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Newfoundland and Labrador, Quebec, Gulf, and Maritimes Regions

Canadian Science Advisory Secretariat
Science Advisory Report 2014/050

OCEANOGRAPHIC CONDITIONS IN THE ATLANTIC ZONE IN 2013

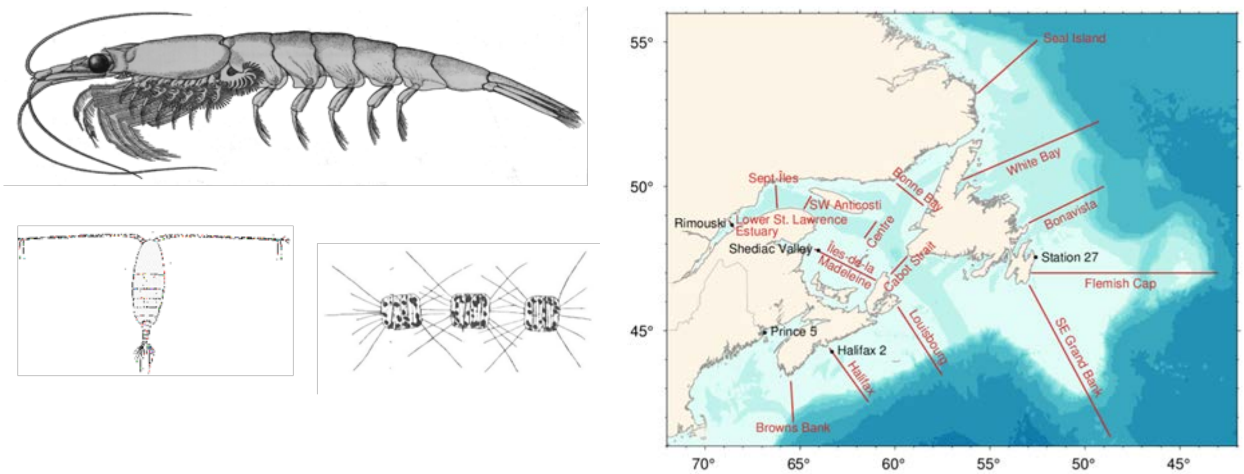

Figure 1. (Left) Key taxa of the pelagic food web: euphausids (top), phytoplankton (bottom right), and copepods (bottom left). Images: Fisheries and Oceans Canada; (Right) Atlantic Zone Monitoring Program high-frequency sampling stations (black) and selected section lines (red).

Context:

The Atlantic Zone Monitoring Program (AZMP) was implemented in 1998 with the aim of increasing DFO's capacity to understand, describe, and forecast the state of the marine ecosystem and to quantify the changes in the ocean's physical, chemical and biological properties.

A description of the seasonal patterns in the distribution of phytoplankton (microscopic plants) and zooplankton (microscopic animals) in relation to the physical environment provides important information about organisms that form the base of the marine food web. An understanding of the production cycles of plankton, and their interannual variability, is an essential part of an ecosystem approach to stock assessment and marine resource management.

SUMMARY

- Sea-surface temperatures were at record highs in September 2013 on the Grand Banks, and generally above-normal during ice-free months across the zone.
- Sea ice volume rebounded somewhat but remained low in the Gulf of St. Lawrence with the 6th lowest volume since 1969, and decreased on the Newfoundland–Labrador (NL) Shelf to the 4th lowest value since 1980. Almost no sea-ice was exported to the Scotian Shelf for the fourth consecutive winter.
- The Gulf of St. Lawrence Cold Intermediate Layer (CIL) was colder and thicker in 2013 than the record conditions (since the 1980s) of 2012, but was still generally thin and warm, similar to conditions of 2011. The Scotian Shelf CIL volume was near-normal (-0.4 SD) after a series record low in 2012, while on the Newfoundland and Labrador Shelves the CIL was mostly thinner than in 2012 with area anomalies ranging from -0.5 to -1.4 SD.

While conditions were bimodal in 2012, being near-normal on the Newfoundland and Labrador Shelves and at record thin levels in the Gulf and on the Scotian Shelf, conditions were more uniform across the zone in 2013 with below-normal areas and volumes (i.e. warm conditions).

