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**Maritimes Region**

# Optical, Chemical, and Biological Oceanographic Conditions on the Scotian Shelf and in the Eastern Gulf of Maine in 2016

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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

The condition of nutrients and plankton on the Scotian Shelf and in the Gulf of Maine were assessed in the context of continued warmer-than-normal surface and near bottom ocean temperatures in 2016, a pattern that started in 2008, and continued higher-than-normal stratification in summer and fall. Overall in 2016, deep nutrient inventories were lower than normal. While deep nitrate anomalies have been mixed in sign in recent years, inventories of deep silicate and phosphate have been mainly negative since 2013. Spring phytoplankton bloom initiation was early and bloom duration short in the east, and bloom magnitude was small and duration short in the central and western Scotian Shelf. The early spring bloom initiation timing in 2016 contrasts with the mainly later initiation timing observed on the Scotian Shelf in recent years. Observations in 2016 provide additional evidence for a persistent plankton community change in recent years.  The abundance of large phytoplankton, including diatoms, continued to be lower than normal. Zooplankton biomass and *Calanus finmarchicus* abundance also continued to be lower than normal, while non-copepod abundance was high. The abundance of arctic *Calanus*, an indicator of cold water on the Scotian Shelf, continued to be lower than normal. Higher than average abundances of *Oithona atlantica* and warm offshore species suggest greater influence of offshore waters in recent years, especially on the western Scotian Shelf. Changes in phytoplankton and zooplankton communities observed in recent years suggest changes in prey fields for planktivorous fish, birds, and mammals and could be associated with changes in the fate of primary production in the ecosystem.

Continuous Plankton Recorder (CPR) data become available one year later than data collected by the Atlantic Zone Monitoring Program. In 2015, there was sampling in only 7 months between April and November on the Western Scotian Shelf (WSS) and in only 5 months between June and November on the Eastern Scotian Shelf (ESS). Due to the poor temporal coverage, annual average abundances and abundance anomalies could not be calculated for 2015.  Sampling on the WSS in April-May indicated (i) near normal levels for three phytoplankton groups and the dominant zooplankton taxa *Calanus* I-IV and *C. finmarchicus* V-VI, (ii) unusually low levels for two Arctic *Calanus* species and hyperiid amphipods, and (iii) low or near normal levels for seven other taxa. Sampling over the entire Scotian Shelf between June and November indicated (i) near normal levels for the three phytoplankton groups, (ii) lower than (June-September) or close to (October-November) normal abundances for *Calanus* I-IV, *C. finmarchicus* V-VI and most other taxa, but higher than normal abundances for coccolithophores and foraminifera on the ESS from September to November.

# 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. High frequency sampling 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 2016. It complements similar assessments for the physical environment of the Maritimes Region (e.g., Hebert et al. 2018), for the pelagic environment in the Gulf of St. Lawrence (e.g., Devine et al. 2017, Galbraith et al. 2017), for the Newfoundland and Labrador shelves and the Grand Banks (e.g., Colbourne et al. 2017, Pepin et al. 2017), and for the Canadian Northwest Atlantic shelf system as a whole (DFO 2017).

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) exhibit significant shifts in temperature, reflecting changes 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 (2010-2016) warmer than average overall (Hebert et al. 2018). The 2016 Maritimes Region composite temperature index, which includes 18 ocean temperature time series from surface to bottom, indicated that 2016 was the second warmest year since 1947, with warmer conditions observed only in 2012. Positive sea surface temperature (SST) anomalies were most pronounced in the winter and late summer-fall on the Scotian Shelf, and positive SST anomalies were observed throughout the year in the Gulf of Maine. Following normal sea ice conditions in 2014-2015, sea ice coverage returned to low levels similar to those observed in 2010-2013. 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, and in 2016, the Scotian Shelf stratification index was above the 1981-2010 average (Hebert et al. 2018). The status of nutrients and plankton in the region in 2016 are reported here 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 six missions (seasonal section cruises, ecosystem trawl surveys, and Cabot Strait and Halifax sections sampling on a mission to the Labrador Sea) during the 2016 calendar year, in addition to day trips to the two high frequency sampling stations. In 2016, AZMP Maritimes performed a total of 572 hydrographic station occupations, at 242 of which net samples were collected (Table 1).

### High Frequency Sampling Stations

The Halifax-2 and Prince-5 high frequency sampling stations (Figure 1) were sampled on 19 and 12 occasions, respectively, similar to sampling frequencies achieved in recent years.

The standard sampling suite for the high frequency sampling 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 and accessory pigments 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 attenuation when possible.

### Shelf Sections

The four primary sections (Browns Bank, Halifax, Louisbourg, Cabot Strait sections; Figure 1), and a number of ancillary sections/stations (gray markers in Figure 2) were sampled in spring and fall (Table 1). Due to operational constraints, the Cabot Strait section was not sampled during the regular seasonal survey (HUD2016-003) but rather as part of the Labrador Sea survey (HUD2016-006) with the sampling of the CSL stations occurring on May 2, 2016, (*i.e.*, five days after the completion of the spring seasonal survey). Results from the ancillary sections/stations and from the 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 high frequency sampling stations as listed above, but phytoplankton are not enumerated.

In addition to the standard suite of analyses from water samples, particulate organic carbon (POC) is performed at standard depths. Results of these ancillary measurements are not reported here.

### Ecosystem Trawl Surveys

AZMP-DFO Maritimes Region participated in three primary ecosystem trawl surveys in 2016: the winter (February-March) Georges Bank survey, the late winter (March) western Scotian Shelf/eastern Gulf of Maine survey and the summer (June-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 high frequency sampling 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 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:

- High frequency sampling 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).

## DERIVED METRICS

### 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 ($\sigma_t$) at 50 m and $z_{min}$, the minimum depth of reliable CTD data, which is typically around 1 or 2 m and always less than ~5 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.

## Phytoplankton Taxonomic Groups

Phytoplankton abundance and taxonomic composition at the high frequency sampling stations were estimated from pooled aliquots of water collected in the upper 100 m using the Utermöhl technique.

Pigment composition was measured using High Performance Liquid Chromatography (HPLC) in surface (between 1 and 5 m deep) water samples, as a proxy for the biomass of phytoplankton taxonomic groups. Phytoplankton pigment composition and concentration represent a first order indicator of phytoplankton community structure, despite the possible occurrence of a given pigment in several taxonomic groups. Absolute concentrations were used rather than the relative contribution compared to chlorophyll-*a* to retain information about biomass. Here, the conservative approach of associating a given taxonomic group with its marker pigment was used as a proxy for the biomass of taxonomic groups:

- Diatoms: Fucoxanthin
- Dinoflagellates: Peridinin

- Nanoflagellates: 19’-Hexanoyloxyfucoxanthin and 19-butanoyloxyfucoxanthin
- Cryptophytes: Alloxanthin
- Cyanobacteria and prochlorophytes: zeaxanthin

In addition, chlorophyll-**b** concentration was used as a marker of picophytoplankton other than cyanobacteria and prochlorophytes.

## 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, SeaWiFS data from January 1998 to December 2007, MODIS data from January 2008 to December 2011 and VIIRS data from January 2012 to December 2016 were combined to construct composite time series of surface chlorophyll in selected sub-regions (Figure 4). Basic statistics (mean, standard deviation) were extracted from semi-monthly composites for the purpose of visualizing the annual cycle and the inter-annual variability of surface chlorophyll for the sub-regions (*e.g.*, Figure 19). Characteristics of the spring bloom (*e.g.*, Figure 20) were estimated from weekly 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 minus the background chlorophyll concentrations).

## 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 high frequency sampling stations and as an overall average along each of the four standard sections are based on general linear models (GLMs; R Core Team 2017) of the form:

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

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

*Density* is in units of $m^{-2}$ (or $L^{-1}$ for microplankton abundance), $\alpha$ is the intercept and $\varepsilon$ is the error. For the high frequency sampling stations, $\beta$ and $\delta$ are categorical effects for year and month, respectively. For the sections, $\beta$, $\delta$ *and* $\gamma$ take into account the effect of year, station, and season, respectively. *Density* in terms of zooplankton or microplankton abundance was log-

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[1] While the SeaWiFS mission ended in December 2010, information about SeaWiFS sensor can be found on the NASA's OceanColor Web SeaWiFS webpage (accessed May 9, 2017).

[2] Additional information about the MODIS sensor can be found on the NASA's OceanColor Web MODIS webpage (accessed May 9, 2017).

[3] Additional information about the VIIRS sensor can be found on the NASA's OceanColor Web VIIRS-SNPP webpage (accessed May 9, 2017).

transformed to deal with the skewed distribution of the observations and one was added to the *Density* term to include observations where *density* values = 0. Average integrated inventories of nutrients, chlorophyll and zooplankton biomass were not log-transformed. An estimate of the least-squares means based on type III sums of squares (Lenth 2017) 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 (2017).

## ACCESS TO DATA PRODUCTS

Data products presented in Figures 6, 8, 10, 11, 15-18, 22-31 have been published on the Government of Canada's Open government website (Open Data).

## 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 were analysed to detect differences in the surface 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 were 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 were 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 reporting lags one year behind AZMP reporting. CPR data collected from January to December 2015 were received in December 2016 and added to the DFO data archive. In 2015, there was CPR sampling during only 7 months on the WSS, and during only 5 on the ESS.

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 2015 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. Since these criteria were not met in either region of the Scotian Shelf in 2015, annual abundance anomalies could not be calculated. 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, the MLD is deepest and stratification lowest during the winter months when surface heating is weak and wind-driven mixing is strong (Figure 6). The MLD shoals in the spring to minimum values from June to August and deepens in the last four months of the year. Similarly, stratification increases in the spring to maximum values in August and September and then declines during the fall months. In 2016, MLDs at Halifax-2 followed the typical annual pattern with higher variability observed during the winter and spring months, values close to climatology during the summer months, and weaker than normal mixing during the fall months (Figure 6). Stratification was mostly weaker than normal at Halifax-2 during winter and spring 2016 and mostly stronger than normal during the summer and early fall.

At Prince-5, the MLD is typically deeper and more variable and stratification weaker than at Halifax-2, 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 2016, MLDs were near normal during the winter months but were markedly deeper than normal during the spring and fall months and shallower than normal in July and August. The stratification index at Prince-5 exhibited mostly typical low values in 2016, with lower than normal stratification in the spring and fall months and slightly above normal values in July and August, concurring with the mixed layer observations in those months.

Episodic wind events observed during the winter and spring months at Halifax Airport, a proxy for Halifax-2 station, may have contributed to the variability observed in the MLD at Halifax-2 during those months. The lower wind gusts observed at Halifax Airport in late January and mid-March (Figure 7) appear to be associated with the transient shoaling of the MLD observed at Halifax-2 (Figure 6) on the sampling dates of February 3rd and March 11th, respectively. Wind observations at Grand Manan, a proxy for Prince-5, closely followed the climatological pattern throughout the year suggesting that the mostly deeper than normal MLDs observed at Prince-5 were more likely tidally driven rather than wind driven.

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. Euphotic depths based on PAR and Secchi disc measurements appear to be slightly shallower or close to normal values throughout the year at Halifax-2 in 2016 (Figure 8). Euphotic depths estimated from PAR measurements were typically mostly shallower than those estimated from Secchi depth measurements at Halifax-2. Unfortunately, euphotic depths associated with the spring phytoplankton bloom at Halifax-2 could not be estimated as a result of low light levels at the time of the measurements.

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 2016, both PAR-based and Secchi-based euphotic depths mainly followed the climatological values throughout the year (Figure 8). The PAR-based euphotic depth estimate for the October measurement can likely be attributed in part to the attenuation coefficient being calculated over a rather shallow water layer as the light measurements below 25 m were unreliable. However, the Secchi-based estimate was also slightly shallower than normal for October.

## 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 phytoplankton taxonomic group succession at Halifax-2 and Prince-5.

### High Frequency Sampling 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 2016 was slightly below normal in the spring and summer months, and well below normal in the fall months (Figure 10), which corresponded with a slightly deeper than normal nitricline during the summer and longer than normal period of surface nitrate depletion during the fall (Figure 9). Deep nitrate inventories at Halifax-2 in 2016 were variable during the winter and spring months but remained mostly lower than normal during the late summer and late fall months (Figure 10). These shifts likely reflected changes in deep water masses present at the station, with lower nitrate concentrations associated with the colder, fresher Labrador Slope Waters (Hebert et al. 2018). Some interesting features of the nutrient dynamics at Halifax-2 in 2016 were the relatively low surface nitrate concentrations early in the year (January) and pulses of nutrient-rich deep water observed in February and March (Figure 9). Overall, the surface nitrate annual anomaly was negative owing to the below-normal surface concentrations during the spring, summer and fall months, and the deep nitrate annual anomaly was also slightly negative as a result of the below-normal inventories in summer and fall (Figure 11). Annual anomalies of surface and deep phosphate and silicate at Halifax-2 in 2016 were also negative, consistent with nitrate anomalies (Figure 11).

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 2016, the surface nitrate inventory was lower than normal throughout most of the year (Figure 10) with earlier than usual nitrate depletion at the surface (Figure 9). The deep nitrate inventory was also slightly lower than normal throughout most of the year (Figure 9). Overall, annual anomalies of both surface and deep nitrate inventories were negative at Prince-5 in 2016 (Figure 11). Surface and deep silicate and surface phosphate anomalies were also negative at Prince-5 in 2016 (Figure 11), while the deep phosphate anomaly was close to normal levels.

### Broad-scale Surveys

The highest nitrate concentrations on the sections are observed in the deep waters of the Scotian slope, Cabot Strait, and deep Emerald Basin in both spring and fall (Figure 12a, b). Surface nitrate concentrations on the sections in spring are strongly dependent on the timing of the sampling relative to the timing of the spring phytoplankton bloom. In spring 2016, the outer Louisbourg section showed surface nitrate depletion (Figure 12a; inner stations not sampled). In contrast, on the Browns Bank section, surface nitrate depletion was only observed on the inshore stations, with the offshore stations showing relatively high surface nitrate concentrations (Figure 12a). On the Halifax section, surface nitrate depletion was observed on the inshore stations while nitrate at the offshore stations was low but not depleted (Figure 12a). On the Cabot Strait section, surface nutrients were depleted. These conditions reflect sampling after the bloom on the Cabot Strait, Louisbourg, and inshore Halifax and Browns Bank sections. During the fall mission, 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 spatially variable on the sections in fall 2016 (Figure 12b) although consistently negative anomalies were observed over the entire water column at the offshore stations on the Browns Bank section. Overall, annual anomalies of deep water nitrate inventories were negative for three of the four sections, and annual anomalies of surface nitrate inventories were mixed (Figure 11). Both the surface and deep silicate and phosphate inventories were below average at all sections in 2016, as it has been the general case since 2013 (Figure 11).

The bottom nitrate concentrations measured during the summer ecosystem trawl survey (late June to mid-August) showed predominantly negative anomalies on the eastern part of the Scotian Shelf, the southwest portion of the Scotian Shelf, and the eastern Gulf of Maine. The most noticeable positive anomalies were observed in the western portion of the eastern Scotian Shelf around Sable Island and Western Bank, the inshore western Scotian Shelf (South Shore, Roseway Bank and LaHave Bank), 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 2016, bottom oxygen saturation values below 60% were observed mainly in and around the deep basins of the central Scotian Shelf (Figure 14), where bottom waters were warmer than normal (Hebert et al. 2018).

## 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).

### High Frequency Sampling Stations

In 2016, the spring bloom at Halifax-2 was characterized by a delayed initiation, shorter duration and lower intensity than normal (Figure 15). The bloom was contained within the top 50 m of the water column, consistent with the mixed layer observed in April (Figure 6). The spring bloom was overwhelmingly dominated by diatoms (Figure 16). A well-defined summer sub-surface chlorophyll maximum centered around 20 m was observed in July and sustained for only a few weeks (Figure 15). The fall phytoplankton bloom was late, relatively intense and deep, and persisted from mid-October until the end of November. Although positive anomalies of 0-100 m integrated chlorophyll were observed in summer and fall, the overall annual integrated chlorophyll anomaly at Halifax-2 was negative in 2016 (Figure 17). The abundance anomaly of diatoms was also negative in 2016, mostly consistent with a pattern that started in 2009, while the anomalies of dinoflagellates, ciliates (microzooplankton), and flagellates abundance were positive or near normal in 2016 (Figure 18). The overall abundance of phytoplankton was particularly low in late spring and late summer/early fall months (Figure 16). The summer phytoplankton community composition showed lower than normal relative abundances of diatoms and higher than normal relative abundances of flagellates, which is possibly related to the sub-surface chlorophyll maximum (Figure 15) and stronger stratification (Figure 6).

The spring phytoplankton bloom at Prince-5 in 2016 was initiated slightly later than usual but with an early peak in intensity (Figure 15). The chlorophyll concentrations observed during the spring bloom were close to normal levels but were sustained over a duration slightly shorter than normal, and were contained in the upper ~40 m of the water column (Figure 15). Phytoplankton abundances were above normal during the spring and summer-fall blooms but otherwise lower than normal (Figure 16). Both the spring and fall blooms were dominated by diatoms (Figure 16). The summer-fall phytoplankton bloom was slightly longer than normal with peak concentrations appearing later than usual, in September rather than August (Figure 15). Maximum chlorophyll concentrations during the summer-fall bloom were similar to normal, but the vertical extent of the bloom was deeper than normal at its peak in September, coinciding with a return to deeper than normal MLD and resulting in higher than normal 0-95 m integrated chlorophyll. A higher than normal surface chlorophyll concentration was also observed in November. The phytoplankton community at Prince-5 is normally dominated year-round by diatoms, but their relative abundance was lower than normal during the summer-fall bloom periods during which the relative abundance of dinoflagellates and ciliates (summer and early fall) and flagellates (fall) was higher than normal (Figure 16). Overall, the annual integrated chlorophyll anomaly at Prince-5 was near normal in 2016 (Figure 17). The abundance anomaly of diatoms was negative in 2016, a condition that has persisted during the last 8 years, while the anomalies of dinoflagellates, ciliates, and flagellates abundance were positive or near normal in 2016 and consistent with the pattern started in 2011 (Figure 18).

## Broad-scale Surveys and Satellite Remote Sensing

Chlorophyll estimates based on satellite remote sensing data indicated earlier than normal spring bloom initiation in Cabot Strait (CS), ESS, and Georges Bank (GB) sub-regions in 2016 (Figure 19a, b, 20). In the Central Scotian Shelf (CSS) and WSS sub-regions, the spring bloom initiation was slightly delayed. However, WSS bloom initiation timing based on model fits (Figure 20) appears to contradict this observation (Figure 19b) suggesting an over-sensitivity of the model to the initial increase in the surface chlorophyll in the context of a weak and variable spring bloom. The spring bloom duration was longer than normal in CS and ESS and shorter than normal in CSS and WSS in 2016 (Figure 19a, b, 20). For WSS, bloom duration based on model fits (Figure 20) contradicts duration based on visual examination of satellite remote sensing data (Figure 19b) due to the model bloom initiation estimate being too early.

The spring bloom amplitude (*i.e.,* peak intensity) was close to normal in CS, ESS and GB in 2016 and lower than normal in CSS, WSS and Lurcher Shoal (LS) (Figure 19a, b, 20). The magnitude of the spring bloom, which is a measure of the intensity and duration of the bloom, was above normal in CS and close to normal in ESS and GB in 2016 (Figure 20) as a result of relatively intense and long bloom conditions that prevailed in those regions. Conversely, the bloom magnitude was lower than normal in CSS, WSS and LS in 2016 (Figure 20) due to relatively short and low amplitude bloom conditions.

The general pattern of the spring bloom (*i.e.*, late initiation, short duration and low intensity) observed in the CSS sub-region was in agreement with bloom characteristics observed *in situ* at Halifax-2 in 2016 (Figure 15, 19a). The low surface chlorophyll annual variability in the tidally mixed LS sub-region is such that bloom conditions are hardly discernable and, therefore, the different bloom metrics should be interpreted with caution. In all sub-regions, the intensity of the fall bloom was lower than normal in 2016 (Figure 19a, b).

Annual integrated chlorophyll anomalies from *in situ* measurements were negative on all sections in 2016 (Figure 17). Diatom biomass annual anomalies were also slightly negative on all sections (Figure 21), consistent with the expectation that diatoms represent an important fraction of total biomass. Dinoflagellate biomass anomalies were mixed in sign in 2016, with the strongest negative anomaly on the Louisbourg section and the strongest positive anomaly on the Cabot Strait section. Nanoflagellate biomass anomalies were negative on all sections, continuing a trend that started in 2008-2009. The biomass anomalies of cryptophytes, which are nanoplankton cells, were mixed, with negative values on the Cabot Strait and Louisbourg sections and a positive value on the Halifax section, where positive values have been observed since 2012. Biomass anomalies of chlorophytes (*i.e.,* green algae) were positive on all section except Louisbourg in 2016. Finally, biomass anomalies of cyanobacteria and prochlorophytes (*i.e.,* picoplankton) were negative on all sections except Cabot Strait. Except for the continuous decrease of nanoflagellates over the last 4~5 years, no other phytoplankton group exhibits a clear trend at the level of the Scotian Shelf.

## ZOOPLANKTON

### High Frequency Sampling 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 22 and Figure 23). In 2016, the zooplankton biomass at Halifax-2 was mainly lower than normal throughout the year except for transient peaks in late-March/early-April, early-August and December (Figure 22). Zooplankton total abundance was highly variable at Halifax-2 and followed a similar pattern with above normal abundances recorded around the periods of high zooplankton biomass, although the peaks in abundance were less clearly defined than peaks in biomass (Figure 23). The zooplankton community was strongly dominated by copepods throughout the year, as usual at Halifax-2 (Figure 23), although a significant pulse of the Cnidaria-Appendicularia group (consisting mainly of the appendicularian *Frittilaria*) was observed during the short spring phytoplankton bloom (late March/early April).

*Calanus finmarchicus* abundance at Halifax-2 was mainly lower than normal throughout 2016, except for transient positive anomalies in late-March/early-April and late November, and near normal abundances in late-July/early-August (Figure 24). The spring production peak of *C. finmarchicus*, usually characterized by high *Calanus* abundance and high copepodite I-IV stage relative abundance, was atypical. Production appeared to start earlier than usual, in February, but the short peak in abundance in late March coincided with a decrease in the relative abundance of copepodite I-III stages. The April – early May peak in copepodite I-IV stage relative abundance was shorter than usual. There was a slightly stronger than usual fall production peak, characterized by a pulse of copepodite I-IV stages and a lower than normal abundance of copepodite V stage (Figure 24).

Total copepod abundance at Halifax-2 in 2016 was highly variable with maximum abundance levels reached in late-March/early-April, late-July/early-August and December (Figure 25a). The copepod community was characterized by lower than normal relative abundance of *C. finmarchicus* in winter and late summer. The relative abundance of the offshore copepod *Oithona atlantica* was higher than normal throughout the year, while the warm waters copepods *Paracalanus* spp. and *Metridia lucens* were relatively more abundant in late-summer/early-fall and late-fall, respectively (Figure 25a). Higher than average abundances for *O. atlantica* have been observed since 2009 (not shown). Overall at Halifax-2 in 2016, annual anomalies for zooplankton biomass, *C. finmarchicus* and *Pseudocalanus* spp. abundance were negative, and total copepods and non-copepods abundance anomalies were 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 the increase in phytoplankton by about a month, before declining to low levels again in the late fall (Figure 22 and Figure 23). In 2016, zooplankton biomass was lower than normal in winter and early spring, and higher than normal in summer and fall (Figure 22). Similarly, the total zooplankton abundance at Prince-5 in 2016 was close to normal during winter and spring, and well above normal in summer and fall (Figure 23). The zooplankton community was mostly dominated by copepods throughout the year, except for larger than normal relative abundance of the Cnidaria and Appendicularia group (consisting mainly of the appendicularian *Frittilaria*, similar to Halifax-2) during spring, lower than normal relative abundance of bivalves in summer, and a slightly greater relative abundance of other non-copepod groups (“Others”) throughout the year (Figure 23).

The abundance of *C. finmarchicus* at Prince-5 was mainly low throughout the year, especially during the winter, early spring, and fall months, but there was a transient abundance peak in July (Figure 24). The relative abundance of *C. finmarchicus* copepodite I stage reached a peak in May coinciding with the spring phytoplankton bloom, with copepodite II and III stages peaks following in June and July. A second pulse of copepodite III and IV stages occurred in fall likely in response to the moderate fall phytoplankton peak. A major feature of the dynamics of *C. finmarchicus* at Prince-5 in 2016 was the complete absence of the species for the April sampling, which is nearly unprecedented.

The annual pattern of total copepod abundance at Prince-5 in 2016 was similar to the pattern of total zooplankton abundance, *i.e.*, highly variable, with close to normal abundances during winter and spring, and well above normal in summer and fall (Figure 25b). The copepod community was characterized by the dominance of copepod nauplii (“Others”) in the spring months, and copepod nauplii also made up a greater part of the community in September and December. Lower than normal relative abundances of *Pseudocalanus* spp. and *Acartia* spp. and higher than normal relative abundance of *Centropages* spp. were observed during the summer and fall months. *Paracalanus* sp. had higher than normal relative abundances during the fall. The relative abundance of *C. finmarchicus* remained lower than normal throughout 2016. Overall at Prince-5 in 2016, the annual abundance anomaly for *C. finmarchicus* was negative, and anomalies of *Pseudocalanus* spp., total copepod abundance, non-copepod abundance, and zooplankton biomass were positive (Figure 17).

## Broad-scale Surveys

Zooplankton biomass was lower than normal in the spring of 2016 on the Cabot Strait, Louisbourg and Browns Bank sections, and slightly higher than normal on the Halifax section, where the positive anomaly appeared to be driven by high biomass at the offshore stations (Figure 26). In the fall, biomass levels were lower than normal on all sections with the exception of the Browns Bank section where zooplankton biomass could not be assessed due to incomplete sampling (small fraction missing) or the presence of salps in massive numbers (Figure 26). Zooplankton biomass levels were slightly below normal on Georges Bank during the winter 2016 ecosystem trawl survey and considerably higher than normal during the 2016 summer trawl survey on the Scotian Shelf (Figure 27). The mainly negative annual anomalies for zooplankton biomass in 2016 over all sections of the Scotian Shelf, with the exception of Halifax section, continued a pattern of low zooplankton biomass observed since 2010 (Figure 17).

The abundance of *C. finmarchicus* was near normal on the Louisbourg section but lower than normal on the Cabot Strait, Halifax and Browns Bank sections in spring of 2016. The anomaly on the Halifax section in spring 2016 was negative despite high abundances recorded at the edge of the shelf (Figure 28). In the fall, the abundance of *C. finmarchicus* was lower than normal on all sections except for the Halifax section, where the positive anomaly was driven by the exceptionally high abundance in Emerald Basin (Figure 28). *Calanus finmarchicus* abundance was lower than normal during the winter ecosystem trawl survey on Georges Bank and near normal during the summer Scotian Shelf survey, with relatively high abundances recorded in the western part of the region (Figure 29). Overall, the low abundance levels of *C. finmarchicus* in 2016 continued the general pattern observed since 2011 (Figure 17).

Annual abundance anomalies for *Pseudocalanus* spp. were negative for all sections in 2016, with the exception of the Louisbourg section where a positive anomaly was recorded (Figure 17). Weakly negative annual abundance anomalies were observed in 2016 for total copepod abundance on all sections except for the Louisbourg section. Positive annual anomalies were observed in 2016 for non-copepods on all four sections, continuing the general trend started in 2012. Among the ten most abundant non-copepod groups, abundance anomalies were positive in 2016 and recent years for larvaceans and pelagic gastropods (small particle feeders) and bivalves and echinoderms (meroplankton), and amphipods, and negative for ostracods (deep water crustaceans) (Figure 30). Thaliaceans, an uncommon group of opportunistic small particle feeders that increased markedly in occurrence in the fall of 2012 and 2013, were again observed in fall of 2016. Thaliaceans observed in 2016 were mainly *Thalia democratica*, which can occur in high density blooms.

