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Biological Oceanographic Conditions in the Northwest Atlantic During 2016

by

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Abstract

Biological and chemical variables collected in 2016 from coastal high frequency monitoring stations, semi-annual oceanographic transects, and ships of opportunity ranging from the Labrador-Newfoundland and Grand Banks Shelf (Subareas 2 and 3), extending west into the Gulf of St. Lawrence (Subarea 4) and further south along the Scotian Shelf and the Bay of Fundy (Subarea 4) and into the Gulf of Maine (Subarea 5) are presented and referenced to previous information from earlier periods when available. We review the interannual variations in inventories of nitrate, chlorophyll *a* and indices of the spring bloom inferred from satellite ocean colour imagery, as well as the abundance of major functional taxa of zooplankton collected as part of the 2015 Atlantic Zone Monitoring Program (AZMP). In general, nitrate inventories in the upper (0-50m) water-column were near to above normal compared to the 1999-2010 climatology throughout the northern Subareas but below normal from the southern Gulf of St. Lawrence down to the Scotian Shelf in 2015-2016. The deeper (50-150m) nitrate inventories continue to remain below normal on the Grand Bank but have increased to near normal on northern transects (3K-2J). The elevated inventories of deep nitrate observed in the Gulf of St. Lawrence and Scotian Shelf in 2015 declined in 2016, particularly on the western Scotian Shelf (4W-4X). The chlorophyll *a* inventories inferred from the seasonal AZMP oceanographic surveys and fixed stations were variable throughout the Gulf of St. Lawrence and Scotian Shelf and remained below normal over the northern transects (2J to 3LNO) in 2015-2016. We noted a positive linear relationship of changes in shallow and deep composite indices of nitrate with the chlorophyll composite time series suggesting regulation of phytoplankton productivity through nitrate availability throughout the zone. Both the magnitude and amplitude metrics of the spring bloom were mostly below the long-term climatology over the 25 Subareas and generally consistent with the observations from the Atlantic Zone Monitoring seasonal surveys in 2016. Some exceptional spring blooms were observed across the Labrador Sea and Gulf of St. Lawrence in 2016. The timing of the spring bloom varied with mixed results throughout the Subareas with later onset in the northern regions including the Labrador Sea and Greenland Shelf, near-normal on the Labrador Shelf (2H) and south to the northeast Newfoundland Shelf (3KL), with both large negative and positive anomalies throughout the Gulf of St. Lawrence, Scotian Shelf and Gulf of Maine. The abundance of key functional zooplankton groups were generally higher in 2015-2016 across the AZMP standard transects and fixed stations. The abundance of an important small grazer copepod (*Pseudocalanus spp.*) remained elevated as in previous years across the northern transects (2J) through the southern Gulf of St. Lawrence

((4T). The abundance of dominant copepods and non-copepods (mostly gelatinous and carnivorous zooplankton) were consistently higher across the entire zone. One exception to this general trend in abundance of key functional zooplankton groups is for the larger grazing copepod, *Calanus finmarchicus,* an important prey to a variety of different life stages of fish, with reduced standing stocks throughout the entire zone. Standing stocks of phytoplankton inferred from ship surveys and remote sensing did not appear to be related to changes in the abundance of zooplankton.

Introduction

We review biological and chemical oceanographic conditions on the Newfoundland and Labrador Shelves, Grand Bank, Gulf of St. Lawrence, Scotian Shelf, and Gulf of Maine during 2016, and reference earlier periods when data are available. More frequent directed sampling from research vessels on oceanographic transects and ships of opportunity at coastal fixed stations by the Atlantic Zone Monitoring Program (AZMP[1]) and the completion of seasonal oceanographic surveys during 2016 provided reasonable spatial and temporal series coverage (more limited surveys were conducted across the Newfoundland and Labrador Region in 2016) of standard variables which afford a foundation for comparison with previous years. Additional details regarding physical, biological and chemical oceanographic conditions in the Northwest Atlantic in 2015 and earlier years can be found in Colbourne *et al.* (2015, 2016), Devine *et al.* (2015), and DFO (2015), Galbraith *et al.* (2015, 2016), Hebert *et al.* (2015, 2016), Johnson *et al*. (2016, 2017), Pepin *et al*. (2015, 2017), Plourde *et al.* (2014), Yashayaev *et al.* (2014).

Methods

Collections of standard AZMP variables are based on sampling protocols outlined by Mitchell *et al*. (2002). Observations for 2016 and earlier years presented in this document are based on seasonal surveys conducted during the spring through the autumn (typically March through December). The coastal stations are typically sampled at twice monthly to monthly intervals during ice-free conditions. The location of the standard oceanographic transects and coastal stations are shown in Figure 1.

Phytoplankton biomass was estimated from ocean colour data collected by the Sea-viewing Wide Field-of-view Sensor (SeaWiFS; http://seawifs.gsfc.nasa.gov/SEAWIFS.html), Moderate Resolution Imaging Spectroradiometer (MODIS) "Aqua" sensor (http://modis.gsfc.nasa.gov/), and the Visible-Infrared Imager Radiometer Suite (VIIRS) sensor (https://oceancolor.gsfc.nasa.gov/data/viirs-snpp/). The SeaWiFS time series began in the September of 1997, MODIS data stream began in July, 2002, and VIIRS availability is January 2012 to present. Satellite data do not provide information on the vertical structure of chlorophyll *a* (chl*a*) in the water column but do provide highly resolved (~1.5 km) data on their geographical distribution in surface waters at the large scale. Composite images of 8-days for chl*a* for the entire NW Atlantic (39-62.5° N Latitude 42-71° W Longitude) were routinely produced from SeaWiFS/MODIS/VIIRS data[2]. Basic statistics (mean, range, standard deviation, etc.) were extracted from the composites for selected statistical sub-regions as shown in Figure 1. We constructed an ocean colour time series from 1998 to 2016 using data from the available satellite sensors using the following periods; 1998-2007 SeaWiFS, 2008-2011 MODIS, and 2012-2016 VIIRS.

Standardized annual anomalies were developed as a method of summarizing the many variables used to represent the state of lower trophic levels. To simplify the information, the time-series of the annual estimate of inventory or abundance for each summary variable was standardized to a mean of zero (for the period 1998/1999 – 2010) and unit standard deviation ([observation – mean]/SD). The standard deviation provides a measure of the variability of an index. The result of this standardization yields a series of annual anomalies. The anomalies serve to illustrate departures from the long term mean across the range of variables. Values near the mean (e.g. 0 anomaly) indicate near normal while positive values indicate above and/orlater or negative values which represent below and/orearlier compared to the climatology. A larger difference between a given year and the climatological mean represents the increasing magnitude of that departure. For the chemical-biological observations, the key variables selected were: (1) near surface (0-50 m) and deep (50-150

[1] http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/azmp-pmza/index-eng.html
[2] http://www.bio.gc.ca/science/newtech-technouvelles/sensing-teledetection/index-en.php

m) nitrate inventories, and (2) 0-100m integrated chl*a*, satellite indices of the magnitude and amplitude, peak timing and duration of the spring bloom (Zhai *et al*. 2011), and zooplankton abundance for different functional zooplankton taxa (*Pseudocalanus spp*., *Calanus finmarchicus,* total copepods, and total non-copepods) for the AZMP fixed stations and seasonal transects.

Annual Variability in Nutrient, Phytoplankton, and Zooplankton Conditions in the NAFO Subareas

Based on the available data, the upper water-column (0-50m integral) nitrate inventories varied throughout the northwest Atlantic with anomalies generally near or slightly above the climatology in northern Subareas (2J to 3LNO) in contrast to ~ 2 standard deviations below normal throughout the Gulf of St. Lawrence and Scotian Shelf in 2016 (Figure 2). The deep (50-150m integral) nitrate inventories were near normal along northern transects (2J-3K) and within the Gulf of St. Lawrence, with increasing levels of depletion southwards along the Scotian Shelf in 2016 (Figure 2). In general, the annual anomaly trends in nitrate inventories in the upper water-column were mostly near or above normal during the first half of the time series followed by an abrupt decline in 2008 to a record-low in 2010 (Figure 3). Shallow inventories have subsequently improved steadily from 2010 to 2015 across the northwest Atlantic with another sharp decline observed in the composite index in 2016. The corresponding time series for deep nitrate inventories generally followed trends similar to that observed in the upper water column (Figure 3). The chl*a* inventories inferred from the seasonal oceanographic surveys, which provides an index of phytoplankton biomass throughout the water-column, were consistently below normal throughout Subareas 2-4 with the largest decline observed over the Grand Bank (3LMNO) in 2016 (Figure 4). The overall trend in chlorophyll *a* biomass is negative from the start of the series until a record-low observed in 2011, punctuated by a brief record-high in 2007 with most transects and fixed stations showing above normal inventories (Figure 5). Biomass subsequently increased from 2011 through 2015 following the decline noted in 2016. The trends in both shallow and deep nitrate inventories based on the composite indices were correlated ($r^2 = 0.33$; $p < 0.05$) and track the changes in chlorophyll biomass across Subareas 2-4 (Figure 5). The shallow and deep inventories accounted for ~ 25 % ($r^2 = 0.24$; $p < 0.05$ for shallow layer; $r^2 = 0.23$; $p = 0.05$ for deep nitrate layer respectively with 1-year lag) of the variability in chlorophyll biomass.

Annual anomalies were computed for each ocean colour metric during 2016 to evaluate spatial patterns of the spring bloom across the different statistical sub-regions. The magnitude (integral of chl*a* biomass over the duration of the bloom) was consistently below normal across the sub-regions except for blooms observed over the Labrador Sea reaching 3 standard deviations above the reference mean in 2016 (Figure 6). The amplitude (peak intensity) of the spring bloom was mostly below normal throughout Subareas 0B to 5 with the exception of unusual high values observed in isolated areas of the Gulf of St. Lawrence (Figure 6). The spatial trend in timing indices (peak timing and duration) of the spring bloom showed variable conditions throughout the northwest Atlantic. Timing of the spring bloom was delayed (positive anomalies) in northern sub-regions 0B to 1F and Grand Bank while near-normal from northern Labrador to the northeast Newfoundland Shelf (Figure 7). Earlier blooms (negative anomalies) characterized the Gulf of St. Lawrence with mixed conditions further south over the Scotian Shelf and Gulf of Maine (Figure 7). The duration of the spring bloom was variable throughout the northern sub-regions but below normal throughout the Gulf of St. Lawrence (Figure 7). The duration of the production cycle was mostly near normal on the Grand Bank and eastern Scotian Shelf with the exception of the Cabot Strait, western Scotian Shelf, and the Flemish Cap, all with exceptional long blooms in 2016.

Time series of standardized anomalies were constructed for each ocean colour metric extending back to the start of SeaWiFS in 1998. In addition, we developed composite indices for each of the ocean colour metrics by summing all of the annual anomalies within a given year across the sub-regions. Overall, the magnitude of the spring bloom showed small changes from 1998 until 2005 followed by an increasing trend from 2006 until a record-high in 2011 and a subsequent decline through 2016 (Figure 8). Changes in the amplitude of the spring bloom closely followed the trends observed in magnitude with limited change through 2005, an increasing trend with a record-high in 2011, followed by a decline through 2016 (Figure 9). Changes in peak timing of the spring bloom shifted between periods of early-late blooms throughout the 19-year time series with a periodicity of 3-5 year cycle (Figure 10). The record-early timing was also associated with 2011 followed by a trend to later onset of the spring bloom through 2016. Record-late timing was observed in 2015 (Figure 10). A gradual reduction in the duration of the spring bloom was detected from the late 1990's through 2011 (record-low) across the sub-regions based on the composite index (Figure 11). The duration of the spring bloom has gradually increased in recent years with the record-high in 2016 as a result of some exceptional long-duration blooms observed at broadly distributed locations throughout the zone ranging from the Hudson Strait in 0B to Subarea 5 in the Gulf of Maine.