- Bottom temperatures were generally above-normal across the zone, but down from record highs of 2012 recorded in the northern Gulf at shallow depths and in parts of the Scotian Shelf. A series record high was however recorded in the northern Gulf in deeper waters (>100 m, +2.0 SD) associated with a warm anomaly first observed in Cabot Strait in 2010 that is propagating toward the heads of channels.
- The most widespread negative anomalies in surface (0-50 m) and subsurface (50-150 m) nitrate inventories of the time series were seen in 2010-2011. The relatively consistent recovery in nutrient inventories seen across most parts of the Scotian Shelf and Gulf of St. Lawrence in 2012 continued in 2013. In contrast, both surface and subsurface inventories of the Newfoundland–Labrador Shelf and Grand Banks were below normal, with the subsurface inventories deepening the decline that started in 2009.
- Chlorophyll inventories were near the long-term average throughout much of the Atlantic Zone in 2013.
- In 2013, zooplankton abundance indices demonstrated relatively large scale coherence. Copepod abundance on the Eastern Scotian Shelf and in the southern Gulf of St. Lawrence was below average in 2013 and had declined relative to 2012, whereas abundance was above normal across most of the Newfoundland Shelf.
- There have been notable changes in the phylogeny of key zooplankton taxa in both the Gulf of St. Lawrence and on the Newfoundland Shelf. On both regions, the period of maximum contribution of young (CI–III) and later (CIV-CV) copepodite stages have progressed toward occurring earlier in the summer, a change which appears to have started in 2006.

BACKGROUND

The Atlantic Zonal Monitoring Program (AZMP) was implemented in 1998 (Therriault et al. 1998) with the aim of: (1) increasing Department of Fisheries and Oceans' (DFO's) capacity to understand, describe, and forecast the state of the marine ecosystem; and (2) 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 physical oceanographic properties and of the distribution and variability of nutrients, phytoplankton and zooplankton.

A description of the distribution in time and space of nutrients and gases dissolved in seawater (nitrate, silicate, phosphate, oxygen) 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. An understanding of the production cycles of plankton is an essential part of an ecosystem approach to stock assessment and fisheries management.

The AZMP derives its information on the state of the marine ecosystem from data collected at a network of sampling locations (high-frequency point stations, cross-shelf sections, ecosystem surveys) in each region (Quebec, Maritimes, Gulf, Newfoundland and Labrador) sampled at a frequency of weekly to once annually (Figure 1). The sampling design provides for basic information on the natural variability in physical, chemical, and biological properties of the

Northwest Atlantic continental shelf. Trawl (groundfish) surveys and cross-shelf sections provide detailed geographic information, but are limited in their seasonal coverage. Strategically placed high-frequency sampling sites complement the broad scale sampling by providing more detailed information on temporal (seasonal) changes in pelagic ecosystem properties.

ASSESSMENT

Physical Environment

This is a summary of physical oceanographic conditions during 2013 for eastern Canadian oceanic waters (Figure 2) as reported annually by the Atlantic Zonal Monitoring Program (AZMP) in three reports (e.g. Colbourne et al. 2014, Galbraith et al. 2014 and Hebert et al. 2014 for conditions of 2013). After setting record highs in 2012, annually-averaged air temperatures decreased but remained above normal in 2013. Temperature anomalies were highest in winter on the Labrador Shelf and Gulf of St. Lawrence, with March air temperatures highest since 1935 at Cartwright, since 1958 at Natashquan, since 1962 at Chevery, since 1965 (series record) at Baie Comeau, and since 1999 at Plum Point, Daniel's Harbour, Stephenville and Port aux Basques. Sea-surface temperatures (SST) during ice-free months were above normal in all but three regions across the zone (Figures 3 to 6). While the seasonal average anomalies were not as high as the record highs observed for many regions in 2012, September temperatures (not shown) were at record levels (since 1985) in 3NOP and 4V, with anomalies ranging from +1.6 SD in 4V to +3.1 SD in 3N. The year ended with cooler air temperatures. They were near-normal in December at Sable Island, but were coldest since 1972 over the Gulf of St. Lawrence (average of -5.1°C anomaly, or -2.3 SD), since 1991 at Cartwright (anomaly of -5.4°C, -1.7 SD), and since 1989 at St. John's (anomaly of -3.0°C, -1.7 SD after correction for days without data).