## Indicator Species

Annual abundance anomalies of Arctic *Calanus* species (*C. hyperboreus* and *C. glacialis*) were negative throughout the region in 2016, continuing the trend started in 2012 (Figure 31). Abundance anomalies of warm offshore copepod species (*Clausocalanus* spp., *Mecynocera clausi*, and *Pleuromamma borealis*) were positive at all sections and high frequency sampling stations in 2016, continuing a pattern observed since 2012. Abundance anomalies of warm shelf copepod species (the summer-fall copepods *Paracalanus* spp. and *Centropages typicus*) were positive on all sections except the Cabot Strait section and at the high frequency sampling stations in 2016. The negative abundance anomalies on the Cabot Strait section and the positive ones at Prince-5 are consistent with the trend observed over the past four years at those locations, while no common pattern has emerged for the shelf sections and Halifax-2 over recent years.

# DISCUSSION

Ocean monitoring observations in 2016 provide further evidence for a shift in the plankton community of the Scotian Shelf since 2010, associated with above-average ocean temperatures, increased stratification, 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, 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.

The Maritimes region shelf ocean environment is characterized by a strong dominant annual frequency of variability in temperature and stratification and by a strong latitudinal and cross-shelf environmental gradient associated the transition from colder, fresher waters advected onto the inshore eastern Scotian Shelf from the Gulf of St. Lawrence to warmer, saltier slope waters, which are advected onto the WSS and CSS (Hebert et al. 2018). In ocean regions where annual-scale environmental variability is a dominant frequency, plankton life histories, behavior and physiology provide adaptations that focus reproductive effort on favorable times of year and minimize exposure to risk at unfavorable times of year; however, unpredictable perturbations in the range of environmental seasonality and in seasonal timing can disrupt these adaptations (Mackas et al. 2015). Large scale shifts in water mass boundaries also influence local plankton community composition (*e.g.,* Keister et al. 2011). Discussion of changes in the plankton community will address the influence of these general processes.

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.

In 2016, phytoplankton biomass was overall lower than normal throughout the Maritimes Region in both *in situ* and satellite observations. Low phytoplankton was associated with a change in pigment composition indicating lower than normal biomass of diatoms, dinoflagellates and nanoflagellates, all large phytoplankton (> ~ 5 μm). Several processes may have contributed to low phytoplankton biomass. First, disruption of bloom development as a result of highly variable physical forcing in the winter may have contributed to a short and weak spring bloom. In 2016, the MLD at Halifax-2 exhibited high variability in the winter, with episodes of wind-driven deepening in late February and late March and shoaling in early March. The abrupt shoaling of the mixed layer depth in early March at Halifax-2 was associated with a rapid decrease in nitrate, shoaling of the euphotic depth, and an increase in phytoplankton biomass driven by the increase of diatom abundance. A strong wind event at Halifax-2 in mid-March deepened the mixed layer depth and resulted in a decrease in diatom abundance and a decrease in phytoplankton biomass that was also observed in satellite observations on the CSS, WSS and LS. This event increased the depth of the mixed layer and might have caused the dilution of the bloom. This transient event had a strong temperature and salinity signature (Hebert et al. 2018). The bloom at Halifax-2 was re-initiated when the stratification increased again in late March – early April. The lower-than-average relative abundance of diatoms in summer and fall was consistent with the pigment signature on the Halifax section in 2016; however, careful interpretation has to be kept in mind given that the sampling of this transect occurred towards the end of the spring bloom. Second, inventories of silicate, a secondary nutrient required by diatoms, have been lower than normal in both surface and deep water since 2014 and may be associated with reduced production of diatoms. Lower than normal inventories of silicate and phosphate are consistent with an increase in the relative contribution of slope water compared to Gulf of St. Lawrence water on the Scotian Shelf (Pepin et al. 2013). Third, stronger than normal stratification in summer and fall may have inhibited phytoplankton production in the second half of the year. This is consistent with the high relative abundance of flagellates at Halifax-2 in summer and fall, which was also evident in the pigment composition over the Halifax section, which indicated an increase in cryptophytes and chlorophytes. It is noteworthy that the deep chlorophyll maximum (DCM) in summer 2016 was shallower than climatology, a trend that started 6 years ago (results not shown) and corresponded to a decrease in the euphotic depth and increase in stratification compared to climatological records.

At Prince-5, annual patterns of physical conditions, nutrient inventories, and phytoplankton dynamics all deviated from normal conditions. The deeper-than-normal MLD in winter and spring was associated with a weak stratification index, but during the summer, a shallow MLD (around 40 m) and higher than average stratification index were associated with a lower than average winds (July to September). Deep nitrate concentrations remained slightly lower than normal during the entire year except in July. This pattern was similar to the surface nitrate, which is not surprising given the strong mixing that occurs at this station. There were two periods of high phytoplankton biomass in 2016: an earlier-than-normal bloom in April-May and a later, stronger-than-normal bloom in July to September. The low biomass in June was associated with a strong increase of surface salinity (Hebert et al. 2018). Similar to Halifax-2, diatom relative abundance has decreased at Prince-5, but to a lesser extent, and silicate inventories were also low at Prince-5. Overall, phytoplankton biomass was only slightly negative in 2016 at Prince-5, but diatom abundance has been below normal since 2009, prior to the onset of below normal silicate levels in 2013.

Zooplankton biomass on the Scotian Shelf and in the eastern Gulf of Maine is normally dominated by large, energy-rich copepods, mainly *C. finmarchicus*, which are important prey for planktivorous fish such as herring and mackerel, North Atlantic Right Whales, and other pelagic species. In 2016, the zooplankton community continued to be characterized by lower than normal abundances of *C. finmarchicus*, low zooplankton biomass, and lower abundances of Arctic *Calanus* and higher than normal abundances of non-copepods, warm offshore copepods, and juvenile stages of several small copepod species. Shifts in the abundance of copepod groups that are indicators of water mass distributions in the region, including Arctic *Calanus* (lower), warm offshore copepods (higher), and offshore *O. atlantica* (higher), in recent years are consistent with a greater influence of offshore water on the central and western Scotian Shelf. The population response of *C. finmarchicus* to environmental changes is complex due to interactions among ocean circulation, annual primary production cycles, and the *Calanus* life history, which focuses reproductive effort on spring bloom production of diatoms and can include a period of late-juvenile-stage dormancy in deep water during less productive seasons. In recent years, *C. finmarchicus* abundance may have been negatively affected by low spring bloom magnitudes and lower than average abundances of diatoms. The short duration of the spring production pulse of *C. finmarchicus* at Halifax-2 is consistent with this interpretation. Populations of *C. finmarchicus* can also be negatively affected by higher than average deep-water temperatures, which can limit the length of the dormant period and result in early emergence from dormancy and a mismatch with spring bloom timing (Saumweber and Durbin 2006). The small pulses of early copepodite stage *C. finmarchicus* in late fall and mid-winter at Halifax-2 may indicate early emergence of part of the population from dormancy and resumption of active production, several months in advance of the spring bloom, as has been observed in the Gulf of Maine (Durbin et al. 1997). The abundance of *C. finmarchicus* at Prince-5 was low at the end of the year, indicating a low overwintering stock to seed production in 2017. Abundance anomalies for *Pseudocalanus* spp., smaller spring-summer copepods that are also important prey for small fish, were mixed but low on the CSS and WSS.

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 and particle-feeding, opportunistic non-copepod species such as larvaceans, pelagic gastropods, and thaliaceans. In addition, mismatches between phytoplankton bloom production and grazing by *C. finmarchicus* may increase export of production from the pelagic environment. Increased export to the benthic environment could have contributed to the higher than normal abundances of meroplankton, such as bivalve echinoderm larvae, observed in recent years. 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 pelagic 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, North Atlantic Right Whales, and pelagic-feeding seabirds 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 and remains relatively high in winter (Figure 32). Dinoflagellate abundance shows no clear seasonal cycle in either region. In 2015, CPR sampling was limited to 7 months on the WSS and 5 months on the ESS. Among the phytoplankton groups, diatom levels in June were higher than normal on the WSS and lower than normal on the ESS. Dinoflagellate levels were higher than normal on the WSS in May and on the ESS in September and November. During the other sampled months, all three phytoplankton indices had near normal values. No annual abundance anomalies could be calculated, due to the poor temporal sampling coverage (Figure 33).

### 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 34). On the ESS, the same peaks in abundance are apparent, although with much lower magnitude (Figure 34). In 2015, abundances of *Calanus* I-IV and *C. finmarchicus* V-VI were near normal on the WSS in April-May. Thereafter levels of these taxa were unusually low over the entire Scotian Shelf in June-September and near normal in October-November. Among the other taxa in April-May (WSS only) abundances were unusually low for two Arctic *Calanus* species and hyperiid amphipods, near normal for small copepods (*Para/Pseudocalanus*) and variable for the other three taxa. Abundances of most taxa over the entire Scotian Shelf were generally relatively low in June rising to near normal values by October-November. Again, no annual abundance anomalies could be calculated, due to the poor temporal sampling coverage (Figure 33).

### ACID SENSITIVE ORGANISMS

In 2015, abundances of coccolithophores (phytoplankton) and foraminifera (microzooplankton) were near normal in April-May (WSS only) and higher than normal in September-November on the ESS. Pteropods (*Limacina* spp.) were unusually abundant in May (WSS only) but at near normal levels otherwise). Annual abundance anomalies are not reported due to the poor temporal sampling coverage (Figure 33).

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

During 2015 *in situ* AZMP sampling of chlorophyll concentration at Halifax-2 and satellite observations of ocean colour in the WSS and CSS region suggested that the spring bloom started later than usual (early-mid April), with higher than (Halifax-2) or normal (WSS and CSS) chlorophyll concentrations during late April (Johnson et al. 2017). CPR observations on the WSS, which did not start until April, were somewhat consistent with the satellite observations for diatom abundance (normal level on the WSS in April), but not for the PCI (unusually low on the

WSS in April). The CPR-abundances for *Calanus* I-IV and *C. finmarchicus* V-VI both peaked in May on the WSS and ESS in 2015, co-incident with the AZMP-abundance peak for *C. finmarchicus* (all stages) at Halifax-2. On the other hand, abundances for the same CPR taxa were at close to normal levels in April, whereas *C. finmarchicus* abundance in April at Halifax-2 was unusually low. 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 (see Fig. 5), and because oceanographic influences are not uniform over the entire Scotian Shelf. The low annual abundance anomaly for *C. finmarchicus* and low summer abundances at Halifax-2 in 2015 were generally consistent with the limited CPR observations. Abundances of two Arctic *Calanus* species were very low in both AZMP and CPR samples in 2015, but the increased abundance of warm offshore taxa, seen in AZMP samples, was not evident in CPR samples.

## SUMMARY

- Observations in 2016 provide evidence that changes in the plankton community observed in recent years have persisted. These changes are likely to alter the fate of production in the ecosystem, with negative impacts already observed in feeding habitat for specialized planktivores such as North Atlantic Right Whales.
- In 2016, both surface and deep silicate and phosphate inventories were mainly lower than average. This follows a trend since 2013 on the Scotian Shelf and a shift from positive anomalies on the Cabot Strait section. Deep nitrate inventories were also mainly lower than average in 2016.
- Phytoplankton biomass anomalies were mainly negative in 2016. Abundances of large phytoplankton at the times series stations were lower than average, continuing a trend that started in 2009. Pigment-based estimates of biomass of large phytoplankton were mainly lower than normal.
- Spring phytoplankton bloom initiation was early and bloom duration short in the east, and bloom magnitude was small and duration short in the central and western Scotian Shelf in 2016
- Zooplankton biomass and *C. finmarchicus* abundance were lower than average, while non-copepod abundance was higher than average, continuing a pattern that started during 2010-2012.
- Changes in the copepod community indicated an increase in the abundance of warm-water offshore species and a decrease in cold water immigrant species on the Scotian Shelf in 2016, continuing a trend that started in 2012.
- The abundance of some small-particle-feeding non-copepod groups and meroplankton have increased in recent years.
- CPR sampling in 2015 was limited to 7 months (April-November) on the Western Scotian Shelf (WSS) and to 5 months (June-November) on the Eastern Scotian Shelf (ESS).
- In 2015, three CPR phytoplankton indices (PCI, diatom and dinoflagellate abundance) were at near normal levels on the WSS in April-May and in both WSS and ESS thereafter.
- In 2015, the biomass dominant zooplankton taxa *Calanus* I-IV and *C. finmarchicus* V-VI were at normal levels on the WSS in April-May, dropping to low levels in both WSS and ESS in June-September, and rising to normal levels in October-November. Among the other taxa two Arctic *Calanus* species were at unusually low levels on the WSS in April-May, while two

acid-sensitive taxa (coccolithophores, foraminifera) were unusually abundant on the ESS in September-November.

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# TABLES

*Table 1. Atlantic Zone Monitoring Program (AZMP) sampling missions in the Maritimes Region, 2016.*

| Group | Location | Mission ID | Dates | # Hydro Stns | # Net Stns |
|---|---|---|---|---|---|
| Trawl Surveys | Georges Bank | TEL2016-002 | Feb 22 - Mar 10 | 48 | 11 |
| | Scotian Shelf | TEL2016-003 | Mar 10 - 25 | 68 | 15 |
| | Scotian Shelf | NED2016-016 | Jun 28 – Aug 15 | 250 | 41 |
| Seasonal Sections | Scotian Shelf | HUD2016-003 | Apr 17 - 27 | 50 | 45 |
| | Labrador Sea/ Cabot Strait | HUD2016-006 | May 02 | 6 | 6 |
| | Halifax Line | | May 21 - 24 | 13 | 5 |
| | Scotian Shelf | HUD2016-027 | Sep 15 – Oct 06 | 106 | 88 |
| High Frequency Stations | Halifax-2 | BCD2016-666 | Jan 01 – Dec 31 | 19(7)[1] | 19(7)[1] |
| | Prince-5 | BCD2016-669 | Jan 01 – Dec 31 | 12 | 12 |
| | | | *Total:* | *572* | *242* |

[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

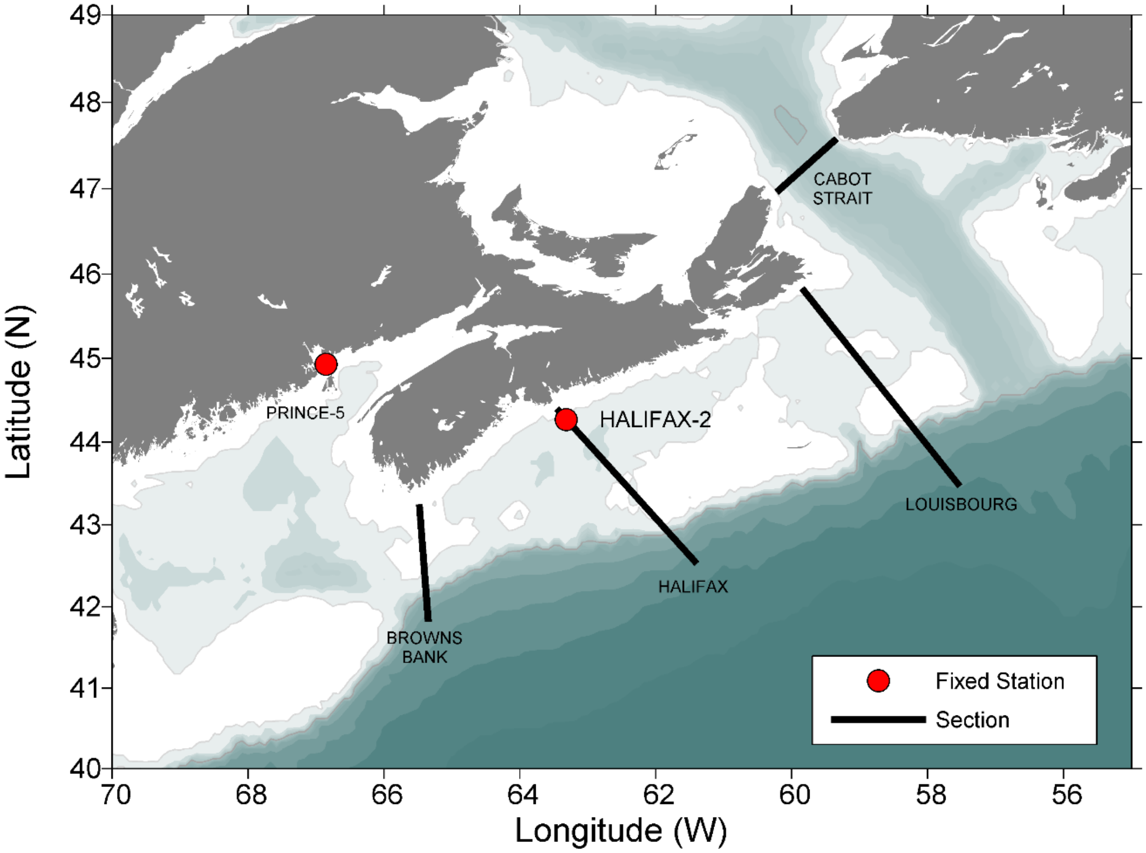


*Figure 1. Map of primary sections (Cabot Strait, Louisbourg, Halifax, and Browns Bank) and high frequency sampling stations (Halifax-2, and Prince-5) sampled in the DFO Maritimes Region.*

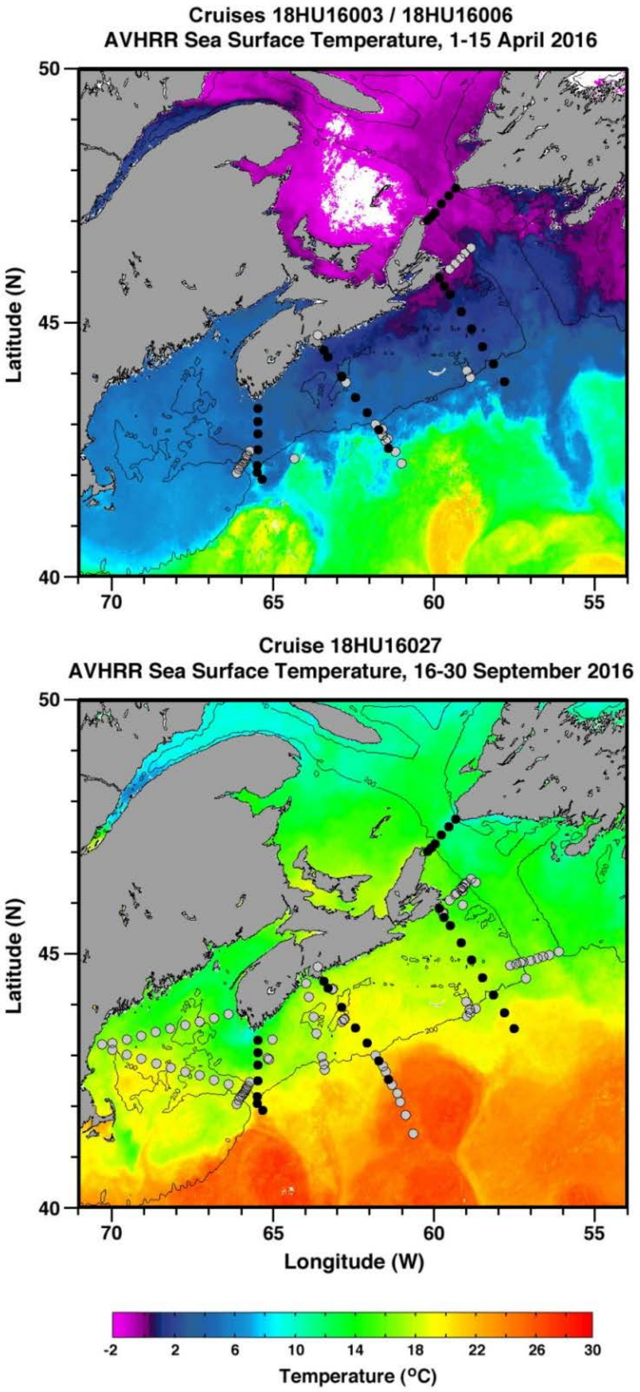


*Figure 2. Stations sampled during the 2016 spring and fall surveys. Station locations are superimposed on sea-surface temperature composite images for dates close to the mission dates. Black markers indicate core stations, and gray markers indicate stations sampled for ancillary programs. Cabot Strait section was sampled in spring 2016 as part of the Labrador Sea survey (18HU16006) for which only the CSL stations are shown.*

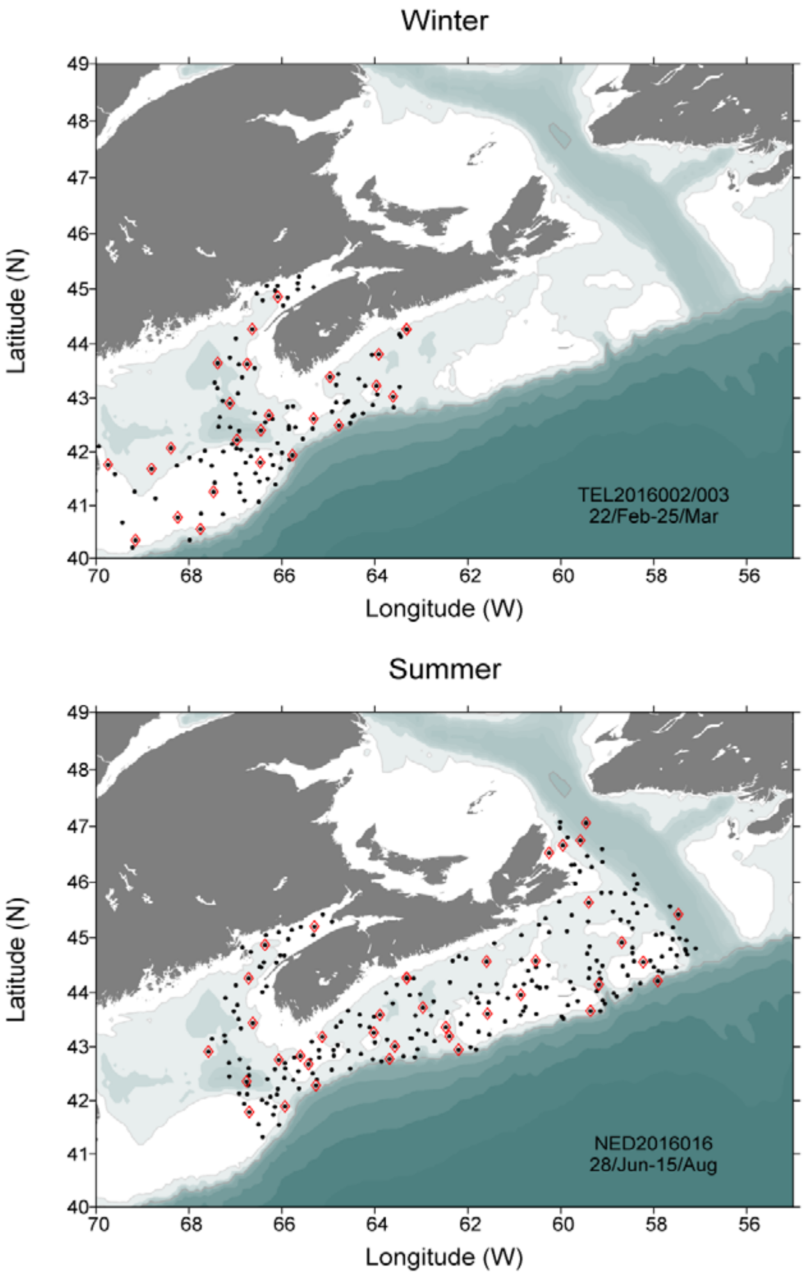
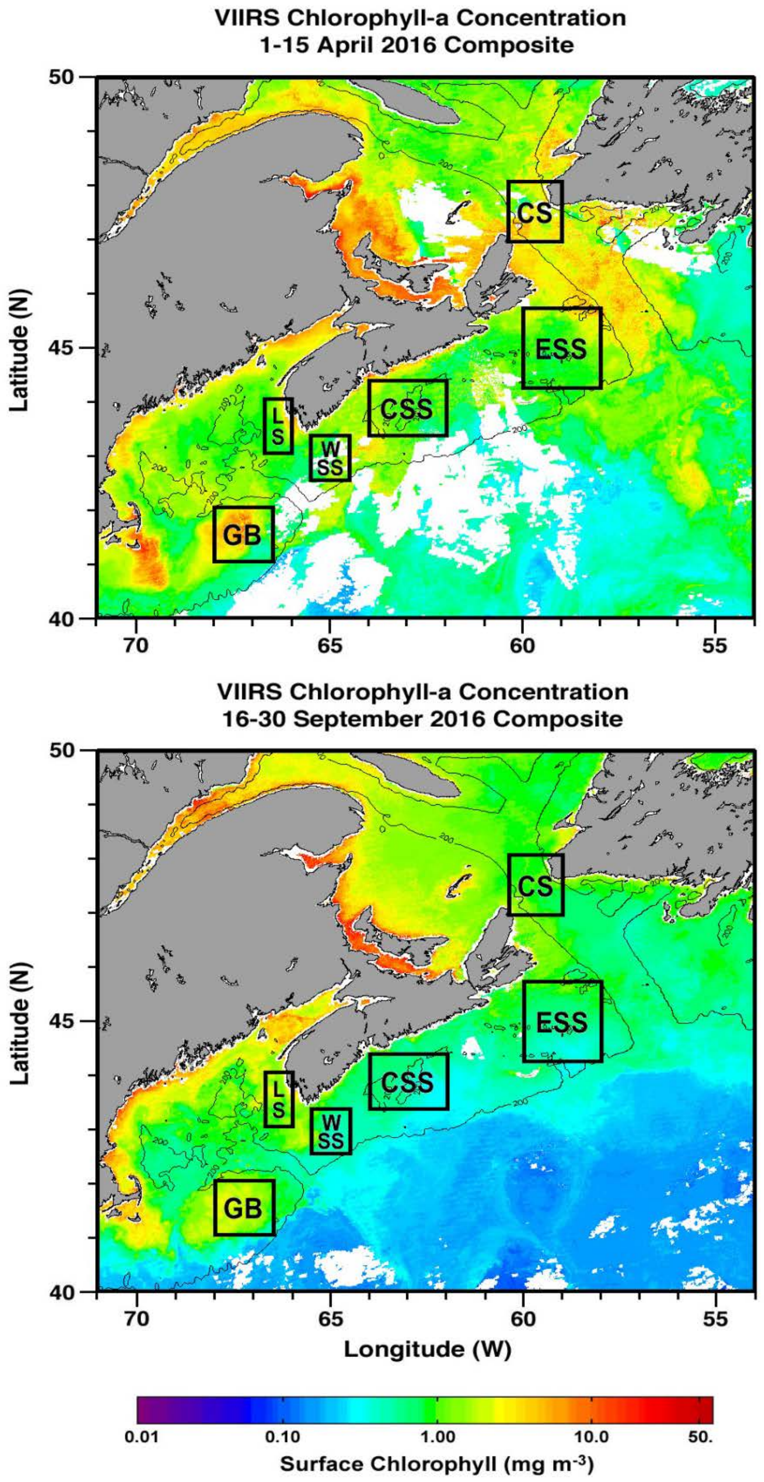


*Figure 3. Stations sampled during primary Maritimes Region ecosystem trawl surveys in 2016. Black solid markers are hydrographic stations; red open diamonds are stations where vertical nets hauls were taken in addition to hydrographic measurements.*



VIIRS Chlorophyll-a Concentration
1-15 April 2016 Composite

VIIRS Chlorophyll-a Concentration
16-30 September 2016 Composite

*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.*

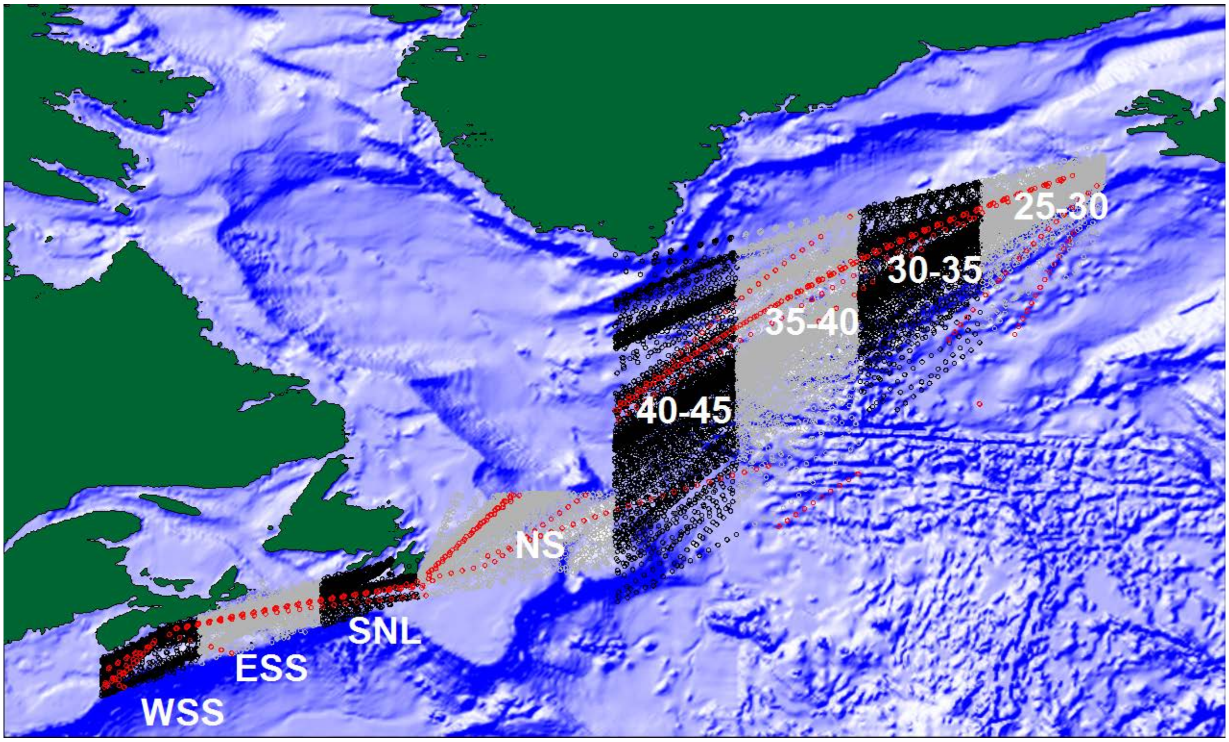


Figure 5. Continuous Plankton recorder (CPR) lines and stations 1957 to 2015. Stations sampled in 2015 are shown in red. Data are analysed by region. Regions are: western Scotian Shelf (WSS), eastern Scotian Shelf (ESS), south Newfoundland Shelf (SNL), Newfoundland Shelf (NS), and between longitudes 40-45°W, 35-40°W, 30-35°W, 25-30°W.

