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Maritimes Region

Optical, chemical, and biological oceanographic conditions on the Scotian Shelf and in the eastern Gulf of Maine in 2012

C. Johnson, G. Harrison, B. Casault, J. Spry, W. Li, and E. Head

Fisheries and Oceans Canada
Bedford Institute of Oceanography
PO Box 1006, 1 Challenger Drive
Dartmouth, Nova Scotia B2Y 4A2

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Foreword

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

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

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ABSTRACT

In 2012, anomalously warm ocean temperatures throughout the water column on the Scotian Shelf and eastern Gulf of Maine influenced the chemical and biological conditions of the region. Stratification was higher than average on the Scotian Shelf. At the Halifax-2 fixed station, upper water column (0-50 m) nitrate was lower than normal throughout 2012, while deep water (50-150 m) nitrate concentrations were much higher than normal, suggesting that stratification may have inhibited nutrient mixing into the upper water column. Deep water nitrate concentrations were also higher than average throughout most of the region. Spring bloom initiation timing at Halifax-2 was about average, and the bloom was average in magnitude but short in duration, but winter chlorophyll concentrations were higher than average. Satellite ocean color observations also indicated high winter chlorophyll concentrations and early and/or short spring bloom timing across much of the Scotian Shelf. Although chlorophyll concentrations were about average following the spring bloom at Halifax-2, light attenuation was high, cell abundances were low, and diatoms and dinoflagellates were less relatively abundant and flagellates and ciliates more relatively abundant than normal, suggesting a shift to a smaller-sized phytoplankton community, possibly including higher than average concentrations of picoplankton. At the Prince-5 fixed station, the seasonal chlorophyll cycle was similar to normal, but chlorophyll values were higher than average in July and August, when chain forming diatoms (July) and dinoflagellates (August) were abundant. Satellite ocean colour indicated higher than average surface chlorophyll across the eastern Gulf of Maine in August and September.

Zooplankton biomass was very low at Halifax-2 throughout 2012, and it was also low on all shelf sections in fall. At Prince-5, zooplankton biomass was mostly low in the first half of the year but rebounded in the fall. At both fixed stations, *Calanus finmarchicus* abundances were low everywhere throughout 2012. *C. finmarchicus* production was likely impacted by its low abundance at the end of 2011 and high temperatures experienced by the dormant stock during the fall and winter of 2011/2012. At Halifax-2, a short phytoplankton bloom and low diatom abundance may have also contributed to low abundances of *C. finmarchicus* and *Pseudocalanus* spp. during 2012. Transient high abundances of small-particle-feeding zooplankton taxa (appendicularians, salps, pteropods) were observed both on the Scotian Shelf and at Prince-5. Cold-associated immigrant species (Arctic *Calanus*) were less abundant and warm offshore species generally more abundant than average in 2012, consistent with warmer temperatures and model estimates of changes in circulation. Overall, lower trophic level changes in 2012 suggest poor feeding conditions for planktivores on the Scotian Shelf, but the late summer-early fall bloom in the eastern Gulf of Maine and Bay of Fundy may have been favorable for some higher trophic level species.

Conditions océanographiques optiques, chimiques et biologiques sur le plateau néo-écossais et dans l'est du golfe du Maine en 2012

RÉSUMÉ

Les températures anormalement chaudes sur toute la colonne d'eau observées en 2012 sur le plateau néo-écossais et dans l'est du golfe du Maine ont influencé les conditions chimiques et biologiques de la région. La stratification était plus élevée que la moyenne sur le plateau néo-écossais. À la station fixe Halifax-2, les concentrations de nitrate de surface (0 à 50 m) étaient inférieures à la normale tout au long de 2012, tandis que les concentrations de nitrate en profondeur (50 à 150 m) étaient beaucoup plus élevées que la normale, suggérant que la stratification pourrait avoir inhibé le mélange de nitrate vers la surface. Les concentrations de nitrate en profondeur étaient également plus élevées que la moyenne dans la majorité de la région. Le début de la période de floraison printanière à la station Halifax-2 correspondait à peu près à la moyenne, et la floraison avait une amplitude moyenne, mais une durée courte. Toutefois, les concentrations hivernales de chlorophylle étaient plus élevées que la moyenne. Les observations satellites de la couleur de l'océan indiquaient également des concentrations hivernales élevées de chlorophylle et une période de floraison printanière tôt ou courte dans une grande partie du plateau néo-écossais. Bien que les concentrations de chlorophylle se situaient dans la moyenne après la floraison printanière à la station Halifax-2, l'atténuation de la lumière était élevée, l'abondance de cellules étaient faibles, et les diatomées et les dinoflagellés étaient relativement moins abondants et les flagellés et les ciliés étaient relativement plus abondants que la normale, suggérant une transition vers une communauté de petit phytoplancton, incluant possiblement des concentrations de picoplancton plus élevées que la moyenne. À la station fixe Prince-5, le cycle saisonnier de la chlorophylle était semblable à la normale, mais les valeurs de chlorophylle étaient plus élevées que la moyenne en juillet et août lorsque les diatomées (juillet) et les dinoflagellés (août) étaient abondants. Les données satellites sur la couleur de l'océan indiquaient la présence plus marquée que la moyenne de la chlorophylle à la surface dans l'est du golfe du Maine en août et septembre.

À la station Halifax-2, la biomasse du zooplancton était très faible tout au long de l'année 2012, et elle était également faible dans toutes les sections du plateau à l'automne. À la station Prince-5, la biomasse du zooplancton était surtout faible dans la première moitié de l'année, mais elle avait rebondi à l'automne. Aux deux stations fixes, l'abondance du *Calanus finmarchicus* était faible partout au cours de l'année 2012. La production de *C. finmarchicus* était vraisemblablement affectée par sa faible abondance à la fin de l'année 2011 et par l'effet des températures élevées sur la population dormante durant l'automne et l'hiver de 2011-2012. À la station Halifax-2, une courte période de floraison du phytoplancton et une faible abondance des diatomées pourraient également avoir contribué aux faibles abondances de *C. finmarchicus* et de *Pseudocalanus* spp. au cours de 2012. Des concentrations temporaires élevées de zooplancton se nourrissant de petites particules (appendiculaires, salpes, ptéropodes) ont été observées sur le plateau néo-écossais et à la station Prince-5. Les espèces immigrantes froides (*Calanus* arctique) étaient moins abondantes et les espèces extra-côtières chaudes étaient plus abondantes que la moyenne en 2012, ce qui correspond aux températures plus chaudes et aux estimations modélisées du changement dans la circulation. Dans l'ensemble, les changements aux niveaux trophiques inférieurs en 2012 suggèrent de mauvaises conditions alimentaires pour la communauté planctivore sur le plateau néo-écossais, mais la prolifération tard dans l'été et au début de l'automne dans l'est du golfe du Maine et la baie de Fundy aurait pu être favorable pour certaines espèces de niveau trophique plus élevé.

INTRODUCTION

The Atlantic Zone Monitoring Program (AZMP) was implemented in 1998 (Therriault et al. 1998) with the aim of increasing Fisheries and Oceans Canada's (DFO's) capacity to understand, describe, and forecast the state of the marine ecosystem, and quantifying the changes in ocean physical, chemical, and biological properties. A critical element in the observational program of AZMP is an annual assessment of the distribution and variability of nutrients and the plankton they support.

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

A description of the distribution in time and space of nutrients (nitrate, silicate, phosphate) and oxygen dissolved in seawater provides important information on the water-mass movements and on the locations, timing, and magnitude of biological production cycles. A description of the distribution of phytoplankton and zooplankton provides important information on the organisms forming the base of the marine foodweb. Understanding the production cycles of plankton is an essential part of an ecosystem approach to fisheries management.

Herein, the optical, chemical, and biological oceanographic (lower trophic levels) conditions observed in 2012 in the Maritimes Region, including the Georges Bank/Gulf of Maine/Bay of Fundy system and the Scotian Shelf are reviewed. Water temperatures in the Maritimes Region have been above normal since 2009 and were well above normal in 2012 (Hebert et al. 2013). Water temperatures were also at record or near-record highs in the other AZMP regions (DFO 2013). In the context of record warm conditions in 2012, this report focused on evaluating changes in phytoplankton and zooplankton annual production cycles and community composition.

METHODS

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

SAMPLE COLLECTION

Maritimes/Gulf AZMP sea-going staff participated in four missions (seasonal section cruises and ecosystem trawl surveys) during the 2012 calendar year, in addition to repeat day-trips to the three fixed stations. In 2012, a total of 587 station occupations were performed by Maritimes Region (Table 1).

Fixed Stations

The aim of the AZMP program is to sample Maritimes and Gulf regions' three fixed stations, Shediac Valley, Halifax-2, and Prince-5 (Figure 1), on a minimum monthly basis with attempted semi-monthly sampling throughout the year at Halifax-2 and during the spring bloom period at Shediac. The responsibility for sampling the Shediac Valley station is shared between the Maritimes and Québec regions, and variability patterns at Shediac Valley are reported by the

Québec Region. As always, the availability of sampling platforms and, to some extent, difficulties with weather and ice, make achieving this sampling frequency a challenge. In 2012, Halifax-2, Prince-5, and Shediac were sampled on 20, 12, and 12 occasions, respectively (Table 1). The Halifax-2 fixed station occupations were close to the best frequency achieved since the start of the time series. The frequency of Shediac fixed station occupation, which is affected by an ice-truncated open-water season and platform availability, was somewhat better than recent years.

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

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

Shelf Sections

Four primary sections (Browns Bank, Halifax, Louisbourg, Cabot Strait sections; Figure 1), and a number of additional sections/stations (Figure 2) are normally sampled in spring (April/May) and fall (October/November). There is often an additional occupation of the Halifax section in the May-July period as part of the Labrador Sea sampling mission. In 2012, the spring mission was not possible as the Canadian Coast Guard Ship (CCGS) *Hudson* was out of service. The four core sections and other stations were successfully sampled on the fall mission (Table 1). There was no opportunity to sample the Halifax section in May/June 2012 on the Labrador Sea mission due to insufficient time, but it was occupied during the spring ecosystem trawl survey on March 16-18, 2012.

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

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

Ecosystem Trawl Surveys

There are four primary ecosystem trawl surveys in which AZMP-Maritimes/Gulf participates: the late winter (February) Georges Bank survey, the spring (March) western Scotian Shelf (WSS) survey, the summer (July) Scotian Shelf/eastern Gulf of Maine survey, and the fall (September) southern Gulf of St. Lawrence survey (Figure 3). These surveys were carried out in 2012 by DFO's Population Ecology Division with AZMP participation. Sampling was seriously curtailed on the March 2012 survey for the WSS (4X Northwest Atlantic Fisheries Organization area) by vessel problems with CCGS *Needler*, including the loss of one of the three survey legs in February/March. The southern Gulf survey was reduced somewhat by a later than normal start for the survey.

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

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

Bottom nitrate concentrations were interpolated on a three minute latitude-longitude grid using optimal estimation (Petrie et al. 1996) to generate maps of bottom nitrate distribution within the ecosystem trawl survey strata. The interpolation method uses the three nearest neighbours, with a horizontal length scale of 30 km and a vertical length scale of 15 m in the upper 50 m, 25 m between 50 and 500 m, and 50 m at depths below 500 m. Data near the interpolation grid point were weighted proportionately more than those farther away.

A reanalysis of ecosystem trawl survey bottom oxygen saturation levels, reflecting corrections to some past values, is underway but was not complete in time for inclusion in this year's (2012) report.

DEPLOYMENT

Conductivity, Temperature, Depth (CTD)

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

Standard depths for water samples include:

- Fixed-stations:
    1. Halifax-2: 1, 5, 10, 20, 30, 40, 50, 75, 100, 140 m,
    2. Shediac: 1, 5, 10, 20, 30, 40, 50, 60, 70, 80 m, and
    3. Prince-5: 1, 10, 25, 50, 95 m.
- Seasonal sections: near-surface, 10, 20, 30, 40, 50, 60, 80, 100, 250, 500, 1000, 1500, 2000 m, near-bottom (depths sampled are limited by bottom depth).
- Ecosystem trawl surveys: 5, 25, 50 m, and near bottom when possible.

Net Tows

Ring nets of a standard 202 µm mesh are towed vertically from near bottom to surface at approximately 1 m/sec. In deep offshore waters, maximum tow depth is 1000 m. The net is hosed carefully, and the sample is collected from the cod-end and preserved in buffered formalin. Enumeration of recovered net sample provides zooplankton abundance and wet weight of large (>1 cm) and small (<1 cm) fractions.

Secchi Depth

The Secchi disc is lowered slowly and the depth where it can no longer be visually detected is recorded, thereby giving a light extinction estimate.

MIXED-LAYER AND STRATIFICATION INDICES

Two simple indices of the vertical physical structure of the water-column were computed for comparison with optical properties:

1. The mixed-layer depth was determined from observations of the minimum depth where the density gradient ($\text{gradient}_z(\sigma_t)$) was equal to or exceeded 0.01 kg m^{-4}.
2. The stratification index ($\text{Strat}_{\text{Ind}}$) was calculated as:

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

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

OPTICAL PROPERTIES

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

1. The downward vertical attenuation coefficient for PAR ($K_{d\text{-}PAR}$) was estimated from the linear regression of $\ln(E_d(z))$ versus depth z (where $E_d(z)$ is the value of downward irradiance at z m) in the depth interval from minimum depth to 50 m (minimum depth is typically around 2 m and is always less than 6 m).
2. The value of the light attenuation coefficient K_d from Secchi disc observations was found using:

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

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

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

VERTICALLY INTEGRATED VARIABLES

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

SATELLITE REMOTE-SENSING OF OCEAN COLOUR

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

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[1] While the SeaWIFS mission ended in December 2010, information about SeaWIFS is archived at the NASA Ocean Color Biology Group website (accessed 1 September 2013).

[2] Additional information about the MODIS sensor can be found on the NASA MODIS website: (accessed 1 September 2013).

SCORECARD

Scorecards of key indices, based on normalized, seasonally adjusted annual anomalies, represent physical, chemical, and biological observations in a compact format. A standard set of indices representing anomalies of nutrient availability, phytoplankton biomass and bloom dynamics, and the abundance of dominant copepod species and groups (*Calanus finmarchicus, Pseudocalanus* spp., total copepods, and total non-copepods) are produced in each of the AZMP regions, including the Maritimes. In addition to the scorecard presented here, a zonal scorecard was prepared for the first time this year (DFO 2013).

In 2012, the scorecard assemblage was compromised by cancelation of the spring survey. Annual section anomalies were generated only for the Halifax section, using the earlier-than-normal section occupation in spring, but anomalies based on the fall mission were presented for the other sections. Nutrient and chlorophyll scorecard values were recalculated for this report using corrected data for all years, resulting in changes in some past values compared to the scorecard presented in 2012 (Johnson et al. 2012), and zooplankton biomass was added to the scorecard.

DATA PRODUCTS

Data products presented in figures 6, 7, 9, 10, and 13–15, and 17–24 are available at the AZMP website. From this link, follow the “Research Document Data” link under the “Data and Products Heading”. To access the compressed files containing the data, click on the “Scotian Shelf and Eastern Gulf of Maine” link and then click on the document citation to reveal a drop down menu containing data downloads. Each compressed file contains a text file with the data required to reproduce the figure, a meta-data text file describing the terms of use and field heading descriptions, and a PDF file of the figure. Chlorophyll bi-weekly estimates and climatologies presented in figures 10 and 16 are available at the FTP websites: ftp://ftp1.dfo-mpo.gc.ca/bodata/bo/hmm/seawifs/GAC-NA/stats/boxes/ and ftp://ftp1.dfo-mpo.gc.ca/bodata/bo/hmm/modis/stats/boxes.

CONTINUOUS PLANKTON RECORDER (CPR)

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

Continuous Plankton Recorder data up to 2011 were made available in January 2013. In 2011, CPRs were towed during most months of the year, but from June to October the route was through the Strait of Belle Isle and into the Gulf of St. Lawrence, rather than across the Newfoundland Shelf to St. John’s (Figure 5). Since this change in route substantially altered the geographical coverage of the CPR survey in 2011, reporting of CPR results will be postponed.

OBSERVATIONS

MIXING AND OPTICAL PROPERTIES

Mixing and optical properties of the upper water column vary by season and location at the Maritimes fixed stations. At Halifax-2 in 2012, mixed layers were shallowest in summer, and stratification was highest in late summer to early fall, similar to long-term average conditions (Figure 6). Mixed layer depths were somewhat deeper than average in the late spring and early summer 2012. The stratification index was higher than the average through most of the winter, spring, and summer, peaking at approximately 0.09 kg m^{-4} in August.

At Prince-5, mixed layer depths are more variable and stratification much lower than at the Halifax-2 station due to strong tidal mixing. The stratification index normally remains below 0.01 kg m^{-4} for most of the year, and mixed layer depth varies from full depth (90 m) in winter to approximately 40 m in summer. In 2012, mixed layer depths were variable at Prince-5, especially in the summer (Figure 6). Full-depth mixing persisted longer than usual in the spring, and returned in October.

The maximum light attenuation and shallowest euphotic zone depths normally coincide with the spring phytoplankton bloom, and euphotic depths are generally deepest after the decline of the bloom and in winter months. This general pattern was observed at Halifax-2 in 2012 (Figure 7). Euphotic depths derived from measurements of PAR were relatively sparse in the spring and early fall at Halifax-2, due to night-time sampling of the station, but overall, euphotic depths were shallower than average. In contrast to PAR-based euphotic depth, Secchi-based euphotic depths were not generally shallower than average at Halifax-2. The Secchi-based euphotic depth was shallowest in late March, when the bloom was under way, and deepest in April after the bloom ended.

At Prince-5, photic depths are relatively constant year round, since the primary attenuator is non-living suspended matter due to tidal action and river input. In 2012, PAR-based and Secchi-based euphotic depths were shallower than usual in the winter and fall and deeper than usual in the late summer (Figure 7).

NUTRIENTS

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

Fixed Stations

Both fixed stations exhibit a spring/early-summer biologically-mediated reduction in near-surface nitrate concentrations, and low surface values persist through the summer and early fall, increasing again during the fall and winter months due to wind-driven surface mixing (Figure 8).

At Halifax-2, the 2012 onset of spring nutrient draw down was earlier than usual (figures 8, 9), and the zone of nitrate depletion (defined as depths where concentrations $\leq$1 mmol m^{-3}) in summer 2012 was unusually deep, approaching 50 m, similar to conditions in summer 2011 (Figure 8). Shallow (<50 m) nitrate inventories at Halifax-2 were much lower than normal in winter 2012, and shallow inventories continued below normal for most of 2012 (Figure 9). In contrast, 2012 deep (>50 m) winter nitrate inventories were higher than average, and higher than average deep water nitrate inventories persisted throughout 2012.