A number of environmental (the North Atlantic Oscillation [NAO] index, RivSum II: the freshwater runoff into the St. Lawrence Estuary, and sea-ice) and oceanographic variables and indices are summarized as time series (1980–2013) values in matrix form in Figure 5. When possible, the variables are displayed as differences (anomalies) relative to their 1981–2010 mean; furthermore, because these series have different units (e.g., °C, m^3, m^2), each anomaly time series is normalized by dividing by its standard deviation (SD), which is also based on the 1981–2010 period. This allows a more direct comparison of the series.

Freshwater runoff in the Gulf of St. Lawrence, particularly within the St. Lawrence Estuary, strongly influences the circulation, salinity, and stratification (and hence upper-layer temperatures) in the Gulf and, via the Nova Scotia Current, on the Scotian Shelf. For example, the average 0–20 m salinity in the Magdalen Shallows (not shown) for the low runoff period of 1999–2007 is approximately 0.5 salinity units more than the average for high runoff years in the 1970s, 80s, and 90s. This represents approximately an extra 17 km^3 of freshwater in the upper 20 m of the Shallows. The St. Lawrence River runoff had been decreasing since the early 1970s but appears to be increasing again since 2001. The mean runoff was near normal (+0.1 SD) in 2013 but the spring freshet was above-normal (not shown).

The NAO is an index of the dominant winter atmospheric forcing over the North Atlantic Ocean. It affects winds, air temperature, precipitation, and the hydrographic properties on the eastern Canadian seaboard either directly or through advection. Strong northwest winds, cold air and sea temperatures, and heavy ice in the Labrador Sea area are usually associated with a high positive NAO index, with opposite effects occurring with a negative NAO index. The tendency of the ocean currents to move from north to south eventually spreads the NAO's influence into the Gulf of St. Lawrence and onto the Scotian Shelf. In 2013, the winter NAO index was near-normal but negative after 2012 (4^{th} largest positive value) and the record negative low of 2010.

For the past decade, ice volumes on the Newfoundland and Labrador Shelf, the Gulf of St. Lawrence and the Scotian Shelf have generally been lower than normal reaching a record-low value in the Gulf of St. Lawrence in 2010 and on the NL Shelf in 2011. In 2013, sea ice volume rebounded somewhat but remained low in the Gulf of St. Lawrence (6^{th} lowest Dec.-Feb. average volume and seasonal peak volume since 1969) and decreased on the NL Shelf to the 5th lowest value since 1967. Almost no sea-ice was exported to the Scotian Shelf for the fourth consecutive winter.

A number of indices derived from oceanographic sections and ecosystem surveys characterize the variability of cold water volumes, areas, and bottom temperatures in the AZMP area. For the latest 30 year period, the highest similarities are found between cold water indices from the southern Labrador and NE Newfoundland Shelf and the northern Grand Bank, followed by similarities between the Gulf of Lawrence and the Scotian Shelf. The Gulf of St. Lawrence CIL rebounded marginally in 2013 after the record (since the early 1980s) warm and thin conditions of 2012, but was still generally warm and less extensive, similar to observations of 2011. The Scotian Shelf CIL volume (T <4°C) was small, yet still near-normal at -0.4 SD, after a record low in 2012. On the NL Shelf, the CIL was mostly thinner than in 2012. Along the Seal Island, White Bay, Bonavista and Flemish Cap Sections the CIL (T <0°C) cross-sectional areas were below-normal (i.e. warm) with values ranging from -0.5 to -1.4 SD. While conditions were bimodal in 2012, being near-normal on the NL Shelf and at record low volumes in the Gulf and on the Scotian Shelf, conditions in 2013 were more uniform across the zone with below-normal areas and volumes.

Bottom temperatures were again above-normal across the zone (except for the near-normal fall values in NAFO Divisions 3LNO), but down from the record highs of 2012 recorded in the northern Gulf at shallow depths (less than 100 m, down from +3.0 SD to +1.0 SD) as well as in Divisions 4W (from +2.4 SD to +0.8 SD) and 4X (from +3.0 SD to +1.5 SD) of the Scotian Shelf. A series record high was recorded in the northern Gulf in deeper waters (depths greater than 100 m, +2.0 SD) as a warm anomaly first observed in Cabot Strait in 2010 is propagating towards the heads of the channels.

