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Maritimes Region

Optical, Chemical, and Biological Oceanographic Conditions on the Scotian Shelf and in the Eastern Gulf of Maine in 2014

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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.

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

The Atlantic Zone 4 Monitoring Program (AZMP) derives its information on the marine environment and ecosystem from data collected at a network of sampling locations (fixed point, high frequency sampling stations, cross-shelf sections, ecosystem trawl surveys) in each Fisheries and Oceans Canada region (DFO; Québec, Gulf, Maritimes, and Newfoundland) sampled at a frequency of twice-monthly to once annually. 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, focusing on conditions in 2014. Surface and deep ocean temperatures were warmer than average overall in the DFO Maritimes Region in 2014, especially in the slope waters and western Scotian Shelf in the second half of the year. Stratification was higher than average at an annual scale, but stratification anomalies were variable at sub-annual scales at the fixed stations and deep mixing events were observed at Halifax-2 in late winter and spring. Although annual average anomalies of surface- and deep-layer nitrate were near normal in most areas, there was substantial sub-annual variability in nitrate anomalies, particularly for deep-layer nitrate at Halifax-2. Scotian Shelf spring phytoplankton bloom magnitudes observed by remote sensing were low, while summer-fall blooms were higher than average in several areas. Spring blooms at the fixed stations were unusually deep, and therefore their magnitude would not have been accurately represented in satellite ocean colour observations. Both zooplankton biomass and *Calanus finmarchicus* abundance were lower than average overall in 2014. The abundance of Arctic *Calanus* species, an indicator of cold water on the Scotian Shelf, was lower than average in 2014, while the abundance of warm offshore species was higher than average on the central and western Scotian Shelf. Higher than average occurrence of thaliaceans (mainly salps) was observed, perhaps related to strong sub-annual variability. Ocean conditions in the DFO Maritimes Region have been characterized by strong sub-annual and mesoscale variability in 2013 and 2014, in addition to warmer temperatures, and interannual variability has been strong during the AZMP period since 1999. It is important to evaluate not only how the ecosystem responds to changes in mean conditions but also the response to changes in sub-annual to interannual variability. Continuous Plankton Recorder (CPR) sampling showed that in 2013 abundances of *Calanus I-IV* and *C. finmarchicus V-VI* returned to normal or relatively high levels from the historically low levels seen in 2012 across the Scotian Shelf. *C. glacialis, C. hyperboreus* and *Oithona* spp. were at near normal levels shelf-wide. Anomalies for three indices of phytoplankton abundance were below or close to normal on the Eastern Scotian Shelf (ESS) but above or close to normal on the Western Scotian Shelf (WSS). Many zooplankton taxa also exhibited contrasting patterns for the annual average abundance on the ESS *versus* the WSS.

Conditions océanographiques optiques, chimiques et biologiques sur le plateau néo-écossais et dans l'est du golfe du Maine en 2014

RÉSUMÉ

Le Programme de Monitorage de la Zone Atlantique (PMZA) dérive l'information sur les conditions de l'environnement et de l'écosystème marins à partir de données recueillies sur un réseau d'échantillonnage (stations fixes à fréquence d'échantillonnage élevée, sections transversales du plateau, relevés écosystémiques au chalut de fond) couvrant chaque région de l'Atlantique desservie par Pêches et Océans Canada (MPO; Québec, Golfe, Maritimes et Terre-Neuve), à une fréquence d'échantillonnage variant de bimensuelle à annuelle. Ce rapport fournit une évaluation de la distribution et de la variabilité des éléments nutritifs et du plancton sur le plateau néo-écossais et dans le golfe du Maine, avec comme intérêt principal les conditions observées en 2014. Des températures de surface et d'eau profonde plus élevées que la moyenne ont été observées dans la région Maritimes du MPO en 2014, en particulier pour les eaux de la pente continentale et de la partie ouest du plateau néo-écossais durant la seconde moitié de l'année. La stratification était plus élevée que la moyenne à l'échelle annuelle, mais des anomalies de stratification variables à l'échelle intra-annuelle et des événements de mélange profond ont été observés à la station fixe Halifax-2 en fin d'hiver et au printemps. Bien que les anomalies annuelles moyennes du nitrate de la couche de surface et de la couche profonde étaient près de la normale pour la plupart des sites échantillonnés, une variabilité intra-annuelle importante des anomalies du nitrate a été observée, spécialement pour le nitrate de la couche profonde à Halifax-2. L'intensité de la floraison printanière du phytoplancton telle qu'observée par télédétection a été en général faible sur le plateau néo-écossais, alors que la floraison d'été-automne était plus élevée que la moyenne dans plusieurs régions. La floraison printanière du phytoplancton a atteint des niveaux de profondeur inhabituels aux stations fixes, sans toutefois être représentée dans les observations par télédétection. La biomasse de zooplancton et l'abondance de *Calanus finmarchicus* étaient inférieures à la moyenne globale en 2014. L'abondance des espèces de *Calanus* arctique, un indicateur d'eaux froides sur le plateau néo-écossais, a été inférieure à la moyenne en 2014, tandis que l'abondance des espèces extra-côtières chaudes était plus élevée que la moyenne à l'ouest et au centre du plateau néo-écossais. Une présence plus élevée de thaliacés (principalement salpes) a été observée, et peut être liée à la forte variabilité intra-annuelle. Les conditions océaniques dans la région Maritimes du MPO ont été caractérisées par une forte variabilité intra-annuelle et à l'échelle moyenne en 2013 et 2014, en plus des températures plus élevées que la moyenne, et par une importante variabilité interannuelle au cours de la période du PMZA depuis 1999. Il est important d'évaluer non seulement la façon dont l'écosystème réagit aux changements des conditions moyennes, mais aussi la réponse aux changements de la variabilité intra-annuelle et interannuelle. Les données d'échantillonnage à l'aide d'enregistreurs de plancton en continu ont montré que l'abondance de *Calanus* I-IV et de *C. finmarchicus* V-VI était revenue à des niveaux normaux ou plus élevés que la normale en 2013 comparativement aux niveaux historiquement bas observés en 2012 sur le plateau néo-écossais. Les espèces *C. glacialis*, *C. hyperboreus* et *Oithona* spp. se sont maintenues à des niveaux quasi normaux à l'échelle du plateau. L'anomalie de trois indices de l'abondance du phytoplancton a été inférieure ou près de la normale sur la partie est du plateau néo-écossais (ESS), mais supérieure ou près de la normale sur la partie ouest du plateau néo-écossais (WSS). Des tendances contradictoires entre ESS et WSS ont aussi été observées dans l'abondance annuelle moyenne de plusieurs taxons de zooplancton.

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 marine environment and ecosystem from data collected at a network of sampling locations (fixed point, high frequency sampling 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 information about broad-scale environmental variability (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 ocean 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, focusing on conditions in 2014. It complements similar assessments for the physical environment of the DFO Maritimes Region (e.g., Hebert et al. 2015), for the pelagic environment in the Gulf of St. Lawrence (Galbraith et al. 2015), for the Newfoundland and Labrador shelves and the Grand Banks (e.g., Colbourne et al. 2014), and for the Canadian Northwest Atlantic shelf system as a whole (DFO 2015).

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 Scotian Shelf 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 influence both plankton community composition and annual biological production cycles, with implications for energy transfer to higher trophic level production.

Ocean temperatures on the Scotian Shelf and in the Gulf of Maine have exhibited strong interdecadal variability since temperature monitoring began in the first half of the twentieth century, with recent years (2010-2014) warmer than average (Hebert et al. 2015). In 2014, positive temperature anomalies were most pronounced in the second half of the year, and warm anomalies were most pronounced in slope water and on the western shelf in the fall. Ocean stratification has been increasing on the Scotian Shelf since the 1950's, driven both by warmer temperatures and lower salinity; in 2014, it was slightly above the 1981-2010 average (Hebert et al. 2014, 2015). Here, we report on the status of nutrients and plankton in the region in 2014 and discuss observations in the context of physical conditions of the marine environment, including both changes in annual mean conditions and recent strong sub-annual and mesoscale variability (Hebert et al. 2015).

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

DFO Maritimes/DFO Gulf regions AZMP sea-going staff participated in seven missions (seasonal section cruises, ecosystem trawl surveys, and Halifax section sampling on a mission to the Labrador Sea) during the 2014 calendar year, in addition to day-trips to the three fixed stations. In 2014, a total of 660 hydrographic station occupations were performed by DFO Maritimes Region, at 242 of which net samples were collected (Table 1).

Fixed Stations

The Halifax-2 and Prince-5 fixed stations were sampled on 23 and 13 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 µm mesh net) for zooplankton biomass (wet weight) and abundance, and
- Secchi depth measurement for light extinction, when possible.

Shelf Sections

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

- The standard sampling suite for the section stations is the same as for the fixed stations as listed above, but phytoplankton are not enumerated.

In addition to the Niskin water bottle sampling for nutrient analyses, calibration salinity, calibration oxygen, and chlorophyll analysis, particulate organic carbon (POC), 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-DFO Maritimes/DFO Gulf regions participate 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 by the DFO Science Population Ecology Division with AZMP participation.

The sampling suite for the ecosystem trawl survey stations includes the measurements listed above for the fixed stations, although the standard set of water bottle sampling depths is more limited and vertical ring net tows (202 µm mesh net) are collected at only a subset of stations (see Figure 3). Sampling also includes sea-surface temperature and 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 data near the interpolation grid point weighted proportionately more than those farther away. The weighting scheme is described in Petrie and Dean-Moore (1996), with horizontal length scales of 30 km, a vertical length scale of 15 m (depth < 50 m) or 25 m (depths between 50 and 500 m). Anomalies of bottom oxygen are not presented here, as 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, and
    2. 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 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. 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 CTD observations as the minimum depth where the vertical density gradient was equal to or exceeded 0.01 kg m^{-4}.
2. The stratification index ($Strat_{Ind}$) 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 density (σ_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 *in-situ* light extinction measurements using a rosette-mounted PAR meter and Secchi depth, according to the following procedures:

1. The downward vertical attenuation coefficient for PAR ($K_{d\text{-}PAR}$) 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.
2. The value of the light attenuation coefficient K_d from Secchi disc observations was found using:

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

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

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

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:

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

SATELLITE REMOTE-SENSING OF OCEAN COLOUR

Near-surface chlorophyll was also estimated from ocean colour data collected by the Sea-viewing Wide Field-of-view (SeaWiFS) satellite sensor[1] launched by National Aeronautics and Space Administration (NASA) in late summer 1997 and the Moderate Resolution Imaging Spectroradiometer (MODIS) "Aqua" sensor[2] launched by NASA in July 2002. Here, MODIS data from January 2008 to December 2014 were combined with SeaWiFS data from January 1998 to December 2007 to construct composite time series of surface chlorophyll *a* in selected sub-regions (Figure 4). Basic statistics (mean, standard deviation, etc.) were extracted from semi-monthly composites for the sub-regions.

SCORECARD

Scorecards of key indices, based on normalized, seasonally-adjusted annual anomalies, represent physical, chemical, and biological observations in a compact format. Annual estimates

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[1] While the SeaWiFS mission ended in December 2010, information about SeaWiFS is archived at the NASA Ocean Color Biology Group website (accessed 17 August 2015).

[2] Additional information about the MODIS sensor can be found on the NASA MODIS website (accessed 17 August 2015).

of water column inventories of nutrients, chlorophyll and the mean abundance of key zooplankton at both the fixed stations and as an overall average along each of the four standard sections are based on general linear models (GLMs) of the form:

$$\ln(Density) = \alpha + \beta_{YEAR} + \delta_{MONTH} + \varepsilon \quad \text{for the fixed stations, and}$$

$$\ln(Density) = \alpha + \beta_{YEAR} + \delta_{STATION} + \gamma_{SEASON} + \varepsilon \quad \text{for the sections.}$$

Density is in units of m^{-2}, α is the intercept and ε is the error. For the fixed stations, β and δ are categorical effects for year and month effects, respectively. For the sections, β, δ *and* γ take into account the effect of year, station, and season, respectively. *Density*, either in terms of numbers or biomass, was log-transformed to deal with the skewed distribution of the observations. In the case of zooplankton, one was added to the *Density* term to include observations where no animals of given taxa were counted in the sample. Average integrated inventories of nutrients and chlorophyll were not transformed. An estimate of the least-squares means based on type III sums of squares was used as the measure of the overall year effect.

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 DFO Maritimes Region. To visualize Northwest Atlantic shelf scale patterns of environmental variation, a zonal scorecard was prepared in addition to the regional scorecards presented here (DFO 2015).

DATA PRODUCTS

Data products presented in Figures 6, 7, 9, 10, 14, 15, and 17-25 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 16 are available at the DFO Maritimes Region 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 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.

The tow routes between Reykjavik and the Gulf of Maine are divided into eight regions: the Western Scotian Shelf (WSS), the Eastern Scotian Shelf (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 DFO Newfoundland and Labrador Region, while data collected in all regions and all decades (i.e., including the four regions in the sub-polar gyre east of 45^{o}W) are presented in annual Atlantic Zone Offshore Monitoring Program (AZOMP) reports. CPR data collected from January to December 2013 were received in January 2015 and added to the DFO data archive. In 2013, there was CPR sampling on the WSS and ESS in 9 months, with none in either region in February or September, and none on the WSS in November or on the ESS in March.

Monthly abundances of 14 taxa ($\log_{10}(N+1)$ transformed) and the 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 1992-2012, and these are compared with values in 2013 for 3 indices of phytoplankton abundance and the *Calanus I-IV* and *C. finmarchicus V-VI* taxa. Annual abundance anomalies were calculated for years where there was sampling in 8 or more months, and where there were no sampling gaps of 3 or more consecutive months. For years with gaps of 1 or 2 months, linear interpolation was used to fill in values for the missing months.

ATLANTIC ZONE MONITORING PROGRAM (AZMP) OBSERVATIONS

MIXING AND OPTICAL PROPERTIES

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. In 2014, MLDs at Halifax-2 were considerably deeper than normal between early March and early May (Figure 6). In summer, MLD values returned to near-normal, while fall MLDs were slightly shallower than normal. Stratification was mostly lower than normal at Halifax-2 during spring 2014 and higher than the typical seasonal maximum in August-September, remaining near or slightly higher than normal during the fall months.

At Prince-5, MLD is more variable and stratification is lower than at the Halifax-2 station due to strong tidal mixing. The stratification index normally remains low (below 0.01 kg m^{-4}) for most of the year, and MLD varies from full depth (90 m) in winter to approximately 40 m in summer. Prince-5 MLDs were on average deeper than normal throughout 2014, with the exception of July, September and December (Figure 6). The stratification index closely followed the climatological values throughout the year with the exception of May and December.

The maximum light attenuation and shallowest euphotic depths normally coincide with the spring phytoplankton bloom, and euphotic depths are generally deepest after the decline of the bloom and in winter months. High attenuation and consequently shallower euphotic depth based on PAR measurements coincided with the spring phytoplankton bloom period at Halifax-2 in 2014 (Figure 7). Outside of the bloom period, euphotic depths estimated from PAR measurements were shallower than normal; however, Secchi-disc-based euphotic depth estimates were generally deeper than normal for most months.

At Prince-5, euphotic depths are relatively constant year round, since the primary attenuator is non-living suspended matter due to tidal action and continental freshwater input. In 2014, both PAR-based and Secchi-based euphotic depths closely followed the climatological values throughout the year (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 DFO 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 nitrate inventory at Halifax-2 in 2014 showed three features departing considerably from the climatological cycle (Figure 8 and Figure 9). First, higher than normal deep nitrate concentrations were observed during the winter months, associated with warmer and saltier deep water (Figure 8 and Hebert et al. 2015). Second, high variability was observed in the deep nitrate inventory during spring (Figure 9), possibly associated with the deep mixing events observed between early March and early May. Third, the nitricline was deeper than normal in late summer and early fall (Figure 8) which was also reflected in a lower than normal surface nitrate inventory in the fall months (Figure 9). Overall, the surface nitrate annual anomaly was slightly negative due to the below normal surface concentrations during the summer and fall months, while the deep nitrate annual anomaly was near normal despite high variability (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 2014, both surface and deep nitrate inventories were lower than normal in winter, higher than normal in spring and summer and then again lower than normal in the fall months (Figure 8 and Figure 9). However, the departure from normal conditions was more pronounced in the surface nitrate inventory than the deep nitrate inventory (Figure 9). Overall, the annual average deep-water and surface water nitrate anomalies were slightly negative at Prince-5 in 2014 (Figure 10).

Broad-scale Surveys

The highest nitrate concentrations on the sections are observed in the deep waters of the Scotian slope and Cabot Strait, with moderately high nitrate concentrations also observed in the Emerald Basin on the Halifax section (Figure 11a,b). In spring 2014, the sections were sampled from west to east as the phytoplankton bloom developed in early to mid-April, and surface layer nitrate concentrations declined from west to east, probably reflecting the timing of sampling relative to the development of the bloom (Figure 11a). Nitrate anomalies were spatially variable on the sections in spring 2014 (Figure 11a). Anomalies were positive in the eastern and deep Cabot Strait, where water flows into the Gulf of St. Lawrence, and mainly positive on the inshore Louisbourg section and in the upper 150 m on the Browns Bank section. During the fall mission (mid-September to early October), near-surface nitrate concentrations were below detection limits throughout most of the region with little evidence for mixing of nutrients from deep to surface waters (Figure 11b). Positive nitrate anomalies were observed in the fall across much of the central and western Cabot Strait section, in deep inshore waters of the Louisbourg section and in the Emerald Basin (Halifax section), and in deep slope water closest to the shelf. A similar pattern of positive near-bottom nitrate anomalies in the western Cabot Strait, inshore Scotian Shelf, and slope water close to the shelf was observed on the July ecosystem trawl survey (Figure 12). Annual average surface layer nitrate inventories were similar to average (Figure 10). Deep layer inventories were also similar to average on the Browns Bank and Halifax sections, while the inventories on the Louisbourg and Cabot Strait sections were slightly low and slightly high, respectively (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 2014, spring bloom initiation at Halifax-2 was slightly delayed compared to normal conditions, but the spring bloom peak was slightly earlier than normal (Figure 14). Spring bloom duration was considerably shorter than normal and characterized by a rapid intensification and decline. The maximum chlorophyll inventory observed during the spring bloom was considerably higher than normal (Figure 14) due to higher than normal chlorophyll concentrations that extended deep in the water column (Figure 13), possibly related to the deep mixing events noted above. There was a stronger than normal summer sub-surface chlorophyll maximum, centered at about 30 m (Figure 13) associated with pulses of diatoms during the summer months (Figure 15). Chlorophyll was also higher than normal in the upper water column in December (Figure 13) associated with a corresponding higher incidence of flagellates in that month (Figure 15). Overall, the annual chlorophyll anomaly was slightly positive in 2014 (Figure 10).

Phytoplankton abundance estimates at Halifax-2 were slightly lower than the climatological average during most of 2014, except: in March and early April during the spring bloom period; in June and July during the period of the sub-surface maxima; and in December during the pulse of flagellates (Figure 15). Variability in the phytoplankton community was higher than normal in 2014 especially during the summer and early fall months, with diatom pulses and corresponding lower relative abundance of dinoflagellates and flagellates (Figure 15).

In 2014, the spring bloom initiation at Prince-5 was considerably later than normal, but peak timing was normal (Figure 14). The spring bloom duration was shorter than normal (Figure 14) and also characterized by a rapid intensification and decline, similar to the bloom dynamics at Halifax-2. The maximum chlorophyll inventory observed during the spring bloom was slightly higher than normal (Figure 14), and high chlorophyll concentrations extended into deep water (Figure 13). The late summer bloom was stronger than normal and also extended deep in the water column. Overall, the annual chlorophyll anomaly at Prince-5 in 2014 was near normal, despite the deep spring and summer blooms. Phytoplankton abundance deviated from the climatological pattern at Prince-5 during 2014, with higher abundance observed during blooms in June and September and considerably lower abundance in April, May, July and August (Figure 15). The phytoplankton community at Prince-5 is normally dominated overwhelmingly by diatoms but their relative abundance was lower than normal, particularly during the winter (more ciliates and flagellates) and in July (more dinoflagellates) (Figure 15).

Broad-scale Surveys and Satellite Remote Sensing

Chlorophyll estimates based on satellite remote sensing data indicated later than normal spring bloom initiation in the Cabot Strait (CS) and ESS in 2014 (11 and 9 d, respectively; DFO 2015). On the central Scotian Shelf (CSS), spring bloom initiation was earlier than normal (9 d) and near-normal on the WSS (2 d early; DFO 2015). Remotely-sensed spring bloom magnitudes were weaker than average (ESS, CSS, WSS) or near average (Georges Bank (GB) and CS) in 2014 (DFO 2015). Uncharacteristic summer blooms were observed on the CSS, WSS, and Lurcher Shoal (LS) in July-August and in CS in August-September (Figure 16a,b). The intense chlorophyll peak observed at Halifax-2 in the spring of 2014 was not evident in the 2014 remote sensing time series for CSS. This discrepancy could be caused by the spatial and temporal averaging involved in the processing of the remote sensing data, which could attenuate the intensity of a short or localized chlorophyll bloom peak. In addition, the strong *in situ* signal captured the high chlorophyll concentrations observed at depth, while the remote sensing signal is restricted to near surface conditions.

While the timing of the spring bloom varies from year-to-year, there does not appear to be a trend in initiation or peak timing over the AZMP years (Figure 16a,b). The magnitude and timing of summer and fall blooms were more variable. Fall and early winter blooms appear more prevalent on the CSS since 2006 (Figure 16a). On the WSS, the typical annual pattern of chlorophyll variability, including a dominant spring bloom and smaller fall bloom, appears to have weakened in recent years, with strong winter blooms observed in 2012 and 2014 (Figure 16b). Chlorophyll is relatively high throughout the year in the tidally mixed regions, LS and GB (Figure 16b). The 2014 summer-fall bloom was unusually early on LS, and on GB, the 2014 summer-fall bloom was strong compared to the spring bloom, following a pattern of relatively strong summer-fall blooms since 2009 (Figure 16b).

Annual chlorophyll anomalies based on the 2014 spring and fall missions were highest on the Cabot Strait and Louisbourg sections and slightly higher than or near normal on the Halifax and Browns Bank sections (Figure 10). This east-west pattern in the chlorophyll signal was not evident in the remote sensing data and may reflect the differences in the timing of spring sampling relative to the spring bloom that were noted above for nitrate.

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 the spring phytoplankton bloom peak timing, before declining to low levels again in the fall (Figure 17 and Figure 18). In 2014, zooplankton biomass (Figure 17), zooplankton abundance (Figure 18), *C. finmarchicus* abundance (Figure 19), and total copepod abundance (Figure 20a) were all lower than normal at Halifax-2 during spring and summer, with the exception of extreme high values of all three variables in early May following the intense phytoplankton spring bloom (Figure 17). High variability was observed for these zooplankton metrics at Halifax-2 during the winter and fall 2014. Higher than average values of zooplankton biomass, total zooplankton abundance and total copepod abundance were observed on several winter and fall occupations, but the highest abundances of *C. finmarchicus* were near-normal (Figure 19). Annual abundance anomalies of copepods and non-copepods were weakly positive while annual anomalies of *C. finmarchicus* and *Pseudocalanus* spp. abundance and zooplankton biomass were weakly negative (Figure 10).

The zooplankton community at Halifax-2 in 2014 was strongly dominated by copepods throughout the year, as is typical (Figure 18), although the abundance of non-copepods was somewhat higher than average (Figure 10). For *C. finmarchicus*, two successive periods of developmental growth occurred as indicated by the distinct peaks in the relative abundance of early stages (Figure 19). The first period extended from March to June, similar to the climatological cycle, while a second, atypical period from July to September was likely related to higher phytoplankton production during the summer. The copepod community was characterized by lower than normal relative abundance of the Arctic copepod *Calanus hyperboreus* in the spring and considerably lower than normal *Oithona similis* relative abundance in the early fall (Figure 20a). The relative abundance of the deep-water copepod *Microcalanus* spp. was higher than normal in the winter, and the relative abundance of the offshore copepod *Oithona atlantica* was higher than normal in the summer and fall (Figure 20a).