The onset timing of nitrate draw-down at Prince-5 was similar to the climatological timing, as was the extent of nitrate depletion (figures 8, 9). Shallow and deep inventories at Prince-5 are generally similar because it is so well mixed. Winter inventories in 2012 were slightly higher than normal for both shallow and deep water, and summer values were close to climatological means.

Shelf Sections

Since there was no spring sampling along standard sections in 2012, observations reported here are mainly from the fall. Surface nitrate anomalies were mixed on the sections during the fall survey in September-October; they were positive on the Halifax section, negative on the Browns Bank section, and close to zero on the two eastern sections (Figure 10). The deep (50-150 m) nitrate inventories were positive on the Cabot Strait and Browns Bank sections and close to zero on the Halifax and Louisbourg sections (Figure 10). Nitrate anomalies were similar in spring and fall on the Halifax section, both for surface and deep water (not shown).

Ecosystem Trawl Survey

Bottom nitrate concentrations are related to bottom water depth on the Scotian Shelf, and the highest levels were observed in the deep basins and slope water in 2012, as in past years (Figure 11). Bottom water nitrate concentrations in July 2012 were higher than the 1999-2010 climatological average across most of the Scotian Shelf, especially on the eastern Scotian Shelf (ESS) (Figure 11).

PHYTOPLANKTON

Fixed Stations

The spring bloom at Halifax-2 in 2012 was short and had an early peak of near-average magnitude (figures 12 and 13; 396 mg Chl m^{-2} in 2012, compared to 451 mg Chl m^{-2} average). Integrated chlorophyll levels were higher than normal in winter 2012 (Figure 13), and thus spring bloom initiation appears very early if based on the usual threshold criterion (>40 mg Chl m^{-2}) for this station, but close to average if bloom initiation timing is calculated as the first date at which chlorophyll has started to increase rapidly (figures 13 and 14). Values based on the latter method were reported here. Integrated chlorophyll was close to average for most of the post-bloom period from May to November (Figure 13).

The evolution of the phytoplankton community composition at Halifax-2 in 2012 was broadly similar to that seen previously, i.e., diatoms dominated in the winter/spring, with >75% of the total count, while flagellates and dinoflagellates dominated (>60% of the total count) the rest of the year, but flagellates and ciliates had a greater relative abundance than usual following the spring bloom (Figure 15). Total microplankton abundance was low outside of the spring bloom period in 2012, and the average concentrations of diatoms, dinoflagellates, and flagellates were about 26–30% of their average values overall.

The phytoplankton growth cycle at Prince-5, in contrast to Halifax-2, is usually characterized by an initial burst of growth in early summer (June) with secondary peaks in late summer or fall (August-September). Once initiated, growth at Prince-5 continues at varying levels until the early fall. In 2012, bloom initiation timing appeared to be near-average (Figure 13), with the caveat that monthly sampling frequency at Prince-5 has very low power to detect bloom timing. The bloom peak magnitude in May (272 mg Chl m^{-2}) was lower than usual (389 mg Chl m^{-2}) (Figure 13). Chlorophyll inventories were higher than average in July and August due to high abundance of large species: diatoms in July (*Pseudo-nitzschia pungens*, *P. delicatissima*, and *P. pseudodelicatissima*) and dinoflagellates in August (*Gonyaulax spinifera*) (Figure 15). Annual average chlorophyll was higher than average at Prince-5 in 2012.

The phytoplankton community at Prince-5 is usually composed almost exclusively of diatoms (>95%) throughout the year (Figure 15). In 2012, diatoms were about half as abundant as the average. Dinoflagellate abundances were almost double the average, and they had an unusually high relative abundance in August. Flagellate abundances were near the long-term average.

Broad-scale Surveys and Satellite Remote Sensing

As noted above, there was no spring survey in 2012, so observations of broad-scale chlorophyll pattern were limited to the summer groundfish survey, fall survey, and satellite remote sensing. Average surface chlorophyll levels during the summer Scotian Shelf survey were lower than normal (0.59 mg Chl m^{-3}, compared to 0.68 mg Chl m^{-3}). In the fall surveys, chlorophyll inventories were similar to the long-term average on the Cabot Strait section, lower than average on the Louisbourg and Halifax sections, and higher than average on the Browns Bank section (Figure 10).

Satellite surface chlorophyll estimates in the central Scotian Shelf (CSS) statistical sub-region (Figure 4) show similar seasonal variability as at Halifax-2, notably elevated winter chlorophyll concentration, slightly early spring bloom peak and short bloom, and chlorophyll concentrations similar to the average after the bloom (Figure 16). Early, short spring bloom peaks were also observed in the Cabot Strait, ESS, and WSS satellite statistical sub-regions. Spring bloom chlorophyll peak magnitudes were variable across the region in 2012, and were highest on the ESS and lowest on the WSS. Chlorophyll concentrations tended to be lower than average in the fall on the Scotian Shelf and Georges Bank, but chlorophyll was markedly higher than average in August and September in the Lurcher Shoal sub-region (Figure 16), and chlorophyll anomalies were high over the eastern and central Gulf of Maine at the end of August and beginning of September (not shown).

ZOOPLANKTON

Fixed Stations

At Halifax-2, zooplankton biomass was lower than normal throughout most of 2012, except for short episodes of normal or higher-than-normal biomass in February, October, and December (Figure 17). During these episodes, small-particle feeding non-copepod taxa (pelagic gastropods in February and December, represented by “Others” in Figure 18, and salps in October, represented by “Cnidaria + Appendicularia”) were more abundant than usual. Although total zooplankton abundance was lower than normal during most of 2012, especially in the late spring and early summer, the community at Halifax-2 was still dominated by copepods, even at the times when non-copepods contributed strongly to zooplankton biomass (Figure 18). The abundance of the large, biomass-dominant copepod *C. finmarchicus* was unusually low throughout 2012 at Halifax-2, particularly in late spring and summer (Figure 19). While spring blooms of zooplankton and *Calanus finmarchicus* were weak at Halifax-2, the timing of their initiation was similar to normal (figures 17 and 19).

A similar set of dominant and sub-dominant copepod species were observed at Halifax-2 as in past years, but the relative abundances of the spring-summer shelf copepod *Pseudocalanus* spp. and cold water *Calanus hyperboreus* were low, while relative abundances of the deep-water species *Oithona atlantica* and *Microcalanus* spp. were high (Figure 20a). In the fall, the relative abundance of the normally abundance-dominant small copepod *Oithona similis* was low, and relative abundances of warm water, summer-associated species *Paracalanus* spp. and *Centropages* spp. were high (Figure 20a). Unidentified copepod nauplii and copepodites were also more abundant than usual (included in “Others” in Figure 20a). Arctic *Calanus* were less abundant, and warm offshore copepods were more abundant in 2012 than in 1999-2010 (Figure 21).

At Prince-5, zooplankton biomass was lower than normal during much of the winter and spring, except during a bloom of appendicularians in May (figures 17 and 19). Zooplankton biomass could not be measured during the summer months, due to interference from copious sticky phytoplankton in the net samples. In the fall, zooplankton biomass was similar to normal (Figure 17). The Prince-5 zooplankton community was dominated by copepods in 2012, as in past years, but in addition to the appendicularian bloom in April, there were also strong pulses of barnacle larvae in April and bivalve larvae in June through August (Figure 18). Euphausiids and decapods made up a smaller portion of the community than normal. The abundance of *C. finmarchicus* was lower than normal throughout 2012 (Figure 17). In addition, the relative abundances of *Pseudocalanus* spp. and the nearshore copepod *Acartia* spp. were lower than normal, while *Paracalanus* spp. was higher than normal in the late summer and fall (Figure 20b). Arctic *Calanus* species were less abundant than normal, while warm offshore copepods were more abundant, but their deviations from the mean were weak (Figure 21).

Shelf Sections

Zooplankton biomass was lower than normal on the Halifax section in spring (Figure 22a), but the earlier than normal timing of sampling may have influenced the observed values. In the fall, zooplankton biomass was low on the Browns Bank section, but near normal on the Cabot Straight and Louisbourg sections. Zooplankton biomass could not be measured at most Halifax section stations in fall 2012 due to very high abundance and biomass of salps, *Thalia democratica,* at HL-2, 3, 4, and 5.

The abundance of *C. finmarchicus* in spring 2012 was the lowest observed in the AZMP years in spring (Figure 22b). While sampling was earlier than usual, the presence of early copepodite stages of *C. finmarchicus* indicated that the *C. finmarchicus* population had emerged from dormancy and was growing. The abundance of *C. finmarchicus* was low on all four sections in the fall of 2012. Similar to the fixed stations, annual abundance anomalies were negative for Arctic *Calanus* and positive for warm offshore copepods on the Halifax section in 2012 (Figure 21). Fall abundance anomalies were also negative for Arctic *Calanus* on all of the sections in 2012, declining from the Cabot Strait section in the east to the Browns Bank section in the west. Fall abundance anomalies for warm offshore species were positive only on the Louisbourg and Halifax sections and weakly negative on the other sections. Fall anomalies for warm shelf copepods were positive on the ESS and negative on the CSS and the WSS.

Ecosystem Trawl Surveys

Zooplankton biomass on the winter Georges Bank survey was nearly as high as in 2000, the highest value on record, but on the summer Scotian Shelf survey, zooplankton biomass was the third lowest recorded (Figure 23a). The abundance of *C. finmarchicus* on Georges Bank in winter was similar to past years since 2006, and it was one of the lowest observed since 1999 on the Scotian Shelf in summer (Figure 23b).

BEDFORD BASIN

In 2012, temperature throughout the water column was the highest recorded in 20 years of observation (Figure 24A,B). Salinity was normal at the surface (Figure 24C), but below normal at depth (Figure 24D). As a result of warmer and fresher water (less dense) at depth, the water column was less stratified than normal (Figure 24E). The concentration of chlorophyll *a* in surface waters was the highest recorded in 20 years (Figure 24F). Higher concentrations of phytoplankton are generally associated with less intense stratification because nutrients at depth are more easily delivered to the surface when the density gradient is weaker. Both the eukaryotic component (Figure 24G) and the prokaryotic component (Figure 24H) of the picophytoplankton were recorded at high levels in 2012.

DISCUSSION

A composite ocean temperature index for the Maritimes region indicated that 2012 was the warmest year since 1981, with an averaged normalized annual anomaly of +2.8 standard deviation (SD), following several years of anomalously warm ocean temperatures in 2009–2011 (Hebert et al. 2013). Both surface and deep water were anomalously warm, and the volume of the cold intermediate layer (CIL; zone of <4°C)on the Scotian Shelf was at a record low (Hebert et al. 2013). Changes in salinity have driven a trend of increasing stratification on the Scotian Shelf since 1950, but the increase in stratification in 2012, compared to 2011, resulted from higher surface temperatures (Hebert et al. 2013). In the context of these changes, chemical and biological conditions were evaluated to identify possible responses to the record warm and stratified conditions on the Scotian Shelf and in the eastern Gulf of Maine in 2012, focusing on changes in nutrient dynamics and their effects on spring bloom timing, annual production dynamics, and phytoplankton community composition and on zooplankton biomass, abundance, and community composition.

Deep water nitrate concentrations were higher than average on the Scotian Shelf and Bay of Fundy in 2012, although fall anomalies were spatially variable. High nitrate concentrations are consistent with persistence of Warm Slope Water (WSW) in deep waters of the shelf (Petrie and Yeats 2000). The low surface nitrate concentrations and high deep water nitrate concentrations observed at Halifax-2 suggests that strong stratification inhibited nutrient mixing into surface waters and thus availability for phytoplankton growth at an annual scale. However, the annual chlorophyll anomaly at Halifax-2 was higher than average, in contrast to expectation.

Changes in stratification can have either positive or negative effects on primary production, depending on water column conditions (Gargett 1997, Mann 1993). In 2012, mild winter conditions and higher-than-average stratification may have contributed to elevated winter phytoplankton production (Townsend et al. 1992). Increased stratification can lead to early and short blooms, as were observed across the Scotian Shelf in 2012 (Ji et al. 2008). The persistence of strong stratification in the late spring and summer may have reduced phytoplankton production, particularly from diatoms, by inhibiting nutrient mixing into surface waters.

Post-bloom observations of average chlorophyll but shallower than average euphotic depths (i.e., high light attenuation) at Halifax-2 suggest that there was a shift to a smaller-sized phytoplankton community in 2012 (Agusti 1991, Kirk 1975). Phytoplankton counts based on settled cells (i.e., Utermöhl method) indicated that diatoms, dinoflagellates, and flagellates were all less abundant than usual, but flagellates and ciliates had a greater than average relative abundance in the post-bloom period. Elevated abundances of picoplankton, which are not accurately quantified using the Utermöhl method, would be consistent with the observations of average chlorophyll and high light attenuation, but additional analysis will be required to confirm this interpretation. Flagellates, ciliates, and picoplankton are typical of a community dominated more by recycled production than new production, consistent with higher nutrient limitation in the post-bloom period. Warmer temperatures are also associated with a shift toward greater picoplankton abundance and smaller phytoplankton size (Li and Harrison 2008, Morán et al. 2010). Indeed, this has been the situation in the Bedford Basin over the past few years, including 2012 (Figure 24G,H).

Annual temperature anomalies in Bedford Basin are correlated with anomalies on the Scotian Shelf (Li 2012). Although surface and deep temperatures were anomalously high in 2012 both in Bedford Basin and on the Scotian Shelf, low stratification in Bedford Basin contrasted with conditions on the Scotian Shelf because the warmer and fresher than average deep water in Bedford Basin compensated for reduced surface density. Although negative salinity anomalies extended to greater than 50 m at the Halifax-2 station on the Scotian Shelf during part of 2012

(Hebert et al. 2013), the greater influence of warm, salty WSW on the deep Scotian Shelf may have contributed to the difference in stratification between the Scotian Shelf and the relatively shallow Bedford Basin.

Vertical diffusion due to tidal mixing is high at Prince-5 throughout the year, and therefore high nutrient concentrations observed in deep water also influenced surface conditions. Although the phytoplankton community at Prince-5 was dominated by diatoms throughout most of 2012, higher light attenuation, despite lower phytoplankton abundance and average chlorophyll, in the winter and fall suggest that smaller phytoplankton could also have been more abundant at the beginning and end of 2012 at Prince-5, perhaps associated with warmer than average conditions (Li and Harrison 2008). Although CDOM (coloured dissolved organic matter) could also increase light attenuation during periods of high river flow (Balch et al. 2012), it is unlikely that this factor contributed to higher light attenuation since salinity anomalies were about average or higher than average at Prince-5 in the winter and fall 2012 (Hebert et al. 2013). In contrast to late summer conditions on the Scotian Shelf, summer blooms of chain-forming diatoms (July) and dinoflagellates (August) formed at Prince-5 and were associated with higher than average chlorophyll and low total phytoplankton abundance and light attenuation. As some of these bloom species are potentially harmful - *Pseudo-nitzschia delicatissima* and *P. pseudodelicatissima* can produce domoic acid, which causes diarrhetic shellfish poisoning, and *Gonyaulax spinifera* can produce yessotoxin, which causes amnesic shellfish poisoning – they had the potential for negative impacts on higher trophic levels and human consumers (Hargraves and Maranda 2002, Paz et al. 2008). Satellite ocean colour observations of high chlorophyll concentrations over a broad area in the eastern and central Gulf of Maine in August and September suggest that the blooms were widespread. However, the dominant species responsible for the remotely sensed blooms are not known, and the factors that triggered the late summer-early fall blooms are also unclear.

The short spring bloom and post-bloom shift to a smaller sized phytoplankton community on the Scotian Shelf may have contributed to low zooplankton biomass observed in 2012. Pulses of higher zooplankton biomass in 2012 were often associated with high abundances of small-particle-feeding zooplankton such as salps and pteropods on the Scotian Shelf and appendicularians at Prince-5. The abundance of *C. finmarchicus* was at a record low in 2012, likely due to low initial abundance following a year of low abundance in 2011, and exacerbated by the short spring bloom and the post-bloom community shift from diatoms to smaller cells. The low abundance of this lipid rich, biomass-dominant species would be expected to inhibit energy transfer from primary producers to species like herring and right whales, for which *C. finmarchicus* is an important prey.

The slightly high annual chlorophyll anomaly at Prince-5 masks more complex seasonal changes that may have influenced feeding conditions for zooplankton in 2012. Low zooplankton biomass at Prince-5 during most of winter and spring 2012, except for a pulse of appendicularians in May, was associated with low *C. finmarchicus* abundance, likely due to low abundance of *C. finmarchicus* emerging from dormancy, similar to conditions at Halifax-2. The zooplankton response to the late summer blooms was difficult to evaluate due to missing measurements, but zooplankton biomass and abundance appear to have recovered in the last quarter of the year, despite continued low *C. finmarchicus* abundance.

In 2012, both low CIL index and model estimates suggested that outflow from the Gulf of St. Lawrence onto the Scotian Shelf was lower than normal (Hebert et al. 2013). Flow into the Gulf of Maine from the inshore Scotian Shelf and through the Northeast Channel are negatively correlated (Smith et al. 2001). In 2012, the estimated portion of inflow from the Northeast Channel was higher than average (Hebert et al. 2013), suggesting greater offshore influence in the eastern Gulf of Maine. Changes in the abundance of immigrant groups in 2012 were consistent with both the warm temperatures and estimates of water sources on the Scotian

Shelf and eastern Gulf of Maine. Warm offshore species were higher than average at the fixed stations while Arctic *Calanus* species were lower than average. Deep water copepods were also more abundant. Arctic *Calanus* were also low on all the sections in the fall, but the anomalies of warm offshore species abundance were mixed. The unexpected negative anomaly of warm offshore species on the WSS (Browns Bank section) in 2012 may reflect the typical nature of fall incursions of warm offshore species onto the WSS, even when conditions are not unusually warm. Anomalies of warm shelf species were lower than expected in 2012, a record warm year, but this may reflect overall low zooplankton abundance and poor feeding conditions in the summer and fall, when these species are normally most abundant. In addition, the extreme high abundance of warm shelf species in 2000 was an outlier that may obscure changes in other years. Pulses of small particle feeding zooplankton taxa at the fixed stations and on Halifax line were consistent with a shift to a smaller phytoplankton community.

Overall, the shift to smaller phytoplankton, low zooplankton biomass and low *C. finmarchicus* and *Pseudocalanus* spp. abundance in 2012 suggests poor feeding conditions for fish larvae, planktivorous fish, and right whales. However, the higher than average late summer – early fall phytoplankton bloom in the eastern Gulf of Maine and Bay of Fundy may have benefitted some species, for example, sea scallops, which had improved condition in some eastern Gulf of Maine and Bay of Fundy regions in 2012 (Nasmith et al. 2013).