The pattern of annual anomalies for the different functional zooplankton groups showed consistent and coherent patterns and spatial gradients across the entire survey area in 2015-2016. The zooplankton abundance anomalies for a key small grazer and dominant copepod in the survey area, *Pseudocalanus spp*., remain high in 2016 similar to the pattern observed in previous years with the largest positive anomalies (> 4 SD units) observed over the Flemish Cap, northwest Gulf of St. Lawrence and Rimouski fixed sampling station (Figure 12). Similar to the trends observed in the previous year, the abundance of *Pseudocalanus spp*. was generally below normal on the western Scotian Shelf. These small epipelagic, subarctic copepods represent an important preferred prey to many early life stages of fish. The abundance anomalies for the large grazing copepod, *Calanus finmarchicus,* another dominant species and important prey item to higher trophic levels and energy transfer was mostly below normal throughout the zone. The large decline in abundance anomalies of *C. finmarchicus* observed in 2015 across the zone remains ongoing into 2016 (Figure 12). In general, the abundance of *C. finmarchicus* averaged between 1-2 SD below normal in 2016 but reduced compared to large negative anomalies reaching up to -7 SD (e.g. Cabot Strait transect) in 2015. The abundance of all combined copepod taxa continue to remain high in 2016 as in the previous year with the largest levels observed along the northern transects and fixed station in the Gulf of St. Lawrence with an exceptional positive anomaly in excess of 8 SD (Figure 13). The non-copepod (mostly larval stages of benthic invertebrates, gelatinous and carnivorous zooplankton) taxa also continue to remain well above normal throughout the northeast Newfoundland Shelf and eastern Gulf of St. Lawrence in 2015-2016.

Time series of standardized anomalies were constructed for each of the functional zooplankton groups extending back to the initiation of the monitoring program in 1999. In addition, we developed composite indices for each of the time series by summing all of the annual anomalies within a given year across the AZMP transects and fixed stations. The abundance time series for the small grazing copepod *Pseudocalanus* spp. has increased dramatically in recent years beginning in 2013 with higher contributions from the Rimouski fixed station and Flemish Cap, eastern and northwest Gulf of St. Lawrence transects (Figure 14). Prior to that period, the abundance anomaly series for *Pseudocalanus* spp. was relatively stable with no distinct trend from 1999-2011. The record-low occurred in 2012 just prior to the transition in abundance (Figure 14). The abundance anomalies for *Calanus finmarchicus* increased slightly through the early years of monitoring during 1999-2005. Thereafter, the abundance peaked in the middle of the series from 2006-2008 and then underwent a sustained decline from 2009 to a record-low in 2015 (Figure 14). Similar patterns of change in the abundance anomalies were observed for total copepods and non-copepod functional groups with relatively limited change from the start of the monitoring program until 2014 when both taxa increased rapidly and continue to remain at much higher levels compared to the reference mean (Figure 15).

Given the links between zonal nitrate inventories and phytoplankton abundance indices, we investigated the relationship between phytoplankton and zooplankton indices across Subareas 2-4. We developed two separate phytoplankton composite indices; one based on survey estimates of integrated chlorophyll biomass while the other used the synoptic ocean colour remote sensing data over Subarea 2-4. The phytoplankton series generally tracked each other from 1998 through until 2008 when we observed a large increase in the ocean colour during 2010-2012 which was not detected in the survey-based biomass series (Figure 16). The differences between these series could be related to changes in the timing of seasonal production cycle since the AZMP surveys are generally conducted at the same time each year. This observation is partially supported by the timing of the spring bloom which indicated the production cycle coincided with a record-early event detected in 2011 (Figure 10). At the time of the large transition in phytoplankton biomass detected by remote sensing data, a corresponding rapid increase in the functional zooplankton groups occurred from 2011 to 2012 (Figure 16). Another rapid increase in the zooplankton composite index was noted between 2012 and 2013 and the composite index has remained stable at these higher levels through to 2016 despite the large decline observed in the phytoplankton series back down to pre-2010 levels. Thus, the changes in phytoplankton standing stocks and metrics derived from remote sensing do not appear to be correlated with the changes in abundance of the functional zooplankton groups. Despite the time series now approaching 20 years in duration for the various biological time series, the number of data points is still rather limited and the full range of environmental variability has not been fully investigated which may hinder our ability to detect linkages between and among the lower trophic levels.

Biological Oceanographic Highlights in 2016

- Nitrate inventories in the upper (0-50m) water-column were near to above normal compared to the 1999-2010 climatology throughout the northern Subareas but below normal from the southern Gulf of St. Lawrence down to the Scotian Shelf in 2016.
- The deeper (50-150m) nitrate inventories continue to remain below normal on the Grand Bank but have increased to near normal on northern transects (2J-3K). The elevated inventories of deep nitrate observed in the Gulf of St. Lawrence and Scotian Shelf in 2015 declined in 2016, particularly on the western Scotian Shelf (4W-4X).
- The chlorophyll *a* inventories inferred from the seasonal AZMP oceanographic surveys and fixed stations were variable throughout the Gulf of St. Lawrence and Scotian Shelf and remained below normal over the northern transects (2J to 3LNO) in 2016.
- We noted a positive linear relationship between shallow and deep nitrate composite indices with the chlorophyll composite time series suggesting regulation of phytoplankton standing stock through nitrate availability across Subareas 2-4.
- Both the magnitude and amplitude metrics of the spring bloom were mostly below the long-term climatology over the 25 Subareas and generally consistent with the observations from the Atlantic Zone Monitoring seasonal surveys.
- Some exceptionally intense spring blooms were observed across the Labrador Sea and Gulf of St. Lawrence in 2016.
- The timing of the spring bloom demonstrated limited spatial coherence among Subareas, with later onset in the northern regions including the Labrador Sea and Greenland Shelf, near-normal on the Labrador Shelf (2H) and south to the northeast Newfoundland Shelf (3KL), with both large negative (early blooms) and positive (late blooms) anomalies throughout the Gulf of St. Lawrence, Scotian Shelf and Gulf of Maine.
- The abundance of key functional zooplankton groups were generally higher in 2016 across the AZMP standard transects and fixed stations but the abundance of energy-rich *Calanus finmarchicus* was below normal throughout most of the zone.
- Standing stocks of phytoplankton inferred from ship surveys and remote sensing do not appear to be related to changes in the abundance of zooplankton.

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References

Colbourne, E., Holden, J., Senciall, D., Bailey, W., Craig, J. and S. Snook. 2015. Physical Oceanographic Conditions on the Newfoundland and Labrador Shelf during 2014. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/053. v+ 37 p.

Colbourne, E., Holden, J., Senciall, D., Bailey, W., Snook, S. and Higdon, J. 2016. Physical Oceanographic Conditions on the Newfoundland and Labrador Shelf during 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/079. v +40 p.

Devine, L., Plourde, S., Starr, M., St-Pierre, J.-F., St-Amand, L., Joly, P. and Galbraith, P. S. 2015. Chemical and Biological Oceanographic Conditions in the Estuary and Gulf of St. Lawrence during 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/013. v + 45 pp.

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

Galbraith, P.S., Chassé, J., Nicot, P., Caverhill, C., Gilbert, D., Pettigrew, B., Lefaivre, D., Brickman, D., Devine, L., and Lafleur, C. 2015. Physical Oceanographic Conditions in the Gulf of St. Lawrence in 2014. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/032. v + 82 p.

Galbraith, P.S., Chassé, J., Caverhill, C., Nicot, P., Gilbert, D., Pettigrew, B., Lefaivre, D., Brickman, D., Devine, L., and Lafleur, C. 2016. Physical Oceanographic Conditions in the Gulf of St. Lawrence in 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/056. v + 90 p.

Head, J.H.E., Pepin, P. 2010. Spatial and inter-decadal variability in plankton abundance and composition in the Northwest Atlantic (1958–2006). J. Plank. Res. 32(12): 1633-1648 pp.

Hebert, D., Pettipas, R., Brickman, D., and Dever, M. 2015. Meteorological, Sea Ice and Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2014. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/040. v + 49 p.

Hebert, D., Pettipas, R., Brickman, D., and Dever, M. 2016. Meteorological, sea ice and physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine during 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/083. v + 49 p.

Johnson, C., Casault, B., Head, E., and Spry, J. 2016. Optical, Chemical, and Biological Oceanographic Conditions on the Scotian Shelf and in the Eastern Gulf of Maine in 2014. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/003. v + 51 p.

Johnson, C., Pepin, P., Curtis, K.A., Lazin, G., Casault, B., Colbourne, E., Galbraith, P.S., Harvey, M., Herbert, D., Maillet, G., and Starr, M. 2014. Indicators of Pelagic Habitat Status in the Northwest Atlantic. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/047. v + 74 p.

References (continued)

Johnson, C., Devred, E., Casault, B., Head, E., and Spry, J. 2017. Optical, Chemical, and Biological Oceanographic Conditions on the Scotian Shelf and in the Eastern Gulf of Maine in 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/012. v + 53 p.

Mitchell, M.R., Harrison, G., Pauley, K., Gagné, A., Maillet, G., and Strain, P. 2002. Atlantic Zone Monitoring Program Sampling Protocol. Canadian Technical Report of Hydrography and Ocean Sciences 223, 23 pp.

Pepin, P., Maillet, G., Fraser, S., Shears, T. and Redmond G. 2015. Optical, chemical, and biological oceanographic conditions on the Newfoundland and Labrador Shelf during 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/027. v + 37p.

Pepin, P., Maillet, G., Fraser, S., Doyle, G., Robar, A., Shears, T., and Redmond, G. 2017 Optical, chemical, and biological oceanographic conditions on the Newfoundland and Labrador Shelf during 2014-2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/009. v + 37 p.

S. Plourde, Starr, M., Devine, L., St-Pierre, J.-F., St-Amand, L., Joly, P., and Galbraith, P. S. 2014. Chemical and biological oceanographic conditions in the Estuary and Gulf of St. Lawrence during 2011 and 2012. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/049. v + 46 pp

Yashayaev, I., Head, E.J.H., Azetsu-Scott, K., Ringuette, M., Wang, Z., Anning, J., and Punshon, S. 2014. Environmental Conditions in the Labrador Sea during 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/105. v +35 p.

Zhai, L., Platt, T., Tang, C., Sathyendranath, S., and Hernández Walls, R. 2011. Phytoplankton phenology on the Scotian Shelf. – ICES Journal of Marine Science, 68: 781–791.