Figure 6 shows three annual composite index time series constructed as the sum of anomalies from Figure 5, representing the state of different parts of the system, with each time series contribution shown as stacked bars. The parts described are sea-surface and bottom temperatures, as well as the cold intermediate layer and sea-ice volume which are both formed in winter. These composite indices measure the overall state of the climate system with positive values representing warm conditions and negative representing cold conditions (e.g. less sea-ice and CIL areas and volumes are translated to positive anomalies). The plot also indicates the degree of coherence between the various measures of the environment and different regions across the zone. Conditions in 2013 were above-normal for each of the three composites, with all regions displaying positive anomalies except for a few with negative SST, but the anomalies were smaller than in 2012.

In 2013, annually averaged temperatures at high-frequency sampling AZMP stations were above-normal (+1.0 to +1.1 SD) at Station 27 (Newfoundland Shelf), Prince 5 (Bay of Fundy) and Shediac Valley (Magdalen Shallows) and near-normal at Halifax 2 after the 2012 33-year record highs of +3.7 SD at Halifax 2 and +3.5 at Prince 5 (Figure 7). The annual 0–50 m salinity anomalies did not display a consistent pattern across the region. They were above-normal at Prince 5 (+0.9 SD), below-normal in the Gulf at Shediac Valley (-1.3 SD) and Rimouski station (- 0.6 SD), and normal at the others. The annual 0–50 m stratification index also did not display a consistent pattern but was either near-normal or above-normal at all stations. Since 1948, there has been an increase in the mean stratification on the Scotian Shelf, resulting in a change in the 0-50 m density difference of 0.37 kg m^{-3} over 50 years. This change in mean stratification is due mainly to a decrease in the surface density. Stratification on the Scotian Shelf was slightly increased in 2013 compared to conditions of 2012, making it the third strongest stratification of the series.

A total of 39 indices listed in Figures 5 and 7 describe ocean conditions related to temperature within the AZMP area (SST; ice; summer CIL areas, volumes, and minimum temperature; bottom temperature; 0–100 m average temperature). Of these, seven were within normal values and thirty two were above normal, indicating a continuation of above normal oceanographic conditions in 2013.

Biogeochemical Environment

Phytoplankton are microscopic plants that form the base of the aquatic food web, occupying a position similar to that of plants on land. There is a wide variation in the size of phytoplankton, ranging from the largest species, members of a group called diatoms, to smaller species, including members of a group called flagellates. Phytoplankton use light to produce organic matter from carbon dioxide and nutrients dissolved in marine waters. The growth rate at which new organic matter is produced depends partly on temperature and the abundance of light and nutrients. In continental shelf waters, the nutrient nitrate is usually the limiting nutrient for phytoplankton growth in surface waters where sufficient light is available. Nitrate from subsurface waters is mixed to the surface in winter, and it is depleted in surface water during the spring bloom. The phytoplankton constitute the primary food source of the animal component of the plankton, zooplankton. In most marine waters, phytoplankton cells undergo a spring-summer explosion in abundance called a bloom. The dominant zooplankton in the oceans are copepods. They represent the critical link between phytoplankton and larger organisms like fish. Young copepods (nauplii) are the principal prey of young fish while the older stages (copepodites) are eaten by larger fish, predominantly juveniles and adults of pelagic species such as capelin and herring.

Indices representing nitrate inventories, phytoplankton and zooplankton standing stocks from the Newfoundland Shelf (Pepin et al. 2013), Gulf of St. Lawrence and Scotian Shelf (Johnson et al. 2013) are summarized as time series (1999–2013) of annual values in matrix form in Figures 8-10. Similar to the description of the physical environment, the variables are displayed as differences (anomalies) relative to their 1999–2010 mean; furthermore, because these series have different units, each anomaly time series is normalized by dividing by its standard deviation (SD), which is also based on the 1999–2010 period. This allows a more direct comparison of the series.

In contrast to the physical oceanographic data available to AZMP, the relatively short time series of biogeochemical variables from the program tend to highlight the high degree of interannual variability in the information rather than the long-term trends that are apparent for the physical environment. The average maximum absolute change from year-to-year across all sections and high frequency sampling sites is approximately 2 SD, with the magnitude of the average maximum year-to-year change increasing slightly from nutrients to phytoplankton to zooplankton. There is a degree of synchrony in the patterns of variation of individual biogeochemical variables at adjacent locations, and the sign of anomalies tends to persist for several years, although in some instances there may be considerable variability among locations within a region.