SUMMARY

- In 2012, ocean temperatures were anomalously warm throughout the water column on the Scotian Shelf and eastern Gulf of Maine, and stratification was higher than average on the Scotian Shelf.
- Deep-water nitrate was higher than average across most of the region.
- On the Scotian Shelf, winter chlorophyll concentrations were higher than average and the spring bloom was earlier and/or short.
- Late summer-early fall chlorophyll concentrations were higher than average in the Bay of Fundy and eastern Gulf of Maine.
- Observations were consistent with a phytoplankton community shift to smaller species on the Scotian Shelf throughout 2012 and in the Bay of Fundy in the first half of 2012, and pulses of small-particle-feeding taxa zooplankton were observed.
- Zooplankton biomass was low throughout most of the region in 2012 but recovered in the second half of the year at Prince-5.
- *C. finmarchicus* and *Pseudocalanus* spp. abundance were low throughout the region in 2012.
- Arctic *Calanus* abundances were lower than average, and warm offshore species abundances were generally higher than average in 2012.
- Overall, lower trophic level changes in 2012 suggest poor feeding conditions for planktivores on the Scotian Shelf, but the late summer-early fall bloom in the eastern Gulf of Maine and Bay of Fundy may have been favorable for some higher trophic level species.

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TABLES

Table 1. Atlantic Zone Monitoring Program (AZMP) sampling missions in the Maritimes/Gulf regions,2012.

Group	Location	Mission ID	Dates	# Hydro Stations	# Net Stations
Ecosystem Trawl Surveys	Georges Bank / Western Scotian Shelf	NED2012-002	Feb 11 – Mar 18	89	28[1]
	Scotian Shelf	NED2012-022	Jul 07 – Aug 05	220	38
	Southern Gulf of St. Lawrence	TEL2012-105	Sept 12 - Oct 02	150	16
Seasonal Sections	Scotian Shelf	HUD2012	No Vessel in April	0	0
	Scotian Shelf	HUD2012-042	Sep 24 – Oct 15	87	75
Fixed Stations	Shediac Valley	BCD2012-668	Apr 20 – Nov 20	12(9)[2]	12(9)[2]
	Halifax-2	BCD2012-666	Jan 01 – Dec 31	20(9)[3]	20(9)[3]
	Prince-5	BCD2012-669	Jan 01 – Dec 31	12	11
			Total:	**587**	**197**

[1] Halifax Section occupations March 16-18, 2012, are reported as representing the spring section, although the timing for these occupations was earlier than usual.

[2] Total station occupations (occupations by Maritimes region).

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

FIGURES

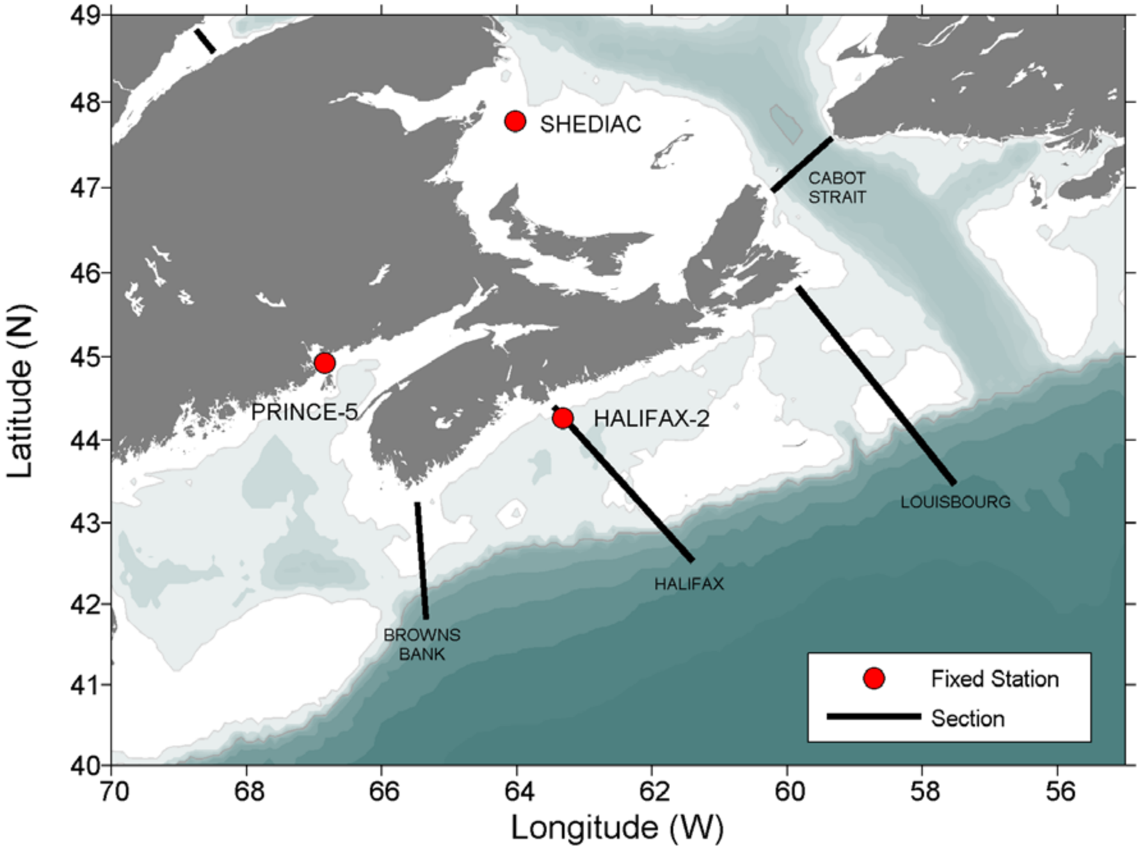


Figure 1. Map of primary sections (Cabot Strait, Louisbourg, Halifax, and Browns Bank) and fixed stations (Shediac, Halifax-2, and Prince-5) sampled in the DFO Maritimes and Gulf regions.

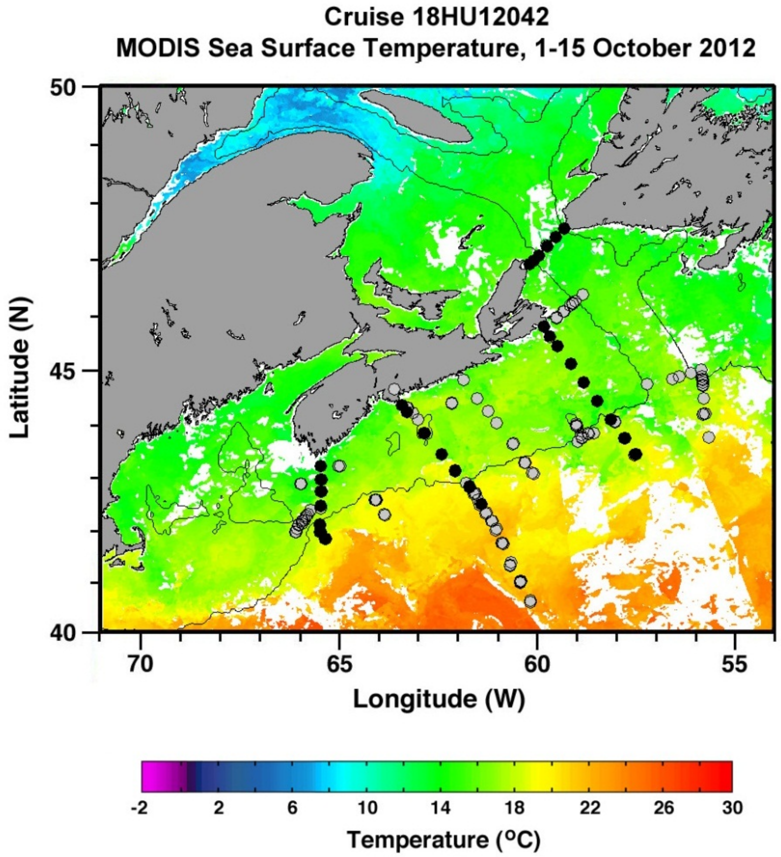


Figure 2. Stations sampled during the 2012 fall survey. Station locations are superimposed on a sea-surface temperature composite image for dates close to the mission dates. Black markers indicate core stations, and gray markers indicate stations sampled for ancillary programs.

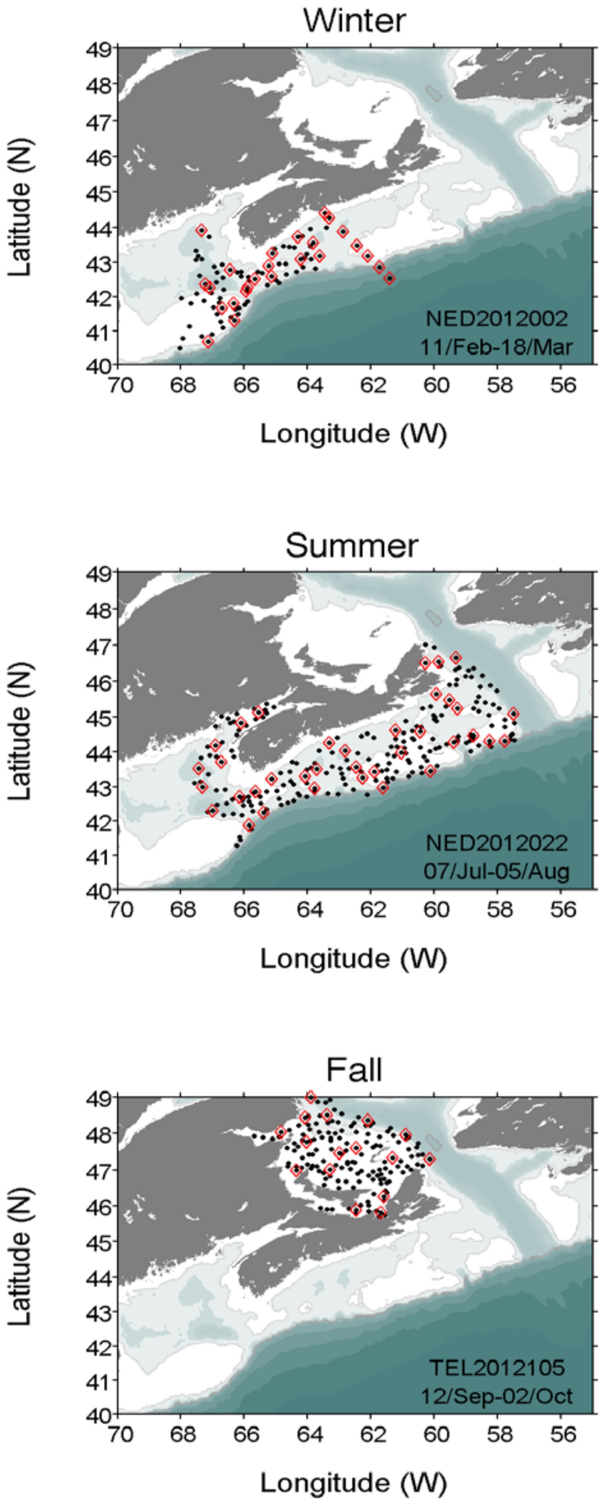


Figure 3. Stations sampled during major Maritimes/Gulf ecosystem trawl surveys in 2012. Black solid markers are hydrographic stations; red open diamonds are stations where vertical nets hauls were taken in addition to hydrographic measurements.

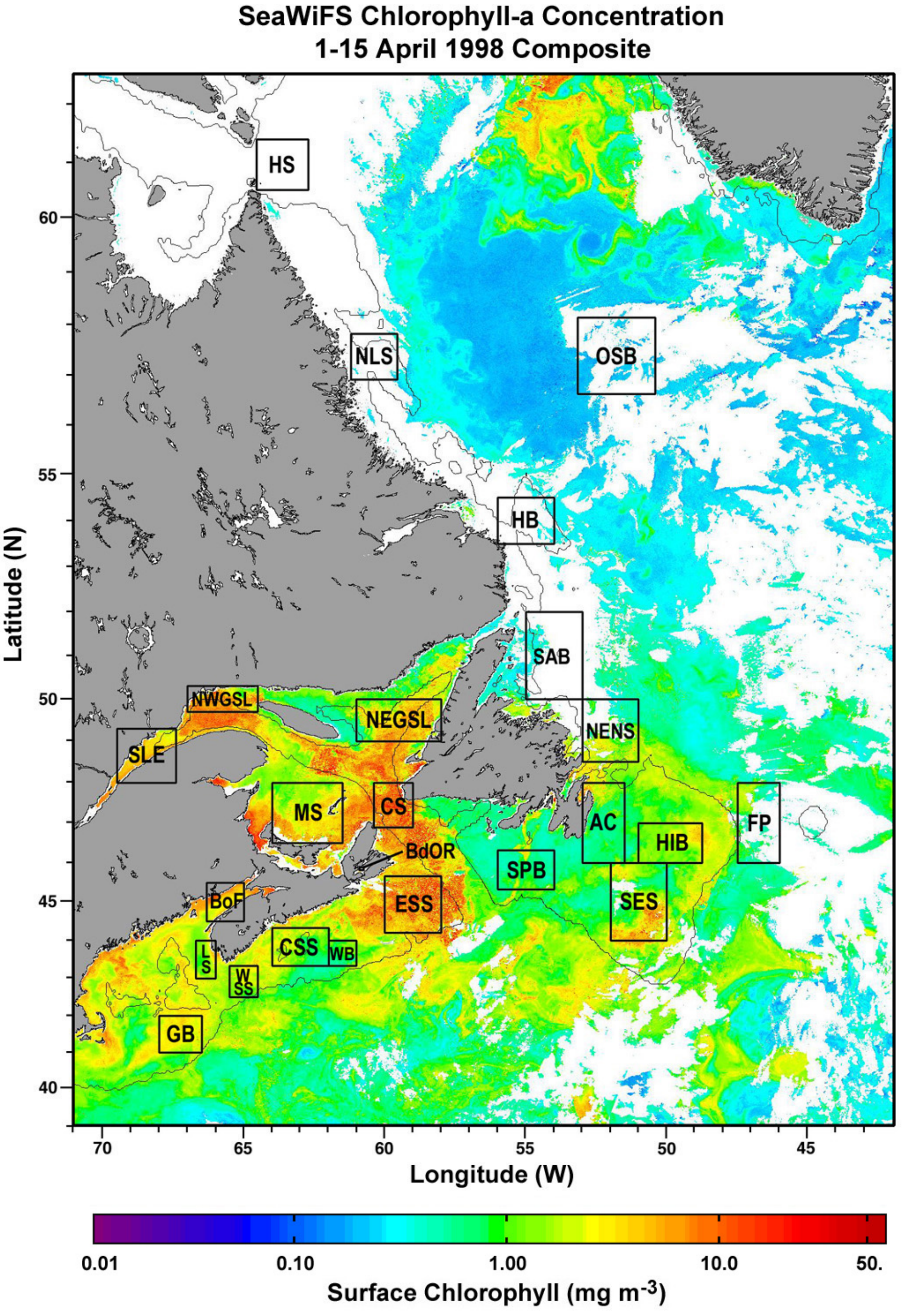


Figure 4. Statistical sub-regions in the Northwest Atlantic identified for spatial/temporal analysis of satellite ocean colour data. AC – Avalon Channel; BdOR – Bras d'Or; BoF – Bay of Fundy; CS – Cabot Strait; CSS – central Scotian Shelf; ESS – eastern Scotian Shelf; FP – Flemish Pass; GB – Georges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

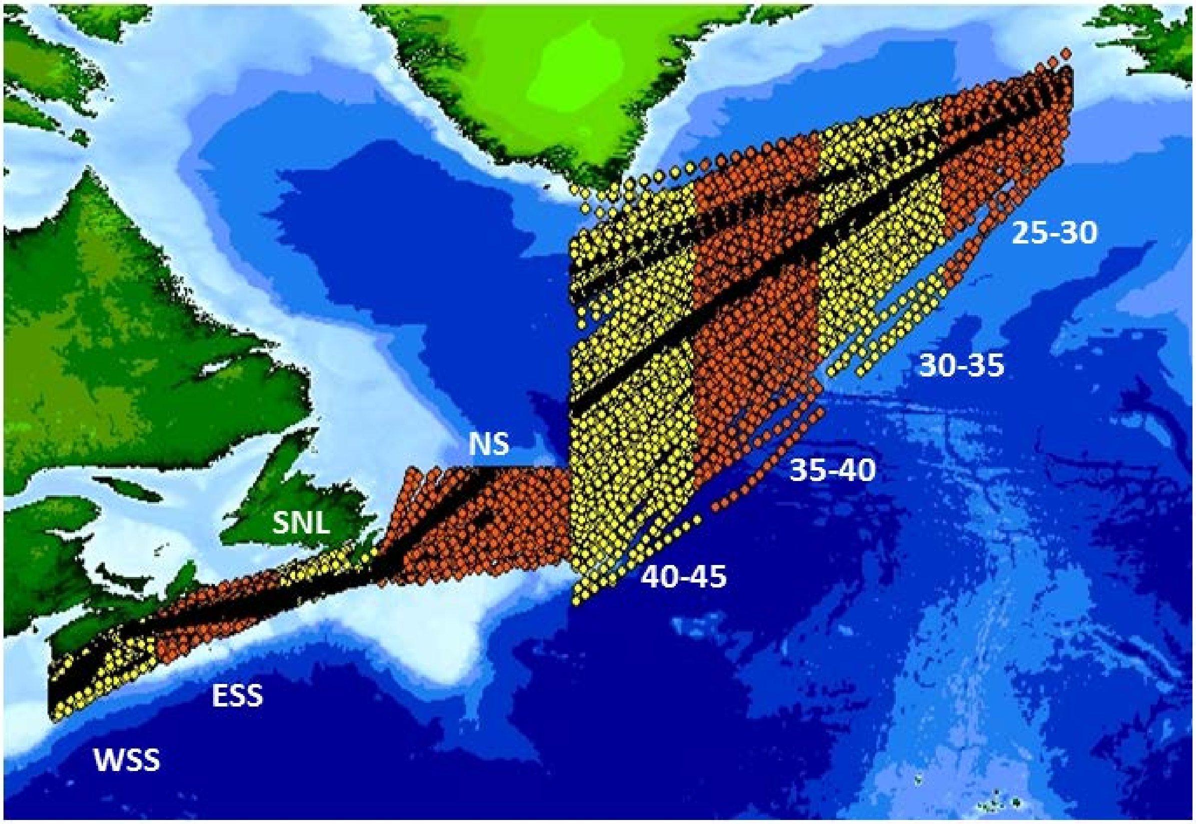


Figure 5. Continuous Plankton Recorder (CPR) lines and stations 1961 to 2011. Only stations that are included in the analysis are shown, with adjacent regions delineated alternately by colour (yellow and orange) in the years preceding 2012. Stations sampled in 2012 are shown in black. WSS - western Scotian Shelf, ESS - eastern Scotian Shelf, SNS - south Newfoundland Shelf, NS - Newfoundland Shelf, and between longitudes 40-45°W , 40-45, 35-40, etc.