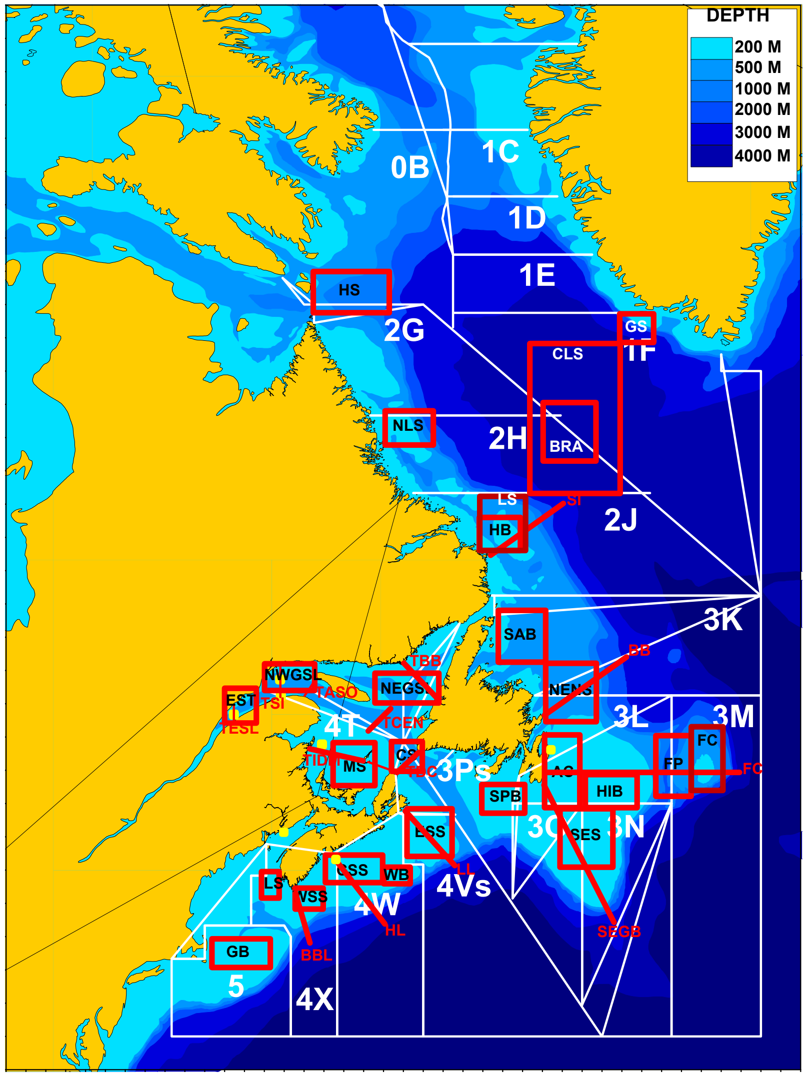

Fig. 1. Location of the NAFO Regulatory Area (white boxes) and standard Atlantic Zone Monitoring Program (AZMP) fixed coastal stations (closed yellow squares) and oceanographic transects (red lines). The statistical sub-regions (Petrie Boxes) shown by the open red boxes (HS=Hudson Strait, GS=Greenland Shelf, CLS=central Labrador Sea, BRA=ocean station Bravo, NLS=northern Labrador Shelf, LS=Labrador Shelf, HB=Hamilton Bank (Seal Island), SAB=St. Anthony Basin, NENS=northeast Newfoundland Shelf, AC=Avalon Channel, FP=Flemish Pass, FC=Flemish Cap, HIB=Hibernia, SPB=St. Pierre Bank, SES=southeast Shoal, CS=Cabot Strait, MS=Magdalen Shallows, NEGSL=northeast Gulf of St. Lawrence, NWGSL=northwest Gulf of St. Lawrence, EST = Estuary, ESS=eastern Scotian Shelf, WB=Western Bank, CSS=central Scotian Shelf, WSS=western Scotian Shelf, LS=Lurcher Shoal, GB=Georges Bank. The standard AZMP transects are SI=Seal Island, BB=Bonavista Bay, FC=Flemish Cap, SEGB=southeast Grand Bank, TESL=Lower St. Lawrence Estuary, TSI=northwest Gulf of St. Lawrence, TASO=southwest Anticosti, TBB=Bonne Bay (northeast Gulf of St. Lawrence), TCEN=Centre Gulf of St. Lawrence, TIDM=Magdalen Shallows, TDC=Cabot Strait, LL=Louisbourg Line, HL=Halifax Line, BBL=Browns Bank Line, and fixed stations (Station 27, Rimouski, Anticosti Gyre, Gaspé Current, Shediac Valley, Halifax-2, and Prince-5).

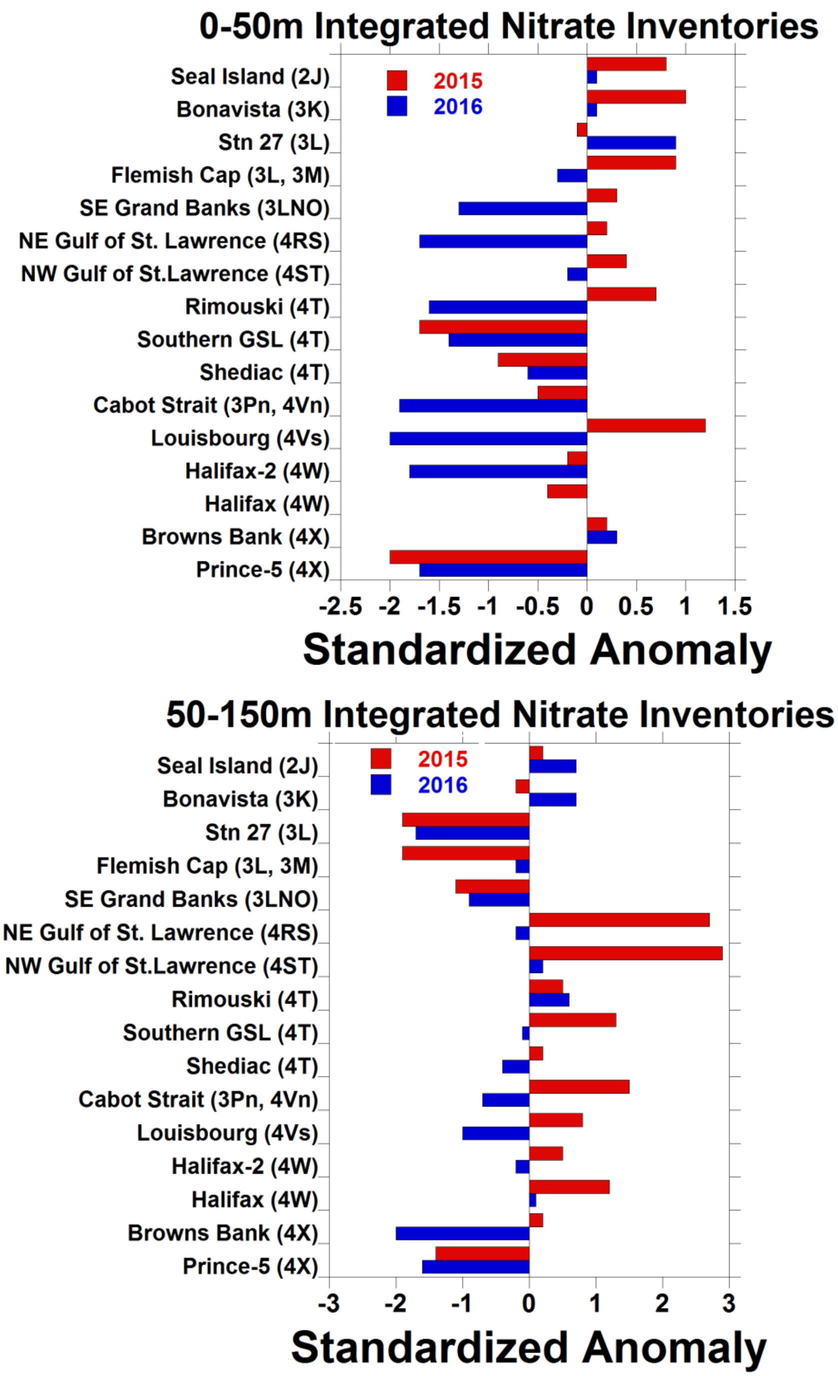

Fig.2. Summary of nitrate (combined nitrate and nitrite which represents the principal limiting nutrient for phytoplankton growth) inventories in upper (0-50m) and lower (50-150m or bottom if shallower) water column from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program during 2015 and 2016. The standardized anomalies are the differences between the annual average for a given year and the long-term mean (1999-2010) divided by the standard deviation. The nutrient anomalies for transects were calculated using a general linear model using station, season, and year while the fixed stations only used season and year as inputs and were based on all available seasonal data. The NAFO Subareas are generally sorted by latitude from north (top) to south (bottom) regions.

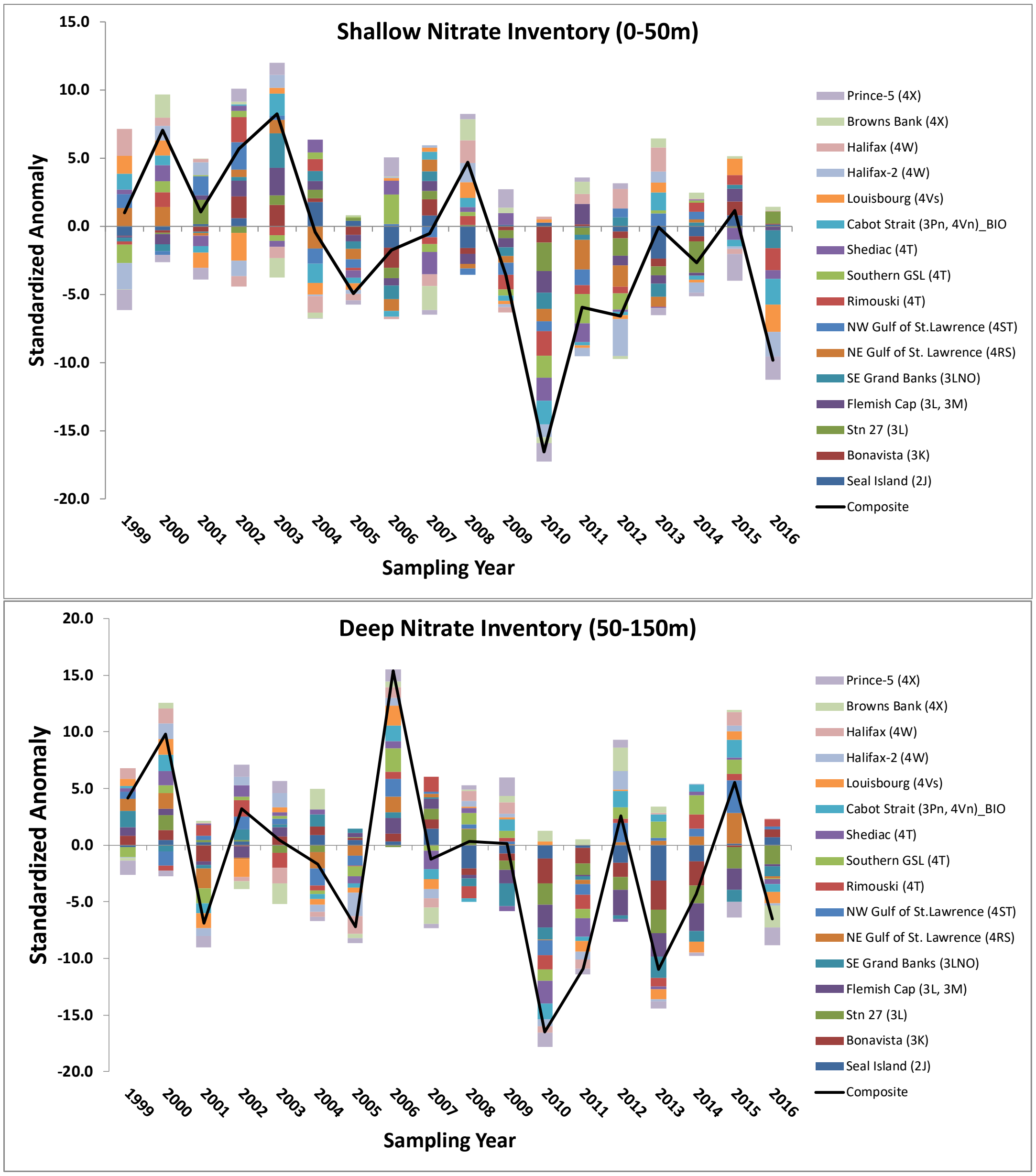

Fig. 3. Time series of shallow (0-50m) and deep (50m-bottom) nitrate (combined nitrite and nitrate) inventory anomalies from different oceanographic transects and fixed stations (in bold) from the Atlantic Zone Monitoring Program during 1999-2016. The anomalies for transects were calculated using a general linear model using station, season, and year while the fixed stations only used season and year as inputs and were based on all available seasonal data. The standardized anomalies are the differences in the annual average value from the long-term mean (1999-2010) divided by the standard deviation. The contribution from each of the NAFO Subareas is represented by colour and height of the vertical bar. The solid black line is the cumulative (composite) anomaly across all Subareas in a given year.