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 (Figure 17 and Figure 18). At Prince-5 in 2014, zooplankton biomass was lower than normal for most of the year with a delay in the start of the growth phase compared to the climatological cycle (Figure 17). The delayed peak was also observed in total zooplankton abundance (Figure 18) and total copepod abundance (Figure 20b). Both total zooplankton abundance and total copepod abundance were higher than normal over the fall months. The total abundance of *C. finmarchicus* remained below normal throughout the year with a rather weak seasonal cycle. Overall, as for Halifax-2, the abundance of copepods and non-copepods was above normal levels and the abundance of *C. finmarchicus* and *Pseudocalanus* spp. and the total zooplankton biomass were below normal levels (Figure 10).

The zooplankton community at Prince-5 is typically dominated by copepods throughout the year, with the strongest dominance in winter and late fall (Figure 18). In 2014, the relative abundance of barnacles (contained in “Others”) was considerably higher than normal in the spring, followed by a markedly lower than normal relative abundance of euphausiids and decapods over the summer and early fall (Figure 18). The copepod community had a higher than usual relative abundance of unidentified copepods, largely nauplii (“Others”), particularly in the fall (Figure 20b). The relative abundance of *C. finmarchicus* was lower than normal throughout the year, and *Pseudocalanus* spp. relative abundance was lower than normal in the spring and fall (Figure 20b). The relative abundance of the deep-water copepod *Microcalanus* spp. was higher than normal in March, and the relative abundance of the warm water copepod *Paracalanus* sp. was lower than normal in the fall.

Broad-scale Surveys

The zooplankton biomass was lower than normal in the spring across the Scotian Shelf in 2014, particularly on the Cabot Strait and Louisbourg sections, where biomass values were the lowest observed in the time series (Figure 21). Biomass levels remained lower than normal in the fall on the eastern shelf (Cabot Strait and Louisbourg), but were higher than normal in the central/western part (Halifax and Browns Bank). These positive anomalies were driven by large biomass values observed at the shelf-break stations on both Halifax and Browns Bank sections during the fall survey, possibly due to salps (Figure 21). Overall, the generally low zooplankton biomass levels in 2014 over the Scotian Shelf continued the pattern observed since 2010 (Figure 10). Zooplankton biomass levels were close to normal on the winter ecosystem trawl survey in the Georges Bank area in 2014 (Figure 22), while biomass levels during the 2014 summer trawl survey on the Scotian Shelf were slightly higher than normal and driven by large biomass values measured in the western part of the CSS, in the eastern Gulf of Maine, and in the Bay of Fundy particularly (Figure 22).

The abundance of *C. finmarchicus* was lower than normal on all four sections on the Scotian Shelf both in the spring and fall of 2014 (Figure 23). Overall, the generally low abundance levels of *C. finmarchicus* in 2014 continued the pattern observed since 2011 (Figure 10). The seasonal anomalies of *C. finmarchicus* abundance for the Halifax section were slightly negative in 2014 (Figure 23), while the corresponding annual anomaly is slightly positive (Figure 10). This apparent contradiction is attributed to the different methods used in calculating these two metrics: the seasonal anomaly is based on measured data, while the annual anomaly is based on annual estimates calculated from linear model fits. *C. finmarchicus* abundance levels from the winter trawl survey on Georges Bank were close to normal in 2014 (Figure 24) compared to considerably higher than normal levels from the 2014 summer trawl survey on the Scotian Shelf. Again, this was driven by large *C. finmarchicus* abundance values measured in the western part of the Scotian Shelf, in the eastern Gulf of Maine, and in the Bay of Fundy (Figure 24).

Indicator Species

In 2014, the abundance anomalies of Arctic *Calanus* species (*C. hyperboreus* and *C. glacialis*) continued to be negative throughout the region (Figure 25). Warm offshore species (*Clausocalanus* spp., *Mecynocera clausi*, and *Pleuromamma borealis*) abundance anomalies were slightly negative on the eastern sections (Cabot Strait, Louisbourg), but positive on the central and western Scotian Shelf (Halifax section, Halifax-2, and Browns Bank section). Warm shelf species (the summer-fall copepods *Paracalanus* sp. and *Centropages typicus*) abundance anomalies were negative on all sections and at Halifax-2, but positive at Prince-5.

In 2014, there were numerous sightings of thaliaceans (mainly salps) from the Gulf of Maine to southern Newfoundland by fishermen, scientists, and other members of the public[3,4,5]. Since thaliaceans are typically observed in localized, short-lived blooms, their abundance variability is not well characterized by AZMP surveys. At Halifax-2, thaliaceans are sometimes observed in September, October, or November (present in 6 of 16 years of the survey); in 2014, they were observed in September. They were also observed in October 2014 at Prince-5, which is a first during the AZMP occupations of the station. Thaliaceans are observed on the sections mainly in the fall (there has only been a single observation of thaliaceans on the spring surveys, in 1999). On the fall section surveys, thaliaceans were observed at a record percentage of stations (46%), compared to an average of 6% of stations in 1999-2010. They were also relatively common in fall of 2013 (38%) and 2012 (20%). Two species have been identified in AZMP samples, *Thalia democratica* and *Salpa maxima*.

BEDFORD BASIN

The 22-year environmental scorecard for Bedford Basin is presented in Figure 26. Analysis of phytoplankton community structure was delayed, therefore only hydrographic, nutrient, and chlorophyll observations are presented for 2014. For the year 2014 as a whole, the upper 10 m of the water column in Bedford Basin was warmer, fresher, less dense, and more stratified than normal, similar to observations in the last three years. Annual average chlorophyll was lower

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[3] Carla Allen, "What's a salp? DFO Scientists seek more info on sea creature", Yarmouth County Vanguard, published on January 12, 2015. (accessed 17 August 2015).

[4] Paul Herridge, "DFO scientists identify 'gooey' sea creatures", The Telegram: The People's Paper, published on October 23, 2014 (accessed 17 August 2015).

[5] Nick Record, "Salp watch 2014", Seascape Projects, published on October 9, 2014 8:04 PM (accessed 17 August 2015).

than normal, consistent with the negative relationship with stratification that has previously been observed. Nitrate was slightly higher than normal, and silicate near-normal. Phosphate levels were at a record low in 2014, continuing below-normal levels observed in the previous three years. Low phosphate levels were coincident with the period since the Halifax Wastewater Treatment Facility was restored to full operation in June 2010 following the system malfunction in 2009.

DISCUSSION

The typical annual pattern of phytoplankton biomass variability on the Scotian Shelf includes a spring bloom dominated by diatoms and a smaller summer-fall bloom. Phytoplankton bloom dynamics in the temperate Atlantic are influenced by the annual cycle of water column stratification. Spring bloom initiation is thought to be controlled by the light environment of phytoplankton, starting when the water column stabilizes in late winter-early spring (Sverdrup 1953). A bloom can develop as phytoplankton growth outpaces losses such as grazing and sinking (Behrenfeld and Boss 2014). Phytoplankton biomass declines after the bloom peak as grazing increases or growth becomes nutrient limited. Although Scotian Shelf phytoplankton biomass is lower in summer, when the phytoplankton community is dominated by smaller taxa such as flagellates, primary production is highest during the early summer (Platt et al. 2008, C. Caverhill, personal communication). A late summer-fall bloom of diatoms can develop when increased mixing replenishes nutrients in the euphotic zone. Changes in stratification can have either positive or negative effects on production depending on water column conditions (Gargett 1997, Mann 1993). In subpolar waters, higher annual mean stratification levels would be expected to limit mixing of nutrients into surface waters where light levels are high enough for phytoplankton growth, limiting new primary production at the annual scale (Li 2014) and lead to an earlier spring bloom and later fall bloom (e.g., Winder and Schindler 2004).

Although annual average stratification was slightly higher than normal in the region in 2014 compared to 1981-2010, the sign of stratification anomalies varied during the year. Variability in chlorophyll anomalies during the year suggests that sub-annual variability in physical conditions, influencing conditions at critical times in the phytoplankton production cycle, had a substantial influence on phytoplankton dynamics. Spatial environmental variability also appeared to influence differences in bloom dynamics across the region.

Early spring phytoplankton bloom initiation timing on the CSS was consistent with the early onset of stratification observed at Halifax-2 in early March. In contrast, late bloom initiation timing in CS was likely influenced by the timing of ice retreat in the area, which was delayed by a similar number of days as the start of the bloom (Hebert et al. 2015). Similar observations of late bloom initiation were also observed in other parts of the Gulf of St. Lawrence in 2014 (Devine et al. 2015). Early bloom initiation in CS during recent years of very low ice cover in the Gulf of St. Lawrence (2006, 2010-2013; Hebert et al. 2015) is also consistent with this interpretation.

The development of the spring bloom on the CSS and WSS appeared to be disrupted by wind-driven mixing during a strong winter storm in the region on March 25. The influence of deep mixing during this event was evident at Halifax-2 in the rapid decline in deep water nitrate concentrations and very deep penetration of high chlorophyll concentrations that developed during the spring bloom. It is unclear how widespread the high deep water chlorophyll concentrations were, as satellite ocean colour measurements are limited to near-surface waters. Below-average satellite-derived spring bloom magnitude estimates in the Scotian Shelf sub-regions would have represented only near-surface chlorophyll (DFO 2015). Although vertical mixing can enhance phytoplankton production by bringing nutrients to the surface, in subpolar waters mixing can have a negative effect on spring phytoplankton abundance due to the dominant influence of light limitation (Dutkiewicz et al. 2001), as may have been the case here.

Wind-driven mixing of nutrients to surface waters during post-tropical storm Arthur, which moved through the region July 5, may have stimulated summer blooms on the CSS, WSS, and eastern Gulf of Maine. Negative sea surface temperature anomalies across much of the Scotian Shelf in the first half of July support this interpretation. Shoaling of the nitricline associated with this event appeared to lead to a bloom of diatoms shortly afterward. Stronger than average stratification in fall may have enhanced phytoplankton production on LS and GB, which are both strongly influenced by tidal mixing. The drivers of the early and persistent late summer-fall bloom in Cabot Strait are not clear, although the pattern has been observed in previous years.

Annual nitrate and chlorophyll anomalies that were mainly low in magnitude and mixed in sign masked substantial sub-annual and mesoscale variability in nutrient and phytoplankton conditions in 2014. This variability was particularly evident in the frequent shifts in phytoplankton community composition observed at Halifax-2 in 2014. Phytoplankton community composition is more sensitive to changes in stratification than is chlorophyll, a bulk property that includes contributions from phytoplankton groups with opposing responses to stratification (Li 2014). The atypical diatom pulses at Halifax-2 in summer and early fall appear to be linked to enhanced mixing from several strong storms that passed through the region in 2014.

The recent pattern of lower than normal annual average zooplankton biomass continued in 2014. Low abundances of the biomass-dominant copepod *C. finmarchicus* across much of the region contributed to low zooplankton biomass. *C. finmarchicus* is a biomass dominant copepod species that feeds on large phytoplankton during the spring bloom and is an important prey for planktivorous fish such as herring and North Atlantic Right Whales. Since this species has a life history suited to take advantage of new primary production in spring and its later stages build up oil to store energy, it has an important role in transferring energy to larger animals. Its abundance has been low recently, which could be related to changes in phytoplankton community size distribution toward smaller sized cells associated with higher stratification and temperature (Li 2014, Li and Harrison 2008).

Although *C. finmarchicus* abundance was lower than average overall in 2013, observations at Halifax-2 suggest that the population recovered at the end of the year, and the abundance of the overwintering stock was close to or above average going into 2014 (Johnson et al. 2014). Nevertheless, *C. finmarchicus* abundance anomalies were mainly negative across the region during 2014, particularly in the east. The summer pulse of young copepodites observed at Halifax-2 and high *C. finmarchicus* abundance observed in the eastern Gulf of Maine in July may have been supported by the summer phytoplankton bloom, but this pulse of higher abundance did not persist in the fall. Abundance anomalies of *Pseudocalanus* spp., smaller spring-summer copepods that are also important prey for small fish, were mainly negative but closer to normal overall.

While strong subannual variability, and particularly deep mixing at the time of the spring bloom, may have had a negative effect on *C. finmarchicus*, which is adapted to take advantage of annually predictable phytoplankton spring bloom production cycles in temperate regions, summer and fall pulses of diatom production may have provided favorable conditions for thaliaceans (gelatinous, filter-feeding zooplankton). Thaliaceans, which feed on a broad range of phytoplankton taxa and can achieve very high growth rates as a result of short generation times, are adapted to event-scale variability (Deibel and Lowen 2012, Boero et al. 2008). They can play an important role in the marine biogeochemical cycles, as their high grazing rates rapidly deplete phytoplankton in surface waters, and their large, rapidly sinking fecal pellets can export substantial amounts of carbon to deep waters (Deibel and Lowen 2012, Ramaswamy et al. 2005). In addition to the two thaliacean species collected by AZMP, reports of very large thaliaceans entangled in lobster nets may have been *Thetys vagina*, which has been observed infrequently in the Gulf of Maine, often associated with warm water intrusions (McAlice 1986).

Abundance anomalies of the immigrant species groups, Arctic *Calanus* and warm offshore copepods, and several deep-water taxa (*Microcalanus* and *O. atlantica* at Halifax-2) are consistent with a strong influence of offshore water on the central and western Scotian Shelf in 2014. These taxa are indicators of shifts in water mass distributions in the region. In contrast, the abundance of warm shelf copepods was lower than average overall despite warm surface temperature in summer and fall. Although the copepods in this group are associated with warm conditions in the summer and fall seasons, they are associated with productive shallow Scotian Shelf banks, and their populations may have been negatively impacted by on-shelf movement of slope water in the fall.

In addition to positive annual temperature and stratification anomalies, ocean conditions in the DFO Maritimes Region have been characterized by strong sub-annual and mesoscale variability in 2013 and 2014, and interannual variability has been strong during the AZMP period since 1999 (Hebert et al. 2015). Trends in sub-annual and mesoscale variability have not been evaluated quantitatively but would not be unexpected in this region, which is influenced by both subpolar and subtropical waters. Observations in 2014 highlight the importance of evaluating not only how the ecosystem responds to changes in annual mean conditions but also its response to changes in higher frequency variability.

CONTINUOUS PLANKTON RECORDER (CPR)

PHYTOPLANKTON

The PCI and diatom abundance have similar climatological seasonal cycles on the WSS and ESS with a peak in March-April (Figure 27). Dinoflagellate abundance shows no clear seasonal cycle in either region. In 2013 the PCI was lower than normal in March (WSS) and April (WSS, ESS) and otherwise close to normal, except for one unusually high value in May (WSS). Diatom abundance was generally close to (WSS) or lower than (ESS) normal, except for one low value in March (WSS) and high values in July and August (ESS). Dinoflagellate abundance on the WSS was generally close to normal, but high in May and June, while on the ESS it was generally lower than normal, especially from June to December. The 2013 annual average PCI anomaly was close to (ESS) or above (WSS) the 1992-2012 average value (Figure 28). The 2013 annual abundance anomalies for diatoms and dinoflagellates were well below average values on the ESS and close to (diatoms) or above (dinoflagellates) average values on the WSS.

ZOOPLANKTON

Calanus I-IV (mostly *C. finmarchicus*) abundances have similar climatological seasonal cycles on the WSS and ESS, with peaks between April and June (Figure 29). On the WSS the climatological seasonal cycle for late stage *C. finmarchicus* has a peak similar to the one for *Calanus* I-IV, although extending into July, while on the ESS there is a broad peak between November and April. For both taxa peak abundances are lower on the ESS than on the WSS. In 2013 the springtime peak for *Calanus* I-IV abundance was broader than normal on the WSS, extending from March to August. On the ESS *Calanus* I-IV abundance was unusually high in January, July, August and November and unusually low in May and June. Monthly abundances for *C. finmarchicus* V-VI were generally above average on the WSS and were above average in January, June and October on the ESS. Annual average abundance anomalies for *Calanus* I-IV and *C. finmarchicus* V-VI in 2013 were above or close to the 1992-2012 averages on the ESS and WSS, rebounding from the historically low levels seen in 2012 (Figure 28). The annual average abundance anomalies for the Arctic species *C. glacialis* and *C. hyperboreus* were close to normal in 2013 in the ESS and WSS. Among the small-sized taxa, annual average abundance anomalies for copepod nauplii were lower than (ESS) or close to (WSS) normal in 2013, while values for *Paracalanus/Pseudocalanus* showed the opposite pattern and those for *Oithona* spp. were close to normal in both regions. On the ESS the annual average abundance anomaly for euphausiids was higher than normal in 2013, while the one for hyperiids (amphipods) was lower than normal; the WSS showed the opposite pattern.

ACID SENSITIVE ORGANISMS

Annual average abundance anomalies of coccolithophores (phytoplankton) and foraminifera (microzooplankton) were lower (ESS) or higher (WSS) than the 1992-2012 average values. The abundance anomaly for pteropods (*Limacina* spp.) was close to (ESS) or higher than (WSS) the 1992-2012 average.

CPR RESULTS *VERSUS* REMOTE SENSING AND *IN SITU* OBSERVATIONS

Both PCI and satellite-based chlorophyll estimates are proxies for near-surface phytoplankton biomass. During the spring bloom in 2013 sea surface chlorophyll levels were unusually high on the ESS and unusually low on the WSS (Johnson et al. 2014). The PCI was also unusually low during the normal bloom period (March-April) on the WSS, but a large peak in the PCI in May was absent from the satellite record. Similarly, a large peak in sea surface chlorophyll observed in late April on the ESS did not appear in the PCI record. On the other hand, both sea surface chlorophyll and PCI levels were higher than normal during the summer of 2013.

Spring (April) and fall (September) abundance anomalies for *C. finmarchicus*, sampled along sections across the Scotian Shelf during AZMP missions, were mostly below average levels. By contrast, CPR sampling in April indicated normal or slightly elevated abundances of *Calanus* I-IV and *C. finmarchicus* V-VI. There was no CPR sampling in September, but over the entire year annual average abundance anomalies were higher than or close to normal. These results are reasonably consistent with the close to normal value for the annual average abundance anomaly of *C. finmarchicus* given by year-round sampling at Halifax-2.

SUMMARY

- In 2014, sub-annual variability in the physical environment, possibly driven by weather events, was reflected in nitrate anomalies and phytoplankton bloom dynamics.
- Spring phytoplankton bloom initiation was late in CS and on the ESS, early on the CSS and near-normal on WSS.
- Scotian Shelf spring phytoplankton bloom magnitudes observed by remote sensing were lower than average, but *in situ* observations at the fixed stations captured an unusually deep and intense spring bloom that would not have been represented in satellite observations.
- Summer phytoplankton blooms were stronger than average on the CSS and WSS and eastern Gulf of Maine, and the summer-fall bloom was stronger than average in CS.
- Zooplankton biomass and *C. finmarchicus* abundance were lower than average.
- Arctic *Calanus* abundance, an indicator of cold water on the Scotian Shelf, was lower than average, and warm offshore copepod abundance was higher than average on the CSS and WSS.

- The occurrence of thaliaceans (salps) was higher than average.
- The upper water column at Bedford Basin was warmer, fresher, less dense, and more stratified than normal, and annual average chlorophyll was lower than normal.
- In 2013, CPR surveys observed contrasting abundance anomaly patterns between the ESS and WSS for several taxa, including phytoplankton (ESS: low or near-normal / WSS: above or close to normal on the WSS); hyperiid amphipods, coccolithophores and Foraminifera (ESS: below normal / WSS: above normal); and euphausiids (ESS: above normal / WSS: below normal).
- In 2013, CPR abundance anomalies of *Calanus* I-IV, *C. finmarchicus* V-VI and *Limacina* spp. abundance anomalies were above normal in both the ESS and WSS, and the anomaly for copepod nauplii was substantially below normal on the ESS.

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REFERENCES

Behrenfeld, M.J., and Boss, E.S. 2014. Resurrecting the ecological underpinnings of ocean plankton blooms. Annu. Rev. Mar. Sci. 6: 167-194.

Boero, F., Bouillon, J., Gravili, C., Miglietta, M. P., Parsons, T., and Piraino, S. 2008. Gelatinous plankton: irregularities rule the world (sometimes). Mar. Ecol. Prog. Ser. 356: 299-310.

Colbourne, E. Holden, J., Craig, J., Senciall, D., Bailey, W., Stead, P., Fitzpatrick, C. 2014. Physical oceanographic conditions on the Newfoundland and Labrador Shelf in 2014. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/094.

DFO. 2000. Chemical and biological oceanographic conditions 1998 and 1999 – Maritimes Region. DFO Sci. Stock Status Rep. G3-03 (2000).

DFO. 2015. Oceanographic conditions in the Atlantic zone in 2014. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/030.

Deibel, D., and Lowen, B. 2012. A review of the life cycles and life-history adaptations of pelagic tunicates to environmental conditions. ICES J. Mar. Sci. 69(3): 358-369.

Devine, L., Plourde, S., Starr, M., St-Pierre, J.-F., St-Amand, L., Joly, P. and Galbraith, P.S. 2015. Chemical and biological oceanographic conditions in the estuary and Gulf of St. Lawrence during 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/013.

Dutkiewicz, S., Follows, M., Marshall, J., and Gregg, W.W. 2001. Interannual variability of phytoplankton abundances in the North Atlantic. Deep-Sea Res. II 48: 2323-2344.

Gargett, A.E. 1997. The optimal stability ‘window’: A mechanism underlying decadal variation in North Pacific salmon stocks? Fish. Oceanogr. 6(2): 109-117.

Galbraith, P.S., Chassé, J., Nicot, P., Caverhill, C., Gilbert, D., Pettigrew, N., Lefaivre, D., Brickman, D., Devine, L., and Lafleur, C. 2015. Physical oceanographic conditions in the Gulf of St. Lawrence in 2014. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/032.

Harrison, G., Colbourne, E., Gilbert, D., and Petrie, B. 2005. Oceanographic observations and data products derived from large-scale fisheries resource assessment and environmental surveys in the Atlantic zone. AZMP/PMZA Bull. 4: 17-23.

Hebert, D., Pettipas, R., Brickman, D., and Dever, M. 2014. Meteorological, sea ice and physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine during 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/070.

Hebert, D., Pettipas, R., Brickman, D., and Dever, M. 2015. Meteorological, sea ice and physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine during 2014. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/040.

Holmes, R.W. 1970. The Secchi disk in turbid coastal waters. Limnol. Oceanogr. 15(5): 688-694.

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.

Johnson, C., Li, W., Head, E., Casault, B., and Spry, J. 2014. Optical, chemical, and biological oceanographic conditions on the Scotian Shelf and in the eastern Gulf of Maine in 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/104.

Li, W.K.W. 2014. The state of phytoplankton and bacterioplankton on the Scotian Shelf and Slope: Atlantic Zone Monitoring Program 1997-2013. Can. Tech. Rep. Hydrogr. Ocean Sci. 303.

Li, W.K.W., and Harrison, W.G. 2008. Propagation of an atmospheric climate signal to phytoplankton in a small marine basin. Limnol. Oceanogr. 53(5): 1734-1745.

Mann, K.H. 1993. Physical oceanography, food chains, and fish stocks: A review. ICES J. Mar. Sci. 50: 150-119.

McAlice, B.J. 1986. Occurrence of *Thetys vagina* Tiselius (Tunicata, Thaliacea) on the coast of Maine. Bull. Mar. Sci. 39(3): 717-718.

Mitchell, M., Harrison, G., Pauley, K., Gagné, A., Maillet, G., and Strain, P. 2002. Atlantic Zonal Monitoring Program sampling protocol. Can. Tech. Rep. Hydrogr. Ocean Sci. 223.

Petrie, B. 2007. Does the North Atlantic Oscillation affect hydrographic properties on the Canadian Atlantic Continental Shelf? Atmos.-Ocean 45(3): 141–151.

Petrie, B., and Dean-Moore, J. 1996. Temporal and spatial scales of temperature and salinity on the Scotian Shelf. Can. Tech. Rep. Hydrogr. Ocean Sci. 203.

Petrie, B., and Yeats, P. 2000. Annual and interannual variability of nutrients and their estimated fluxes in the Scotian Shelf – Gulf of Maine region. Can. J. Fish. Aquat. Sci. 57: 2536-2546.

Petrie, B., Drinkwater, K., Gregory, D., Pettipas, R., and Sandström, A. 1996. Temperature and salinity atlas for the Scotian Shelf and the Gulf of Maine. Can. Data. Rep. Hydrog. Ocean Sci. 171.

Petrie, B., Yeats, P., and Strain, P. 1999. Nitrate, silicate and phosphate atlas for the Scotian Shelf and the Gulf of Maine. Can. Tech. Rep. Hydrogr. Ocean Sci. 203.