The most widespread negative anomalies in surface (0-50 m) and subsurface (50-150 m) nitrate inventories of the time series were seen in 2010-2011. The relatively consistent recovery in nutrient inventories seen across most parts of the Scotian Shelf and Gulf of St. Lawrence in

2012 continued in 2013, when surface inventories (0-50 m) remained at similar levels throughout much of these areas but increased on the eastern Scotian Shelf, whereas subsurface inventories (50-150 m) declined slightly to average or slightly above average levels (Figure 8). There was considerable variability in the size of the anomalies among adjacent areas. In contrast, both surface and subsurface inventories of the Newfoundland–Labrador Shelf and Grand Banks were below normal, with the subsurface inventories deepening the decline that started in 2009.

Chlorophyll inventories (0-100 m; Figure 9), a proxy for phytoplankton biomass, demonstrated a high degree of year-to-year variability in which exceptional values either above or below the long term average were often confined to a small portion of a region. There has been limited consistency in the pattern of variation in chlorophyll across the entire Atlantic Zone until very recently. Chlorophyll inventories were near the long-term average throughout much of the Atlantic Zone in 2013, within approximately ± 0.5 SD units of the 1999-2010 average. Chlorophyll anomalies have been below normal across much of the Newfoundland & Labrador Shelf since 2011 but increased slightly on the Grand Banks in 2013. Because of the reliance of phytoplankton on nutrient availability, it is tempting to link patterns of variation in the two variables but the outcome of such a comparison across the entire Atlantic Zone indicates that there is no significant association between inventories of nitrate and phytoplankton at the annual scale, whether we consider the surface or subsurface sources of nutrients. This does not imply that local variations in the seasonal production cycle are not linked to nutrient availability but rather that many factors are likely to be influencing local nutrient-phytoplankton dynamics and that the balance of these factors is likely to differ when considered at the very large spatial scale (from the Gulf of Maine to southern Labrador) and including estuarine to oceanic environments.

Zooplankton indices of abundance tended to demonstrate a greater degree of temporal consistency within regions than was apparent for chlorophyll. Populations of mesozooplankton (0.2-20 mm in size) sampled by the AZMP in one region potentially have a high degree of connectivity with adjacent areas because these organisms are greatly influenced by the effects of ocean currents.

In 2013, zooplankton abundance indices demonstrated relatively large scale coherence (Figure 10). Copepod abundance on the Eastern Scotian Shelf and in the southern Gulf of St. Lawrence was below average in 2013 and had declined relative to 2012. In the case of *Pseudocalanus spp.,* an important prey for many species of young fish, their abundance increased throughout almost the entire Atlantic Zone in 2013, which represent a shift from the previous year and slightly higher than values in 2009-2011. Record abundance levels were achieved on the Newfoundland Shelf, Grand Banks, off Halifax and the Bay of Fundy. Abundance was near normal in the Gulf of St. Lawrence. The abundance of *Calanus finmarchicus*, a key species in most ecosystems of the North Atlantic, reached the lowest levels on record in parts of the Gulf of St. Lawrence and on the eastern edge of the Scotian Shelf, whereas abundance levels are slightly above normal across most the of the Newfoundland and Labrador Shelf.

There have been notable changes in the phylogeny, the seasonal succession of developmental stages, of key zooplankton taxa in both the Gulf of St. Lawrence (*Calanus finmarchicus, Calanus hyperboreus*) and on the Newfoundland Shelf (*Calanus finmarchicus, Pseudocalanus spp.*). In both regions, the period of maximum contribution of young copepodite stages (CI–III) have progressed toward occurring earlier in the summer, a change which appears to have started in 2006. The pattern is mirrored in the occurrence of later stages of development (CIV-CV) as well. In the Gulf of St. Lawrence, the occurrence of a second generation of *Calanus finmarchicus* CI–IV in late summer and/or late fall has also become more common. On the

Newfoundland Shelf there is evidence of an increased occurrence of adult copepodites of both *Calanus finmarchicus* and *Pseudocalanus spp*.in the fall. Modifications to the phenology may be the result of the direct effects of changes in the physical (ice dynamics, surface temperature) and biological (phytoplankton bloom timing, duration, and amplitude) environment that have occurred.

