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Maritimes Region

Optical, Chemical, and Biological Oceanographic Conditions on the Scotian Shelf and in the Eastern Gulf of Maine in 2015

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Foreword

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

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ABSTRACT

As warm and variable ocean conditions persisted in the Maritimes Region in 2015, there was increasing evidence of a shift in both phytoplankton and zooplankton communities away from the dominance of large phytoplankton and copepods toward smaller phytoplankton and copepod species. Although deep-water nitrate inventories were mainly higher than average in 2015, deep silicate and phosphate inventories were lower than average on the Scotian Shelf for the third year in a row. The spring bloom started later than normal and was weaker in magnitude and shorter in duration than usual. Phytoplankton biomass anomalies were mixed across the Shelf, but the abundance of large phytoplankton, particularly diatoms, was lower than average, continuing a pattern started in 2009. The abundance of the biomass-dominant copepod species *Calanus finmarchicus* and zooplankton biomass overall were lower than average overall in 2015, as was the abundance of Arctic *Calanus* species, continuing a pattern started during the last 4-7 years. In contrast, the abundances of offshore copepods were higher than average. Changes in phytoplankton and zooplankton communities observed in recent years indicate poor feeding conditions for planktivorous fish, birds, and mammals. Continuous Plankton Recorder sampling, the reporting of which lags Atlantic Zone Monitoring Program sampling by one year, indicated that in 2014 the spring phytoplankton bloom occurred earlier and was of shorter duration than normal over the entire Scotian Shelf and that the springtime peaks in abundance of the dominant zooplankton taxa *Calanus* I-IV and *C. finmarchicus* V-VI were also relatively early and relatively short-lived. 2014 annual abundance anomalies were unusually high for hyperiid amphipods and foraminifera over the entire Scotian Shelf in 2014, and unusually low for euphausiids. Annual abundance anomalies for most other taxa were at near normal levels on the western Scotian Shelf and below normal levels on the eastern Scotian Shelf.

Conditions océanographiques optiques, chimiques et biologiques sur le plateau néo écossais et dans l'est du golfe du Maine en 2015

RÉSUMÉ

Les conditions océaniques clémentes et variables ayant persisté dans la région des Maritimes en 2015 ont contribué à mettre en évidence le changement au niveau des communautés de phytoplancton et de zooplancton normalement dominées par les espèces plus imposantes de phytoplancton et de copépodes à la faveur d'espèces de phytoplancton et de copépodes de taille inférieure. Bien que l'inventaire de nitrate d'eau profonde était majoritairement supérieur à la moyenne en 2015, ceux de silicate et de phosphate d'eau profonde étaient inférieurs à la moyenne sur le plateau néo-écossais pour une troisième année consécutive. La floraison printanière du phytoplancton a débuté plus tard que la normale et a été plus faible en amplitude et d'une durée plus courte que la normale. L'anomalie de la biomasse du phytoplancton était variable sur le plateau, mais l'abondance du gros phytoplancton, en particulier des diatomées, était inférieure à la moyenne, poursuivant ainsi une tendance a amorcée en 2009. La biomasse totale de zooplancton ainsi que l'abondance de *Calanus finmarchicus*, espèce dominante de la biomasse de zooplancton, étaient inférieures à la moyenne en 2015, tout comme l'abondance des espèces de *Calanus* arctiques, poursuivant une tendance amorcée durant les 4 à 7 dernières années. En revanche, l'abondance des copépodes extracôtiers était plus élevée que la moyenne. Les changements dans les communautés de phytoplancton et de zooplancton observées au cours des dernières années indiquent des conditions déficientes d'alimentation pour les poissons, oiseaux, et mammifères planctivores. Les données d'échantillonnage à l'aide d'enregistreurs de plancton en continu, dont la disponibilité est décalée d'une année par rapport au Programme de Monitorage de la Zone Atlantique, ont indiqué qu'en 2014, la floraison printanière du phytoplancton a eu lieu plus tôt et était d'une durée plus courte que la normale sur l'ensemble du plateau néo-écossais, et que les pointes printanières de l'abondance des espèces dominantes *Calanus* I-IV et *C. finmarchicus* V-VI ont également été relativement précoces et relativement de courte durée. L'anomalie annuelle de l'abondance des amphipodes hypéridés et des foraminifères était anormalement élevée sur l'ensemble du plateau néo-écossais en 2014, et exceptionnellement basse pour les euphausiacés. L'anomalie annuelle de l'abondance des autres espèces était à des niveaux près de la normale sur le le plateau néo-écossais de l'ouest et en dessous des niveaux normaux sur le le plateau néo-écossais de le plateau néo-écossais de l'est.

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 2015. It complements similar assessments for the physical environment of the Maritimes Region (e.g., Hebert et al. 2016), for the pelagic environment in the Gulf of St. Lawrence (e.g., Devine et al. 2015, Galbraith et al. 2016), for the Newfoundland and Labrador shelves and the Grand Banks (e.g., Colbourne et al. 2015, Pepin et al. 2015), and for the Canadian Northwest Atlantic shelf system as a whole (DFO 2016).

The Scotian Shelf is located in a transition zone influenced by both sub-polar waters, mainly flowing into the region from the Gulf of St. Lawrence and the Newfoundland Shelf, and warmer offshore waters. The deep-water properties of the western Scotian Shelf (WSS) are strongly variable, reflecting shifts in the source of deep slope water to the shelf between cold, lower nutrient Labrador Slope Water (LSW), and more nutrient rich Warm Slope Water (WSW) that can be driven by changes in large-scale atmospheric pressure patterns (Petrie 2007). Temperature and salinity on the Scotian 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 (2010-2015) warmer than average overall (Hebert et al. 2016). In 2015, positive sea surface temperature (SST) anomalies were most pronounced in the early winter and in the second half of the year, while SST anomalies were negative or near-normal in the region in late winter and spring. Following very low ice conditions in 2010-2013, sea ice coverage was above normal in 2014-2015. Bottom temperatures surveyed in July were above average across nearly the entire Scotian Shelf, and strong subsurface temperature anomalies were observed in eastern and central Scotian slope waters. Ocean stratification has shown an increasing trend on the Scotian Shelf since the 1950s, driven both by warmer temperatures and lower salinity, but in 2015, the Scotian Shelf stratification index was slightly below the 1981-2010 average (Hebert et al. 2016). Here, is reported the status of nutrients and plankton in the region in 2015 and discuss nutrient and plankton observations in the context of changing physical conditions of the marine environment.

METHODS

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

MISSIONS

AZMP-DFO Maritimes Region sea-going staff participated in 5 missions (seasonal section cruises, ecosystem trawl surveys, and Halifax section sampling on a mission to the Labrador Sea) during the 2015 calendar year, in addition to day-trips to the 2 fixed stations. In 2015, AZMP Maritimes performed a total of 441 hydrographic station occupations, at 229 of which net samples were collected (Table 1).

Fixed Stations

The Halifax-2 and Prince-5 fixed stations (Figure 1) were sampled on 23 and 12 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, and photosynthetically active radiation (PAR),
- 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), except for Cabot Strait for which spring sampling was cancelled due to a combination of operational issues and ice conditions in the area. Results from the additional sections/stations and from the 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 standard suite of analyses from water samples, 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 Region participated in two primary ecosystem trawl surveys in 2015: the late winter (March) Georges Bank survey and the summer (July-August) Scotian Shelf/eastern Gulf of Maine survey (Figure 3). These surveys were led 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, but the standard set of water bottle sampling depths is more limited, and vertical ring net tows (202 µm mesh net) are collected at only at a subset of stations (Figure 3).

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). Bottom oxygen concentrations were optimally interpolated using the same technique as for nitrate. Oxygen concentrations were measured using a CTD-mounted oxygen sensor which was calibrated against oxygen concentrations measured by Winkler titration. Anomalies of bottom oxygen are not presented here, as the quality of oxygen data collected prior to 2015 is under review.

GEAR DEPLOYMENT

Conductivity, Temperature, Depth (CTD)

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

Standard depths for water samples include:

- Fixed stations:
    1. Halifax-2: 1, 5, 10, 20, 30, 40, 50, 75, 100, 140 m,
    2. 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/s. 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 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 from *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 $K_{d\text{-}Secchi}$ from Secchi disc observations was found using:

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

   where Z_{sd} = depth in m at which the Secchi disc disappears from view (Holmes 1970).

The estimate of euphotic depth (Z_{eu}) was made using the following expression:

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

VERTICALLY INTEGRATED VARIABLES

Integrated chlorophyll and nutrient inventories 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 the National Aeronautics and Space Administration (NASA) in late summer 1997, the Moderate Resolution Imaging Spectroradiometer (MODIS) “Aqua” sensor[2] launched by NASA in July 2002 and the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor[3] launched by NASA and the National Oceanic and Atmospheric Administration (NOAA) in October 2011. Here, VIIRS data for 2015 (January to December) were combined with MODIS data from January 2008 to December 2014 and SeaWiFS data from January 1998 to December 2007 to construct composite time series of surface chlorophyll in selected sub-regions (Figure 4). Basic statistics (mean, standard

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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 February 6, 2017).

[2] Additional information about the MODIS sensor can be found on the NASA MODIS website (accessed February 6, 2017).

[3] Additional information about the VIIRS sensor can be found on the NASA VIIRS website (accessed February 6, 2017).

deviation) were extracted from semi-monthly composites for the sub-regions. Characteristics of the spring bloom were estimated from satellite data using the shifted Gaussian function of time model (Zhai et al. 2011). Four metrics were computed to describe the spring bloom characteristics: start date (day of year), cycle duration (days), magnitude (the integral of chlorophyll concentration under the Gaussian curve), and amplitude (maximum chlorophyll).

SCORECARD

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

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

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

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, 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 a given taxon were counted in the sample. Average integrated inventories of nutrients and chlorophyll were not log-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 the abundance of dominant copepod species and groups (*C. finmarchicus*, *Pseudocalanus* spp., total copepods, and total non-copepods) are produced in each of the AZMP regions, including the Maritimes. To visualize northwest Atlantic shelf scale patterns of environmental variation, a zonal scorecard including observations from all of the AZMP regions is presented in DFO (2016).

DATA PRODUCTS

Data products presented in figures (6, 8, 10, 11, 15-18, 20-28) are available at the Atlantic Zone Monitoring Program (AZMP) website in the “Research Document Data” link under the “Data and Products” heading. To access the compressed files containing the data, click on the “Scotian Shelf and Eastern Gulf of Maine” link and then click on the document citation to reveal a drop-down menu containing data downloads. Each compressed file contains a text file with the data required to reproduce the figure, a meta-data text file describing the terms of use and field heading descriptions, and a PDF file of the figure. Chlorophyll bi-weekly estimates and climatologies presented in Figure 19 are available at the DFO Maritimes SeaWiFS FTP website, MODIS FTP website and VIIRS 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 Newfoundland region, while data collected in all regions and all decades (i.e. including the four regions in the sub-polar gyre east of 45° W) are presented in annual Atlantic Zone Offshore Monitoring Program (AZOMP) reports. CPR data collected from January to December 2014 were received in January 2016 and added to the DFO data archive. In 2014, there was no CPR sampling in January on the WSS, and none on the ESS in January, June or October.

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 1992-2010, and these are compared with values in 2014 for three 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.

OBSERVATIONS

MIXING AND OPTICAL PROPERTIES

At Halifax-2, stratification is lowest and the 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 2015, MLDs at Halifax-2 followed the typical annual pattern with higher variability observed during the winter months and values closer to the climatology during the summer months (Figure 6). Stratification was mostly weaker than normal at Halifax-2 during winter and spring 2015 (though within the 95% confidence interval) and mostly stronger than normal during the summer and early fall. Transient shoaling of the mixed layer and a corresponding temporary increase in the stratification index were observed in February (sampling date of February 18, 2015).

At Prince-5, the MLD is deeper and more variable and stratification is weaker 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 the MLD varies from nearly full depth (90 m) in winter to approximately 40 m in summer (Figure 6). In 2015, MLDs were markedly deeper than normal during the first half of the year, shallower than normal in July and August, and about average in the last four months of the year. The stratification index at Prince-5 exhibited typical low values in 2015, with lower than normal stratification in April when the index would typically rise, suggesting delayed onset of stratification in 2015.

Wind-driven mixing may have contributed to deep MLDs in the first half of the year. High-wind events occurred in the winter at both Halifax Airport, a proxy for Halifax-2, and at Grand Manan, a proxy for Prince-5, with daily maximum wind gusts well above the climatology values (1998-2010 average; Figure 7). These episodic wind events continued well into late spring (mid-June) at Halifax-2, whereas the pattern returned to more typical conditions at Prince-5 by mid-April. A strong wind event occurred mid-summer at Halifax-2, after which the wind remained above the climatological condition during most of the fall. At Prince-5, maximum daily wind speed remained below the climatological value for most of summer, fall, and winter except for a strong wind event in mid-September. At Halifax-2, the fall wind conditions were similar to the climatology.

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. The highest attenuation and consequently shallowest euphotic depth based on PAR and Secchi disc measurements coincided with the April spring phytoplankton bloom observed at Halifax-2 in 2015 (Figure 8). Euphotic depths estimated from PAR measurements were shallower than those estimated from Secchi depth measurements at Halifax-2.

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 2015, both PAR-based and Secchi-based euphotic depths closely followed the climatological values throughout the year (Figure 8), except for two outliers for the PAR-based estimates in February and August. For these two profiles, the attenuation coefficient was calculated over a rather shallow water layer as the light measurements below 30-35 m were unreliable.

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 this reason and because the availability of nitrogen is most often associated with phytoplankton growth limitation in coastal waters of the Maritimes Region (DFO 2000), this report focuses mainly on variability patterns for nitrate, with information on silicate and phosphate concentrations presented mainly to help interpret microphytoplankton taxonomic group succession at Halifax-2 and Prince-5.

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 9). 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 surface nitrate inventory at Halifax-2 in 2015 was below normal in the summer and fall months (Figure 10) which corresponded with a deeper than normal nitricline observed in those months (Figure 9). The deep nitrate inventory at Halifax-2 in 2015 was above normal during the spring and summer months, associated with warmer and saltier deep water during this period (Hebert et al. 2016). 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 above normal as a result of the spring and summer above-normal concentrations (Figure 11). Surface phosphate and silicate anomalies exhibited negative trends similar to the one for surface nitrate, but the 2015 anomalies for deep phosphate and silicate inventories were null or negative while nitrate showed a positive anomaly (Figure 11). An interesting feature of the nutrient dynamics at Halifax-2 in 2015 was the relatively low concentration observed at mid-depth (approximately 75 m) in February (Figure 9), which was associated with an unusual and transient chlorophyll increase at the same time and depth (Figure 15).

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 9). 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 2015, the nitrate concentrations throughout the water column were lower than normal during winter and spring (Figure 9) with nitrate depletion starting earlier than usual (Figure 10). The surface nitrate inventory remained mostly lower than normal for the rest of the year while the deep nitrate inventory was close to normal levels during the second half of the year (Figure 9). Overall, both the surface and the deep nitrate inventories showed negative annual anomalies at Prince-5 in 2015 (Figure 17).

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 deep Emerald Basin on the Halifax section (Figure 12a, b). In spring 2015, low surface nitrate concentrations were observed along each section (Figure 12a) as a result of the timing of the sampling (April 17 to 27, 2015) closely coinciding the spring phytoplankton bloom as observed from remote sensing (Figure 4). Nitrate anomalies were spatially variable on the sections in spring 2015 (Figure 12a) but appeared to be dominantly positive on the inshore part of all sections, except for CSL for which no data were collected during that mission. During the fall mission (mid-September to mid-October), near-surface nitrate concentrations were at minimum values throughout the entire region with a fairly uniform nitricline depth along each section (Figure 12b). Nitrate anomalies were also spatially variable on the sections in fall 2015 (Figure 12b), but consistently positive below the nitricline on the CSL section. Overall, annual anomalies of deep water nitrate inventories were positive for all four sections, and both positive and negative annual anomalies were observed for the surface nitrate inventory (Figure 11). The bottom nitrate concentrations measured during the summer ecosystem trawl survey (late June to mid-August) showed predominantly positive anomalies on the eastern part of the Scotian Shelf, with the exception of the Banquereau area, and mostly negative anomalies in the eastern Gulf of Maine (Georges Basin) and in the Bay of Fundy (Figure 13).

The lowest oxygen saturation levels are typically observed in deep basins and deep slope waters, where nutrients are highest. In July 2015, bottom oxygen saturation values below 60% were observed mainly in and around the deep basins of the central Scotian Shelf (Figure 14), where the bottom waters were warmest (Hebert et al. 2016).

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 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 2015, the spring bloom at Halifax-2 was characterized by a delayed initiation, a shorter duration and a higher intensity than normal (Figure 15). The bloom was contained within the top 50 m of the water column, consistent with the relatively shallow mixed layer observed in April (Figure 6) and thus, the 0-100 m integrated chlorophyll index somewhat under-represented the intensity of the bloom. The spring bloom was overwhelmingly dominated by diatoms (Figure 16). A well-defined summer sub-surface chlorophyll maximum, centered between 30 and 40 m, was observed with an intensity and duration above normal conditions (Figure 15). The integrated chlorophyll index does not resolve the summer sub-surface maximum due to its low intensity and limited vertical extent. Chlorophyll sub-surface maxima in summer and early fall were associated with higher relative abundances of flagellates (Figure 16). The fall phytoplankton bloom was late and weak but persisted from October to December. An unusual characteristic of the phytoplankton dynamic at Halifax-2 in 2015 was the temporary period of growth observed early in the year (February). This transitory event was rather unusual as it happened well ahead of the development of the spring bloom and deep within the water column (Figure 15). Overall, the annual integrated chlorophyll anomaly at Halifax-2 was positive in 2015 (Figure 17). Abundance anomalies of diatoms were negative in 2015, a pattern that started in 2009 and has been almost consistent since 2009 (Figure 18). At Halifax-2, anomalies of dinoflagellates, ciliates (microzooplankton), and flagellates have also been mainly negative since 2009, while at Prince-5, flagellates showed the same pattern. This decrease in large phytoplankton abundance is not reflected in the entire phytoplankton biomass since chlorophyll concentration shows a positive anomaly (Figure 17).

The spring phytoplankton bloom at Prince-5 in 2015 was earlier, deeper, and longer than normal (Figure 15). The chlorophyll concentrations observed during the spring bloom were higher than normal and extended deep into the water column (Figure 15), associated with deeper than usual mixing during the spring (Figure 6). Phytoplankton abundances were above normal during the spring bloom and were dominated by diatoms (Figure 16). The summer phytoplankton bloom was about a month earlier than normal but of normal duration (Figure 15). Maximum chlorophyll concentrations were similar to normal, but the vertical extent of the bloom was shallower than normal, resulting in a lower than normal 0-95 m integrated chlorophyll index during the summer and fall months. The phytoplankton community at Prince-5 is normally dominated year-round by diatoms, but their relative abundance was lower than normal at times of low phytoplankton abundance, when the relative abundance of dinoflagellates (winter and early fall) or ciliates (microzooplankton, late spring) was higher than normal (Figure 16 and Figure 18). Overall, the annual integrated chlorophyll anomaly at Prince-5 was positive in 2015 (Figure 17).

Broad-scale Surveys and Satellite Remote Sensing

Chlorophyll estimates based on satellite remote sensing data indicated later than normal spring bloom initiation in Scotian Shelf sub-regions and Cabot Strait (CS), but earlier than normal bloom initiation on Georges Bank (GB) in 2015 (Figure 19a, b). For CS, late bloom initiation was likely associated with the late departure of ice in the area (Hebert et al. 2016), which also forced the cancellation of *in situ* sampling in that area during the spring of 2015. The magnitude of the 2015 spring bloom, which is a measure of the intensity and duration of the spring bloom, was lower than normal in all sub-regions except for GB, where the bloom intensity was higher than normal. The late timing, short duration, and moderately strong peak of the spring bloom in the Central Scotian Shelf (CSS) sub-region were in agreement with bloom characteristics observed *in situ* at Halifax-2. While the timing of the spring bloom varies from year to year, there is no clear trend in the initiation or peak timing over the AZMP years (Figure 19a, b).

The timing and magnitude of summer and fall blooms are more variable than the spring bloom (Figure 19a, b). In 2015, the summer and fall surface chlorophyll levels were mainly below-normal or near-normal in 2015. The onset of the fall phytoplankton bloom was later than normal on the ESS, CSS, WSS and GB (Figure 19a, b). Chlorophyll was relatively high throughout the year in the tidally mixed Lurcher Shoal (LS) and GB sub-regions. Annual variability on Lurcher Shoal (LS) is such that bloom conditions have been hardly discernable since 2012 for the spring bloom, and since 2013 for the fall bloom.

Annual integrated chlorophyll anomalies were mixed in sign and within one standard deviation of the mean on the sections in 2015 (Figure 17).

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 20 and Figure 21). In 2015, the zooplankton biomass was mainly lower than normal and substantially lower than normal during the spring and summer (Figure 20). Zooplankton total abundance was higher than normal in winter, lower than normal in early spring, and close to normal for the rest of the year, with strong transient peaks in abundance in late summer and early fall (Figure 21). The zooplankton community was strongly dominated by copepods throughout the year, as is typical at Halifax-2 (Figure 21).

Calanus finmarchicus abundance was below normal throughout the year, except for one occasion in May, about one month following the spring phytoplankton bloom, when abundance increased to about normal (Figure 22). The relative abundance of *C. finmarchicus* copepodite I stages increased in March, similar to normal timing of production, but later copepodite stages did not increase in relative abundance until May. The relative abundance of *C. finmarchicus* copepodite V stages increased in August, similar to normal timing (Figure 22).

