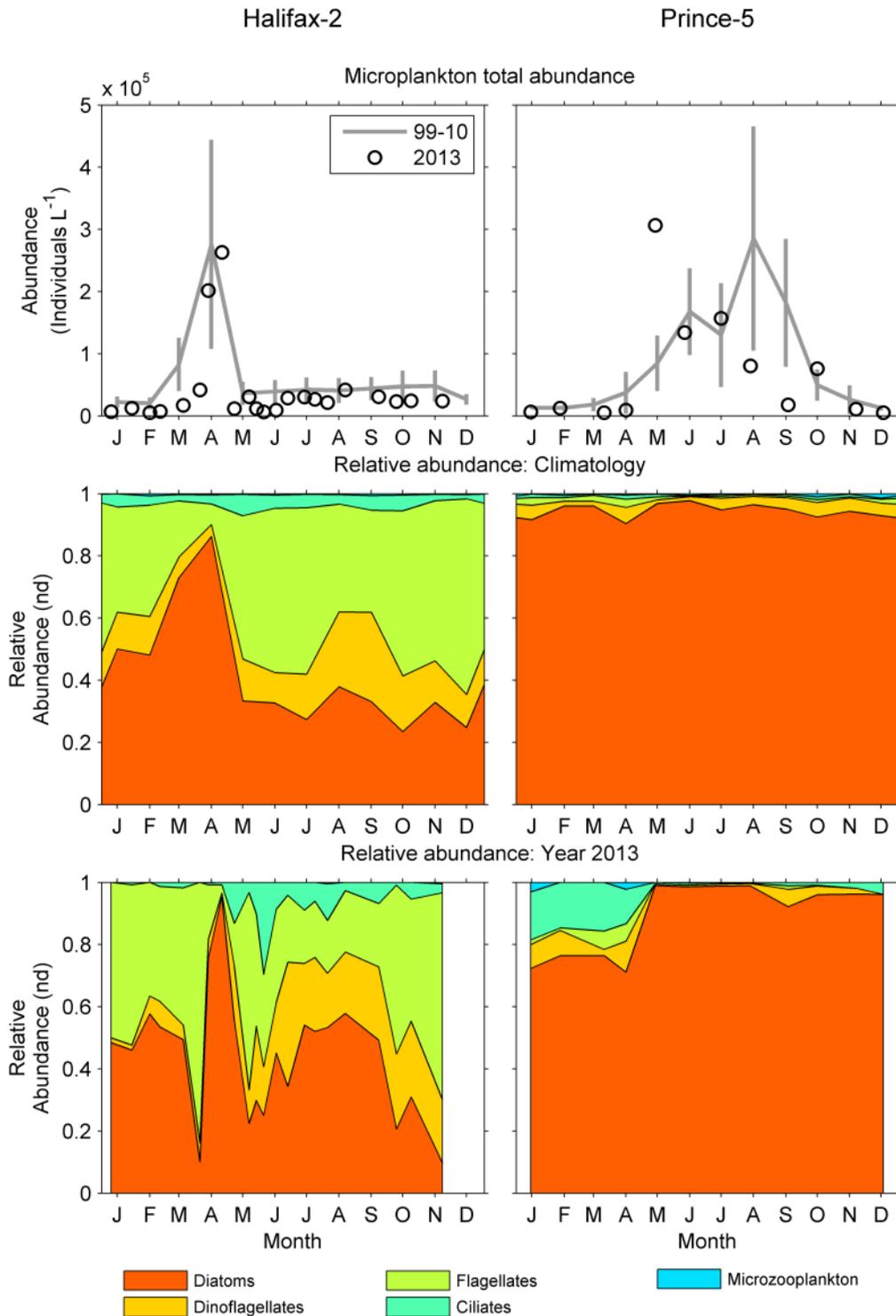


Figure 14. Comparison of 2013 microplankton (phytoplankton and protists) abundance and community composition with mean conditions from 1999–2010 at the Maritimes fixed stations (Halifax-2 right panels; Prince-5 left panels). Upper panels: 2013 microplankton abundance (open circle) compared with mean conditions from 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the annual averages. Middle panels: Climatological microplankton relative abundance from 1999–2010. Lower panels: 2013 microplankton relative abundance. nd = no dimensions.

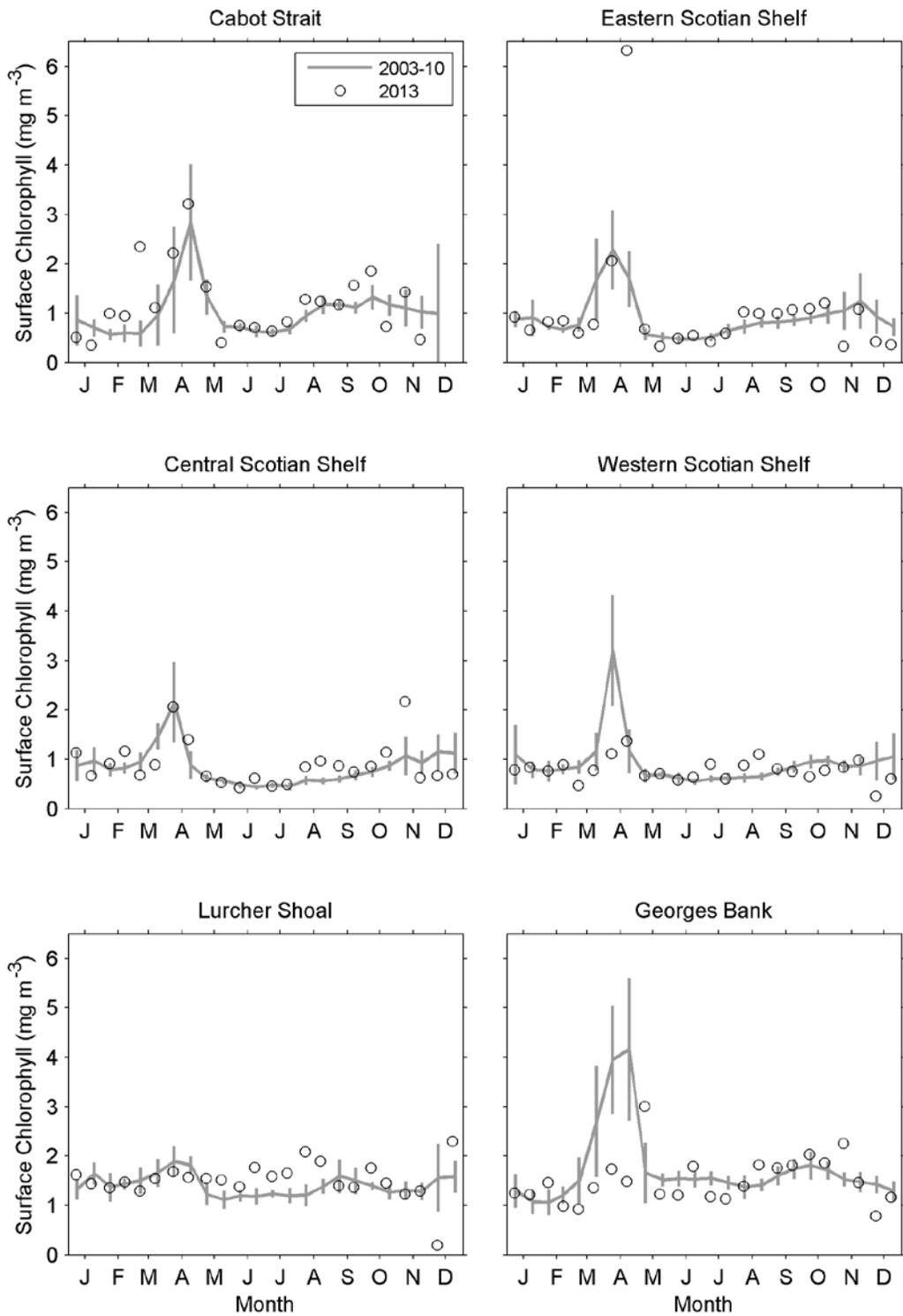


Figure 15. Comparison of 2013 (open circle) surface chlorophyll estimates from satellite ocean colour with mean conditions from 2003–2010 (solid line) in the Cabot Strait, Eastern Scotian Shelf, Central Scotian Shelf, Western Scotian Shelf, Lurcher Shoal, and Georges Bank statistical sub-regions (Figure 4) Vertical lines are 95% confidence intervals of the annual averages.