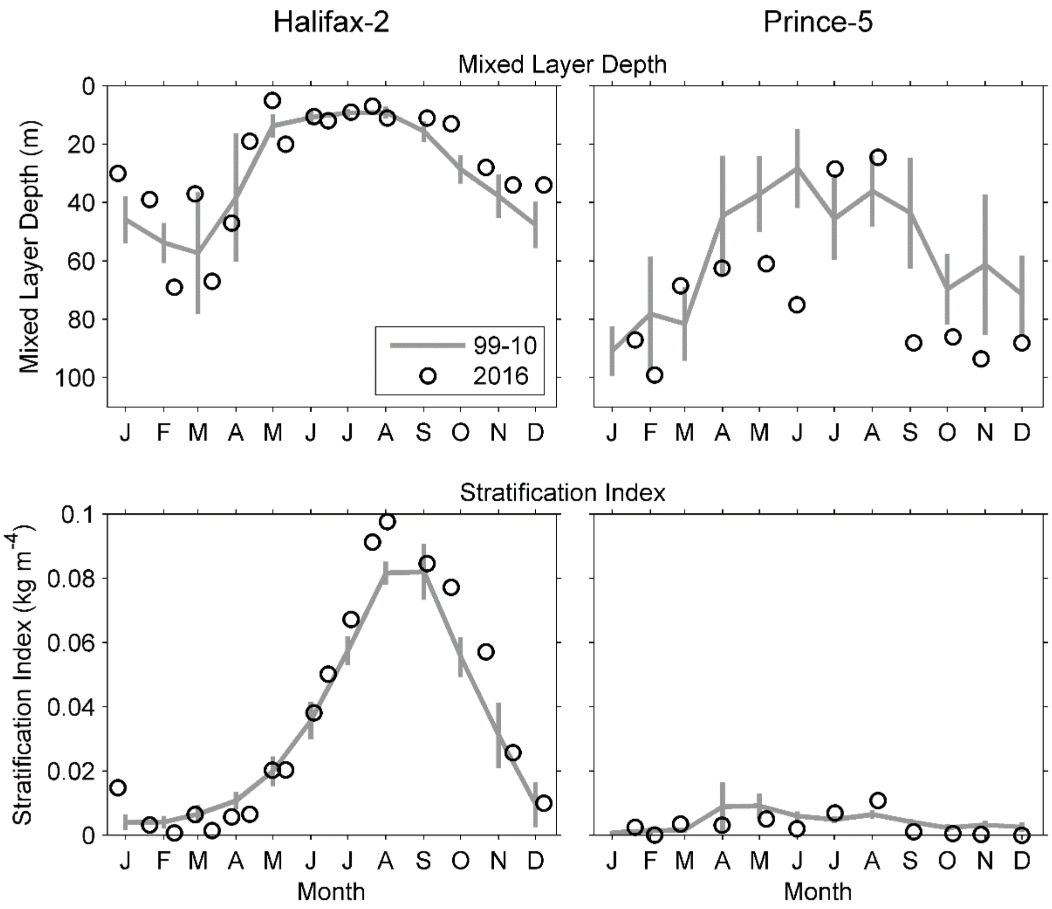


*Figure 6. Mixing properties (mixed layer depth, stratification index) at the Maritimes high frequency sampling stations comparing 2016 data (open circle) with mean conditions from 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the monthly means.*

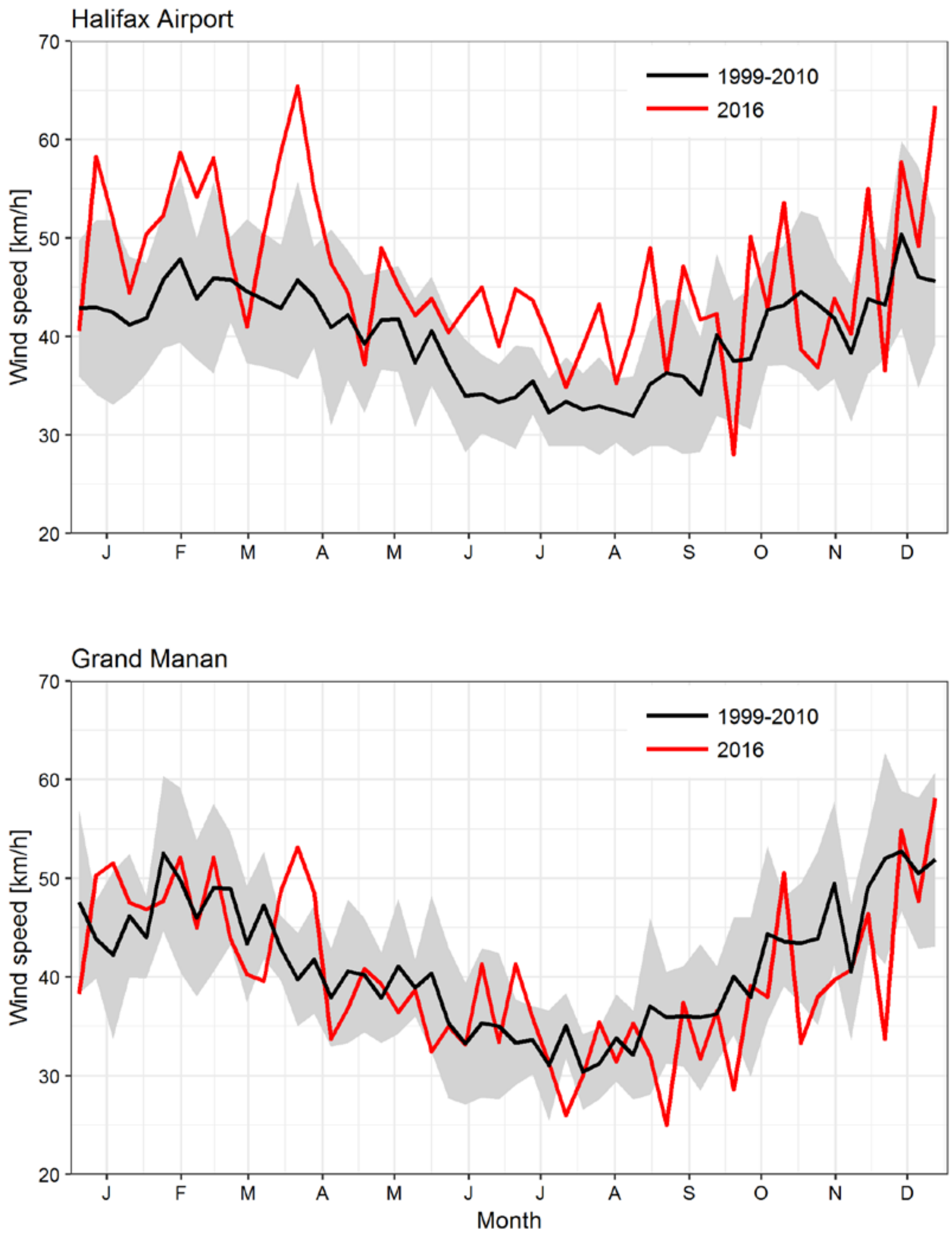


*Figure 7. Mean daily maximum wind gust at Grand Manan Island (representative of wind conditions at Prince-5) and Halifax International airport (representative of wind conditions at Halifax-2) for the year 2016 (red line) and the 1998-2010 climatology (black line). The gray shaded area represents the standard deviation to the climatology computed over 13 years.*

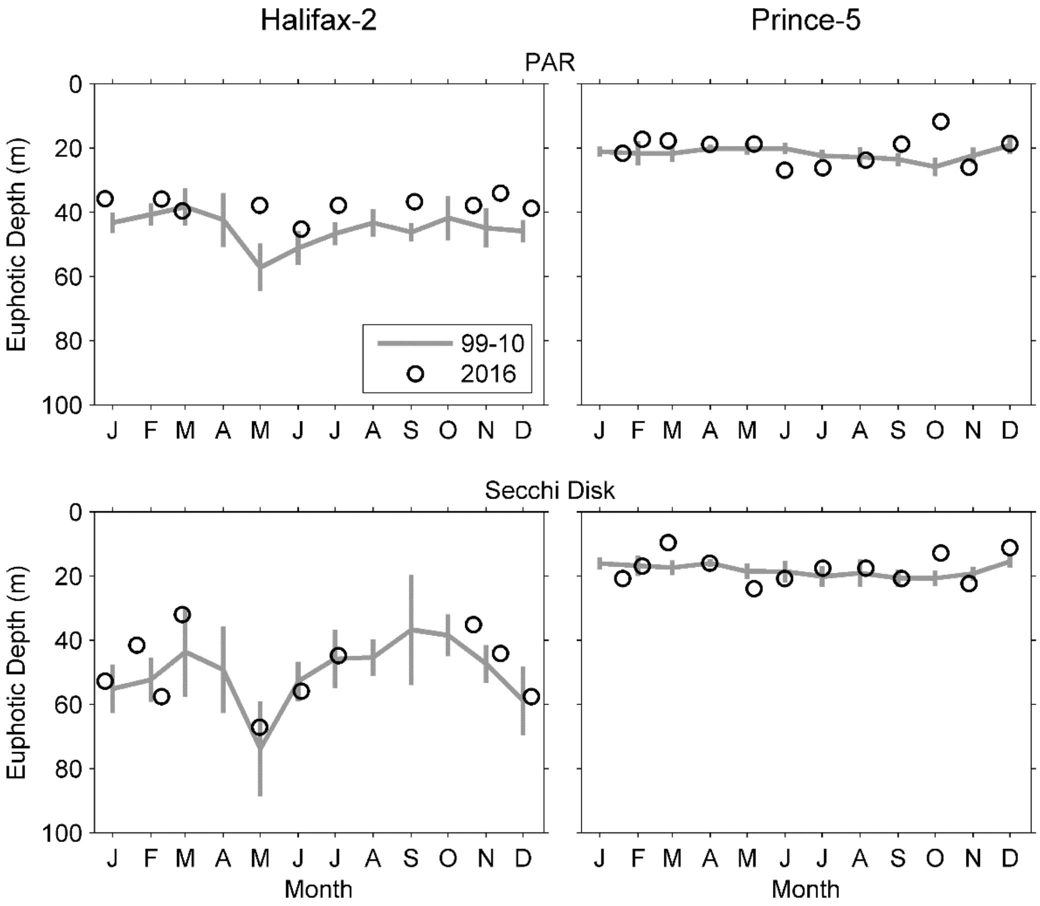


*Figure 8. Optical properties (euphotic depth from PAR irradiance meter and Secchi disc) at the Maritimes high frequency sampling stations. Year 2016 data (circles) compared with mean conditions from 1999–2010 (solid line), except 2001–2010 for euphotic depth from PAR at Prince-5. Vertical lines are 95% confidence intervals of the monthly means.*

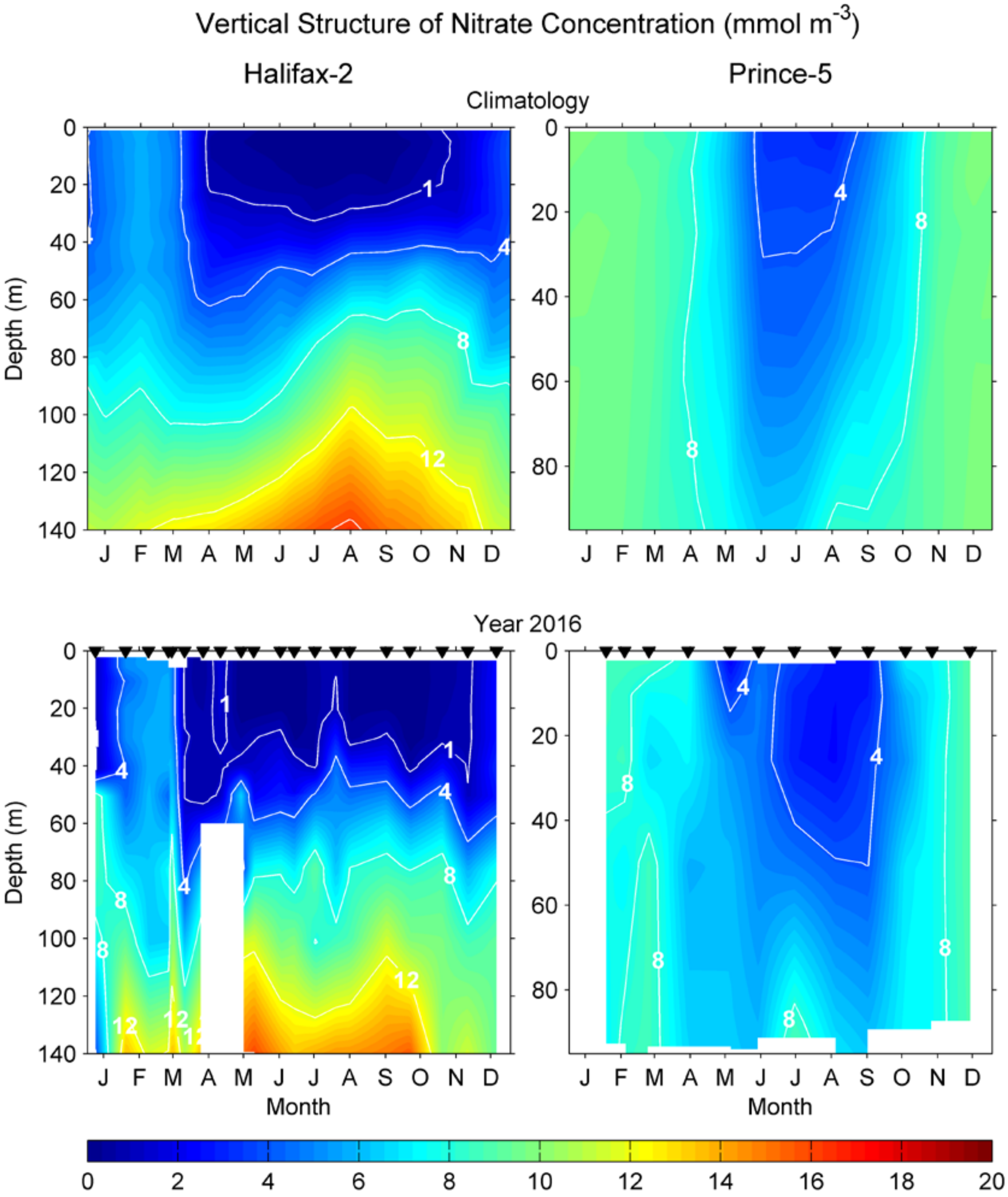


*Figure 9. Comparison of annual changes in the vertical structure of nitrate concentrations (mmol m$^{-3}$) in 2016 (bottom panels) with climatological mean conditions from 1999–2010 (upper panels) at the Maritimes high frequency sampling stations.*

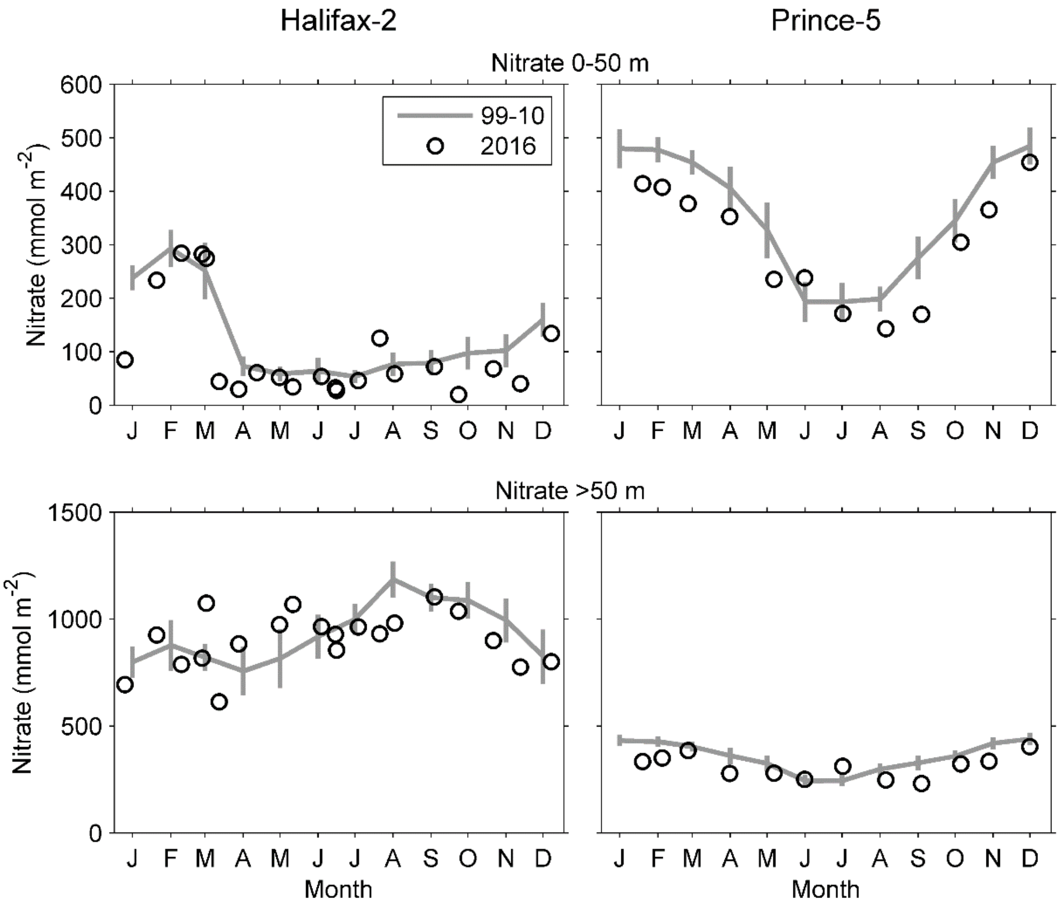
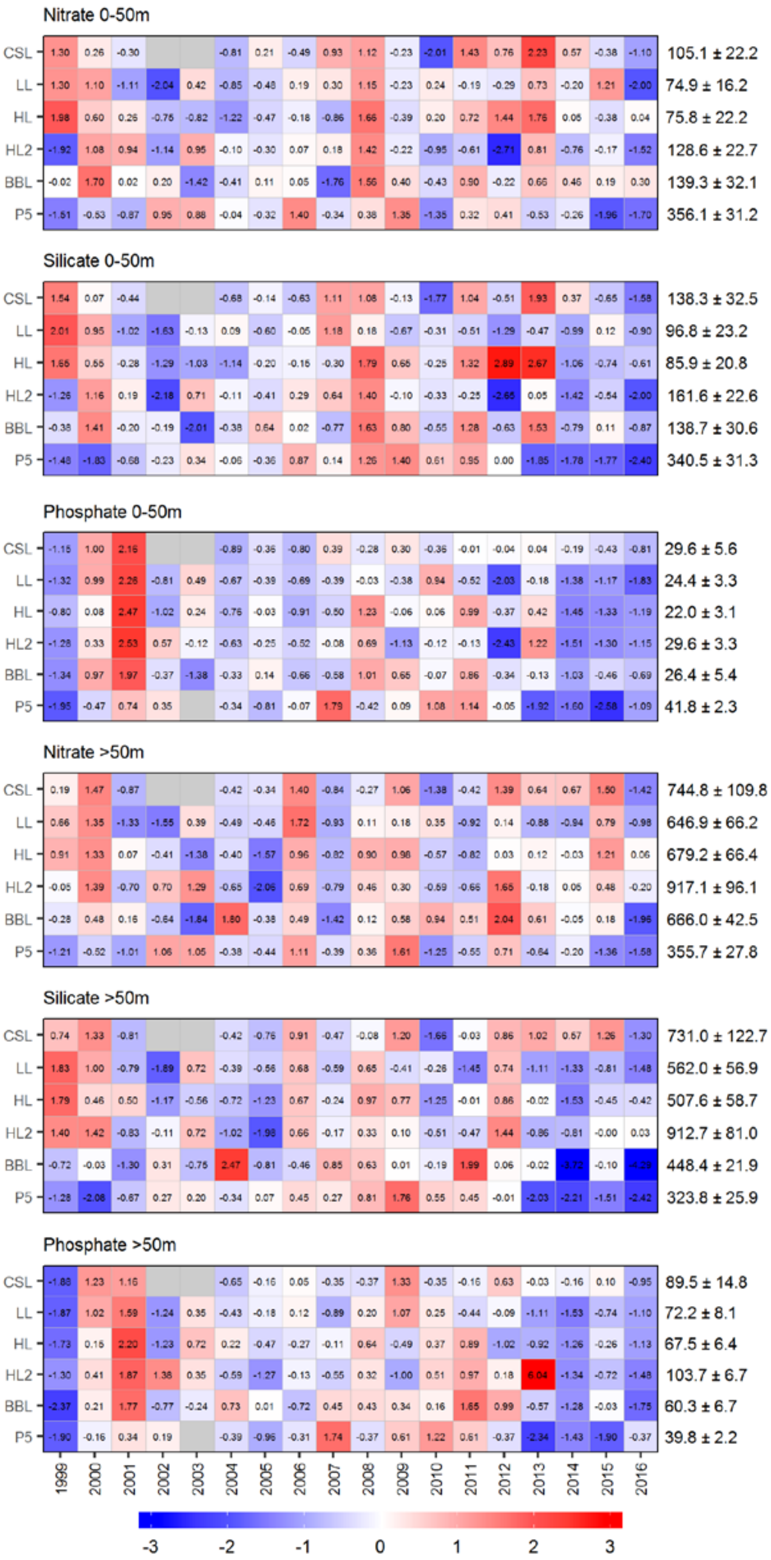


*Figure 10. Comparison of 2016 (open circle) data with mean conditions from 1999–2010 (solid line) at the Maritimes high frequency sampling stations. Upper panels: surface (0–50 m) nitrate inventory. Lower panels: deep (>50 m) nitrate inventory. Vertical lines are 95% confidence intervals of the monthly means.*



Nitrate 0-50m

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | 1.30 | 0.26 | -0.30 | | | -0.81 | 0.21 | -0.49 | 0.93 | 1.12 | -0.23 | -2.01 | 1.43 | 0.76 | 2.23 | 0.57 | -0.38 | -1.10 | 105.1 ± 22.2 |
| LL | 1.30 | 1.10 | -1.11 | -2.04 | 0.42 | -0.85 | -0.48 | 0.19 | 0.30 | 1.15 | -0.23 | 0.24 | -0.19 | -0.29 | 0.73 | -0.20 | 1.21 | -2.00 | 74.9 ± 16.2 |
| HL | 1.98 | 0.60 | 0.26 | -0.76 | -0.82 | -1.22 | -0.47 | -0.18 | -0.86 | 1.66 | -0.39 | 0.20 | 0.72 | 1.44 | 1.76 | 0.06 | -0.38 | 0.04 | 75.8 ± 22.2 |
| HL2 | -1.92 | 1.08 | 0.94 | -1.14 | 0.95 | -0.10 | -0.30 | 0.07 | 0.18 | 1.42 | -0.22 | -0.95 | -0.61 | -2.71 | 0.81 | -0.76 | -0.17 | -1.52 | 128.6 ± 22.7 |
| BBL | -0.02 | 1.70 | 0.02 | 0.20 | -1.42 | -0.41 | 0.11 | 0.05 | -1.76 | 1.56 | 0.40 | -0.43 | 0.90 | -0.22 | 0.66 | 0.46 | 0.19 | 0.30 | 139.3 ± 32.1 |
| P5 | -1.51 | -0.53 | -0.87 | 0.96 | 0.88 | -0.04 | -0.32 | 1.40 | -0.34 | 0.38 | 1.35 | -1.35 | 0.32 | 0.41 | -0.53 | -0.26 | -1.96 | -1.70 | 356.1 ± 31.2 |

Silicate 0-50m

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | 1.54 | 0.07 | -0.44 | | | -0.68 | -0.14 | -0.63 | 1.11 | 1.08 | -0.13 | -1.77 | 1.04 | -0.51 | 1.93 | 0.37 | -0.65 | -1.58 | 138.3 ± 32.5 |
| LL | 2.01 | 0.95 | -1.02 | -1.63 | -0.13 | 0.09 | -0.60 | -0.05 | 1.18 | 0.18 | -0.67 | -0.31 | -0.51 | -1.29 | -0.47 | -0.99 | 0.12 | -0.90 | 96.8 ± 23.2 |
| HL | 1.66 | 0.66 | -0.28 | -1.29 | -1.03 | -1.14 | -0.20 | -0.16 | -0.30 | 1.79 | 0.65 | -0.25 | 1.32 | 2.89 | 2.67 | -1.06 | -0.74 | -0.61 | 85.9 ± 20.8 |
| HL2 | -1.26 | 1.16 | 0.19 | -2.18 | 0.71 | -0.11 | -0.41 | 0.29 | 0.64 | 1.40 | -0.10 | -0.33 | -0.25 | -2.65 | 0.05 | -1.42 | -0.54 | -2.00 | 161.6 ± 22.6 |
| BBL | -0.38 | 1.41 | -0.20 | -0.19 | -2.01 | -0.38 | 0.64 | 0.02 | -0.77 | 1.63 | 0.80 | -0.55 | 1.28 | -0.63 | 1.53 | -0.79 | 0.11 | -0.87 | 138.7 ± 30.6 |
| P5 | -1.48 | -1.83 | -0.68 | -0.23 | 0.34 | -0.06 | -0.36 | 0.87 | 0.14 | 1.26 | 1.40 | 0.61 | 0.95 | 0.00 | -1.85 | -1.78 | -1.77 | -2.40 | 340.5 ± 31.3 |