Total copepod abundance at Halifax-2 in 2015 was higher than normal in winter, somewhat low in spring and summer, and variable in fall, with high counts recorded in early fall (Figure 23a). Higher than average total abundance in winter was associated with abundant copepod nauplii and *Oithona similis*. The copepod community was characterized by lower than normal relative abundance of *C. finmarchicus* throughout the year. The relative abundance of the offshore copepod *Oithona atlantica* was higher than normal in the summer months, while the deep-water copepods *Microcalanus* spp. and *Metridia lucens* were relatively more abundant in late fall (Figure 23a). Higher than average abundances have been observed for *O. atlantica* and Microcalanus spp. since 2009 (not shown).

Overall at Halifax-2 in 2015, annual anomalies for zooplankton biomass and *C. finmarchicus* abundance were strongly negative, *Pseudocalanus* spp. abundance anomalies about average, and total copepod and non-copepod abundance anomalies weakly positive (Figure 17).

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 20 and Figure 21). In 2015, zooplankton biomass was lower than normal in winter and late fall, and higher than normal in spring and early fall (Figure 20). Total zooplankton abundance at Prince-5 in 2015 was close to normal during much of the year, but higher than normal in April and May and lower than normal in October (Figure 21). The zooplankton community was mostly dominated by copepods throughout the year, except for larger than normal relative abundance of barnacles (“Others”) during spring and of Cladocera and Bivalvia in August (Figure 21).

The abundance of *C. finmarchicus* was mainly low throughout the year, especially during the winter, early summer, and fall months, but reached near-normal levels in late spring (Figure 22). The relative abundance of *C. finmarchicus* copepodite stage I reached a peak in April, earlier and shorter than normal and coinciding with the spring phytoplankton bloom, with later copepodite stages appearing in May and June. A second pulse of early stage copepodites occurred in early fall, as is typical.

The total copepod abundance at Prince-5 in 2015 was close to normal throughout the year but variable in summer and early fall (Figure 23b). The copepod community was characterized by lower than normal relative abundance of *C. finmarchicus* throughout the year and low relative abundance of *Pseudocalanus* spp. in spring. *Temora longicornis* and *Paracalanus* sp. had higher than normal relative abundances during summer and fall, respectively. A higher than normal abundance of copepod nauplii (“Others”) was observed throughout the year, particularly in April (Figure 23b).

Overall at Prince-5 in 2015, annual abundance anomalies for *C. finmarchicus* and *Pseudocalanus* spp. were weakly negative, and anomalies of total copepod and non-copepod abundance and zooplankton biomass were positive (Figure 17).

Broad-scale Surveys

Zooplankton biomass was lower than normal in the spring of 2015 on the Louisbourg section, near normal on the Halifax section, and higher than normal on the Browns Bank section, where the large positive anomaly appeared to be driven by high biomass at the shelf-break station (Figure 24). In the fall, biomass levels were lower than normal on all sections except for the Halifax section where they were near normal (Figure 24). The mainly negative annual anomalies for zooplankton biomass in 2015 over all sections of the Scotian Shelf continued a pattern of low zooplankton biomass observed since 2010 (Figure 17). Zooplankton biomass levels were near normal during the winter 2015 ecosystem trawl survey but considerably lower than normal during the 2015 summer trawl survey on the Scotian Shelf (Figure 25). For the winter survey, sampling was limited and concentrated in the eastern part of Georges Bank (Figure 25).

The abundance of *C. finmarchicus* was lower than normal on all four sections on the Scotian Shelf both in the spring and fall of 2015, with the exception of the Halifax section where it was normal in the fall and the Cabot Strait section which was not sampled in the spring (Figure 26). *C. finmarchicus* abundance was also lower than normal during the winter ecosystem trawk survey on Georges Bank and the lowest yet observed on the summer Scotian Shelf survey (Figure 27). Overall, the low abundance levels of *C. finmarchicus* in 2015 continued the generalized pattern observed since 2011 (Figure 17).

Annual abundance anomalies for *Pseudocalanus* spp. were near-normal or weakly negative for all sections in 2015, except for a positive anomaly on the Cabot Strait section, which was sampled only in the fall (Figure 17). Positive annual abundance anomalies were observed in 2015 for copepods and non-copepods on all four sections.

Indicator Species

In 2015, the abundance anomalies for the Arctic *Calanus* species (*C. hyperboreus* and *C. glacialis*) continued to be negative throughout the region, particularly on the Cabot Strait section, continuing the trend started in 2012 (Figure 28). Warm offshore species

(*Clausocalanus* spp., *Mecynocera clausi*, and *Pleuromamma borealis*) abundance anomalies were positive or near normal on the Scotian Shelf area (Louisbourg, Halifax and Browns Bank sections and Halifax-2) but were negative on CSL and at Prince-5. Abundance anomalies for the warm shelf species (the summer-fall copepods *Paracalanus* spp. and *Centropages typicus*) were strongly negative on the Cabot Strait section, weakly positive at Prince-5, and near normal on the Scotian Shelf section and at Halifax-2, contrary to expectation.

In contrast to 2014, when numerous sightings of thaliaceans were reported from the Gulf of Maine to southern Newfoundland (Johnson et al. 2016), few occurrences of thaliaceans were recorded in 2015. *Salpa maxima* was present in the spring on the Browns Bank section (BBL6, BBL7), and *Thalia democratica* was present in the fall, also on the Browns Bank section (BBL3).

DISCUSSION

Evidence is emerging for a shift in the plankton community of the Scotian Shelf since 2010, associated with above average ocean temperatures and strong sub-annual variability in the physical environment. A variety of metrics have exhibited mainly negative anomalies in recent years, including deep silicate and phosphate concentrations since 2013, spring bloom duration since 2011, diatom and other large phytoplankton abundances since 2009, zooplankton biomass since 2010, *C. finmarchicus* abundance since 2011, and Arctic *Calanus* abundance since 2012, while abundance anomalies of warm offshore copepods and non-copepods have been mainly positive in the central and western part of the region since 2012. Spring bloom onset timing has frequently been late and bloom magnitude low since 2011.

Deviations of MLD and stratification from normal conditions observed in 2015 at the time series stations may have influenced phytoplankton dynamics. Strong variability in MLD and stratification at Halifax-2 and a deep MLD at Prince-5 in the first half of the year were likely related to unusually windy conditions in winter and spring. However, the implied increase in mixing did not translate into a systematic increase of surface nutrient on the Scotian Shelf and at Prince-5. Instead, surface layer nitrate, silicate, and phosphate inventories were lower than the climatological values. The development of a short-lived deep chlorophyll maximum at the bottom of the MLD at Halifax-2 (around 80m, Figure 15) early in the winter was associated with an incursion of warm, salty slope waters at depth on the Scotian Shelf, which could have replenished nutrients in the deep water.

The typical annual pattern of phytoplankton biomass variability on the Scotian Shelf includes a spring bloom dominated by diatoms and a secondary, 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 as well as temperature, starting when the water column stabilizes in late winter-early spring (Sverdrup 1953). A bloom develops 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. The late initiation of the spring phytoplankton bloom on the Scotian Shelf in 2015 is consistent with late onset of stratification which occurred in late April when the MLD shoaled to a depth of about 40 m, corresponding to the bottom of the euphotic zone at Halifax-2. The later, less intense, and shorter than usual spring bloom in other parts of the Scotian Shelf, as revealed by satellite observations of surface chlorophyll, could be explained by the same unusual pattern in hydrodynamic forcing (late onset of stratification and colder temperature) which occurred over the entire Scotian Shelf, but not on Georges Banks, for the second consecutive year. Satellite data for 2015 show that the spring shelf survey occurred during the peak of the bloom on the

ESS, CSS, and WSS when nutrients were still at high levels compared to the climatology (Figure 12a, b), except for the central part of the Halifax and Louisburg sections.

A late summer-fall bloom of diatoms and dinoflagellates can develop when atmospheric forcing increases mixing, which 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). High frequency variations in stratification and MLD at Halifax-2 in summer 2015 seem to have been related to atmospheric forcing (Figure 7). Unusually strong wind events in mid-June and early August deepened the MLD, likely mixing nutrients into the euphotic zone and leading to an increase in phytoplankton biomass at the base of the euphotic zone. Relative abundances of both diatoms and dinoflagellates increased to about 45% of total microplankton abundance during these short events, similar to the relative abundance of flagellates. The occurrence of such sporadic events plays an important role in biogeochemical cycles and the transfer of energy to higher trophic levels at a time of year when resources are scarce. Unlike nitrate, the phosphate and silicate anomalies were negative for the second consecutive year (except for Cabot Strait). Depletion of silicate and phosphate but not nitrate in recent years is consistent with an increased influence of WSW on the shelf, as silicate is lower than nitrate in WSW but similar to nitrate in LSW (Yeats et al. 2010), and could lead to reduced diatom production. Microscope counts showed a decrease in abundance of all groups of microplankton (i.e., large phytoplankton), including diatoms, in 2015 at both Halifax-2 and Prince-5, a trend that started in 2008 and coincided with the continuing positive anomaly of water temperature (Hebert et al. 2016). However, the decrease in microplankton abundance was not reflected in phytoplankton biomass, which has increased over the last few years. As for the spring bloom, the fall bloom appeared to be delayed and less intense than climatology in all regions of the Scotian Shelf except on the Browns Bank section.

Annual anomalies revealed continuous decreases in silicate and phosphate concentrations over the last two years at all locations, while the trends in nitrate were spatially variable, with positive nitrate anomalies on the eastern and western Scotian Shelf and negative nitrate anomalies elsewhere. This suggests that silicate or phosphate could be limiting in the development and growth of phytoplankton, especially larger phytoplankton such as diatoms and dinoflagellates at the time series stations. Generalization of this result to the entire Scotian Shelf would be speculative without additional measurements of phytoplankton community structure. The decrease in microplankton at Halifax-2 and Prince-5 is not associated with a decrease in phytoplankton total biomass, as indicated by chlorophyll concentration, suggesting that a shift in phytoplankton assemblage may be occurring.

Continued low abundances of the biomass-dominant, energy-rich copepod *C. finmarchicus* and associated low zooplankton biomass in 2015 indicated poor feeding conditions for planktivorous fish such as herring and mackerel and North Atlantic Right Whales. *C. finmarchicus* is close to the southern end of its range in the Gulf of Maine, and its abundance may have been negatively affected by anomalously warm conditions on the Scotian Shelf and eastern Gulf of Maine, in particular in deep waters where the length of its dormant period and its ability to survive through its overwintering period may be limited at warm temperatures (Saumweber and Durbin 2006). Lower than normal abundances in upstream source regions such as the southern Gulf of St. Lawrence likely also influenced the *C. finmarchicus* population in the Maritimes Region (Devine et al. 2015). Since *C. finmarchicus* has a life history that focuses reproductive effort on spring bloom production of diatoms, the late bloom initiation, short bloom duration, low bloom magnitude, and lower than average abundance of diatoms observed in recent years may also have had a negative impact on population size. In 2015, *C. finmarchicus* developmental stage distributions at Halifax-2 indicated normal timing of reproduction but late timing of recruitment to later stages, suggesting that the mortality of early stages may have been high during late winter and early spring. In contrast to previous recent years, *C. finmarchicus* population abundances at both Halifax-2 and Prince-5 were low at the end of the year, indicating a low overwintering stock to seed production in 2016 (Johnson et al. 2016). Abundance anomalies for *Pseudocalanus* spp., smaller spring-summer copepods that are also important prey for small fish, were mainly closer to normal overall.

Shifts in the abundance of subdominant copepod groups that are indicators of water mass distributions in the region, including Arctic *Calanus* (lower), warm offshore copepods (higher), deep-water *Microcalanus* (higher) and offshore *O. atlantica* (higher), in the last 4-7 years are consistent with a greater influence of offshore water on the central and western Scotian Shelf. In contrast, the absence of a similar shift toward a higher abundance of warm shelf copepods, despite warmer surface temperature in summer and fall, may be due to changes in phytoplankton production or community composition or to displacement of outer shelf bank water due to on-shelf movement of slope water in the fall. Despite warm and variable conditions on the Scotian Shelf in 2015, blooms of thaliacians (gelatinous, filter-feeding zooplankton) were not observed in 2015 as they had been in 2014 and 2013. The prevalence of thaliacean blooms in 2013 and 2014 was hypothesized to be associated with pulses of summer or fall production of large phytoplankton such as diatoms (Johnson et al. 2016), which were uncommon in 2015.

As warm ocean conditions persist in the Maritimes region, there is increasing evidence of a shift in both phytoplankton and zooplankton communities away from the dominance of large phytoplankton cells and large, energy rich copepods like *C. finmarchicus* and toward smaller phytoplankton and copepod species. Since "classical" type food webs dominated by diatoms and *C. finmarchicus* food webs are associated with higher transfer efficiency of energy to higher trophic level animals than are food webs dominated by small phytoplankton cells and small zooplankton taxa, this shift may indicate a change to less productive conditions for planktivorous fish, marine mammals, and birds in the Maritimes Region.

CONTINUOUS PLANKTON RECORDER (CPR)

PHYTOPLANKTON

On the WSS and ESS, climatological seasonal cycles of PCI and diatom abundance show peaks in spring (March-April) and low values in summer. In fall and winter the PCI is low, but diatom abundance increases in fall, remaining relatively high in winter (Figure 29). Dinoflagellate abundance shows no clear seasonal cycle in either region. In 2014 the spring peaks for the PCI on the WSS and ESS were early (March) decreasing to relatively low values by April: in other months they were near normal. Diatom abundance on the WSS was near normal throughout the year, but on the ESS after a peak in March, it was lower than normal in April and May, near normal in July and August, and low in the fall. Dinoflagellate abundance on the WSS was generally near normal, but low in June and high in October. On the ESS, dinoflagellate abundance was unusually variable with higher than normal values in March-April and August-September and lower than normal values in February, May and November. The 2014 annual average PCI anomalies were close to the 1992-2010 averages for the WSS and ESS (Figure 30) and the annual abundance anomalies for diatoms and dinoflagellates were below (diatoms, ESS) or close to average values.

ZOOPLANKTON

CPR-derived climatological seasonal cycles for *Calanus* I-IV (mostly *C. finmarchicus*) and late stage *C. finmarchicus* have broad spring-summer (April-July) peaks in abundance on the WSS (Figure 31). On the ESS, the same peaks in abundance are apparent, although with much lower magnitudes (Figure 31). In 2014, the springtime peak for *Calanus* I-IV was earlier than normal (March) and abundances dropped to very low levels by June (WSS) or May (ESS). Thereafter, abundances were either normal or lower than normal. The abundance of late stage *C. finmarchicus* V-VI was highest in March in both regions and unusually high on the WSS. Thereafter, levels remained close to normal until June (WSS) or April (ESS) and were then very low until increasing to normal in December. Annual average abundance anomalies were close to normal in both regions for *Calanus* I-IV and lower than (ESS) or close to (WSS) normal for late stage *C. finmarchicus* V-VI (Figure 30). For the Arctic *Calanus* species, the annual average abundance anomalies were close to (WSS) or lower than (ESS) normal in 2014 for *C. glacialis*, and close to (ESS) or higher than (WSS) normal for *C. hyperboreus*. Among the small-sized taxa, annual average abundance anomalies for copepod nauplii and *Paracalanus / Pseudocalanus* were lower than (ESS) or close to (WSS) normal in 2014, while values for *Oithona* spp. were close to normal in both regions. The annual average abundance anomalies for euphausiids were lower than normal in both regions in 2014, while those for hyperiid amphipods were higher than normal in both regions.

ACID SENSITIVE ORGANISMS

Annual average abundance anomalies for coccolithophores (phytoplankton) were higher than (ESS) or close to (WSS) normal in 2014, while those for foraminifera (microzooplankton) were higher than normal in both regions. The abundance anomaly for pteropods (*Limacina* spp.) was close to the 1992-2010 average in both regions (Figure 30).

CPR RESULTS VERSUS REMOTE SENSING AND IN SITU OBSERVATIONS

During 2014, *in situ* AZMP sampling of chlorophyll concentration at Halifax-2 in AZMP suggested that the spring bloom was earlier and more intense than usual, based mainly on one especially high value in late March. The CPR observations of the PCI, and to a lesser extent diatom abundance, provide support for this view. By contrast, satellite observations of sea surface chlorophyll did not show especially high values in March in western, central or eastern regions of the Scotian Shelf, an inconsistency that may have occurred because the spring bloom, as observed at Halifax-2, was unusually deep (Johnson et al. 2016). The CPR-derived abundances of *Calanus* I-IV and *C. finmarchicus* V-VI both peaked in March on the WSS and ESS, whereas at Halifax-2 the abundance peak for *C. finmarchicus* (all stages) was in April. This apparent inconsistency may be because AZMP sampling is at a single station (Halifax-2) throughout the entire water column, whereas CPR sampling is in the near-surface layer at broadly dispersed sites (Figure 5), and because oceanographic influences are not uniform over the entire Scotian Shelf and neither are the population dynamics or abundances of *C. finmarchicus*. Overall, AZMP and CPR sampling gave similar results for abundance anomalies for *C. finmarchicus* for 2014: lower than normal on the ESS and near normal in central and western regions. The contrast between abundance anomalies of Arctic *Calanus* species observed on the WSS with the CPR (high or normal) and with nets (low) may have occurred if conditions were too warm and food too low for these species to accumulate the lipid reserves required for dormancy initiation and migration to deep waters, which could allow these species to be available for sampling by the CPR in surface waters for a longer period.

SUMMARY

- In 2015, deep silicate and phosphate inventories were mainly lower than average for a third consecutive year, except on the Cabot Strait section where silicate has been higher than average in recent years. Deep nitrate inventories were mainly higher than average in 2015.
- Phytoplankton biomass anomalies were mixed in sign in 2015, but abundances of large phytoplankton at the times series stations were lower than average, continuing a trend that started in 2009.
- The 2015 phytoplankton spring bloom started later and was weaker in magnitude and shorter in duration than normal.
- Both *Calanus finmarchicus* abundance and zooplankton biomass were lower than average overall in 2015, continuing a trend that started in 2011 or 2010.
- Changes in the copepod community indicated an increase in the abundance of offshore species and a decrease in cold water immigrant species on the Scotian Shelf in 2015, continuing a trend that started in recent years.
- Warm ocean conditions in recent years have been associated with changes in the phytoplankton and zooplankton communities, with declines in taxa associated with higher lower trophic level productivity.
- In 2014 CPR phytoplankton indices (PCI, diatom abundance) in both the western and eastern Scotian Shelf indicated that the spring bloom was earlier and of shorter duration than usual.
- In 2014 spring peaks in the CPR-derived abundances of *Calanus* I-IV and *C. finmarchicus* V-VI were relatively early and short-lived.
- In 2014, CPR abundance anomalies for two taxa (hyperiid amphipods, foraminifera) were unusually high over the entire Scotian Shelf, while one (euphausiids) was unusually low. Otherwise, most taxa were at near normal annual average levels on the WSS and below normal levels on the ESS.

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TABLES

Table 1. Atlantic Zone Monitoring Program (AZMP) sampling missions in the Maritimes Region, 2015.

Group	Location	Mission ID	Dates	# Hydro Stns	# Net Stns
Trawl Surveys	Georges Bank	NED2015-002	Mar 13 – 27	28	7
	Scotian Shelf	NED2015-017	Jun 29 – Aug 17	217	38
Seasonal Sections	Scotian Shelf	HUD2015-004	Apr 17 – 27	57	50
	Labrador Sea/ Halifax Line	HUD2015-006	May 04 – 22	2	1
	Scotian Shelf	HUD2015-030	Sep 20 – Oct 11	115	111
Fixed Stations	Halifax-2	BCD2015-666	Jan 01 – Dec 31	23(10)[1]	23(10)[1]
	Prince-5	BCD2015-669	Jan 01 – Dec 31	12	12
			Total:	*441*	*229*

[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

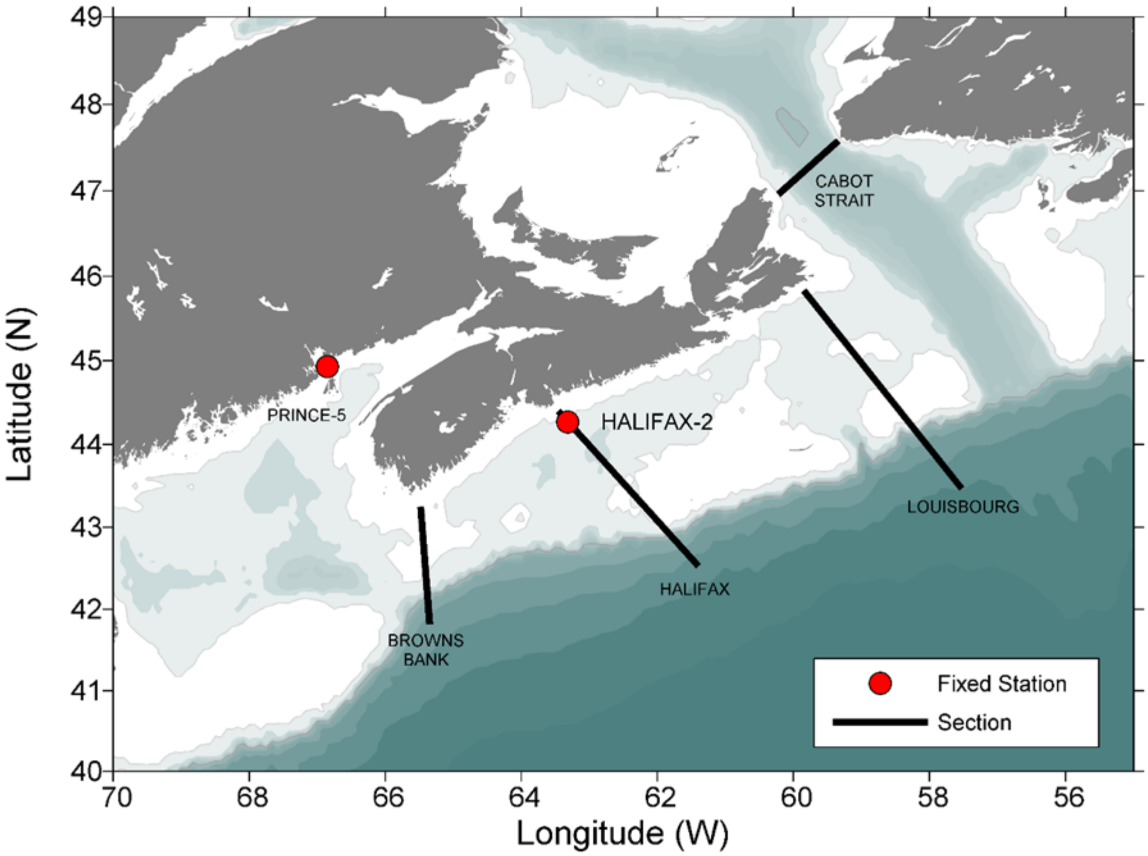

Figure 1. Map of primary sections (Cabot Strait, Louisbourg, Halifax, and Browns Bank) and fixed stations (Halifax-2, and Prince-5) sampled in the DFO Maritimes Region.