Platt, T., Sathyendranath, S., Forget, M.-H., White, G.N.III, Caverhill, C., Bouman, H., Devred, E., and Son, S.H. 2008. Operational estimation of primary production at large geographical scales. Remote Sens. Environ. 112: 3437-3448.

Ramaswamy, V., Sarin, M.M., and Rengarajan, R. 2005. Enhanced export of carbon by salps during the northeast monsoon period in the northern Arabian Sea. Deep-Sea Res. II 52: 1922-1929.

Richardson, A.J., Walne, A.W., John, A.W.G., Jonas, T.D., Lindley, J.A., Sims, D.W., Stevens, D., and Witt, M. 2006. Using continuous plankton recorder data. Progr. Oceanogr. 68: 27-74.

Sverdrup, H.U. 1953. On conditions for the vernal blooming of phytoplankton. J. Cons. Perm. Int Explor. Mer. 18: 287-295.

Therriault, J.-C., Petrie, B., Pepin, P., Gagnon, J., Gregory, D., Helbig, J., Herman, A., Lefaivre, D., Mitchell, M., Pelchat, B., Runge, J., and Sameoto, D. 1998. Proposal for a Northwest Atlantic Zonal Monitoring Program. Can. Tech. Rep. Hydrogr. Ocean Sci. 194.

Winder, M., and Schindler, D.E. 2004. Climatic effects on lake processes. Glob. Change Biol. 10(11): 1844-1856.

TABLES

Table 1. Atlantic Zone Monitoring Program (AZMP) sampling missions in the DFO Maritimes/DFO Gulf regions, 2014.

Group	Location	Mission ID	Dates	# Hydro Stns	# Net Stns
Trawl Surveys	Georges Bank / Western Scotian Shelf	NED2014-002 NED2014-101	Feb 17-Mar 03 Mar 07-Mar 22	43 55	12 10
	Scotian Shelf	NED2014-018	Jul 07-Aug 16	205	42
	Southern Gulf of St. Lawrence	TEL2014-133	Sept 04-28	163	14
Seasonal Sections	Scotian Shelf	HUD2014-004	Apr 04-23	101	89
	Scotian Shelf	HUD2014-007	May 22-24	6	6
	Scotian Shelf	HUD2014-030	Sep 19-Oct 08	66	49
Fixed Stations	Halifax-2	BCD2014-666	Jan 01-Dec 31	23(8)[1]	23(8)[1]
	Prince-5	BCD2014-669	Jan 01-Dec 31	13	12
	Total:			660	242

Note:

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

FIGURES

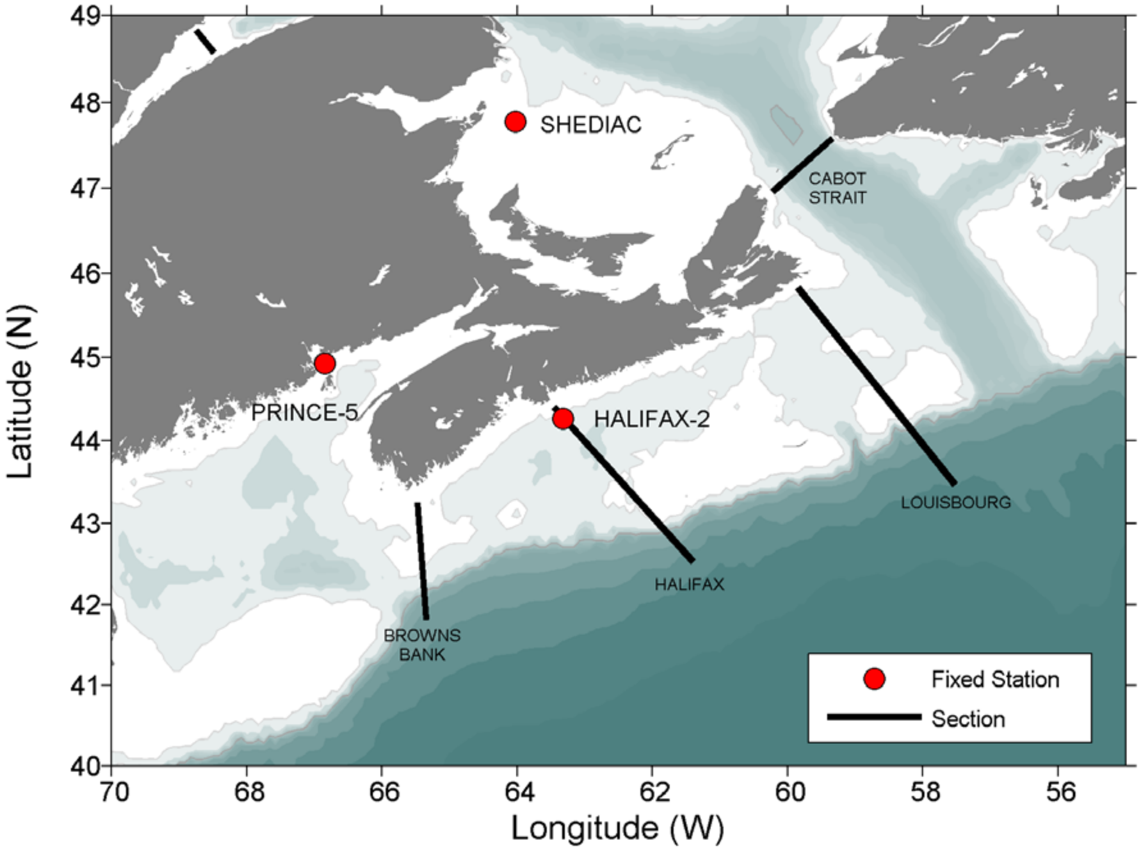


Figure 1. Map of primary sections (Cabot Strait, Louisbourg, Halifax, and Browns Bank) and fixed stations (Shediac, Halifax-2, and Prince-5) sampled in the DFO Maritimes/DFO Gulf regions.

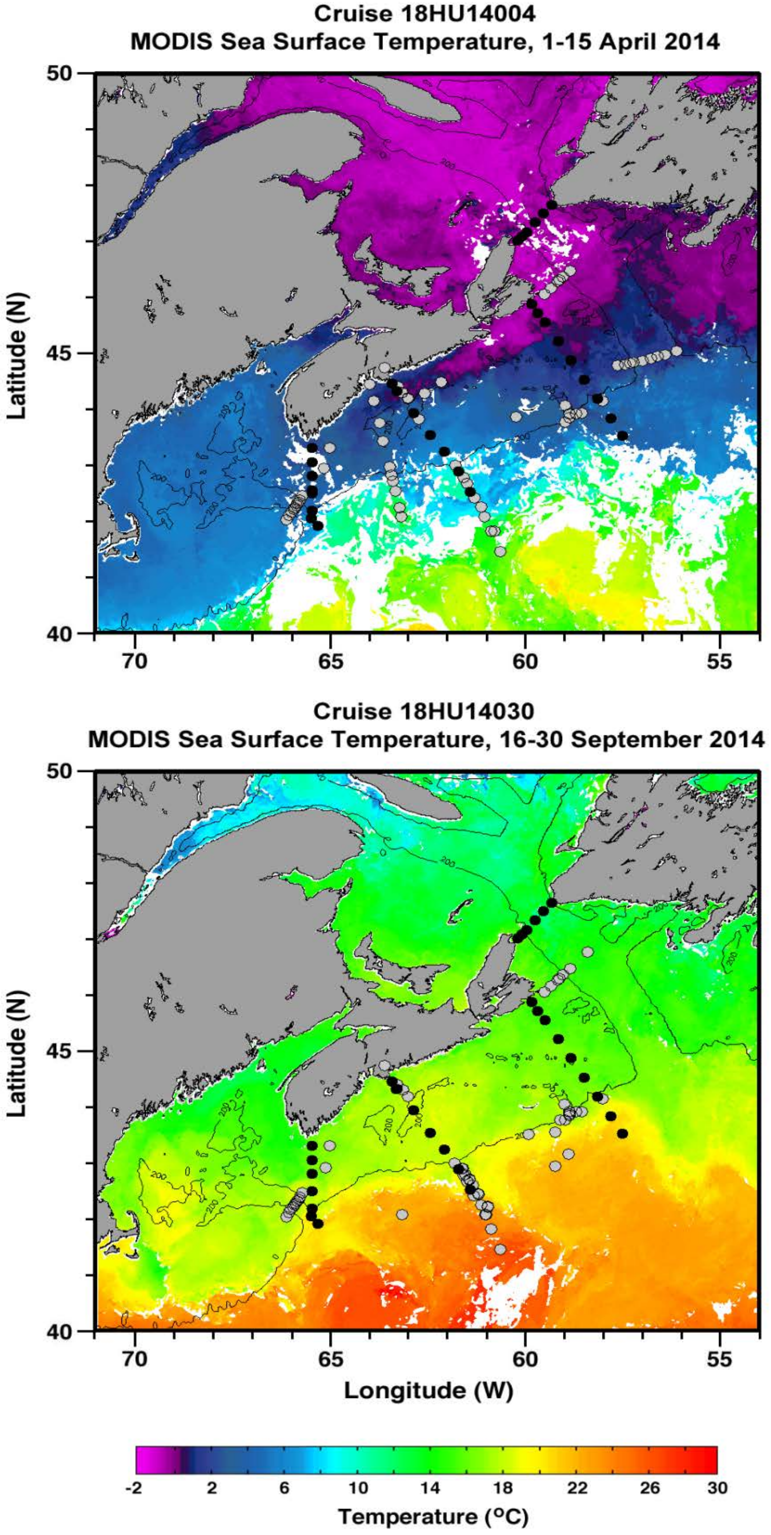
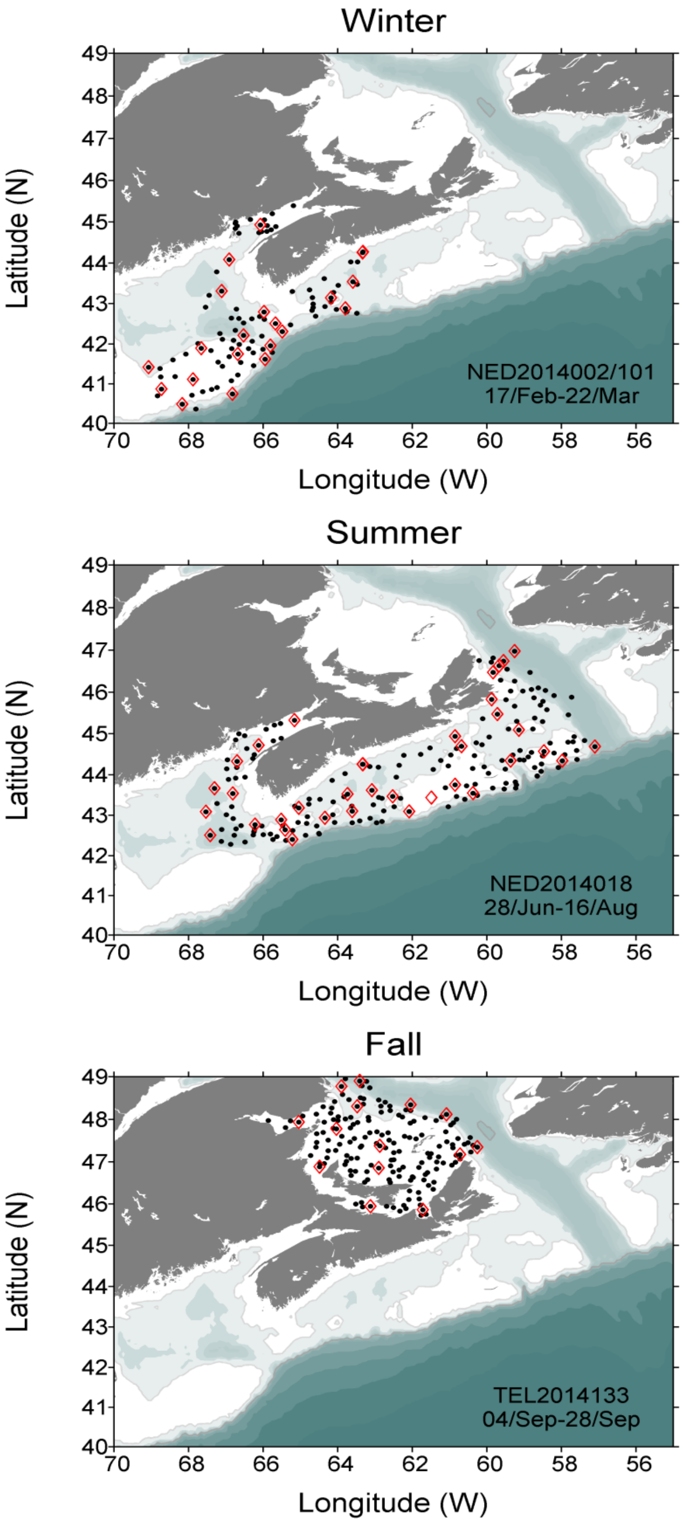


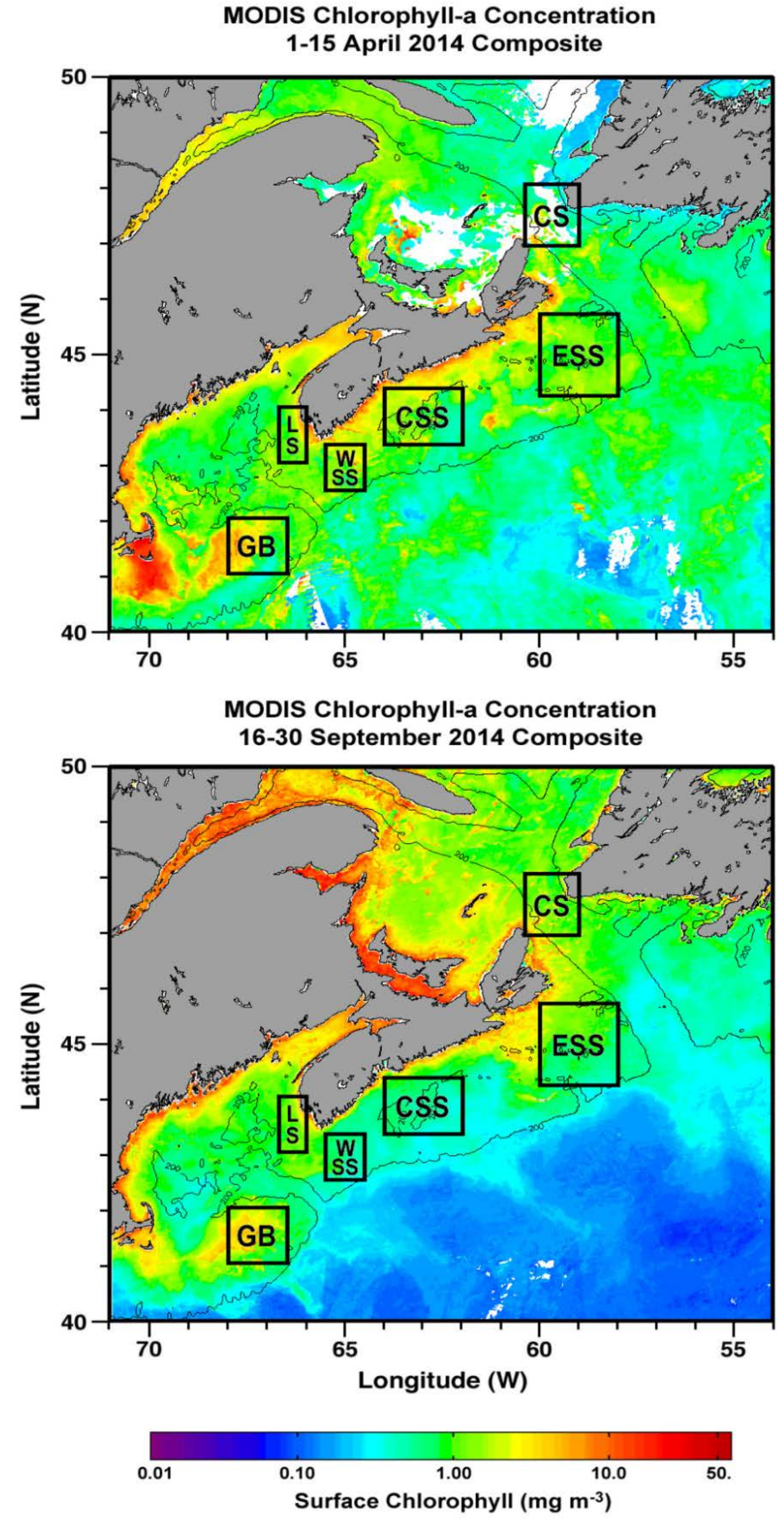
Figure 2. Map of stations sampled during the 2014 spring and fall surveys. Station locations are superimposed on a sea-surface temperature composite image for dates close to the mission dates. Black markers indicate core stations, and gray markers indicate stations sampled for ancillary programs.


Winter

Summer

Fall

Figure 3. Map of stations sampled during major DFO Maritimes/DFO Gulf regions ecosystem trawl surveys in 2014 (winter, summer, and fall). Black solid markers are hydrographic stations; red open diamonds are stations where vertical nets hauls were taken in addition to hydrographic measurements.



MODIS Chlorophyll-a Concentration
1-15 April 2014 Composite

MODIS Chlorophyll-a Concentration
16-30 September 2014 Composite

Figure 4. Statistical sub-regions in the DFO Maritimes Region identified for spatial/temporal analysis of satellite ocean colour data as of 2014. Sub-regions are superimposed on surface chlorophyll composite image for dates close to the mission dates. CS – Cabot Strait; CSS – central Scotian Shelf; ESS – Eastern Scotian Shelf; GB – Georges Bank; LS – Lurcher Shoal; WSS – Western Scotian Shelf.

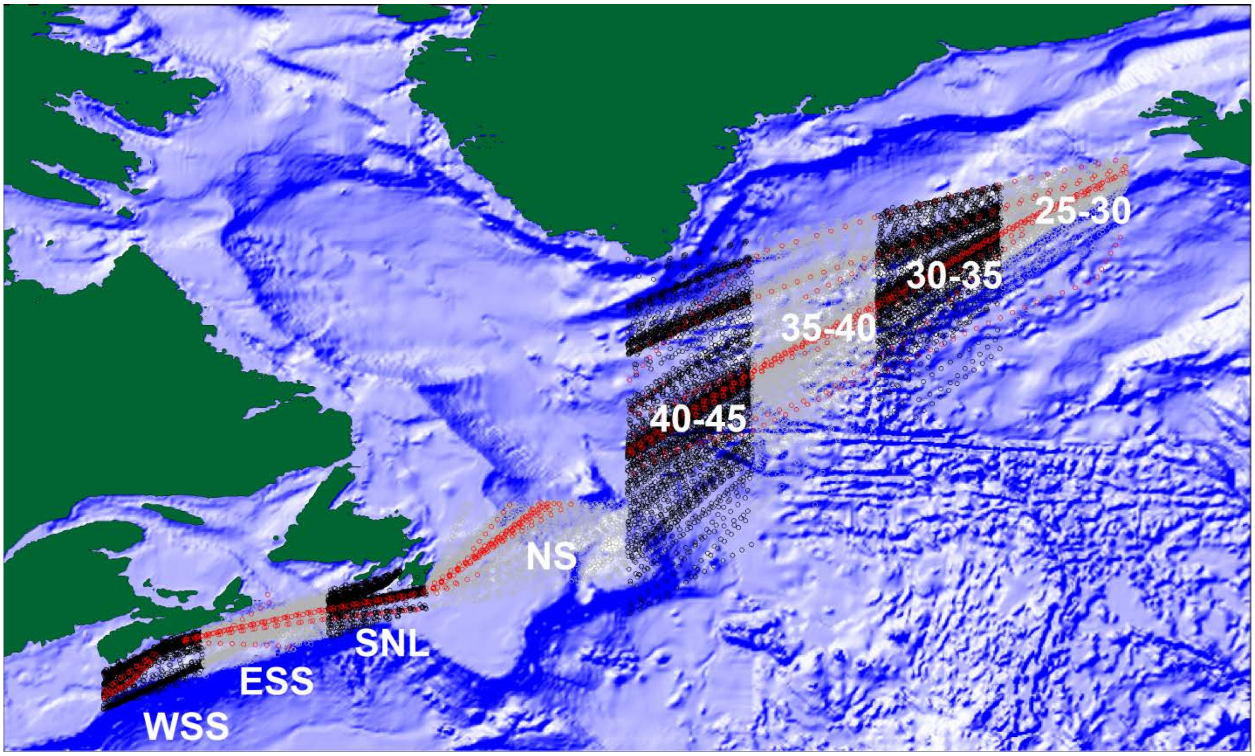


Figure 5. Map of Continuous Plankton recorder (CPR) lines and stations on the Scotian Shelf, Newfoundland Shelf, and in the Irminger Sea, 1957 to 2013. Stations sampled in 2013 are shown in red. Data were analysed by region. Regions are: Western Scotian Shelf (WSS), Eastern Scotian Shelf (ESS), South Newfoundland Shelf (SNL), Newfoundland Shelf (NS), and between longitudes 40-45^{o}W, 35-40^{o}W, 30-35^{o}W, 25-30^{o}W.

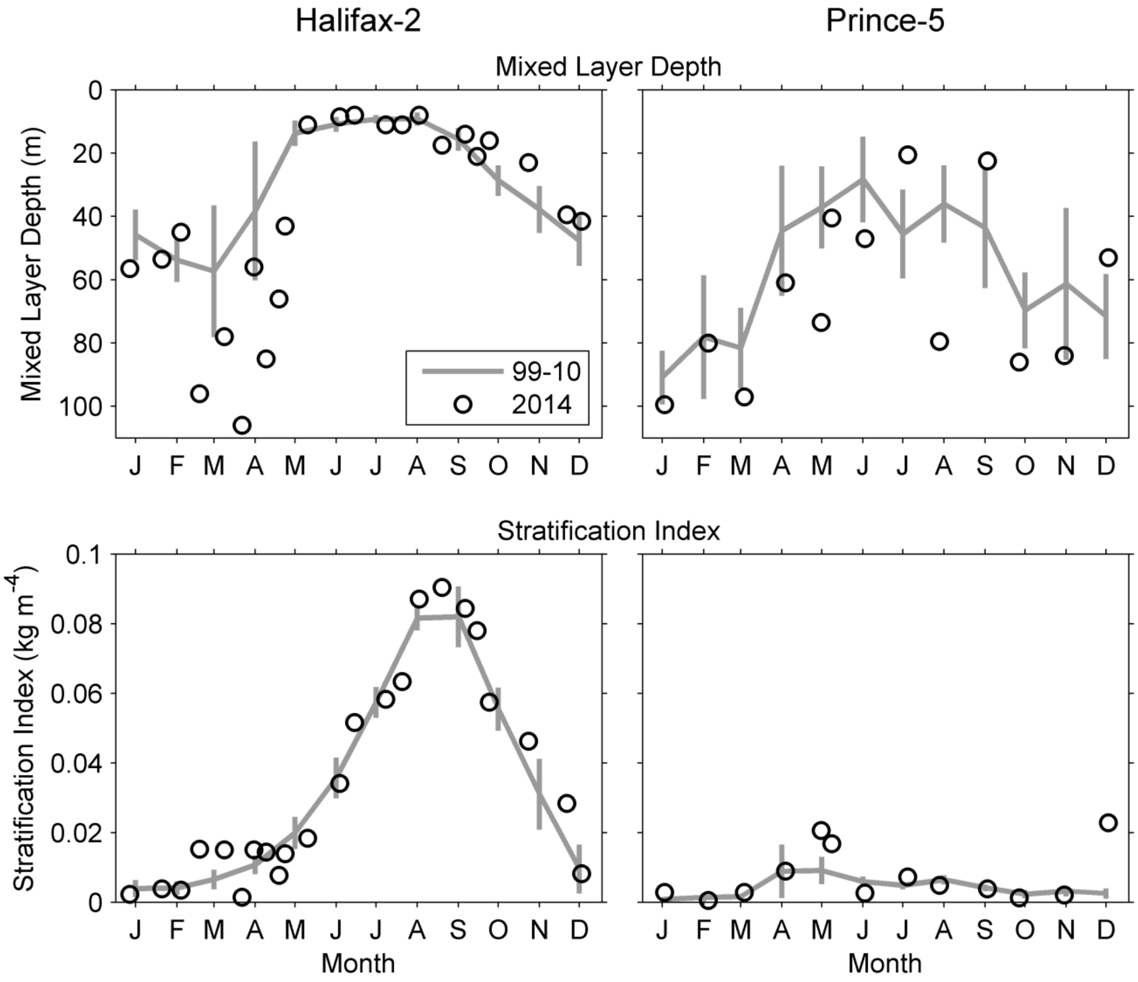


Figure 6. Mixing properties (MLD, stratification index) at the DFO Maritimes Region fixed stations (Halifax-2 left panels; Prince-5 right panels) comparing 2014 data (open circle) with mean conditions from 1999-2010 (solid line). Vertical lines are 95% confidence intervals of the monthly means.