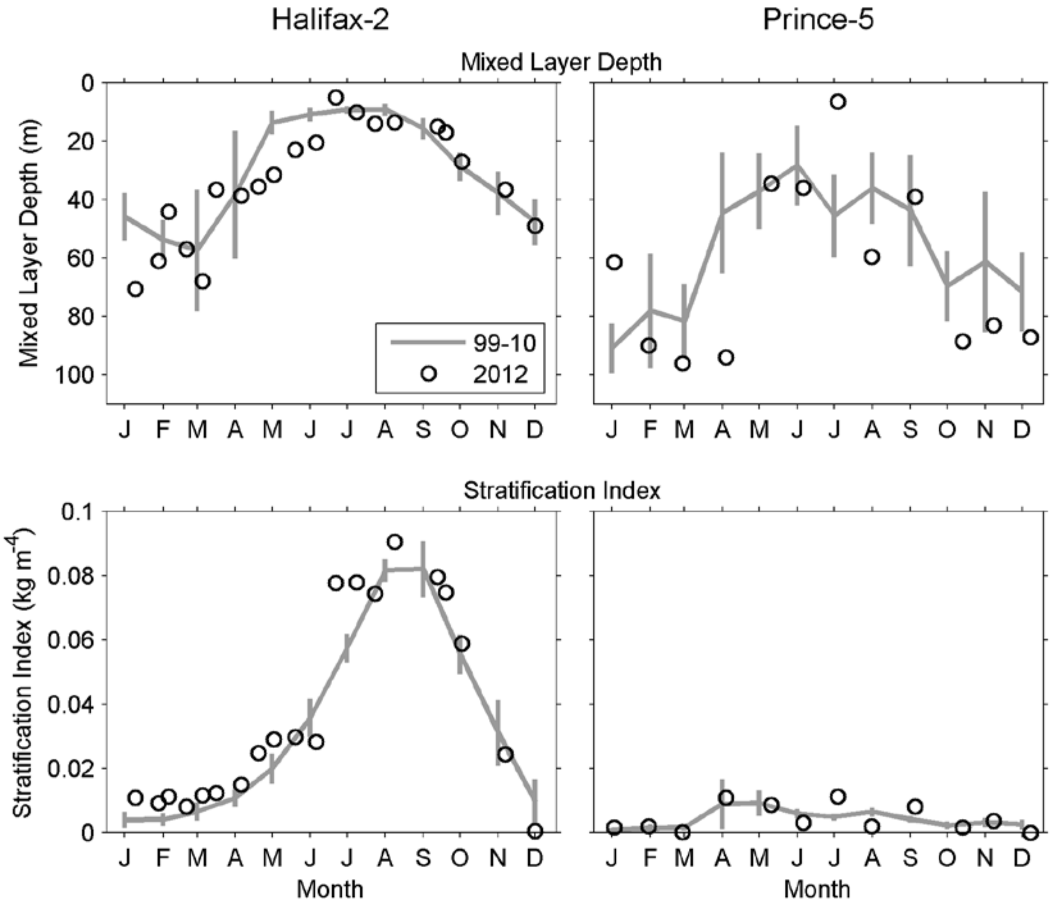


Figure 6. Mixing properties (mixed-layer depth, stratification index) at the Maritimes fixed stations comparing 2012 data (open circle) with mean conditions from 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the observations.

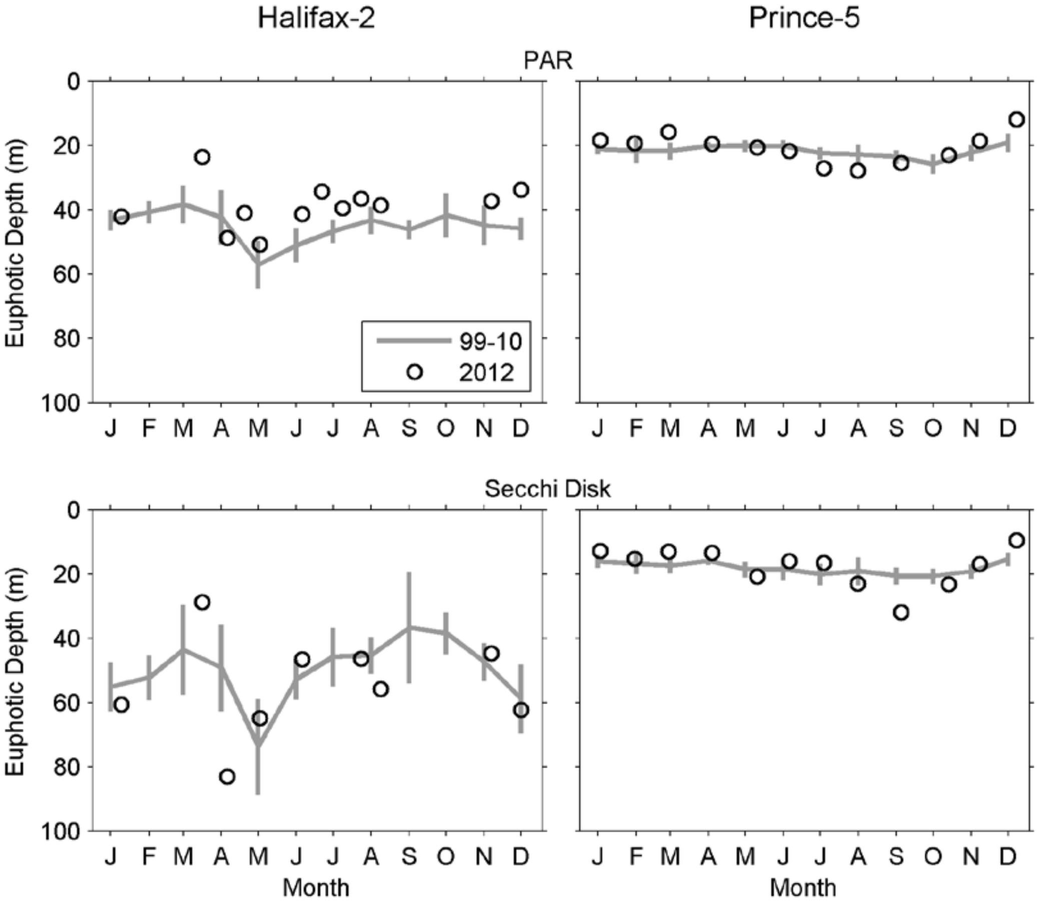


Figure 7. Optical properties (euphotic depth from PAR irradiance meter and Secchi disc) at the Maritimes fixed stations. Year 2012 data (circles) compared with mean conditions from 1999–2010 (solid line), except 2001–2010 for euphotic depth from PAR at Prince-5. Vertical lines are 95% confidence intervals of the observations.

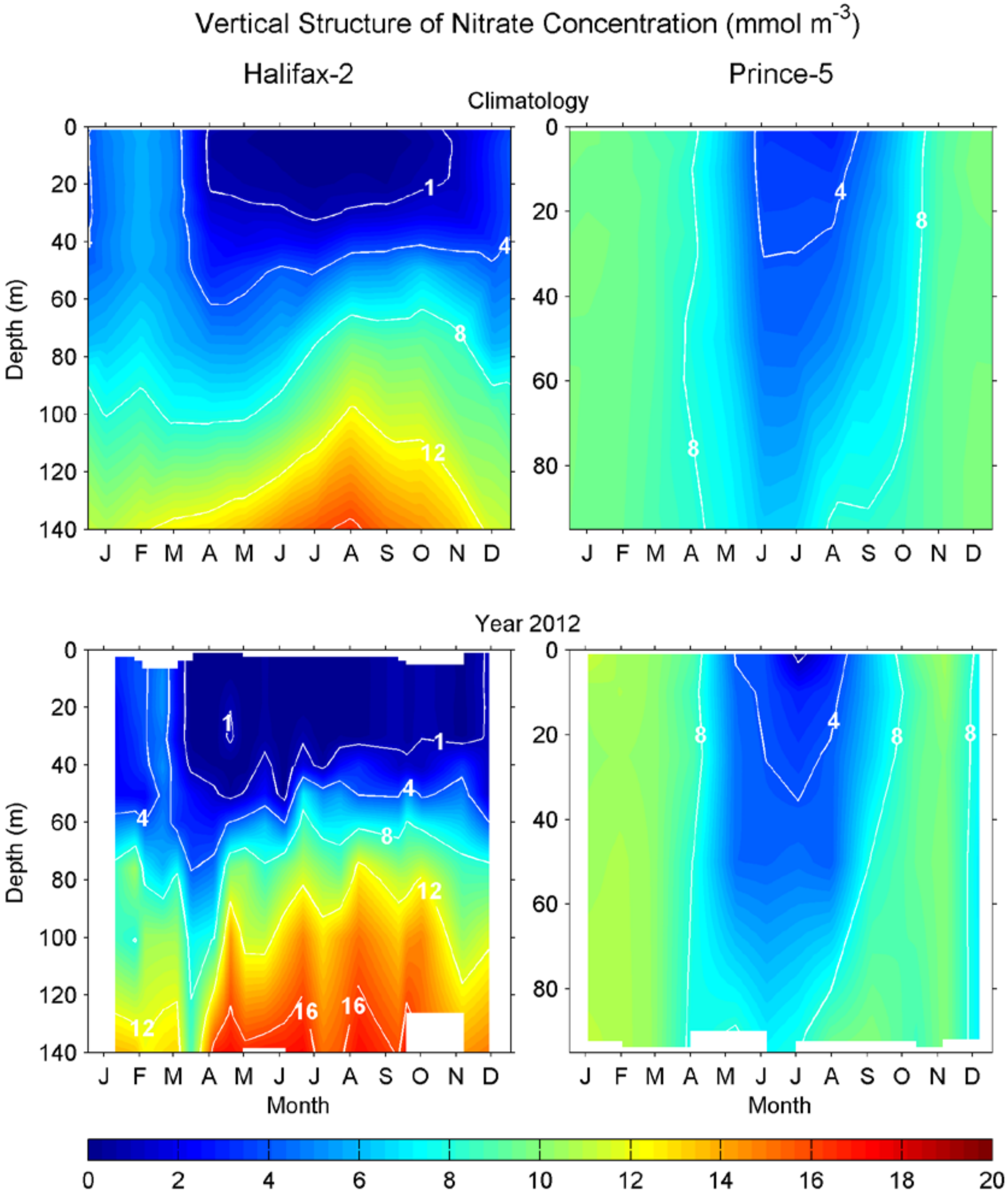


Figure 8. Comparison of vertical structure of nitrate concentrations (mmol m^{-3}) in 2012 (bottom panels) with climatological mean conditions from 1999–2010 (upper panels) at the Maritimes fixed stations.

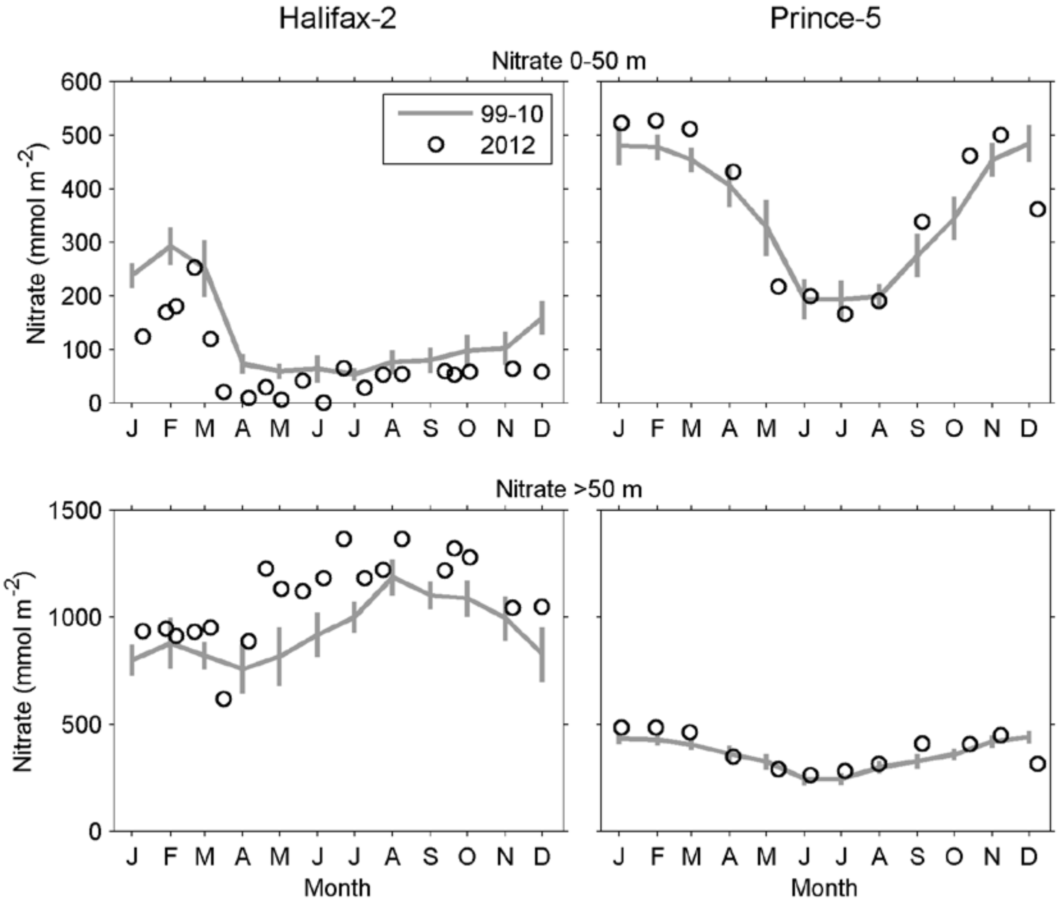
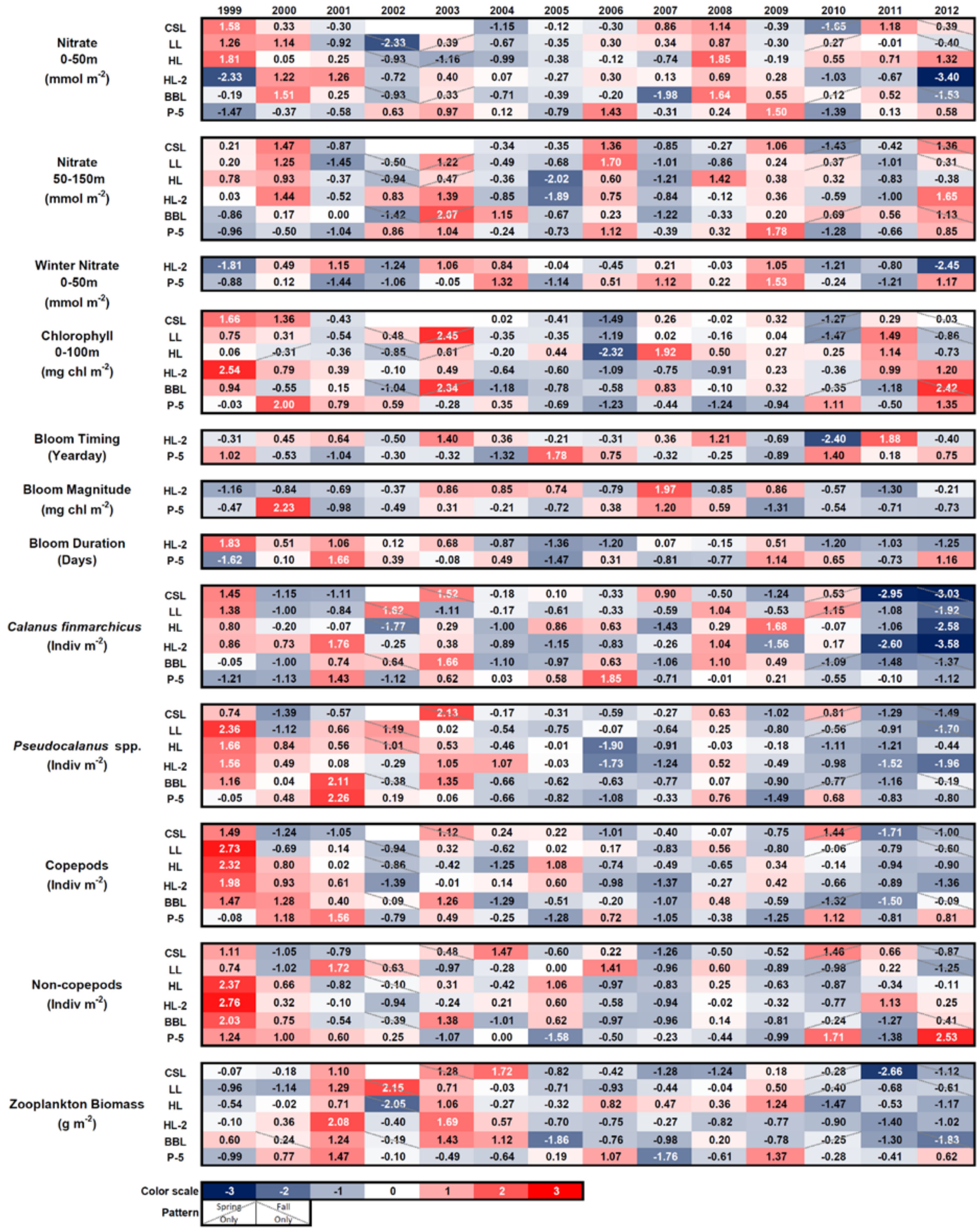


Figure 9. Comparison of 2012 (open circle) data with mean conditions from 1999–2010 (solid line) at the Maritimes fixed stations. Upper panels: surface (0–50 m) nitrate inventory. Lower panels: deep (>50 m) nitrate inventory. Vertical lines are 95% confidence intervals of the annual averages.