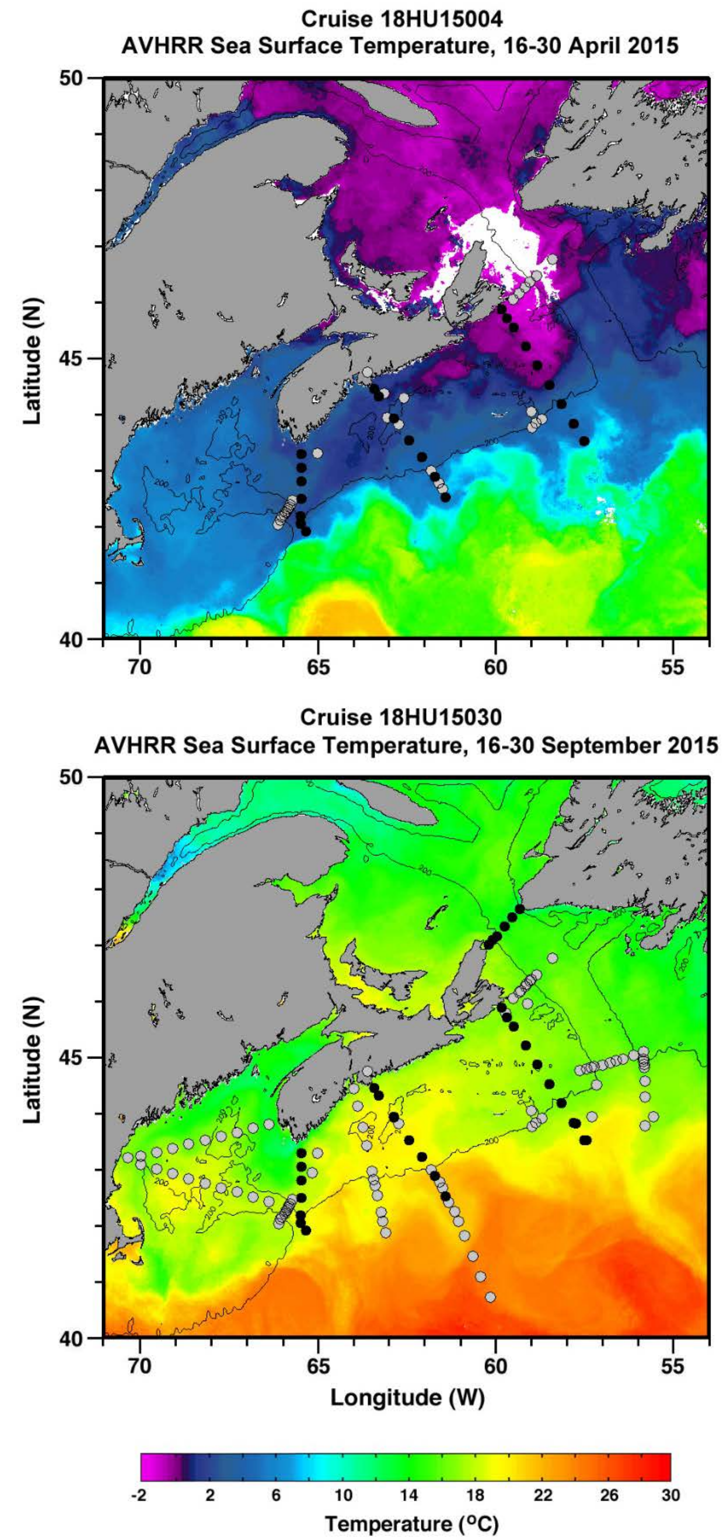

Figure 2. Stations sampled during the 2015 spring and fall surveys. Station locations are superimposed on sea-surface temperature composite images for dates close to the mission dates. Black markers indicate core stations, and gray markers indicate stations sampled for ancillary programs.

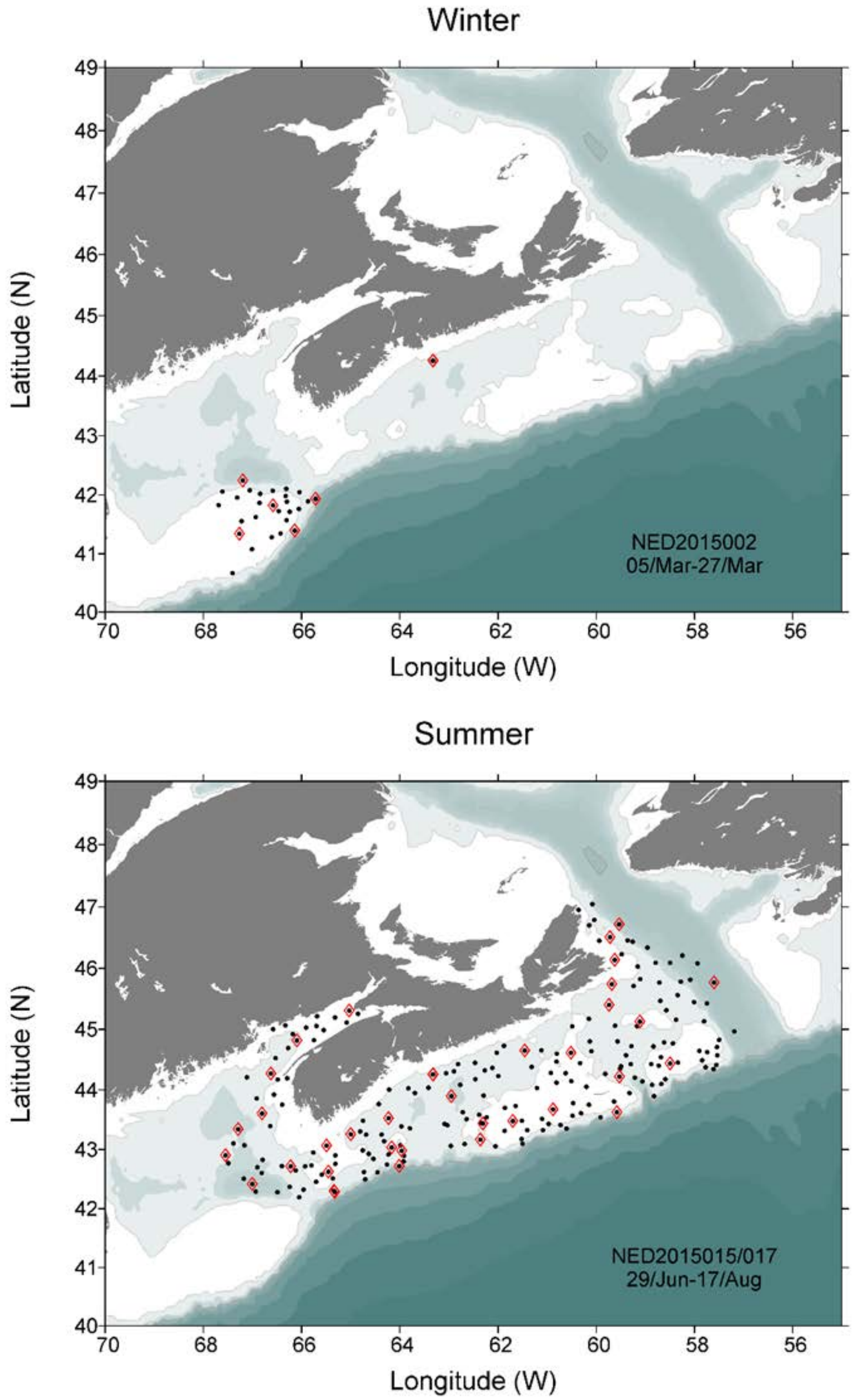

Figure 3. Stations sampled during primary Maritimes Region ecosystem trawl surveys in 2015. Black solid markers are hydrographic stations; red open diamonds are stations where vertical nets hauls were taken in addition to hydrographic measurements.

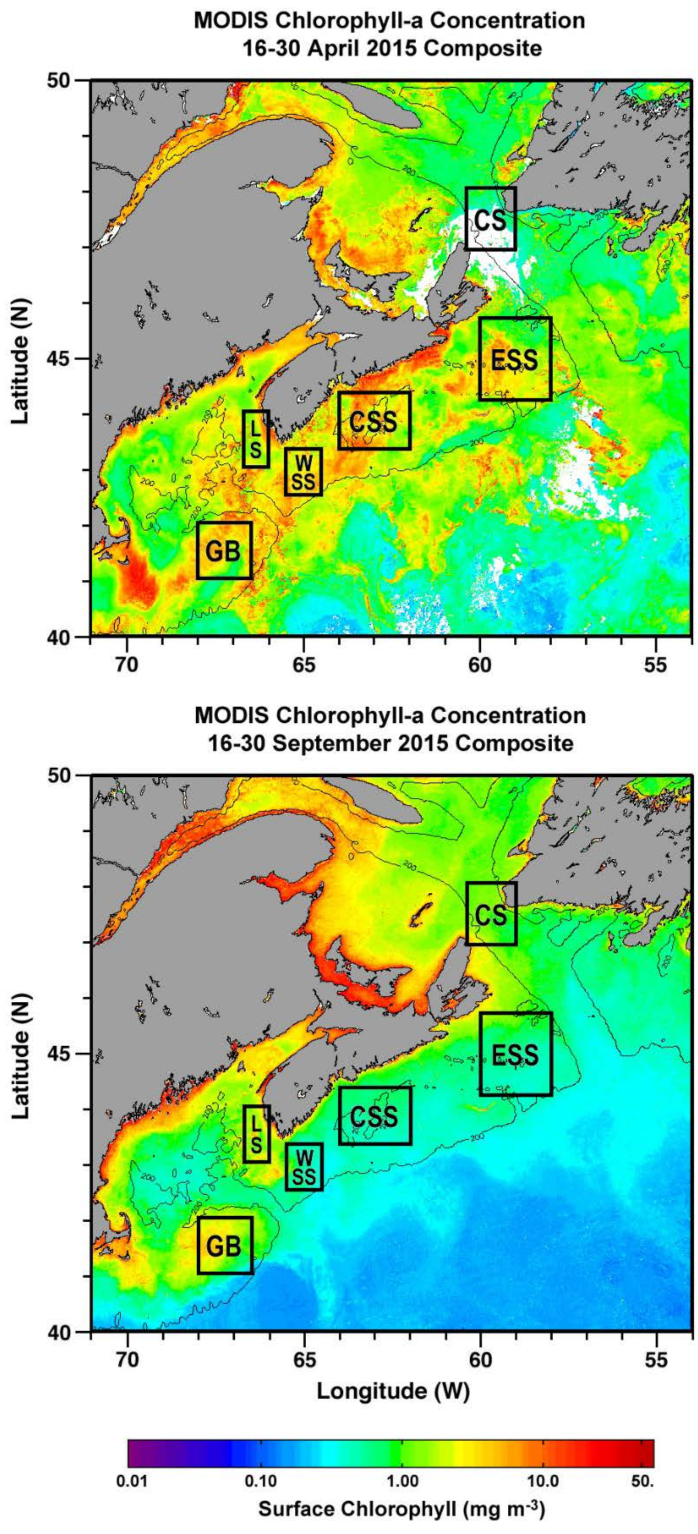

Figure 4. Statistical sub-regions in the Maritimes Region identified for spatial/temporal analysis of satellite ocean colour data. Sub-regions are superimposed on surface chlorophyll composite images for dates close to the mission dates. CS – Cabot Strait; CSS – central Scotian Shelf; ESS – eastern Scotian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

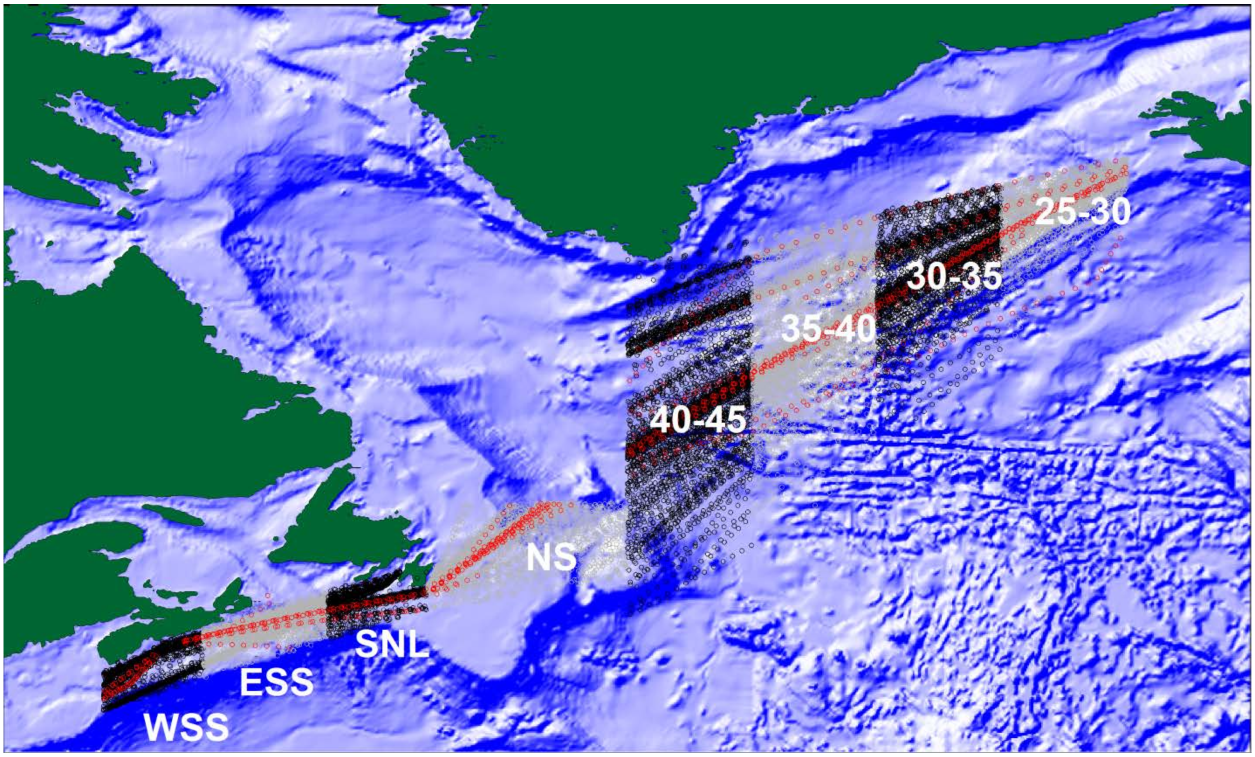

Figure 5. Continuous Plankton recorder (CPR) lines and stations 1957 to 2014. Stations sampled in 2014 are shown in red. Data are analysed by region. Regions are: western Scotian Shelf (WSS), eastern Scotian Shelf (ESS), south Newfoundland Shelf (SNL), Newfoundland Shelf (NS), and between longitudes 40-45°W, 35-40°W, 30-35°W, 25-30°W.

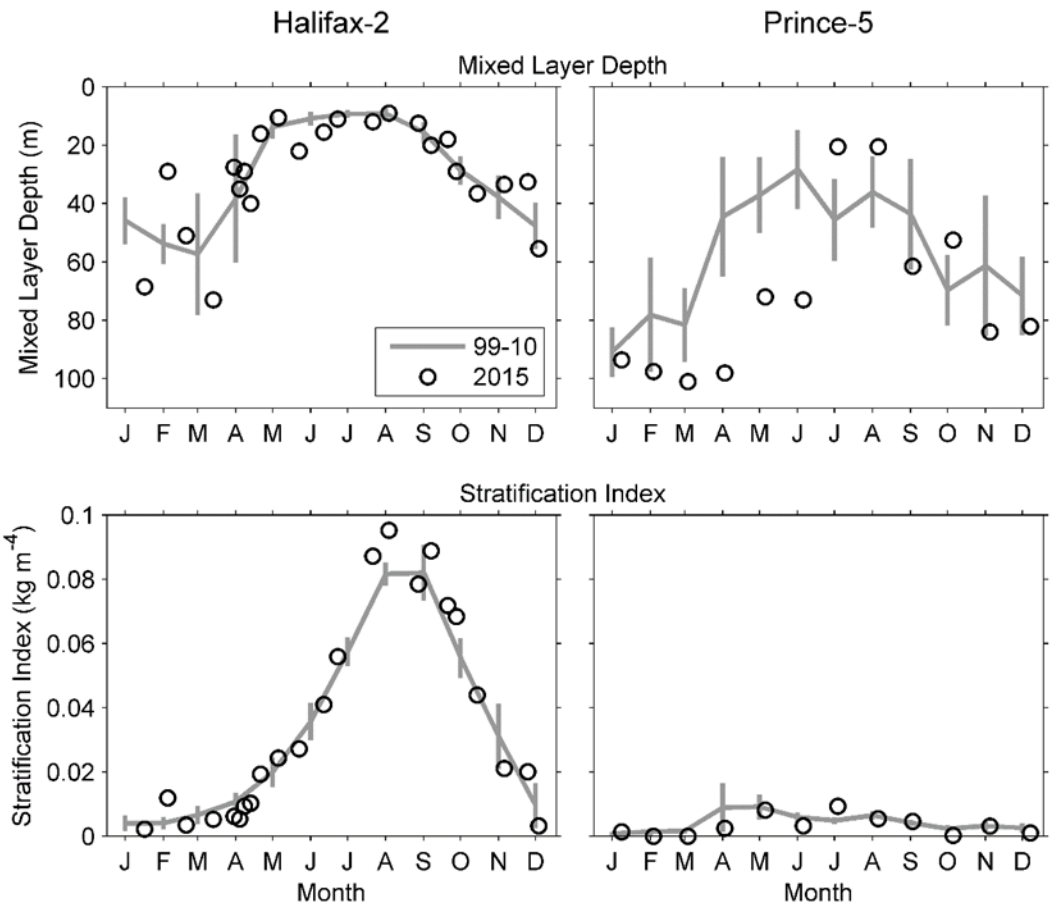

Figure 6. Mixing properties (mixed layer depth, stratification index) at the Maritimes fixed stations comparing 2015 data (open circle) with mean conditions from 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the monthly means.