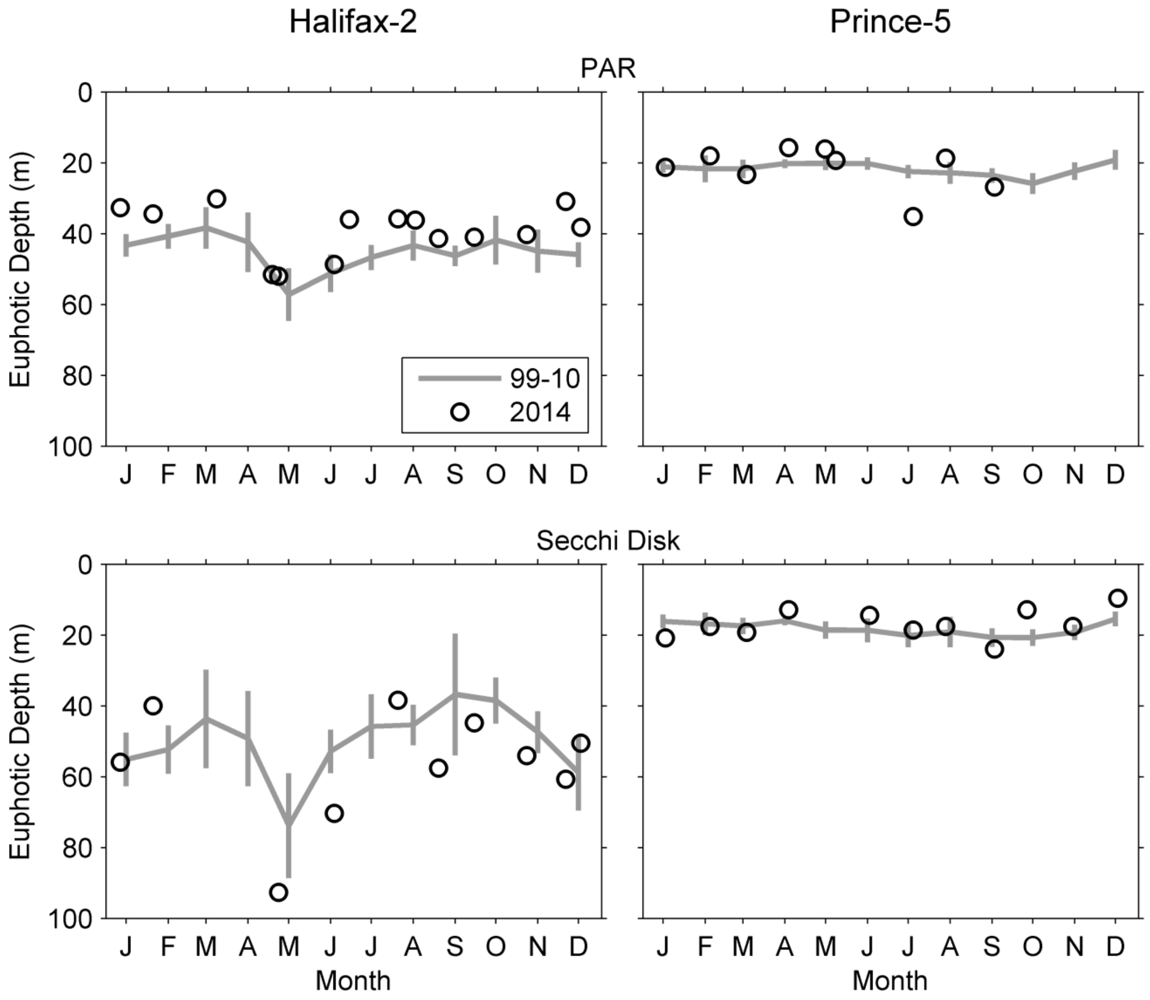


Figure 7. Annual variability in optical properties (euphotic depth from PAR irradiance meter and Secchi disc) at the DFO Maritimes Region fixed stations (Halifax-2 left panels; Prince-5 right panels). Year 2014 data (circles) compared with mean conditions from 1999-2010 (solid line), except 2001-2010 for euphotic depth from PAR at Prince-5. Vertical lines are 95% confidence intervals of the monthly means.

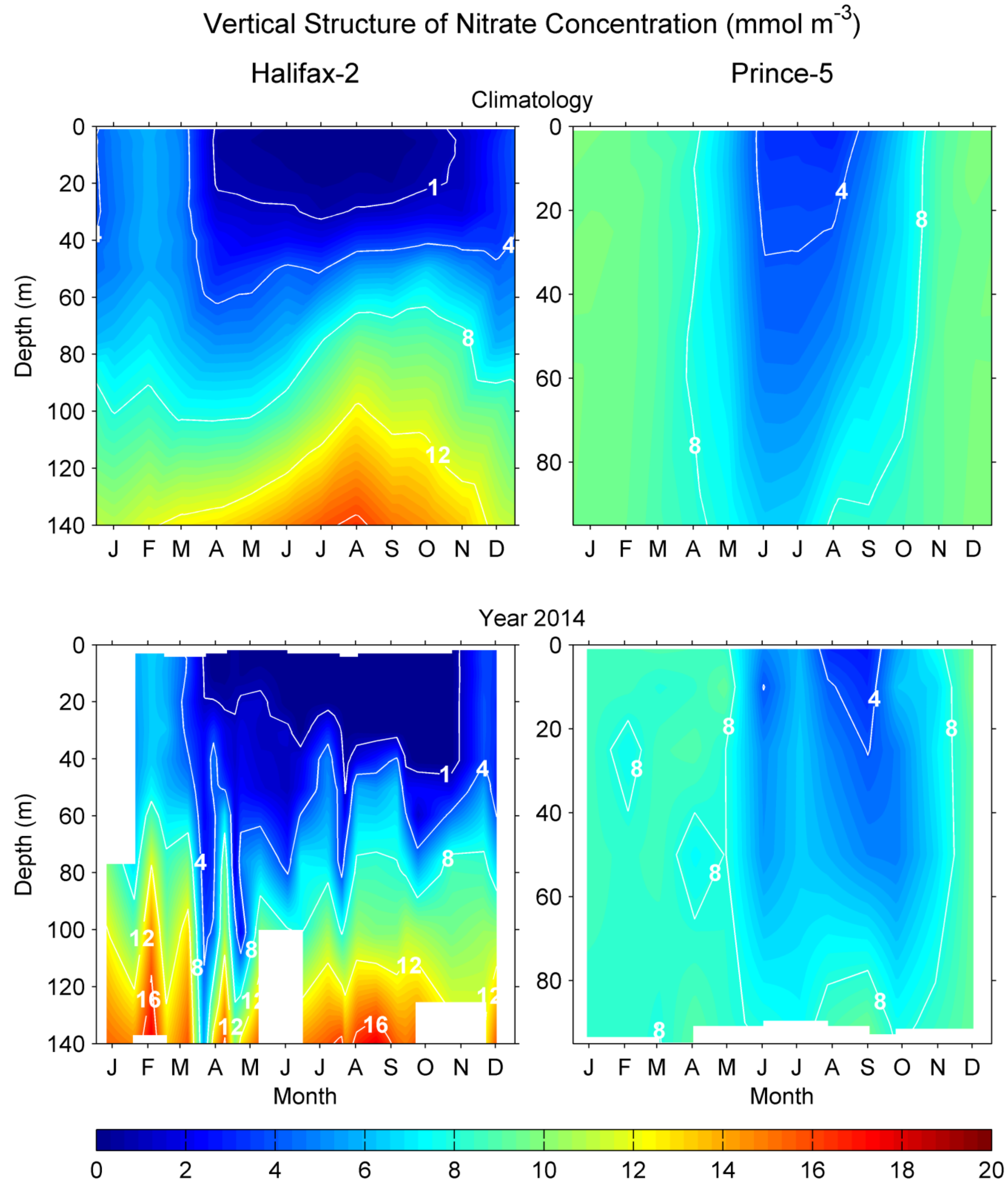


Figure 8. Comparison of vertical structure of nitrate concentrations (mmol m^{-3}) in 2014 (bottom panels) with climatological mean conditions from 1999-2010 (upper panels) at the DFO Maritimes Region fixed stations (Halifax-2 right panels; Prince-5 left panels).

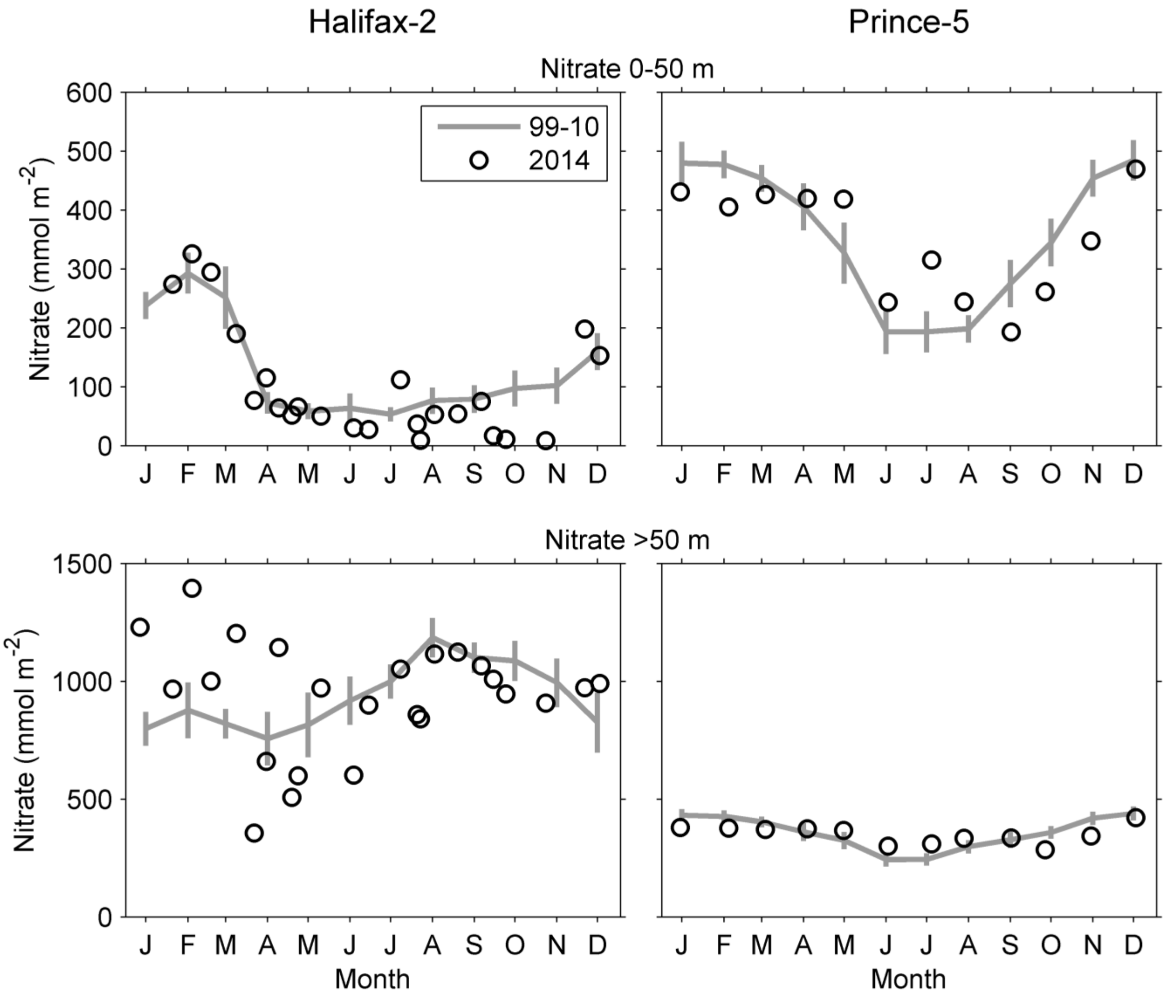
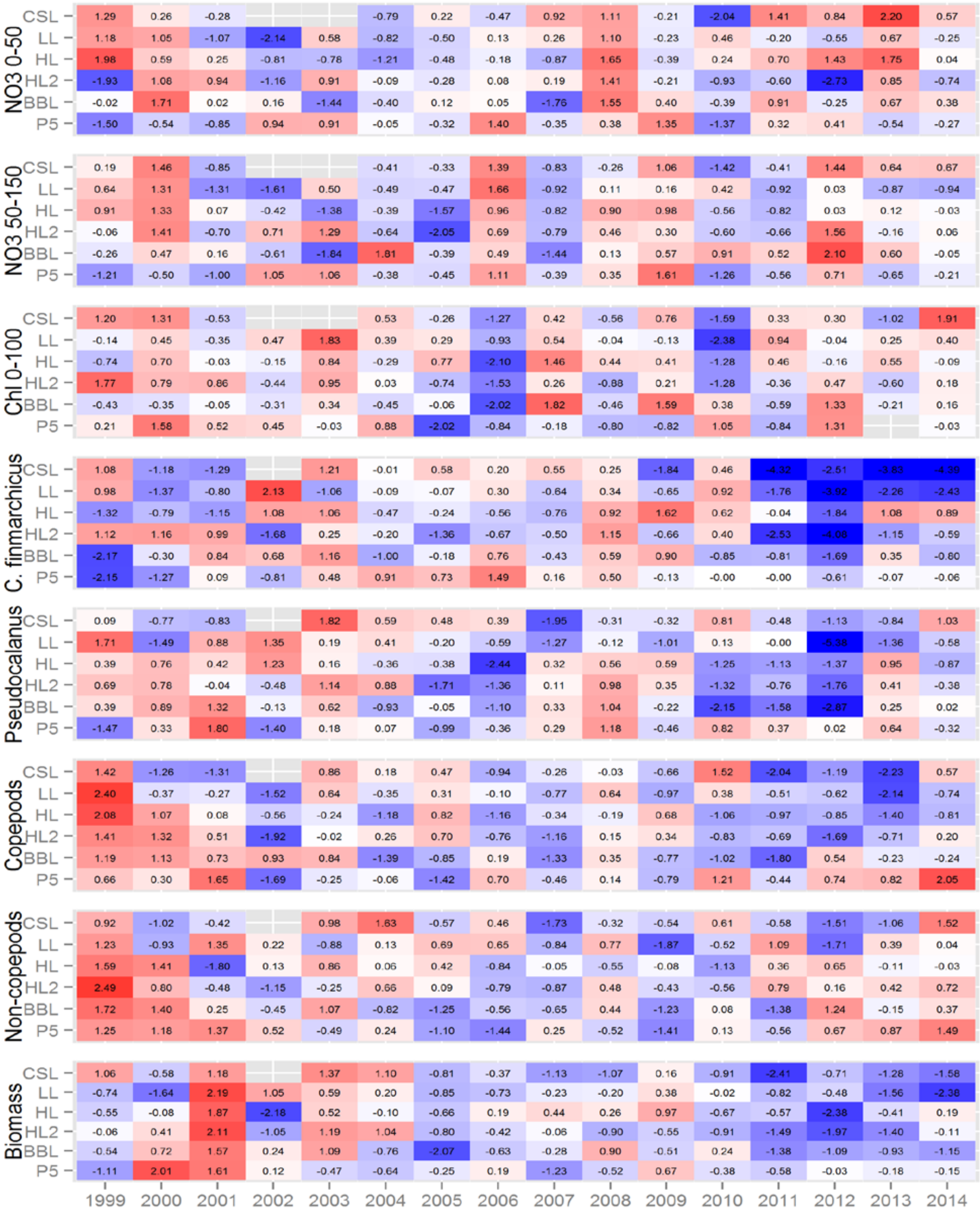


Figure 9. Comparison of annual variability in nitrate inventories in 2014 (open circle) with mean conditions from 1999-2010 (solid line) at the DFO Maritimes Region fixed stations (Halifax-2 left panels; Prince-5 right panels). Upper panels: surface (0–50 m) nitrate inventory. Lower panels: deep (>50 m) nitrate inventory. Vertical lines are 95% confidence intervals of the monthly means.



		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
NO3 0-50	CSL	1.29	0.26	-0.28			-0.79	0.22	-0.47	0.92	1.11	-0.21	-2.04	1.41	0.84	2.20	0.57
	LL	1.18	1.05	-1.07	-2.14	0.58	-0.82	-0.50	0.13	0.26	1.10	-0.23	0.46	-0.20	-0.55	0.67	-0.25
	HL	1.98	0.59	0.25	-0.81	-0.78	-1.21	-0.48	-0.18	-0.87	1.65	-0.39	0.24	0.70	1.43	1.75	0.04
	HL2	-1.93	1.08	0.94	-1.16	0.91	-0.09	-0.28	0.08	0.19	1.41	-0.21	-0.93	-0.60	-2.73	0.85	-0.74
	BBL	-0.02	1.71	0.02	0.16	-1.44	-0.40	0.12	0.05	-1.76	1.55	0.40	-0.39	0.91	-0.25	0.67	0.38
	P5	-1.50	-0.54	-0.85	0.94	0.91	-0.05	-0.32	1.40	-0.35	0.38	1.35	-1.37	0.32	0.41	-0.54	-0.27
NO3 50-150	CSL	0.19	1.46	-0.85			-0.41	-0.33	1.39	-0.83	-0.26	1.06	-1.42	-0.41	1.44	0.64	0.67
	LL	0.64	1.31	-1.31	-1.61	0.50	-0.49	-0.47	1.66	-0.92	0.11	0.16	0.42	-0.92	0.03	-0.87	-0.94
	HL	0.91	1.33	0.07	-0.42	-1.38	-0.39	-1.57	0.96	-0.82	0.90	0.98	-0.56	-0.82	0.03	0.12	-0.03
	HL2	-0.06	1.41	-0.70	0.71	1.29	-0.64	-2.05	0.69	-0.79	0.46	0.30	-0.60	-0.66	1.56	-0.16	0.06
	BBL	-0.26	0.47	0.16	-0.61	-1.84	1.81	-0.39	0.49	-1.44	0.13	0.57	0.91	0.52	2.10	0.60	-0.05
	P5	-1.21	-0.50	-1.00	1.05	1.06	-0.38	-0.45	1.11	-0.39	0.35	1.61	-1.26	-0.56	0.71	-0.65	-0.21
Chl 0-100	CSL	1.20	1.31	-0.53			0.53	-0.26	-1.27	0.42	-0.56	0.76	-1.59	0.33	0.30	-1.02	1.91
	LL	-0.14	0.45	-0.35	0.47	1.83	0.39	0.29	-0.93	0.54	-0.04	-0.13	-2.38	0.94	-0.04	0.25	0.40
	HL	-0.74	0.70	-0.03	-0.15	0.84	-0.29	0.77	-2.10	1.46	0.44	0.41	-1.28	0.46	-0.16	0.55	-0.09
	HL2	1.77	0.79	0.86	-0.44	0.95	0.03	-0.74	-1.53	0.26	-0.88	0.21	-1.28	-0.36	0.47	-0.60	0.18
	BBL	-0.43	-0.35	-0.05	-0.31	0.34	-0.45	-0.06	-2.02	1.82	-0.46	1.59	0.38	-0.59	1.33	-0.21	0.16
	P5	0.21	1.58	0.52	0.45	-0.03	0.88	-2.02	-0.84	-0.18	-0.80	-0.82	1.05	-0.84	1.31		-0.03
C. finmarchicus	CSL	1.08	-1.18	-1.29		1.21	-0.01	0.58	0.20	0.55	0.25	-1.84	0.46	-4.32	-2.51	-3.83	-4.39
	LL	0.98	-1.37	-0.80	2.13	-1.06	-0.09	-0.07	0.30	-0.64	0.34	-0.65	0.92	-1.76	-3.92	-2.26	-2.43
	HL	-1.32	-0.79	-1.15	1.08	1.06	-0.47	-0.24	-0.56	-0.76	0.92	1.62	0.62	-0.04	-1.84	1.08	0.89
	HL2	1.12	1.16	0.99	-1.68	0.25	-0.20	-1.36	-0.67	-0.50	1.15	-0.66	0.40	-2.53	-4.08	-1.15	-0.59
	BBL	-2.17	-0.30	0.84	0.68	1.16	-1.00	-0.18	0.76	-0.43	0.59	0.90	-0.85	-0.81	-1.69	0.35	-0.80
	P5	-2.15	-1.27	0.09	-0.81	0.48	0.91	0.73	1.49	0.16	0.50	-0.13	-0.00	-0.00	-0.61	-0.07	-0.06
Pseudocalanus	CSL	0.09	-0.77	-0.83		1.82	0.59	0.48	0.39	-1.95	-0.31	-0.32	0.81	-0.48	-1.13	-0.84	1.03
	LL	1.71	-1.49	0.88	1.35	0.19	0.41	-0.20	-0.59	-1.27	-0.12	-1.01	0.13	-0.00	-5.38	-1.36	-0.58
	HL	0.39	0.76	0.42	1.23	0.16	-0.36	-0.38	-2.44	0.32	0.56	0.59	-1.25	-1.13	-1.37	0.95	-0.87
	HL2	0.69	0.78	-0.04	-0.48	1.14	0.88	-1.71	-1.36	0.11	0.98	0.35	-1.32	-0.76	-1.76	0.41	-0.38
	BBL	0.39	0.89	1.32	-0.13	0.62	-0.93	-0.05	-1.10	0.33	1.04	-0.22	-2.15	-1.58	-2.87	0.25	0.02
	P5	-1.47	0.33	1.80	-1.40	0.18	0.07	-0.99	-0.36	0.29	1.18	-0.46	0.82	0.37	0.02	0.64	-0.32
Copepods	CSL	1.42	-1.26	-1.31		0.86	0.18	0.47	-0.94	-0.26	-0.03	-0.66	1.52	-2.04	-1.19	-2.23	0.57
	LL	2.40	-0.37	-0.27	-1.52	0.64	-0.35	0.31	-0.10	-0.77	0.64	-0.97	0.38	-0.51	-0.62	-2.14	-0.74
	HL	2.08	1.07	0.08	-0.56	-0.24	-1.18	0.82	-1.16	-0.34	-0.19	0.68	-1.06	-0.97	-0.85	-1.40	-0.81
	HL2	1.41	1.32	0.51	-1.92	-0.02	0.26	0.70	-0.76	-1.16	0.15	0.34	-0.83	-0.69	-1.69	-0.71	0.20
	BBL	1.19	1.13	0.73	0.93	0.84	-1.39	-0.85	0.19	-1.33	0.35	-0.77	-1.02	-1.80	0.54	-0.23	-0.24
	P5	0.66	0.30	1.65	-1.69	-0.25	-0.06	-1.42	0.70	-0.46	0.14	-0.79	1.21	-0.44	0.74	0.82	2.05
Non-copepods	CSL	0.92	-1.02	-0.42		0.98	1.63	-0.57	0.46	-1.73	-0.32	-0.54	0.61	-0.58	-1.51	-1.06	1.52
	LL	1.23	-0.93	1.35	0.22	-0.88	0.13	0.69	0.65	-0.84	0.77	-1.87	-0.52	1.09	-1.71	0.39	0.04
	HL	1.59	1.41	-1.80	0.13	0.86	0.06	0.42	-0.84	-0.05	-0.55	-0.08	-1.13	0.36	0.65	-0.11	-0.03
	HL2	2.49	0.80	-0.48	-1.15	-0.25	0.66	0.09	-0.79	-0.87	0.48	-0.43	-0.56	0.79	0.16	0.42	0.72
	BBL	1.72	1.40	0.25	-0.45	1.07	-0.82	-1.25	-0.56	-0.65	0.44	-1.23	0.08	-1.38	1.24	-0.15	0.37
	P5	1.25	1.18	1.37	0.52	-0.49	0.24	-1.10	-1.44	0.25	-0.52	-1.41	0.13	-0.56	0.67	0.87	1.49
Biomass	CSL	1.06	-0.58	1.18		1.37	1.10	-0.81	-0.37	-1.13	-1.07	0.16	-0.91	-2.41	-0.71	-1.28	-1.58
	LL	-0.74	-1.64	2.19	1.05	0.59	0.20	-0.85	-0.73	-0.23	-0.20	0.38	-0.02	-0.82	-0.48	-1.56	-2.38
	HL	-0.55	-0.08	1.87	-2.18	0.52	-0.10	-0.66	0.19	0.44	0.26	0.97	-0.67	-0.57	-2.38	-0.41	0.19
	HL2	-0.06	0.41	2.11	-1.05	1.19	1.04	-0.80	-0.42	-0.06	-0.90	-0.55	-0.91	-1.49	-1.97	-1.40	-0.11
	BBL	-0.54	0.72	1.57	0.24	1.09	-0.76	-2.07	-0.63	-0.28	0.90	-0.51	0.24	-1.38	-1.09	-0.93	-1.15
	P5	-1.11	2.01	1.61	0.12	-0.47	-0.64	-0.25	0.19	-1.23	-0.52	0.67	-0.38	-0.58	-0.03	-0.18	-0.15

Figure 10. DFO Maritimes Region scorecard: time series of chemical and biological variables, 1999-2014. A blank cell indicates missing data. Red (blue) cells indicate higher (lower) than normal nutrient, phytoplankton, zooplankton levels. 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.