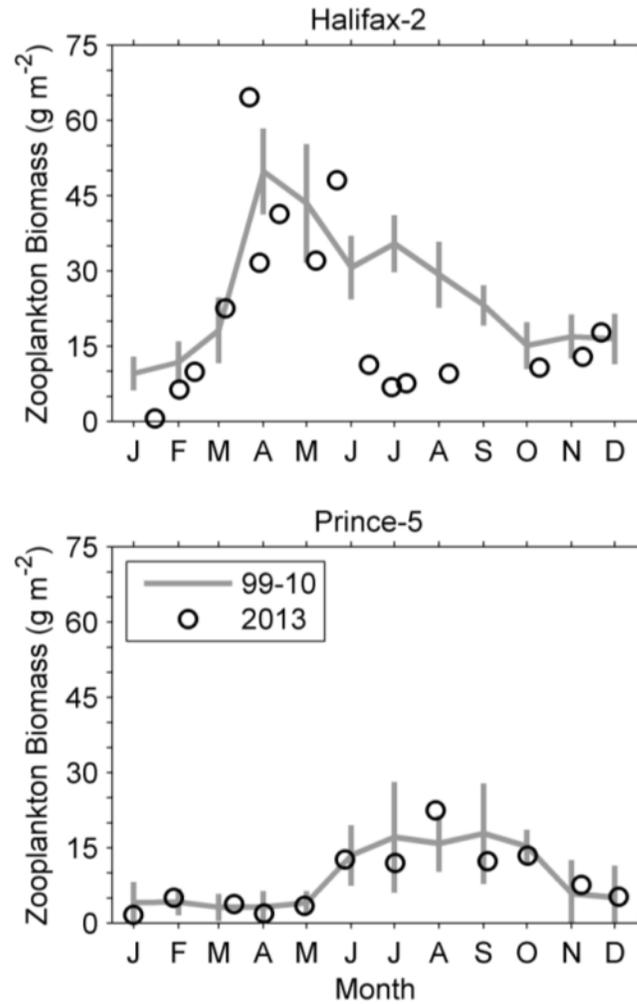


Figure 16. Comparison of 2013 (open circle) zooplankton biomass (surface to bottom) with mean conditions from 1999–2010 (solid line) at the Maritimes fixed stations. Upper panel: Halifax-2; lower panel: Prince-5. Vertical lines are 95% confidence intervals of the annual averages.

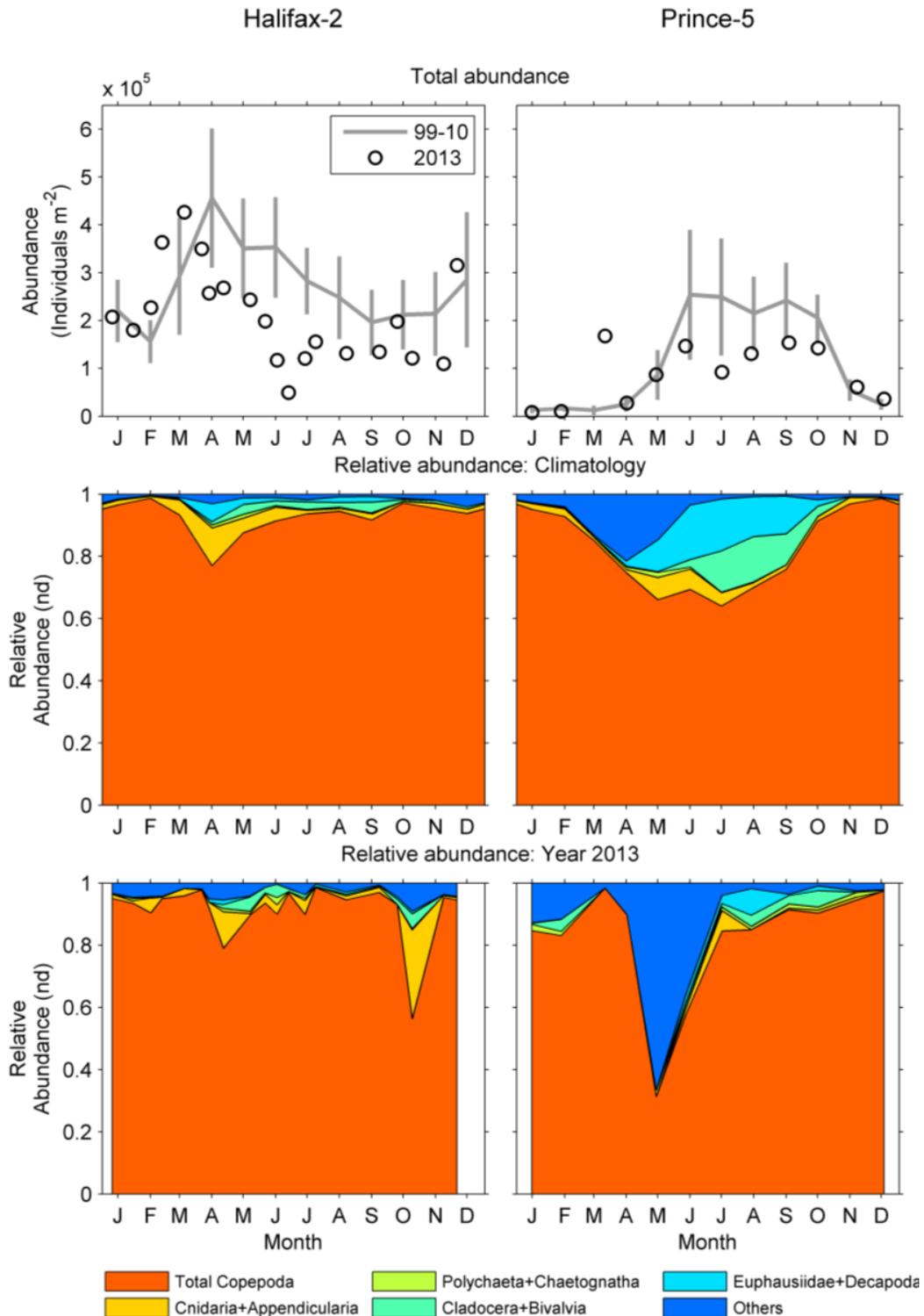


Figure 17. Comparison of 2013 zooplankton (>200 μm) abundance and community composition with mean conditions from 1999–2010 at the Maritimes fixed stations (Halifax-2, left panels; Prince-5, right panels). Upper panels: 2013 zooplankton abundance (open circle) compared with mean conditions from 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the annual averages. Middle panels: Climatology of major group abundance from 1999–2010. Lower panels: 2013 major group abundance. nd = no dimensions.

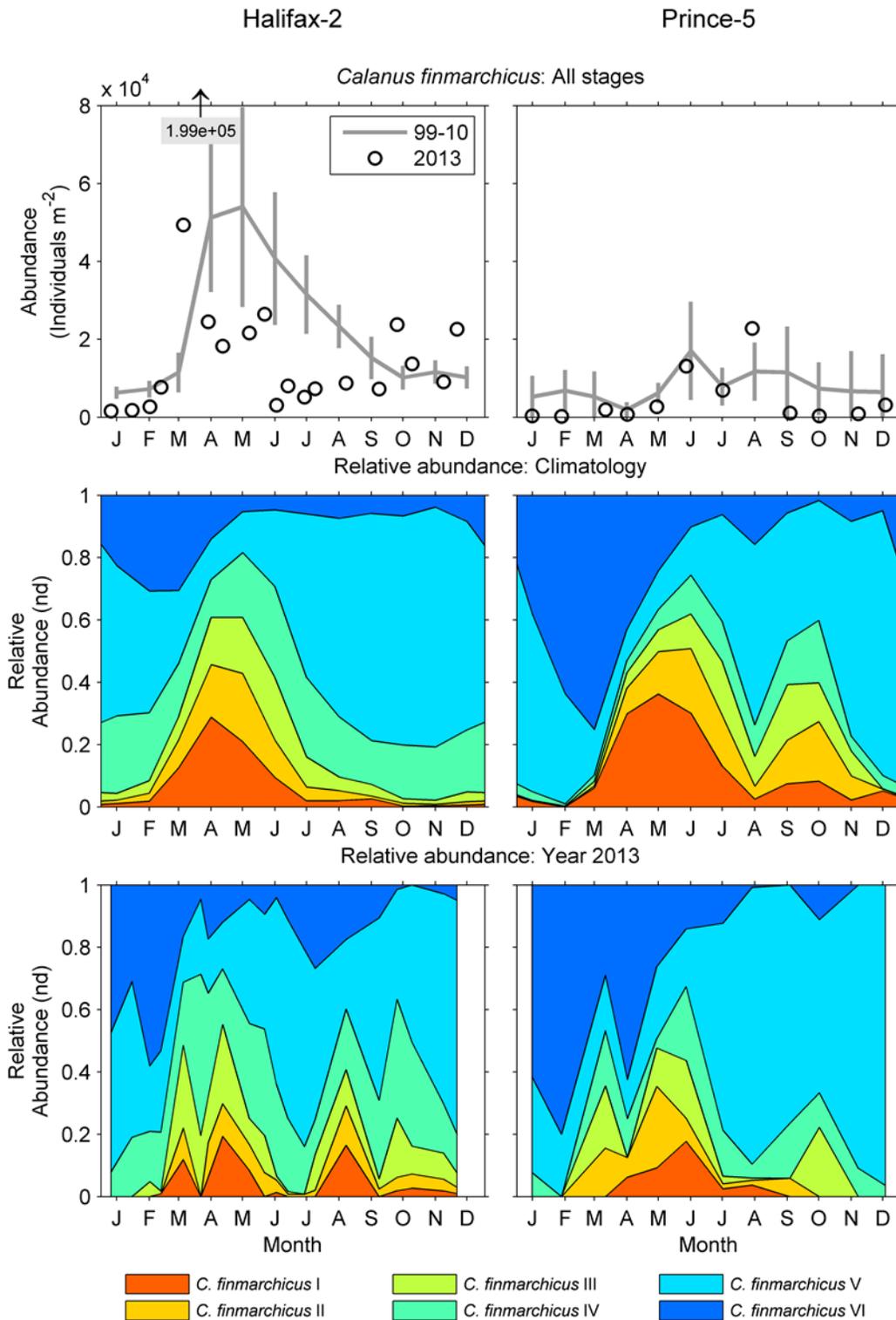


Figure 18. Comparison of 2013 *C. finmarchicus* abundance and developmental stage distributions with mean conditions from 1999–2010 at the Maritimes fixed stations (Halifax-2, left panels; Prince-5, right panels). Upper panels: 2013 *C. finmarchicus* abundance (open circle) compared with mean conditions from 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the annual averages. Middle panels: Climatological *C. finmarchicus* stage relative abundance from 1999–2010. Lower panels: 2013 *C. finmarchicus* stage relative abundance. nd = no dimensions.