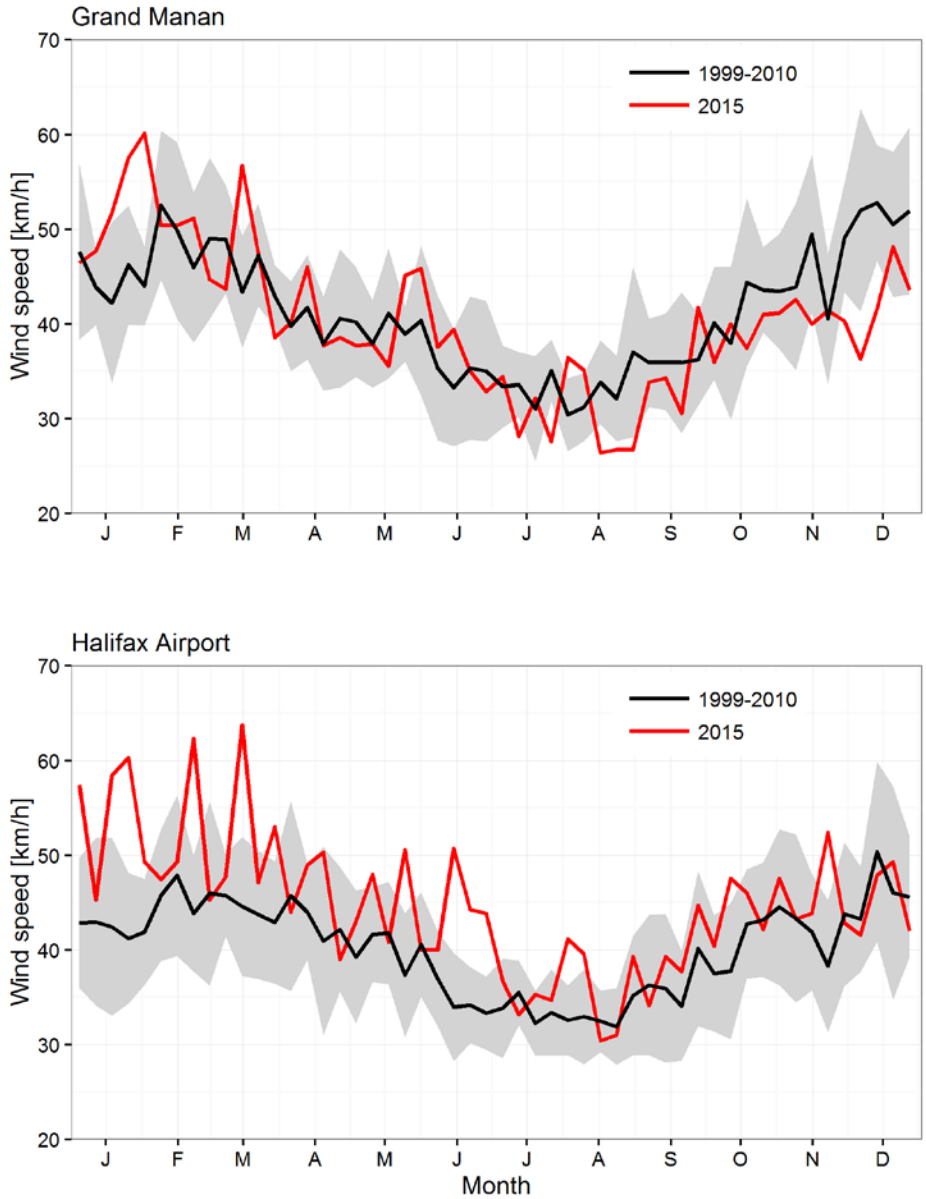

Figure 7. Mean daily maximum wind gust at Grand Manan Island (representative of wind conditions at Prince-5) and Halifax International airport (representative of wind conditions at Halifax-2) for the year 2015 (red line) and the 1998-2010 climatology (black line). The gray shaded area represents the standard deviation to the climatology computed over 13 years.

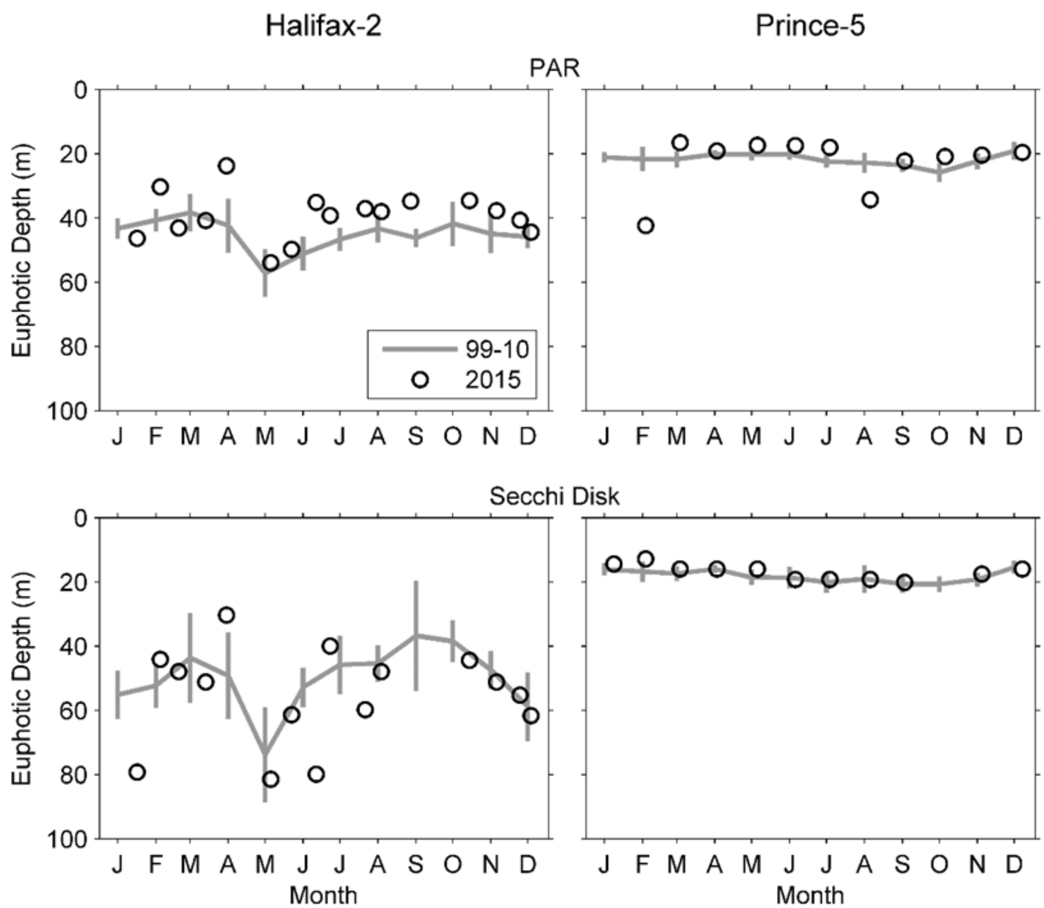

Figure 8. Optical properties (euphotic depth from PAR irradiance meter and Secchi disc) at the Maritimes fixed stations. Year 2015 data (circles) compared with mean conditions from 1999–2010 (solid line), except 2001–2010 for euphotic depth from PAR at Prince-5. Vertical lines are 95% confidence intervals of the monthly means.

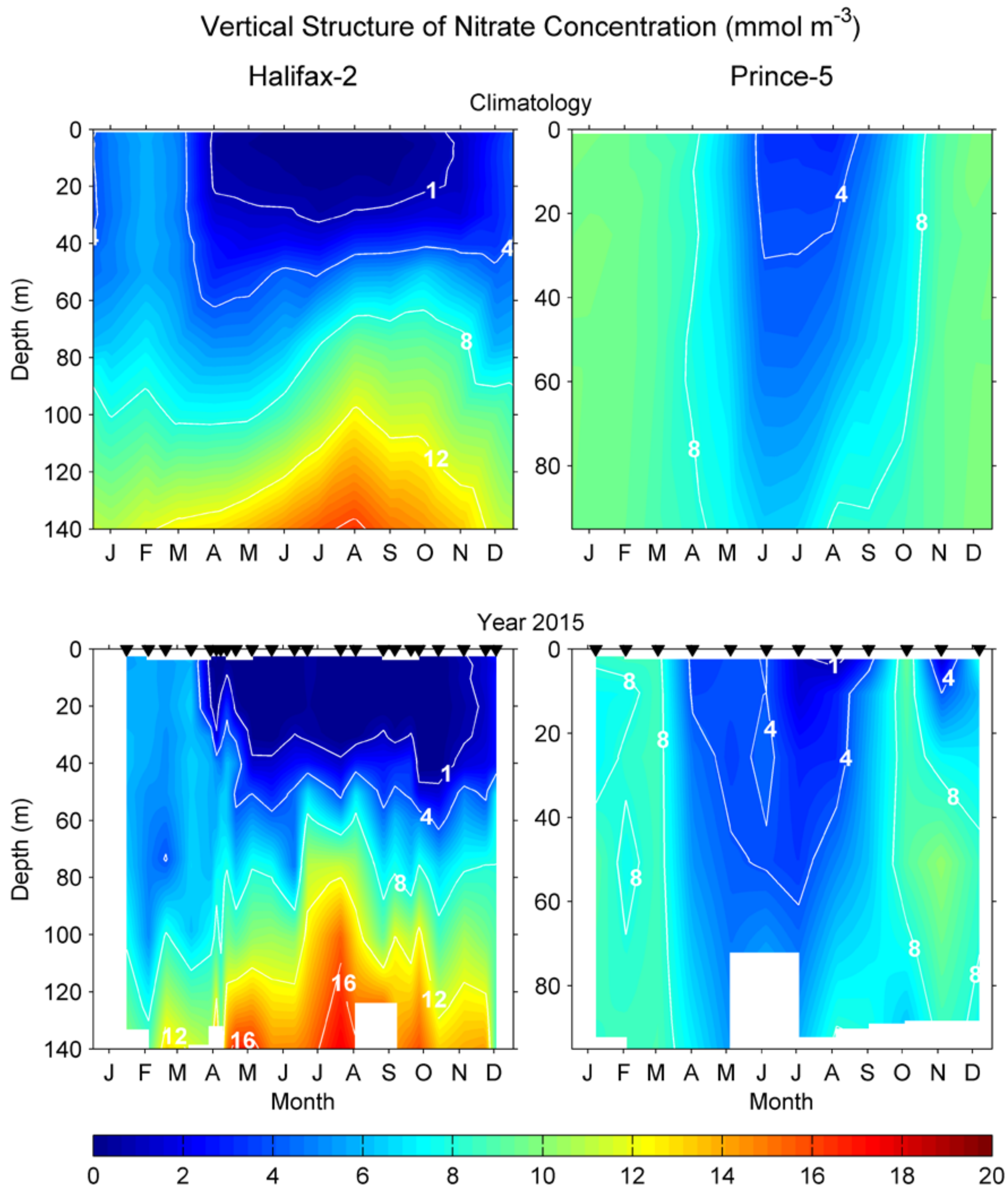

Figure 9. Comparison of annual changes in the vertical structure of nitrate concentrations (mmol m^{-3}) in 2015 (bottom panels) with climatological mean conditions from 1999–2010 (upper panels) at the Maritimes fixed stations.

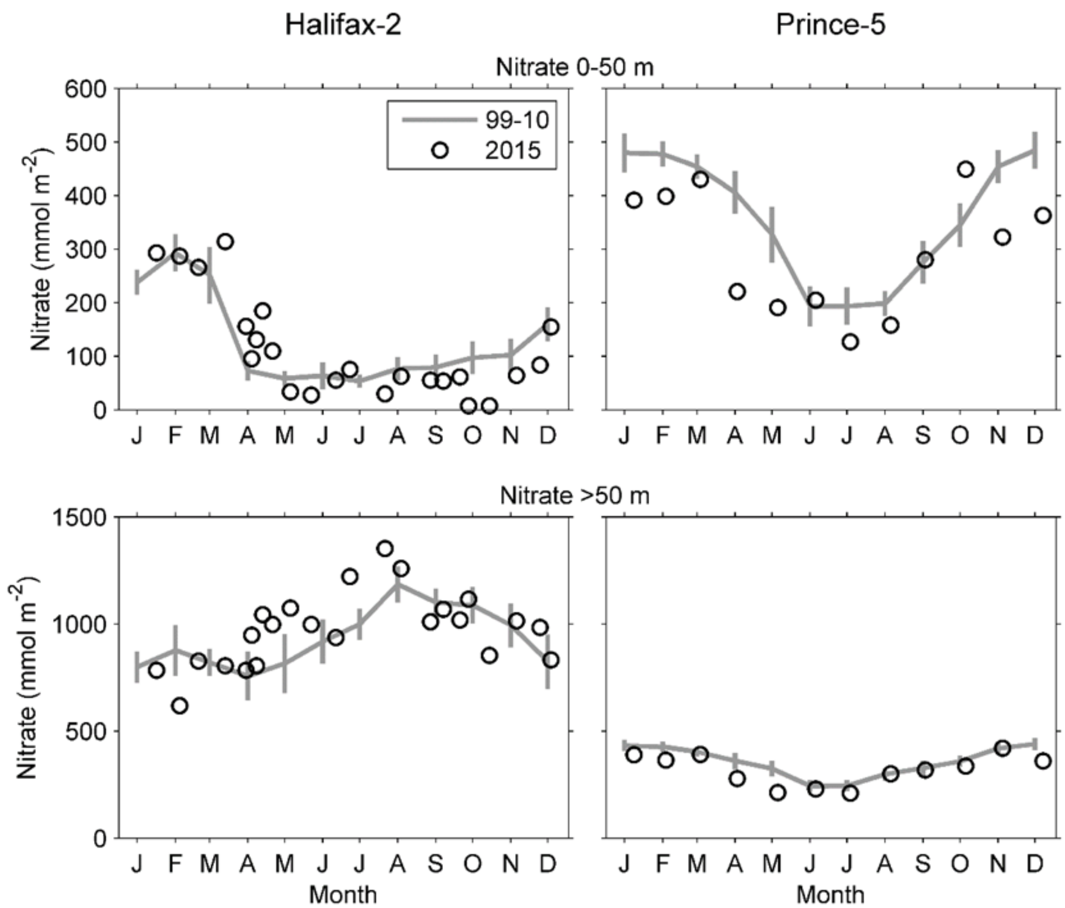

Figure 10. Comparison of 2015 (open circle) data with mean conditions from 1999–2010 (solid line) at the Maritimes fixed stations. Upper panels: surface (0–50 m) nitrate inventory. Lower panels: deep (>50 m) nitrate inventory. Vertical lines are 95% confidence intervals of the monthly means.

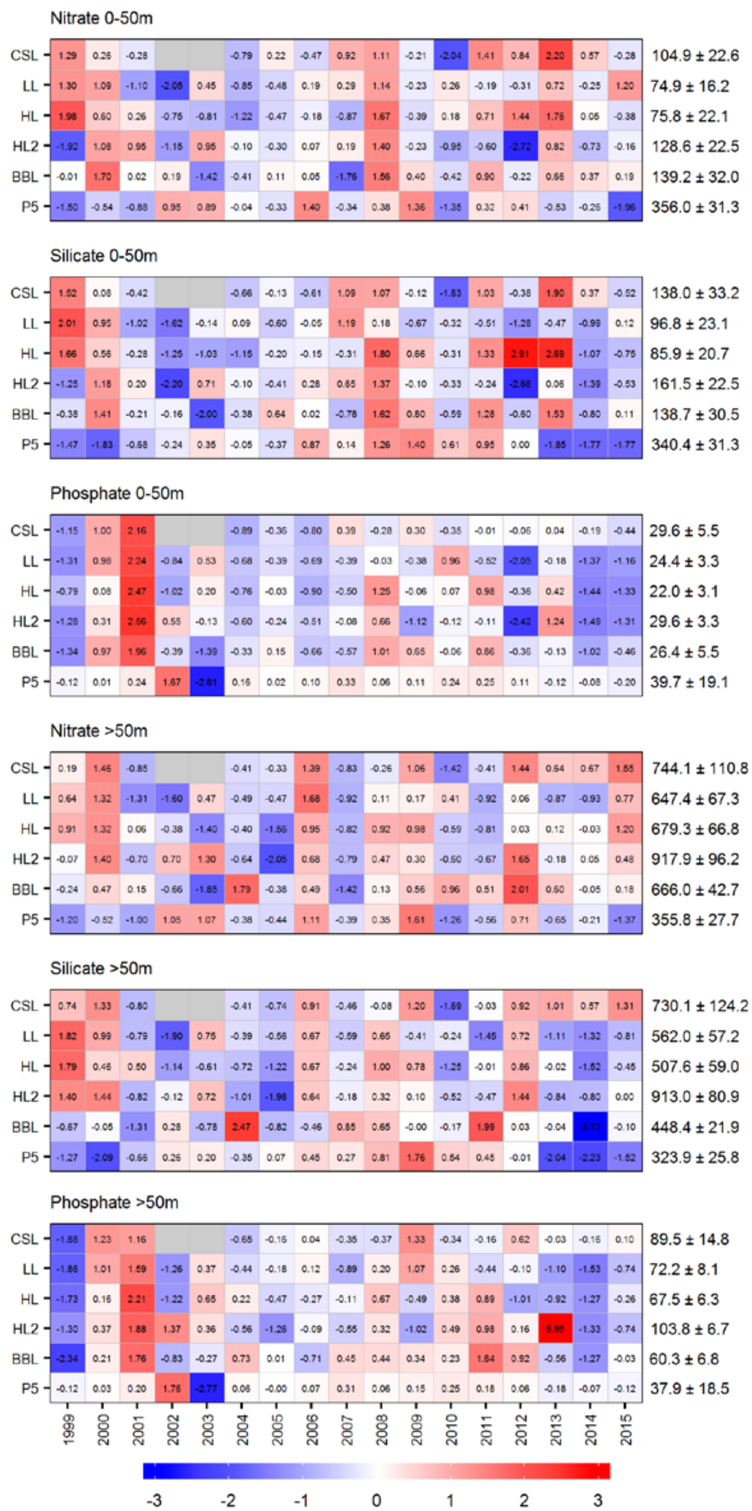

Figure 11. Annual anomaly scorecard for surface (0-50 m) and deep (50-150 m) nitrate, silicate and phosphate inventories. Values in each cell are anomalies from the mean for the reference period, 1999-2010, in standard deviation (sd) units (mean and sd listed at right). A blank cell indicates missing data. Red (blue) cells indicate higher (lower) than normal nutrient levels. CSL: Cabot Strait section; LL: Louisbourg section; HL: Halifax section; HL2: Halifax-2; BBL: Browns Bank section; P5: Prince-5.

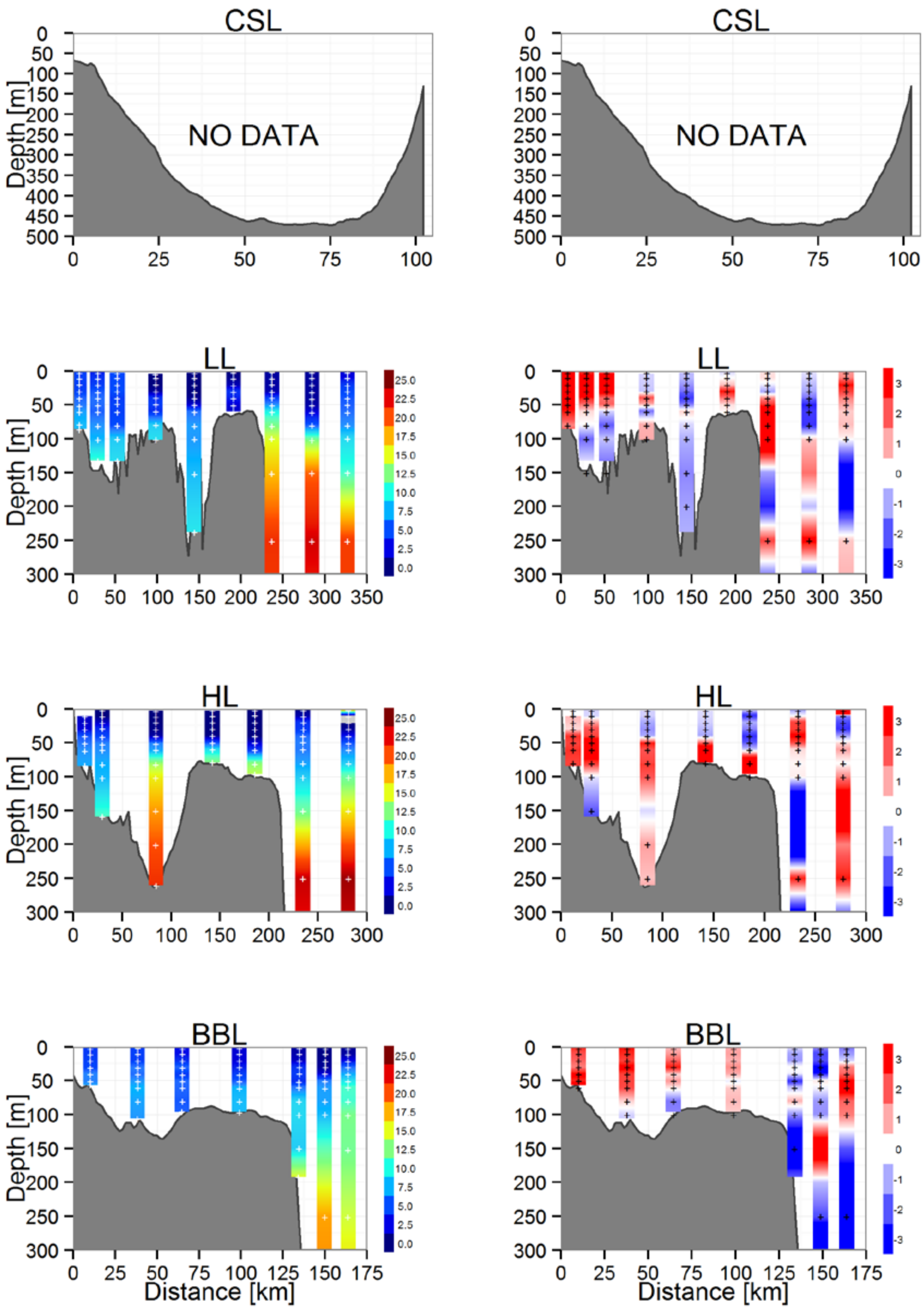

Figure 12a. Vertical profiles of nitrate concentration (mmol m^{-3}) (left panels) and their anomalies (mmol m^{-3}) from 1999–2010 conditions (right panels) on the Scotian Shelf sections in spring 2015. White markers on the left panels indicate the actual sampling depths for 2015. Black markers on the right panels indicate the depths at which station-specific climatological values were calculated.