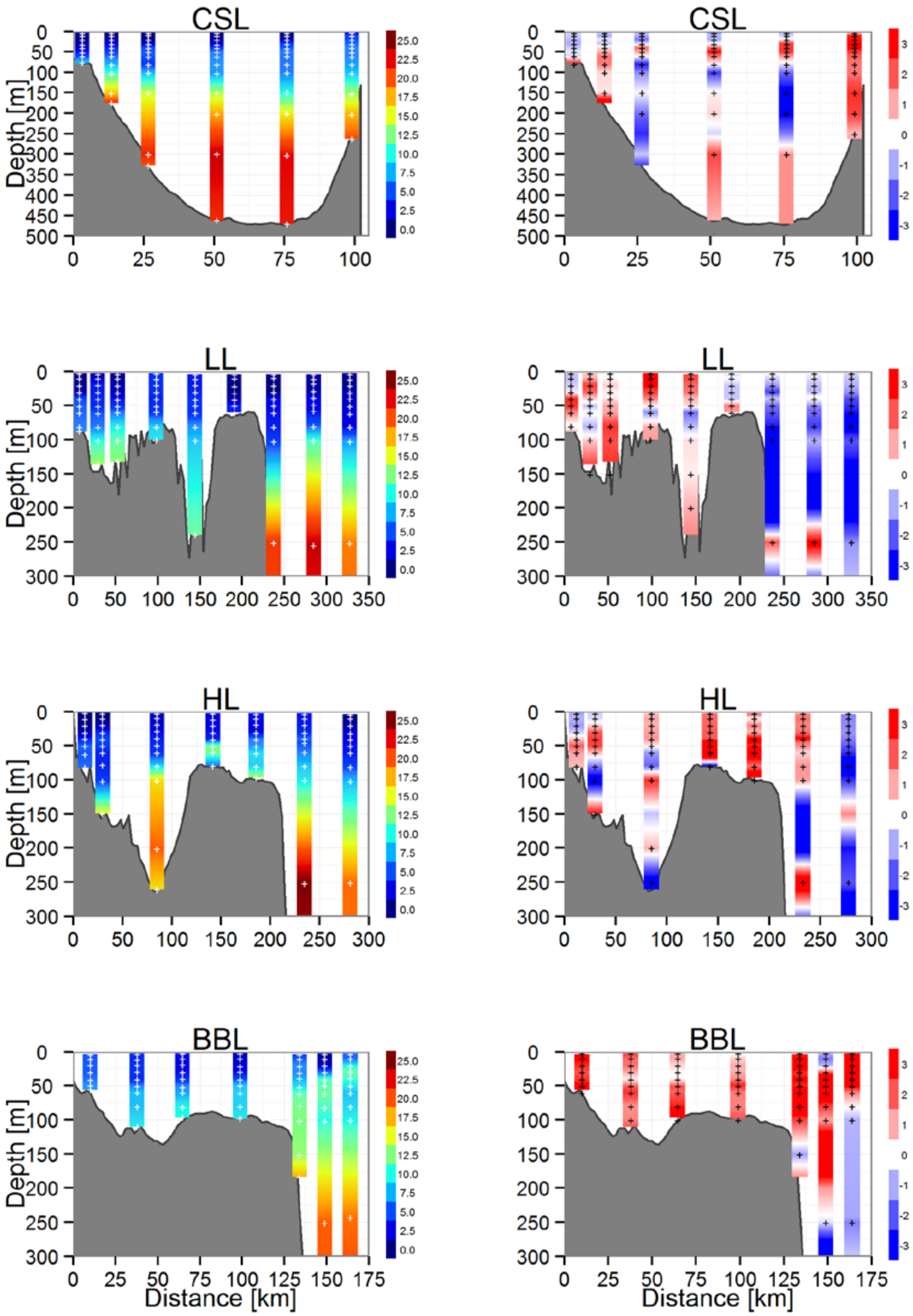


Figure 11a. Vertical profiles of nitrate concentrations (mmol m^{-3}) (left panels) and anomalies (mmol m^{-3}) from 1999-2010 conditions (right panels) on the Scotian Shelf sections in spring 2014. White markers on the left panels indicate the actual sampling depths for 2014. Black markers on the right panels indicate the depths at which station-specific climatological values were calculated. CSL: Cabot Strait section; LL: Louisbourg section; HL: Halifax section; BBL: Browns Bank section.

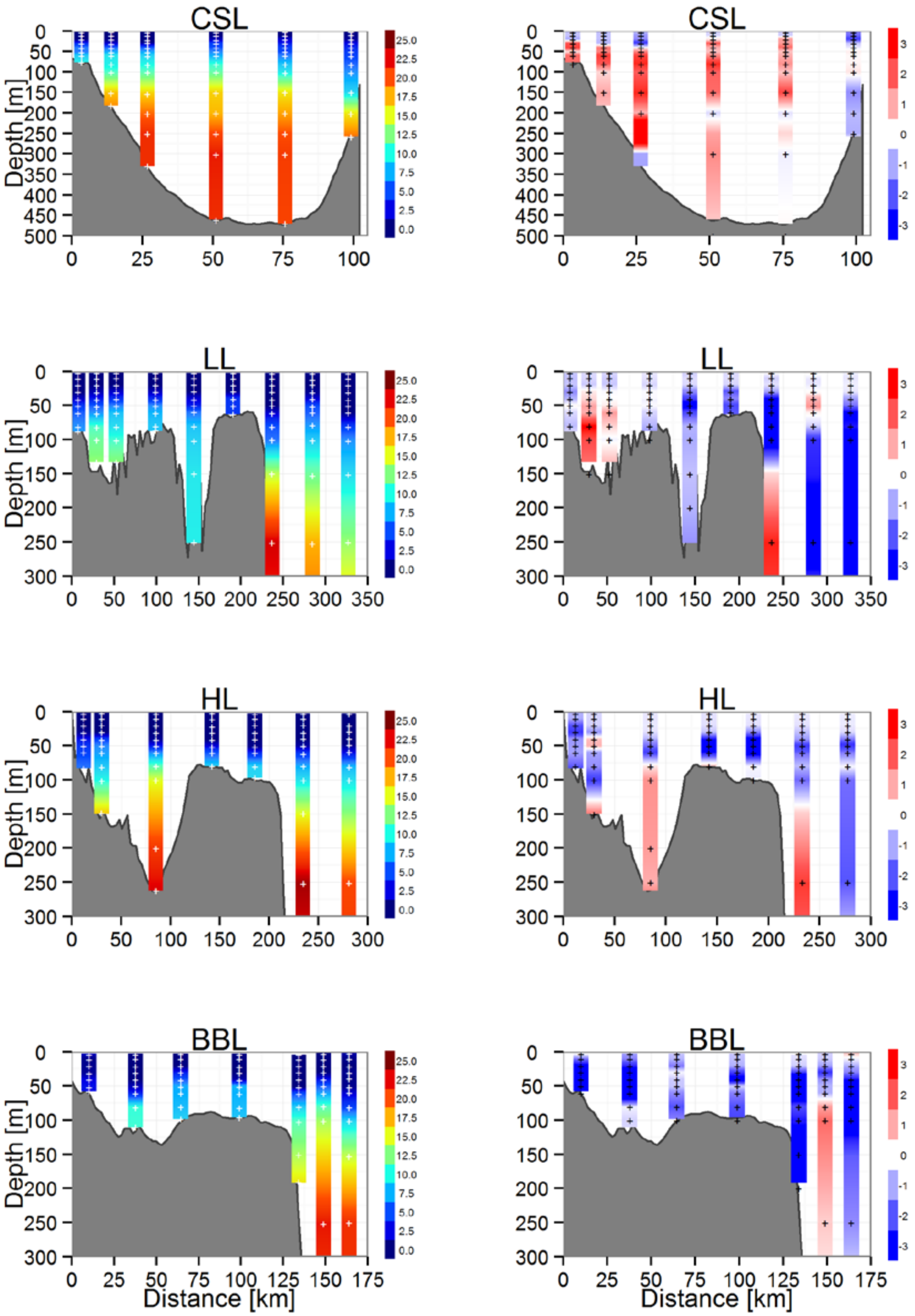


Figure 11b. Vertical profiles of nitrate concentrations (mmol m^{-3}) (left panels) and anomalies (mmol m^{-3}) from 1999-2010 conditions (right panels) on the Scotian Shelf sections in fall 2014. White markers on the left panels indicate the actual sampling depths for 2014. Black markers on the right panels indicate the depths at which station-specific climatological values were calculated. CSL: Cabot Strait section; LL: Louisbourg section; HL: Halifax section; BBL: Browns Bank section.

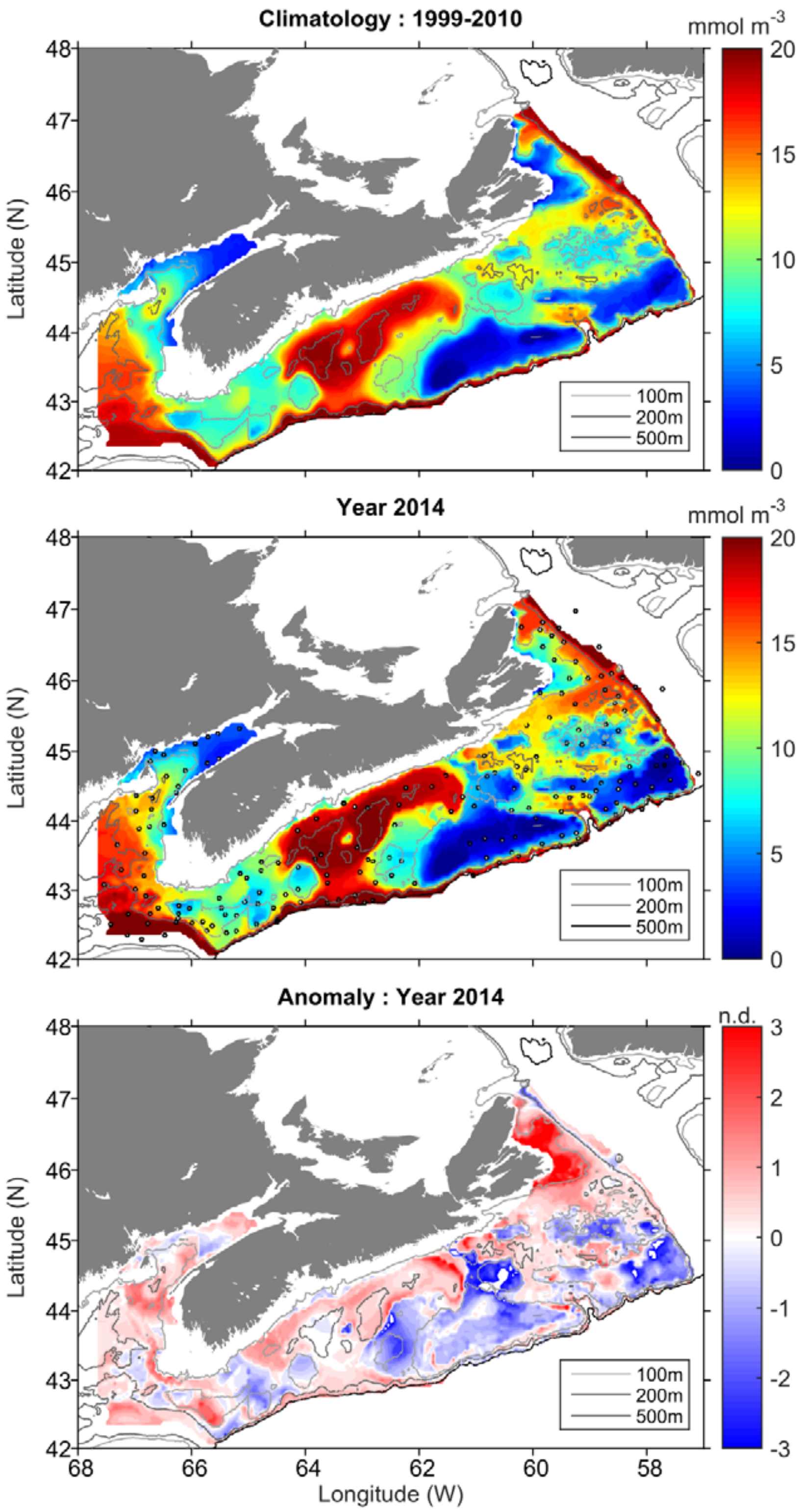


Figure 12. Bottom nitrate concentration on the Scotian Shelf during the annual July ecosystem trawl survey: 1999-2010 climatology (upper panel), 2014 conditions (middle panel), and normalized anomalies from climatology (lower panel). Markers in middle panel represent the 2014 sampling locations. nd = no dimensions.

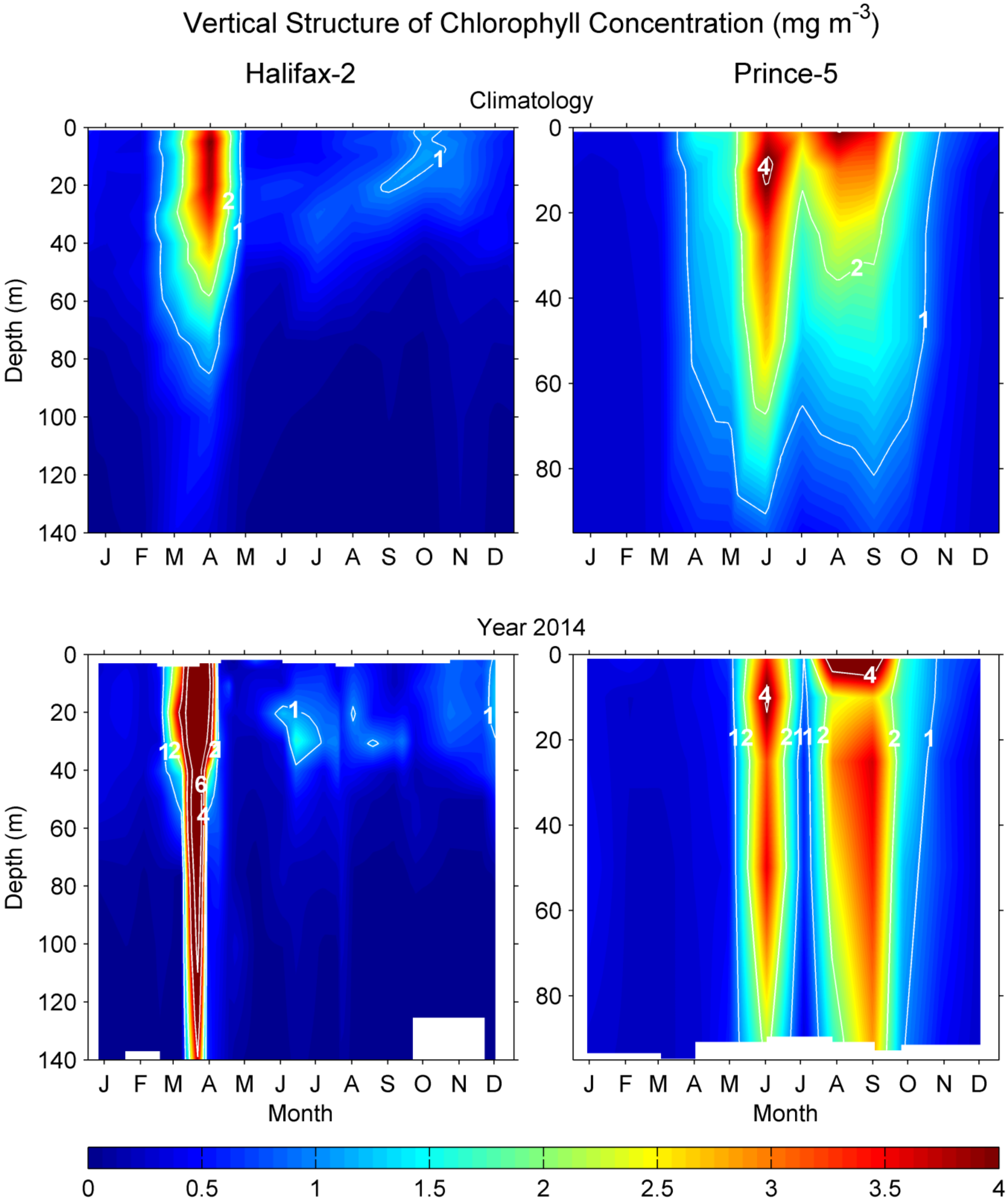


Figure 13. Comparison of vertical structure of chlorophyll concentrations (mg m^{-3}) in 2014 (bottom panels) with mean conditions from 1999-2010 (upper panels) at the DFO Maritimes Region fixed stations (Halifax-2 left panels; Prince-5 right panels). Colour scale chosen to emphasize change near estimated food saturation levels for large copepods.

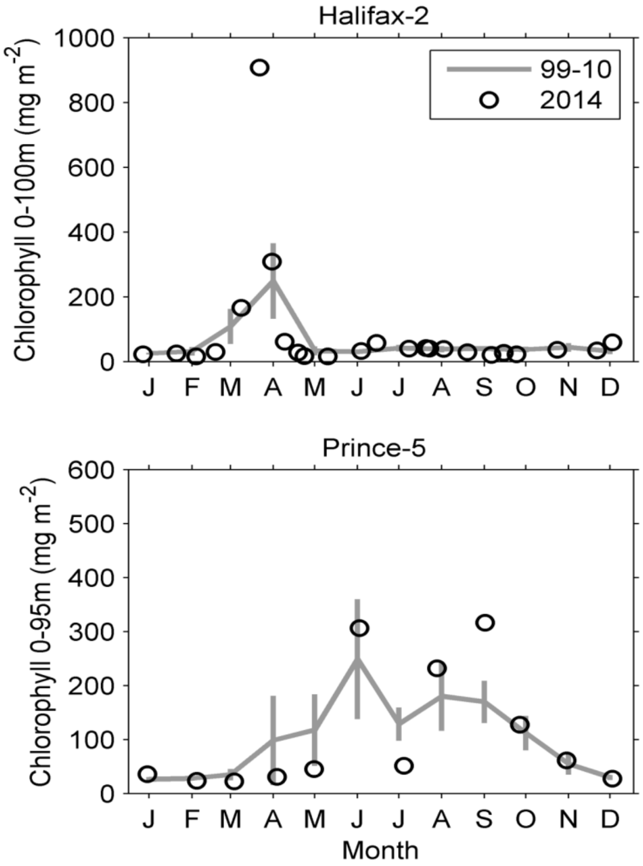


Figure 14. Comparison of annual variability in chlorophyll inventories in 2014 (open circle) with mean conditions from 1999-2010 (solid line) at the DFO Maritimes Region fixed stations (Halifax-2 upper panel; Prince-5 lower panel). Vertical lines are 95% confidence intervals of the monthly means.

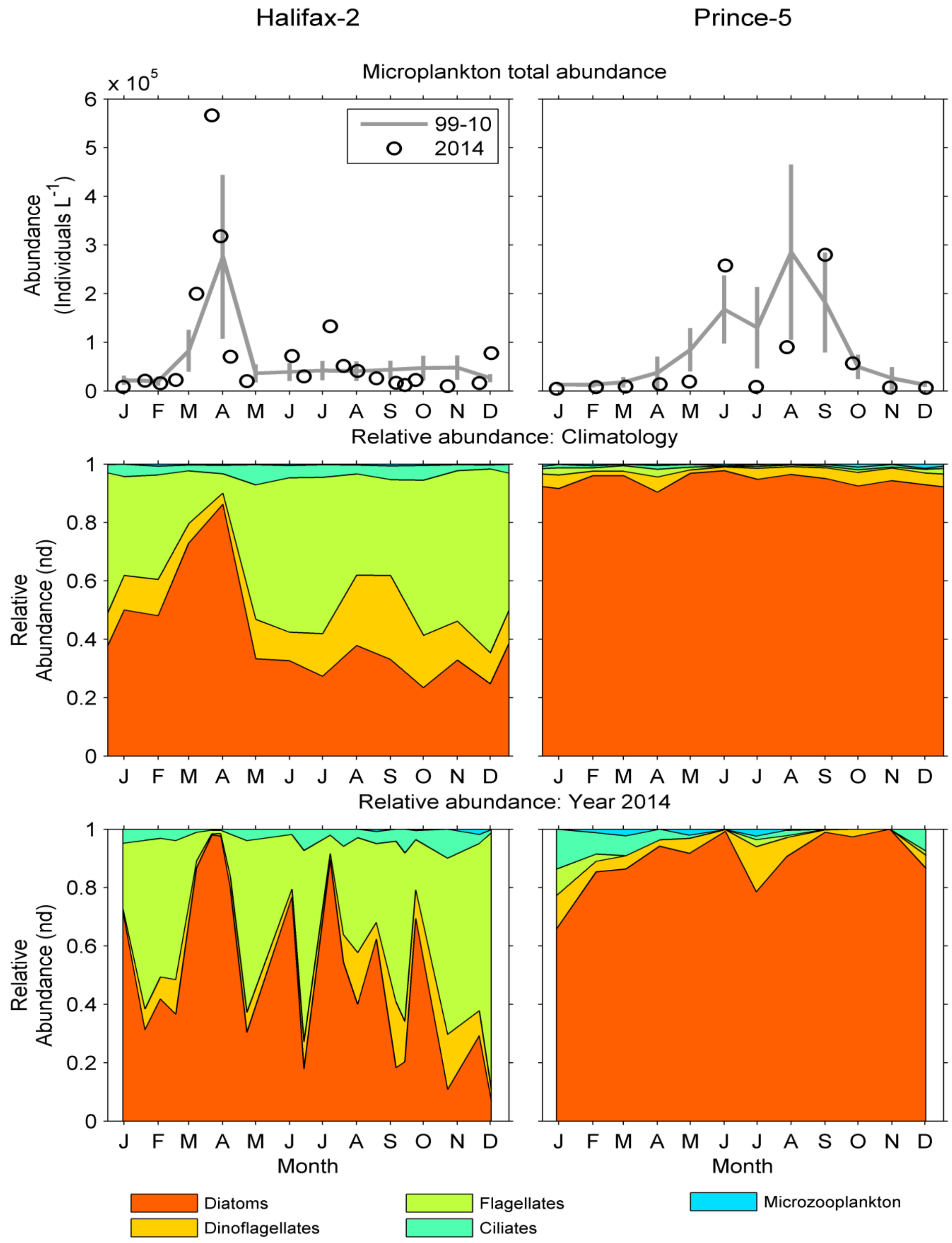


Figure 15. Comparison of annual variability in microplankton (phytoplankton and protists) abundance and community composition in 2014 with mean conditions from 1999–2010 at the DFO Maritimes Region fixed stations (Halifax-2 right panels; Prince-5 left panels). Upper panels: 2014 microplankton abundance (open circle) compared with mean conditions from 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the monthly means. Middle panels: Climatological microplankton relative abundance from 1999-2010. Lower panels: 2014 microplankton relative abundance. nd = no dimensions.