		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Nitrate 0-50m (mmol m^{-2})	CSL	1.58	0.33	-0.30			-1.15	-0.12	-0.30	0.86	1.14	-0.39	-1.65	1.18	0.39
	LL	1.26	1.14	-0.92	-2.33	0.39	-0.67	-0.35	0.30	0.34	0.87	-0.30	0.27	-0.01	-0.40
	HL	1.81	0.05	0.25	-0.93	-1.16	-0.99	-0.38	-0.12	-0.74	1.85	-0.19	0.55	0.71	1.32
	HL-2	-2.33	1.22	1.26	-0.72	0.40	0.07	-0.27	0.30	0.13	0.69	0.28	-1.03	-0.67	-3.40
	BBL	-0.19	1.51	0.25	-0.93	0.33	-0.71	-0.39	-0.20	-1.98	1.64	0.55	0.12	0.52	-1.53
	P-5	-1.47	-0.37	-0.58	0.63	0.97	0.12	-0.79	1.43	-0.31	0.24	1.50	-1.39	0.13	0.58
Nitrate 50-150m (mmol m^{-2})	CSL	0.21	1.47	-0.87			-0.34	-0.35	1.36	-0.85	-0.27	1.06	-1.43	-0.42	1.36
	LL	0.20	1.25	-1.45	-0.50	1.22	-0.49	-0.68	1.70	-1.01	-0.86	0.24	0.37	-1.01	0.31
	HL	0.78	0.93	-0.37	-0.94	0.47	-0.36	-2.02	0.60	-1.21	1.42	0.38	0.32	-0.83	-0.38
	HL-2	0.03	1.44	-0.52	0.83	1.39	-0.85	-1.89	0.75	-0.84	-0.12	0.36	-0.59	-1.00	1.65
	BBL	-0.86	0.17	0.00	-1.42	2.07	1.15	-0.67	0.23	-1.22	-0.33	0.20	0.69	0.56	1.13
	P-5	-0.96	-0.50	-1.04	0.86	1.04	-0.24	-0.73	1.12	-0.39	0.32	1.78	-1.28	-0.66	0.85
Winter Nitrate 0-50m (mmol m^{-2})	HL-2	-1.81	0.49	1.15	-1.24	1.06	0.84	-0.04	-0.45	0.21	-0.03	1.05	-1.21	-0.80	-2.45
	P-5	-0.88	0.12	-1.44	-1.06	-0.05	1.32	-1.14	0.51	1.12	0.22	1.53	-0.24	-1.21	1.17
Chlorophyll 0-100m (mg chl m^{-2})	CSL	1.66	1.36	-0.43			0.02	-0.41	-1.49	0.26	-0.02	0.32	-1.27	0.29	0.03
	LL	0.75	0.31	-0.54	0.48	2.45	-0.35	-0.35	-1.19	0.02	-0.16	0.04	-1.47	1.49	-0.86
	HL	0.06	-0.31	-0.36	-0.85	0.61	-0.20	0.44	-2.32	1.92	0.50	0.27	0.25	1.14	-0.73
	HL-2	2.54	0.79	0.39	-0.10	0.49	-0.64	-0.60	-1.09	-0.75	-0.91	0.23	-0.36	0.99	1.20
	BBL	0.94	-0.55	0.15	-1.04	2.34	-1.18	-0.78	-0.58	0.83	-0.10	0.32	-0.35	-1.18	2.42
	P-5	-0.03	2.00	0.79	0.59	-0.28	0.35	-0.69	-1.23	-0.44	-1.24	-0.94	1.11	-0.50	1.35
Bloom Timing (Yearday)	HL-2	-0.31	0.45	0.64	-0.50	1.40	0.36	-0.21	-0.31	0.36	1.21	-0.69	-2.40	1.88	-0.40
	P-5	1.02	-0.53	-1.04	-0.30	-0.32	-1.32	1.78	0.75	-0.32	-0.25	-0.89	1.40	0.18	0.75
Bloom Magnitude (mg chl m^{-2})	HL-2	-1.16	-0.84	-0.69	-0.37	0.86	0.85	0.74	-0.79	1.97	-0.85	0.86	-0.57	-1.30	-0.21
	P-5	-0.47	2.23	-0.98	-0.49	0.31	-0.21	-0.72	0.38	1.20	0.59	-1.31	-0.54	-0.71	-0.73
Bloom Duration (Days)	HL-2	1.83	0.51	1.06	0.12	0.68	-0.87	-1.36	-1.20	0.07	-0.15	0.51	-1.20	-1.03	-1.25
	P-5	-1.62	0.10	1.66	0.39	-0.08	0.49	-1.47	0.31	-0.81	-0.77	1.14	0.65	-0.73	1.16
Calanus finmarchicus (Indiv m^{-2})	CSL	1.45	-1.15	-1.11		1.52	-0.18	0.10	-0.33	0.90	-0.50	-1.24	0.53	-2.95	-3.03
	LL	1.38	-1.00	-0.84	1.62	-1.11	-0.17	-0.61	-0.33	-0.59	1.04	-0.53	1.15	-1.08	-1.92
	HL	0.80	-0.20	-0.07	-1.77	0.29	-1.00	0.86	0.63	-1.43	0.29	1.68	-0.07	-1.06	-2.58
	HL-2	0.86	0.73	1.76	-0.25	0.38	-0.89	-1.15	-0.83	-0.26	1.04	-1.56	0.17	-2.60	-3.58
	BBL	-0.05	-1.00	0.74	0.64	1.66	-1.10	-0.97	0.63	-1.06	1.10	0.49	-1.09	-1.48	-1.37
	P-5	-1.21	-1.13	1.43	-1.12	0.62	0.03	0.58	1.85	-0.71	-0.01	0.21	-0.55	-0.10	-1.12
Pseudocalanus spp. (Indiv m^{-2})	CSL	0.74	-1.39	-0.57		2.13	-0.17	-0.31	-0.59	-0.27	0.63	-1.02	0.81	-1.29	-1.49
	LL	2.36	-1.12	0.66	1.19	0.02	-0.54	-0.75	-0.07	-0.64	0.25	-0.80	-0.56	-0.91	-1.70
	HL	1.66	0.84	0.56	1.01	0.53	-0.46	-0.01	-1.90	-0.91	-0.03	-0.18	-1.11	-1.21	-0.44
	HL-2	1.56	0.49	0.08	-0.29	1.05	1.07	-0.03	-1.73	-1.24	0.52	-0.49	-0.98	-1.52	-1.96
	BBL	1.16	0.04	2.11	-0.38	1.35	-0.66	-0.62	-0.63	-0.77	0.07	-0.90	-0.77	-1.16	-0.19
	P-5	-0.05	0.48	2.26	0.19	0.06	-0.66	-0.82	-1.08	-0.33	0.76	-1.49	0.68	-0.83	-0.80
Copepods (Indiv m^{-2})	CSL	1.49	-1.24	-1.05		1.12	0.24	0.22	-1.01	-0.40	-0.07	-0.75	1.44	-1.71	-1.00
	LL	2.73	-0.69	0.14	-0.94	0.32	-0.62	0.02	0.17	-0.83	0.56	-0.80	-0.06	-0.79	-0.60
	HL	2.32	0.80	0.02	-0.86	-0.42	-1.25	1.08	-0.74	-0.49	-0.65	0.34	-0.14	-0.94	-0.90
	HL-2	1.98	0.93	0.61	-1.39	-0.01	0.14	0.60	-0.98	-1.37	-0.27	0.42	-0.66	-0.89	-1.36
	BBL	1.47	1.28	0.40	0.09	1.26	-1.29	-0.51	-0.20	-1.07	0.48	-0.59	-1.32	-1.50	-0.09
	P-5	-0.08	1.18	1.56	-0.79	0.49	-0.25	-1.28	0.72	-1.05	-0.38	-1.25	1.12	-0.81	0.81
Non-copepods (Indiv m^{-2})	CSL	1.11	-1.05	-0.79		0.48	1.47	-0.60	0.22	-1.26	-0.50	-0.52	1.46	0.66	-0.87
	LL	0.74	-1.02	1.72	0.63	-0.97	-0.28	0.00	1.41	-0.96	0.60	-0.89	-0.98	0.22	-1.25
	HL	2.37	0.66	-0.82	-0.10	0.31	-0.42	1.06	-0.97	-0.83	0.25	-0.63	-0.87	-0.34	-0.11
	HL-2	2.76	0.32	-0.10	-0.94	-0.24	0.21	0.60	-0.58	-0.94	-0.02	-0.32	-0.77	1.13	0.25
	BBL	2.03	0.75	-0.54	-0.39	1.38	-1.01	0.62	-0.97	-0.96	0.14	-0.81	-0.24	-1.27	0.41
	P-5	1.24	1.00	0.60	0.25	-1.07	0.00	-1.58	-0.50	-0.23	-0.44	-0.99	1.71	-1.38	2.53
Zooplankton Biomass (g m^{-2})	CSL	-0.07	-0.18	1.10		1.28	1.72	-0.82	-0.42	-1.28	-1.24	0.18	-0.28	-2.66	-1.12
	LL	-0.96	-1.14	1.29	2.15	0.71	-0.03	-0.71	-0.93	-0.44	-0.04	0.50	-0.40	-0.68	-0.61
	HL	-0.54	-0.02	0.71	-2.05	1.06	-0.27	-0.32	0.82	0.47	0.36	1.24	-1.47	-0.53	-1.17
	HL-2	-0.10	0.36	2.08	-0.40	1.69	0.57	-0.70	-0.75	-0.27	-0.82	-0.77	-0.90	-1.40	-1.02
	BBL	0.60	0.24	1.24	-0.19	1.43	1.12	-1.86	-0.76	-0.98	0.20	-0.78	-0.25	-1.30	-1.83
	P-5	-0.99	0.77	1.47	-0.10	-0.49	-0.64	0.19	1.07	-1.76	-0.61	1.37	-0.28	-0.41	0.62

Color scale	-3	-2	-1	0	1	2	3
Pattern	Spring Only	Fall Only					

Figure 10. Maritimes Region scorecard: time series of chemical and biological variables, 1999–2012. A blank cell indicates missing data. Red (blue) cells indicate higher (lower) than normal nutrient, phytoplankton, zooplankton levels or later and longer (earlier or shorter) than normal duration of phytoplankton blooms. Reference period is 1999–2010. The numbers in the cells are the anomaly values. CSL: Cabot Strait section; LL: Louisbourg section; HL: Halifax section; HL2: Halifax-2; BBL: Browns Bank section; P5: Prince-5.

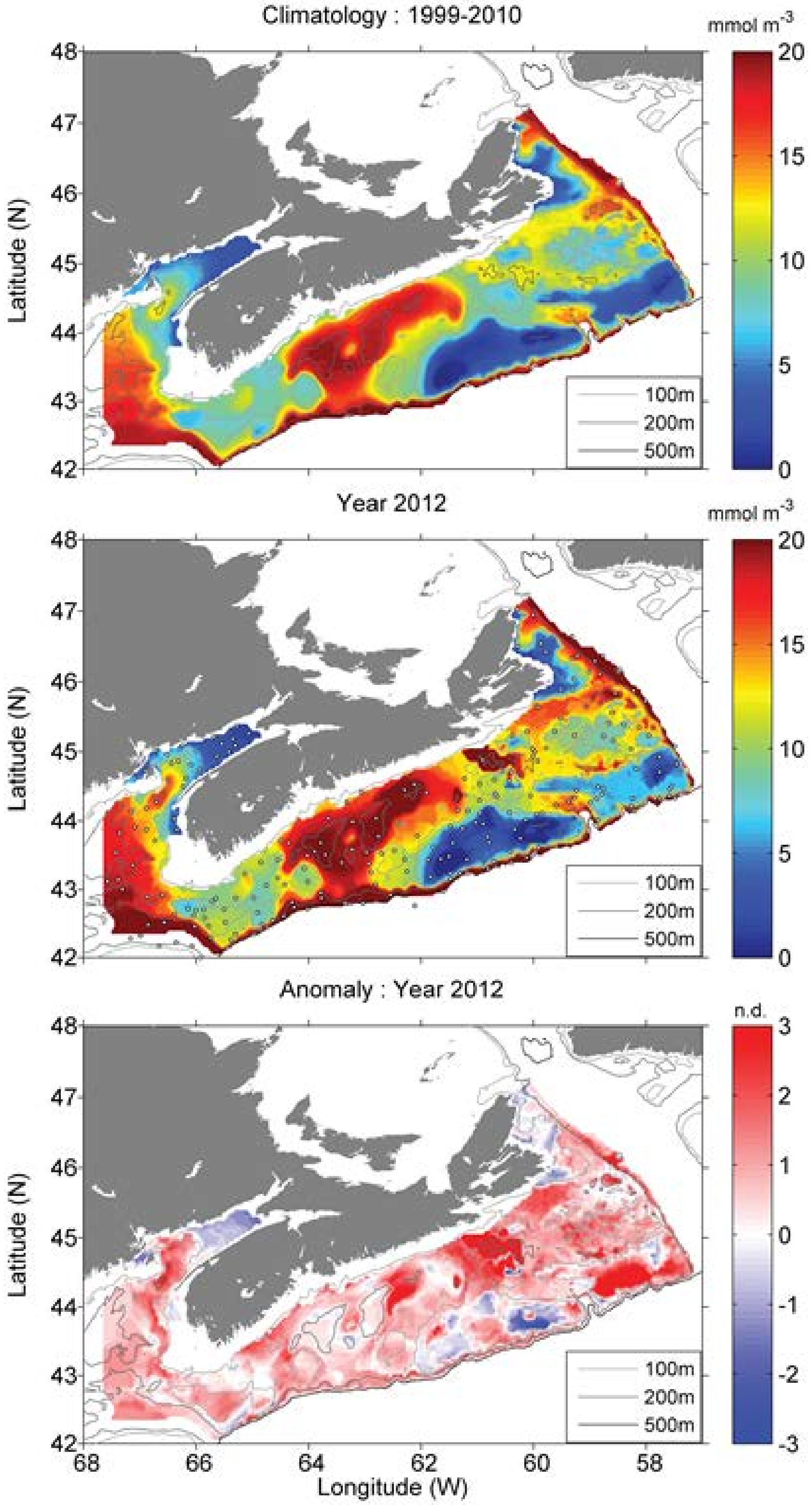


Figure 11. Bottom nitrate concentration on the Scotian Shelf during the annual July ecosystem trawl survey: 1999-2010 climatology (upper panel), 2012 conditions (middle panel), and anomalies of 2012 from climatology (lower panel). Markers in middle panel represent the 2012 sampling locations. nd = no dimensions.

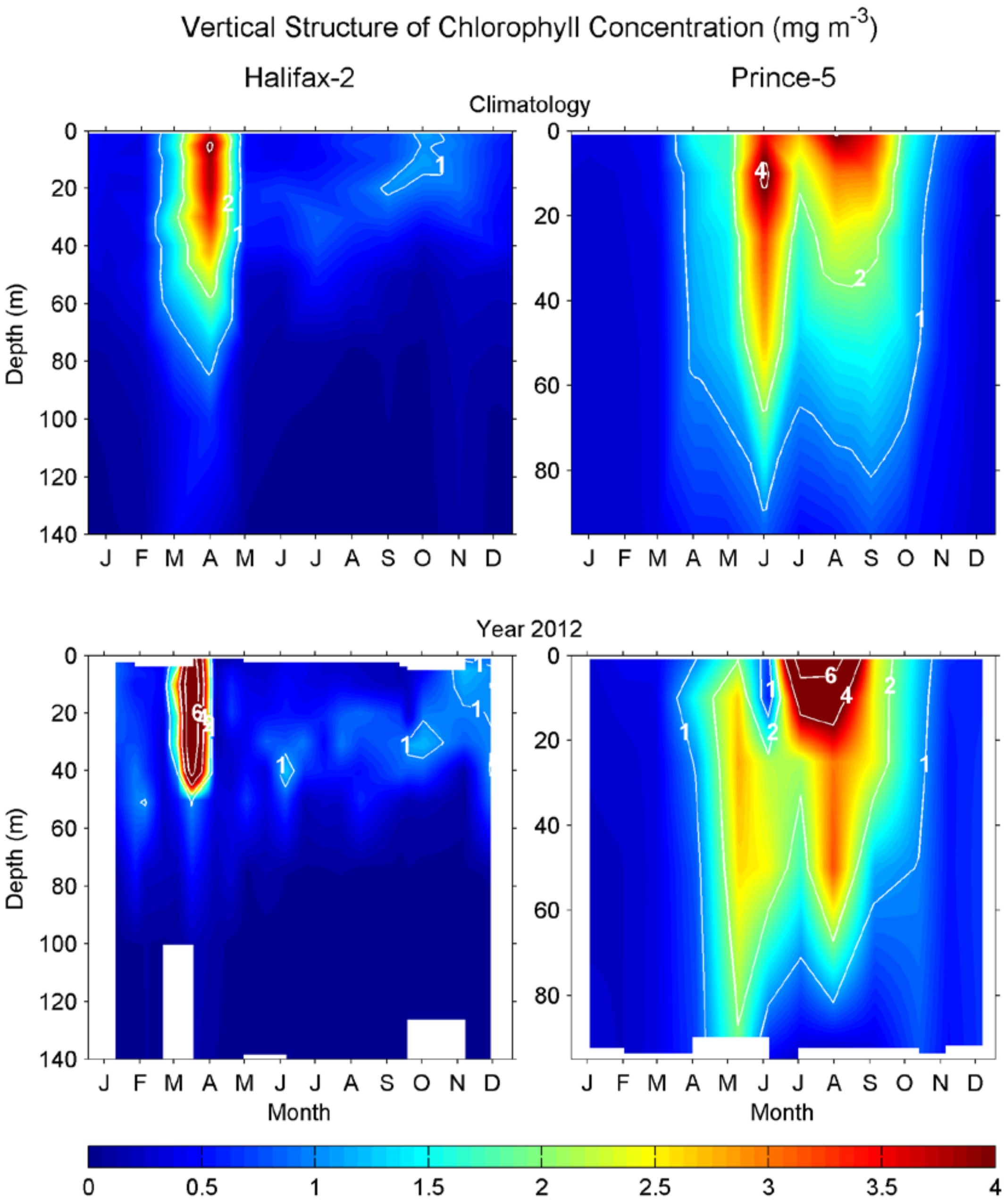


Figure 12. Comparison of vertical structure of chlorophyll concentrations (mg m^{-3}) in 2012 (bottom panels) with mean conditions from 1999–2010 (upper panels) at the Maritimes fixed stations. Colour scale chosen to emphasize change near estimated food saturation levels for large copepods.