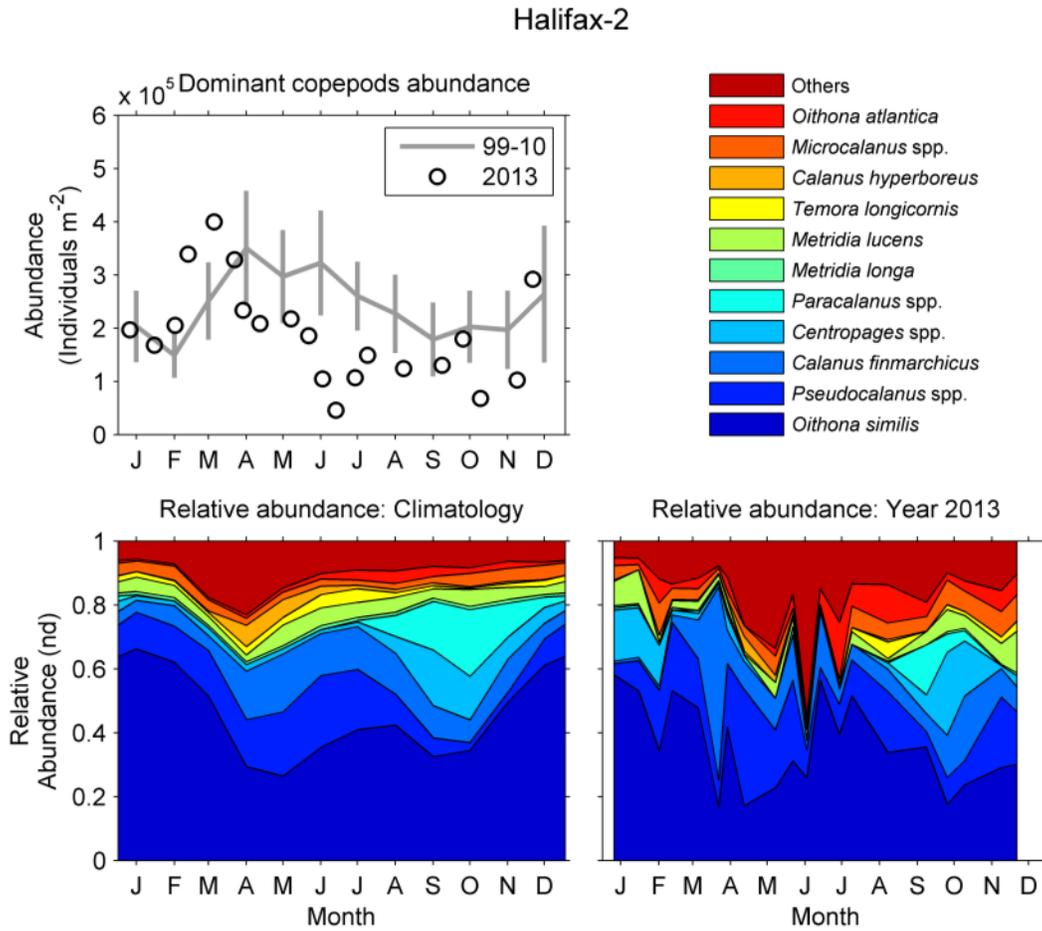


Figure 19a. Seasonal variability of dominant copepods at Halifax-2. The top 95% of identified copepod taxa by abundance, 1999–2010, are shown individually; others, including unidentified copepods (mostly nauplii) are grouped as “others.” Upper left panel: 2013 copepod abundance (open circle) compared with mean conditions from 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the annual averages. Lower left panel: Climatology of copepod relative abundance from 1999–2010. Lower right panel: 2013 copepod relative abundance. nd = no dimensions.

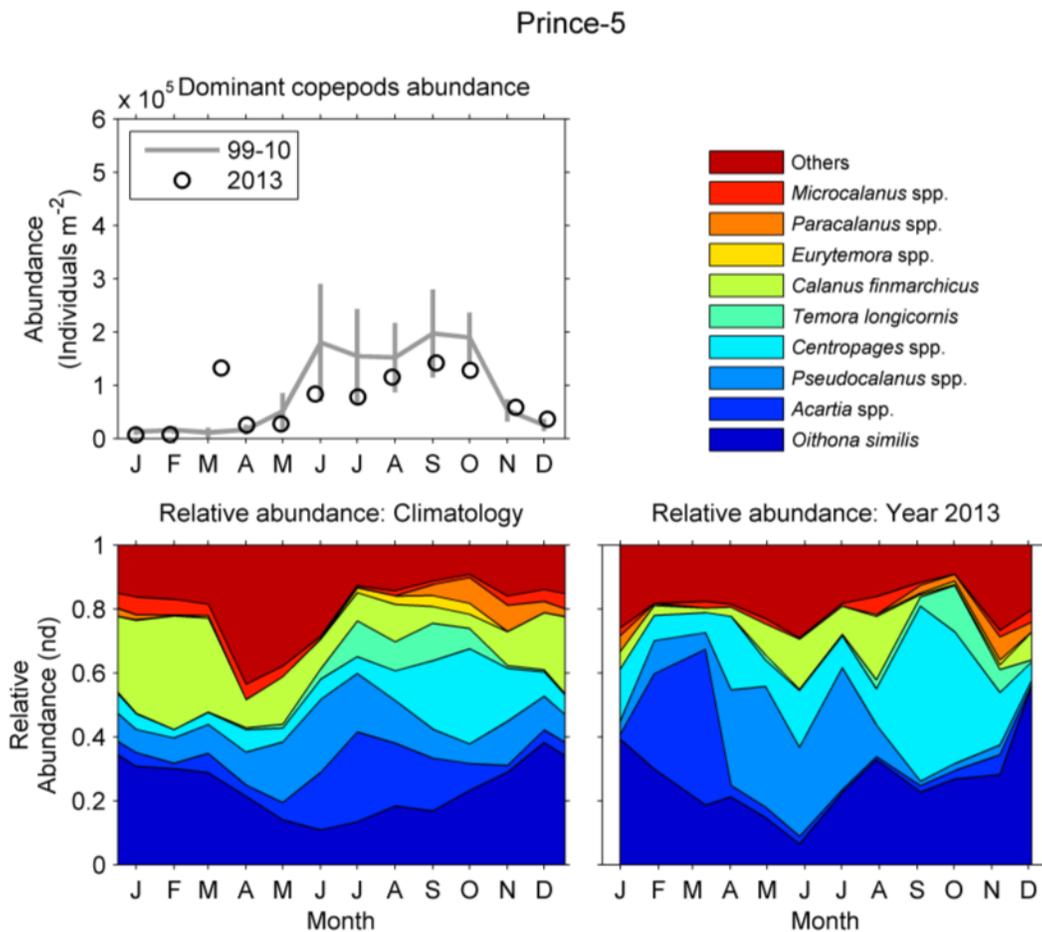


Figure 19b. Seasonal variability of dominant copepods at Prince-5. The top 95% of identified copepod taxa by abundance, 1999-2010, are shown individually; others, including unidentified copepods (mostly nauplii) are grouped as "others." Upper left panel: 2013 copepod abundance (open circle) compared with mean conditions from 1999-2010 (solid line). Vertical lines are 95% confidence intervals of the annual averages. Lower left panel: Climatology of copepod relative abundance from 1999-2010. Lower right panel: 2013 copepod relative abundance. nd = no dimensions.