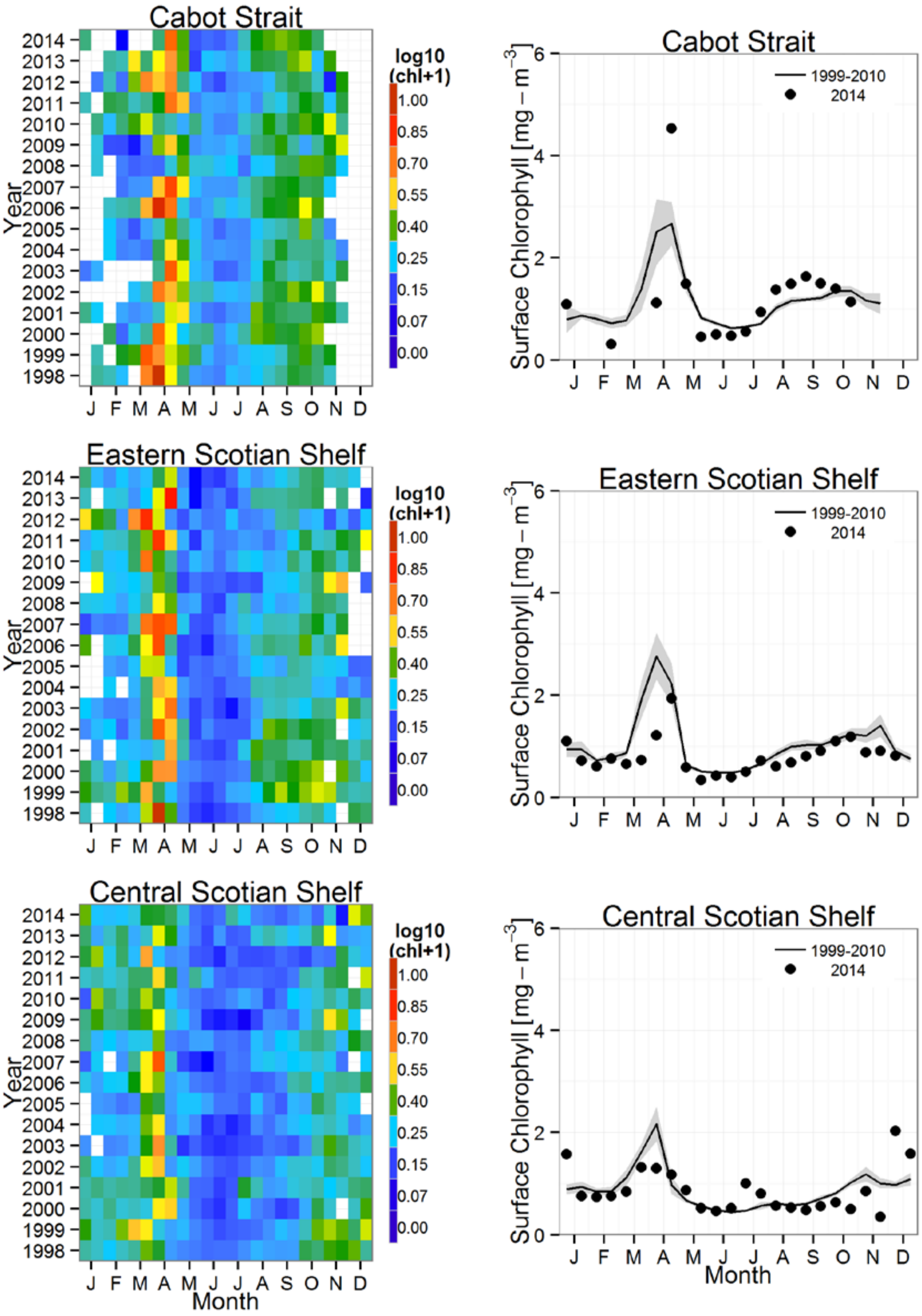


Figure 16a. Left panels: Time series of surface chlorophyll concentrations from twice-monthly MODIS ocean colour data in the Cabot Strait (top panels), Eastern Scotian Shelf (middle panels), and Central Scotian Shelf (lower panels) statistical subregions (see Figure 4). Right panels: Comparison of 2014 (open circle) surface chlorophyll estimates from satellite ocean colour with mean conditions from 1999-2010 (solid line) in the same sub-regions. Gray ribbon is the 95% confidence interval of the semi-monthly means.

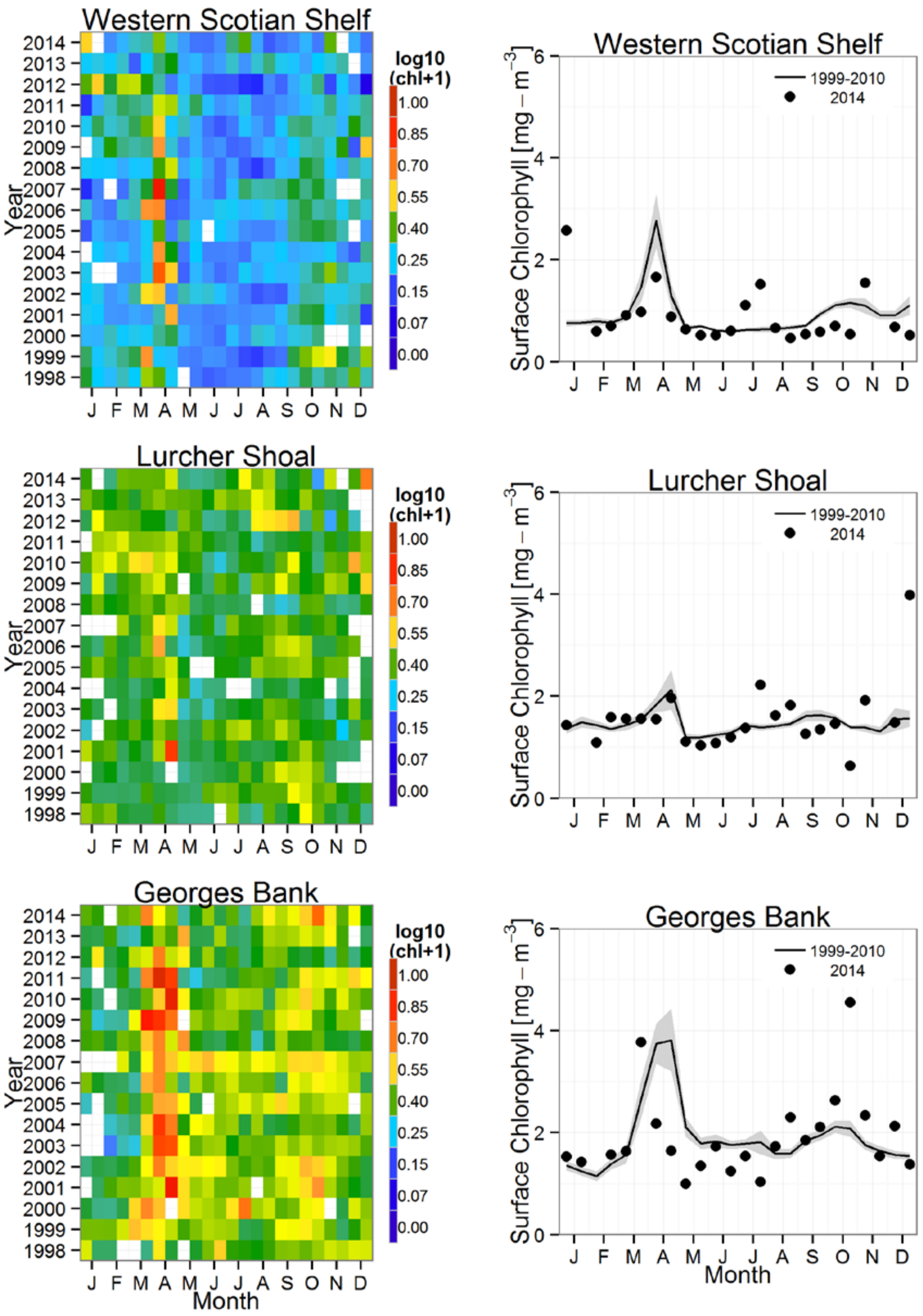


Figure 16b. Left panels: Time series of surface chlorophyll concentrations from twice-monthly MODIS ocean colour data in the Western Scotian Shelf, Lurcher Shoal, and Georges Bank statistical subregions (see Figure 4). Right panels: Comparison of 2014 (open circle) surface chlorophyll estimates from satellite ocean colour with mean conditions from 1999-2010 (solid line) in the same sub-regions. Gray ribbon is the 95% confidence interval of the semi-monthly means.

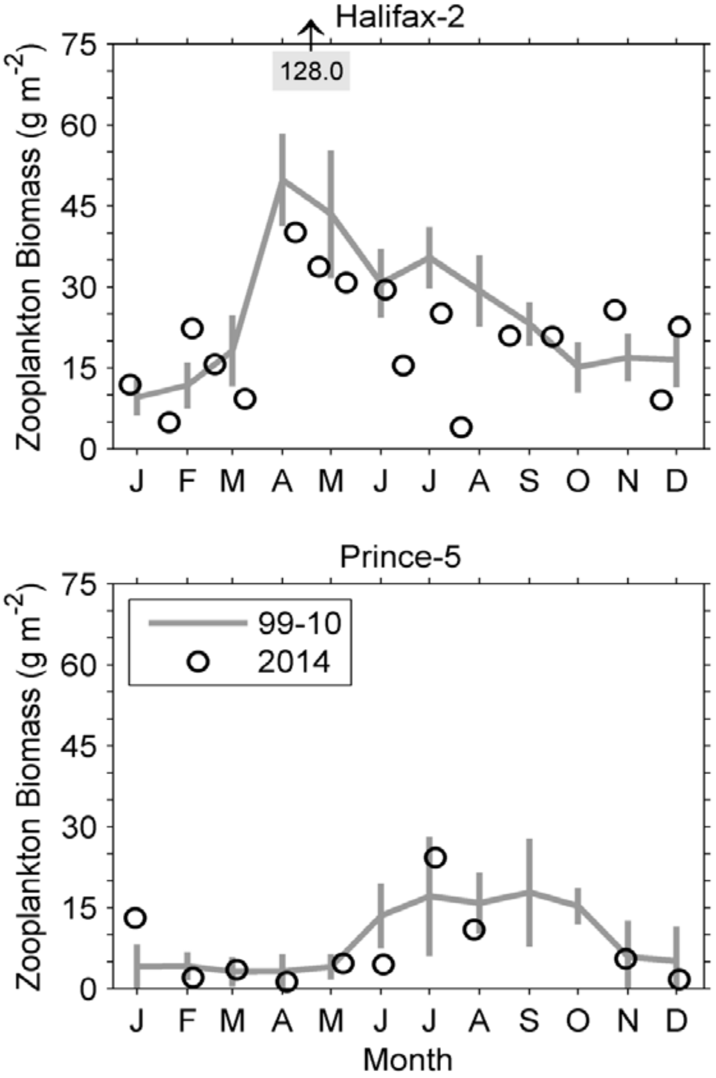


Figure 17. Comparison of 2014 (open circle) zooplankton biomass (surface to bottom) with mean conditions from 1999-2010 (solid line) at the Maritimes fixed stations. Upper panel: Halifax-2; lower panel: Prince-5. Vertical lines are 95% confidence intervals of the monthly means.

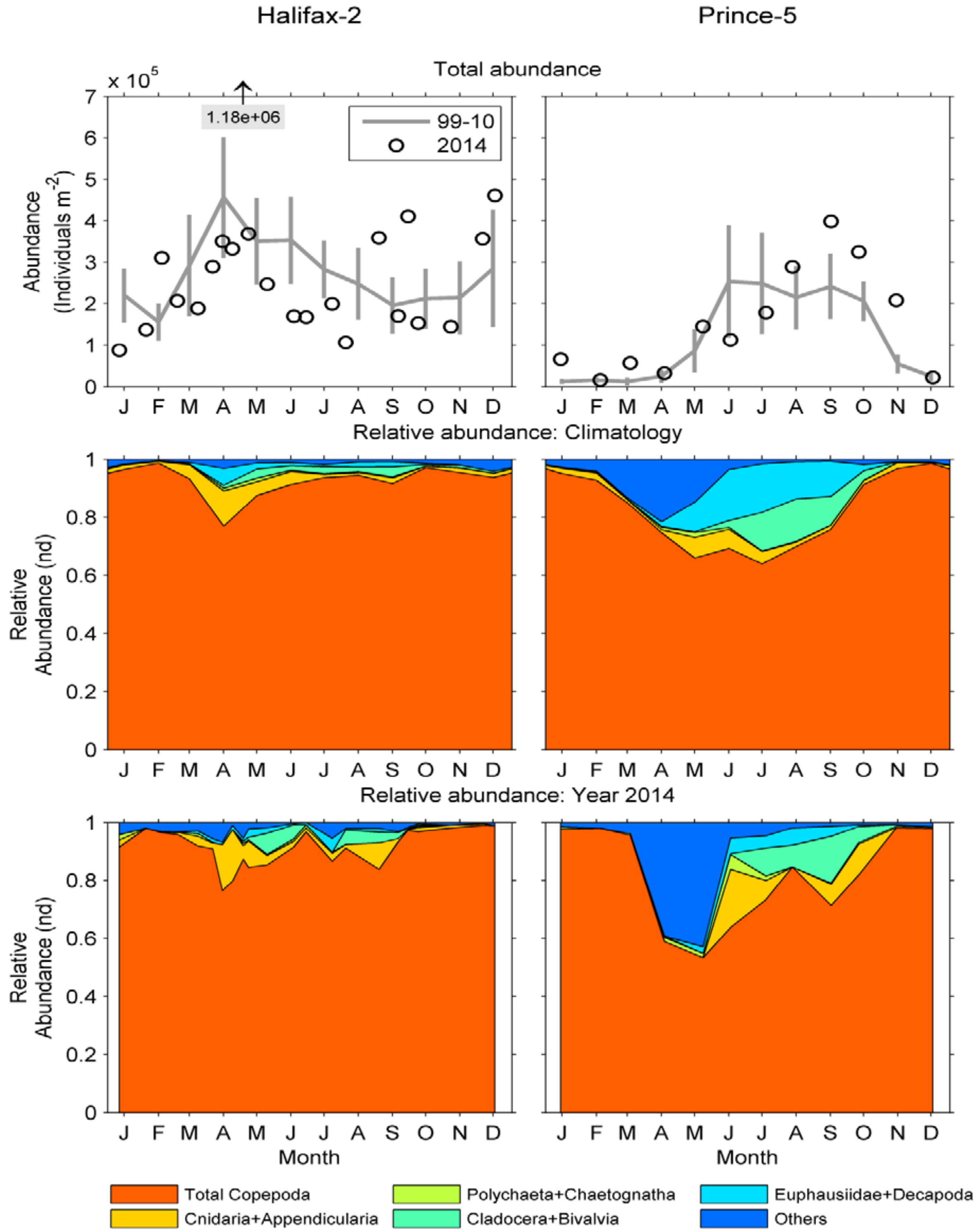


Figure 18. Comparison of 2014 zooplankton (>200 µm) abundance and community composition with mean conditions from 1999-2010 at the DFO Maritimes Region fixed stations (Halifax-2 left panels; Prince-5 right panels). Upper panels: 2014 zooplankton abundance (open circle) compared with mean conditions from 1999-2010 (solid line). Vertical lines are 95% confidence intervals of the monthly means. Middle panels: Climatology of major group abundance from 1999-2010. Lower panels: 2014 major group abundance. nd = no dimensions.

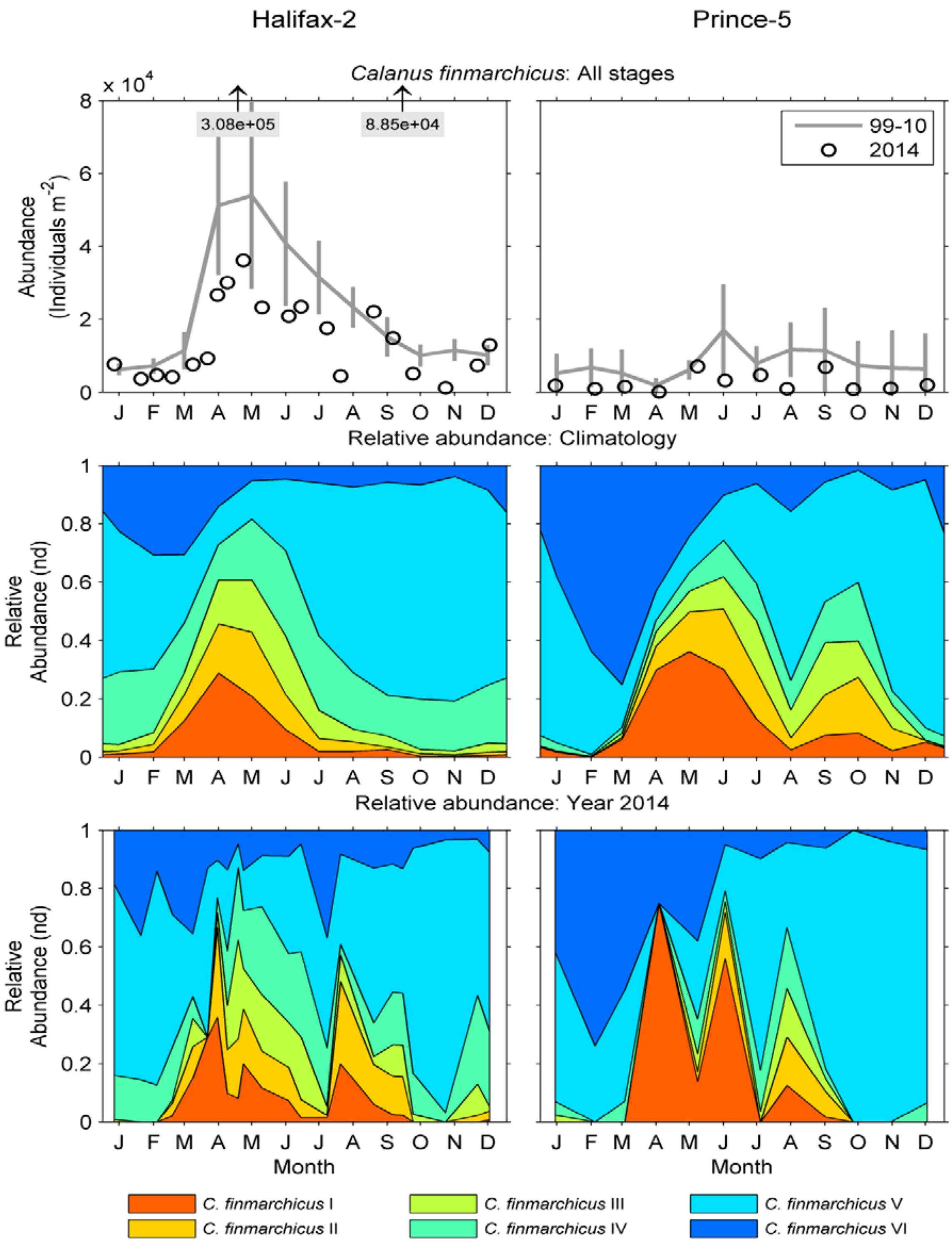


Figure 19. Comparison of 2014 C. finmarchicus abundance and developmental stage distributions with mean conditions from 1999-2010 at the DFO Maritimes Region fixed stations (Halifax-2 left panels; Prince-5 right panels). Upper panels: 2014 C. finmarchicus abundance (open circle) compared with mean conditions from 1999-2010 (solid line). Vertical lines are 95% confidence intervals of the monthly means. Middle panels: Climatological C. finmarchicus stage relative abundance from 1999-2010. Lower panels: 2014 C. finmarchicus stage relative abundance. nd = no dimensions.

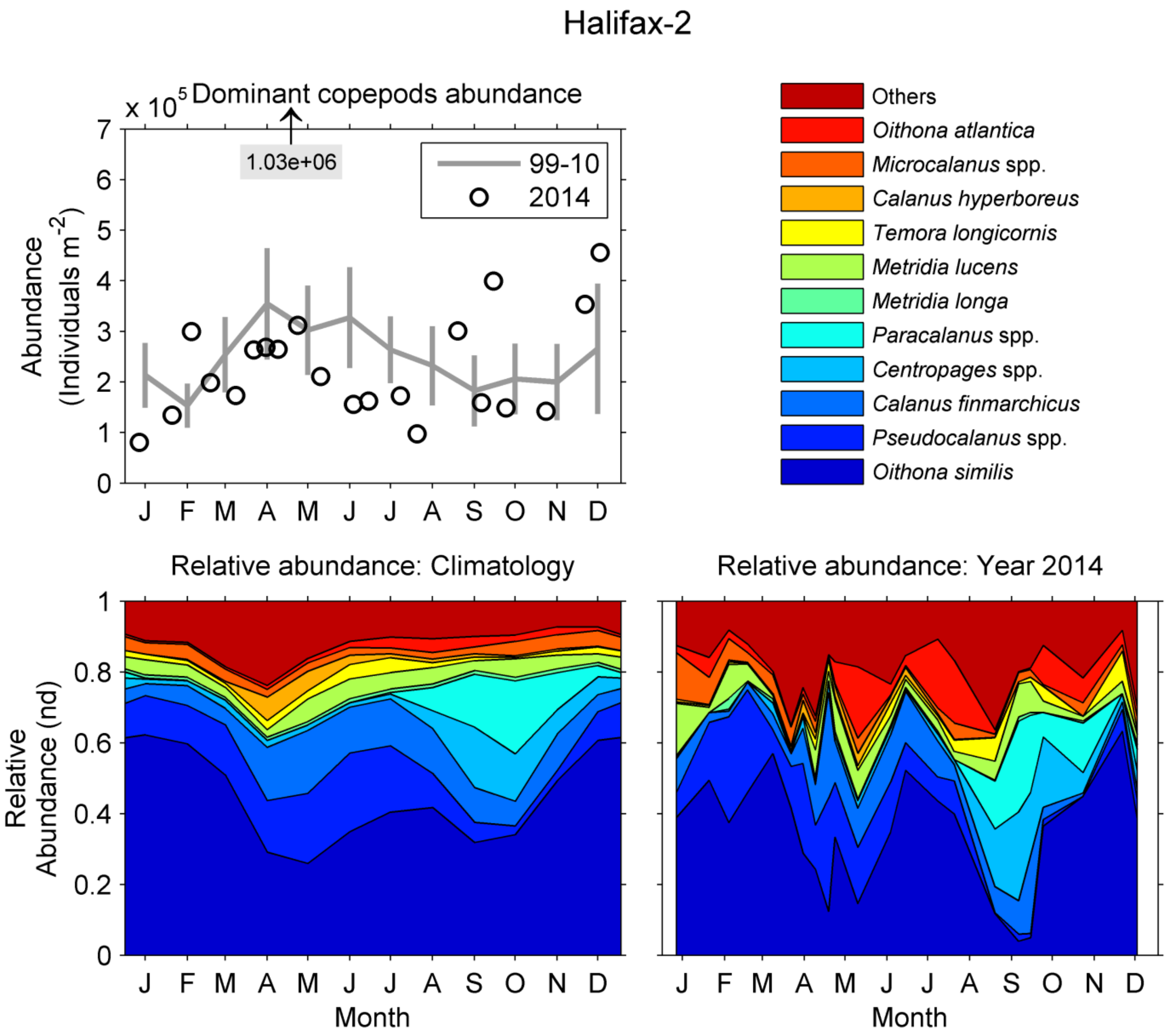


Figure 20a. Seasonal variability of dominant copepods at Halifax-2. The top 95% of identified copepod taxa by abundance, 1999-2010, are shown individually; others, including unidentified copepods (mostly nauplii) are grouped as "others." Upper left panel: 2014 copepod abundance (open circle) compared with mean conditions from 1999-2010 (solid line). Vertical lines are 95% confidence intervals of the monthly means. Lower left panel: Climatology of copepod relative abundance from 1999-2010. Lower right panel: 2014 copepod relative abundance. nd = no dimensions.