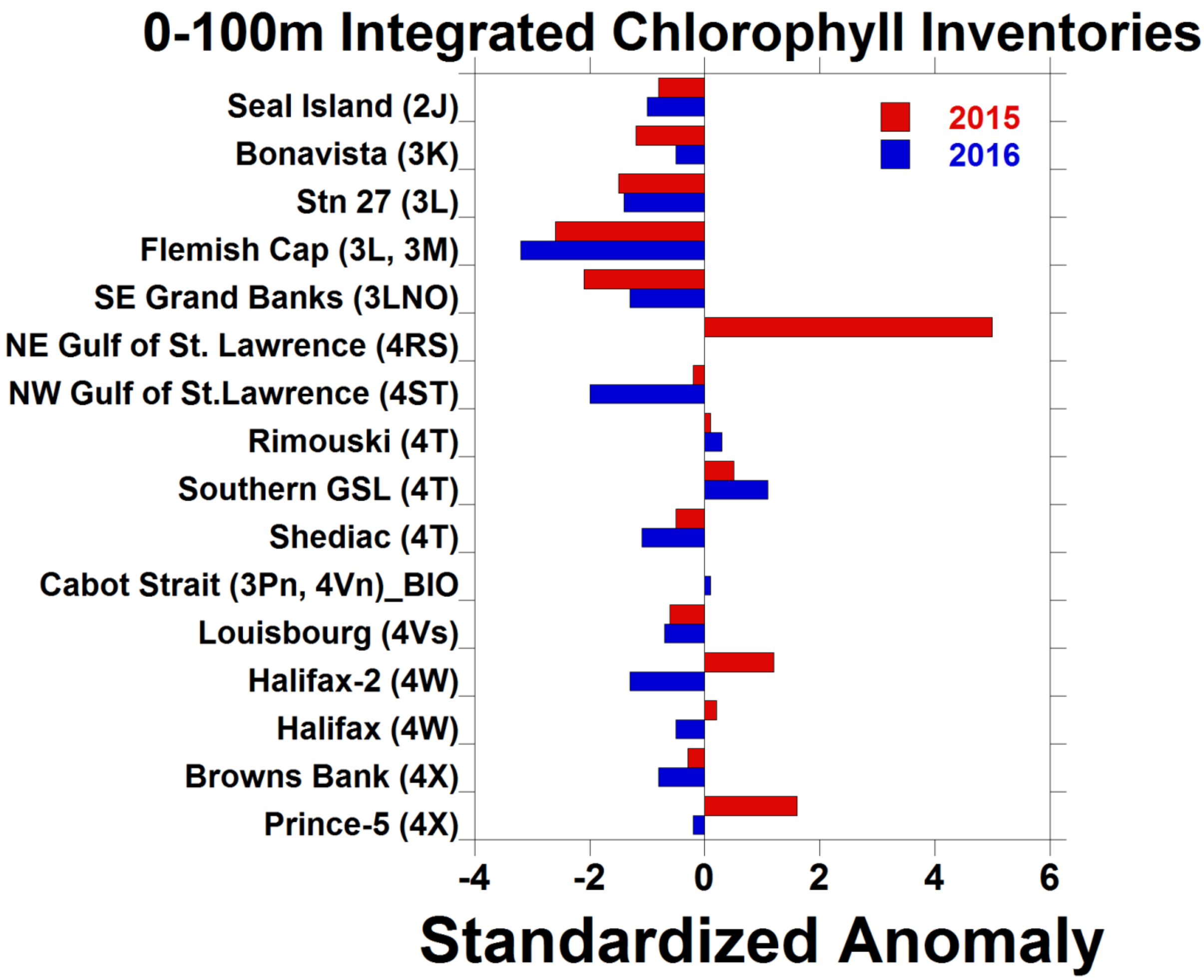

Fig. 4. Summary of chlorophyll *a* inventories (0-100m integral) from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program during 2015 and 2016. The standardized anomalies are the differences between the annual average for a given year and the long-term mean (1999-2010) divided by the standard deviation. The chlorophyll *a* anomalies for transects were calculated using a general linear model using station, season, and year while the fixed stations only used season and year as inputs and were based on all available seasonal data. The NAFO Subareas are generally sorted by latitude from north (top) to south (bottom) regions.

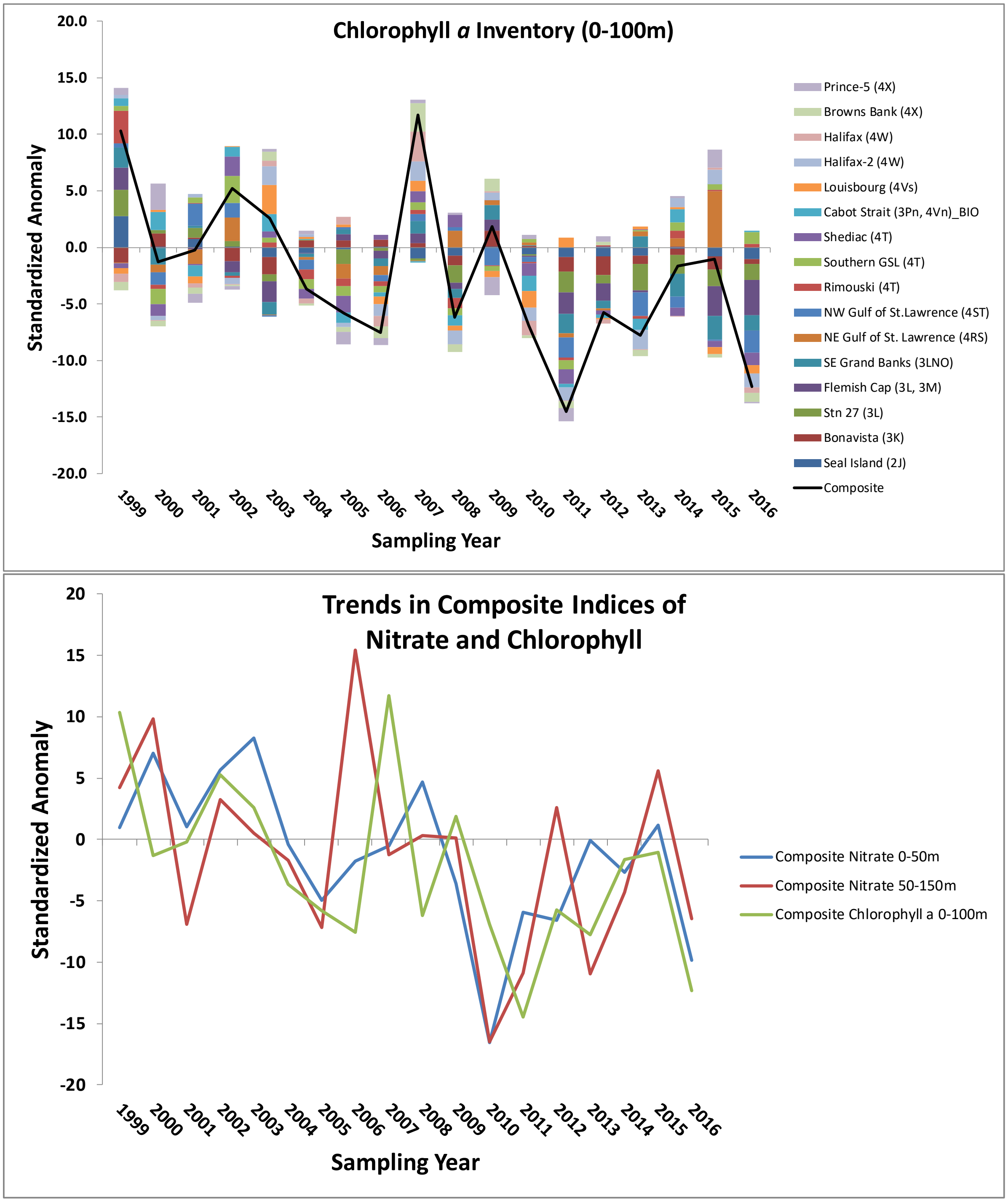

Fig. 5. Time series of chlorophyll *a* (0-100m) inventory anomalies from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program during 1999-2016 (top panel). The anomalies for each area were calculated using a general linear model using station, season, and year while the fixed stations only used season and year as inputs and were based on all available seasonal data. The contribution from each of the NAFO Subareas is represented by colour and height of the vertical bar. The solid black line is the cumulative (composite) anomaly across all Subareas in a given year. The relationship between shallow and deep nitrate and chlorophyll *a* composite time series shown in bottom panel.