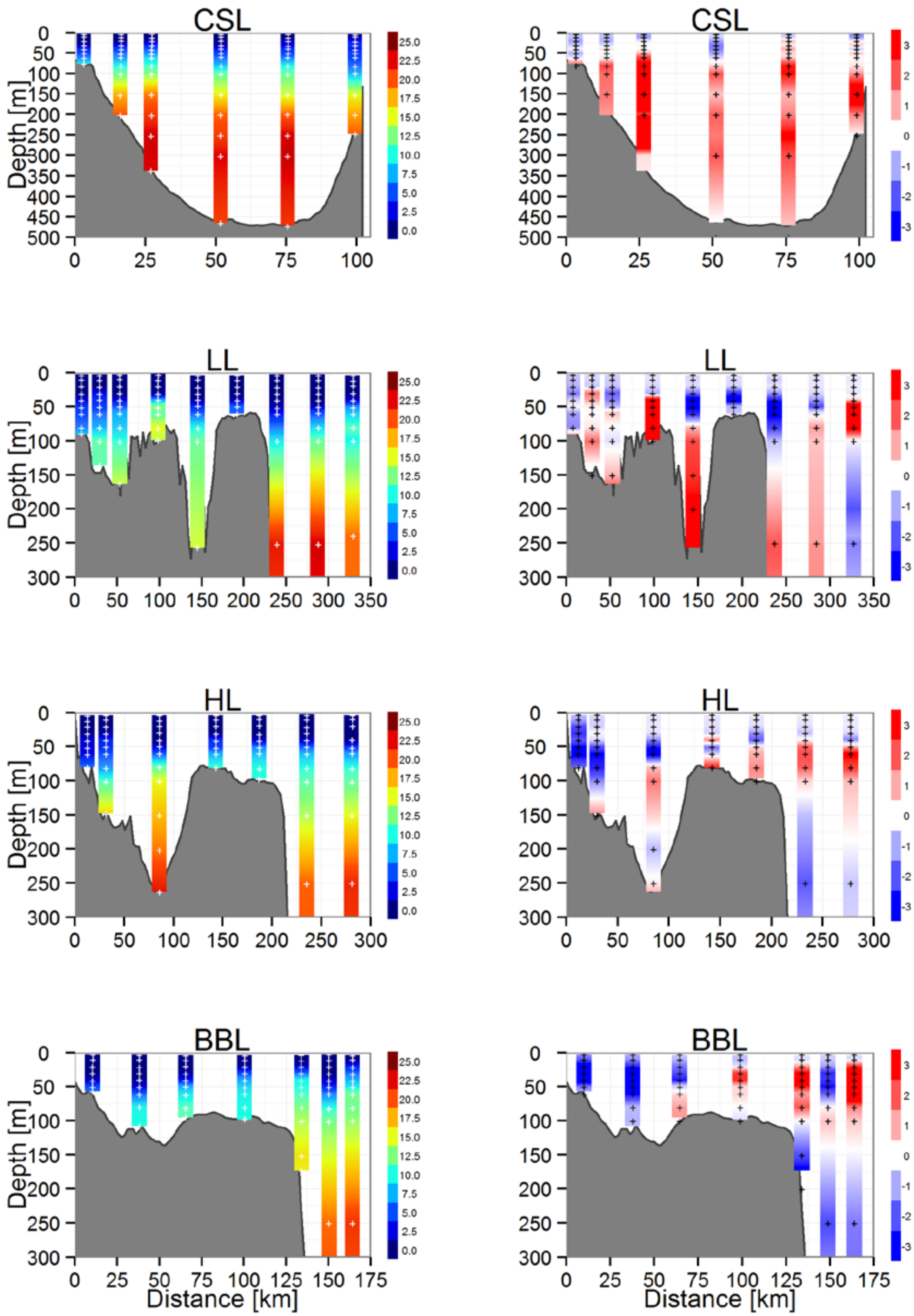

Figure 12b. Vertical profiles of nitrate concentration (mmol m^{-3}) (left panels) and their anomalies (mmol m^{-3}) from 1999–2010 conditions (right panels) on the Scotian Shelf sections in fall 2015. White markers on the left panels indicate the actual sampling depths for 2015. Black markers on the right panels indicate the depths at which station-specific climatological values were calculated.

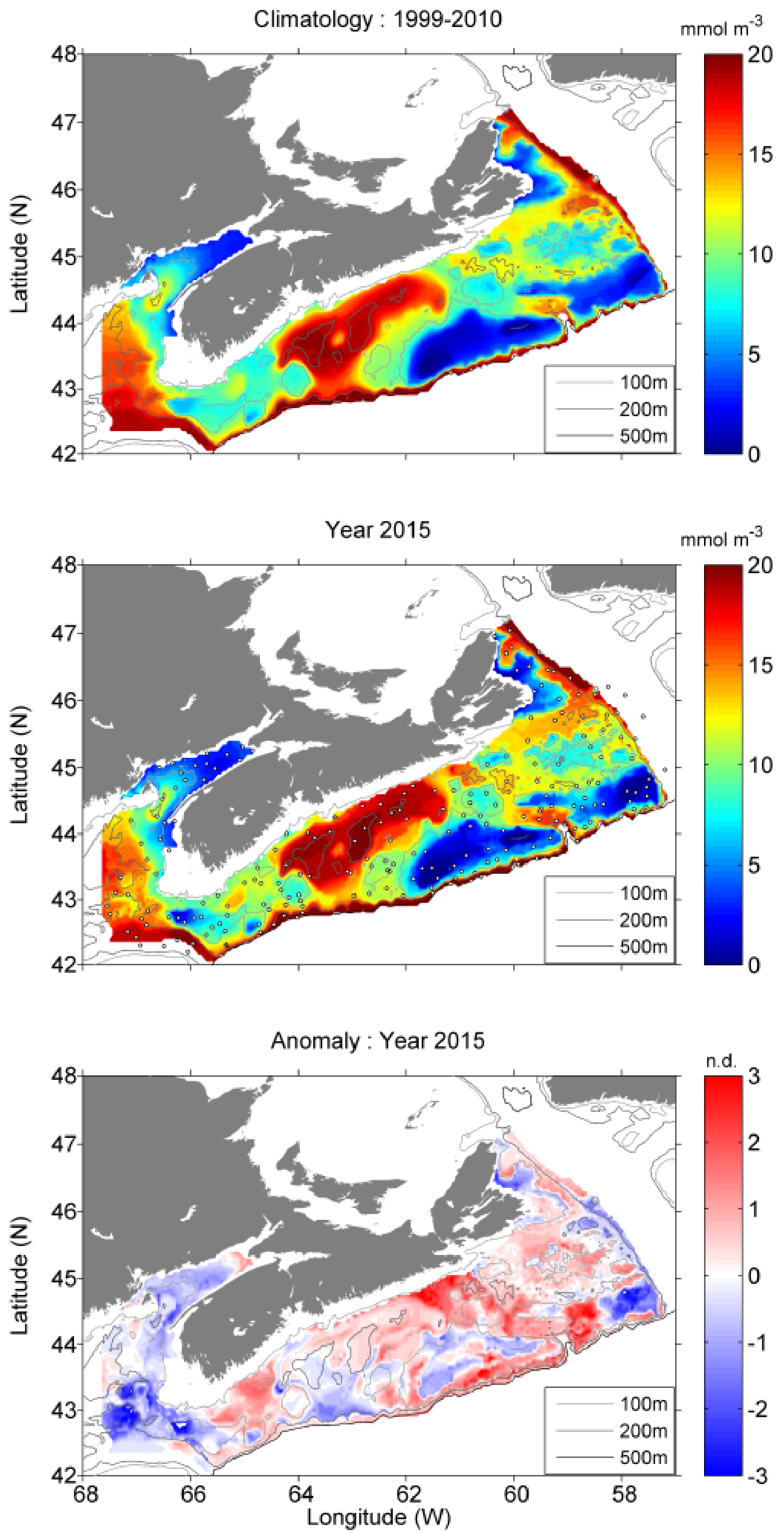

Figure 13. Bottom nitrate concentration on the Scotian Shelf during the annual July ecosystem trawl survey: 1999-2010 climatology (upper panel), 2015 conditions (middle panel), and normalized anomalies from climatology (lower panel). Markers in middle panel represent the 2015 sampling locations. nd = no dimensions.

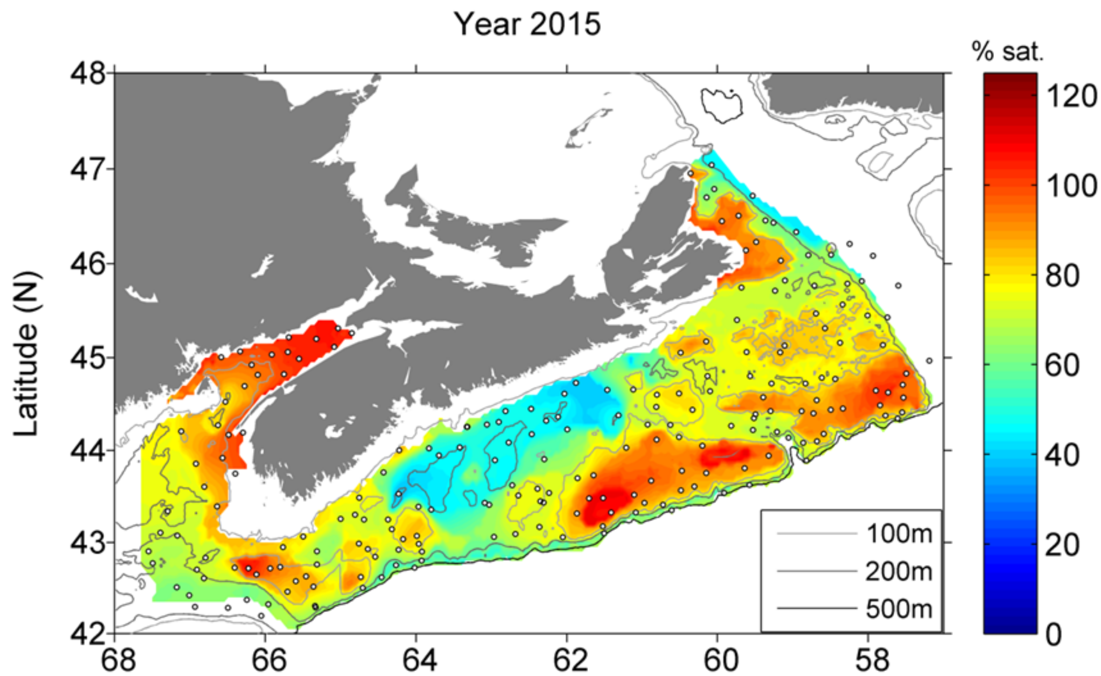

Figure 14. Bottom oxygen saturation level on the Scotian Shelf during the annual July ecosystem trawl survey in 2015. Markers represent the 2015 sampling locations.

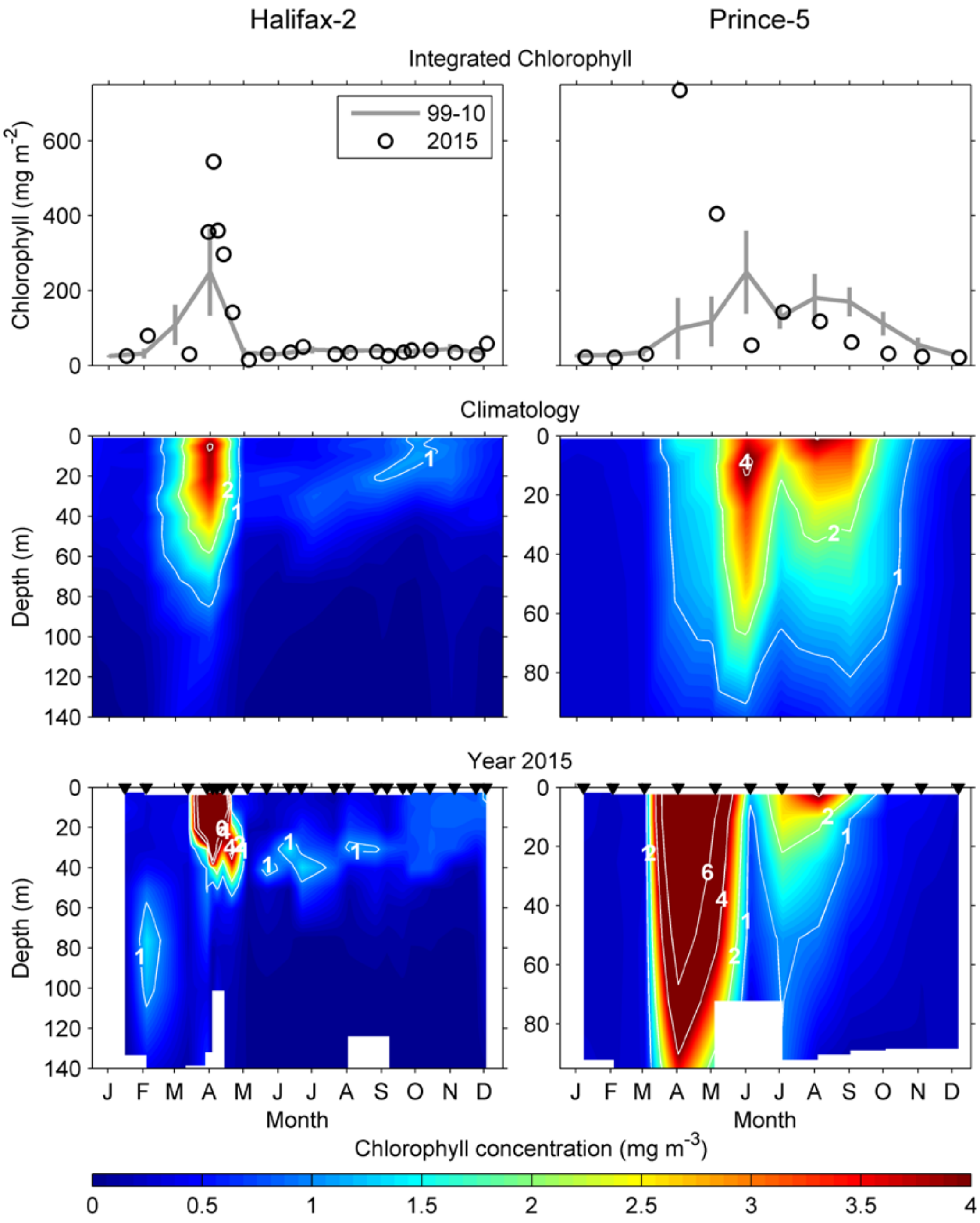

Figure 15. Annual variability in chlorophyll concentration at the Maritimes time series stations (left column: Halifax-2, right column: Prince-5). Top row: chlorophyll inventories (0-100 m at Halifax-2, 0-95 m at Prince-5) in 2015 (open circles) and mean values 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the monthly means. Middle row: Mean (1999–2010) seasonal cycle of the vertical structure of chlorophyll concentration (mg m^{-3}). Bottom row: seasonal cycle of the vertical structure of chlorophyll concentration in 2015. Colour scale chosen to emphasize changes near the estimated food saturation levels for large copepods.

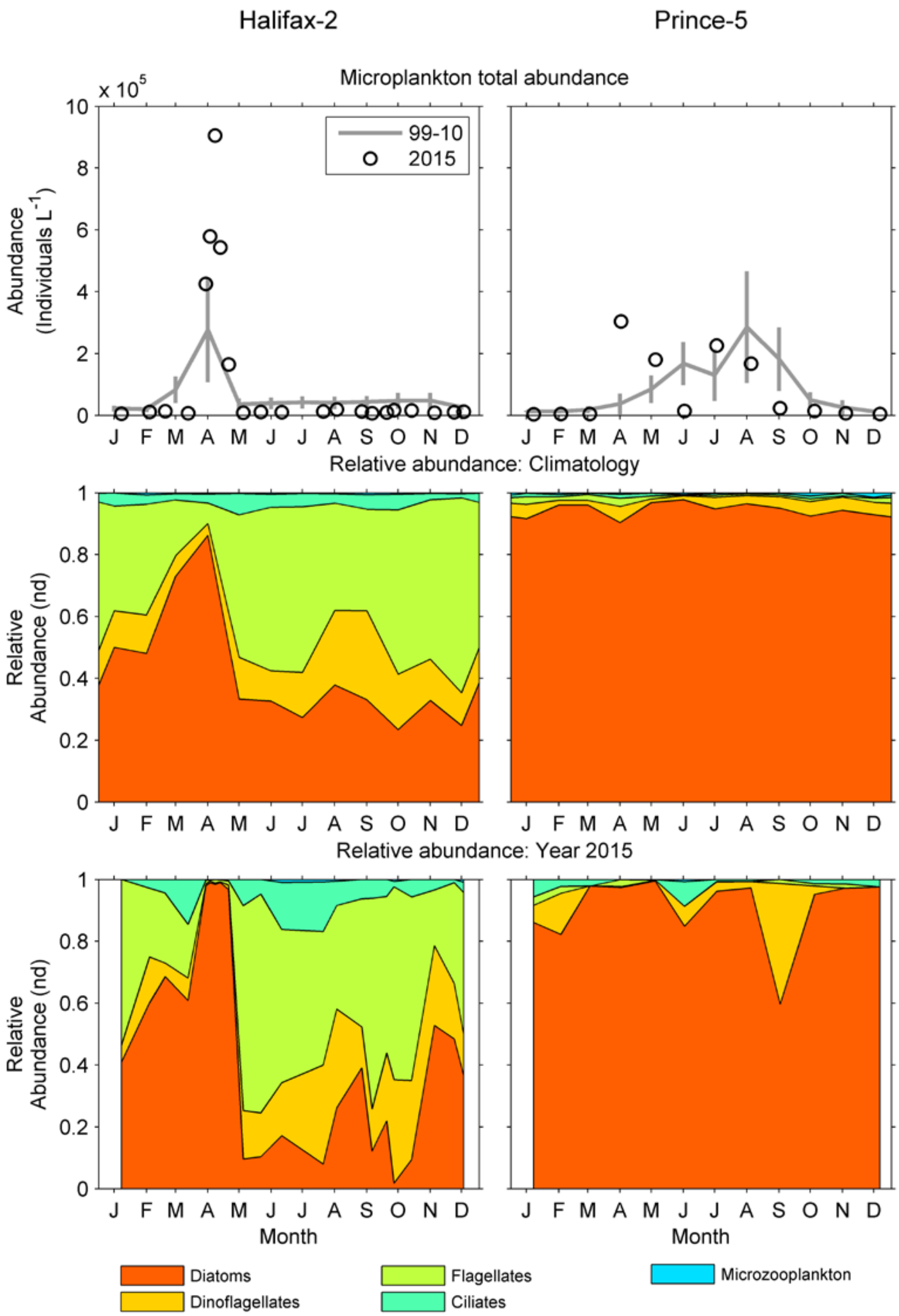

Figure 16. Comparison of 2015 microplankton (phytoplankton and protists) abundance and community composition with mean conditions from 1999–2010 at the Maritimes fixed stations (Halifax-2 right panels; Prince-5 left panels). Upper panels: 2015 microplankton abundance (open circle) and mean conditions 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: 2015 microplankton relative abundance. nd = no dimensions.

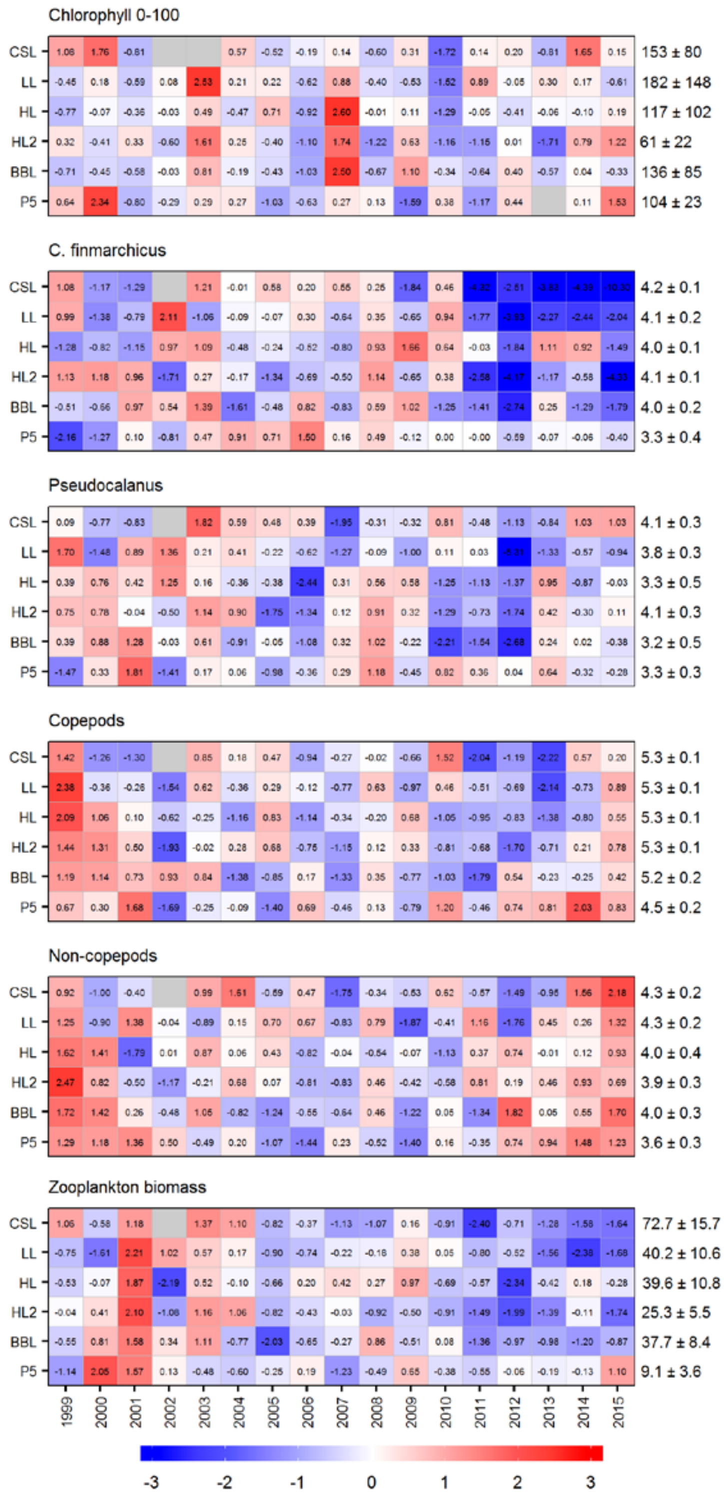

Figure 17. Annual anomaly scorecard for phytoplankton (chlorophyll) and zooplankton abundance or biomass. Values in each cell are anomalies from the mean for the reference period, 1999-2010, in standard deviation (sd) units (mean and sd listed at right). A blank cell indicates missing data. Red (blue) cells indicate higher (lower) than normal nutrient levels. CSL: Cabot Strait section; LL: Louisbourg section; HL: Halifax section; HL2: Halifax-2; BBL: Browns Bank section; P5: Prince-5.