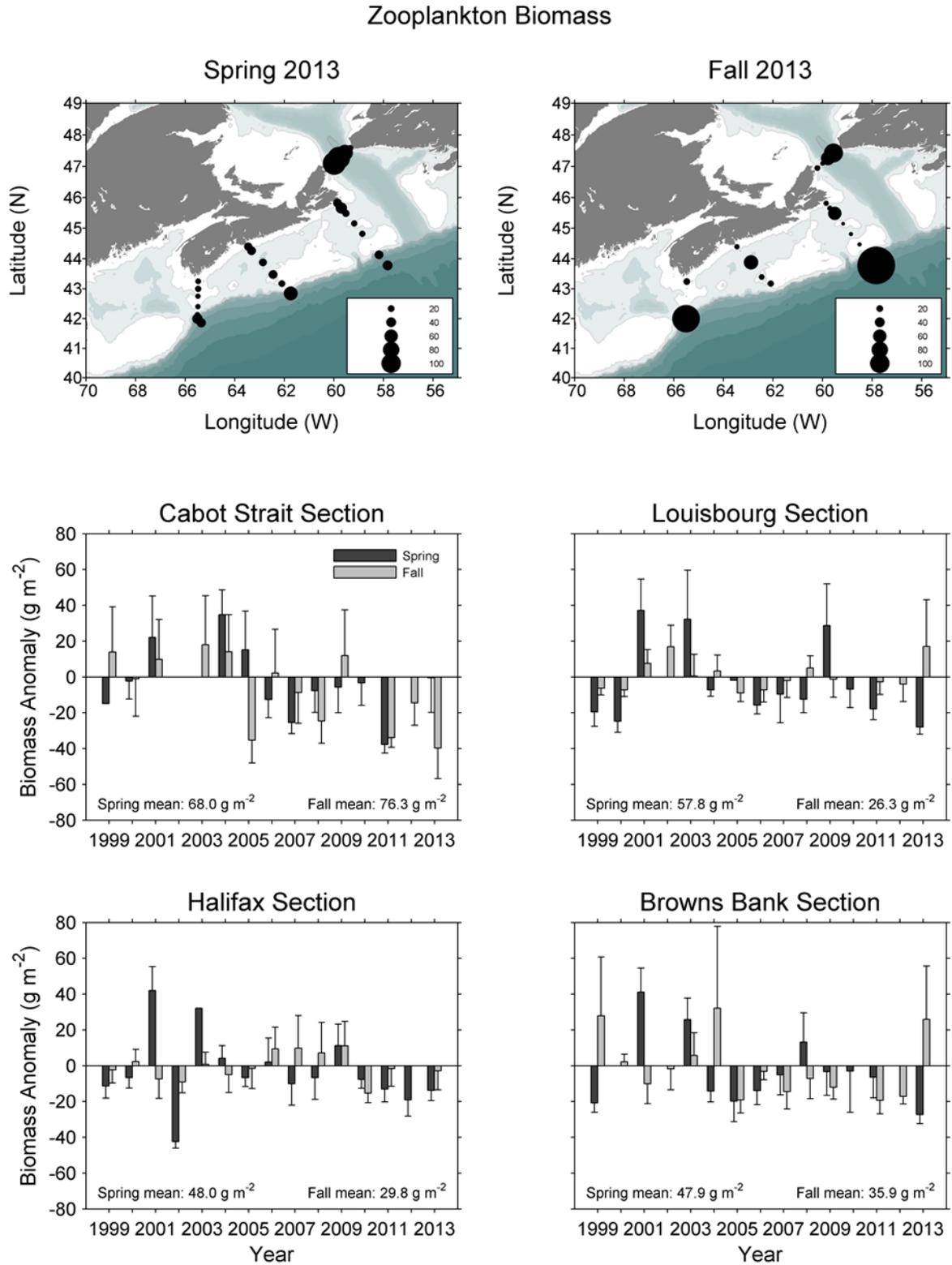


Figure 20. Spatial distribution of zooplankton biomass in 2013 (upper panels) and time series of zooplankton biomass anomalies on Scotian Shelf sections (middle and lower panels) in spring and fall, 1999-2013. Vertical lines in lower panels represent standard error.

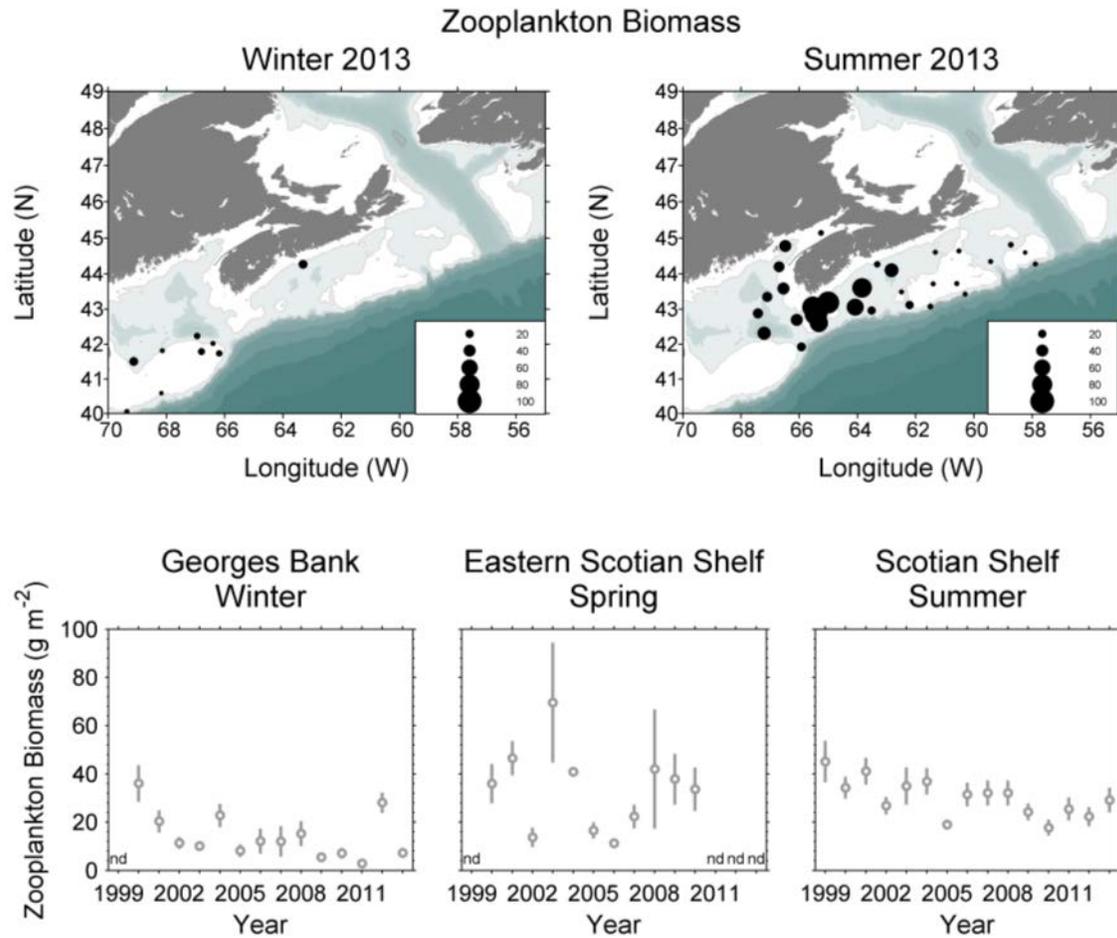


Figure 21. Zooplankton biomass from ecosystem trawl surveys on Georges Bank (February), the eastern Scotian Shelf (March) and the Scotian Shelf and eastern Gulf of Maine (summer): upper panels show 2013 spatial distributions, lower panels show survey mean biomass, 1999–2013 (vertical lines are standard errors; nd = no survey in that year)