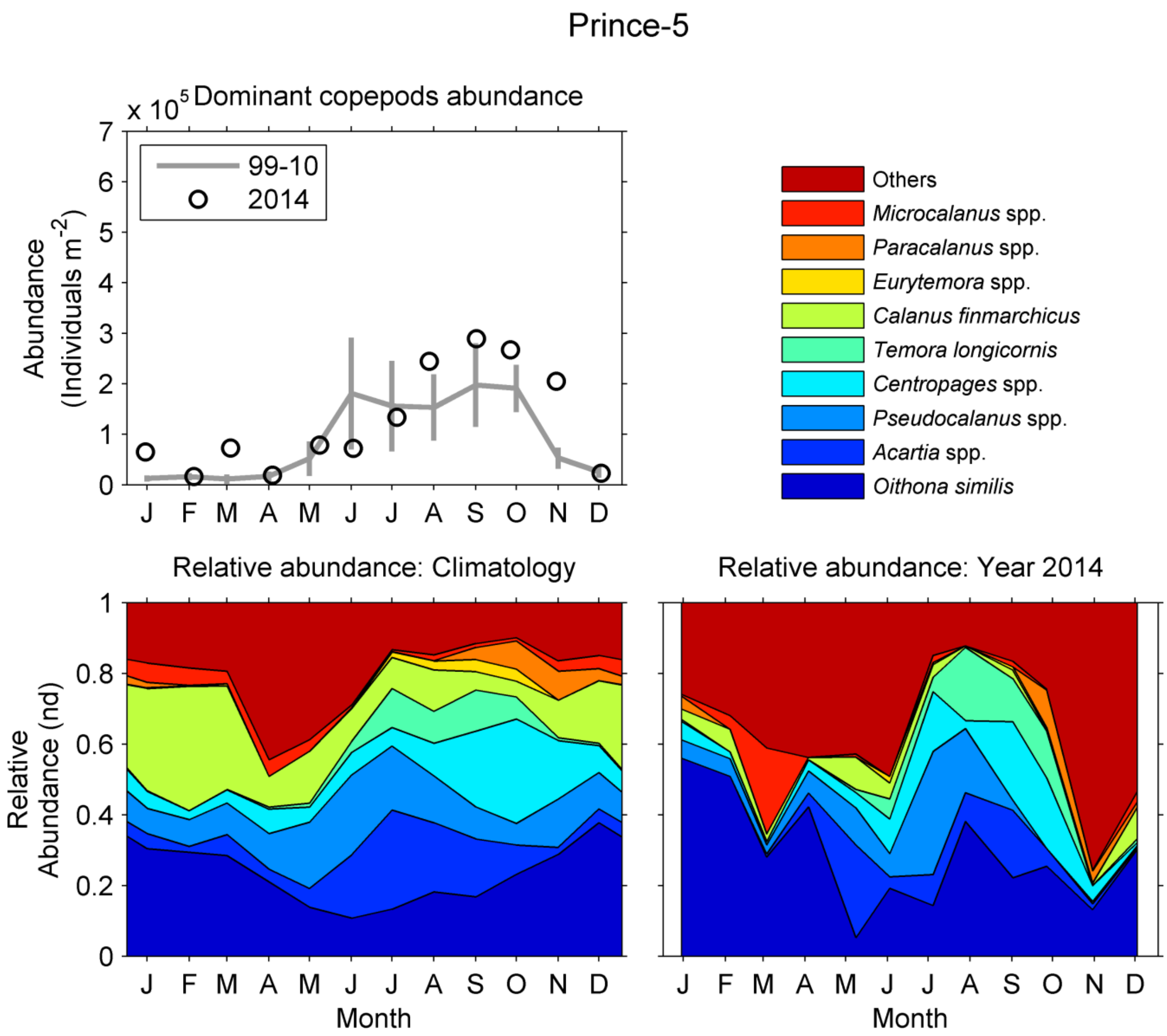


Figure 20b. Seasonal variability of dominant copepods at Prince-5. The top 95% of identified copepod taxa by abundance, 1999-2010, are shown individually; others, including unidentified copepods (mostly nauplii) are grouped as "others." Upper left panel: 2014 copepod abundance (open circle) compared with mean conditions from 1999-2010 (solid line). Vertical lines are 95% confidence intervals of the monthly means. Lower left panel: Climatology of copepod relative abundance from 1999-2010. Lower right panel: 2014 copepod relative abundance. nd = no dimensions.

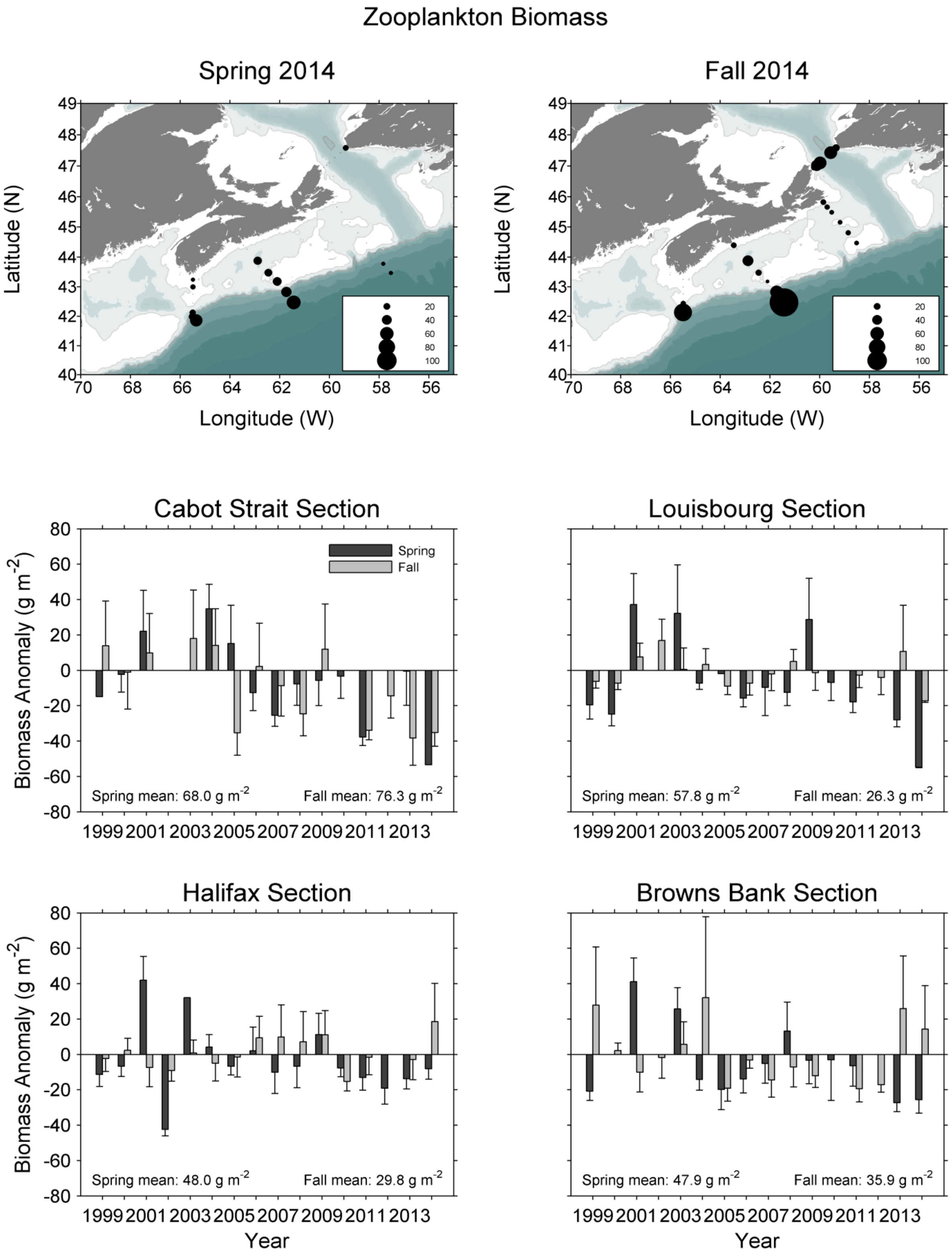


Figure 21. Spatial distribution of zooplankton biomass in 2014 (upper panels) and time series of zooplankton biomass anomalies on Scotian Shelf sections (middle and lower panels) in spring and fall, 1999-2014. Vertical lines in lower panels represent standard error.

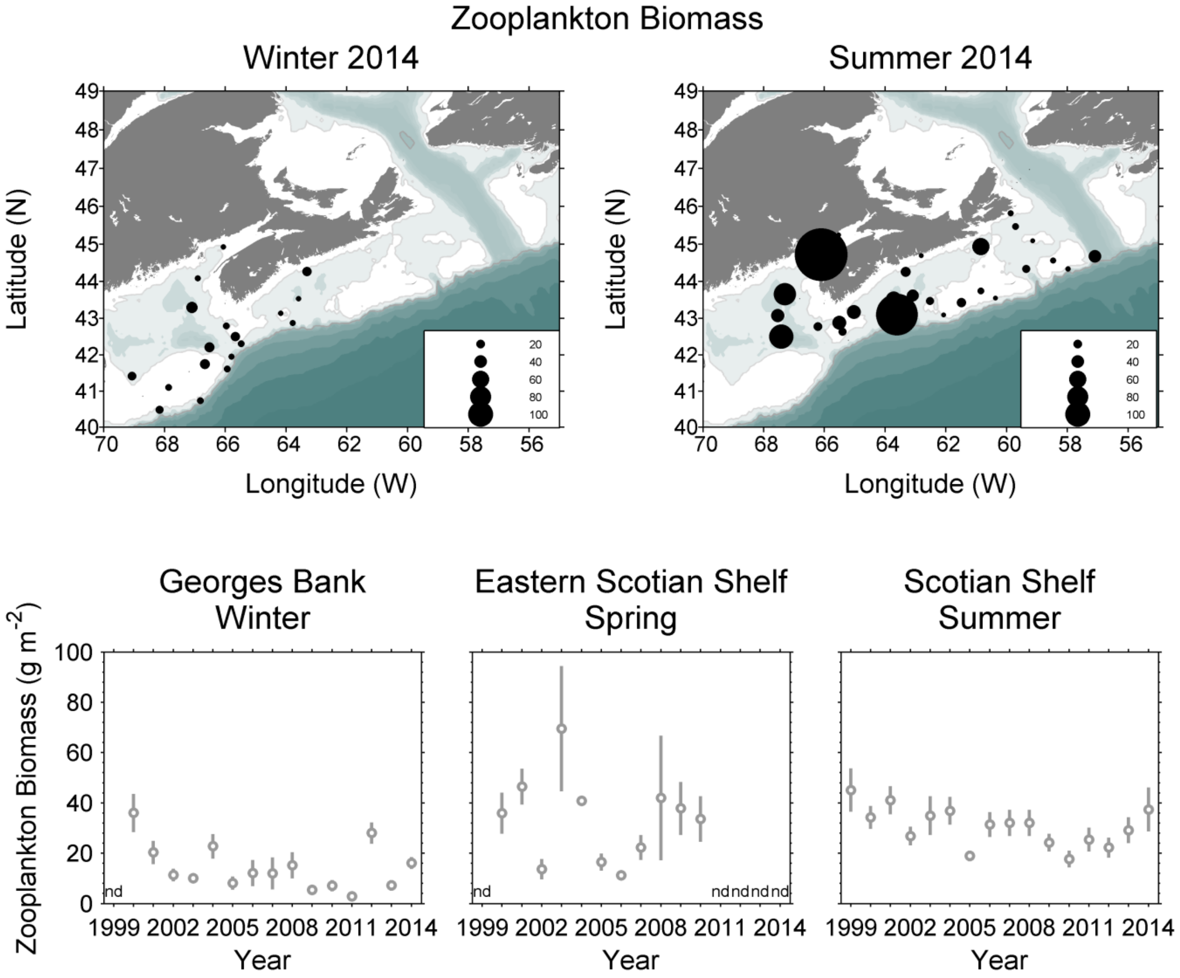


Figure 22. Zooplankton biomass from ecosystem trawl surveys on Georges Bank (February), the Eastern Scotian Shelf (March) and the Scotian Shelf and eastern Gulf of Maine (summer): upper panels show 2014 spatial distributions, lower panels show survey mean biomass, 1999-2014 (vertical lines are standard errors; nd = no survey in that year).

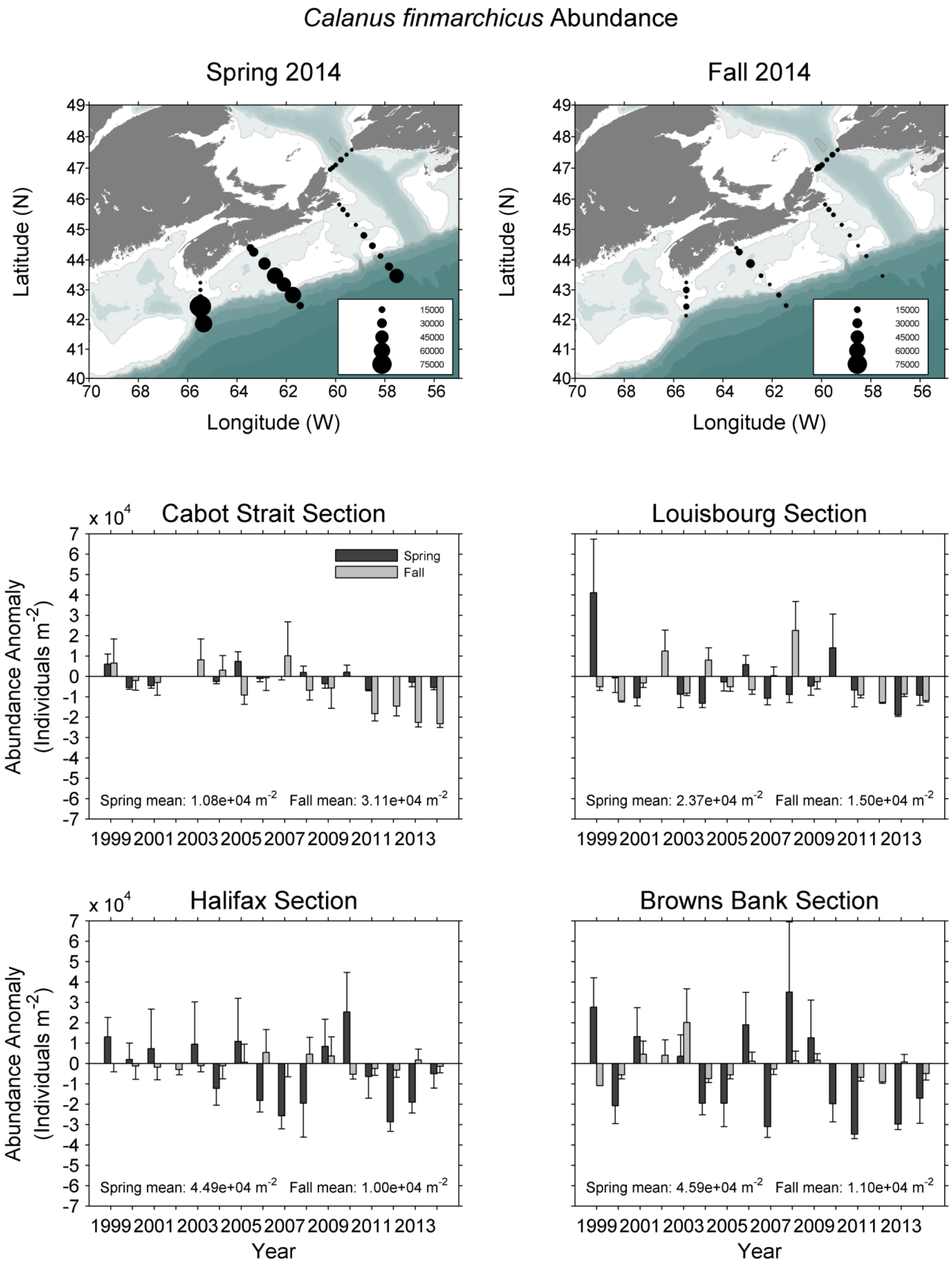


Figure 23. Spatial distribution of C. finmarchicus abundance in 2014 (upper panels) and time series of average C. finmarchicus abundance anomalies on Scotian Shelf sections (middle and lower panels) in spring and fall, 1999-2014. Vertical lines in lower panels represent standard error.

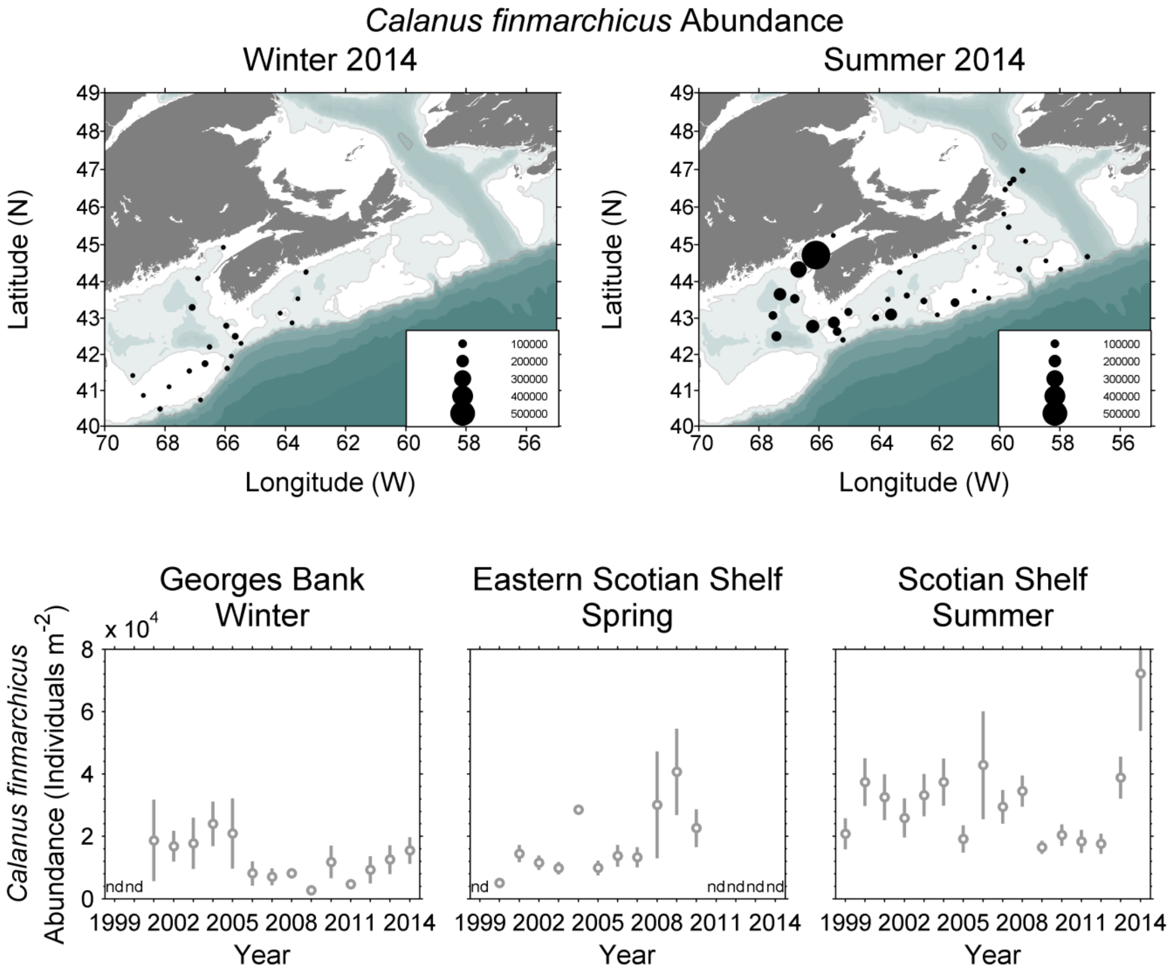
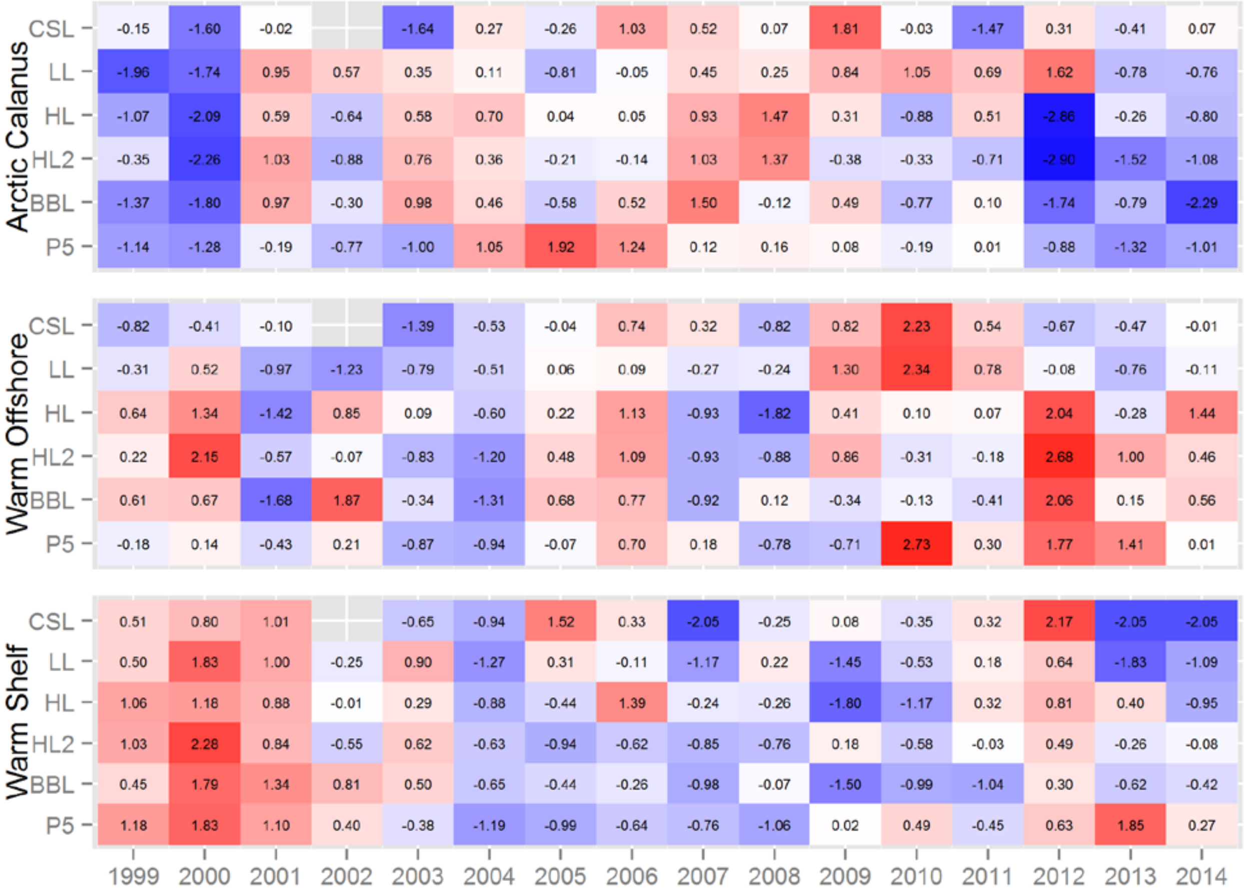


Figure 24. C. finmarchicus abundance from ecosystem trawl surveys on Georges Bank (February), the Eastern Scotian Shelf (March) and the Scotian Shelf and eastern Gulf of Maine (summer): upper panels show 2014 spatial distributions, lower panels show survey mean abundance, 1999–2014 (vertical bars are standard errors; nd = no survey in that year).