Phosphate 0-50m

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | -1.16 | 1.00 | 2.16 | | | -0.89 | -0.36 | -0.80 | 0.39 | -0.28 | 0.30 | -0.36 | -0.01 | -0.04 | 0.04 | -0.19 | -0.43 | -0.81 | 29.6 ± 5.6 |
| LL | -1.32 | 0.99 | 2.26 | -0.81 | 0.49 | -0.67 | -0.39 | -0.69 | -0.39 | -0.03 | -0.38 | 0.94 | -0.52 | -2.03 | -0.18 | -1.38 | -1.17 | -1.83 | 24.4 ± 3.3 |
| HL | -0.80 | 0.08 | 2.47 | -1.02 | 0.24 | -0.76 | -0.03 | -0.91 | -0.50 | 1.23 | -0.06 | 0.06 | 0.99 | -0.37 | 0.42 | -1.46 | -1.33 | -1.19 | 22.0 ± 3.1 |
| HL2 | -1.28 | 0.33 | 2.53 | 0.57 | -0.12 | -0.63 | -0.25 | -0.52 | -0.08 | 0.69 | -1.13 | -0.12 | -0.13 | -2.43 | 1.22 | -1.51 | -1.30 | -1.15 | 29.6 ± 3.3 |
| BBL | -1.34 | 0.97 | 1.97 | -0.37 | -1.38 | -0.33 | 0.14 | -0.66 | -0.58 | 1.01 | 0.65 | -0.07 | 0.86 | -0.34 | -0.13 | -1.03 | -0.46 | -0.69 | 26.4 ± 5.4 |
| P5 | -1.95 | -0.47 | 0.74 | 0.35 | | -0.34 | -0.81 | -0.07 | 1.79 | -0.42 | 0.09 | 1.08 | 1.14 | -0.05 | -1.92 | -1.60 | -2.58 | -1.09 | 41.8 ± 2.3 |

Nitrate >50m

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | 0.19 | 1.47 | -0.87 | | | -0.42 | -0.34 | 1.40 | -0.84 | -0.27 | 1.06 | -1.38 | -0.42 | 1.39 | 0.64 | 0.67 | 1.50 | -1.42 | 744.8 ± 109.8 |
| LL | 0.66 | 1.35 | -1.33 | -1.55 | 0.39 | -0.49 | -0.46 | 1.72 | -0.93 | 0.11 | 0.18 | 0.35 | -0.92 | 0.14 | -0.88 | -0.94 | 0.79 | -0.98 | 646.9 ± 66.2 |
| HL | 0.91 | 1.33 | 0.07 | -0.41 | -1.38 | -0.40 | -1.57 | 0.96 | -0.82 | 0.90 | 0.98 | -0.57 | -0.82 | 0.03 | 0.12 | -0.03 | 1.21 | 0.06 | 679.2 ± 66.4 |
| HL2 | -0.05 | 1.39 | -0.70 | 0.70 | 1.29 | -0.65 | -2.06 | 0.69 | -0.79 | 0.46 | 0.30 | -0.69 | -0.66 | 1.66 | -0.18 | 0.06 | 0.48 | -0.20 | 917.1 ± 96.1 |
| BBL | -0.28 | 0.48 | 0.16 | -0.64 | -1.84 | 1.80 | -0.38 | 0.49 | -1.42 | 0.12 | 0.58 | 0.94 | 0.51 | 2.04 | 0.61 | -0.05 | 0.18 | -1.96 | 666.0 ± 42.5 |
| P5 | -1.21 | -0.52 | -1.01 | 1.06 | 1.05 | -0.38 | -0.44 | 1.11 | -0.39 | 0.36 | 1.61 | -1.25 | -0.55 | 0.71 | -0.64 | -0.20 | -1.36 | -1.58 | 355.7 ± 27.8 |

Silicate >50m

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | 0.74 | 1.33 | -0.81 | | | -0.42 | -0.76 | 0.91 | -0.47 | -0.08 | 1.20 | -1.66 | -0.03 | 0.86 | 1.02 | 0.67 | 1.26 | -1.30 | 731.0 ± 122.7 |
| LL | 1.83 | 1.00 | -0.79 | -1.89 | 0.72 | -0.39 | -0.56 | 0.68 | -0.59 | 0.65 | -0.41 | -0.26 | -1.45 | 0.74 | -1.11 | -1.33 | -0.81 | -1.48 | 562.0 ± 56.9 |
| HL | 1.79 | 0.46 | 0.50 | -1.17 | -0.56 | -0.72 | -1.23 | 0.67 | -0.24 | 0.97 | 0.77 | -1.25 | -0.01 | 0.86 | -0.02 | -1.53 | -0.45 | -0.42 | 507.6 ± 58.7 |
| HL2 | 1.40 | 1.42 | -0.83 | -0.11 | 0.72 | -1.02 | -1.98 | 0.66 | -0.17 | 0.33 | 0.10 | -0.51 | -0.47 | 1.44 | -0.86 | -0.81 | -0.00 | 0.03 | 912.7 ± 81.0 |
| BBL | -0.72 | -0.03 | -1.30 | 0.31 | -0.76 | 2.47 | -0.81 | -0.46 | 0.85 | 0.63 | 0.01 | -0.19 | 1.99 | 0.06 | -0.02 | -3.72 | -0.10 | -4.29 | 448.4 ± 21.9 |
| P5 | -1.28 | -2.08 | -0.67 | 0.27 | 0.20 | -0.34 | 0.07 | 0.45 | 0.27 | 0.81 | 1.76 | 0.55 | 0.45 | -0.01 | -2.03 | -2.21 | -1.51 | -2.42 | 323.8 ± 25.9 |

Phosphate >50m

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | -1.88 | 1.23 | 1.16 | | | -0.65 | -0.16 | 0.05 | -0.35 | -0.37 | 1.33 | -0.35 | -0.16 | 0.63 | -0.03 | -0.16 | 0.10 | -0.95 | 89.5 ± 14.8 |
| LL | -1.87 | 1.02 | 1.59 | -1.24 | 0.35 | -0.43 | -0.18 | 0.12 | -0.89 | 0.20 | 1.07 | 0.25 | -0.44 | -0.09 | -1.11 | -1.53 | -0.74 | -1.10 | 72.2 ± 8.1 |
| HL | -1.73 | 0.16 | 2.20 | -1.23 | 0.72 | 0.22 | -0.47 | -0.27 | -0.11 | 0.64 | -0.49 | 0.37 | 0.89 | -1.02 | -0.92 | -1.26 | -0.26 | -1.13 | 67.5 ± 6.4 |
| HL2 | -1.30 | 0.41 | 1.87 | 1.38 | 0.35 | -0.59 | -1.27 | -0.13 | -0.55 | 0.32 | -1.00 | 0.51 | 0.97 | 0.18 | 6.04 | -1.34 | -0.72 | -1.48 | 103.7 ± 6.7 |
| BBL | -2.37 | 0.21 | 1.77 | -0.77 | -0.24 | 0.73 | 0.01 | -0.72 | 0.45 | 0.43 | 0.34 | 0.16 | 1.65 | 0.99 | -0.57 | -1.28 | -0.03 | -1.75 | 60.3 ± 6.7 |
| P5 | -1.90 | -0.16 | 0.34 | 0.19 | | -0.39 | -0.96 | -0.31 | 1.74 | -0.37 | 0.61 | 1.22 | 0.61 | -0.37 | -2.34 | -1.43 | -1.90 | -0.37 | 39.8 ± 2.2 |

Figure 11. Annual anomaly scorecard for surface (0-50 m) and deep (>50 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 grey 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.

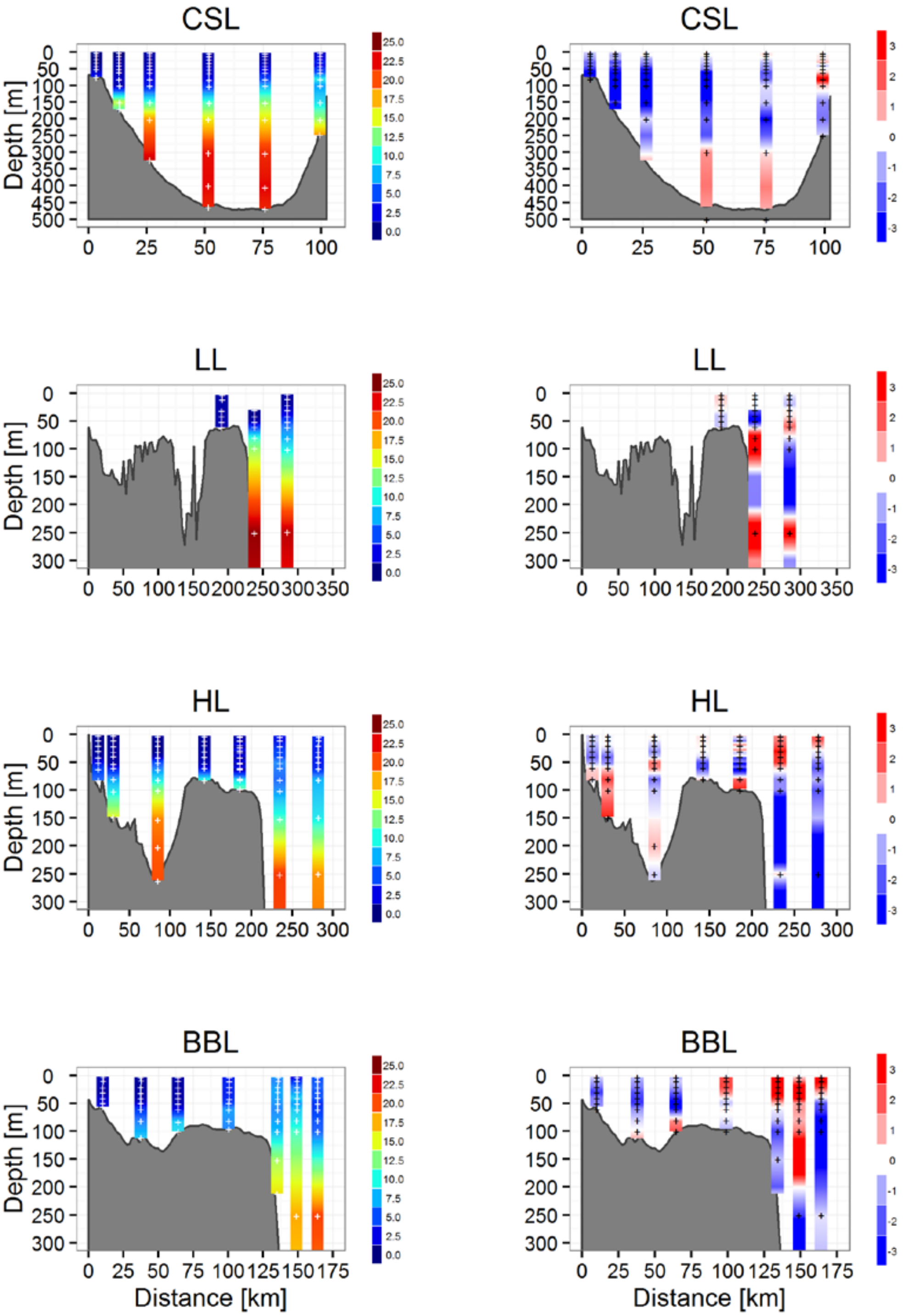


*Figure 12a. Vertical profiles of nitrate concentration (mmol m$^{-3}$) (left panels) and their anomalies (mmol m$^{-3}$) from 1999–2010 conditions (right panels) on the Scotian Shelf sections in spring 2016. White markers on the left panels indicate the actual sampling depths for 2016. Black markers on the right panels indicate the depths at which station-specific climatological values were calculated.*

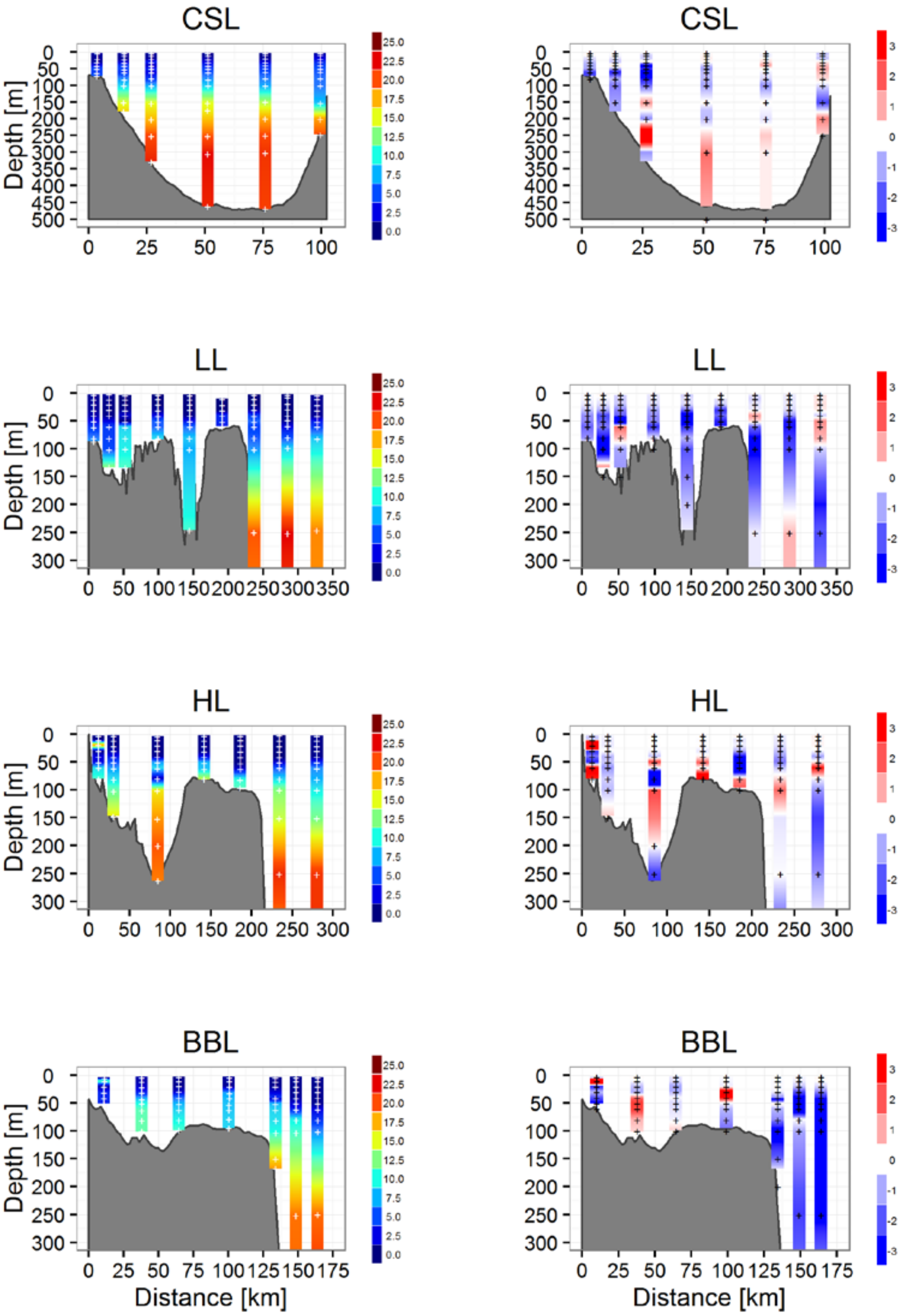


*Figure 12b. Vertical profiles of nitrate concentration (mmol m$^{-3}$) (left panels) and their anomalies (mmol m$^{-3}$) from 1999–2010 conditions (right panels) on the Scotian Shelf sections in fall 2016. White markers on the left panels indicate the actual sampling depths for 2016. Black markers on the right panels indicate the depths at which station-specific climatological values were calculated.*

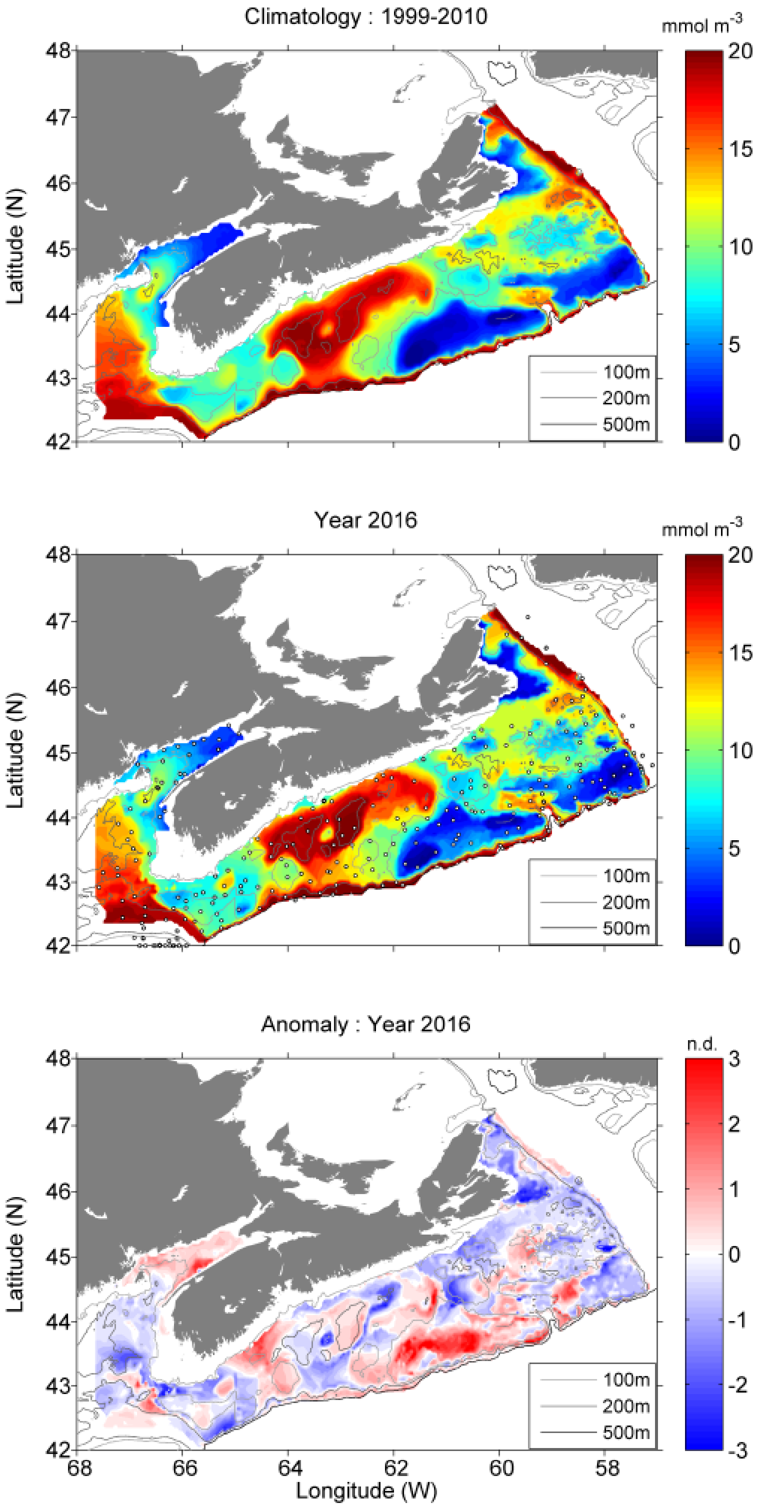


*Figure 13. Bottom nitrate concentration on the Scotian Shelf during the annual July ecosystem trawl survey: 1999-2010 climatology (upper panel), 2016 conditions (middle panel), and normalized anomalies from climatology (lower panel). Markers in middle panel represent the 2016 sampling locations. nd = no dimensions.*

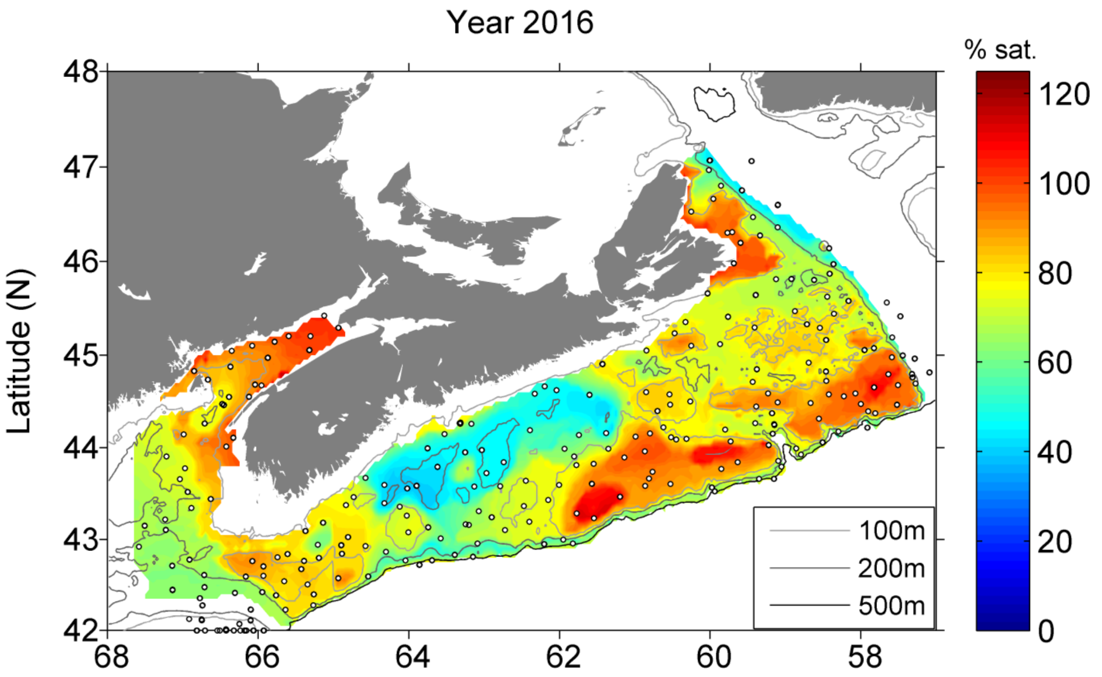


*Figure 14. Bottom oxygen saturation level on the Scotian Shelf during the annual July ecosystem trawl survey in 2016. Markers represent the 2016 sampling locations.*

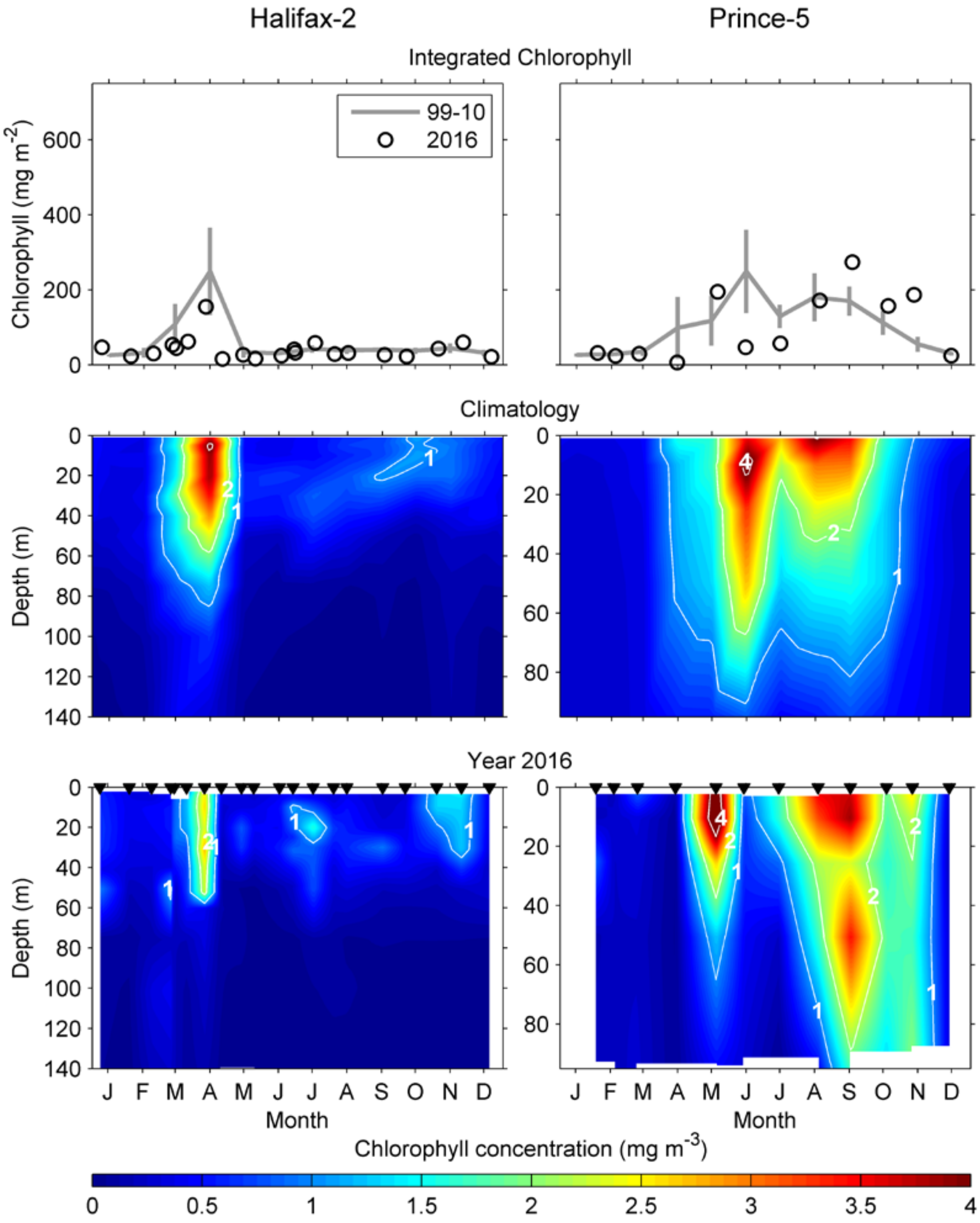


*Figure 15. Annual variability in chlorophyll concentration at the Maritimes time series stations (left column: Halifax-2, right column: Prince-5). Top row: chlorophyll inventories (0-100 m at Halifax-2, 0-95 m at Prince-5) in 2016 (open circles) and mean values 1999–2010 (solid line). Vertical lines 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 2016. Colour scale chosen to emphasize changes near the estimated food saturation levels for large copepods.*