*Calanus finmarchicus* Abundance

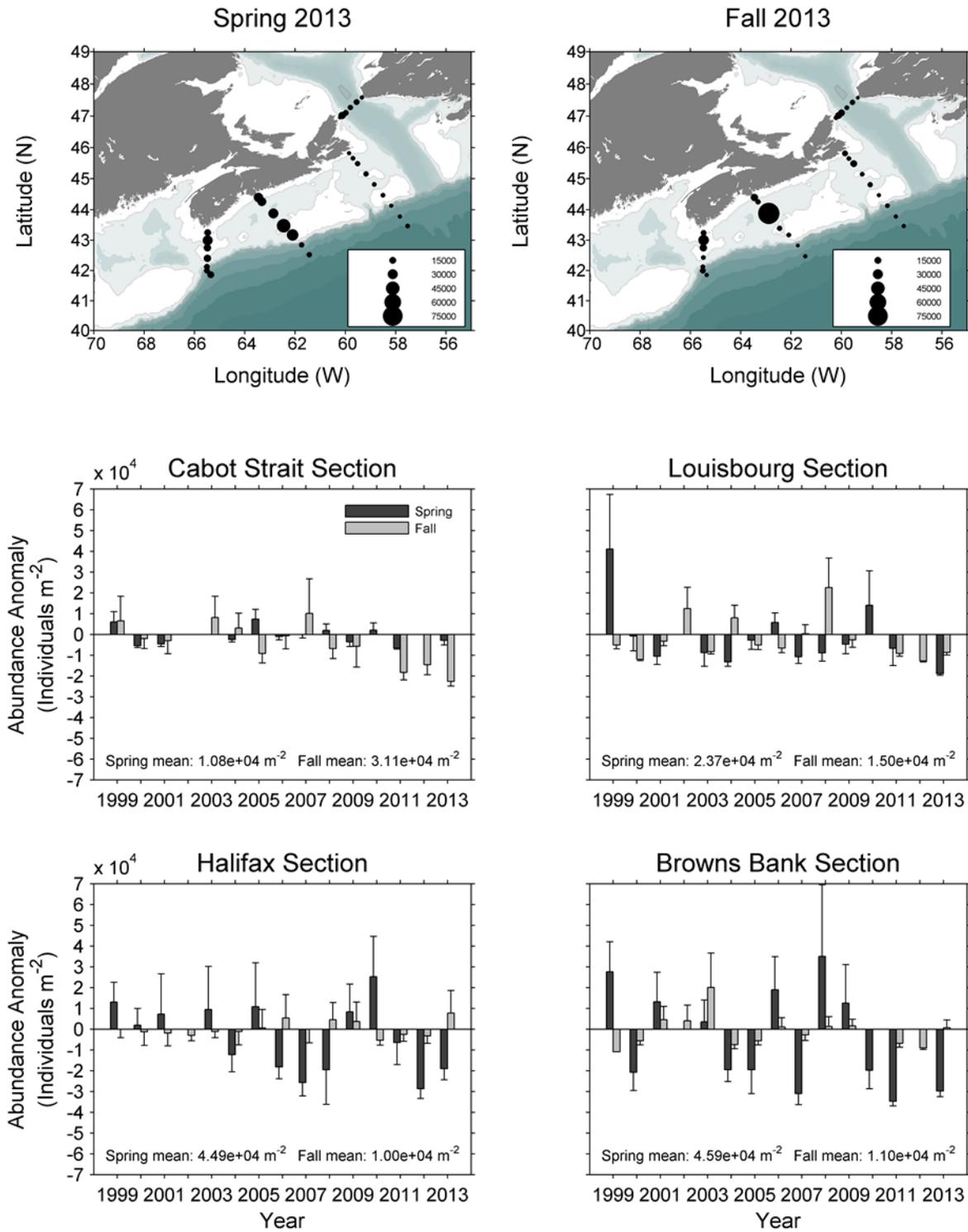


Figure 22. Spatial distribution of *C. finmarchicus* abundance in 2013 (upper panels) and time series of average *C. finmarchicus* abundance anomalies on Scotian Shelf sections (middle and lower panels) in spring and fall, 1999-2013. Vertical lines in lower panels represent standard error.

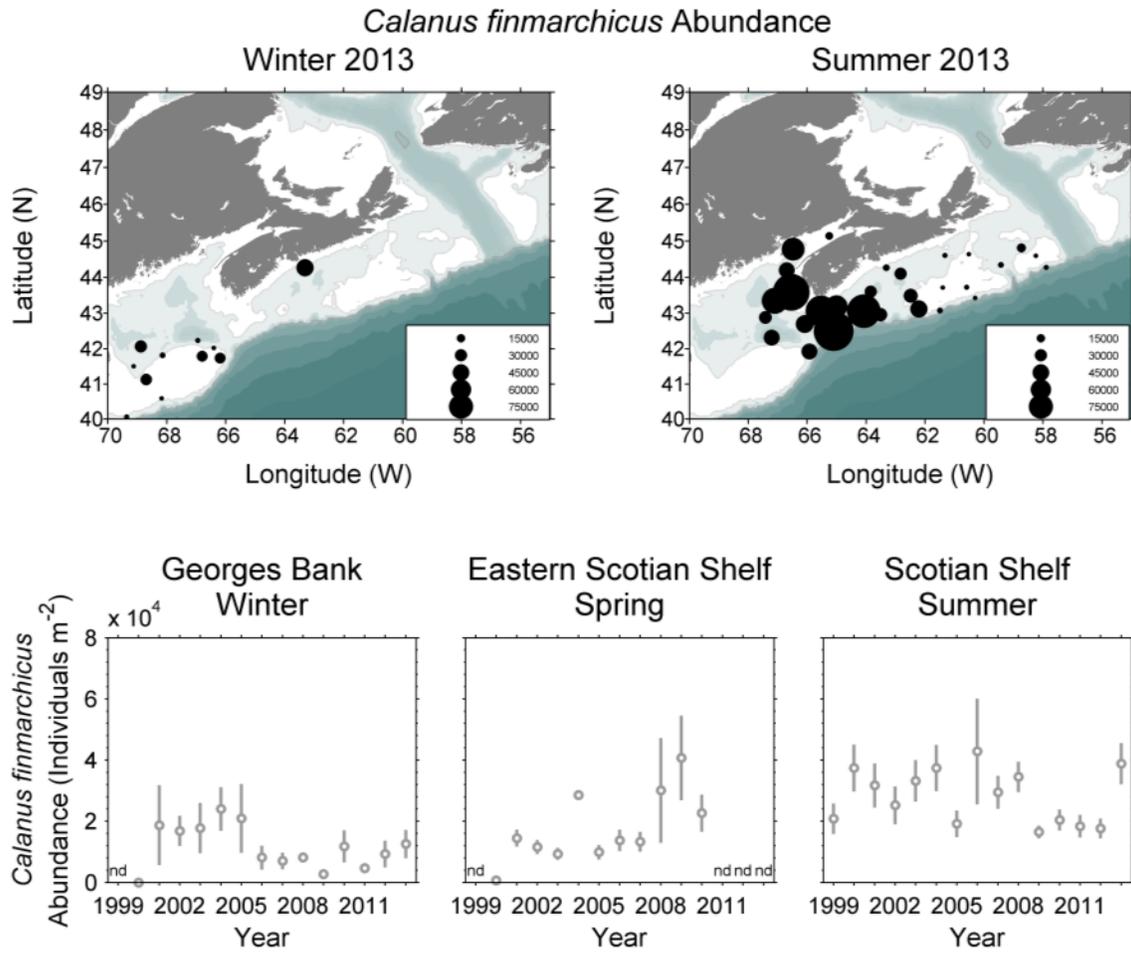


Figure 23. *C. finmarchicus* abundance from ecosystem trawl surveys on Georges Bank (February), the eastern Scotian Shelf (March) and the Scotian Shelf and eastern Gulf of Maine (summer): upper panels show 2013 spatial distributions, lower panels show survey mean abundance, 1999–2013 (vertical bars are standard errors; nd = no survey in that year).

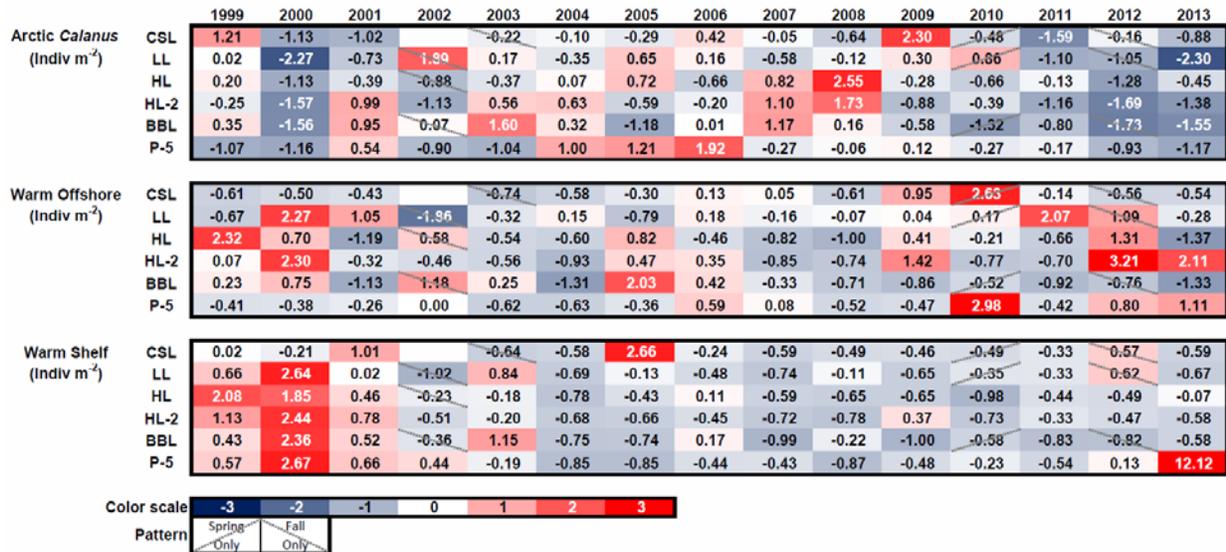


Figure 24. Immigrant species group scorecard: time series of zooplankton community index normalized annual anomalies, 1999–2013. A white cell indicates missing data. Red (blue) cells indicate higher (lower) than normal zooplankton group abundance. Reference period is 1999–2010. The numbers in the cells are the anomaly values. CSL: Cabot Strait section; LL: Louisbourg section; HL: Halifax section; HL-2: Halifax-2; BBL: Browns Bank section; P-5: Prince-5.