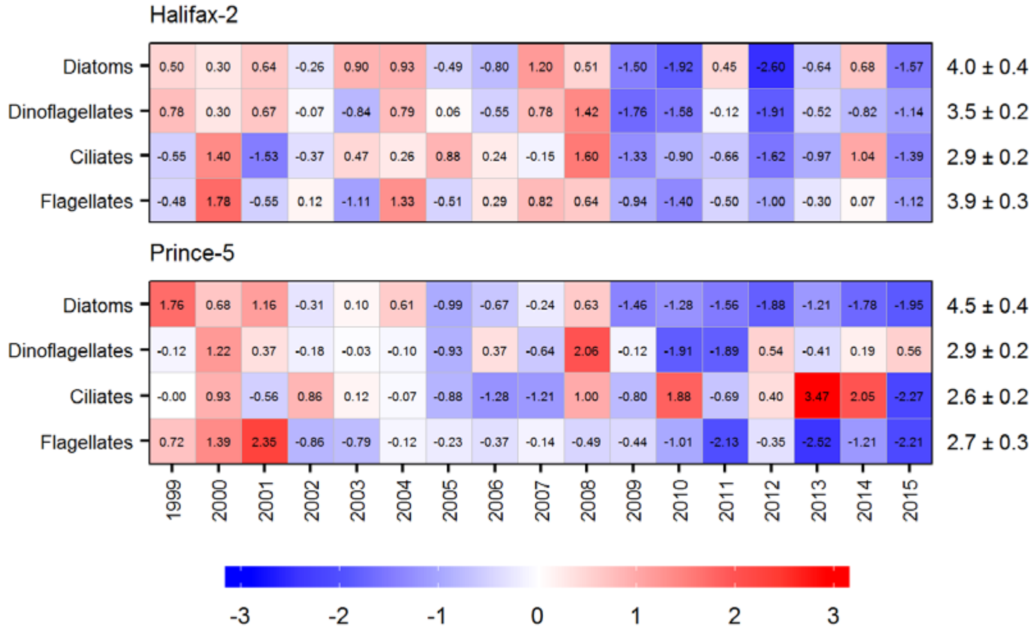

Figure 18. Annual anomaly scorecard for microplankton abundance. Values in each cell are anomalies from the mean for the reference period, 1999-2010, in standard deviation (sd) units (mean and sd listed at right). A blank cell indicates missing data. Red (blue) cells indicate higher (lower) than normal nutrient levels. CSL: Cabot Strait section; LL: Louisbourg section; HL: Halifax section; HL2: Halifax-2; BBL: Browns Bank section; P5: Prince-5.

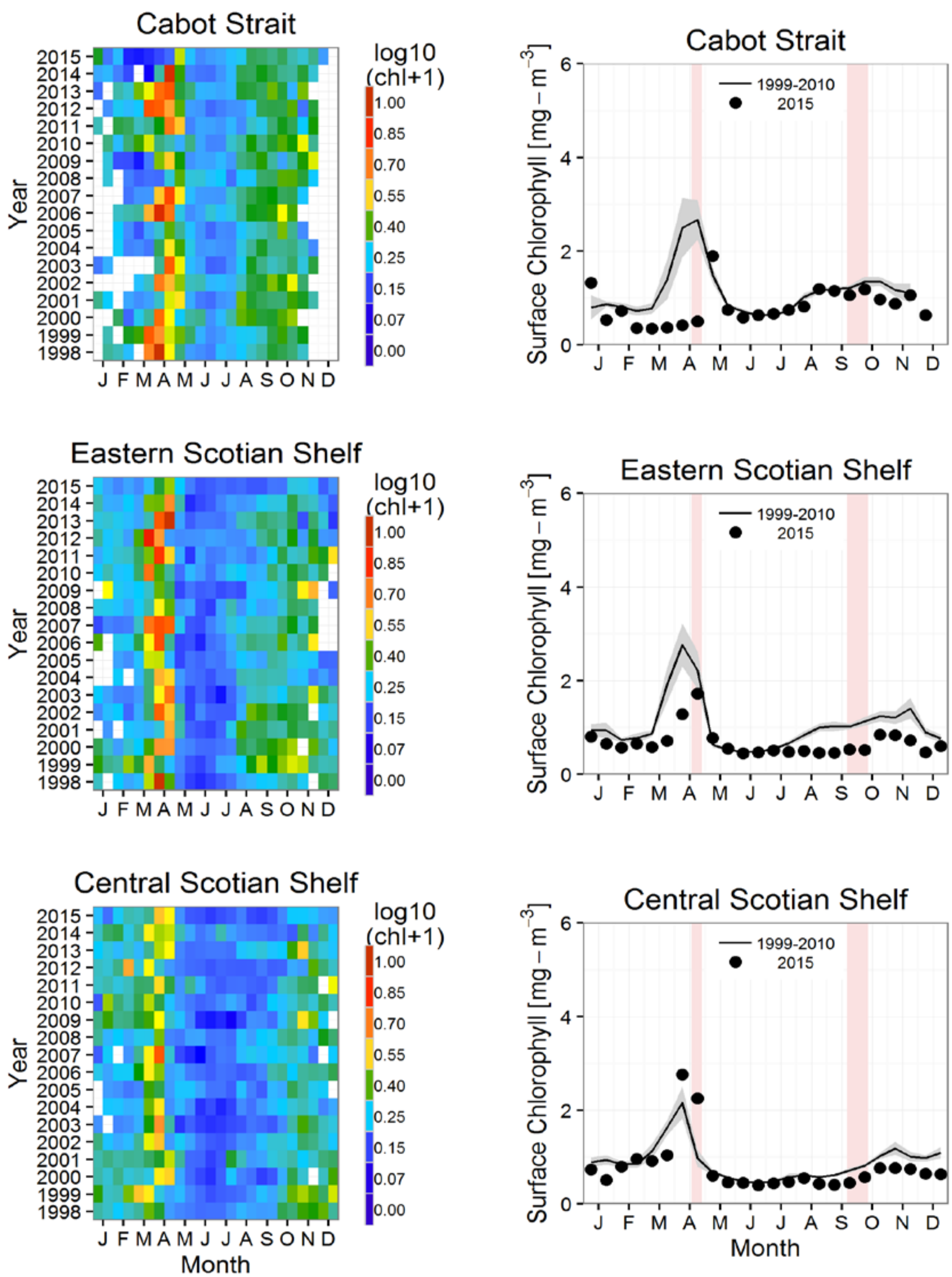

Figure 19a. Estimates of surface chlorophyll concentrations from remotely sensed ocean colour data in the Cabot Strait (top), Eastern Scotian Shelf (middle), and Central Scotian Shelf (bottom) statistical sub-regions (see Figure 4). Data from SeaWiFS 1998-2003; MODIS 2004-2011; VIIRS 2012-2015. Left panels: Time series of annual variation in chlorophyll concentrations. Right panels: Comparison of 2015 (open circle) surface chlorophyll estimates with mean conditions from 1999–2010 (solid line) in the same sub-regions. Gray ribbon is the 95% confidence interval of the semi-monthly mean. Pink vertical stripes indicate the timing of the seasonal missions.

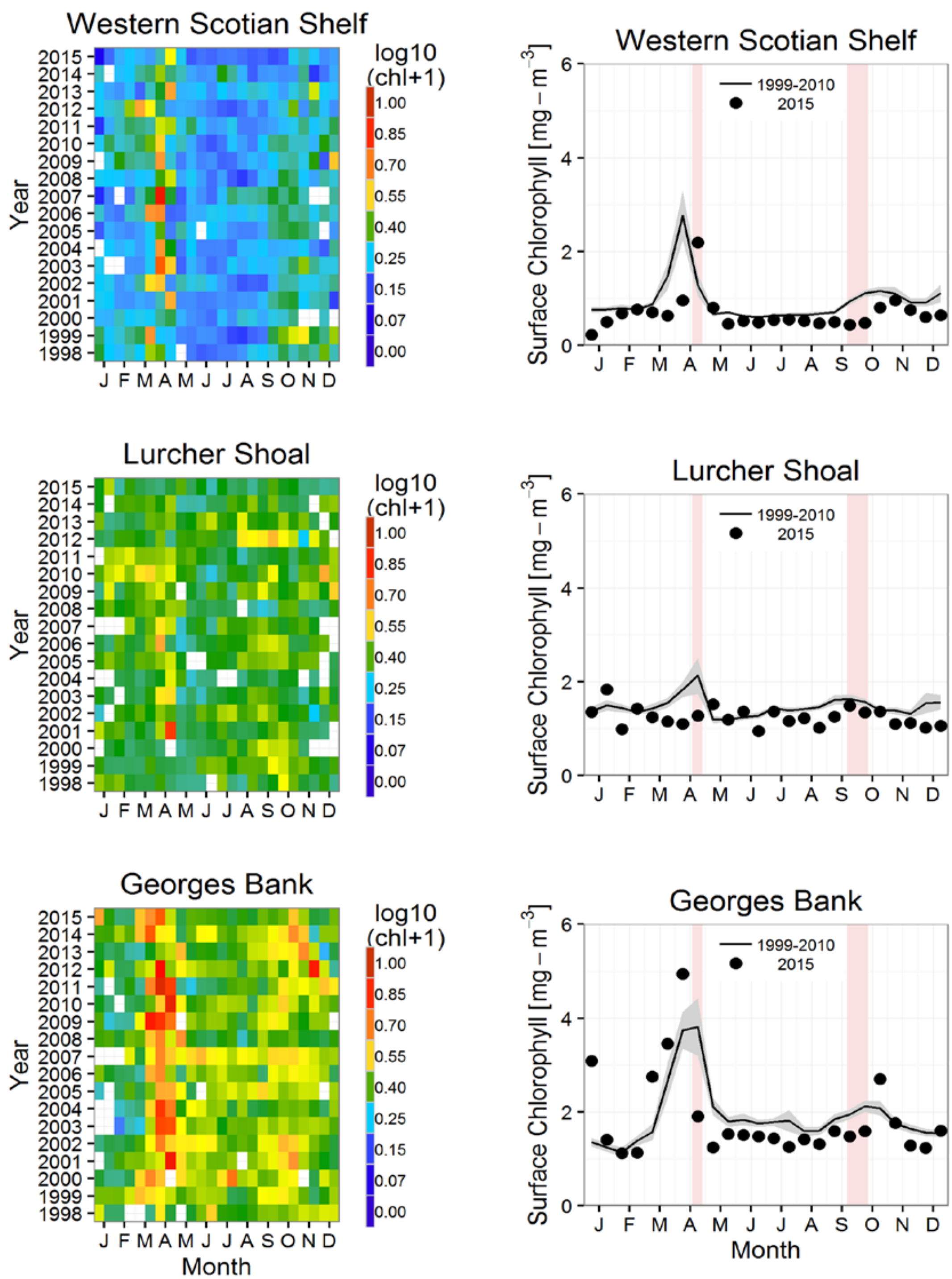

Figure 19b. Estimates of surface chlorophyll concentrations from remotely sensed ocean colour data in the Western Scotian Shelf (top), Lurcher Shoal (middle), and Georges Bank (bottom) statistical sub-regions (see Figure 4). Data from SeaWiFS 1998-2003; MODIS 2004-2011; VIIRS 2012-2015. Left panels: Time series of annual variation in chlorophyll concentrations. Right panels: Comparison of 2015 (open circle) surface chlorophyll estimates with mean conditions from 1999–2010 (solid line) in the same sub-regions. Gray ribbon is the 95% confidence interval of the semi-monthly mean. Pink vertical stripes indicate the timing of the seasonal missions.

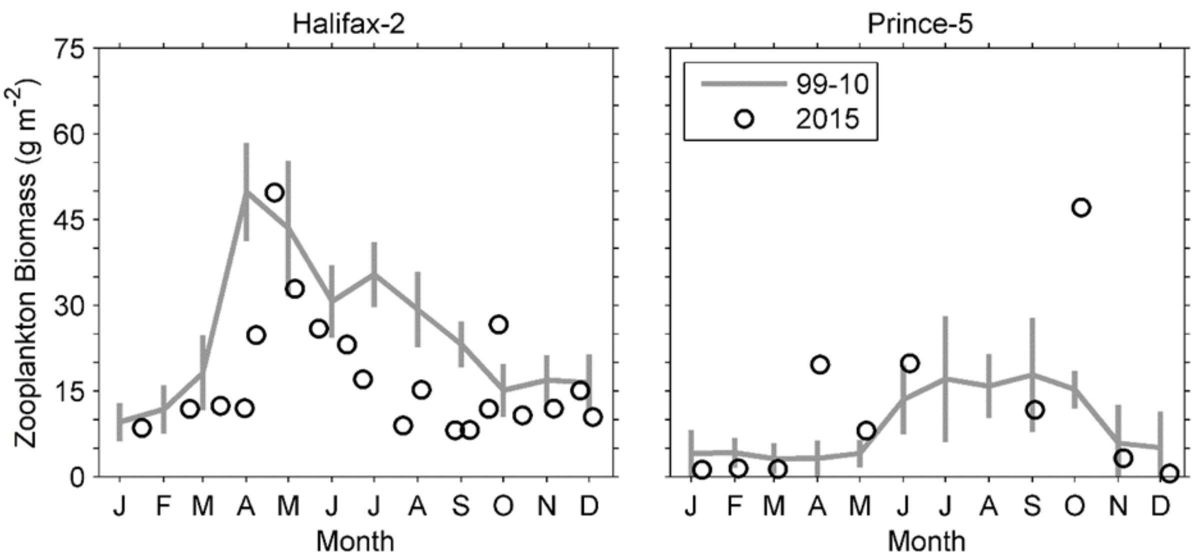

Figure 20. Zooplankton biomass (integrated surface to bottom) in 2015 (open circle) and mean conditions 1999–2010 (solid line) at the Maritimes fixed stations. Left panel: Halifax-2; right panel: Prince-5. Vertical lines are 95% confidence intervals of the monthly means.

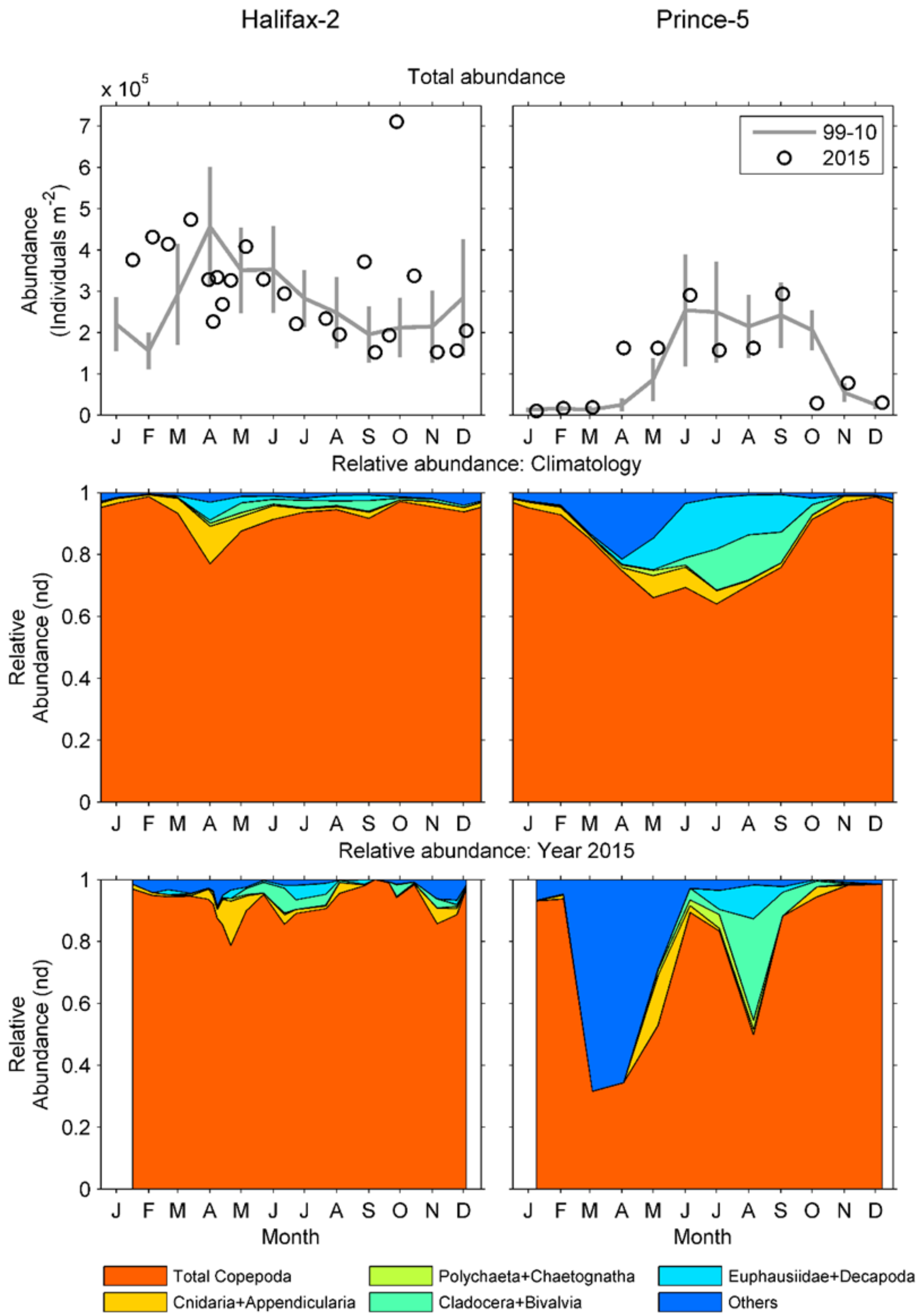

Figure 21. Zooplankton (>200 µm) abundance and community composition in 2015 and mean conditions 1999–2010 at the Maritimes fixed stations (Halifax-2, left panels; Prince-5, right panels). Upper panels: Zooplankton abundance in 2015 (open circle) and mean conditions 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the monthly means. Middle panels: Climatology of major group relative abundances 1999–2010. Lower panels: major group abundances in 2015. nd = no dimensions.