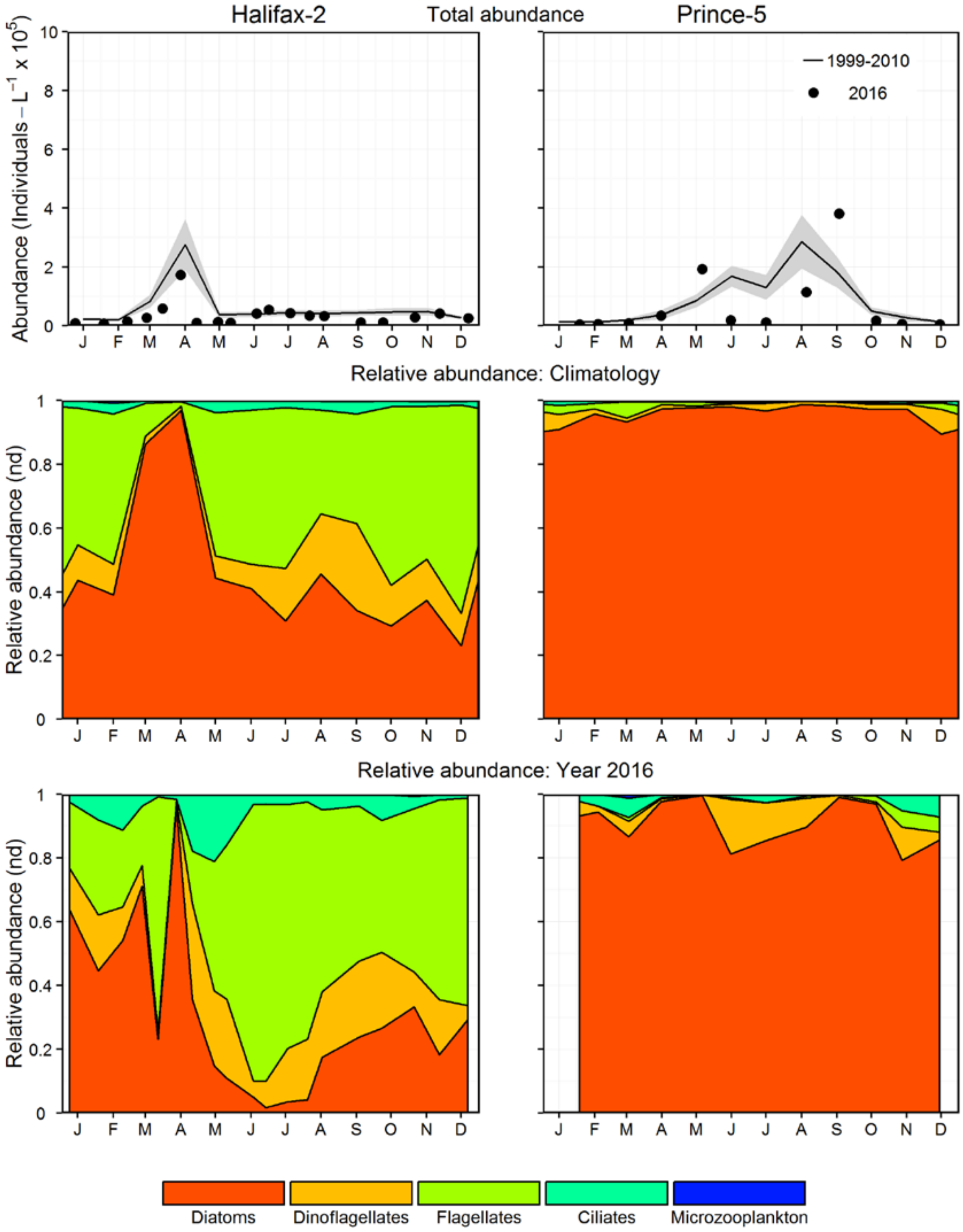
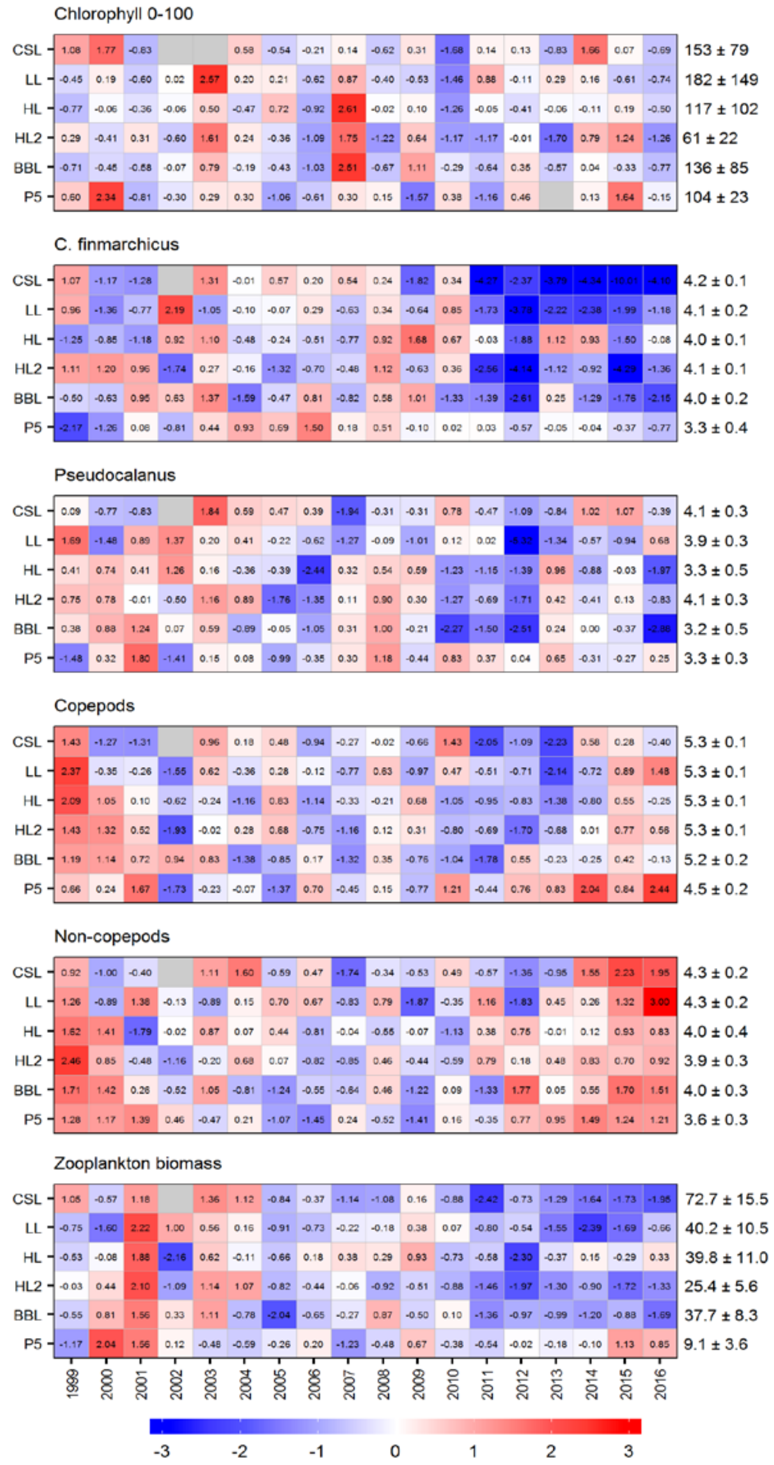


*Figure 16. Comparison of 2016 microplankton (phytoplankton and protists) abundance and community composition with mean conditions from 1999–2010 at the Maritimes high frequency sampling stations (Halifax-2 right panels; Prince-5 left panels). Upper panels: 2016 microplankton abundance (open circle) 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: 2016 microplankton relative abundance. nd = no dimensions.*



Chlorophyll 0-100

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | 1.08 | 1.77 | -0.83 | | | 0.58 | -0.54 | -0.21 | 0.14 | -0.62 | 0.31 | -1.68 | 0.14 | 0.13 | -0.83 | 1.66 | 0.07 | -0.69 | 153 ± 79 |
| LL | -0.45 | 0.19 | -0.60 | 0.02 | 2.57 | 0.20 | 0.21 | -0.62 | 0.87 | -0.40 | -0.53 | -1.46 | 0.88 | -0.11 | 0.29 | 0.16 | -0.61 | -0.74 | 182 ± 149 |
| HL | -0.77 | -0.06 | -0.36 | -0.06 | 0.50 | -0.47 | 0.72 | -0.92 | 2.61 | -0.02 | 0.10 | -1.26 | -0.05 | -0.41 | -0.06 | -0.11 | 0.19 | -0.50 | 117 ± 102 |
| HL2 | 0.29 | -0.41 | 0.31 | -0.60 | 1.61 | 0.24 | -0.36 | -1.09 | 1.75 | -1.22 | 0.64 | -1.17 | -1.17 | -0.01 | -1.70 | 0.79 | 1.24 | -1.26 | 61 ± 22 |
| BBL | -0.71 | -0.45 | -0.58 | -0.07 | 0.79 | -0.19 | -0.43 | -1.03 | 2.51 | -0.67 | 1.11 | -0.29 | -0.64 | 0.35 | -0.57 | 0.04 | -0.33 | -0.77 | 136 ± 85 |
| P5 | 0.60 | 2.34 | -0.81 | -0.30 | 0.29 | 0.30 | -1.06 | -0.61 | 0.30 | 0.15 | -1.57 | 0.38 | -1.16 | 0.46 | | 0.13 | 1.64 | -0.15 | 104 ± 23 |

C. finmarchicus

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | 1.07 | -1.17 | -1.28 | | 1.31 | -0.01 | 0.57 | 0.20 | 0.54 | 0.24 | -1.82 | 0.34 | -4.27 | -2.37 | -3.79 | -4.34 | -10.01 | -4.10 | 4.2 ± 0.1 |
| LL | 0.96 | -1.36 | -0.77 | 2.19 | -1.05 | -0.10 | -0.07 | 0.29 | -0.63 | 0.34 | -0.64 | 0.85 | -1.73 | -3.78 | -2.22 | -2.38 | -1.99 | -1.18 | 4.1 ± 0.2 |
| HL | -1.25 | -0.85 | -1.18 | 0.92 | 1.10 | -0.48 | -0.24 | -0.51 | -0.77 | 0.92 | 1.68 | 0.67 | -0.03 | -1.88 | 1.12 | 0.93 | -1.50 | -0.08 | 4.0 ± 0.1 |
| HL2 | 1.11 | 1.20 | 0.96 | -1.74 | 0.27 | -0.16 | -1.32 | -0.70 | -0.48 | 1.12 | -0.63 | 0.36 | -2.56 | -4.14 | -1.12 | -0.92 | -4.29 | -1.36 | 4.1 ± 0.1 |
| BBL | -0.50 | -0.63 | 0.95 | 0.63 | 1.37 | -1.59 | -0.47 | 0.81 | -0.82 | 0.58 | 1.01 | -1.33 | -1.39 | -2.61 | 0.25 | -1.29 | -1.76 | -2.15 | 4.0 ± 0.2 |
| P5 | -2.17 | -1.26 | 0.06 | -0.81 | 0.44 | 0.93 | 0.69 | 1.50 | 0.18 | 0.51 | -0.10 | 0.02 | 0.03 | -0.57 | -0.05 | -0.04 | -0.37 | -0.77 | 3.3 ± 0.4 |

Pseudocalanus

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | 0.09 | -0.77 | -0.83 | | 1.84 | 0.59 | 0.47 | 0.39 | -1.94 | -0.31 | -0.31 | 0.78 | -0.47 | -1.09 | -0.84 | 1.02 | 1.07 | -0.39 | 4.1 ± 0.3 |
| LL | 1.69 | -1.48 | 0.89 | 1.37 | 0.20 | 0.41 | -0.22 | -0.62 | -1.27 | -0.09 | -1.01 | 0.12 | 0.02 | -5.32 | -1.34 | -0.57 | -0.94 | 0.68 | 3.9 ± 0.3 |
| HL | 0.41 | 0.74 | 0.41 | 1.26 | 0.16 | -0.36 | -0.39 | -2.44 | 0.32 | 0.54 | 0.59 | -1.23 | -1.15 | -1.39 | 0.96 | -0.88 | -0.03 | -1.97 | 3.3 ± 0.5 |
| HL2 | 0.75 | 0.78 | -0.01 | -0.50 | 1.16 | 0.89 | -1.76 | -1.35 | 0.11 | 0.90 | 0.30 | -1.27 | -0.69 | -1.71 | 0.42 | -0.41 | 0.13 | -0.83 | 4.1 ± 0.3 |
| BBL | 0.38 | 0.88 | 1.24 | 0.07 | 0.59 | -0.89 | -0.05 | -1.05 | 0.31 | 1.00 | -0.21 | -2.27 | -1.50 | -2.51 | 0.24 | 0.00 | -0.37 | -2.88 | 3.2 ± 0.5 |
| P5 | -1.48 | 0.32 | 1.80 | -1.41 | 0.15 | 0.08 | -0.99 | -0.35 | 0.30 | 1.18 | -0.44 | 0.83 | 0.37 | 0.04 | 0.65 | -0.31 | -0.27 | 0.25 | 3.3 ± 0.3 |

Copepods

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | 1.43 | -1.27 | -1.31 | | 0.96 | 0.18 | 0.48 | -0.94 | -0.27 | -0.02 | -0.66 | 1.43 | -2.05 | -1.09 | -2.23 | 0.58 | 0.28 | -0.40 | 5.3 ± 0.1 |
| LL | 2.37 | -0.35 | -0.26 | -1.55 | 0.62 | -0.36 | 0.28 | -0.12 | -0.77 | 0.63 | -0.97 | 0.47 | -0.51 | -0.71 | -2.14 | -0.72 | 0.89 | 1.48 | 5.3 ± 0.1 |
| HL | 2.09 | 1.05 | 0.10 | -0.62 | -0.24 | -1.16 | 0.83 | -1.14 | -0.33 | -0.21 | 0.68 | -1.05 | -0.95 | -0.83 | -1.38 | -0.80 | 0.55 | -0.25 | 5.3 ± 0.1 |
| HL2 | 1.43 | 1.32 | 0.52 | -1.93 | -0.02 | 0.28 | 0.68 | -0.75 | -1.16 | 0.12 | 0.31 | -0.80 | -0.69 | -1.70 | -0.68 | 0.01 | 0.77 | 0.56 | 5.3 ± 0.1 |
| BBL | 1.19 | 1.14 | 0.72 | 0.94 | 0.83 | -1.38 | -0.85 | 0.17 | -1.32 | 0.35 | -0.76 | -1.04 | -1.78 | 0.55 | -0.23 | -0.25 | 0.42 | -0.13 | 5.2 ± 0.2 |
| P5 | 0.66 | 0.24 | 1.67 | -1.73 | -0.23 | -0.07 | -1.37 | 0.70 | -0.45 | 0.15 | -0.77 | 1.21 | -0.44 | 0.76 | 0.83 | 2.04 | 0.84 | 2.44 | 4.5 ± 0.2 |

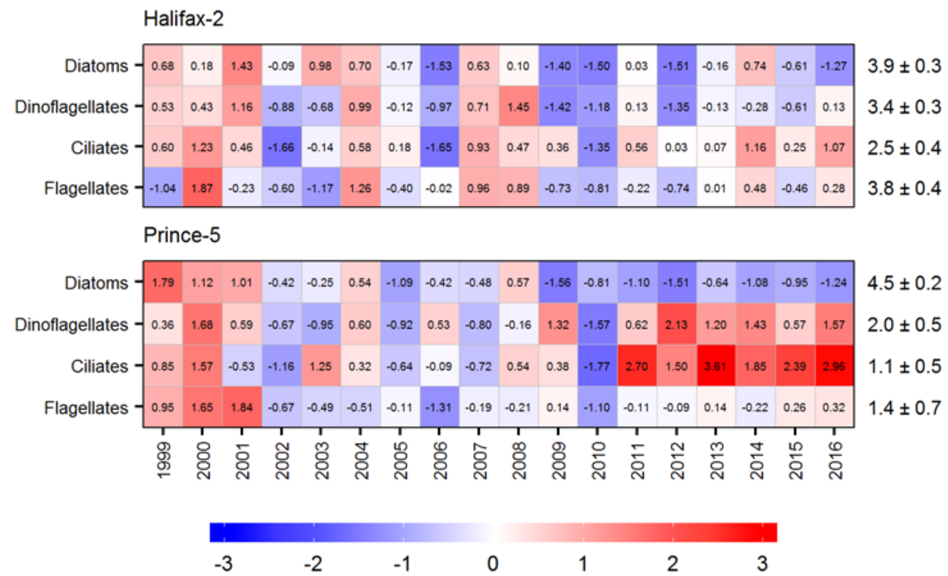
Non-copepods

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | 0.92 | -1.00 | -0.40 | | 1.11 | 1.60 | -0.59 | 0.47 | -1.74 | -0.34 | -0.53 | 0.49 | -0.57 | -1.36 | -0.95 | 1.55 | 2.23 | 1.95 | 4.3 ± 0.2 |
| LL | 1.26 | -0.89 | 1.38 | -0.13 | -0.89 | 0.15 | 0.70 | 0.67 | -0.83 | 0.79 | -1.87 | -0.35 | 1.16 | -1.83 | 0.45 | 0.26 | 1.32 | 3.00 | 4.3 ± 0.2 |
| HL | 1.62 | 1.41 | -1.79 | -0.02 | 0.87 | 0.07 | 0.44 | -0.81 | -0.04 | -0.55 | -0.07 | -1.13 | 0.38 | 0.75 | -0.01 | 0.12 | 0.93 | 0.83 | 4.0 ± 0.4 |
| HL2 | 2.46 | 0.85 | -0.48 | -1.16 | -0.20 | 0.68 | 0.07 | -0.82 | -0.85 | 0.46 | -0.44 | -0.59 | 0.79 | 0.18 | 0.48 | 0.83 | 0.70 | 0.92 | 3.9 ± 0.3 |
| BBL | 1.71 | 1.42 | 0.26 | -0.52 | 1.05 | -0.81 | -1.24 | -0.55 | -0.64 | 0.46 | -1.22 | 0.09 | -1.33 | 1.77 | 0.05 | 0.55 | 1.70 | 1.51 | 4.0 ± 0.3 |
| P5 | 1.28 | 1.17 | 1.39 | 0.46 | -0.47 | 0.21 | -1.07 | -1.45 | 0.24 | -0.52 | -1.41 | 0.16 | -0.35 | 0.77 | 0.95 | 1.49 | 1.24 | 1.21 | 3.6 ± 0.3 |

Zooplankton biomass

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | 1.05 | -0.57 | 1.18 | | 1.36 | 1.12 | -0.84 | -0.37 | -1.14 | -1.08 | 0.16 | -0.88 | -2.42 | -0.73 | -1.29 | -1.64 | -1.73 | -1.95 | 72.7 ± 15.5 |
| LL | -0.75 | -1.60 | 2.22 | 1.00 | 0.56 | 0.16 | -0.91 | -0.73 | -0.22 | -0.18 | 0.38 | 0.07 | -0.80 | -0.54 | -1.55 | -2.39 | -1.69 | -0.66 | 40.2 ± 10.5 |
| HL | -0.53 | -0.08 | 1.88 | -2.16 | 0.62 | -0.11 | -0.66 | 0.18 | 0.38 | 0.29 | 0.93 | -0.73 | -0.58 | -2.30 | -0.37 | 0.15 | -0.29 | 0.33 | 39.8 ± 11.0 |
| HL2 | -0.03 | 0.44 | 2.10 | -1.09 | 1.14 | 1.07 | -0.82 | -0.44 | -0.06 | -0.92 | -0.51 | -0.88 | -1.46 | -1.97 | -1.30 | -0.90 | -1.72 | -1.33 | 25.4 ± 5.6 |
| BBL | -0.55 | 0.81 | 1.56 | 0.33 | 1.11 | -0.78 | -2.04 | -0.65 | -0.27 | 0.87 | -0.50 | 0.10 | -1.36 | -0.97 | -0.99 | -1.20 | -0.88 | -1.69 | 37.7 ± 8.3 |
| P5 | -1.17 | 2.04 | 1.56 | 0.12 | -0.48 | -0.59 | -0.26 | 0.20 | -1.23 | -0.48 | 0.67 | -0.38 | -0.54 | -0.02 | -0.18 | -0.10 | 1.13 | 0.85 | 9.1 ± 3.6 |

*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 grey cell indicates missing data. Red (blue) cells indicate higher (lower) than normal levels of the variable. CSL: Cabot Strait section; LL: Louisbourg section; HL: Halifax section; HL2: Halifax-2; BBL: Browns Bank section; P5: Prince-5.*



Halifax-2

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diatoms | 0.68 | 0.18 | 1.43 | -0.09 | 0.98 | 0.70 | -0.17 | -1.53 | 0.63 | 0.10 | -1.40 | -1.50 | 0.03 | -1.51 | -0.16 | 0.74 | -0.61 | -1.27 | 3.9 ± 0.3 |
| Dinoflagellates | 0.53 | 0.43 | 1.16 | -0.88 | -0.68 | 0.99 | -0.12 | -0.97 | 0.71 | 1.45 | -1.42 | -1.18 | 0.13 | -1.35 | -0.13 | -0.28 | -0.61 | 0.13 | 3.4 ± 0.3 |
| Ciliates | 0.60 | 1.23 | 0.46 | -1.66 | -0.14 | 0.58 | 0.18 | -1.65 | 0.93 | 0.47 | 0.36 | -1.35 | 0.56 | 0.03 | 0.07 | 1.16 | 0.25 | 1.07 | 2.5 ± 0.4 |
| Flagellates | -1.04 | 1.87 | -0.23 | -0.60 | -1.17 | 1.26 | -0.40 | -0.02 | 0.96 | 0.89 | -0.73 | -0.81 | -0.22 | -0.74 | 0.01 | 0.48 | -0.46 | 0.28 | 3.8 ± 0.4 |

Prince-5

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diatoms | 1.79 | 1.12 | 1.01 | -0.42 | -0.25 | 0.54 | -1.09 | -0.42 | -0.48 | 0.57 | -1.56 | -0.81 | -1.10 | -1.51 | -0.64 | -1.08 | -0.95 | -1.24 | 4.5 ± 0.2 |
| Dinoflagellates | 0.36 | 1.68 | 0.59 | -0.67 | -0.95 | 0.60 | -0.92 | 0.53 | -0.80 | -0.16 | 1.32 | -1.57 | 0.62 | 2.13 | 1.20 | 1.43 | 0.57 | 1.57 | 2.0 ± 0.5 |
| Ciliates | 0.85 | 1.57 | -0.53 | -1.16 | 1.25 | 0.32 | -0.64 | -0.09 | -0.72 | 0.54 | 0.38 | -1.77 | 2.70 | 1.50 | 3.61 | 1.85 | 2.39 | 2.96 | 1.1 ± 0.5 |
| Flagellates | 0.95 | 1.65 | 1.84 | -0.67 | -0.49 | -0.51 | -0.11 | -1.31 | -0.19 | -0.21 | 0.14 | -1.10 | -0.11 | -0.09 | 0.14 | -0.22 | 0.26 | 0.32 | 1.4 ± 0.7 |

*Figure 18. Annual anomaly scorecard for microplankton abundance at the Maritimes high frequency sampling stations. 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). Red (blue) cells indicate higher (lower) than normal microplankton abundance levels.*

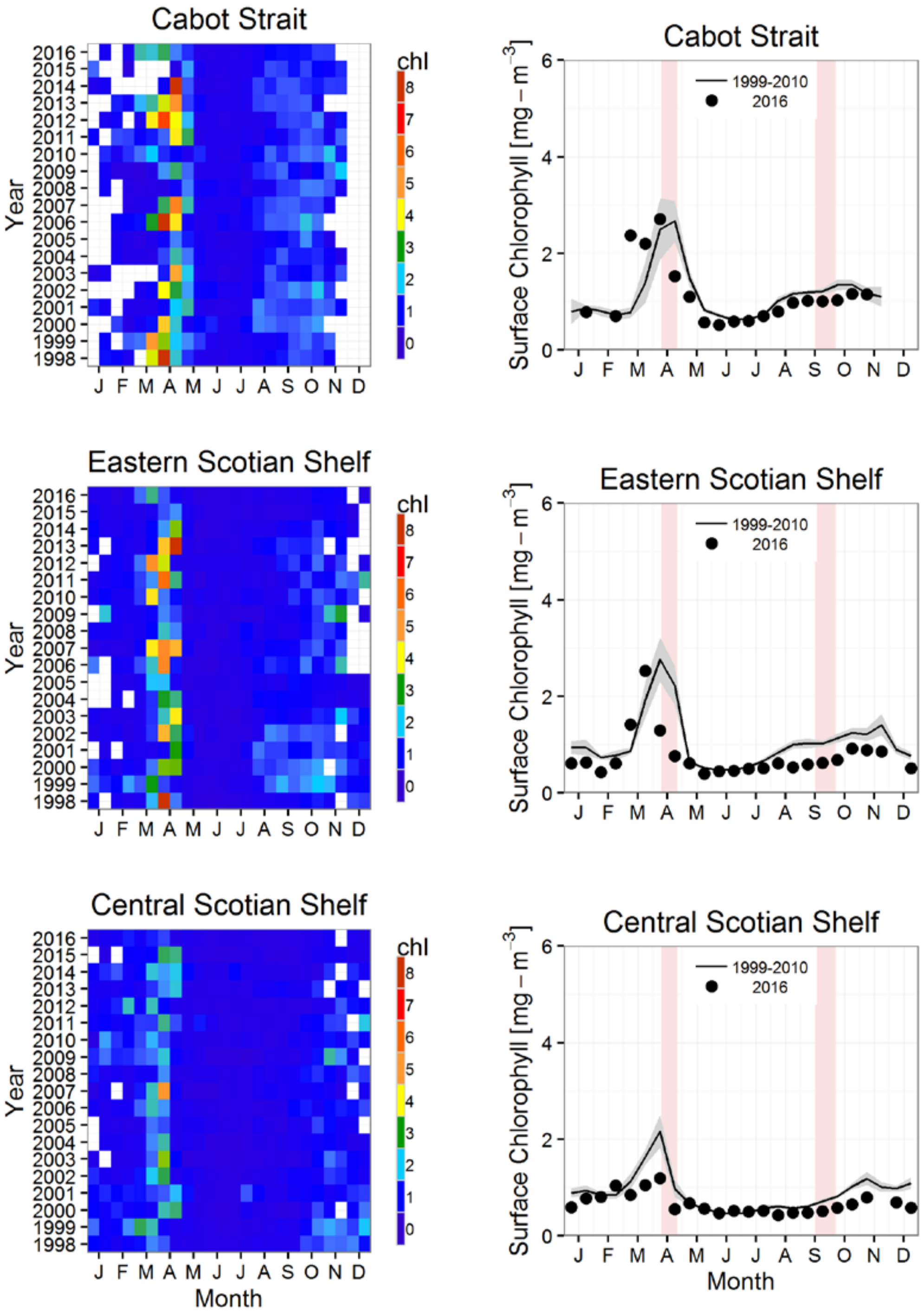


*Figure 19a. Estimates of surface chlorophyll concentrations from semi-monthly remotely sensed ocean colour data in the Cabot Strait (top), Eastern Scotian Shelf (middle), and Central Scotian Shelf (bottom) statistical sub-regions (see Figure 4). Data from SeaWiFS 1998-2003; MODIS 2004-2011; VIIRS 2012-2016. Left panels: Time series of annual variation in chlorophyll concentrations. Right panels: Comparison of 2016 (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.*