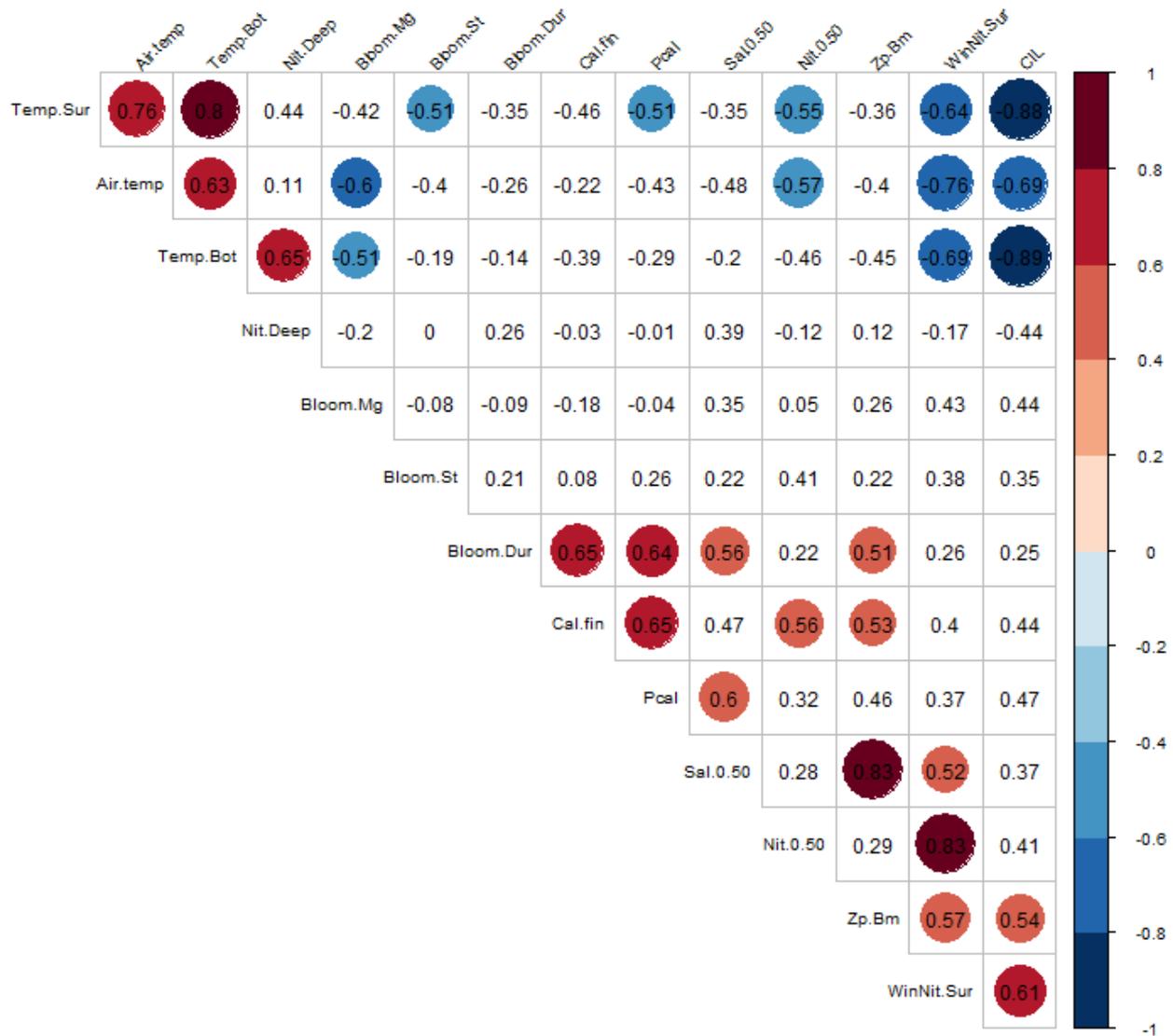


Figure 25. Corrgram for selected annual anomaly metrics evaluating the influence of environmental drivers on the phytoplankton bloom and dominant zooplankton. Significant correlations ( $p < 0.05$ ,  $d.f. = 13$ ) are indicated with coloured circles. R values for each correlation are noted in the matrix cells. Parameters are ordered by their first principal component scores. Temp.Sur – average temperature (0-50 m); Air.temp – air temperature; Temp.Bot – bottom temperature; Nit.deep – nitrate inventory (50-150 m); Bloom.Mg – magnitude (maximum 0-100 m chlorophyll) of the spring bloom; Bloom.St – day of year of spring phytoplankton bloom initiation; Bloom.Dur – duration of spring bloom; Cal.fin – *C. finmarchicus* abundance; Pcal – *Pseudocalanus* spp. abundance; Sal0.50 – average salinity (0-50 m); Nit0.50 – nitrate inventory (0-50 m); Zp.Bm – zooplankton biomass; WinNitSur – winter (Jan-Mar) surface layer (0-50 m) nitrate inventory; CIL – cold intermediate layer volume.

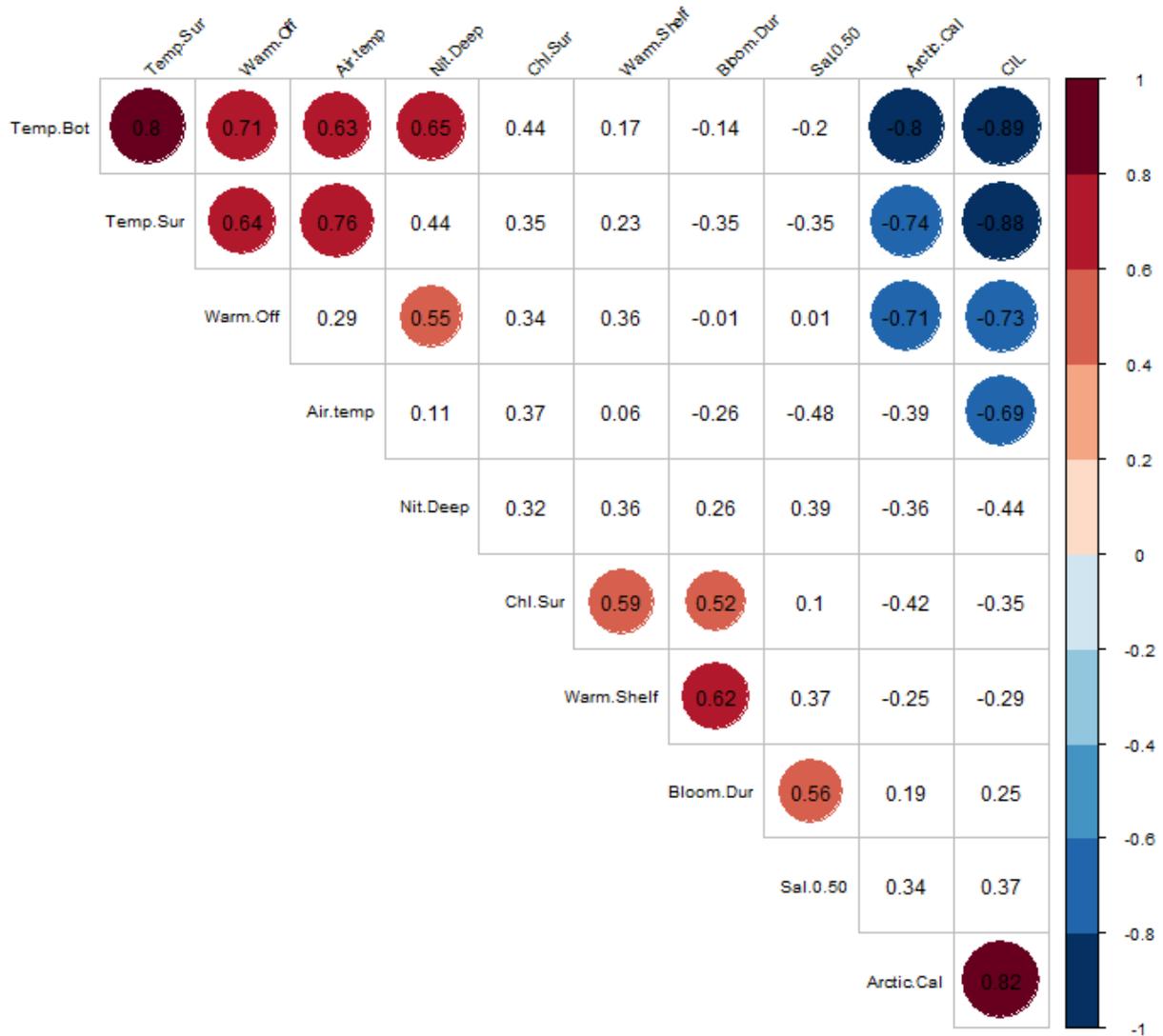


Figure 26. Corrgram for selected annual anomaly metrics evaluating the influence of environmental variability on sub-dominant and immigrant copepod groups. Significant correlations ( $p < 0.05$ ,  $d.f. = 13$ ) are indicated with coloured circles. R values for each correlation are noted in the matrix cells. Parameters are ordered by their first principal component scores. Temp.Bot – bottom temperature; Temp.Sur – average temperature (0-50 m); Warm.off – warm offshore copepod abundance ; Air.temp – air temperature; Nit.deep – deep nitrate inventory (50-150 m); Chl.Sur – annual average chlorophyll inventories (0-100 m); Warm.Shelf – warm shelf copepod abundance; Bloom.Dur – duration of spring bloom; Sal0.50 – average salinity (0-50 m); Arctic.Cal – Arctic *Calanus* abundance; CIL – cold intermediate layer volume.