		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Arctic Calanus	CSL	-0.15	-1.60	-0.02		-1.64	0.27	-0.26	1.03	0.52	0.07	1.81	-0.03	-1.47	0.31	-0.41	0.07
	LL	-1.96	-1.74	0.95	0.57	0.35	0.11	-0.81	-0.05	0.45	0.25	0.84	1.05	0.69	1.62	-0.78	-0.76
	HL	-1.07	-2.09	0.59	-0.64	0.58	0.70	0.04	0.05	0.93	1.47	0.31	-0.88	0.51	-2.86	-0.26	-0.80
	HL2	-0.35	-2.26	1.03	-0.88	0.76	0.36	-0.21	-0.14	1.03	1.37	-0.38	-0.33	-0.71	-2.90	-1.52	-1.08
	BBL	-1.37	-1.80	0.97	-0.30	0.98	0.46	-0.58	0.52	1.50	-0.12	0.49	-0.77	0.10	-1.74	-0.79	-2.29
	P5	-1.14	-1.28	-0.19	-0.77	-1.00	1.05	1.92	1.24	0.12	0.16	0.08	-0.19	0.01	-0.88	-1.32	-1.01
Warm Offshore	CSL	-0.82	-0.41	-0.10		-1.39	-0.53	-0.04	0.74	0.32	-0.82	0.82	2.23	0.54	-0.67	-0.47	-0.01
	LL	-0.31	0.52	-0.97	-1.23	-0.79	-0.51	0.06	0.09	-0.27	-0.24	1.30	2.34	0.78	-0.08	-0.76	-0.11
	HL	0.64	1.34	-1.42	0.85	0.09	-0.60	0.22	1.13	-0.93	-1.82	0.41	0.10	0.07	2.04	-0.28	1.44
	HL2	0.22	2.15	-0.57	-0.07	-0.83	-1.20	0.48	1.09	-0.93	-0.88	0.86	-0.31	-0.18	2.68	1.00	0.46
	BBL	0.61	0.67	-1.68	1.87	-0.34	-1.31	0.68	0.77	-0.92	0.12	-0.34	-0.13	-0.41	2.06	0.15	0.56
	P5	-0.18	0.14	-0.43	0.21	-0.87	-0.94	-0.07	0.70	0.18	-0.78	-0.71	2.73	0.30	1.77	1.41	0.01
Warm Shelf	CSL	0.51	0.80	1.01		-0.65	-0.94	1.52	0.33	-2.05	-0.25	0.08	-0.35	0.32	2.17	-2.05	-2.05
	LL	0.50	1.83	1.00	-0.25	0.90	-1.27	0.31	-0.11	-1.17	0.22	-1.45	-0.53	0.18	0.64	-1.83	-1.09
	HL	1.06	1.18	0.88	-0.01	0.29	-0.88	-0.44	1.39	-0.24	-0.26	-1.80	-1.17	0.32	0.81	0.40	-0.95
	HL2	1.03	2.28	0.84	-0.55	0.62	-0.63	-0.94	-0.62	-0.85	-0.76	0.18	-0.58	-0.03	0.49	-0.26	-0.08
	BBL	0.45	1.79	1.34	0.81	0.50	-0.65	-0.44	-0.26	-0.98	-0.07	-1.50	-0.99	-1.04	0.30	-0.62	-0.42
	P5	1.18	1.83	1.10	0.40	-0.38	-1.19	-0.99	-0.64	-0.76	-1.06	0.02	0.49	-0.45	0.63	1.85	0.27

Figure 25. Immigrant species group scorecard: time series of zooplankton community index normalized annual anomalies, 1999-2014. 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.

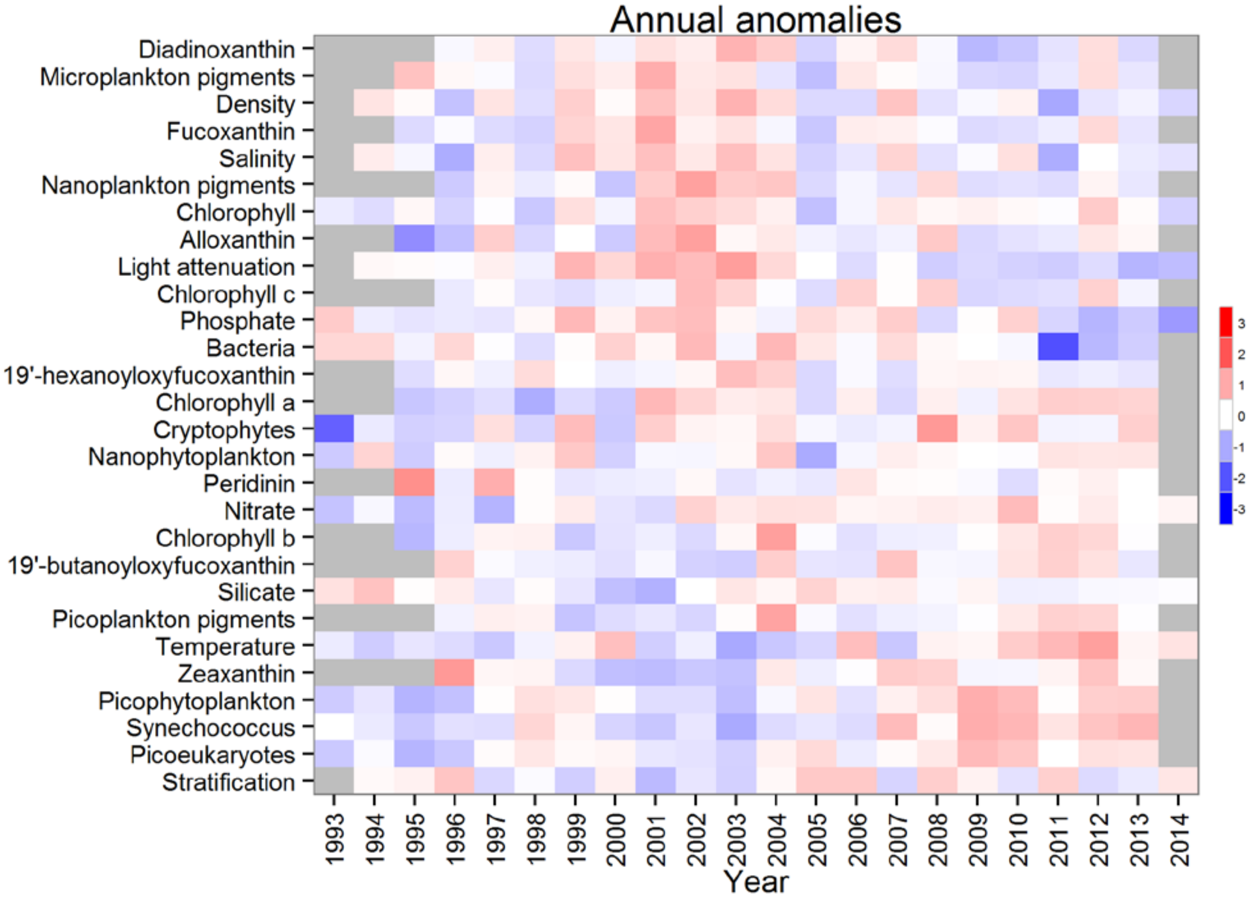


Figure 26. Environmental scorecard for Bedford Basin, 1993-2014. System variables are ordered for display according to their first principal component loadings for the 1993-2013 period.

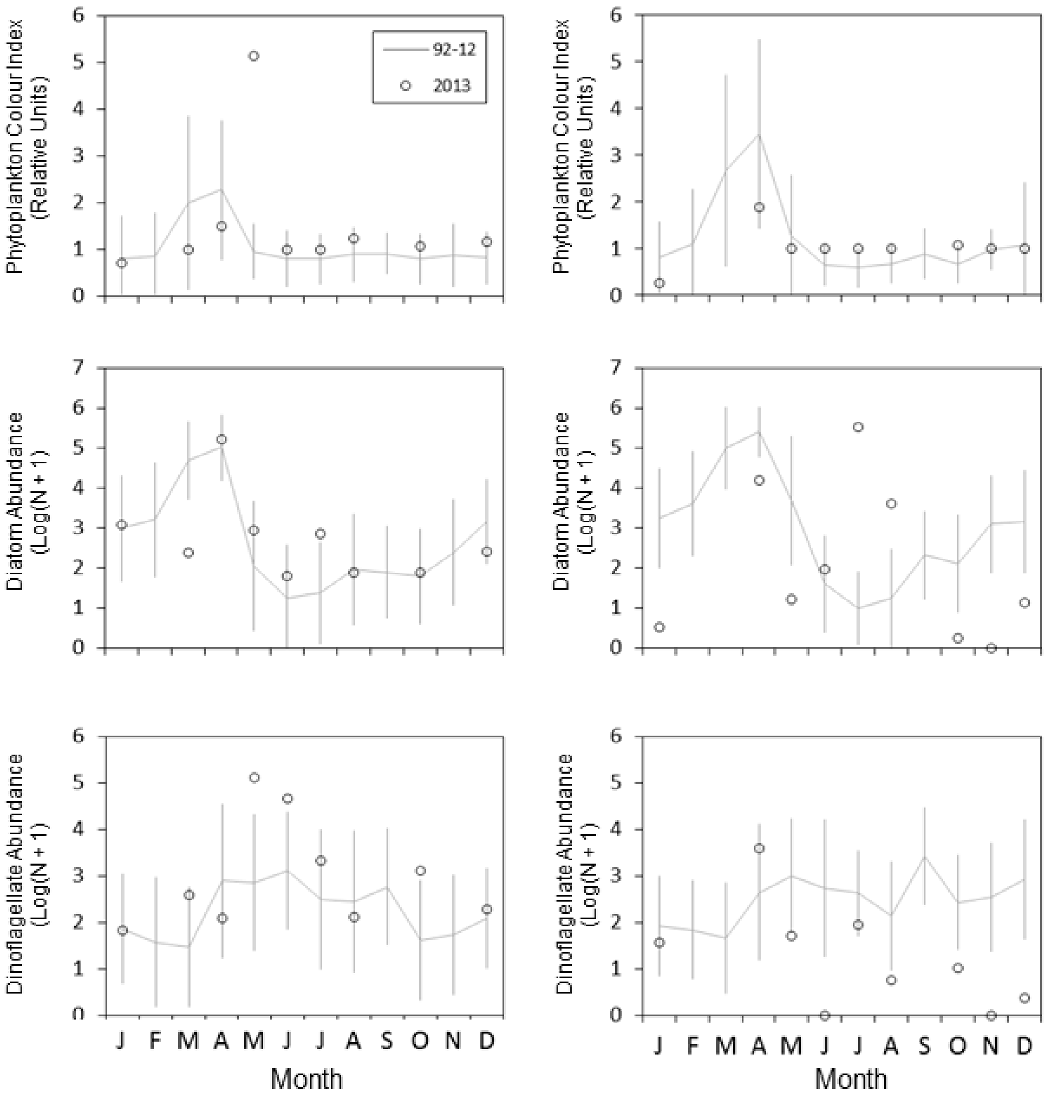
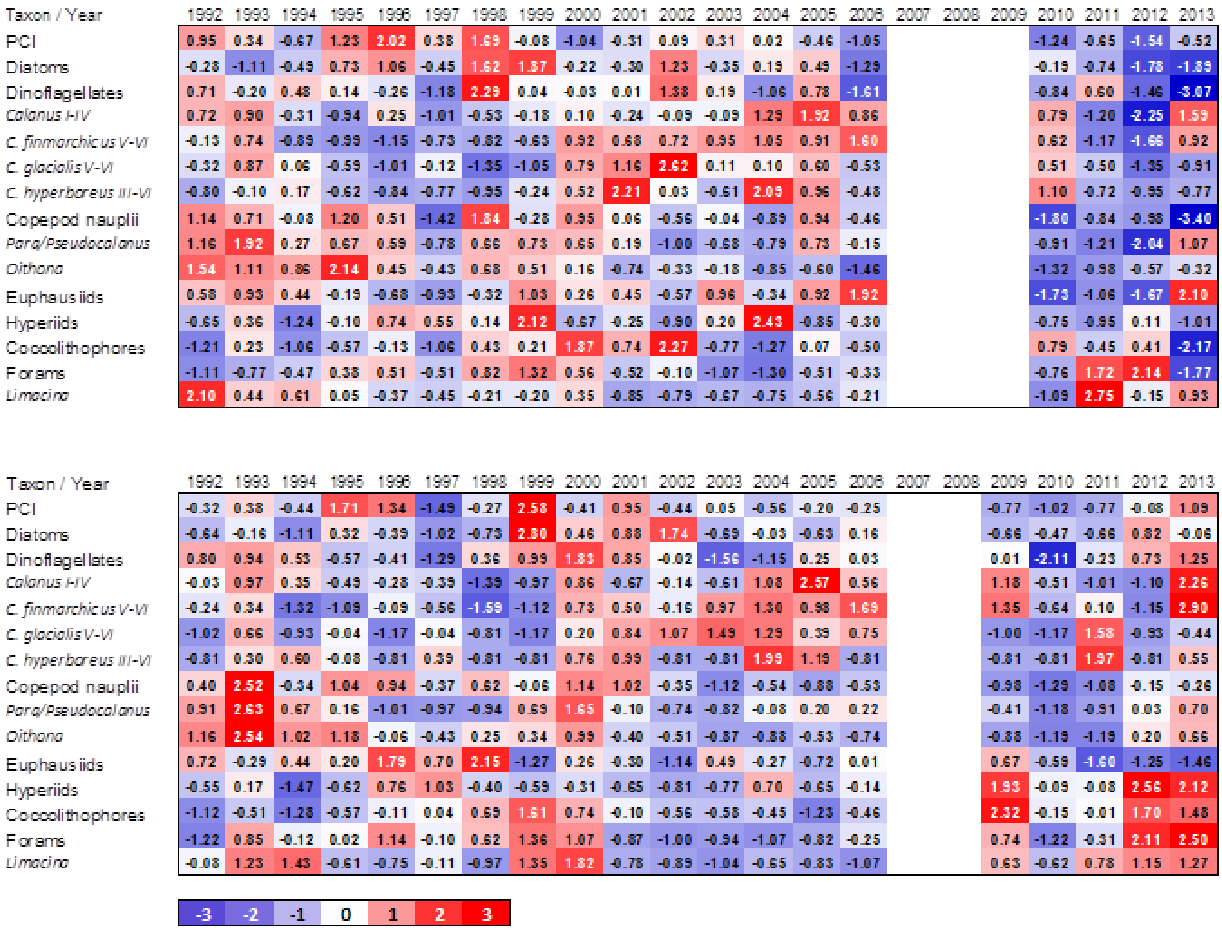


Figure 27. Comparison of 2013 (open circles) CPR phytoplankton abundance indices with mean conditions from 1992-2012 (solid line) on the Western Scotian Shelf (left-hand column) and Eastern Scotian Shelf (right-hand column). Vertical lines show the standard deviations of the monthly averages.



Taxon / Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
PCI	0.95	0.34	-0.67	1.23	2.02	0.38	1.69	-0.08	-1.04	-0.31	0.09	0.31	0.02	-0.46	-1.05				-1.24	-0.65	-1.54	-0.52
Diatoms	-0.28	-1.11	-0.49	0.73	1.06	-0.45	1.62	1.87	-0.22	-0.30	1.23	-0.35	0.19	0.49	-1.29				-0.19	-0.74	-1.78	-1.89
Dinoflagellates	0.71	-0.20	0.48	0.14	-0.26	-1.18	2.29	0.04	-0.03	0.01	1.38	0.19	-1.06	0.78	-1.61				-0.84	0.60	-1.46	-3.07
Calanus I-IV	0.72	0.90	-0.31	-0.94	0.25	-1.01	-0.53	-0.18	0.10	-0.24	-0.09	-0.09	1.29	1.92	0.86				0.79	-1.20	-2.25	1.59
C. finmarchicus V-VI	-0.13	0.74	-0.89	-0.99	-1.15	-0.73	-0.82	-0.63	0.92	0.68	0.72	0.95	1.05	0.91	1.60				0.62	-1.17	-1.66	0.92
C. glacialis V-VI	-0.32	0.87	0.06	-0.59	-1.01	-0.12	-1.35	-1.05	0.79	1.16	2.62	0.11	0.10	0.60	-0.53				0.51	-0.50	-1.35	-0.91
C. hyperboreus III-VI	-0.80	-0.10	0.17	-0.62	-0.84	-0.77	-0.95	-0.24	0.52	2.21	0.03	-0.61	2.09	0.96	-0.48				1.10	-0.72	-0.95	-0.77
Copepod nauplii	1.14	0.71	-0.08	1.20	0.51	-1.42	1.84	-0.28	0.95	0.06	-0.56	-0.04	-0.89	0.94	-0.46				-1.80	-0.84	-0.98	-3.40
Para/Pseudocalanus	1.16	1.92	0.27	0.67	0.59	-0.78	0.66	0.73	0.65	0.19	-1.00	-0.68	-0.79	0.73	-0.15				-0.91	-1.21	-2.04	1.07
Oithona	1.54	1.11	0.86	2.14	0.45	-0.43	0.68	0.51	0.16	-0.74	-0.33	-0.18	-0.85	-0.60	-1.46				-1.32	-0.98	-0.57	-0.32
Euphausiids	0.58	0.93	0.44	-0.19	-0.68	-0.93	-0.32	1.03	0.26	0.45	-0.57	0.96	-0.34	0.92	1.92				-1.73	-1.06	-1.67	2.10
Hyperiids	-0.65	0.36	-1.24	-0.10	0.74	0.55	0.14	2.12	-0.67	-0.25	-0.90	0.20	2.43	-0.85	-0.30				-0.75	-0.95	0.11	-1.01
Coccolithophores	-1.21	0.23	-1.06	-0.57	-0.13	-1.06	0.43	0.21	1.87	0.74	2.27	-0.77	-1.27	0.07	-0.50				0.79	-0.45	0.41	-2.17
Forams	-1.11	-0.77	-0.47	0.38	0.51	-0.51	0.82	1.32	0.56	-0.52	-0.10	-1.07	-1.30	-0.51	-0.33				-0.76	1.72	2.14	-1.77
Limacina	2.10	0.44	0.61	0.05	-0.37	-0.45	-0.21	-0.20	0.35	-0.85	-0.79	-0.67	-0.75	-0.56	-0.21				-1.09	2.75	-0.15	0.93

Taxon / Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
PCI	-0.32	0.38	-0.44	1.71	1.34	-1.49	-0.27	2.58	-0.41	0.95	-0.44	0.05	-0.56	-0.20	-0.25			-0.77	-1.02	-0.77	-0.08	1.09
Diatoms	-0.64	-0.16	-1.11	0.32	-0.39	-1.02	-0.73	2.80	0.46	0.88	1.74	-0.69	-0.03	-0.63	0.16			-0.66	-0.47	-0.66	0.82	-0.06
Dinoflagellates	0.80	0.94	0.53	-0.57	-0.41	-1.29	0.36	0.99	1.83	0.85	-0.02	-1.56	-1.15	0.25	0.03			0.01	-2.11	-0.23	0.73	1.25
Calanus I-IV	-0.03	0.97	0.35	-0.49	-0.28	-0.39	-1.39	-0.97	0.86	-0.67	-0.14	-0.61	1.08	2.57	0.56			1.18	-0.51	-1.01	-1.10	2.26
C. finmarchicus V-VI	-0.24	0.34	-1.32	-1.09	-0.09	-0.56	-1.59	-1.12	0.73	0.50	-0.16	0.97	1.30	0.98	1.69			1.35	-0.64	0.10	-1.15	2.90
C. glacialis V-VI	-1.02	0.66	-0.93	-0.04	-1.17	-0.04	-0.81	-1.17	0.20	0.84	1.07	1.49	1.29	0.39	0.75			-1.00	-1.17	1.58	-0.93	-0.44
C. hyperboreus III-VI	-0.81	0.30	0.60	-0.08	-0.81	0.39	-0.81	-0.81	0.76	0.99	-0.81	-0.81	1.99	1.19	-0.81			-0.81	-0.81	1.97	-0.81	0.55
Copepod nauplii	0.40	2.52	-0.34	1.04	0.94	-0.37	0.62	-0.06	1.14	1.02	-0.35	-1.12	-0.54	-0.88	-0.53			-0.98	-1.29	-1.08	-0.15	-0.26
Para/Pseudocalanus	0.91	2.63	0.67	0.16	-1.01	-0.97	-0.94	0.69	1.65	-0.10	-0.74	-0.82	-0.08	0.20	0.22			-0.41	-1.18	-0.91	0.03	0.70
Oithona	1.16	2.54	1.02	1.18	-0.06	-0.43	0.25	0.34	0.99	-0.40	-0.51	-0.87	-0.88	-0.53	-0.74			-0.88	-1.19	-1.19	0.20	0.66
Euphausiids	0.72	-0.29	0.44	0.20	1.79	0.70	2.15	-1.27	0.26	-0.30	-1.14	0.49	-0.27	-0.72	0.01			0.67	-0.59	-1.60	-1.25	-1.46
Hyperiids	-0.55	0.17	-1.47	-0.62	0.76	1.03	-0.40	-0.59	-0.31	-0.65	-0.81	-0.77	0.70	-0.65	-0.14			1.93	-0.09	-0.08	2.56	2.12
Coccolithophores	-1.12	-0.51	-1.28	-0.57	-0.11	0.04	0.69	1.61	0.74	-0.10	-0.56	-0.58	-0.45	-1.23	-0.46			2.32	-0.15	-0.01	1.70	1.48
Forams	-1.22	0.85	-0.12	0.02	1.14	-0.10	0.62	1.36	1.07	-0.87	-1.00	-0.94	-1.07	-0.82	-0.25			0.74	-1.22	-0.31	2.11	2.50
Limacina	-0.08	1.23	1.43	-0.61	-0.75	-0.11	-0.97	1.35	1.82	-0.78	-0.89	-1.04	-0.65	-0.83	-1.07			0.63	-0.62	0.78	1.15	1.27

-3	-2	-1	0	1	2	3

Figure 28. DFO Maritimes Region CPR scorecard: time series for the annual averages for the abundances of phytoplankton and zooplankton taxa, 1992-2013, on the Eastern Scotian Shelf (upper panel) and Western Scotian Shelf (lower panel). Blank cells correspond to years where either there was sampling in 8 or fewer months, or years where there was a gap in sampling of 3 or more consecutive months. Red (blue) cells indicate higher (lower) than normal values. The references period is 1992-2012. The numbers in the cells are the standardised anomalies.

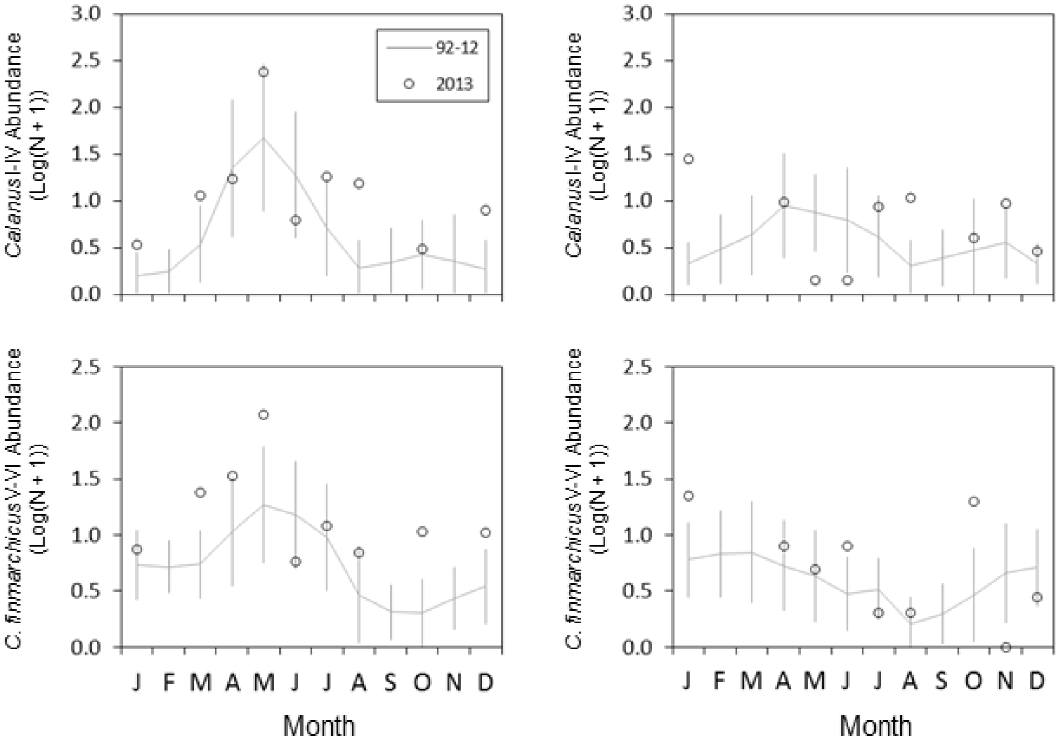


Figure 29. Comparison of 2013 (open circles) CPR abundance indices for Calanus I-IV (mostly C. finmarchicus, upper row) and C. finmarchicus V-VI (lower row) mean conditions from 1992-2012 (solid line) on the Western Scotian Shelf (left-hand column) and Eastern Scotian Shelf (right-hand column). Vertical lines show the standard deviations of the monthly averages.