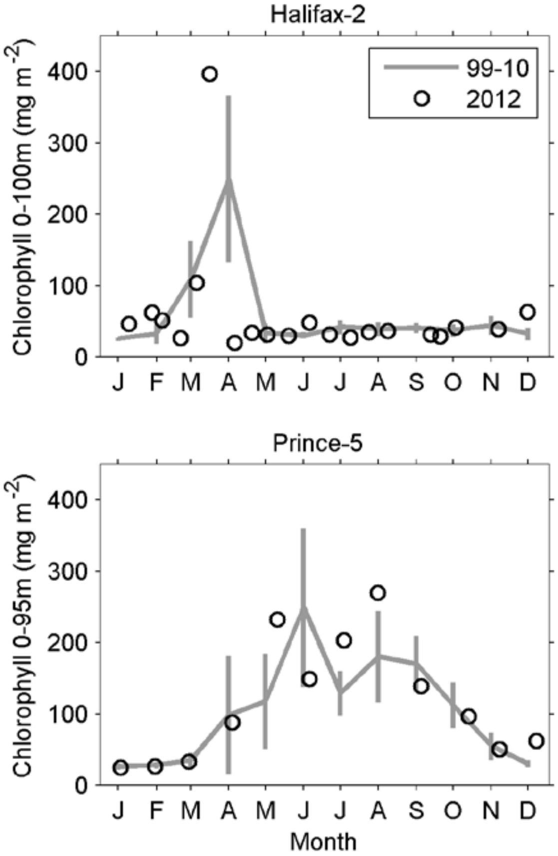


Figure 13. Comparison of 2012 (open circle) chlorophyll inventories with mean conditions from 1999–2010 (solid line) at the Maritimes fixed stations. Vertical lines are 95% confidence intervals of the annual averages.

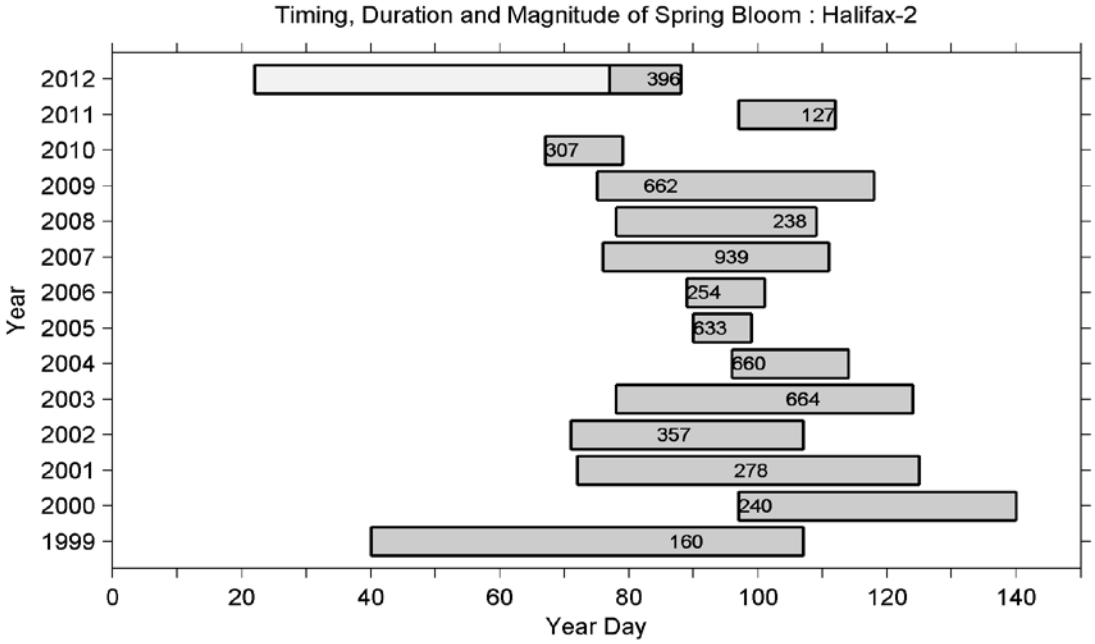


Figure 14. Dynamics of the spring phytoplankton bloom at the Halifax-2 fixed station, 1999–2012. Timing and duration are based on a 40 mg Chl m^{-2} threshold for determining start and end of the bloom). Bloom magnitude is indicated by numbers inside horizontal bars, printed at the year day of their occurrence. In 2012, winter chlorophyll levels were >40 mg Chl m^{-2} from the start of sampling in January; bloom initiation timing was also determined based on the start of a rapid increase in chlorophyll, indicated by the dark gray box.

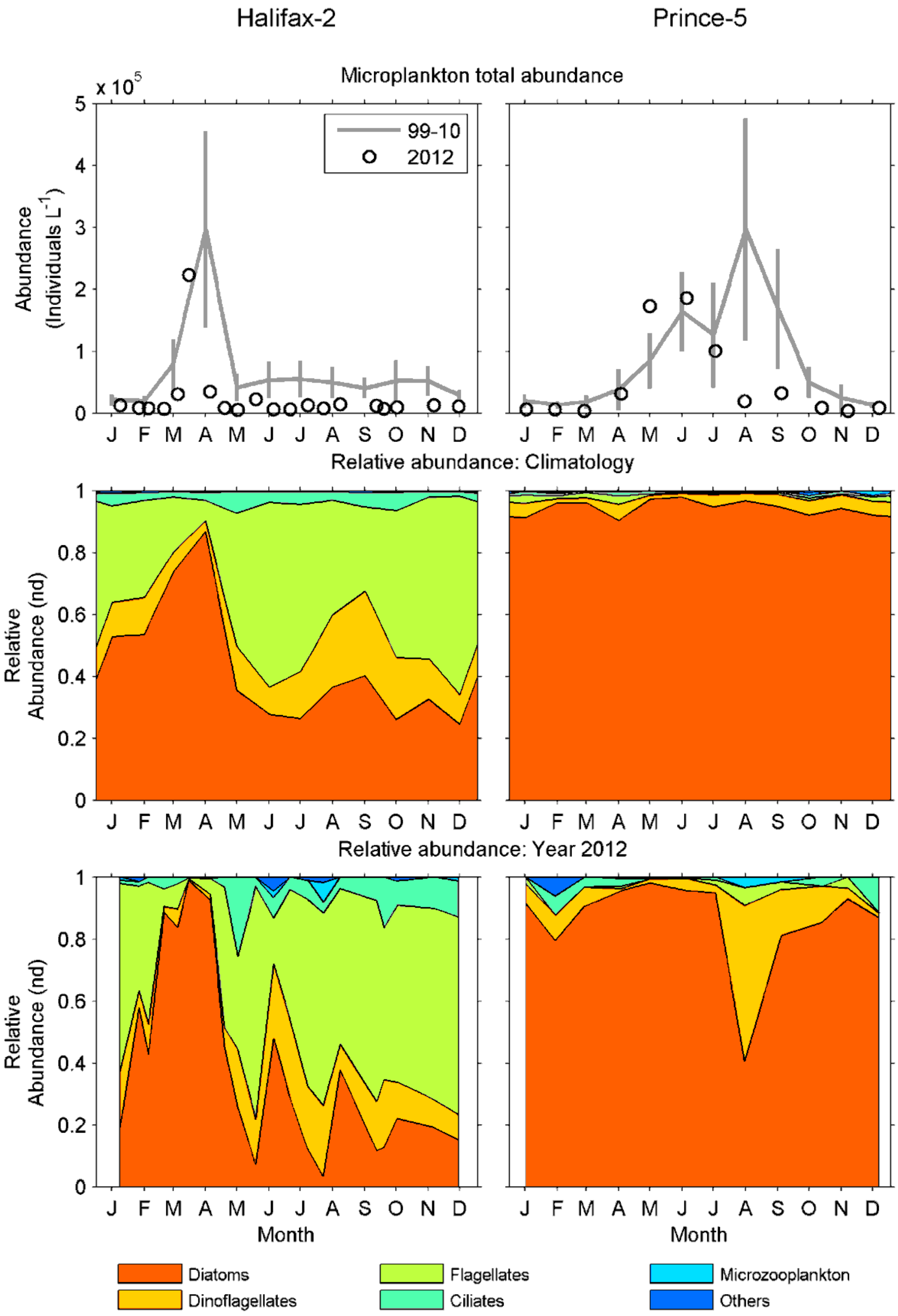


Figure 15. Comparison of 2012 microplankton (phytoplankton and protists) abundance and community composition with mean conditions from 1999–2010 at the Maritimes fixed stations (Halifax-2 right panels; Prince-5 left panels). Upper panels: 2012 microplankton abundance (open circle) compared with mean conditions from 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the annual averages. Middle panels: Climatological microplankton relative abundance from 1999–2010. Lower panels: 2012 microplankton relative abundance. nd = no dimensions.

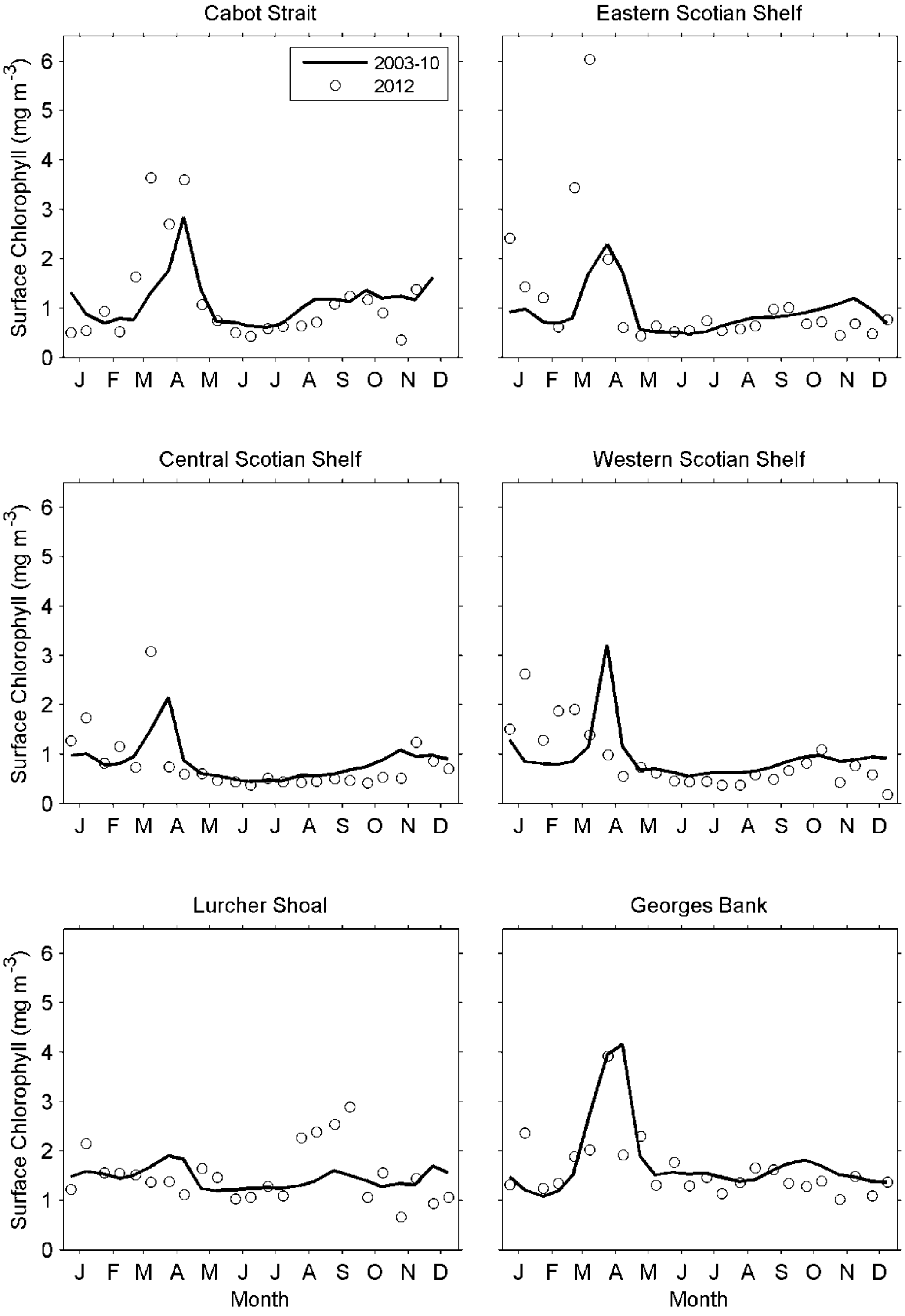


Figure 16. Comparison of 2012 (open circle) surface chlorophyll estimates from satellite ocean colour with mean conditions from 2003–2010 (solid line) in the Cabot Strait, Eastern Scotian Shelf, Central Scotian Shelf, Western Scotian Shelf, Lurcher Shoal, and Georges Bank statistical subregions (Figure 4).

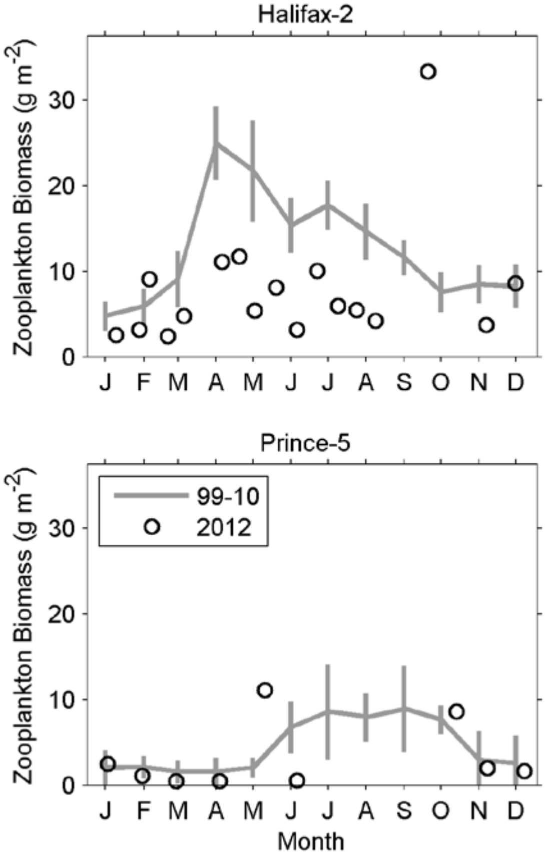


Figure 17. Comparison of 2012 (open circle) zooplankton biomass (surface to bottom) with mean conditions from 1999–2010 (solid line) at the Maritimes fixed stations. Upper panel: Halifax-2; lower panel: Prince-5. Vertical lines are 95% confidence intervals of the annual averages.

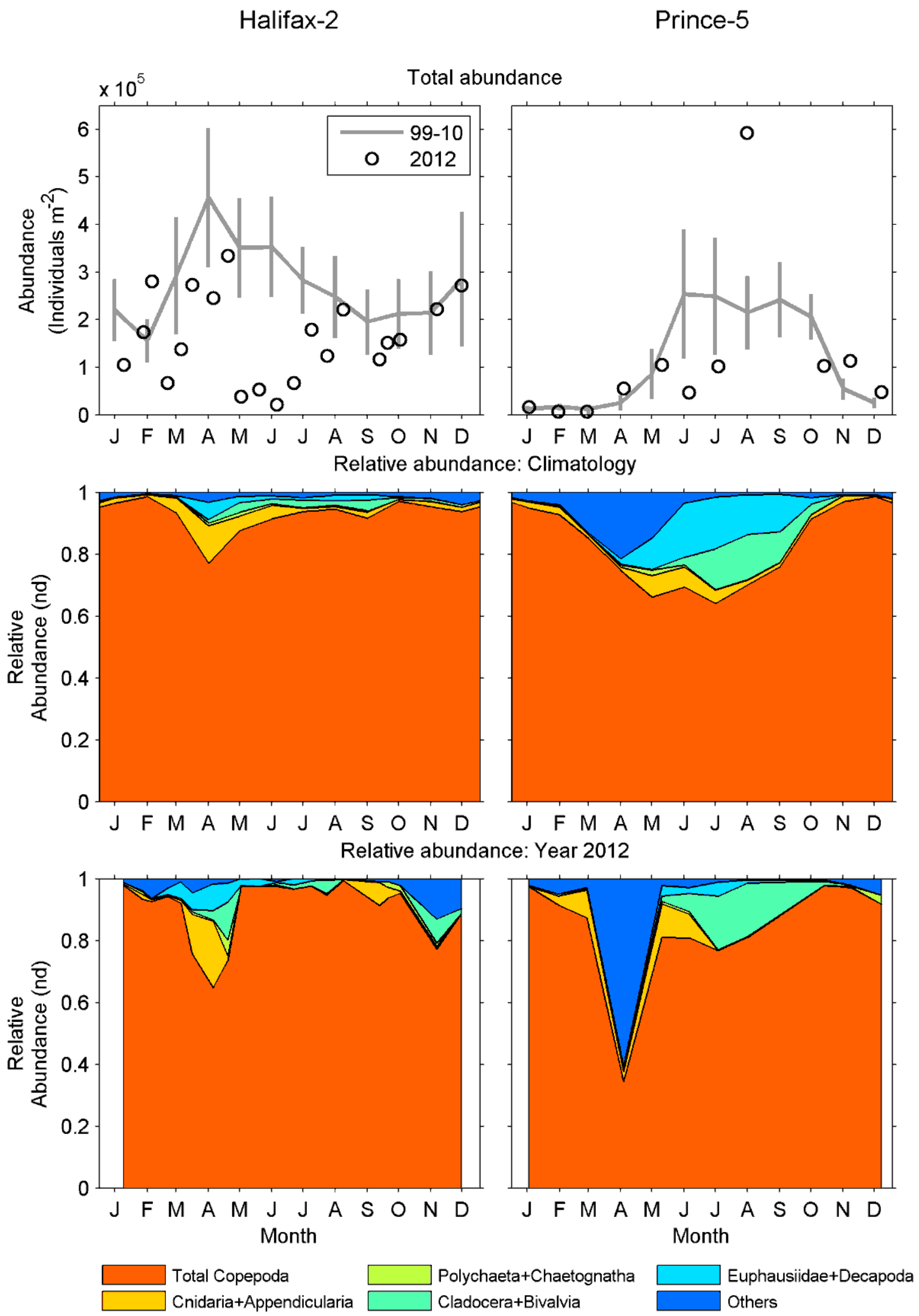


Figure 18. Comparison of 2012 zooplankton (>200 µm) abundance and community composition with mean conditions from 1999–2010 at the Maritimes fixed stations (Halifax-2, left panels; Prince-5, right panels). Upper panels: 2012 zooplankton abundance (open circle) compared with mean conditions from 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the annual averages. Middle panels: Climatology of major group abundance from 1999–2010. Lower panels: 2012 major group abundance. nd = no dimensions.