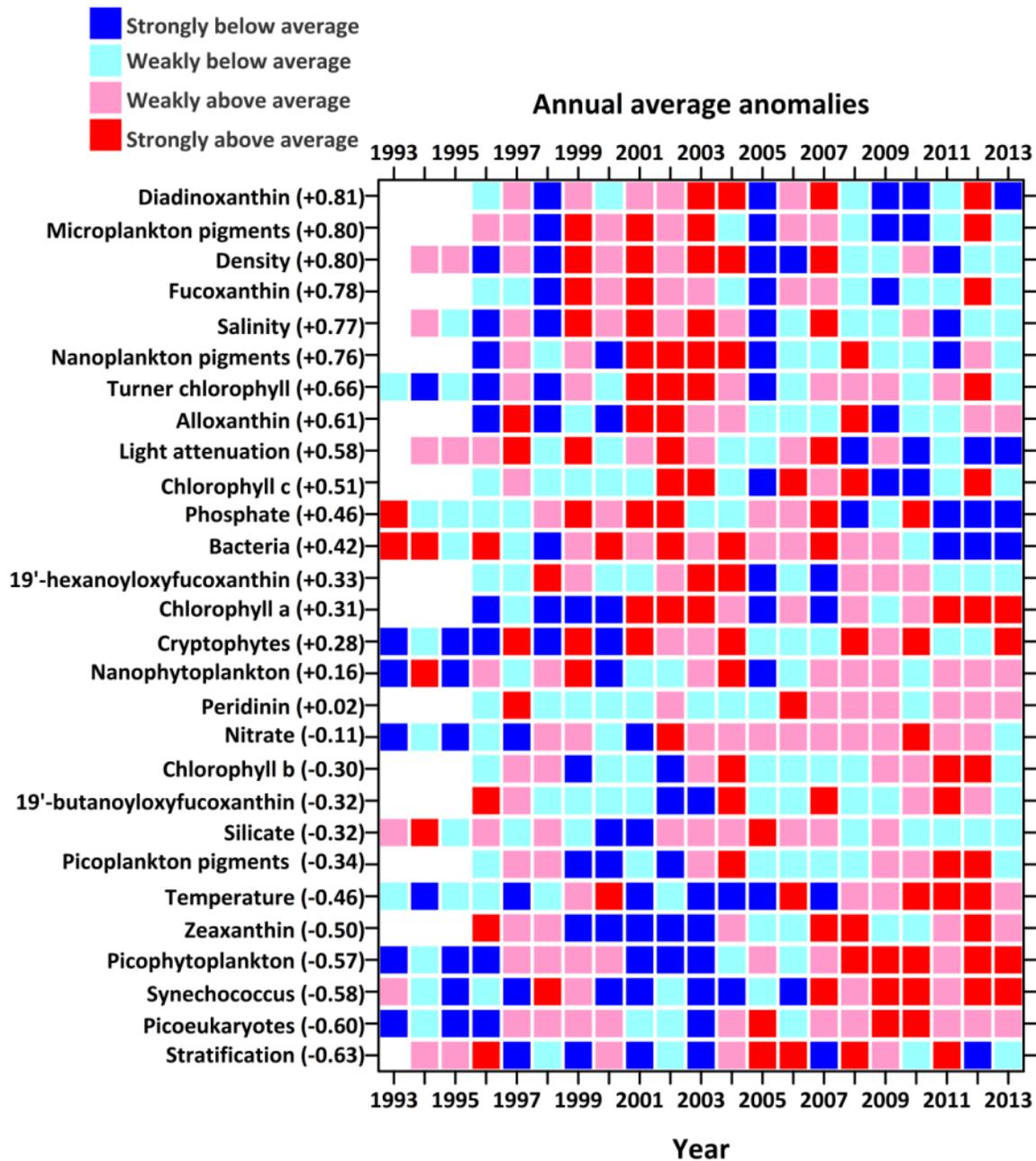


Figure 27. Environmental scorecard for Bedford Basin 1993-2013. Numeric values associated with system variables indicate the loading of the first principal component which is used to rank the variables for display.

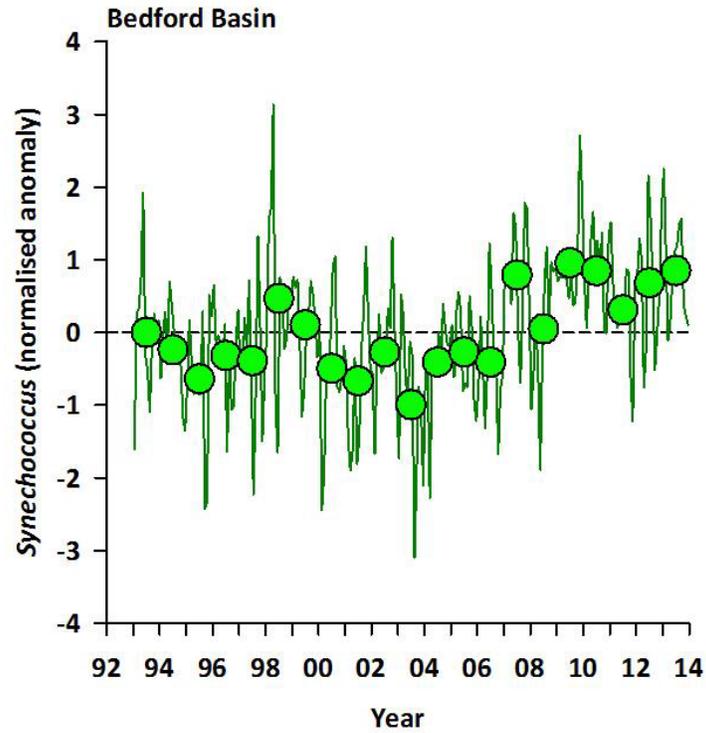


Figure 28. Time series for *Synechococcus* 1993-2013. Normalised monthly anomalies are shown by the green line. The annual averages of the 12 monthly anomalies in each year are shown by the green circles.

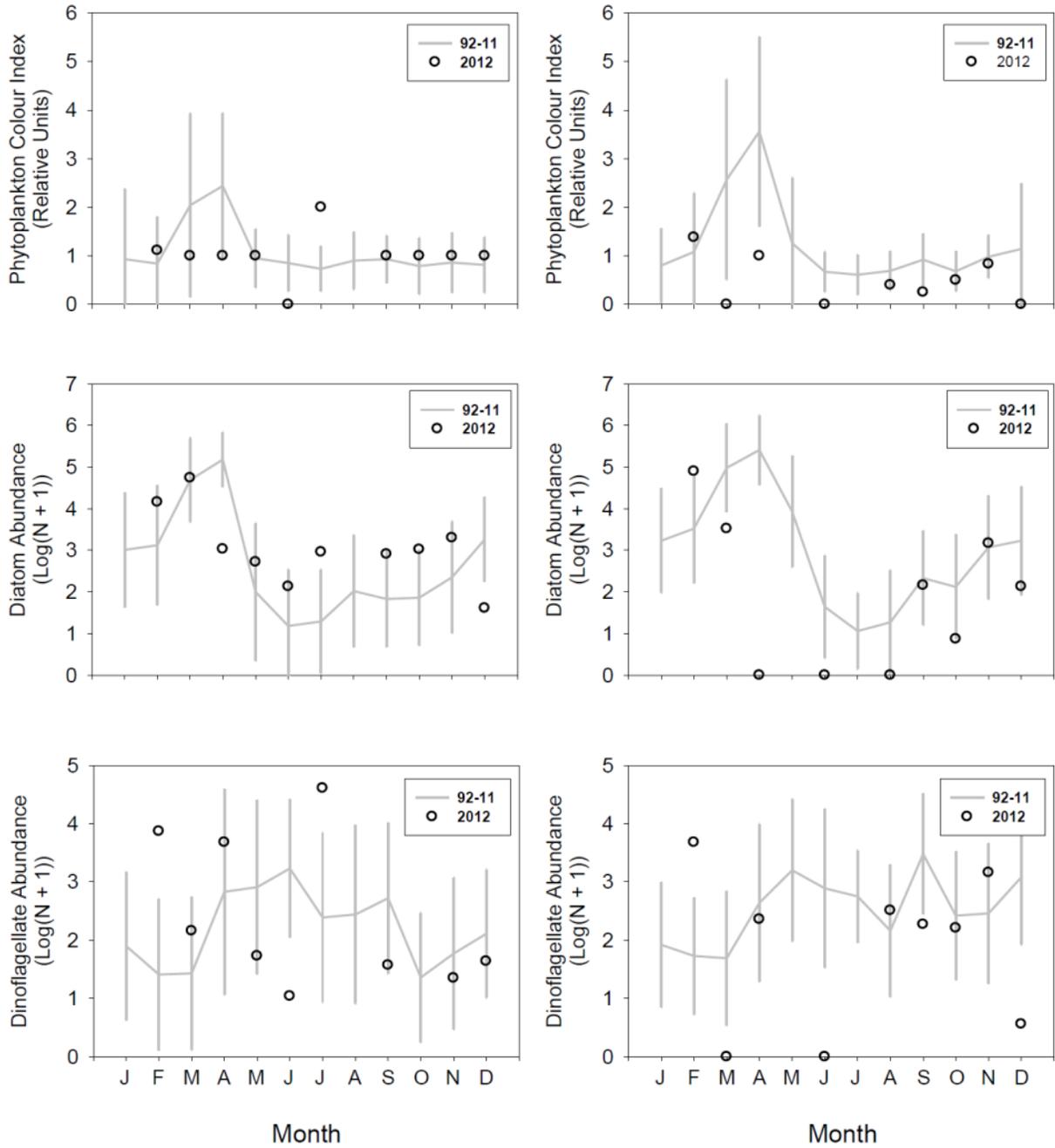


Figure 29. Comparison of 2012 (open circles) CPR phytoplankton abundance indices with mean conditions from 1992-2011 (solid line) on the Western Scotian Shelf (left-hand column) and Eastern Scotian Shelf (right-hand column). Vertical lines show the standard deviations of the monthly averages.