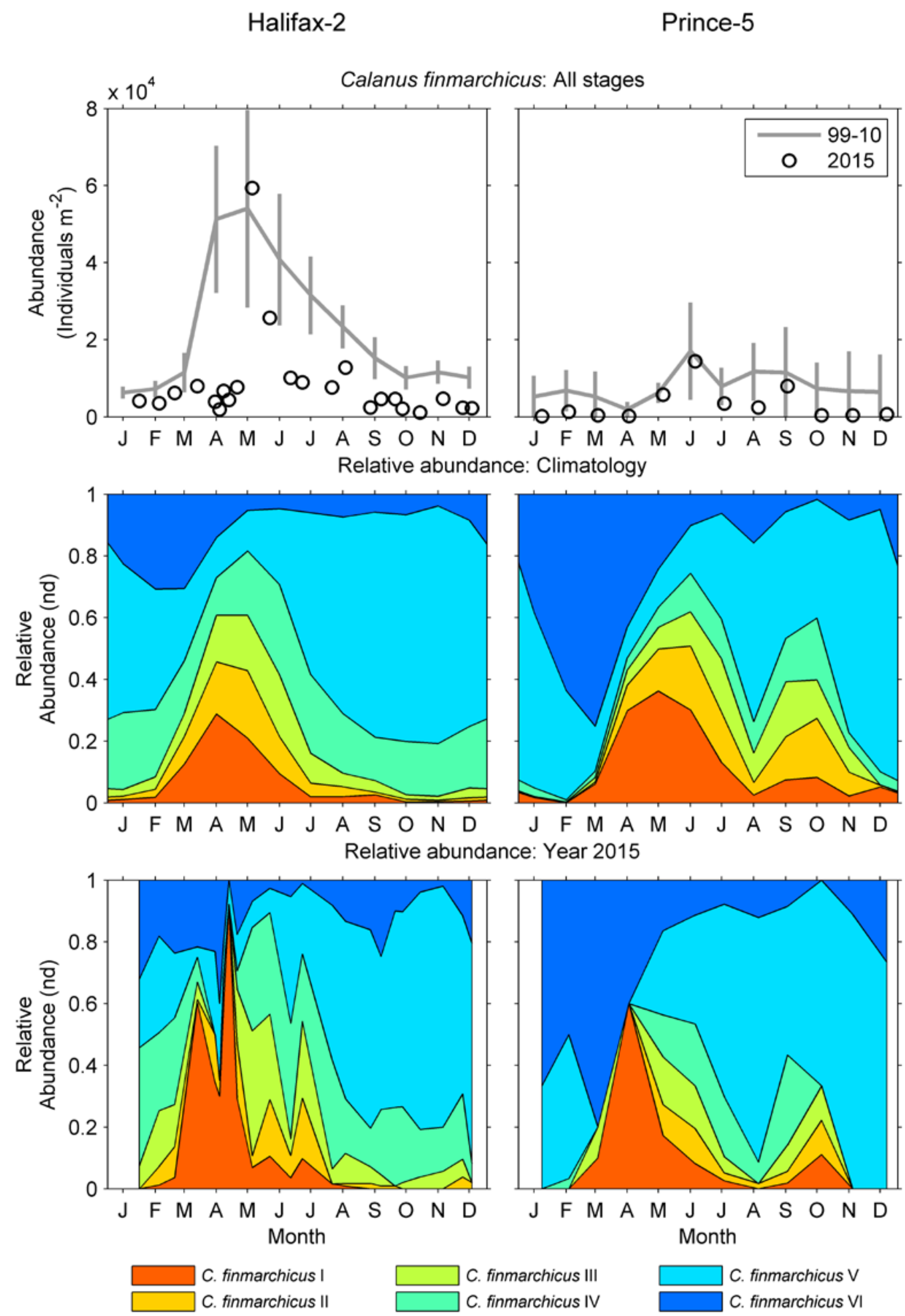

Figure 22. C. finmarchicus *abundance and developmental stage distributions in 2015 and mean conditions 1999–2010 at the Maritimes fixed stations (Halifax-2, left panels; Prince-5, right panels). Upper panels:* C. finmarchicus *abundance in 2015 (open circle) and mean conditions 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the monthly means. Middle panels: Climatological* C. finmarchicus *stage relative abundances, 1999–2010. Lower panels:* C. finmarchicus *stage relative abundances in 2015. nd = no dimensions.*

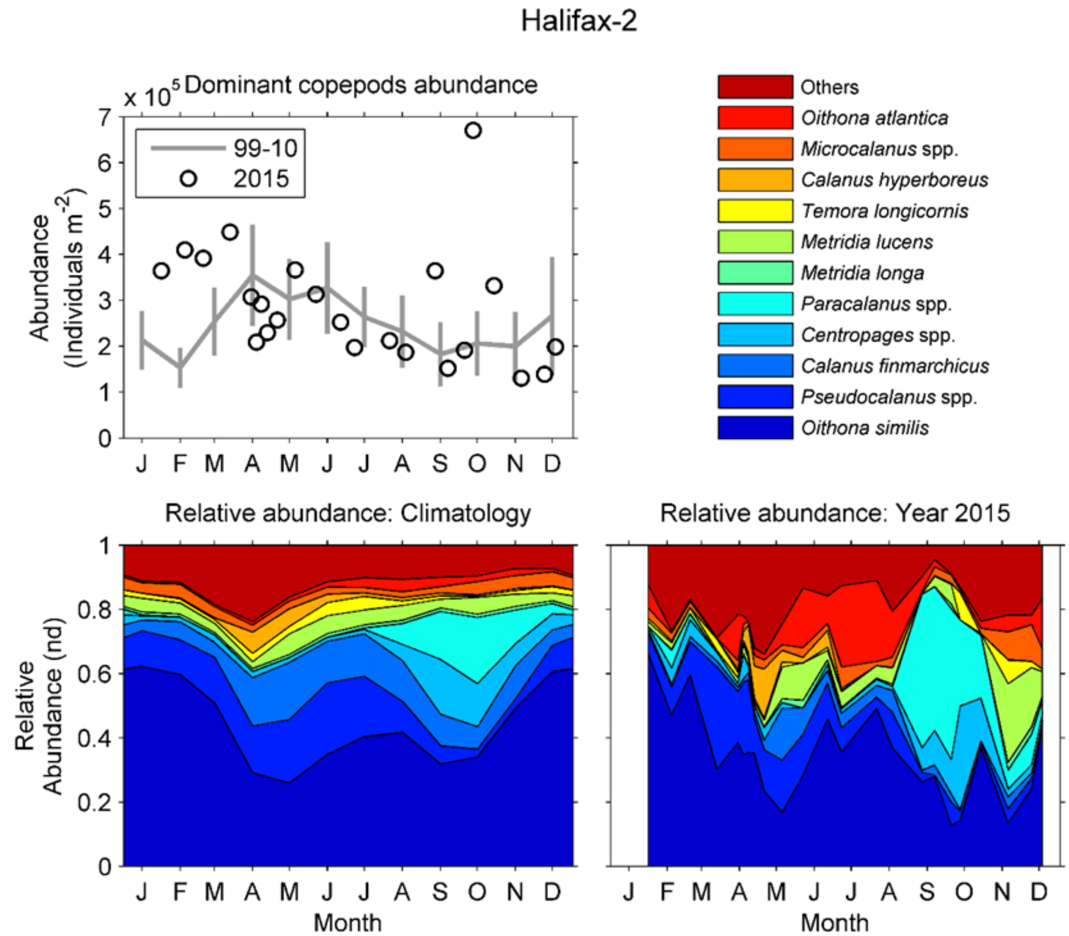

Figure 23a. Seasonal variability of dominant copepods at Halifax-2. The top 95% of identified copepod taxa by abundance, 1999-2010, are shown individually; others, including unidentified copepods (mostly nauplii) are grouped as “others.” Upper left panel: copepod abundance in 2015 (open circle) and mean conditions, 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the monthly means. Lower left panel: Climatology of copepod relative abundances, 1999–2010. Lower right panel: copepod relative abundance in 2015. nd = no dimensions.

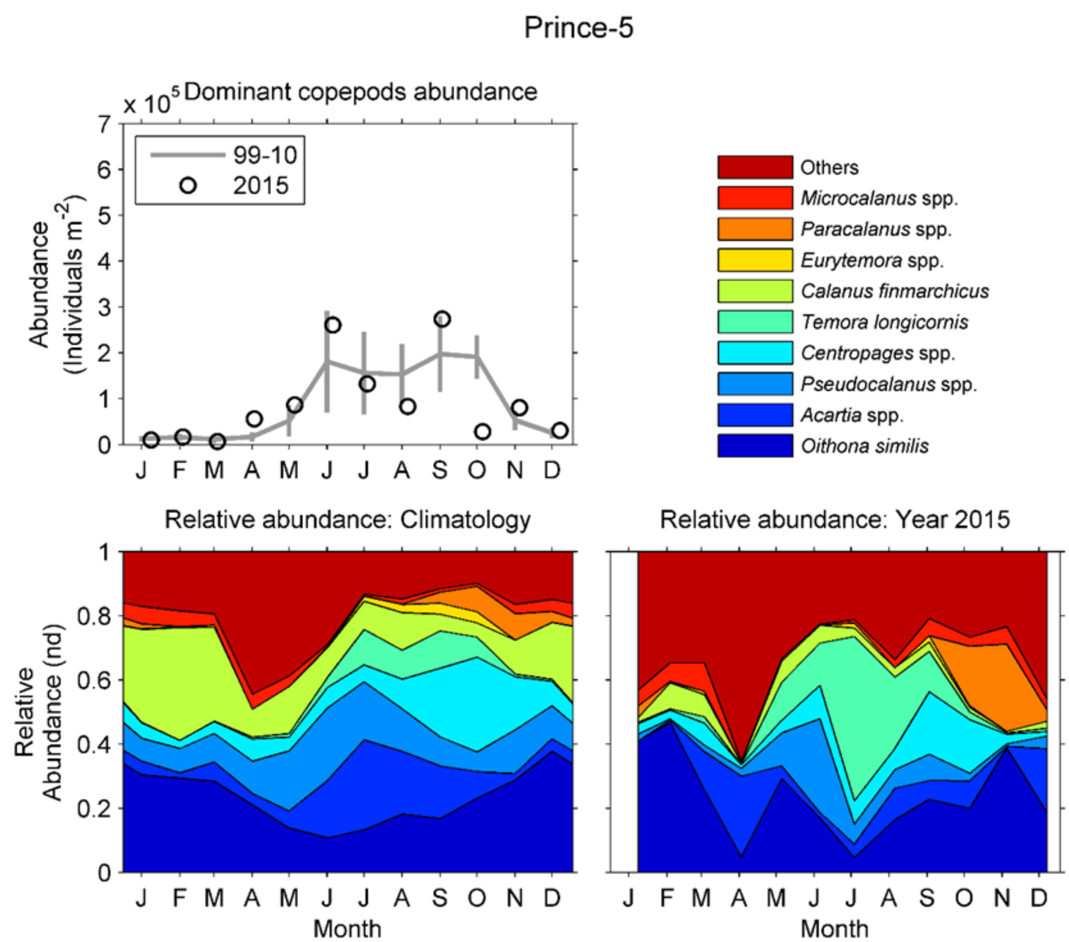

Figure 23b. Seasonal variability of dominant copepods at Prince-5. The top 95% of identified copepod taxa by abundance, 1999-2010, are shown individually; others, including unidentified copepods (mostly nauplii) are grouped as "others." Upper left panel: copepod abundance in 2015 (open circle) and mean conditions, 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the monthly means. Lower left panel: Climatology of copepod relative abundances, 1999–2010. Lower right panel: copepod relative abundances in 2015. nd = no dimensions.

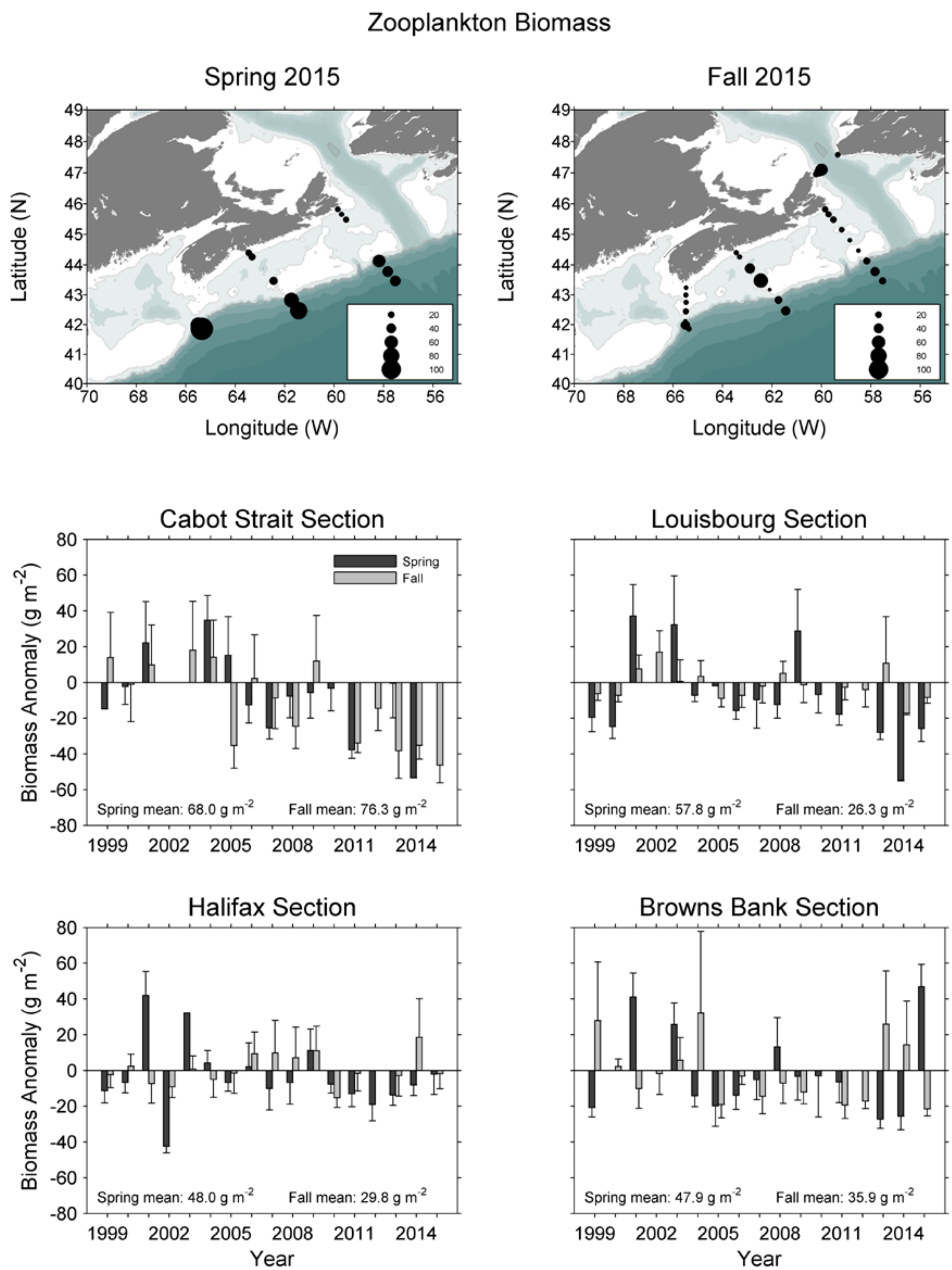

Figure 24. Spatial distribution of zooplankton biomass in 2015 (upper panels) and time series of zooplankton biomass anomalies on Scotian Shelf sections (middle and lower panels) in spring and fall, 1999-2015. Vertical lines in lower panels represent standard errors.

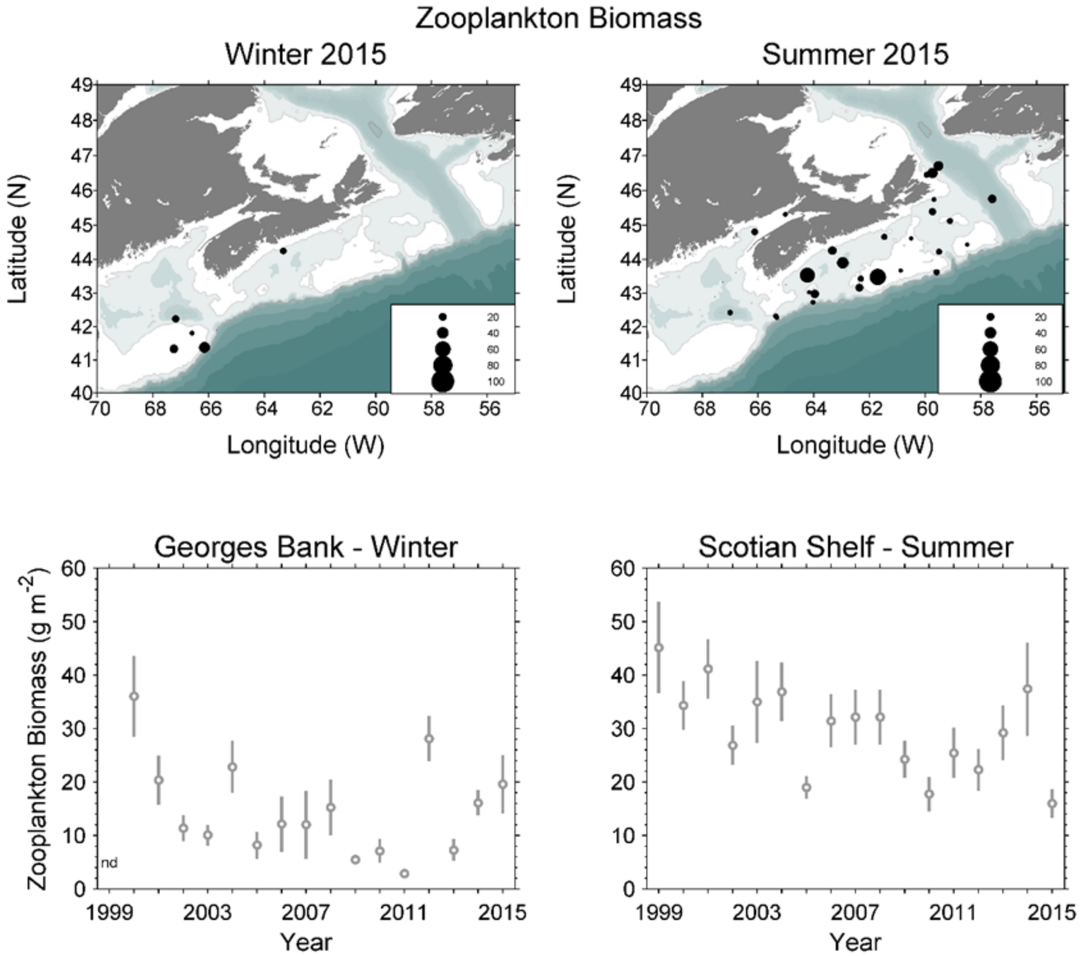

Figure 25. Zooplankton biomass from ecosystem trawl surveys on Georges Bank (February), the eastern Scotian Shelf (March) and the Scotian Shelf and eastern Gulf of Maine (summer): upper panels show 2015 spatial distributions, lower panels show survey mean biomass, 1999–2015 (vertical lines are standard errors; nd = no survey in that year).

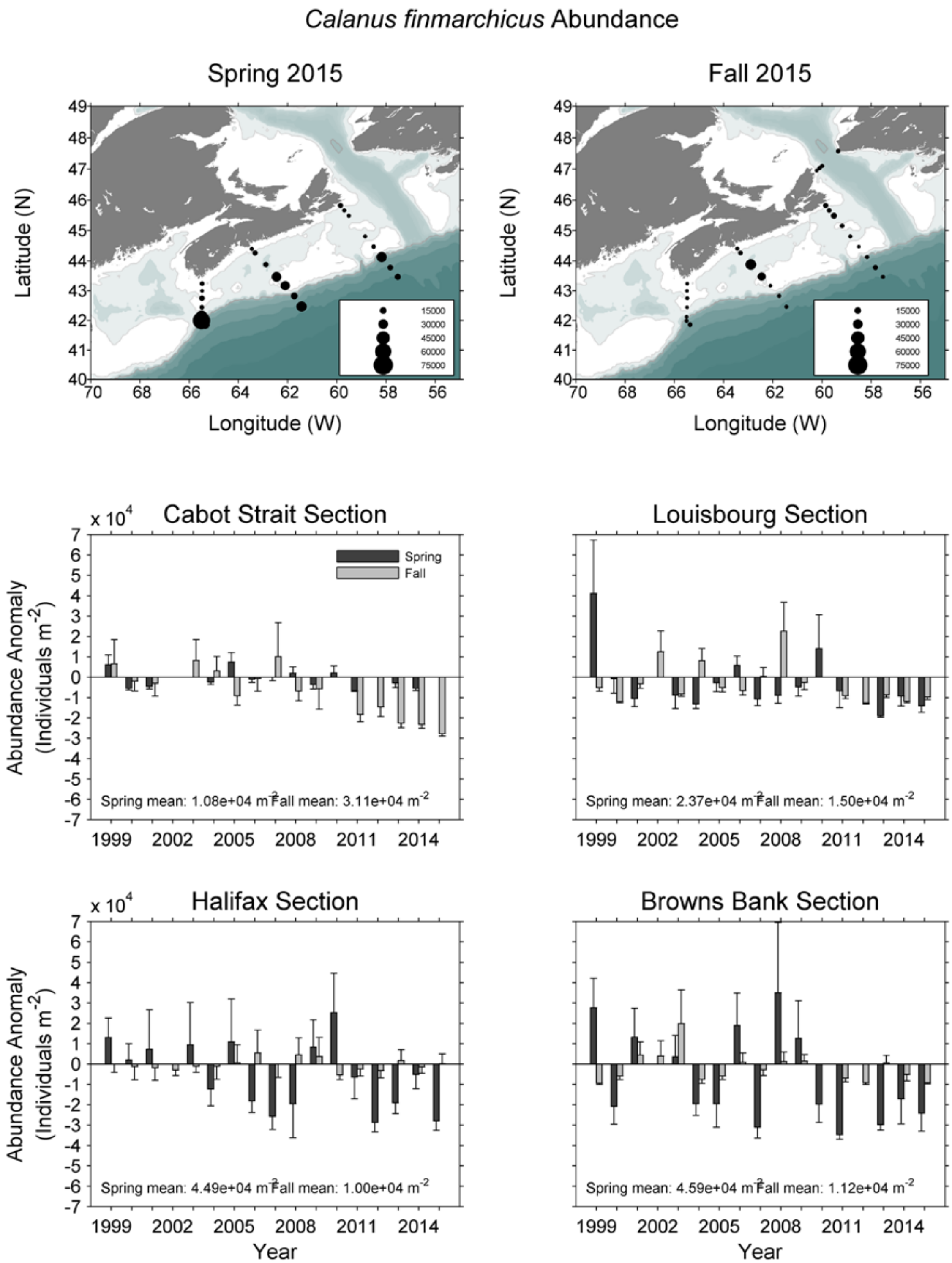

Figure 26. Spatial distribution of C. finmarchicus *abundance in 2015 (upper panels) and time series of average* C. finmarchicus *abundance anomalies on Scotian Shelf sections (middle and lower panels) in spring and fall, 1999-2015. Vertical lines in lower panels represent standard errors.*