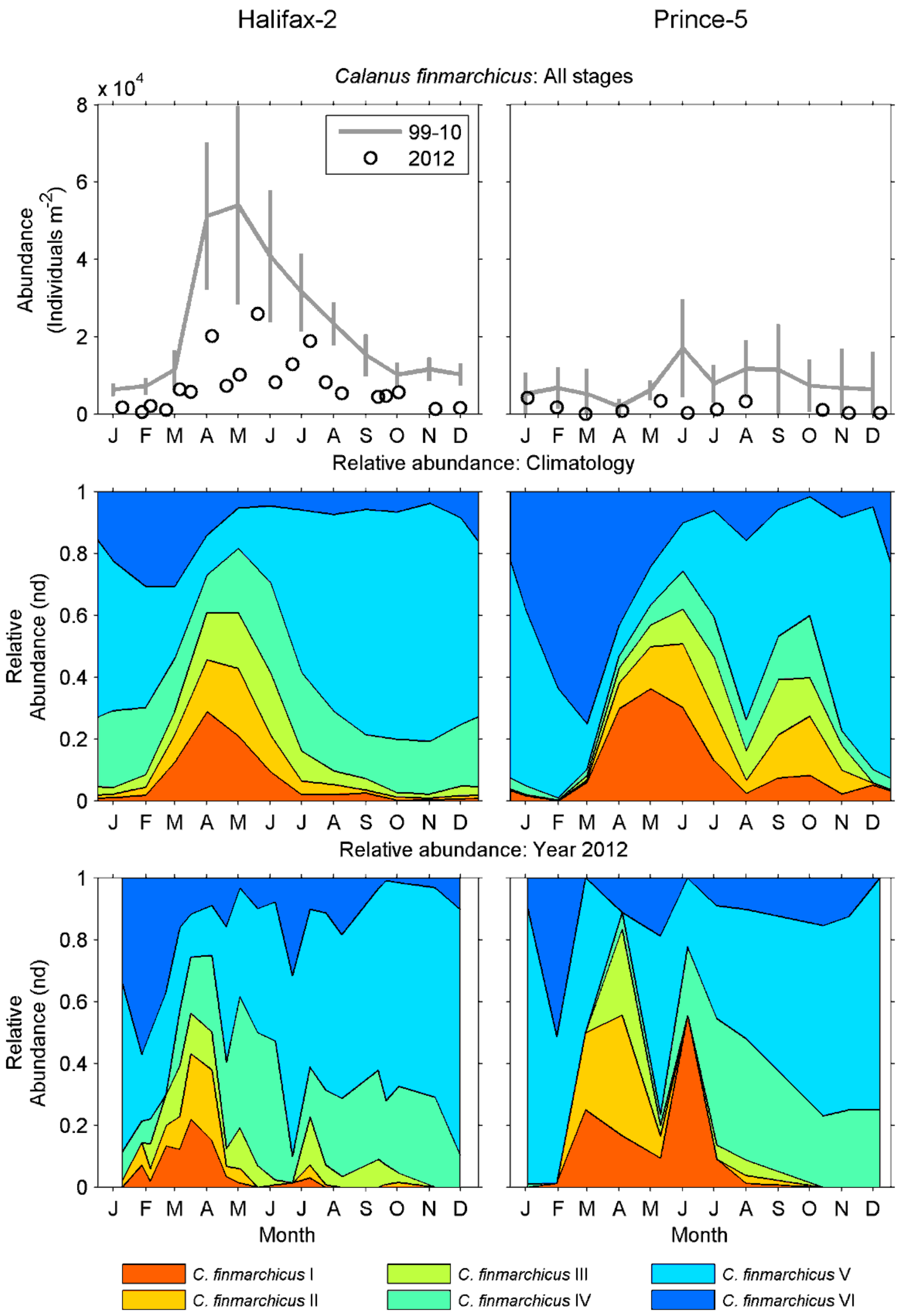


Figure 19. Comparison of 2012 C. finmarchicus abundance and developmental stage distributions with mean conditions from 1999–2010 at the Maritimes fixed stations (Halifax-2, left panels; Prince-5, right panels). Upper panels: 2012 C. finmarchicus abundance (open circle) compared with mean conditions from 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the annual averages. Middle panels: Climatological C. finmarchicus stage relative abundance from 1999–2010. Lower panels: 2012 C. finmarchicus stage relative abundance. nd = no dimensions.

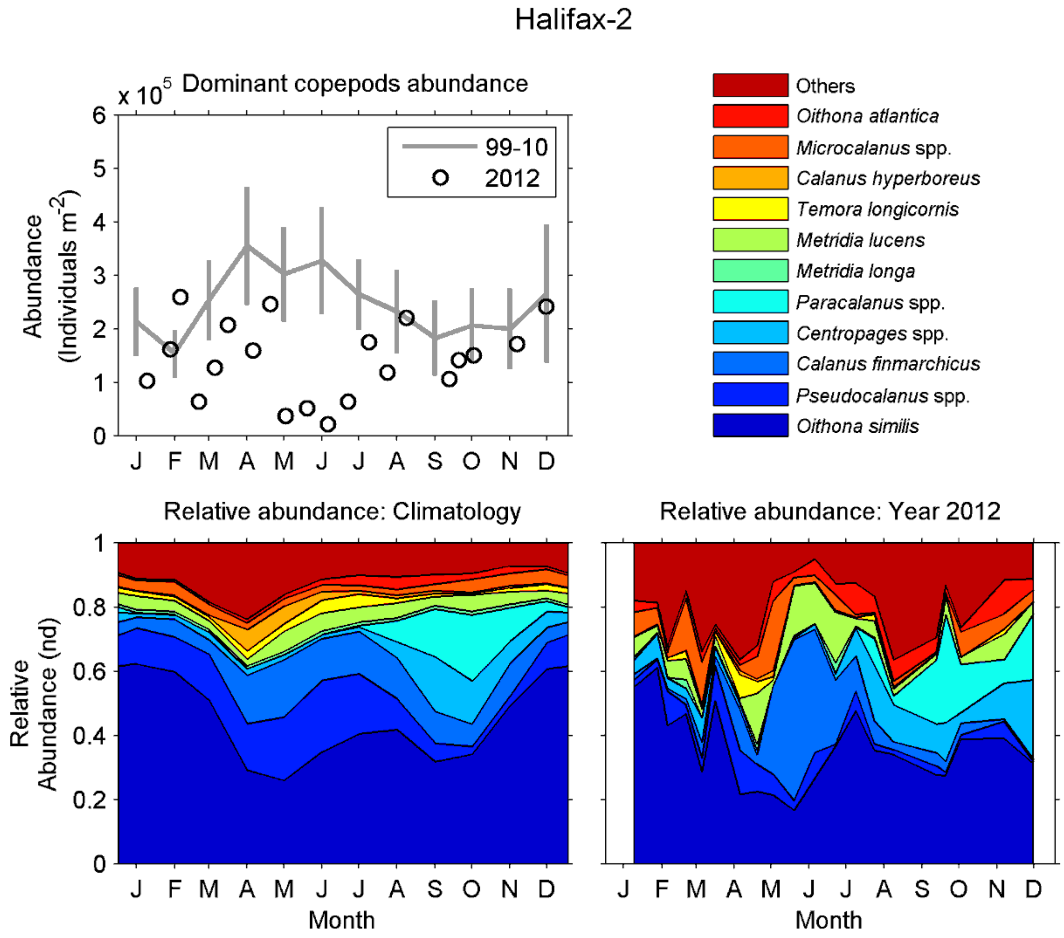


Figure 20a. Seasonal variability of dominant copepods at Halifax-2. The top 95% of identified copepod taxa by abundance, 1999-2010, are shown individually; others, including unidentified copepods (mostly nauplii) are grouped as "others." Upper left panel: 2012 copepod abundance (open circle) compared with mean conditions from 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the annual averages. Lower left panel: Climatology of copepod relative abundance from 1999–2010. Lower right panel: 2012 copepod relative abundance. nd = no dimensions.

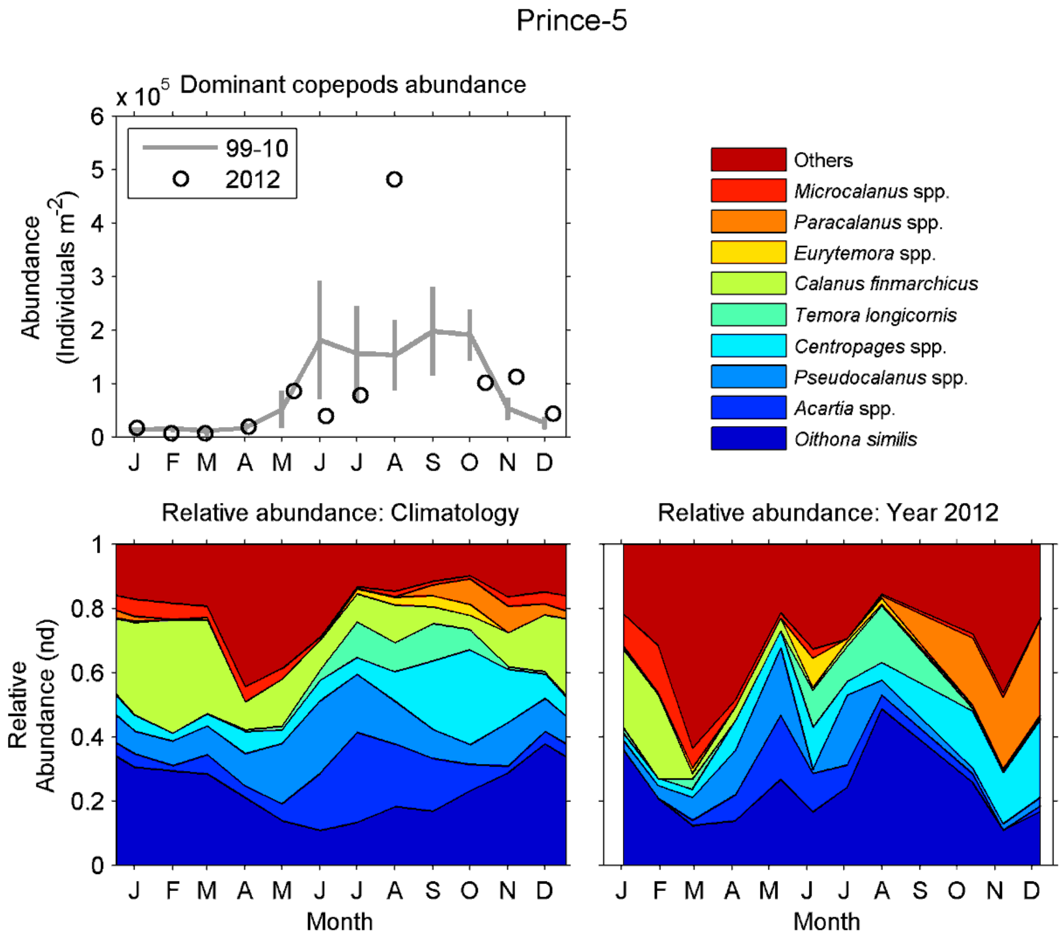
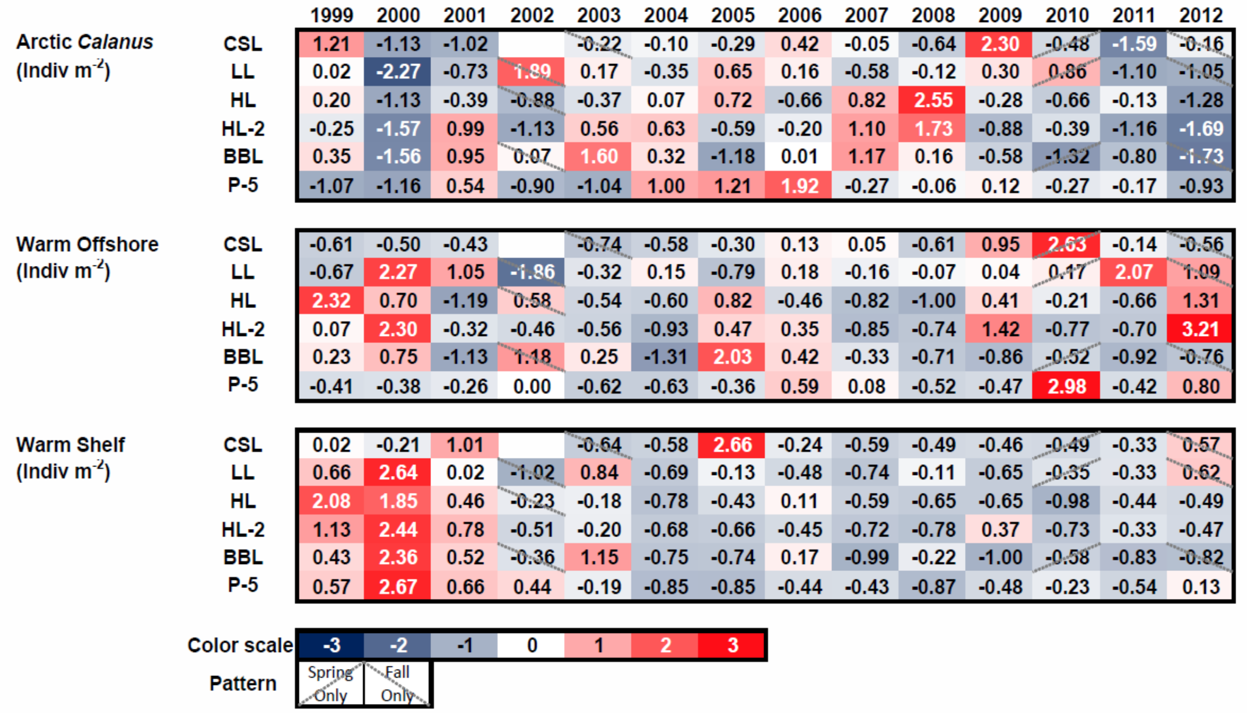


Figure 20b. Seasonal variability of dominant copepods at Prince-5. The top 95% of identified copepod taxa by abundance, 1999-2010, are shown individually; others, including unidentified copepods (mostly nauplii) are grouped as "others." Upper left panel: 2012 copepod abundance (open circle) compared with mean conditions from 1999–2010 (solid line). Vertical lines are 95% confidence intervals of the annual averages. Lower left panel: Climatology of copepod relative abundance from 1999–2010. Lower right panel: 2012 copepod relative abundance. nd = no dimensions.



		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Arctic *Calanus* (Indiv m^{-2})	CSL	1.21	-1.13	-1.02		-0.22	-0.10	-0.29	0.42	-0.05	-0.64	2.30	-0.48	-1.59	-0.16
	LL	0.02	-2.27	-0.73	1.89	0.17	-0.35	0.65	0.16	-0.58	-0.12	0.30	0.86	-1.10	-1.05
	HL	0.20	-1.13	-0.39	-0.88	-0.37	0.07	0.72	-0.66	0.82	2.55	-0.28	-0.66	-0.13	-1.28
	HL-2	-0.25	-1.57	0.99	-1.13	0.56	0.63	-0.59	-0.20	1.10	1.73	-0.88	-0.39	-1.16	-1.69
	BBL	0.35	-1.56	0.95	0.07	1.60	0.32	-1.18	0.01	1.17	0.16	-0.58	-1.32	-0.80	-1.73
	P-5	-1.07	-1.16	0.54	-0.90	-1.04	1.00	1.21	1.92	-0.27	-0.06	0.12	-0.27	-0.17	-0.93
Warm Offshore (Indiv m^{-2})	CSL	-0.61	-0.50	-0.43		-0.74	-0.58	-0.30	0.13	0.05	-0.61	0.95	2.63	-0.14	-0.56
	LL	-0.67	2.27	1.05	-1.86	-0.32	0.15	-0.79	0.18	-0.16	-0.07	0.04	0.17	2.07	1.09
	HL	2.32	0.70	-1.19	0.58	-0.54	-0.60	0.82	-0.46	-0.82	-1.00	0.41	-0.21	-0.66	1.31
	HL-2	0.07	2.30	-0.32	-0.46	-0.56	-0.93	0.47	0.35	-0.85	-0.74	1.42	-0.77	-0.70	3.21
	BBL	0.23	0.75	-1.13	1.18	0.25	-1.31	2.03	0.42	-0.33	-0.71	-0.86	-0.52	-0.92	-0.76
	P-5	-0.41	-0.38	-0.26	0.00	-0.62	-0.63	-0.36	0.59	0.08	-0.52	-0.47	2.98	-0.42	0.80
Warm Shelf (Indiv m^{-2})	CSL	0.02	-0.21	1.01		-0.64	-0.58	2.66	-0.24	-0.59	-0.49	-0.46	-0.49	-0.33	0.57
	LL	0.66	2.64	0.02	-1.02	0.84	-0.69	-0.13	-0.48	-0.74	-0.11	-0.65	-0.35	-0.33	0.62
	HL	2.08	1.85	0.46	-0.23	-0.18	-0.78	-0.43	0.11	-0.59	-0.65	-0.65	-0.98	-0.44	-0.49
	HL-2	1.13	2.44	0.78	-0.51	-0.20	-0.68	-0.66	-0.45	-0.72	-0.78	0.37	-0.73	-0.33	-0.47
	BBL	0.43	2.36	0.52	-0.36	1.15	-0.75	-0.74	0.17	-0.99	-0.22	-1.00	-0.58	-0.83	-0.82
	P-5	0.57	2.67	0.66	0.44	-0.19	-0.85	-0.85	-0.44	-0.43	-0.87	-0.48	-0.23	-0.54	0.13

Color scale	-3	-2	-1	0	1	2	3
Pattern	Spring Only	Fall Only					

Figure 21. Immigrant species group scorecard: time series of zooplankton community index normalized annual anomalies, 1999–2012. A white cell indicates missing data. Red (blue) cells indicate higher (lower) than normal zooplankton group abundance. Reference period is 1999–2010. The numbers in the cells are the anomaly values. CSL: Cabot Strait section; LBL: Louisbourg section; HL: Halifax section; HL-2: Halifax-2; BBL: Browns Bank section; P-5: Prince-5.