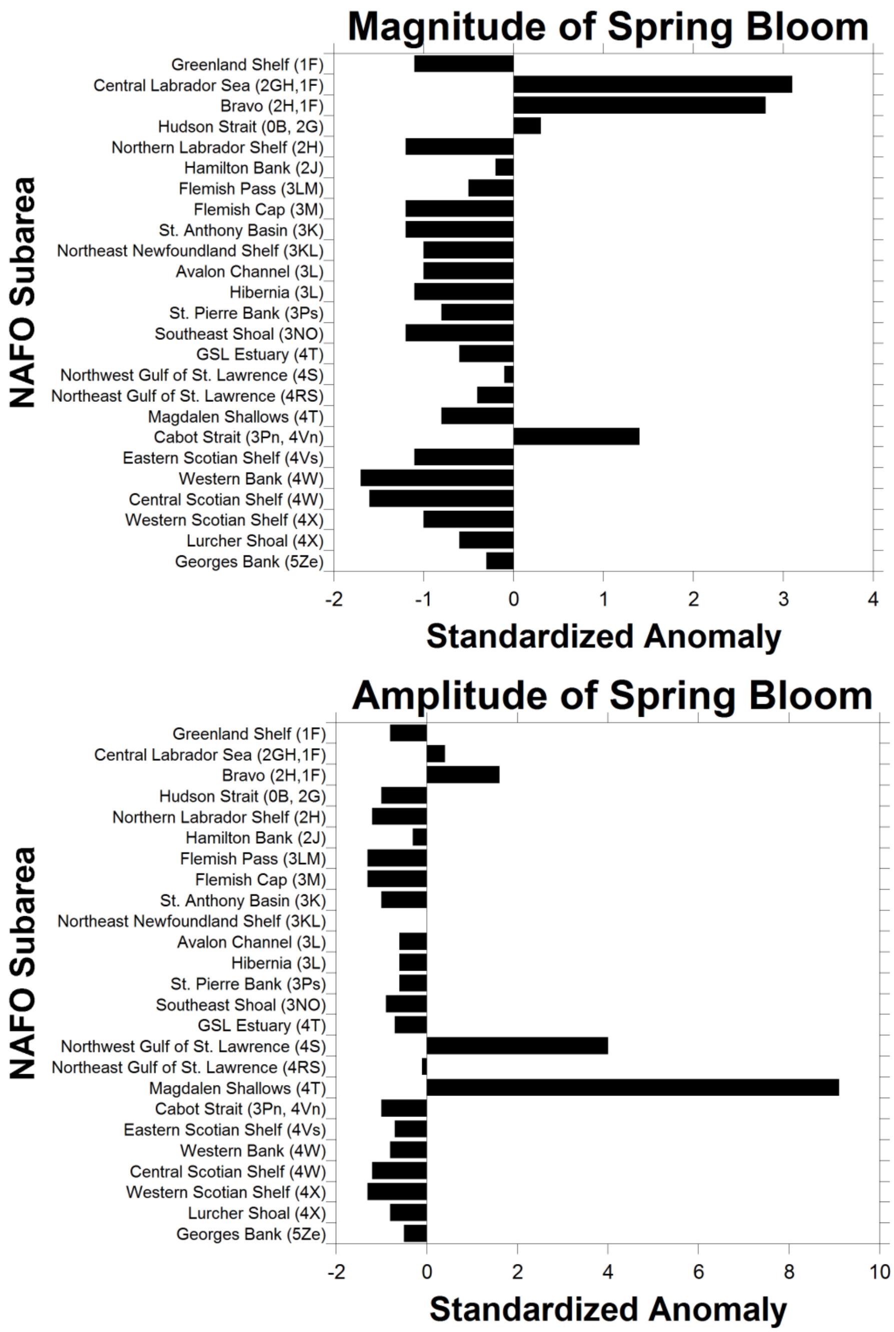

Fig. 6. Summary of annual ocean colour anomalies from SeaWiFS, MODIS "Aqua", and VIIRS sensors across the different statistical sub-regions during 2016. The top panel shows the magnitude while the bottom panel shows the peak amplitude (intensity) of the spring bloom. The standardized anomalies are the differences between the annual average for a given year and the long-term mean (1998-2010) divided by the standard deviation. The NAFO Subareas are sorted from open sea to regional shelf regions.

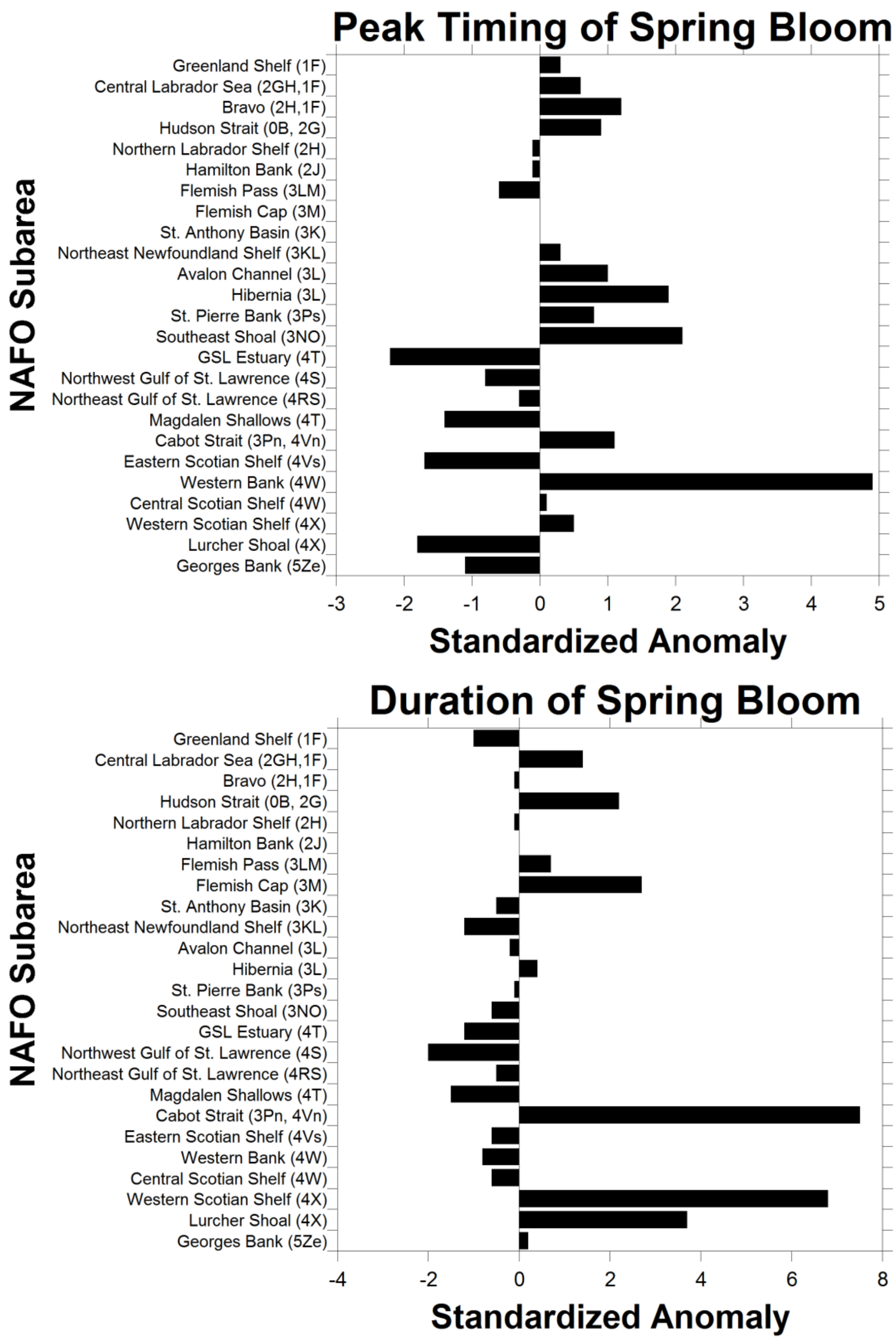

Fig. 7. Summary of annual ocean colour anomalies from SeaWiFS, MODIS "Aqua", and VIIRS sensors across the different statistical sub-regions during 2016. The top panel shows the peak timing (midpoint of bloom) while the bottom panel shows the duration of the spring bloom. The standardized anomalies are the differences between the annual average for a given year and the long-term mean (1998-2010) divided by the standard deviation. The NAFO Subareas are sorted from open sea to regional shelf regions. Negative anomalies for the timing indices indicate earlier/shorter blooms while positive anomalies indicate the opposite.

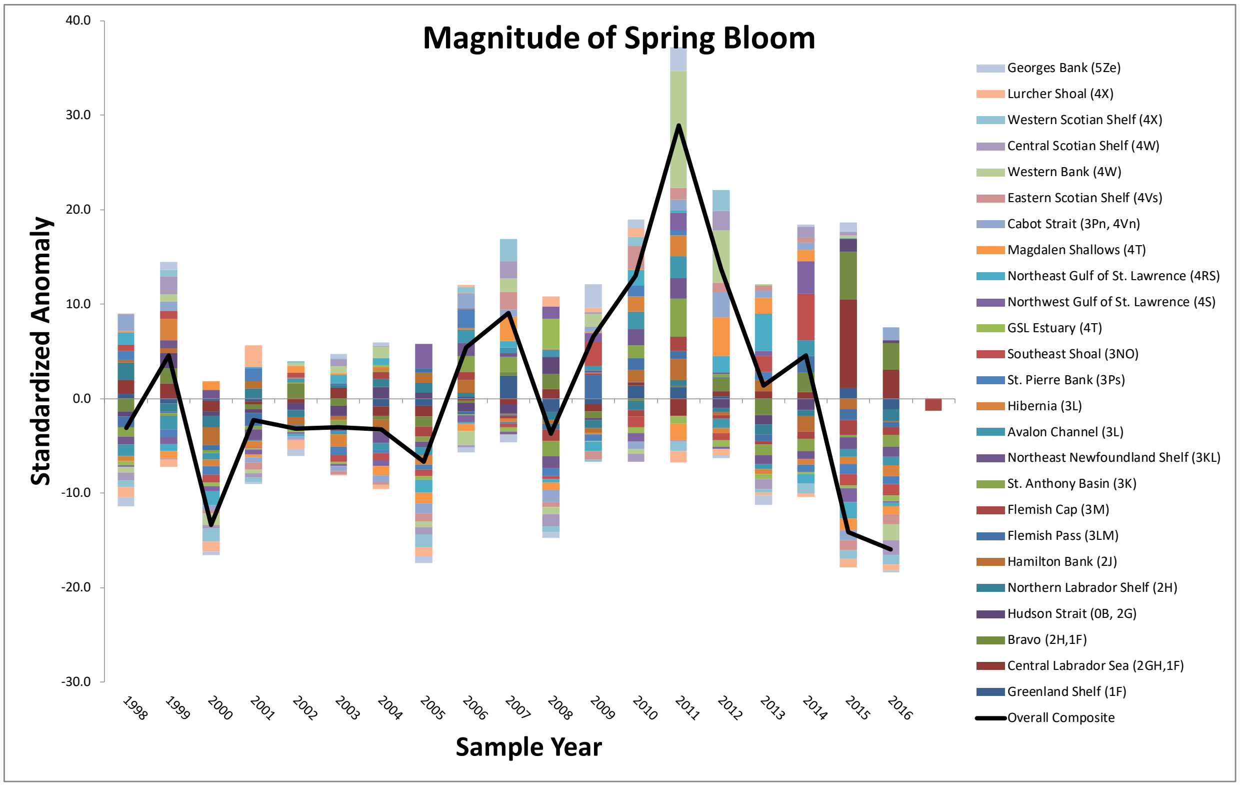

Fig. 8. Annual anomalies of the magnitude (integral of chlorophyll *a* concentration during the bloom in mg m^{-2} d^{-1}) of the spring bloom derived from weekly SeaWiFS, MODIS "Aqua", and VIIRS sensor imagery across the different NAFO Subareas extending from Georges Bank to the Hudson Strait during 1998-2016. The anomalies are the differences between a given year and the long-term mean (1998-2010) divided by the standard deviation during the reference period. The NAFO Subareas are sorted from open sea to regional shelf regions. Data for Flemish Cap were not available during 1998-2002. The contribution from each of the NAFO Subareas is represented by colour and height of the vertical bar. The solid black line is the cumulative (composite) anomaly across all Subareas in a given year.