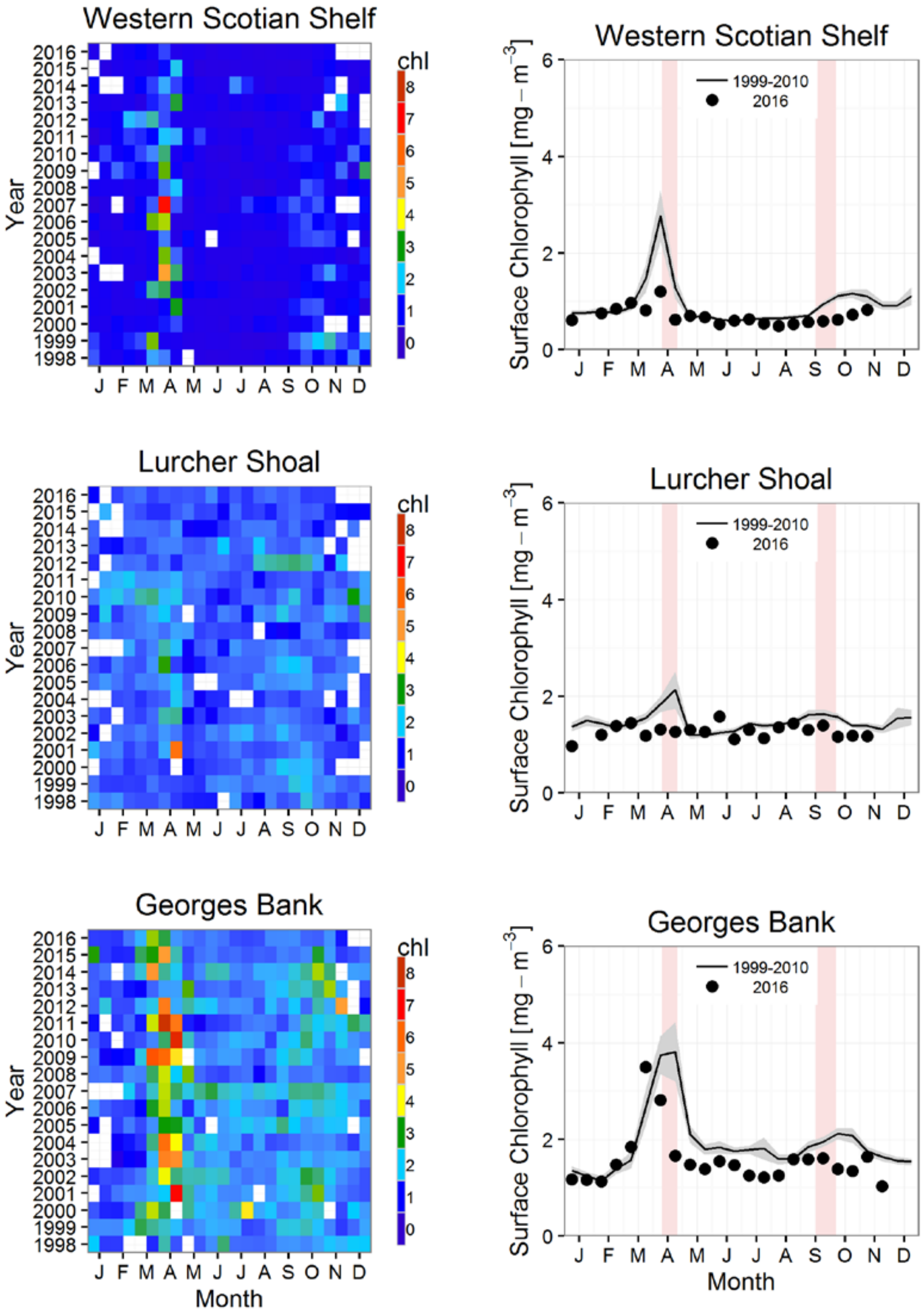
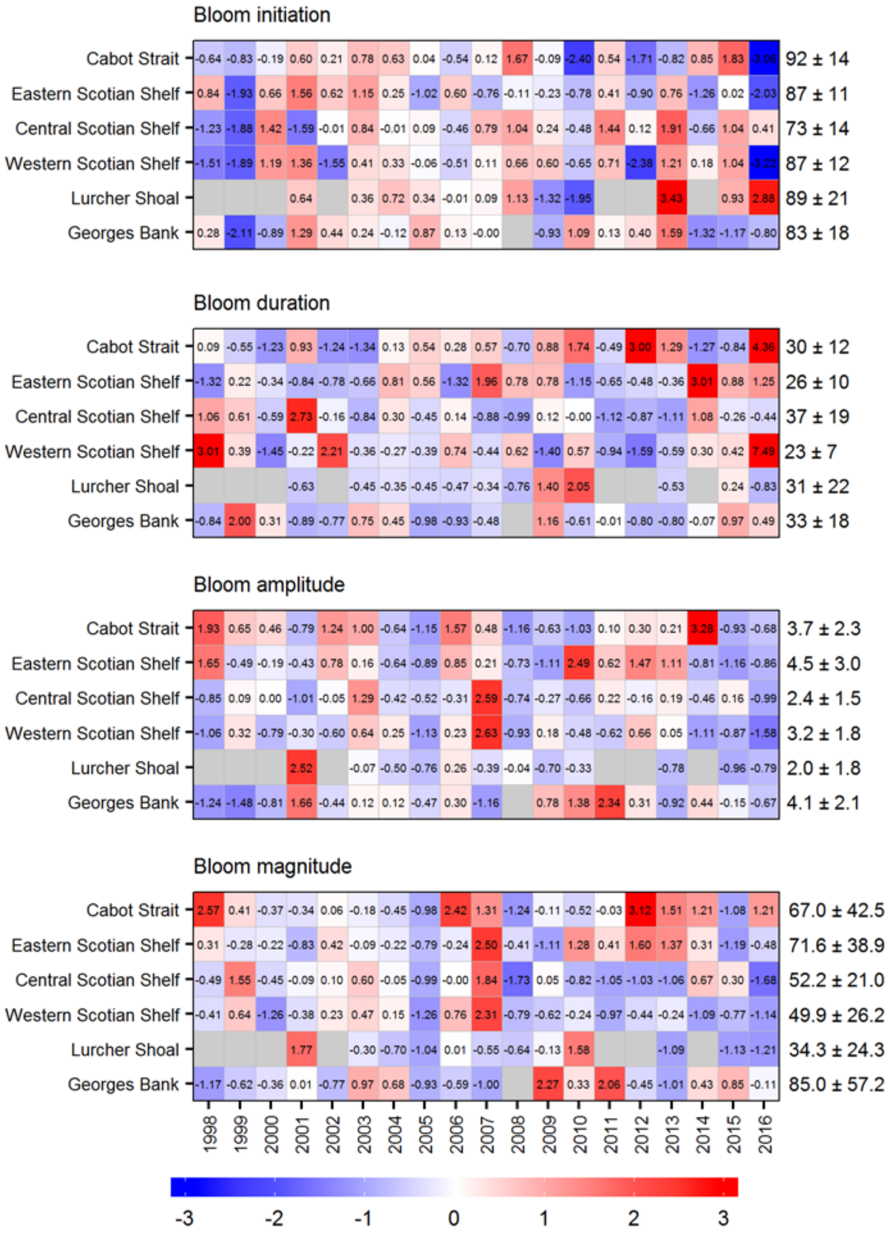
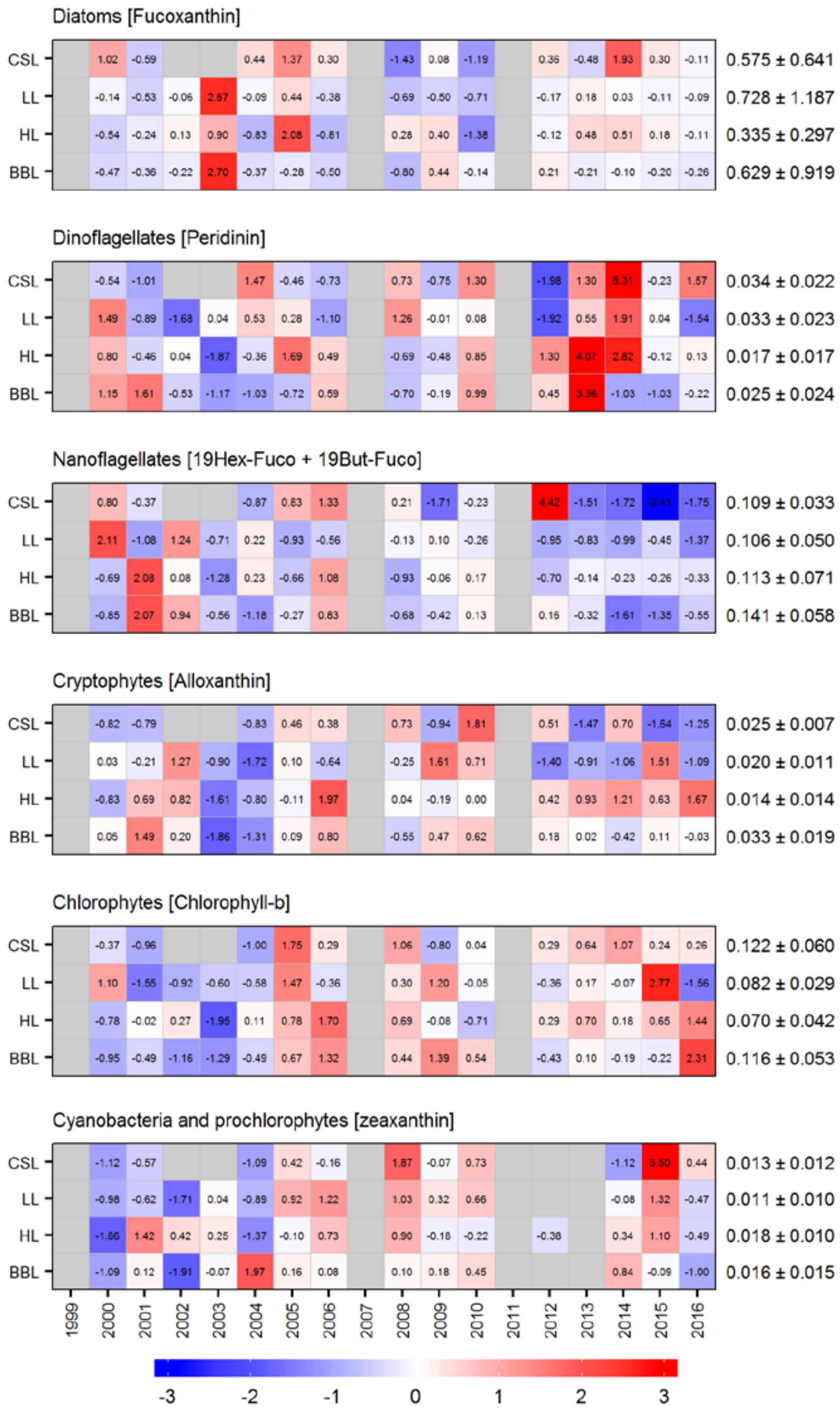


*Figure 19b. Estimates of surface chlorophyll concentrations from semi-monthly remotely sensed ocean colour data in the Western Scotian Shelf (top), Lurcher Shoal (middle), and Georges Bank (bottom) statistical sub-regions (see Figure 4). Data from SeaWiFS 1998-2003; MODIS 2004-2011; VIIRS 2012-2016. Left panels: Time series of annual variation in chlorophyll concentrations. Right panels: Comparison of 2016 (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.*



|  | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Bloom initiation** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Cabot Strait | -0.64 | -0.83 | -0.19 | 0.60 | 0.21 | 0.78 | 0.63 | 0.04 | -0.54 | 0.12 | 1.67 | -0.09 | -2.40 | 0.54 | -1.71 | -0.82 | 0.85 | 1.83 | -3.06 | 92 ± 14 |
| Eastern Scotian Shelf | 0.84 | -1.93 | 0.66 | 1.56 | 0.62 | 1.15 | 0.25 | -1.02 | 0.60 | -0.76 | -0.11 | -0.23 | -0.78 | 0.41 | -0.90 | 0.76 | -1.26 | 0.02 | -2.03 | 87 ± 11 |
| Central Scotian Shelf | -1.23 | -1.88 | 1.42 | -1.59 | -0.01 | 0.84 | -0.01 | 0.09 | -0.46 | 0.79 | 1.04 | 0.24 | -0.48 | 1.44 | 0.12 | 1.91 | -0.66 | 1.04 | 0.41 | 73 ± 14 |
| Western Scotian Shelf | -1.51 | -1.89 | 1.19 | 1.36 | -1.55 | 0.41 | 0.33 | -0.06 | -0.51 | 0.11 | 0.66 | 0.60 | -0.65 | 0.71 | -2.38 | 1.21 | 0.18 | 1.04 | -3.22 | 87 ± 12 |
| Lurcher Shoal |  |  |  | 0.64 |  | 0.36 | 0.72 | 0.34 | -0.01 | 0.09 | 1.13 | -1.32 | -1.95 |  |  | 3.43 |  | 0.93 | 2.88 | 89 ± 21 |
| Georges Bank | 0.28 | -2.11 | -0.89 | 1.29 | 0.44 | 0.24 | -0.12 | 0.87 | 0.13 | -0.00 |  | -0.93 | 1.09 | 0.13 | 0.40 | 1.59 | -1.32 | -1.17 | -0.80 | 83 ± 18 |
| **Bloom duration** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Cabot Strait | 0.09 | -0.55 | -1.23 | 0.93 | -1.24 | -1.34 | 0.13 | 0.54 | 0.28 | 0.57 | -0.70 | 0.88 | 1.74 | -0.49 | 3.00 | 1.29 | -1.27 | -0.84 | 4.36 | 30 ± 12 |
| Eastern Scotian Shelf | -1.32 | 0.22 | -0.34 | -0.84 | -0.78 | -0.66 | 0.81 | 0.56 | -1.32 | 1.96 | 0.78 | 0.78 | -1.15 | -0.65 | -0.48 | -0.36 | 3.01 | 0.88 | 1.25 | 26 ± 10 |
| Central Scotian Shelf | 1.06 | 0.61 | -0.59 | 2.73 | -0.16 | -0.84 | 0.30 | -0.45 | 0.14 | -0.88 | -0.99 | 0.12 | -0.00 | -1.12 | -0.87 | -1.11 | 1.08 | -0.26 | -0.44 | 37 ± 19 |
| Western Scotian Shelf | 3.01 | 0.39 | -1.45 | -0.22 | 2.21 | -0.36 | -0.27 | -0.39 | 0.74 | -0.44 | 0.62 | -1.40 | 0.57 | -0.94 | -1.59 | -0.59 | 0.30 | 0.42 | 7.49 | 23 ± 7 |
| Lurcher Shoal |  |  |  | -0.63 |  | -0.45 | -0.35 | -0.45 | -0.47 | -0.34 | -0.76 | 1.40 | 2.05 |  |  | -0.53 |  | 0.24 | -0.83 | 31 ± 22 |
| Georges Bank | -0.84 | 2.00 | 0.31 | -0.89 | -0.77 | 0.75 | 0.45 | -0.98 | -0.93 | -0.48 |  | 1.16 | -0.61 | -0.01 | -0.80 | -0.80 | -0.07 | 0.97 | 0.49 | 33 ± 18 |
| **Bloom amplitude** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Cabot Strait | 1.93 | 0.65 | 0.46 | -0.79 | 1.24 | 1.00 | -0.64 | -1.15 | 1.57 | 0.48 | -1.16 | -0.63 | -1.03 | 0.10 | 0.30 | 0.21 | 3.28 | -0.93 | -0.68 | 3.7 ± 2.3 |
| Eastern Scotian Shelf | 1.65 | -0.49 | -0.19 | -0.43 | 0.78 | 0.16 | -0.64 | -0.89 | 0.85 | 0.21 | -0.73 | -1.11 | 2.49 | 0.62 | 1.47 | 1.11 | -0.81 | -1.16 | -0.86 | 4.5 ± 3.0 |
| Central Scotian Shelf | -0.85 | 0.09 | 0.00 | -1.01 | -0.05 | 1.29 | -0.42 | -0.52 | -0.31 | 2.59 | -0.74 | -0.27 | -0.66 | 0.22 | -0.16 | 0.19 | -0.46 | 0.16 | -0.99 | 2.4 ± 1.5 |
| Western Scotian Shelf | -1.06 | 0.32 | -0.79 | -0.30 | -0.60 | 0.64 | 0.25 | -1.13 | 0.23 | 2.63 | -0.93 | 0.18 | -0.48 | -0.62 | 0.66 | 0.05 | -1.11 | -0.87 | -1.58 | 3.2 ± 1.8 |
| Lurcher Shoal |  |  |  | 2.52 |  | -0.07 | -0.50 | -0.76 | 0.26 | -0.39 | -0.04 | -0.70 | -0.33 |  |  | -0.78 |  | -0.96 | -0.79 | 2.0 ± 1.8 |
| Georges Bank | -1.24 | -1.48 | -0.81 | 1.66 | -0.44 | 0.12 | 0.12 | -0.47 | 0.30 | -1.16 |  | 0.78 | 1.38 | 2.34 | 0.31 | -0.92 | 0.44 | -0.15 | -0.67 | 4.1 ± 2.1 |
| **Bloom magnitude** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Cabot Strait | 2.57 | 0.41 | -0.37 | -0.34 | 0.06 | -0.18 | -0.45 | -0.98 | 2.42 | 1.31 | -1.24 | -0.11 | -0.52 | -0.03 | 3.12 | 1.51 | 1.21 | -1.08 | 1.21 | 67.0 ± 42.5 |
| Eastern Scotian Shelf | 0.31 | -0.28 | -0.22 | -0.83 | 0.42 | -0.09 | -0.22 | -0.79 | -0.24 | 2.50 | -0.41 | -1.11 | 1.28 | 0.41 | 1.60 | 1.37 | 0.31 | -1.19 | -0.48 | 71.6 ± 38.9 |
| Central Scotian Shelf | -0.49 | 1.55 | -0.45 | -0.09 | 0.10 | 0.60 | -0.05 | -0.99 | -0.00 | 1.84 | -1.73 | 0.05 | -0.82 | -1.05 | -1.03 | -1.06 | 0.67 | 0.30 | -1.68 | 52.2 ± 21.0 |
| Western Scotian Shelf | -0.41 | 0.64 | -1.26 | -0.38 | 0.23 | 0.47 | 0.15 | -1.26 | 0.76 | 2.31 | -0.79 | -0.62 | -0.24 | -0.97 | -0.44 | -0.24 | -1.09 | -0.77 | -1.14 | 49.9 ± 26.2 |
| Lurcher Shoal |  |  |  | 1.77 |  | -0.30 | -0.70 | -1.04 | 0.01 | -0.55 | -0.64 | -0.13 | 1.58 |  |  | -1.09 |  | -1.13 | -1.21 | 34.3 ± 24.3 |
| Georges Bank | -1.17 | -0.62 | -0.36 | 0.01 | -0.77 | 0.97 | 0.68 | -0.93 | -0.59 | -1.00 |  | 2.27 | 0.33 | 2.06 | -0.45 | -1.01 | 0.43 | 0.85 | -0.11 | 85.0 ± 57.2 |

*Figure 20. Annual anomaly scorecard for spring bloom parameters. 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 grey cell indicates missing data. Red (blue) cells indicate later (earlier) initiation, longer (shorter) duration or higher (lower) amplitude or magnitude than normal.*



Diatoms [Fucoxanthin]

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | | 1.02 | -0.59 | | | 0.44 | 1.37 | 0.30 | | -1.43 | 0.08 | -1.19 | | 0.36 | -0.48 | 1.93 | 0.30 | -0.11 | 0.575 ± 0.641 |
| LL | | -0.14 | -0.53 | -0.06 | 2.67 | -0.09 | 0.44 | -0.38 | | -0.69 | -0.50 | -0.71 | | -0.17 | 0.18 | 0.03 | -0.11 | -0.09 | 0.728 ± 1.187 |
| HL | | -0.54 | -0.24 | 0.13 | 0.90 | -0.83 | 2.08 | -0.81 | | 0.28 | 0.40 | -1.38 | | -0.12 | 0.48 | 0.51 | 0.18 | -0.11 | 0.335 ± 0.297 |
| BBL | | -0.47 | -0.36 | -0.22 | 2.70 | -0.37 | -0.28 | -0.50 | | -0.80 | 0.44 | -0.14 | | 0.21 | -0.21 | -0.10 | -0.20 | -0.26 | 0.629 ± 0.919 |

Dinoflagellates [Peridinin]

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | | -0.54 | -1.01 | | | 1.47 | -0.46 | -0.73 | | 0.73 | -0.75 | 1.30 | | -1.98 | 1.30 | 5.31 | -0.23 | 1.57 | 0.034 ± 0.022 |
| LL | | 1.49 | -0.89 | -1.68 | 0.04 | 0.53 | 0.28 | -1.10 | | 1.26 | -0.01 | 0.08 | | -1.92 | 0.55 | 1.91 | 0.04 | -1.54 | 0.033 ± 0.023 |
| HL | | 0.80 | -0.46 | 0.04 | -1.87 | -0.36 | 1.69 | 0.49 | | -0.69 | -0.48 | 0.85 | | 1.30 | 4.07 | 2.82 | -0.12 | 0.13 | 0.017 ± 0.017 |
| BBL | | 1.15 | 1.61 | -0.53 | -1.17 | -1.03 | -0.72 | 0.59 | | -0.70 | -0.19 | 0.99 | | 0.45 | 3.36 | -1.03 | -1.03 | -0.22 | 0.025 ± 0.024 |

Nanoflagellates [19Hex-Fuco + 19But-Fuco]

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | | 0.80 | -0.37 | | | -0.87 | 0.83 | 1.33 | | 0.21 | -1.71 | -0.23 | | 4.42 | -1.51 | -1.72 | -3.41 | -1.75 | 0.109 ± 0.033 |
| LL | | 2.11 | -1.08 | 1.24 | -0.71 | 0.22 | -0.93 | -0.56 | | -0.13 | 0.10 | -0.26 | | -0.95 | -0.83 | -0.99 | -0.45 | -1.37 | 0.106 ± 0.050 |
| HL | | -0.69 | 2.08 | 0.08 | -1.28 | 0.23 | -0.66 | 1.08 | | -0.93 | -0.06 | 0.17 | | -0.70 | -0.14 | -0.23 | -0.26 | -0.33 | 0.113 ± 0.071 |
| BBL | | -0.85 | 2.07 | 0.94 | -0.56 | -1.18 | -0.27 | 0.83 | | -0.68 | -0.42 | 0.13 | | 0.16 | -0.32 | -1.61 | -1.35 | -0.55 | 0.141 ± 0.058 |

Cryptophytes [Alloxanthin]

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | | -0.82 | -0.79 | | | -0.83 | 0.46 | 0.38 | | 0.73 | -0.94 | 1.81 | | 0.51 | -1.47 | 0.70 | -1.64 | -1.25 | 0.025 ± 0.007 |
| LL | | 0.03 | -0.21 | 1.27 | -0.90 | -1.72 | 0.10 | -0.64 | | -0.25 | 1.61 | 0.71 | | -1.40 | -0.91 | -1.06 | 1.51 | -1.09 | 0.020 ± 0.011 |
| HL | | -0.83 | 0.69 | 0.82 | -1.61 | -0.80 | -0.11 | 1.97 | | 0.04 | -0.19 | 0.00 | | 0.42 | 0.93 | 1.21 | 0.63 | 1.67 | 0.014 ± 0.014 |
| BBL | | 0.05 | 1.49 | 0.20 | -1.86 | -1.31 | 0.09 | 0.80 | | -0.55 | 0.47 | 0.62 | | 0.18 | 0.02 | -0.42 | 0.11 | -0.03 | 0.033 ± 0.019 |

Chlorophytes [Chlorophyll-b]

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | | -0.37 | -0.96 | | | -1.00 | 1.75 | 0.29 | | 1.06 | -0.80 | 0.04 | | 0.29 | 0.64 | 1.07 | 0.24 | 0.26 | 0.122 ± 0.060 |
| LL | | 1.10 | -1.55 | -0.92 | -0.60 | -0.58 | 1.47 | -0.36 | | 0.30 | 1.20 | -0.05 | | -0.36 | 0.17 | -0.07 | 2.77 | -1.56 | 0.082 ± 0.029 |
| HL | | -0.78 | -0.02 | 0.27 | -1.95 | 0.11 | 0.78 | 1.70 | | 0.69 | -0.08 | -0.71 | | 0.29 | 0.70 | 0.18 | 0.65 | 1.44 | 0.070 ± 0.042 |
| BBL | | -0.95 | -0.49 | -1.16 | -1.29 | -0.49 | 0.67 | 1.32 | | 0.44 | 1.39 | 0.54 | | -0.43 | 0.10 | -0.19 | -0.22 | 2.31 | 0.116 ± 0.053 |

Cyanobacteria and prochlorophytes [zeaxanthin]

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | | -1.12 | -0.57 | | | -1.09 | 0.42 | -0.16 | | 1.87 | -0.07 | 0.73 | | | | -1.12 | 3.50 | 0.44 | 0.013 ± 0.012 |
| LL | | -0.98 | -0.62 | -1.71 | 0.04 | -0.89 | 0.92 | 1.22 | | 1.03 | 0.32 | 0.66 | | | | -0.08 | 1.32 | -0.47 | 0.011 ± 0.010 |
| HL | | -1.86 | 1.42 | 0.42 | 0.25 | -1.37 | -0.10 | 0.73 | | 0.90 | -0.18 | -0.22 | | -0.38 | | 0.34 | 1.10 | -0.49 | 0.018 ± 0.010 |
| BBL | | -1.09 | 0.12 | -1.91 | -0.07 | 1.97 | 0.16 | 0.08 | | 0.10 | 0.18 | 0.45 | | | | 0.84 | -0.09 | -1.00 | 0.016 ± 0.015 |

*Figure 21. Annual anomaly scorecard of surface (1 – 5 m) pigment indicators of seven taxonomic groups: Diatoms, Dinoflagellates, Nanoflagellates, Cryptophytes, Chlorophytes, and combined Cyanobacteria and Prochlorophytes (grouped under the same pigment marker: zeaxanthin). 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 grey cell indicates missing data. Red (blue) cells indicate higher (lower) than normal pigment indicator levels. CSL: Cabot Strait section; LL: Louisbourg section; HL: Halifax section; BBL: Browns Bank section.*

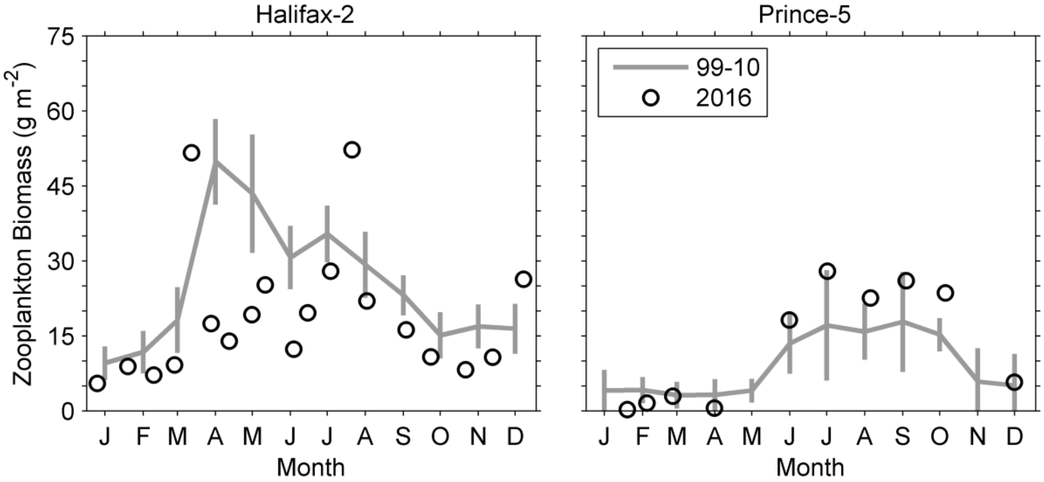


*Figure 22. Zooplankton biomass (integrated surface to bottom) in 2016 (open circle) and mean conditions 1999–2010 (solid line) at the Maritimes high frequency sampling stations. Left panel: Halifax-2; right panel: Prince-5. Vertical lines are 95% confidence intervals of the monthly means.*