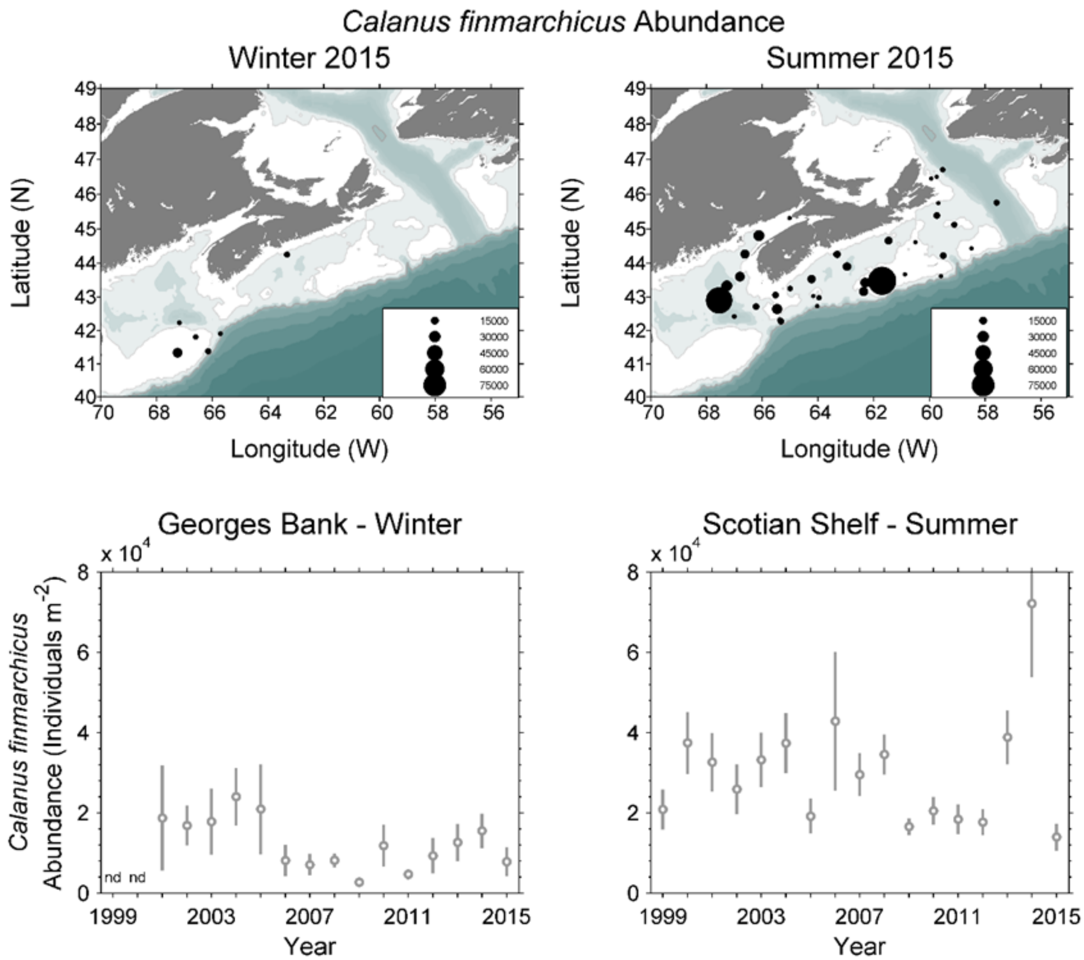

Figure 27. C. finmarchicus *abundance from ecosystem trawl surveys on Georges Bank (February), the eastern Scotian Shelf (March) and the Scotian Shelf and eastern Gulf of Maine (summer): upper panels show 2015 spatial distributions, lower panels show survey mean abundance, 1999–2015 (vertical bars are standard errors; nd = no survey in that year).*

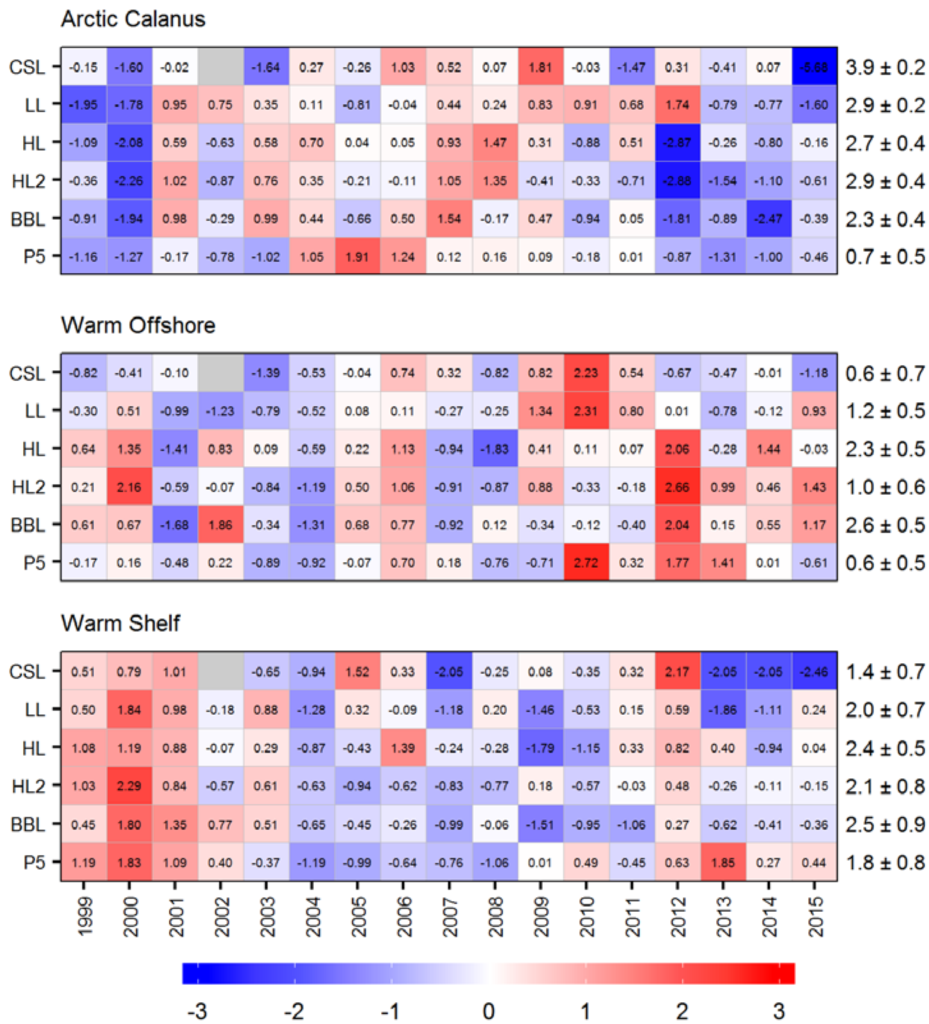

Figure 28. Annual anomaly scorecard for copepod indicator species group abundances. Values in each cell are anomalies from the mean for the reference period, 1999-2010, in standard deviation (sd) units (mean and sd listed at right). A blank cell indicates missing data. Red (blue) cells indicate higher (lower) than normal nutrient levels. CSL: Cabot Strait section; LL: Louisbourg section; HL: Halifax section; HL2: Halifax-2; BBL: Browns Bank section; P5: Prince-5.

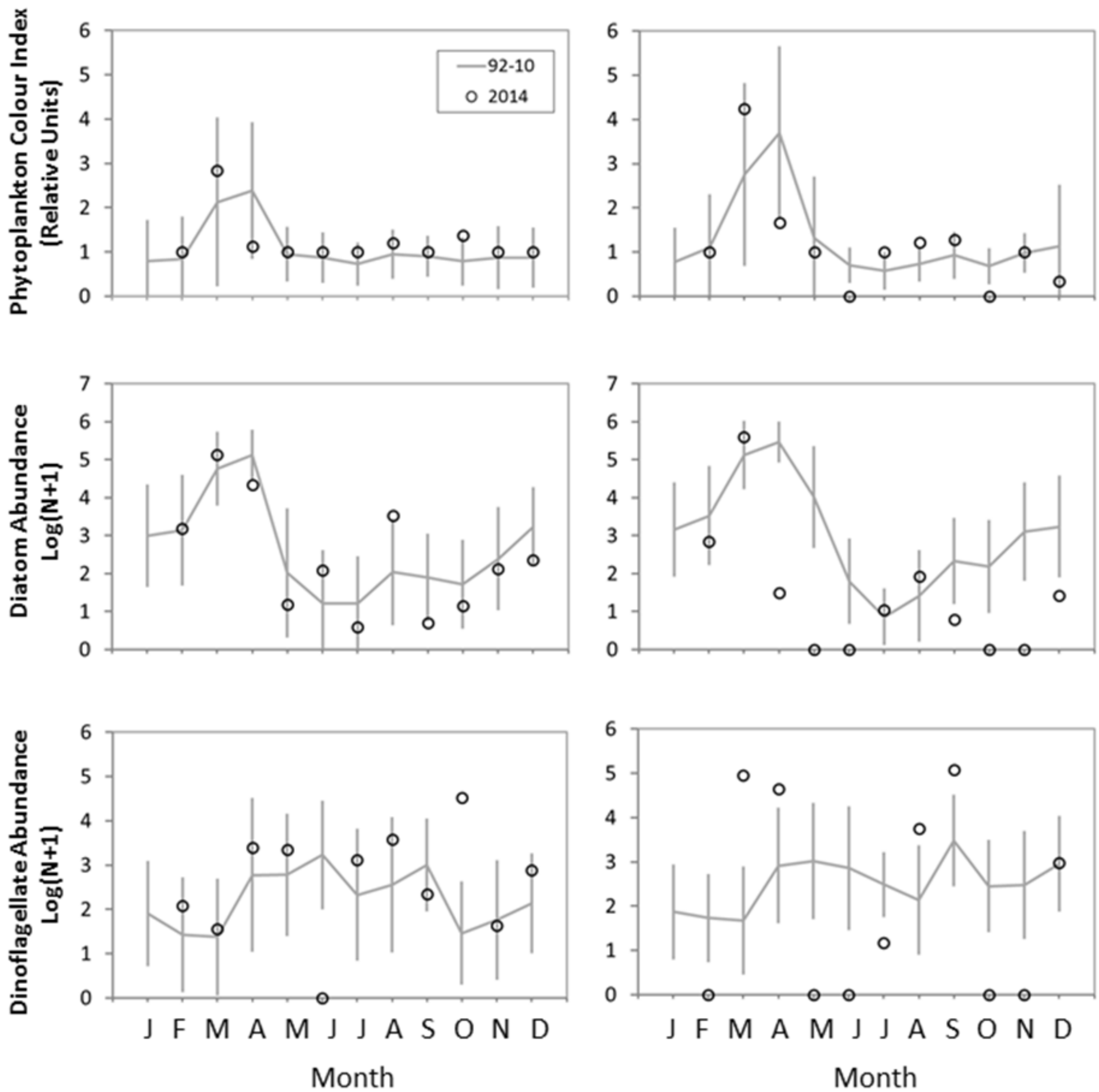

Figure 29. CPR phytoplankton abundance indices in 2014 and mean conditions, 1992-2010 (solid line) on the western Scotian Shelf (left-hand column) and eastern Scotian Shelf (right-hand column). Vertical lines show the standard deviations of the monthly averages.

Taxon / Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
PCI	0.84	0.20	-0.85	1.13	1.95	0.27	1.61	-0.16	-1.24	-0.47	-0.03	0.17	-0.12	-0.63	-1.24				-1.43	-0.82	-1.75	-0.69	-0.03
Diatoms	-0.47	-1.37	-0.70	0.62	0.97	-0.65	1.58	1.84	-0.41	-0.49	1.16	-0.54	0.04	0.36	-1.57				-0.37	-0.97	-2.09	-1.75	-3.50
Dinoflagellates	0.67	-0.26	0.43	0.09	-0.31	-1.26	2.28	-0.01	-0.08	-0.04	1.35	0.14	-1.14	0.74	-1.70				-0.91	0.56	-1.55	-0.42	-0.97
Calanus I-IV	0.63	0.85	-0.66	-1.43	0.04	-1.52	-0.93	-0.49	-0.14	-0.56	-0.37	-0.38	1.33	2.12	0.80				0.72	-1.75	-3.05	0.55	-0.37
C. finmarchicus V-VI	-0.33	0.62	-1.17	-1.29	-1.47	-1.00	-1.10	-0.89	0.82	0.56	0.60	0.85	0.96	0.80	1.57				0.48	-1.49	-2.03	0.52	-1.35
C. glacialis V-VI	-0.44	0.76	-0.06	-0.72	-1.13	-0.24	-1.48	-1.18	0.68	1.05	2.53	-0.01	-0.01	0.49	-0.65				0.39	-0.62	-1.48	-0.24	-1.44
C. hyperboreus III-VI	-0.89	-0.20	0.07	-0.72	-0.93	-0.86	-1.04	-0.34	0.41	2.07	-0.07	-0.70	1.96	0.84	-0.58				0.99	-0.81	-1.04	0.36	-0.98
Copepod nauplii	1.02	0.60	-0.20	1.08	0.39	-1.53	1.72	-0.39	0.84	-0.05	-0.67	-0.16	-1.00	0.82	-0.57				-1.90	-0.95	-1.09	-0.89	-2.32
Para/Pseudocalanus	1.13	2.03	0.07	0.55	0.46	-1.16	0.54	0.62	0.52	-0.01	-1.42	-1.04	-1.18	0.62	-0.42				-1.31	-1.67	-2.64	-1.34	-2.72
Oithona	1.42	1.00	0.75	2.01	0.35	-0.51	0.57	0.40	0.06	-0.82	-0.42	-0.27	-0.93	-0.69	-1.52				-1.39	-1.06	-0.65	-1.05	-0.91
Euphausiids	0.44	0.83	0.29	-0.39	-0.92	-1.20	-0.54	0.94	0.10	0.30	-0.81	0.86	-0.56	0.82	1.91				-2.07	-1.34	-2.01	-0.61	-1.84
Hyperiids	-0.68	0.30	-1.25	-0.15	0.67	0.48	0.09	2.00	-0.69	-0.29	-0.92	0.14	2.30	-0.87	-0.34				-0.78	-0.97	0.06	3.37	5.59
Coccolithophores	-1.15	0.21	-1.01	-0.55	-0.12	-1.01	0.41	0.19	1.78	0.70	2.15	-0.73	-1.21	0.06	-0.47				0.75	-0.43	0.39	-0.19	1.62
Forams	-1.16	-0.69	-0.31	0.82	0.99	-0.36	1.41	2.07	1.06	-0.37	0.19	-1.09	-1.40	-0.36	-0.12				-0.69	2.59	3.15	-1.65	3.74
Limacina	2.92	0.78	1.00	0.27	-0.27	-0.37	-0.06	-0.05	0.66	-0.89	-0.81	-0.65	-0.75	-0.51	-0.06				-1.19	3.75	0.02	-0.22	-0.15

Taxon / Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
PCI	-0.37	0.29	-0.34	1.60	1.36	-1.51	-0.32	2.36	-0.45	0.83	-0.48	-0.02	-0.59	-0.25	-0.30			-0.34	-0.41	-0.34	-0.15	0.96	0.36
Diatoms	-0.61	-0.14	-1.07	0.32	-0.37	-0.98	-0.70	2.73	0.46	0.86	1.71	-0.66	-0.02	-0.61	0.16			-0.07	-0.03	-0.07	0.26	-0.05	-0.33
Dinoflagellates	0.79	0.93	0.54	-0.52	-0.36	-1.21	0.37	0.98	1.79	0.84	0.01	-1.46	-1.07	0.27	0.06			-0.12	-0.57	-0.17	0.04	1.23	0.57
Calanus I-IV	-0.15	0.86	0.23	-0.62	-0.41	-0.52	-1.54	-1.11	0.75	-0.81	-0.27	-0.74	0.98	2.49	0.45			0.27	-0.16	-0.28	-0.31	2.17	-0.02
C. finmarchicus V-VI	-0.29	0.27	-1.35	-1.13	-0.15	-0.61	-1.62	-1.16	0.65	0.43	-0.22	0.89	1.22	0.90	1.60			0.34	-0.06	0.09	-0.17	2.79	-0.38
C. glacialis V-VI	-1.03	0.73	-0.94	0.00	-1.19	0.00	-0.81	-1.19	0.25	0.92	1.16	1.60	1.39	0.45	0.83			-1.45	-1.60	0.83	-1.39	-0.42	0.72
C. hyperboreus III-VI	-0.81	0.40	0.74	-0.01	-0.81	0.50	-0.81	-0.81	0.90	1.16	-0.81	-0.81	2.25	1.38	-0.81			-4.24	-4.24	-0.49	-4.24	0.67	2.63
Copepod nauplii	0.32	2.39	-0.40	0.95	0.85	-0.43	0.54	-0.13	1.05	0.93	-0.41	-1.17	-0.60	-0.93	-0.59			-0.55	-0.67	-0.59	-0.23	-0.33	0.38
Para/Pseudocalanus	0.83	2.50	0.60	0.10	-1.02	-0.99	-0.96	0.62	1.54	-0.15	-0.77	-0.84	-0.13	0.15	0.17			0.09	-0.17	-0.08	0.24	0.63	-0.70
Oithona	1.09	2.45	0.94	1.11	-0.12	-0.48	0.19	0.28	0.91	-0.45	-0.56	-0.92	-0.92	-0.58	-0.78			-0.47	-0.64	-0.64	0.10	0.59	-0.03
Euphausiids	0.61	-0.50	0.29	0.04	1.77	0.58	2.17	-1.57	0.10	-0.51	-1.43	0.35	-0.48	-0.97	-0.17			0.65	0.26	-0.05	0.05	-1.78	-1.75
Hyperiids	-0.49	0.38	-1.59	-0.57	1.08	1.41	-0.31	-0.54	-0.19	-0.61	-0.80	-0.75	1.01	-0.61	0.01			-0.32	-1.40	-1.40	0.02	2.72	3.20
Coccolithophores	-1.05	-0.42	-1.22	-0.49	-0.01	0.15	0.81	1.77	0.87	0.00	-0.47	-0.50	-0.36	-1.17	-0.37			2.11	0.26	0.37	1.65	1.64	-0.42
Forams	-1.22	1.05	-0.02	0.14	1.36	0.00	0.80	1.61	1.30	-0.84	-0.98	-0.92	-1.06	-0.78	-0.16			-0.50	-1.92	-1.26	0.50	2.87	1.68
Limacina	0.04	1.35	1.55	-0.50	-0.64	0.00	-0.86	1.47	1.94	-0.67	-0.78	-0.93	-0.54	-0.72	-0.96			0.88	-0.13	1.01	1.30	1.39	-0.35

-3	-2	-1	0	1	2	3

Figure 30. Annual anomaly scorecard for the abundances of phytoplankton and zooplankton taxa observed with the CPR 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 reference period is 1992-2010. The numbers in the cells are the standardised anomalies.

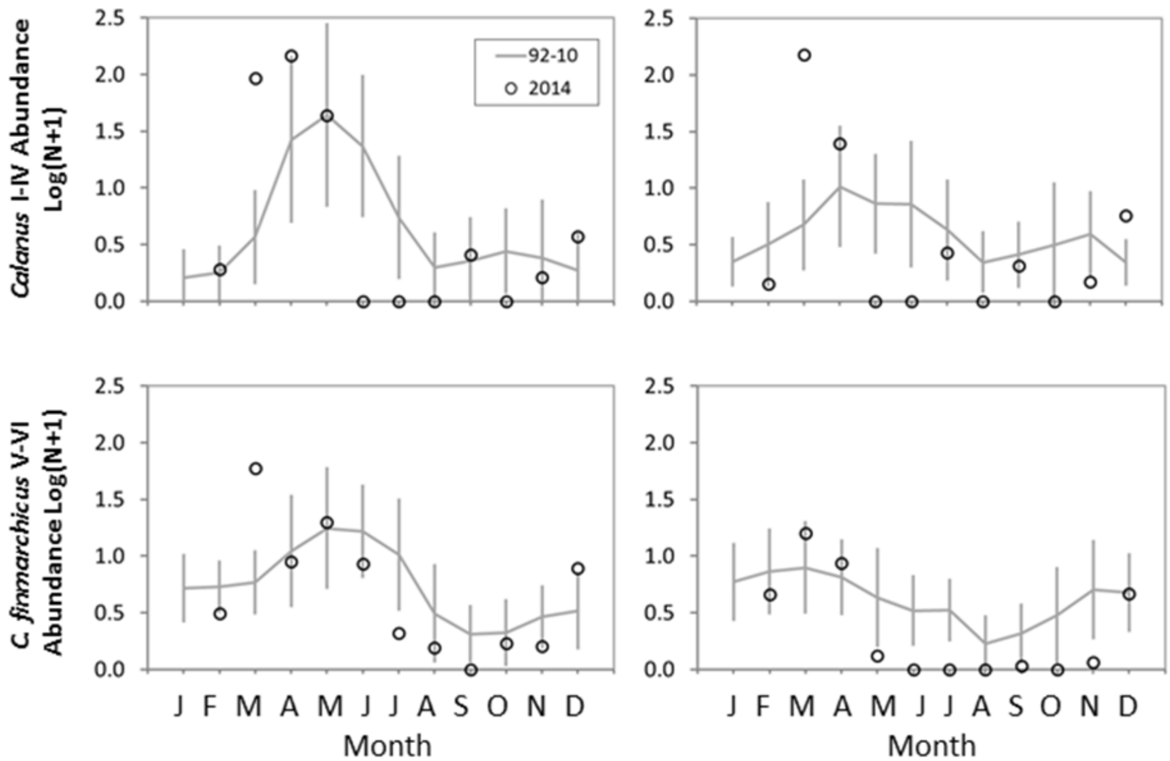

Figure 31. CPR abundance indices for Calanus *I-IV (mostly* C. finmarchicus*, upper row) and* C. finmarchicus *V-VI (lower row) in 2014 and mean conditions, 1992-2010 (solid line) on the western Scotian Shelf (left-hand column) and eastern Scotian Shelf (right-hand column). Vertical lines represent standard deviations of the monthly averages.*