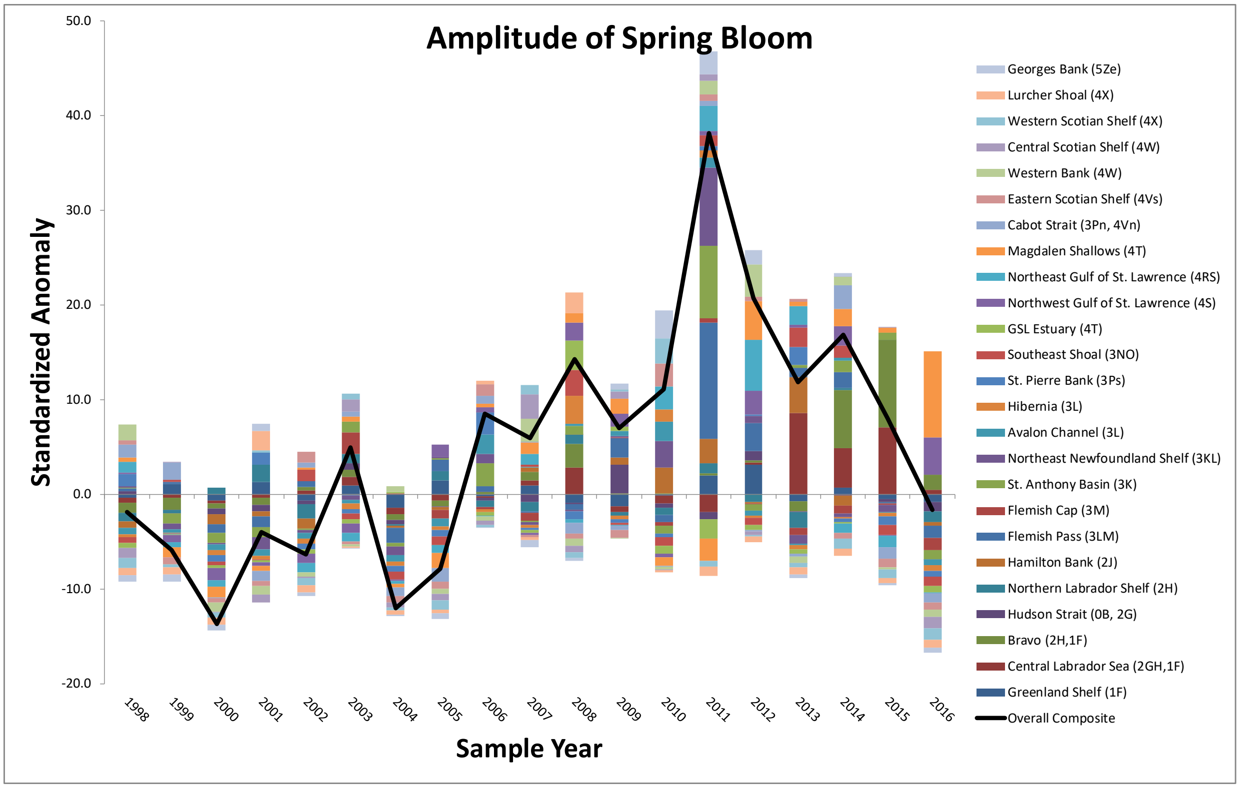

Fig. 9. Annual anomalies of the amplitude (peak intensity in mg m^{-3}) of the spring bloom derived from weekly SeaWiFS, MODIS "Aqua", and VIIRS sensor imagery across the different NAFO Subareas extending from Georges Bank to the Hudson Strait during 1998-2016. The anomalies are the differences between a given year and the long-term mean (1998-2010) divided by the standard deviation during the reference period. The NAFO Subareas are sorted from open sea to regional shelf regions. Data for Flemish Cap were not available during 1998-2002. The contribution from each of the NAFO Subareas is represented by colour and height of the vertical bar. The solid black line is the cumulative (composite) anomaly across all Subareas in a given year.

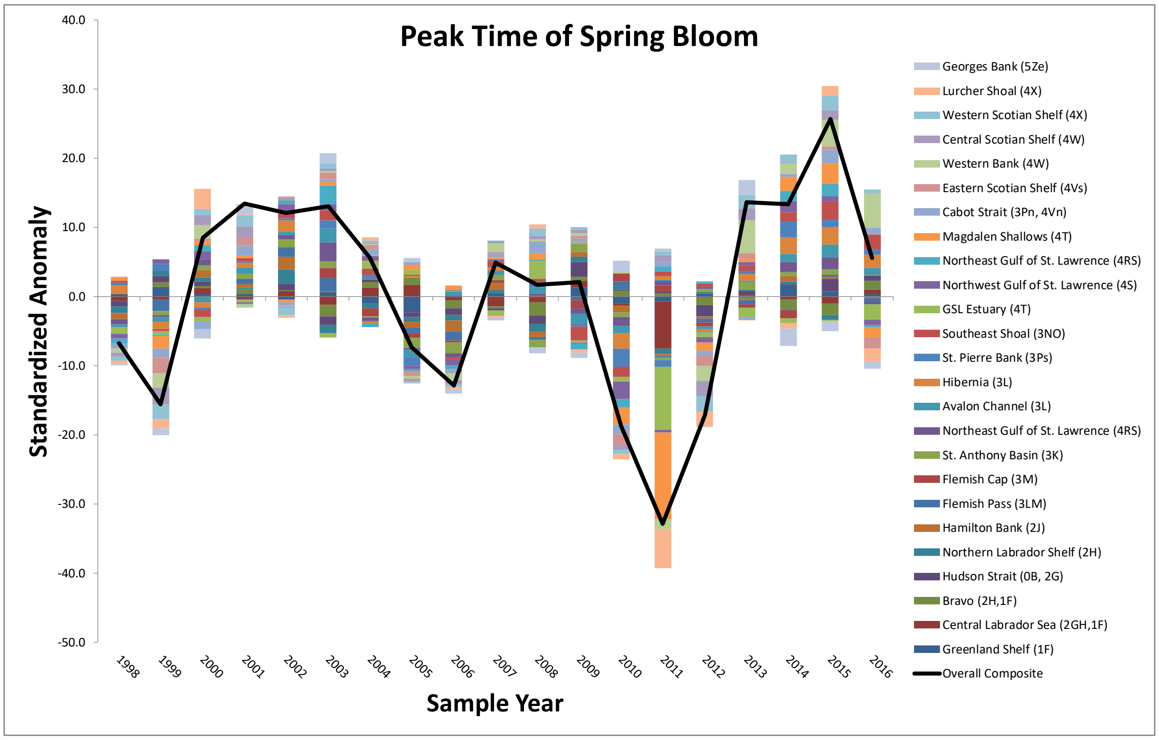

Fig. 10. Annual anomalies of the peak timing (day of year) of the spring bloom derived from SeaWiFS, MODIS "Aqua", and VIIRS sensor imagery across the different NAFO Subareas extending from Georges Bank to the Hudson Strait during 1998-2016. The anomalies are the differences between a given year and the long-term mean (1998-2010) divided by the standard deviation during the reference period. The NAFO Subareas are sorted from open sea to regional shelf regions. Data for Flemish Cap were not available during 1998-2002. The contribution from each of the NAFO Subareas is represented by colour and height of the vertical bar. The solid black line is the cumulative (composite) anomaly across all Subareas in a given year.

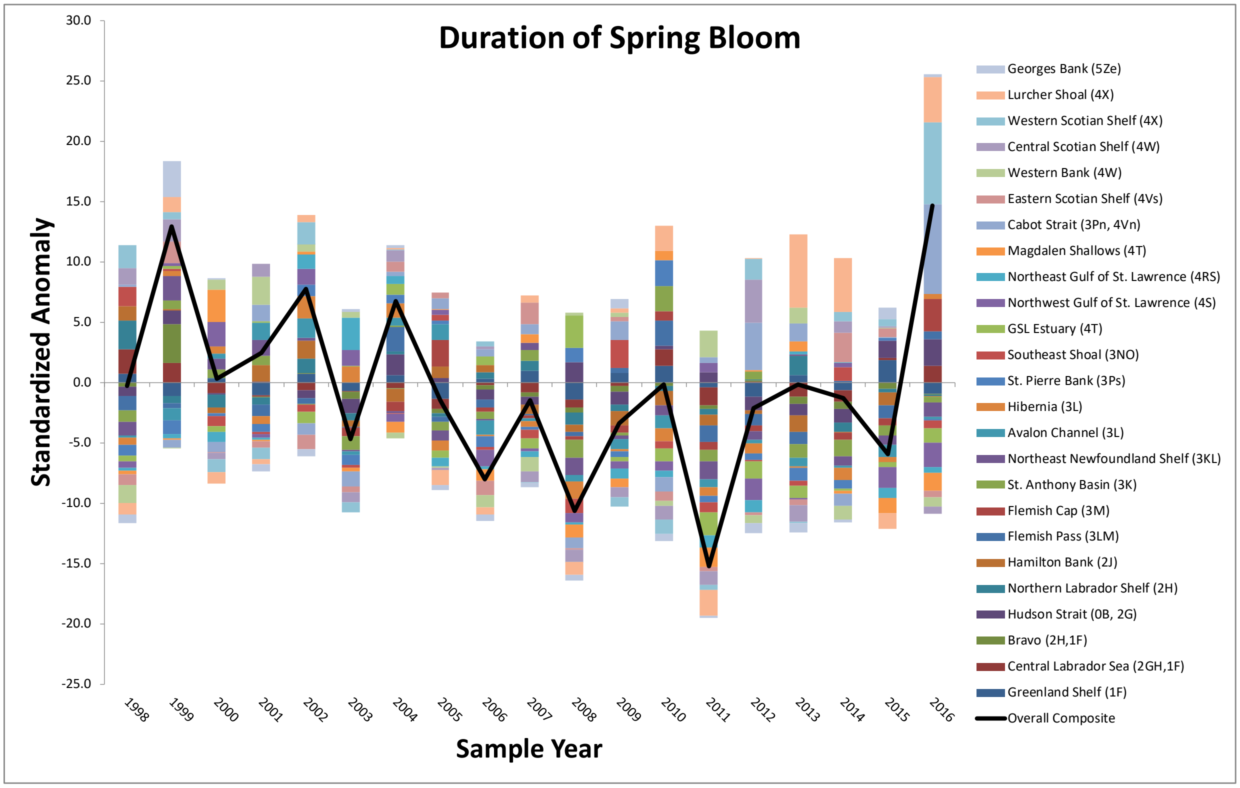

Fig. 11. Annual anomalies of the duration (in days) of the spring bloom derived from SeaWiFS, MODIS "Aqua", and VIIRS sensor imagery across the different NAFO Subareas extending from Georges Bank to the Hudson Strait during 1998-2016. The anomalies are the differences between a given year and the long-term mean (1998-2010) divided by the standard deviation during the reference period. The NAFO Subareas are sorted from open sea to regional shelf regions. Data for Flemish Cap were not available during 1998-2002. The contribution from each of the NAFO Subareas is represented by colour and height of the vertical bar. The solid black line is the cumulative (composite) anomaly across all Subareas in a given year.