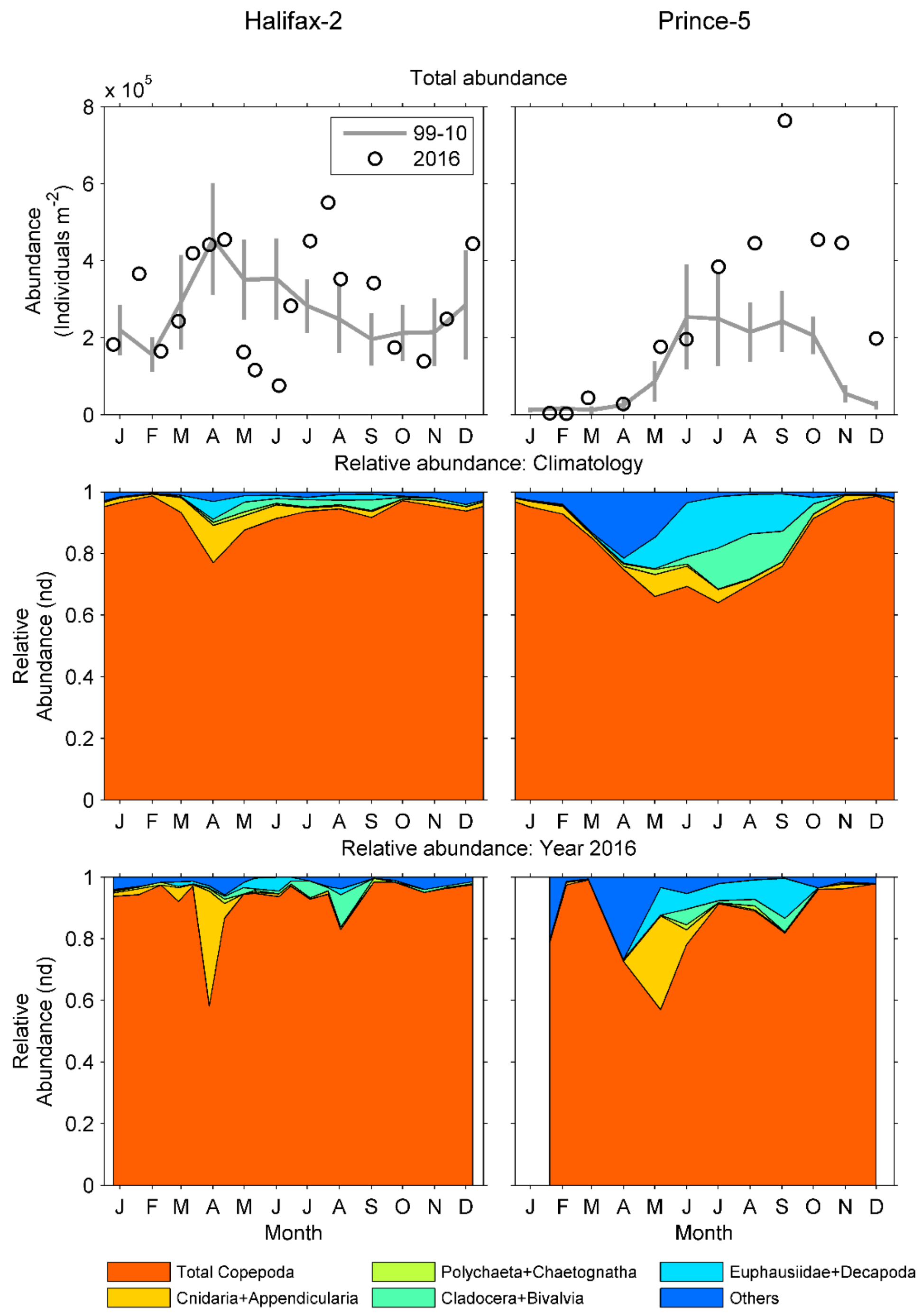


*Figure 23. Zooplankton (>200 µm) abundance and community composition in 2016 and mean conditions 1999–2010 at the Maritimes high frequency sampling stations (Halifax-2, left panels; Prince-5, right panels). Upper panels: Zooplankton abundance in 2016 (open circle) and mean conditions 1999–2010 (solid 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 2016. nd = no dimensions.*

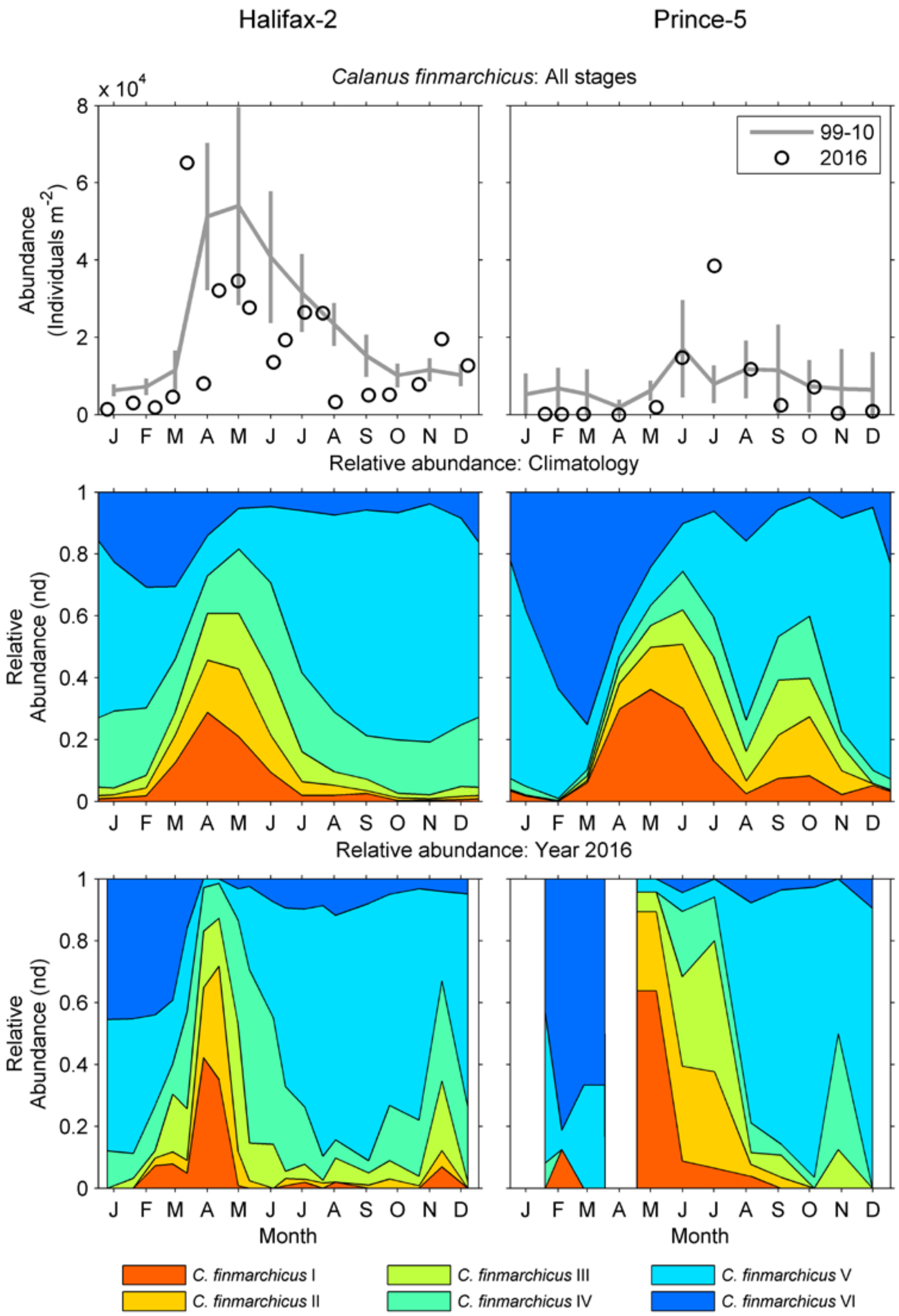


*Figure 24. Calanus finmarchicus abundance and developmental stage distributions in 2016 and mean conditions 1999–2010 at the Maritimes high frequency sampling stations (Halifax-2, left panels; Prince-5, right panels). Upper panels: C. finmarchicus abundance in 2016 (open circle) and mean conditions 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 2016. nd = no dimensions.*

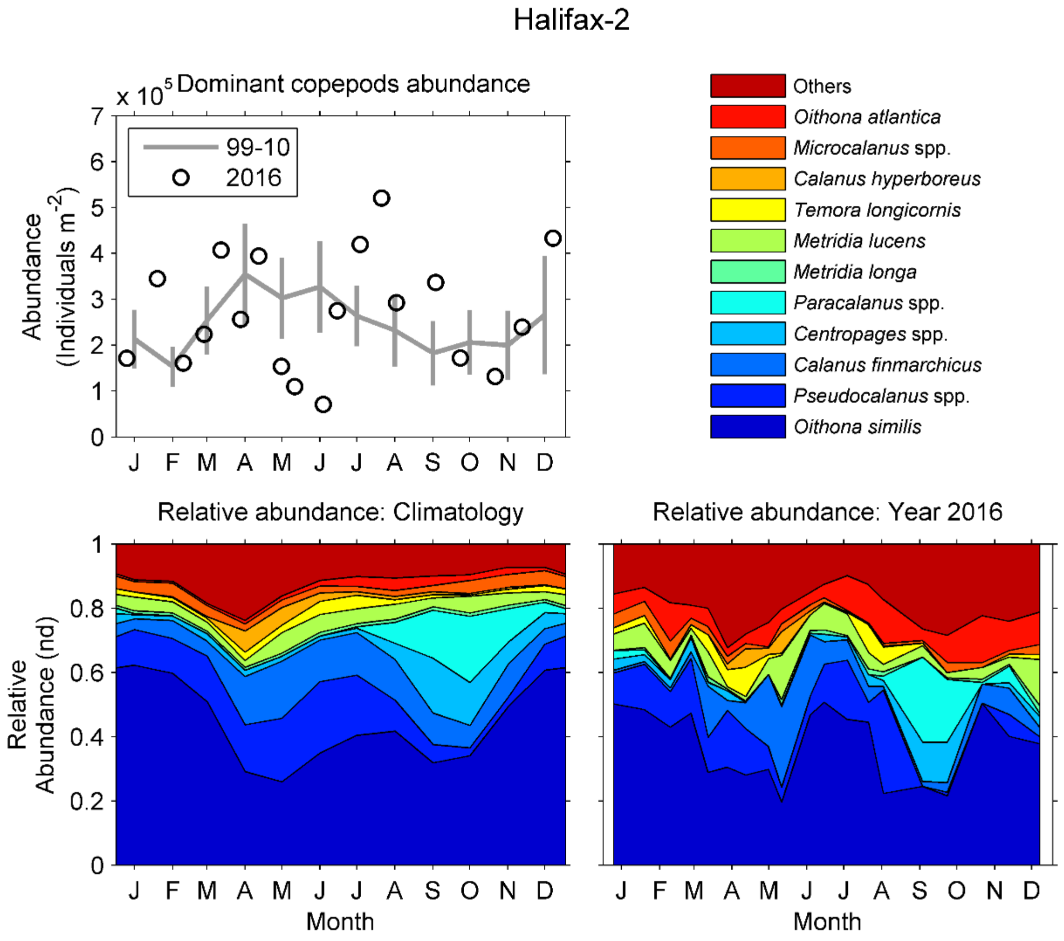


*Figure 25a. Seasonal variability of dominant copepods at Halifax-2. The top 95% of identified copepod taxa by abundance, 1999-2010, are shown individually; others, including unidentified copepods (mostly nauplii) are grouped as "others." Upper left panel: copepod abundance in 2016 (open circle) and 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 2016. nd = no dimensions.*

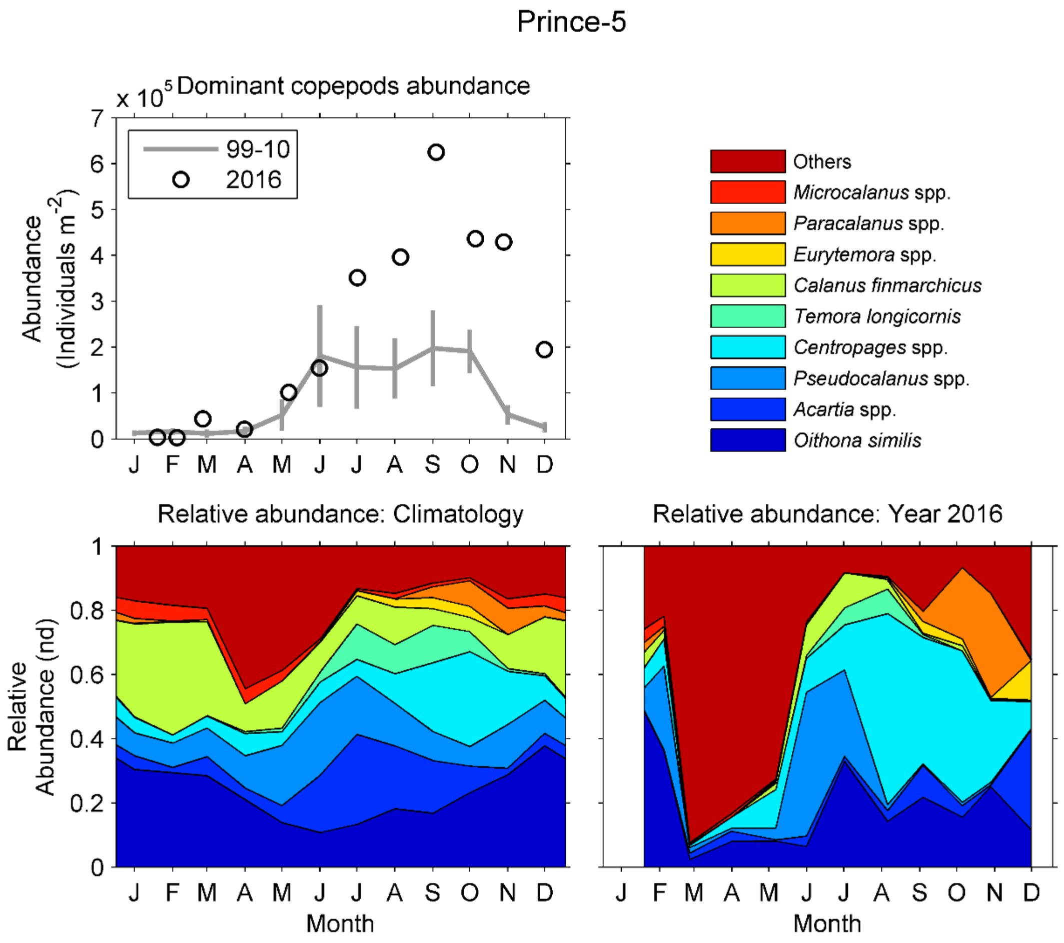


*Figure 25b. Seasonal variability of dominant copepods at Prince-5. The top 95% of identified copepod taxa by abundance, 1999-2010, are shown individually; others, including unidentified copepods (mostly nauplii) are grouped as "others." Upper left panel: copepod abundance in 2016 (open circle) and mean 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 2016. nd = no dimensions.*

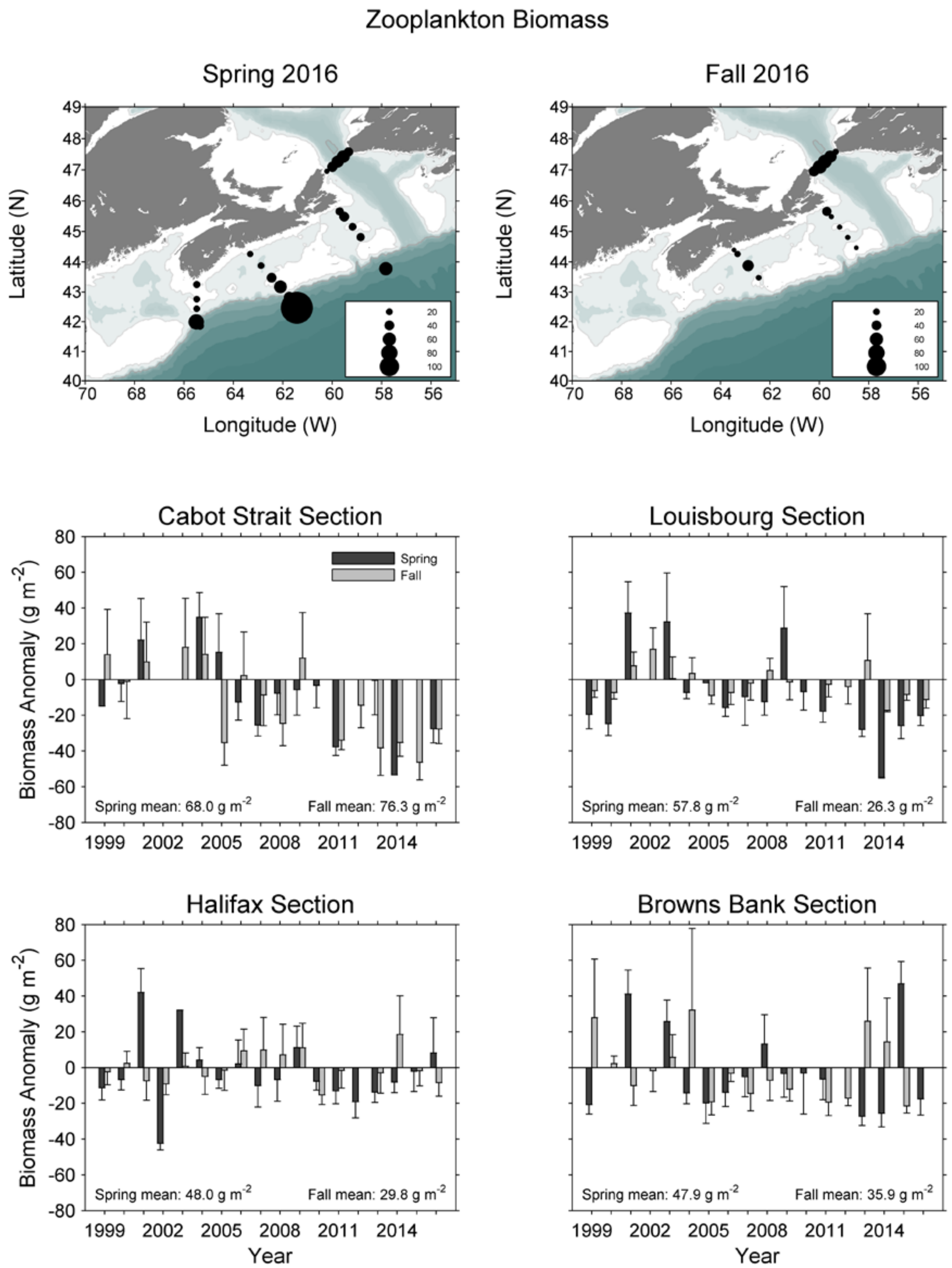


*Figure 26. Spatial distribution of zooplankton biomass in 2016 (upper panels) and time series of zooplankton biomass anomalies on Scotian Shelf sections (middle and lower panels) in spring and fall, 1999-2016. Vertical lines in lower panels represent standard errors.*

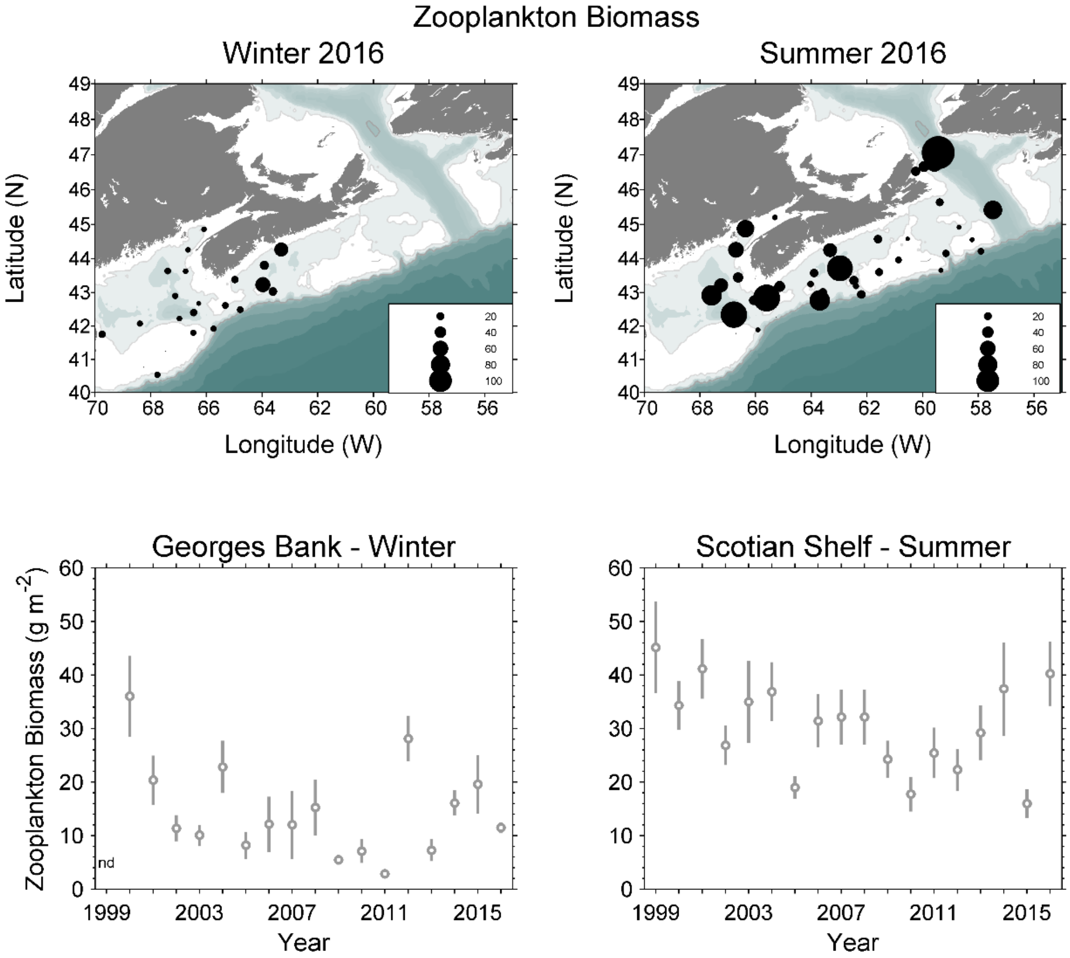


*Figure 27. Zooplankton biomass from ecosystem trawl surveys on Georges Bank (February), the eastern Scotian Shelf (March) and the Scotian Shelf and eastern Gulf of Maine (summer): upper panels show 2016 spatial distributions, lower panels show survey mean biomass, 1999–2016 (vertical lines are standard errors; nd = no survey in that year).*

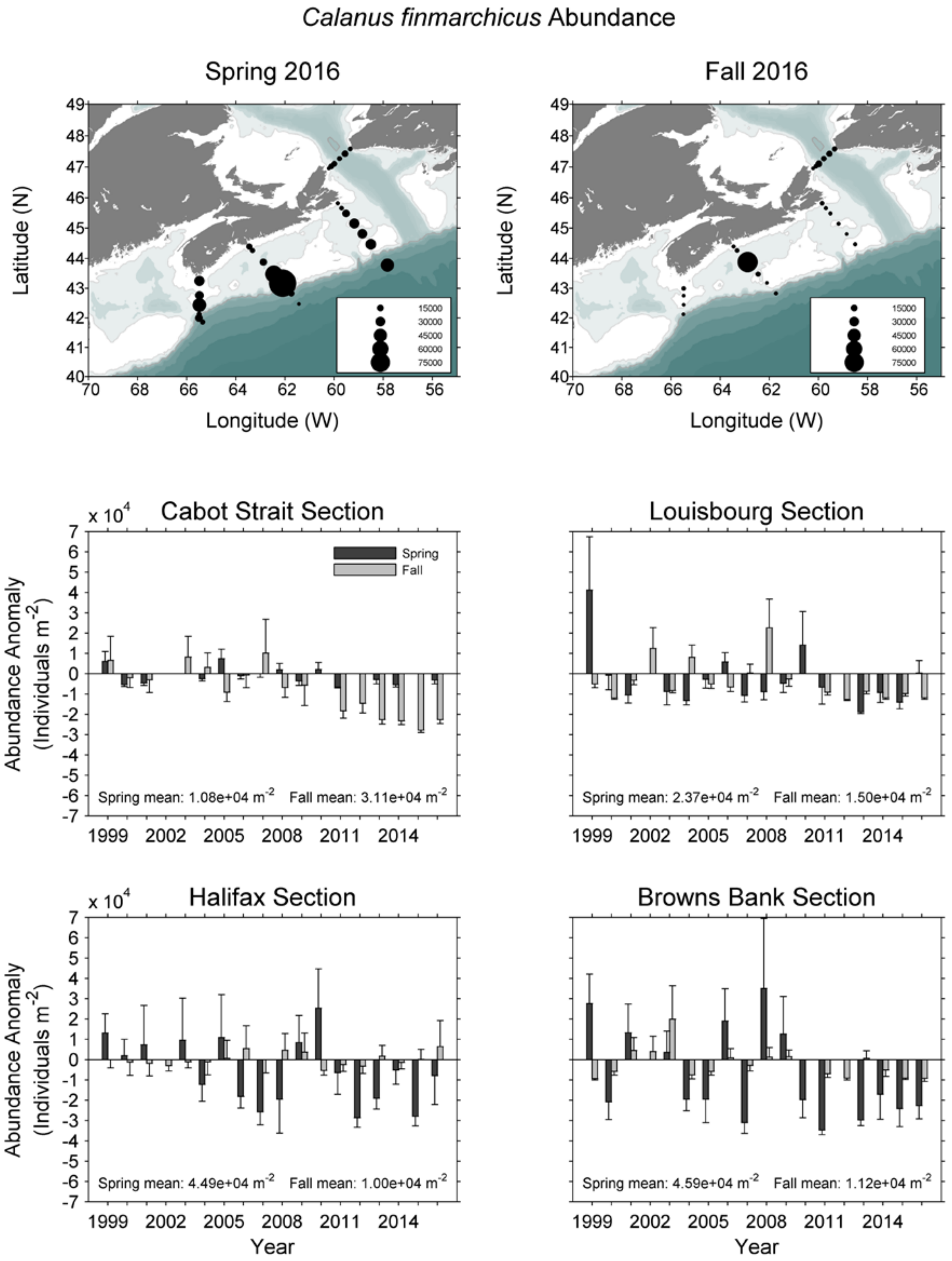


*Figure 28. Spatial distribution of Calanus finmarchicus abundance in 2016 (upper panels) and time series of average C. finmarchicus abundance anomalies on Scotian Shelf sections (middle and lower panels) in spring and fall, 1999-2016. Vertical lines in lower panels represent standard errors.*