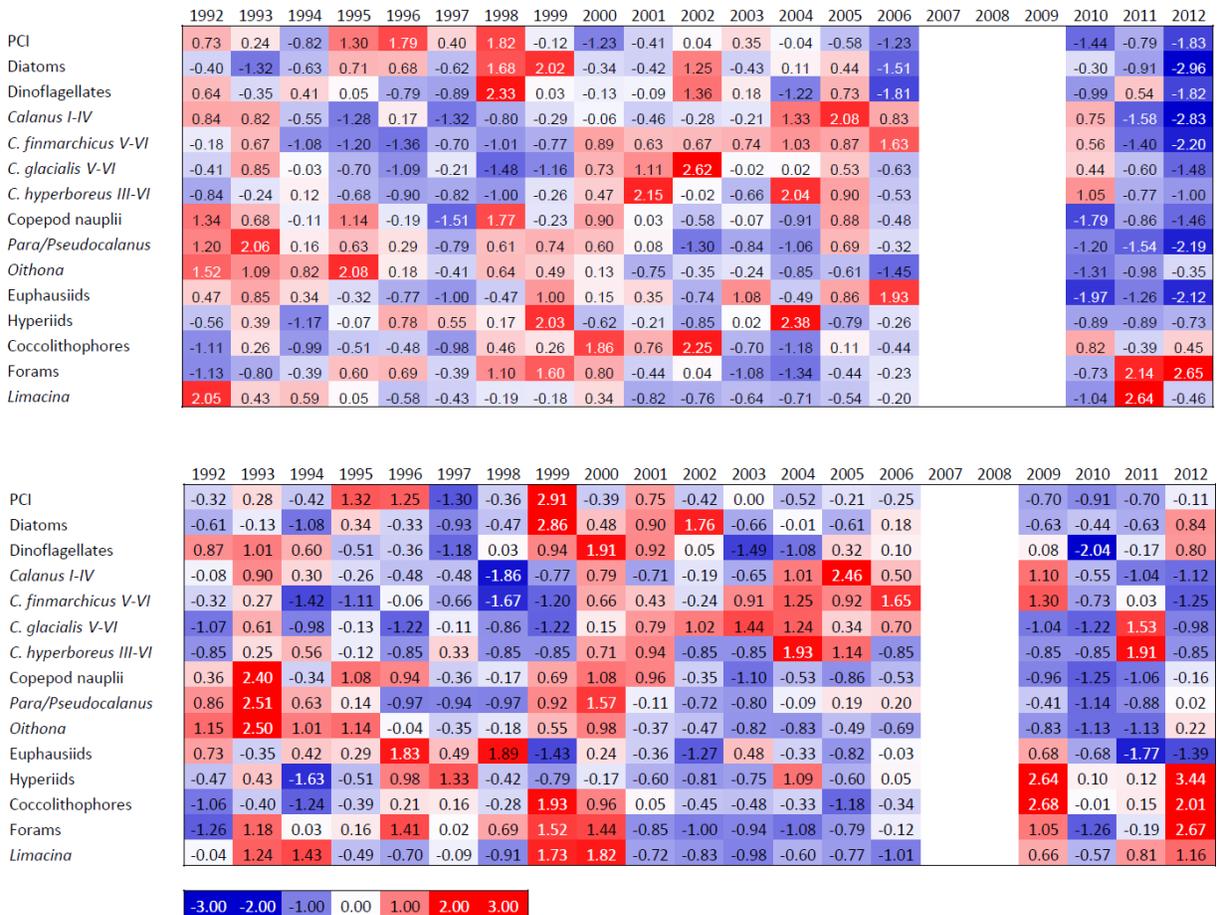


Figure 30. Maritimes Region CPR scorecard: time series for the annual averages for the abundances of phytoplankton and zooplankton taxa, 1992-2012, on the Eastern Scotian Shelf (upper panel) and Western Scotian Shelf (lower panel). Blank cells correspond to years where either there was sampling in eight or fewer months, or years where there was a gap in sampling of three or more consecutive months. Red (blue) cells indicate higher (lower) than normal values. The references period is 1992-2011. The numbers in the cells are the standardized anomalies.

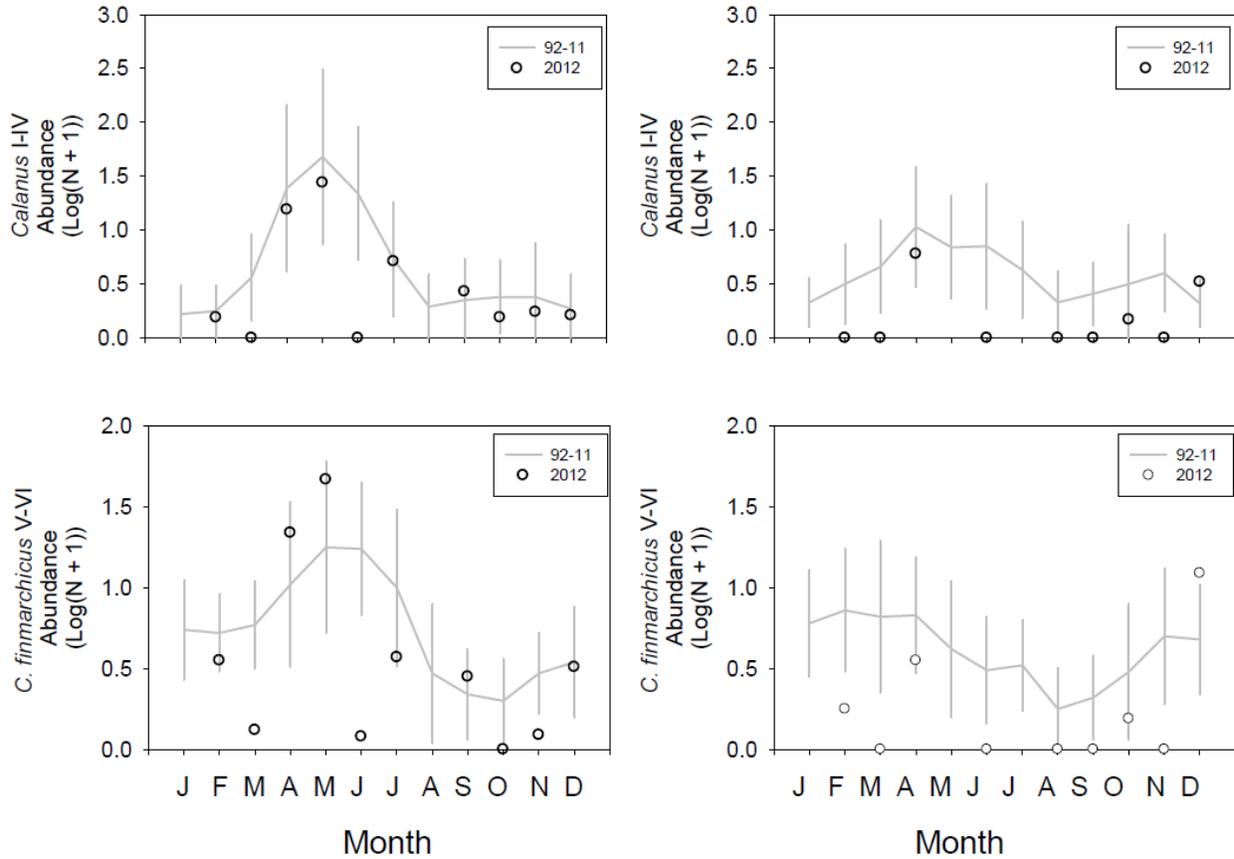


Figure 31. Comparison of 2012 (open circles) CPR abundance indices for *Calanus* I-IV (mostly *C. finmarchicus*, upper row) and *C. finmarchicus* V-VI (lower row) mean conditions from 1992-2011 (solid line) on the Western Scotian Shelf (left-hand column) and Eastern Scotian Shelf (right-hand column). Vertical lines show the standard deviations of the monthly averages.