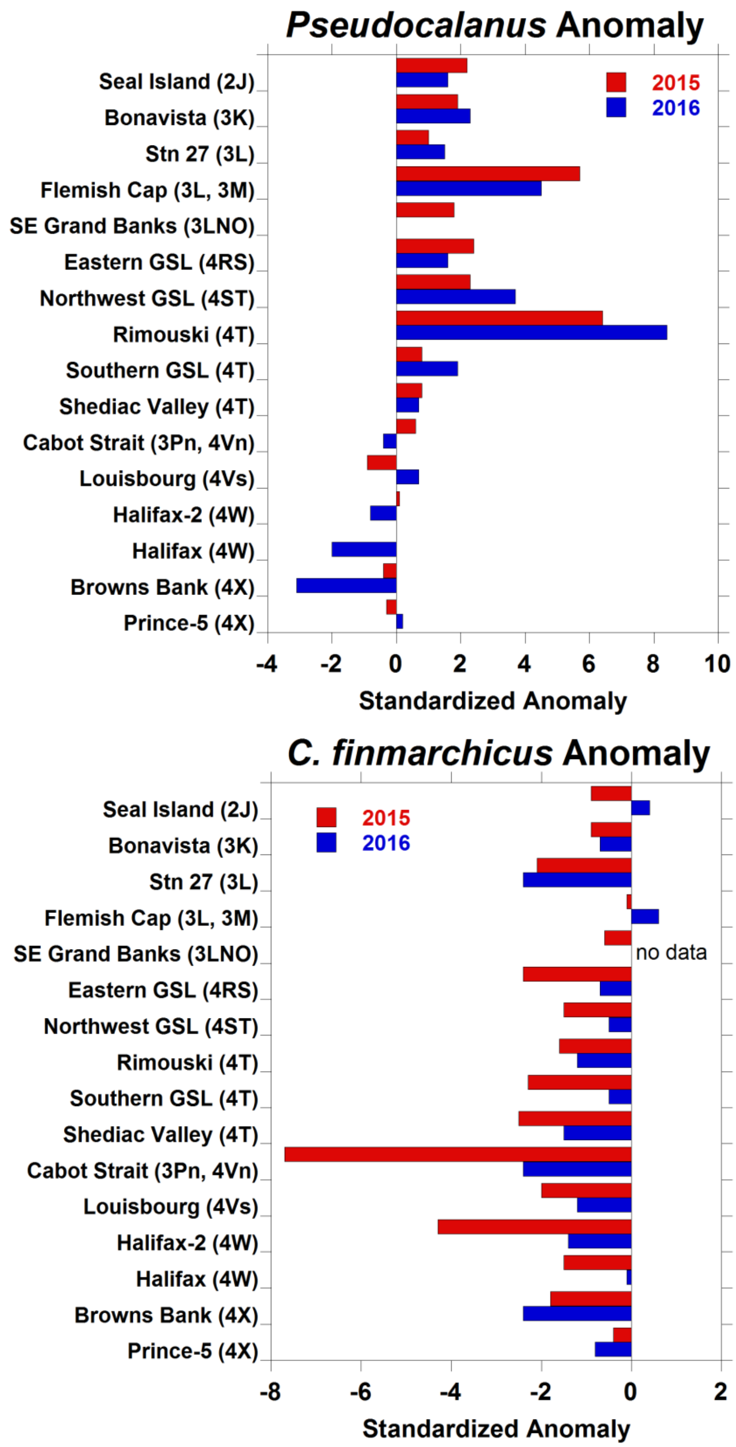

Fig. 12. Summary of zooplankton abundance anomalies from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program during 2015 and 2016. *Pseudocalanus* spp. (top panel) and *Calanus finmarchicus* (bottom panel) represent dominant and ecological important copepod taxa in the northwest Atlantic. The zooplankton abundance anomalies for transects were calculated using a general linear model using station, season, and year while the fixed stations only used season and year as inputs and were based on all available seasonal data. The NAFO Subareas are generally sorted by latitude from the southern Labrador Shelf - 2J (top) to southern Scotian Shelf - 4X (bottom).

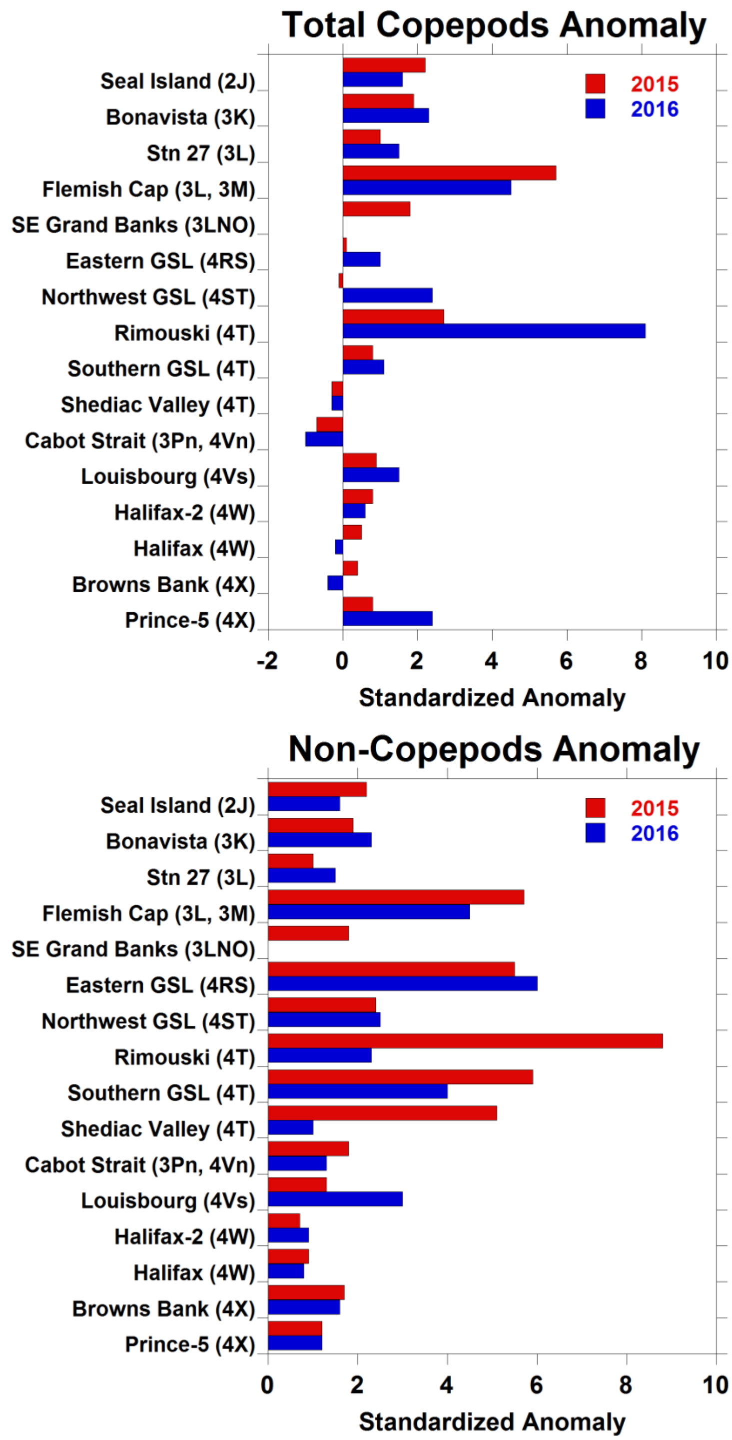

Fig. 13. Summary of zooplankton abundance anomalies from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program during 2015 and 2016. Total copepods (top panel) and non-copepod taxa (bottom panel). The zooplankton abundance anomalies for transects were calculated using a general linear model using station, season, and year while the fixed stations only used season and year as inputs and were based on all available seasonal data. The NAFO Subareas are sorted by latitude from the southern Labrador Shelf - 2J (top) to southern Scotian Shelf - 4X (bottom).

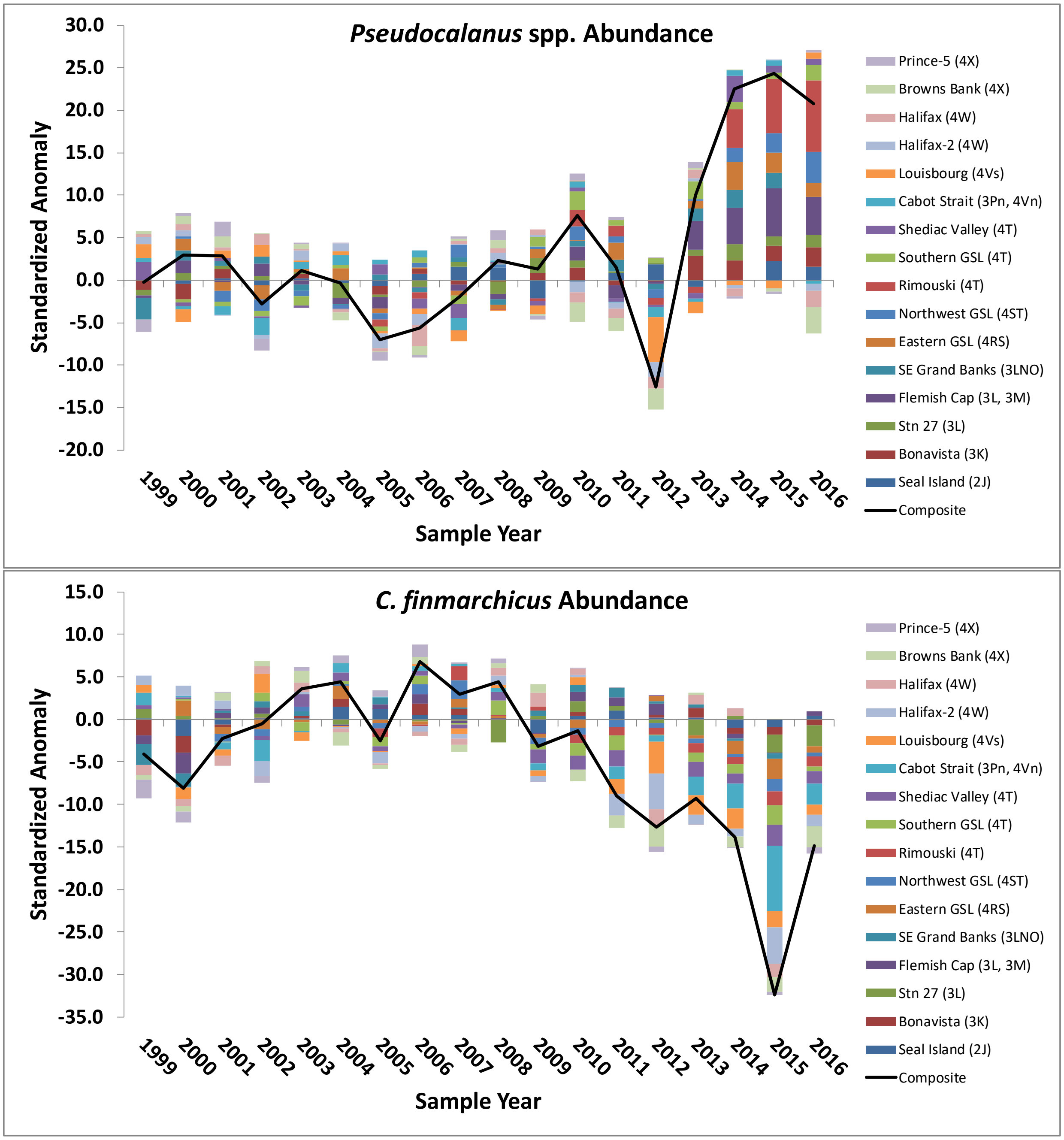

Fig.14. Time series of dominant copepods *Pseudocalanus spp*. (top panel), and *Calanus finmarchicus* (lower panel) abundance anomalies from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program during 1999-2016. The copepod abundance anomalies for transects were calculated using a general linear model using station, season, and year while the fixed stations only used season and year as inputs and were based on all available seasonal data. The standardized anomalies are the differences from the long-term mean (1999-2010) divided by the standard deviation. The contribution from each of the NAFO Subareas is represented by colour and height of the vertical bar. The solid black line is the cumulative (composite) anomaly across all Subareas in a given year.