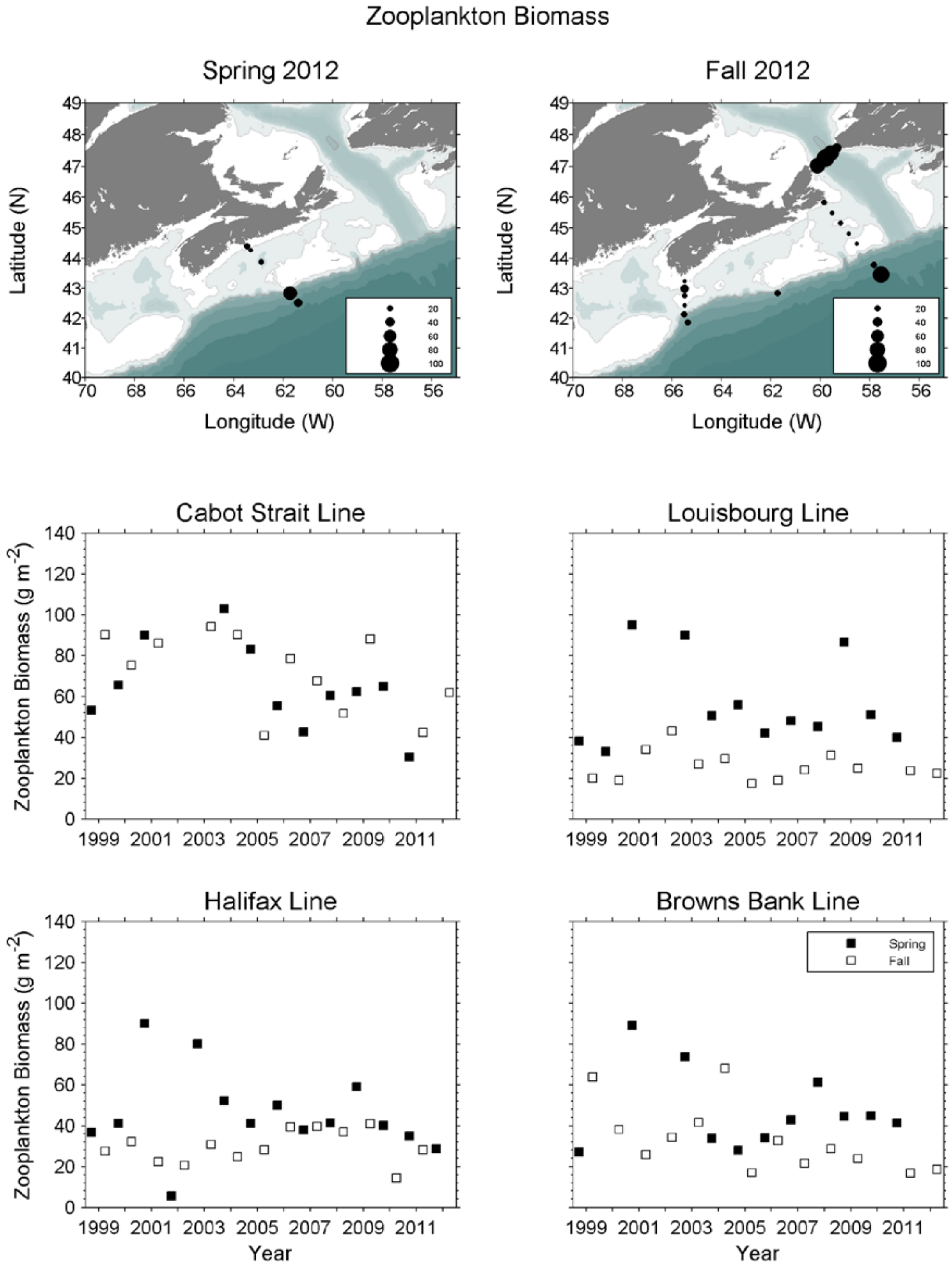


Figure 22a. Spatial distribution of zooplankton biomass in 2012 (upper panels) and average zooplankton biomass on Scotian Shelf sections (middle and lower panels) in spring and fall, 1999-2012. Halifax section was sampled on the ecosystem trawl survey in spring 2012. Zooplankton biomass could not be measured for most Halifax section stations in fall 2012 due to high salp abundance and is not reported here.

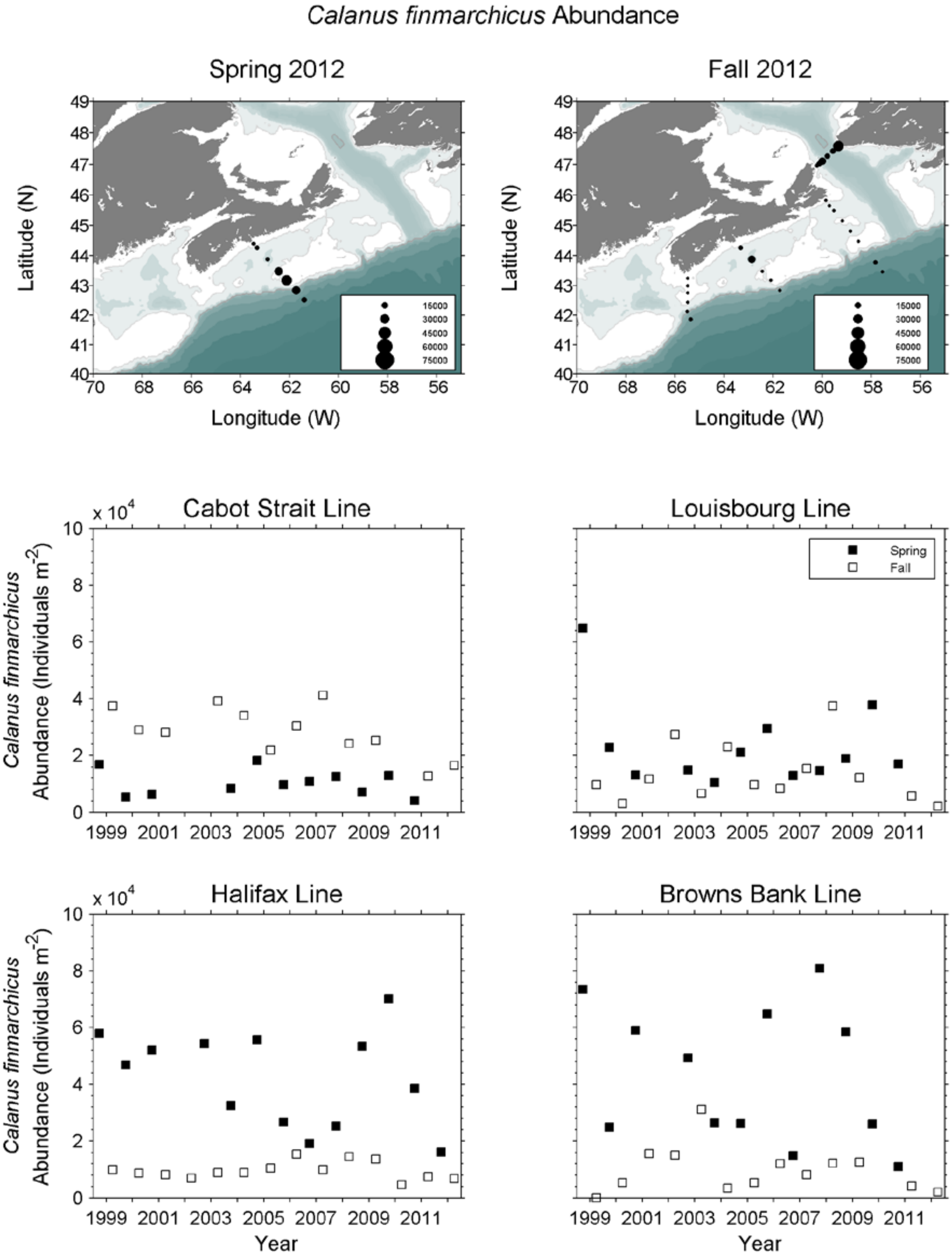


Figure 22b. Spatial distribution of <u>C. finmarchicus</u> abundance in 2012 (upper panels) and average <u>C. finmarchicus</u> abundance on Scotian Shelf sections (middle and lower panels) in spring and fall, 1999-2012. Halifax section was sampled on the ecosystem trawl survey in spring 2012.

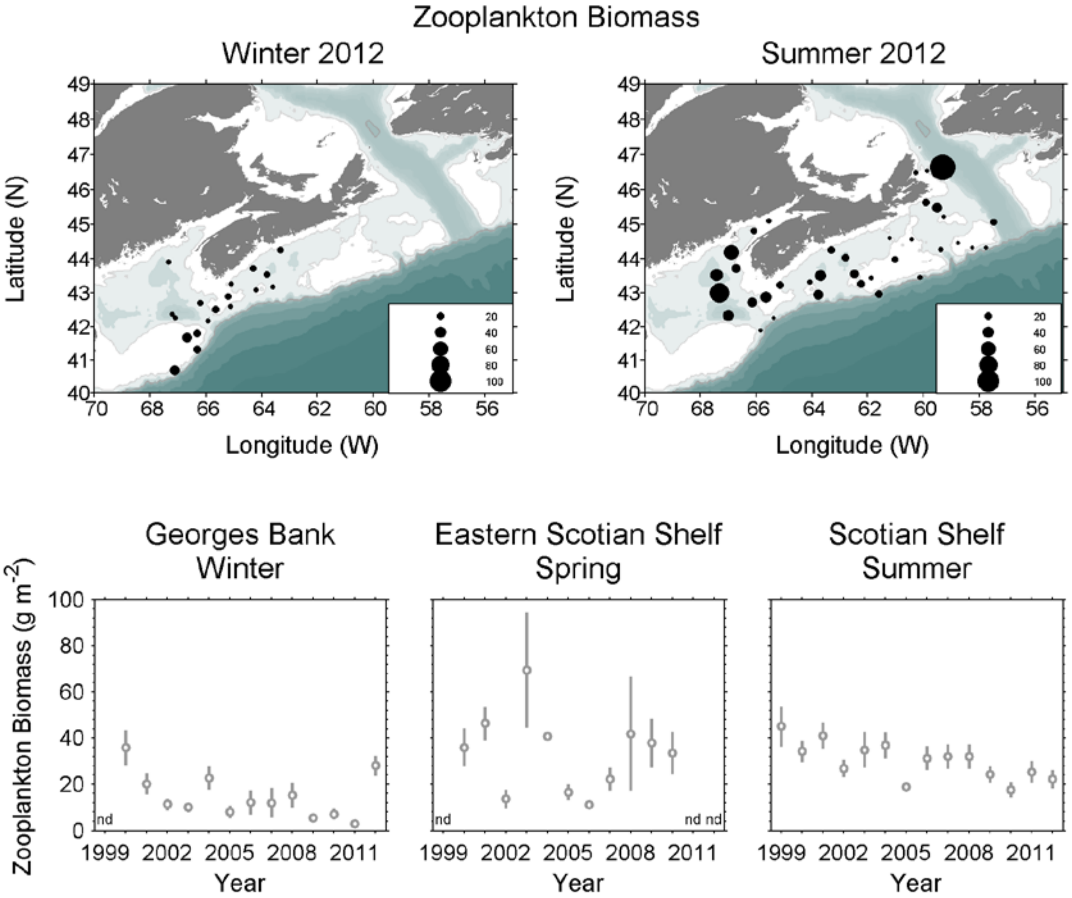


Figure 23a. Zooplankton biomass from ecosystem trawl surveys on Georges Bank (February), the eastern Scotian Shelf (March) and the Scotian Shelf and eastern Gulf of Maine (summer): upper panels show 2012 spatial distributions, lower panels show survey mean biomass, 1999–2010 (vertical bars are standard errors; nd = no survey in that year).

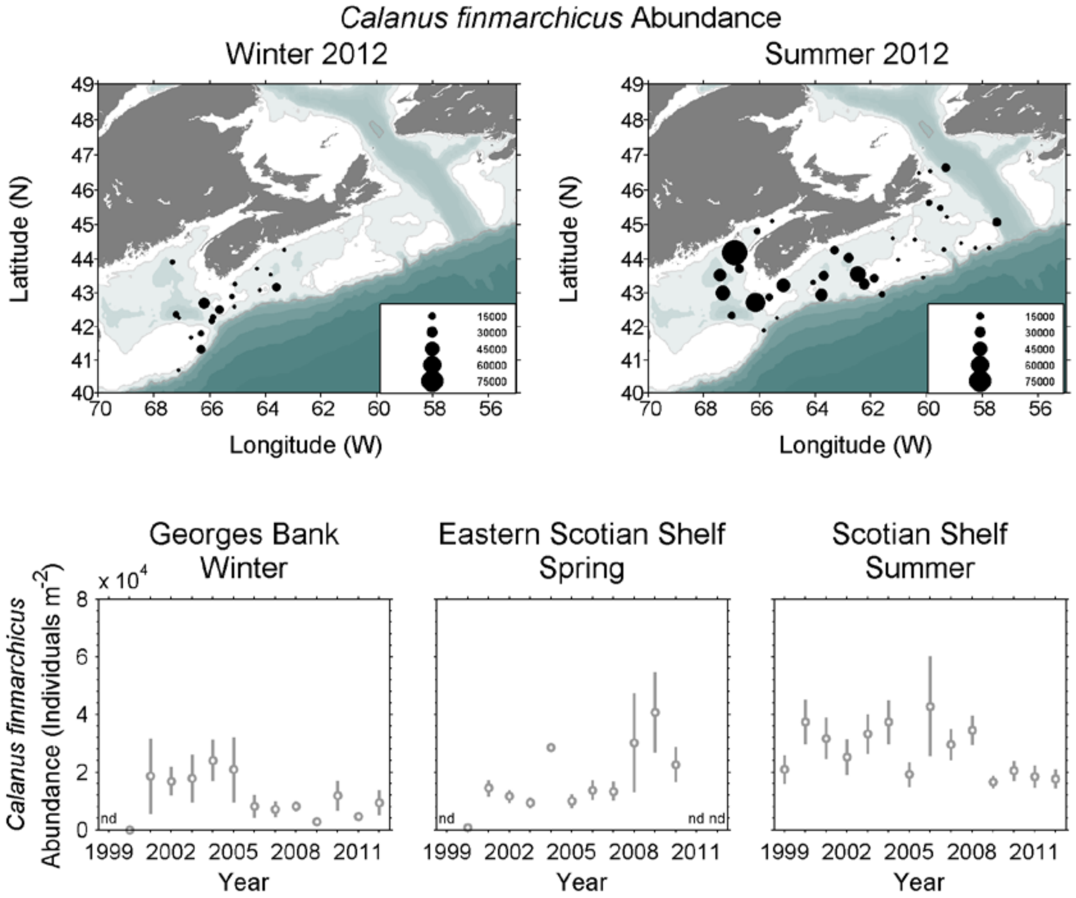


Figure 23b. Calanus finmarchicus abundance from ecosystem trawl surveys on Georges Bank (February), the eastern Scotian Shelf (March) and the Scotian Shelf and eastern Gulf of Maine (summer): upper panels show 2012 spatial distributions, lower panels show survey mean abundance, 1999–2010 (vertical bars are standard errors; nd = no survey in that year).

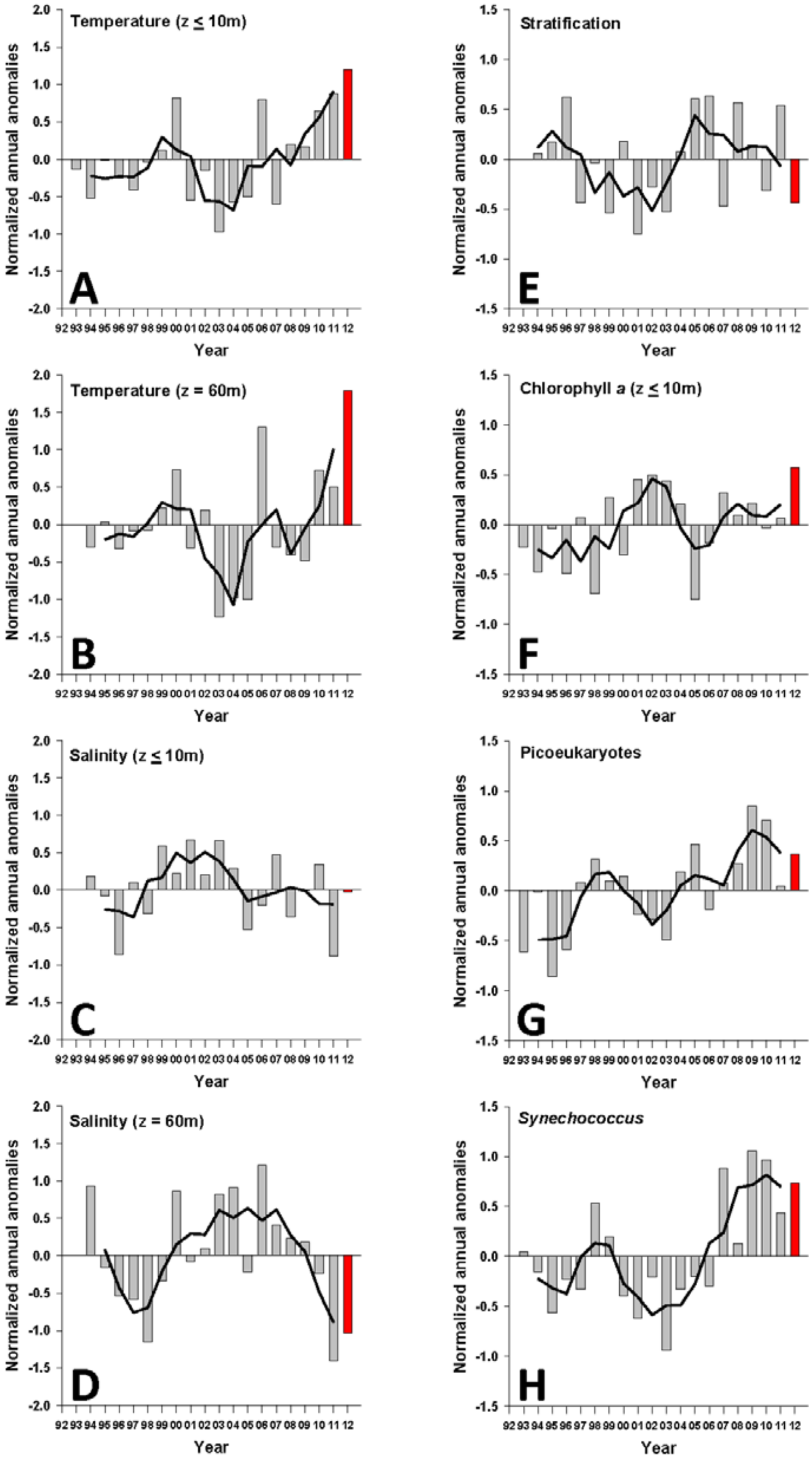


Figure 24. The state of Bedford Basin in 2012 (red) in a 20-year time series indicated by normalized annual anomalies (bars) and three-year running average (lines) for (A) surface temperature, (B) deep temperature, (C) surface salinity, (D) deep salinity, (E) stratification index, (F), surface chlorophyll a, (G) picoeukaryotic algae, and (H) picocyanobacteria Synechococcus.