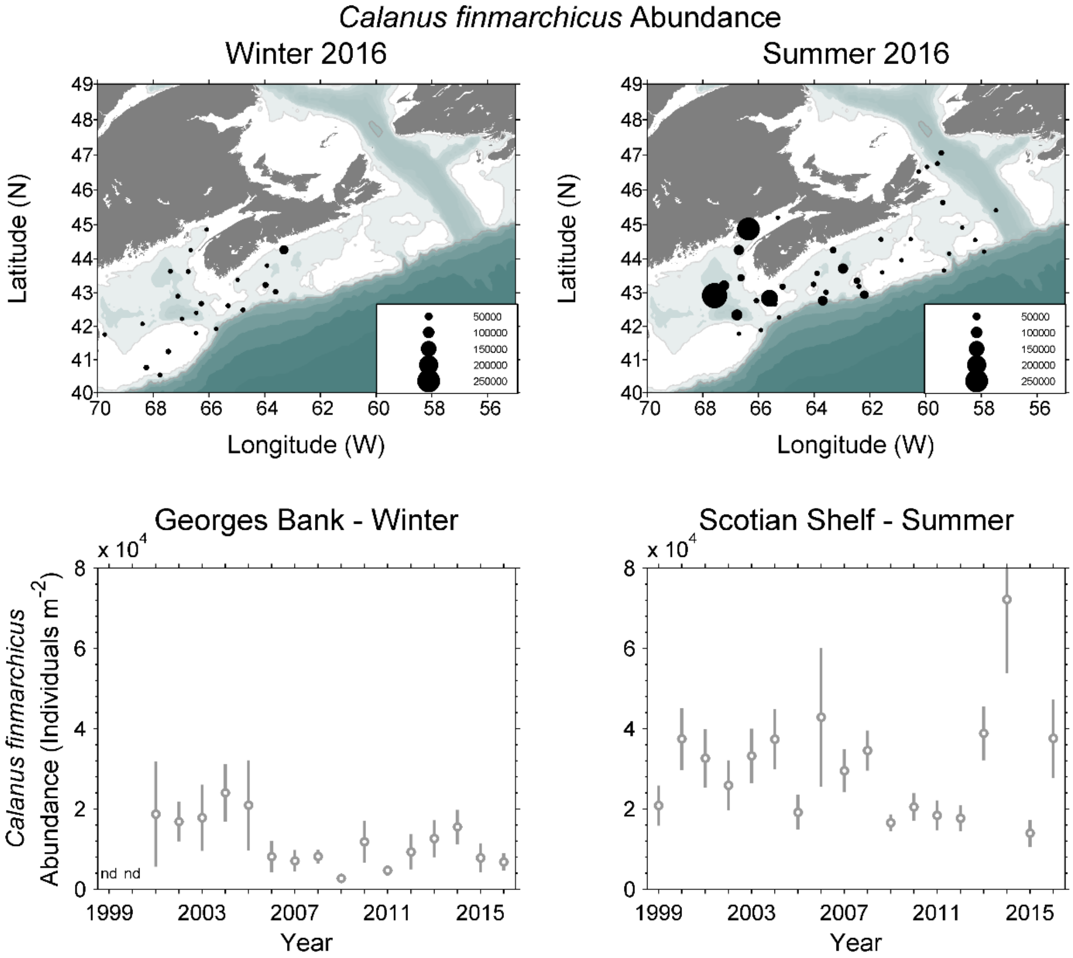
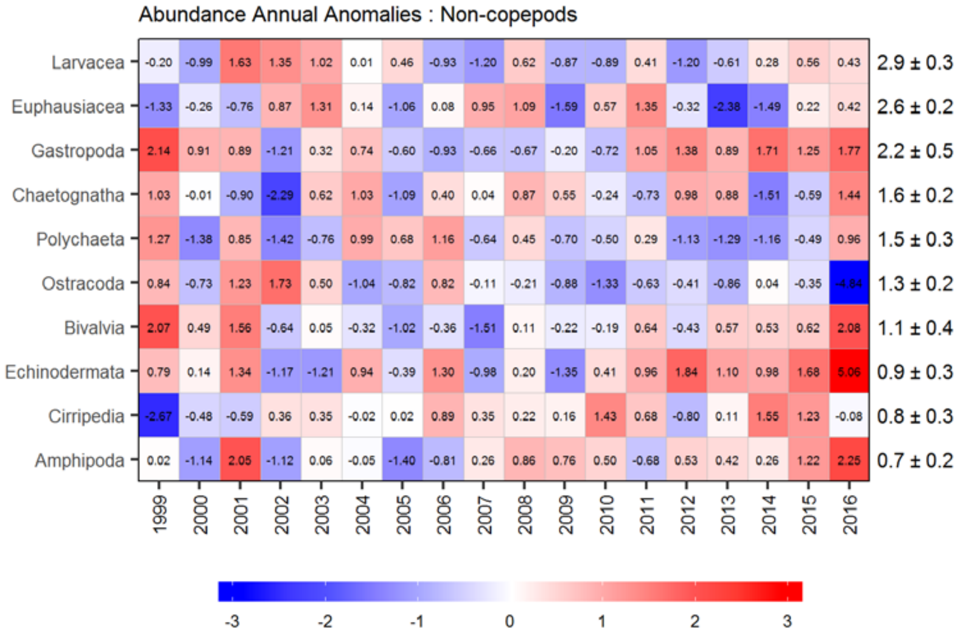
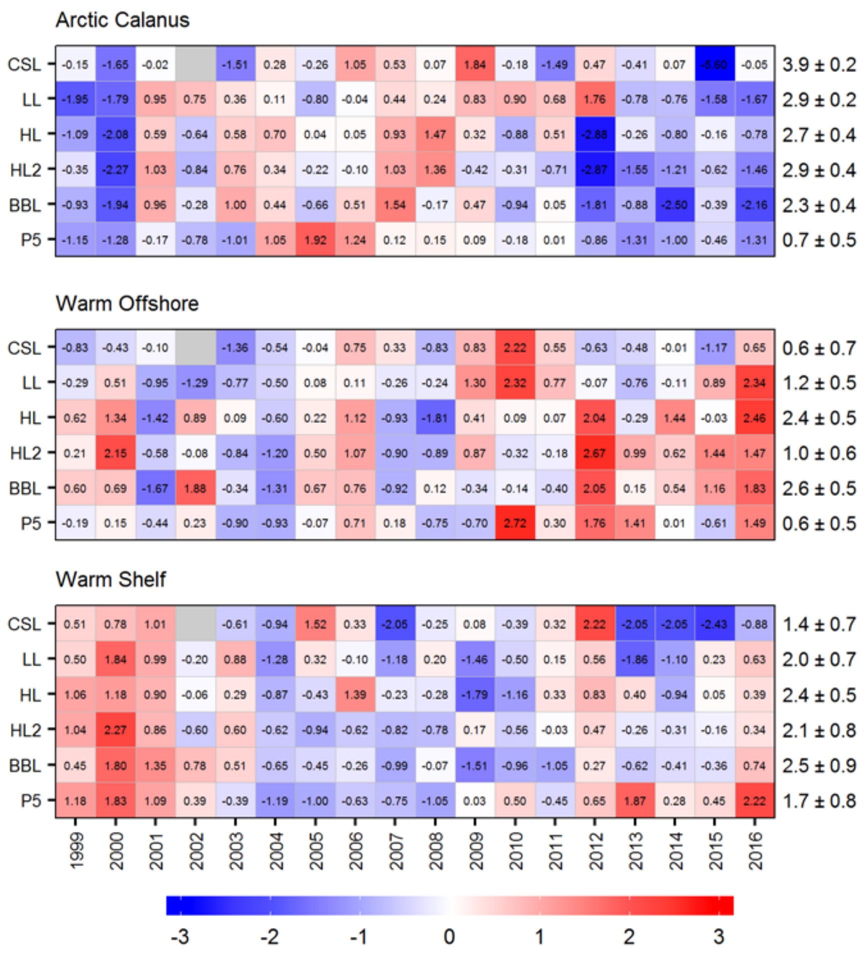


*Figure 29. Calanus finmarchicus abundance from ecosystem trawl surveys on Georges Bank (February), the eastern Scotian Shelf (March) and the Scotian Shelf and eastern Gulf of Maine (summer): upper panels show 2016 spatial distributions, lower panels show survey mean abundance, 1999–2016 (vertical bars 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 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Larvacea | -0.20 | -0.99 | 1.63 | 1.35 | 1.02 | 0.01 | 0.46 | -0.93 | -1.20 | 0.62 | -0.87 | -0.89 | 0.41 | -1.20 | -0.61 | 0.28 | 0.56 | 0.43 | 2.9 ± 0.3 |
| Euphausiacea | -1.33 | -0.26 | -0.76 | 0.87 | 1.31 | 0.14 | -1.06 | 0.08 | 0.95 | 1.09 | -1.59 | 0.57 | 1.35 | -0.32 | -2.38 | -1.49 | 0.22 | 0.42 | 2.6 ± 0.2 |
| Gastropoda | 2.14 | 0.91 | 0.89 | -1.21 | 0.32 | 0.74 | -0.60 | -0.93 | -0.66 | -0.67 | -0.20 | -0.72 | 1.05 | 1.38 | 0.89 | 1.71 | 1.25 | 1.77 | 2.2 ± 0.5 |
| Chaetognatha | 1.03 | -0.01 | -0.90 | -2.29 | 0.62 | 1.03 | -1.09 | 0.40 | 0.04 | 0.87 | 0.55 | -0.24 | -0.73 | 0.98 | 0.88 | -1.51 | -0.59 | 1.44 | 1.6 ± 0.2 |
| Polychaeta | 1.27 | -1.38 | 0.85 | -1.42 | -0.76 | 0.99 | 0.68 | 1.16 | -0.64 | 0.45 | -0.70 | -0.50 | 0.29 | -1.13 | -1.29 | -1.16 | -0.49 | 0.96 | 1.5 ± 0.3 |
| Ostracoda | 0.84 | -0.73 | 1.23 | 1.73 | 0.50 | -1.04 | -0.82 | 0.82 | -0.11 | -0.21 | -0.88 | -1.33 | -0.63 | -0.41 | -0.86 | 0.04 | -0.35 | -4.84 | 1.3 ± 0.2 |
| Bivalvia | 2.07 | 0.49 | 1.56 | -0.64 | 0.05 | -0.32 | -1.02 | -0.36 | -1.51 | 0.11 | -0.22 | -0.19 | 0.64 | -0.43 | 0.57 | 0.53 | 0.62 | 2.08 | 1.1 ± 0.4 |
| Echinodermata | 0.79 | 0.14 | 1.34 | -1.17 | -1.21 | 0.94 | -0.39 | 1.30 | -0.98 | 0.20 | -1.35 | 0.41 | 0.96 | 1.84 | 1.10 | 0.98 | 1.68 | 5.06 | 0.9 ± 0.3 |
| Cirripedia | -2.67 | -0.48 | -0.59 | 0.36 | 0.35 | -0.02 | 0.02 | 0.89 | 0.35 | 0.22 | 0.16 | 1.43 | 0.68 | -0.80 | 0.11 | 1.55 | 1.23 | -0.08 | 0.8 ± 0.3 |
| Amphipoda | 0.02 | -1.14 | 2.05 | -1.12 | 0.06 | -0.05 | -1.40 | -0.81 | 0.26 | 0.86 | 0.76 | 0.50 | -0.68 | 0.53 | 0.42 | 0.26 | 1.22 | 2.25 | 0.7 ± 0.2 |

*Figure 30. Annual anomaly scorecard for non-copepod group abundances on the Scotian Shelf sections, ordered from higher to lower abundance groups. 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 grey cell indicates missing data. Red (blue) cells indicate higher (lower) than normal abundance levels.*



Arctic Calanus

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | -0.15 | -1.65 | -0.02 | | -1.51 | 0.28 | -0.26 | 1.05 | 0.53 | 0.07 | 1.84 | -0.18 | -1.49 | 0.47 | -0.41 | 0.07 | -5.60 | -0.05 | 3.9 ± 0.2 |
| LL | -1.95 | -1.79 | 0.95 | 0.75 | 0.36 | 0.11 | -0.80 | -0.04 | 0.44 | 0.24 | 0.83 | 0.90 | 0.68 | 1.76 | -0.78 | -0.76 | -1.58 | -1.67 | 2.9 ± 0.2 |
| HL | -1.09 | -2.08 | 0.59 | -0.64 | 0.58 | 0.70 | 0.04 | 0.05 | 0.93 | 1.47 | 0.32 | -0.88 | 0.51 | -2.88 | -0.26 | -0.80 | -0.16 | -0.78 | 2.7 ± 0.4 |
| HL2 | -0.35 | -2.27 | 1.03 | -0.84 | 0.76 | 0.34 | -0.22 | -0.10 | 1.03 | 1.36 | -0.42 | -0.31 | -0.71 | -2.87 | -1.55 | -1.21 | -0.62 | -1.46 | 2.9 ± 0.4 |
| BBL | -0.93 | -1.94 | 0.96 | -0.28 | 1.00 | 0.44 | -0.66 | 0.51 | 1.54 | -0.17 | 0.47 | -0.94 | 0.05 | -1.81 | -0.88 | -2.50 | -0.39 | -2.16 | 2.3 ± 0.4 |
| P5 | -1.15 | -1.28 | -0.17 | -0.78 | -1.01 | 1.05 | 1.92 | 1.24 | 0.12 | 0.15 | 0.09 | -0.18 | 0.01 | -0.86 | -1.31 | -1.00 | -0.46 | -1.31 | 0.7 ± 0.5 |

Warm Offshore

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | -0.83 | -0.43 | -0.10 | | -1.36 | -0.54 | -0.04 | 0.75 | 0.33 | -0.83 | 0.83 | 2.22 | 0.55 | -0.63 | -0.48 | -0.01 | -1.17 | 0.65 | 0.6 ± 0.7 |
| LL | -0.29 | 0.51 | -0.95 | -1.29 | -0.77 | -0.50 | 0.08 | 0.11 | -0.26 | -0.24 | 1.30 | 2.32 | 0.77 | -0.07 | -0.76 | -0.11 | 0.89 | 2.34 | 1.2 ± 0.5 |
| HL | 0.62 | 1.34 | -1.42 | 0.89 | 0.09 | -0.60 | 0.22 | 1.12 | -0.93 | -1.81 | 0.41 | 0.09 | 0.07 | 2.04 | -0.29 | 1.44 | -0.03 | 2.46 | 2.4 ± 0.5 |
| HL2 | 0.21 | 2.15 | -0.58 | -0.08 | -0.84 | -1.20 | 0.50 | 1.07 | -0.90 | -0.89 | 0.87 | -0.32 | -0.18 | 2.67 | 0.99 | 0.62 | 1.44 | 1.47 | 1.0 ± 0.6 |
| BBL | 0.60 | 0.69 | -1.67 | 1.88 | -0.34 | -1.31 | 0.67 | 0.76 | -0.92 | 0.12 | -0.34 | -0.14 | -0.40 | 2.05 | 0.15 | 0.54 | 1.16 | 1.83 | 2.6 ± 0.5 |
| P5 | -0.19 | 0.15 | -0.44 | 0.23 | -0.90 | -0.93 | -0.07 | 0.71 | 0.18 | -0.75 | -0.70 | 2.72 | 0.30 | 1.76 | 1.41 | 0.01 | -0.61 | 1.49 | 0.6 ± 0.5 |

Warm Shelf

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSL | 0.51 | 0.78 | 1.01 | | -0.61 | -0.94 | 1.52 | 0.33 | -2.05 | -0.25 | 0.08 | -0.39 | 0.32 | 2.22 | -2.05 | -2.05 | -2.43 | -0.88 | 1.4 ± 0.7 |
| LL | 0.50 | 1.84 | 0.99 | -0.20 | 0.88 | -1.28 | 0.32 | -0.10 | -1.18 | 0.20 | -1.46 | -0.50 | 0.15 | 0.56 | -1.86 | -1.10 | 0.23 | 0.63 | 2.0 ± 0.7 |
| HL | 1.06 | 1.18 | 0.90 | -0.06 | 0.29 | -0.87 | -0.43 | 1.39 | -0.23 | -0.28 | -1.79 | -1.16 | 0.33 | 0.83 | 0.40 | -0.94 | 0.05 | 0.39 | 2.4 ± 0.5 |
| HL2 | 1.04 | 2.27 | 0.86 | -0.60 | 0.60 | -0.62 | -0.94 | -0.62 | -0.82 | -0.78 | 0.17 | -0.56 | -0.03 | 0.47 | -0.26 | -0.31 | -0.16 | 0.34 | 2.1 ± 0.8 |
| BBL | 0.45 | 1.80 | 1.35 | 0.78 | 0.51 | -0.65 | -0.45 | -0.26 | -0.99 | -0.07 | -1.51 | -0.96 | -1.05 | 0.27 | -0.62 | -0.41 | -0.36 | 0.74 | 2.5 ± 0.9 |
| P5 | 1.18 | 1.83 | 1.09 | 0.39 | -0.39 | -1.19 | -1.00 | -0.63 | -0.75 | -1.05 | 0.03 | 0.50 | -0.45 | 0.65 | 1.87 | 0.28 | 0.45 | 2.22 | 1.7 ± 0.8 |

*Figure 31. 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 grey cell indicates missing data. Red (blue) cells indicate higher (lower) than normal abundance levels. CSL: Cabot Strait section; LL: Louisbourg section; HL: Halifax section; HL2: Halifax-2; BBL: Browns Bank section; P5: Prince-5.*

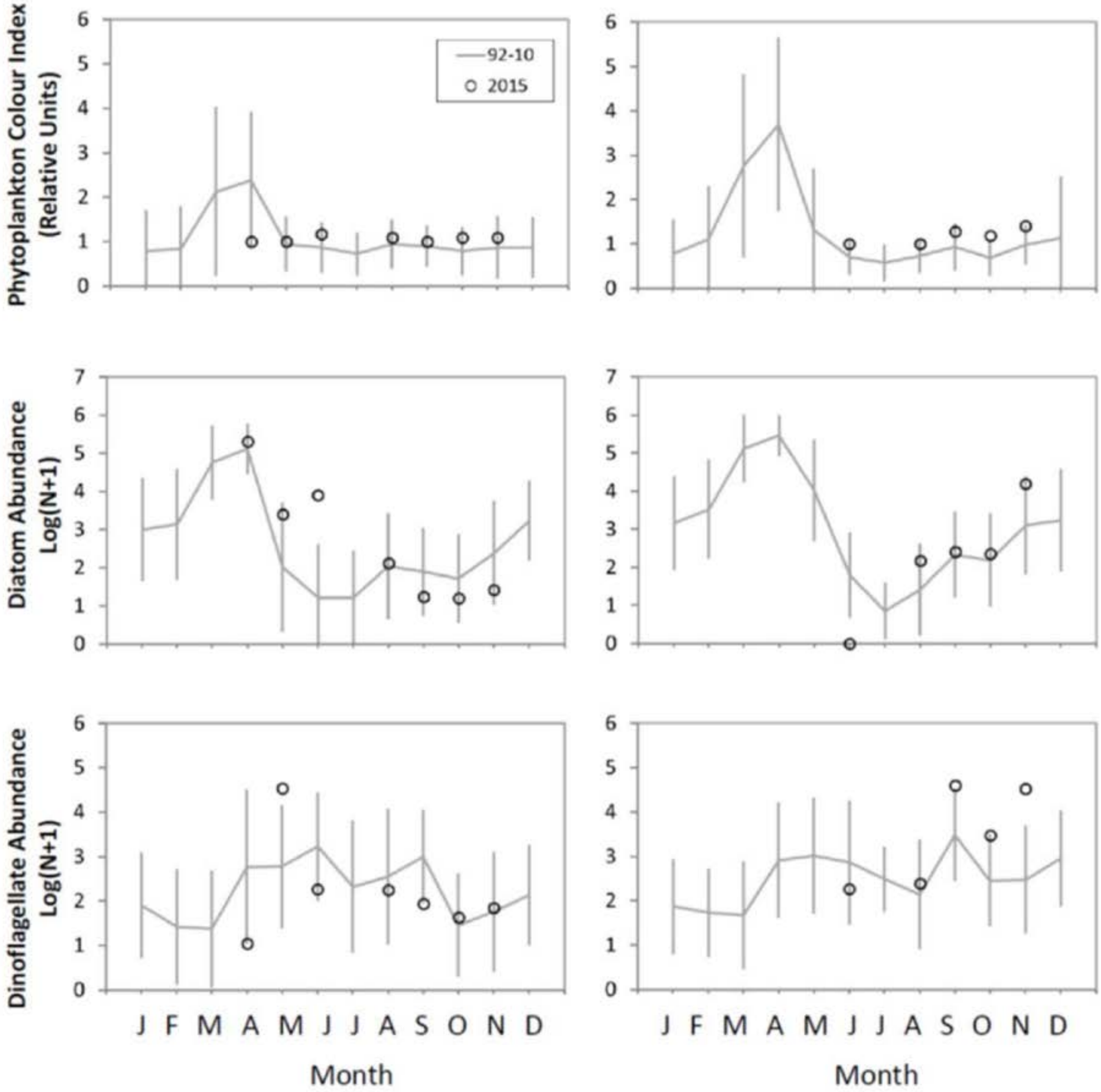
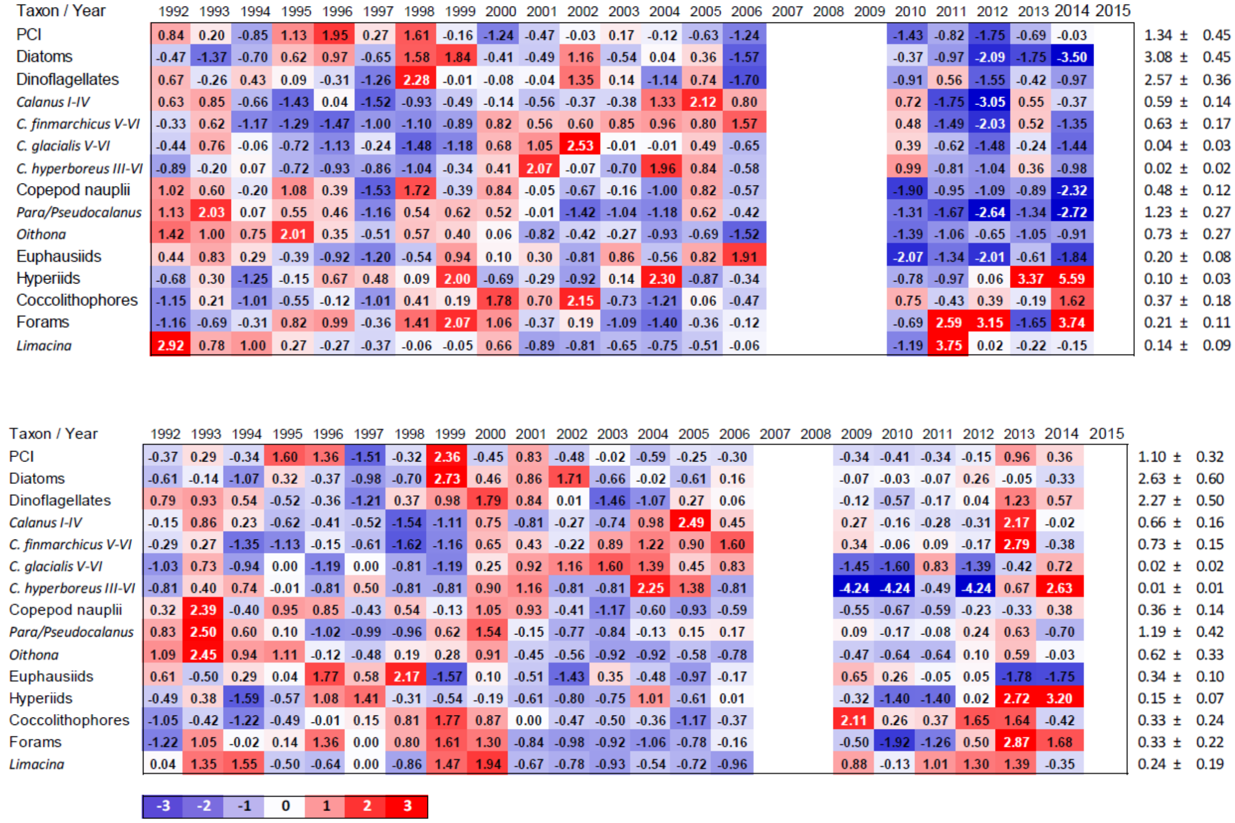


*Figure 32. CPR phytoplankton abundance indices in 2015 and mean conditions, 1992-2010 (solid line) on the western Scotian Shelf (left-hand column) and eastern Scotian Shelf (right-hand column). Vertical lines show the standard deviations of the monthly averages.*



| 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 | 2015 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | | 1.34 ± 0.45 |
| 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 | | 3.08 ± 0.45 |
| 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 | | 2.57 ± 0.36 |
| *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 | | 0.59 ± 0.14 |
| *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 | | 0.63 ± 0.17 |
| *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 | | 0.04 ± 0.03 |
| *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 | | 0.02 ± 0.02 |
| 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 | | 0.48 ± 0.12 |
| *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 | | 1.23 ± 0.27 |
| *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 | | 0.73 ± 0.27 |
| 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 | | 0.20 ± 0.08 |
| 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 | | 0.10 ± 0.03 |
| 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 | | 0.37 ± 0.18 |
| 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 | | 0.21 ± 0.11 |
| *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 | | 0.14 ± 0.09 |

| 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 | 2015 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | | 1.10 ± 0.32 |
| 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 | | 2.63 ± 0.60 |
| 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 | | 2.27 ± 0.50 |
| *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 | | 0.66 ± 0.16 |
| *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 | | 0.73 ± 0.15 |
| *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 | | 0.02 ± 0.02 |
| *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 | | 0.01 ± 0.01 |
| 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 | | 0.36 ± 0.14 |
| *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 | | 1.19 ± 0.42 |
| *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 | | 0.62 ± 0.33 |
| 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 | | 0.34 ± 0.10 |
| 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 | | 0.15 ± 0.07 |
| 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 | | 0.33 ± 0.24 |
| 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 | | 0.33 ± 0.22 |
| *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 | | 0.24 ± 0.19 |

*Figure 33. 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.*

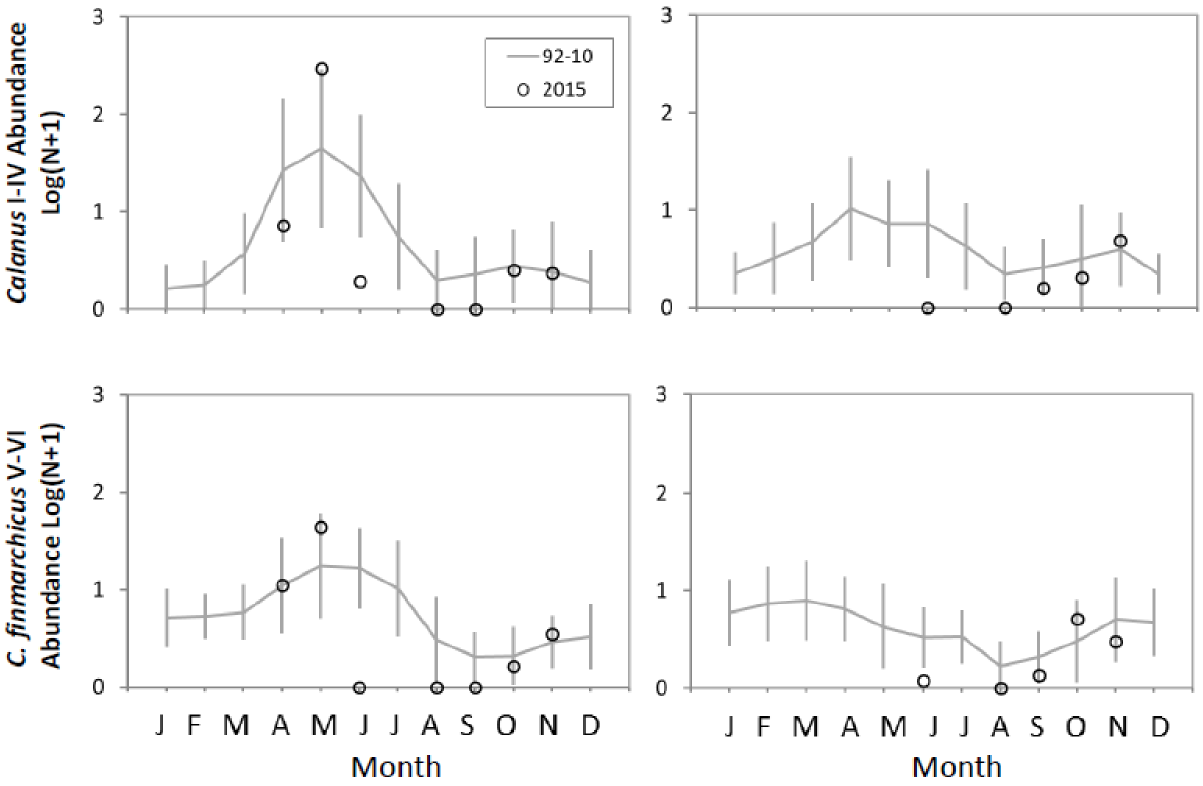


*Figure 34. CPR abundance indices for Calanus I-IV (mostly C. finmarchicus, upper row) and C. finmarchicus V-VI (lower row) in 2015 and mean conditions, 1992-2010 (solid line) on the western Scotian Shelf (left-hand column) and eastern Scotian Shelf (right-hand column). Vertical lines represent standard deviations of the monthly averages.*