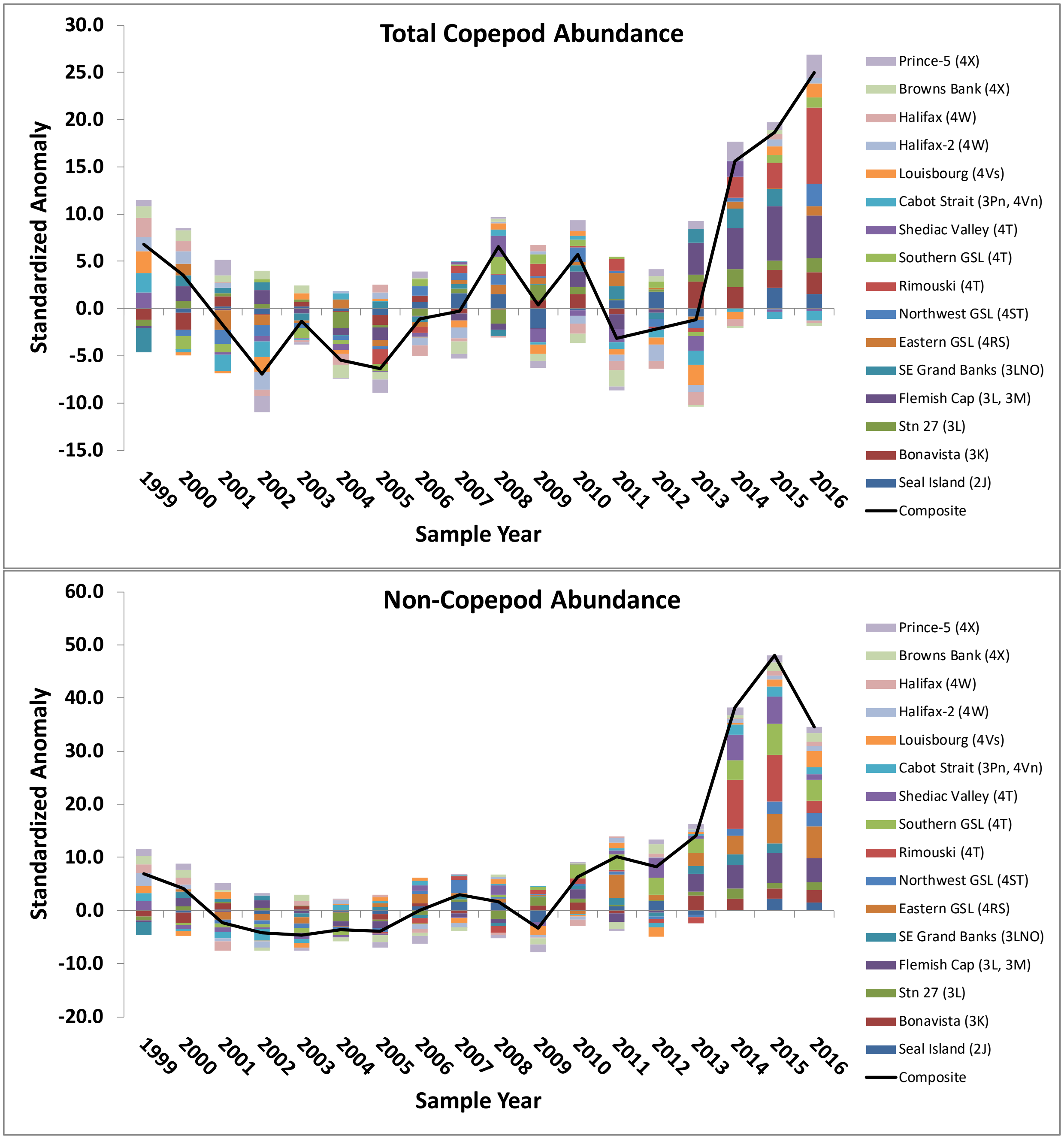

Fig. 15. Time series of total copepod (top panel) and non-copepod (lower panel) abundance anomalies from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program during 1999-2016. The zooplankton abundance anomalies for transects were calculated using a general linear model using station, season, and year while the fixed stations only used season and year as inputs and were based on all available seasonal data. The standardized anomalies are the differences from the long-term mean (1999-2010) divided by the standard deviation. The contribution from each of the NAFO Subareas is represented by colour and height of the vertical bar. The solid black line is the cumulative (composite) anomaly across all Subareas in a given year.

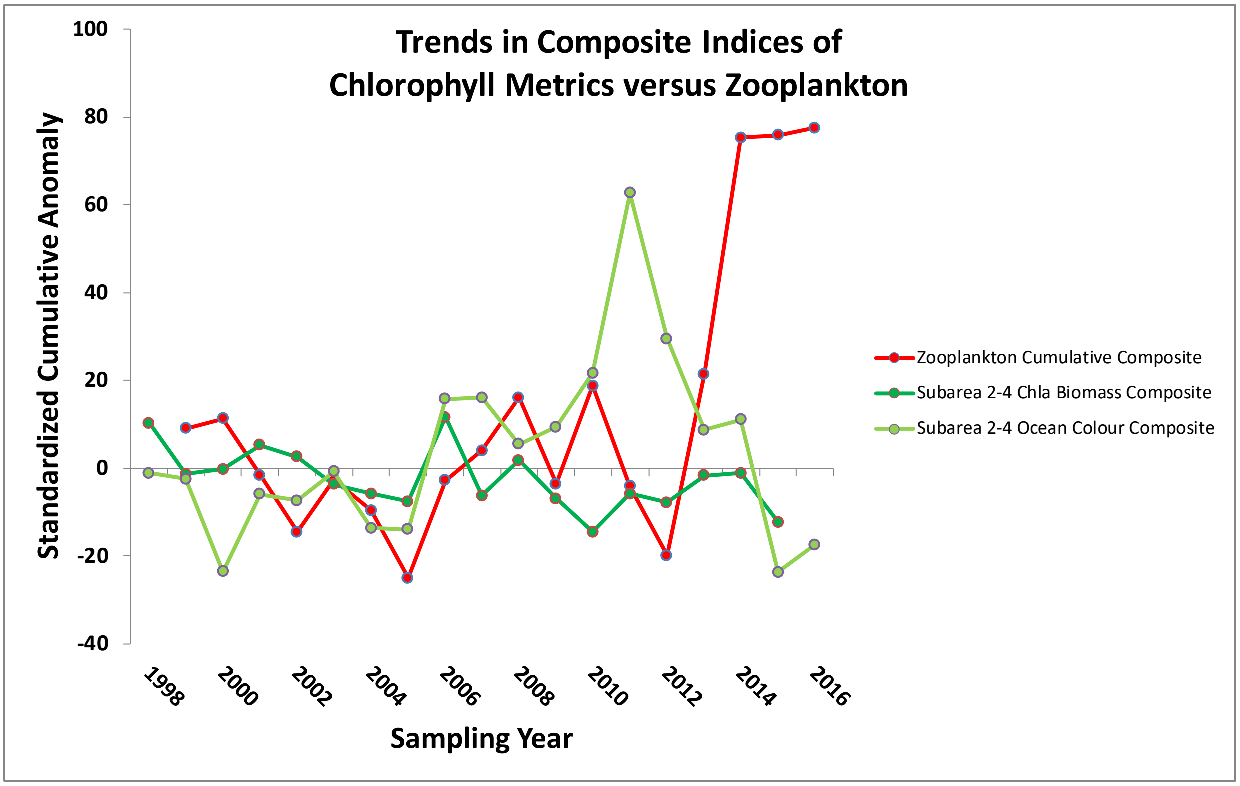

Fig. 16. Composite time series of cumulative annual anomalies across Subareas 2-4 for phytoplankton indices; integrated chlorophyll a biomass from AZMP surveys and ocean colour indices (magnitude and amplitude) with corresponding zooplankton (sum of different functional groups) composite series.

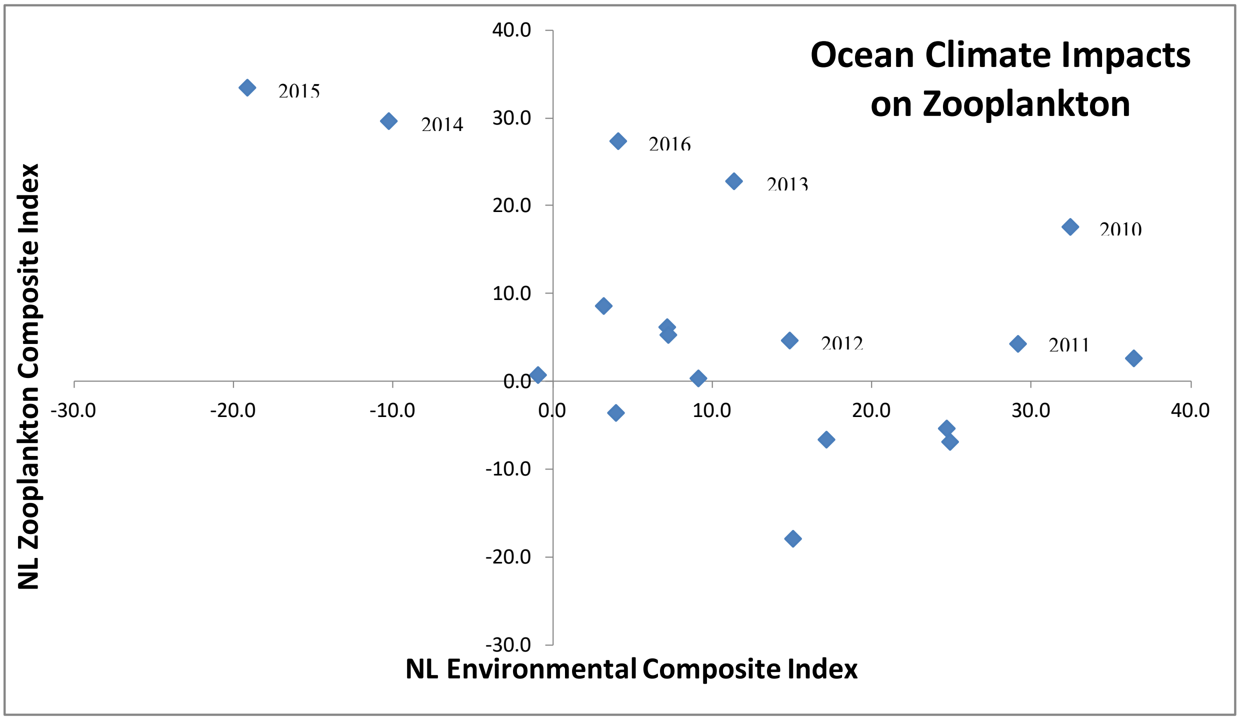

Fig.17. Relationship between the environmental composite index composed of 28 time series which include meteorological, sea ice, temperature and salinity variables from the Newfoundland and Labrador Region (from Colbourne et al. 2016) and the combined zooplankton functional groups (*Pseudocalanus* spp., *Calanus finmarchicus*, total copepod and non-copepod taxa) derived from the same region. The most recent observations back to 2010 are provided in the figure.