Non-copepod zooplankton consists principally of the larval stages of benthic invertebrates but also include many of the carnivores that feed on other zooplankton. In 2013 this group was highly abundant on the Newfoundland Shelf, Grand Banks, western Gulf of St. Lawrence and lower Estuary as well as the Magdalen Shallows. In 2011, this group of organisms had been particularly abundant throughout the Gulf of St. Lawrence while the above average abundance levels on the Grand Banks have persisted since 2010.

The patterns of variation of copepods and non-copepods demonstrate a statistically significant association that accounts for about 18 % of the variation. Until 2011, the patterns of variations of these two groups followed a regional progression in anomalies that originated in the northern most reaches of the Atlantic Zone, starting at the Seal Island section off Labrador (see negative anomaly in the upper left corner of Figure 10), and moved across Newfoundland and into the upper reaches of the Gulf of St. Lawrence after which the anomalies appear to have progressed into the southern Gulf and onto the Scotian Shelf (Figure 11). Although there is considerable variability around the general trend, normal or positive anomalies have persisted throughout much of the Newfoundland and Gulf of St. Lawrence regions after low abundance levels in 1999–2001 and 1999–2004 respectively. Conditions on the Scotian Shelf have contrasted those of the Newfoundland Shelf, with high zooplankton abundance levels during 1999–2001 and below average levels since then. However, there has been considerable variability in overall zooplankton abundance among different parts of the Gulf of St. Lawrence in 2012 and 2013.

Sources of Uncertainty

The general spatial and seasonal patterns of physical, chemical and biological oceanographic variables in the Northwest Atlantic monitored by AZMP have remained relatively consistent since the start of the program. Although there are seasonal variations in the distribution of water masses, plants and animals, these variations show generally predictable patterns. However, there is considerable uncertainty in estimates of overall abundance of phytoplankton and zooplankton. This uncertainty is caused in part by the life cycle of the animals, their patchy distribution in space, and by the limited coverage of the region by the monitoring program.

Physical (temperature, salinity) and chemical (nutrients) oceanographic variables are effectively sampled, because they exhibit fairly conservative properties that are unlikely to show precipitous changes either spatially or from year-to-year. Also, measurements of these variables are made with a good degree of precision. The only exception occurs in surface waters where rapid changes in the abundance of phytoplankton, particularly during the spring bloom, can cause rapid depletion of nutrients.

The greatest source of uncertainty comes in our estimates of phytoplankton abundance because of the difficulties in describing the inter-annual variations in the timing, magnitude and duration of the spring phytoplankton bloom. Phytoplankton may undergo rapid changes in abundance, on time scales of days to weeks. Because our sampling is limited in time, and occasionally suffers from gaps in coverage as a result of vessel unavailability or weather, which often occurs in the sampling at our high-frequency sampling stations during the winter months, we may not sample the spring phytoplankton and other important variables adequately. Also, variations in the timing of the spring phytoplankton bloom across a region and in relation to spring oceanographic surveys may limit our ability to determine inter-annual variations in maximum phytoplankton abundance. In contrast, we are better capable of describing inter-annual variations in the abundance of dominant zooplankton species because their seasonal cycle occurs at time scales of weeks to months as a result of their longer generation times relative to phytoplankton. However, zooplankton show greater variability in their spatial distribution. Although inter-annual variations in the abundance of dominant groups, such as copepods, can be adequately assessed, variations in the abundance of rare, patchily distributed or ephemeral species cannot be reliably estimated at this time.

In several areas, the occupation of high frequency sampling stations during the winter and early spring is particularly limited, causing us to sometimes miss major events in the seasonal cycle (e.g. the onset of the spring phytoplankton bloom). Additionally, reductions in vessel scheduling within regions have also reduced the number of full observations at some sites.

CONCLUSIONS

While a shift to warmer ocean conditions occurred prior the implementation of the AZMP, the past decade has seen further increases in water temperatures. Sea-surface temperatures reached record values across the zone in summer 2012, remaining generally above-normal in 2013 with record September values on the Grand Banks. Sea-ice cover has been low for four consecutive winters and summertime CIL conditions were fairly uniform across the zone in 2013 with below-normal areas and volumes. Bottom temperatures were above-normal across almost the entire zone with record highs recorded in the deeper waters of the northern Gulf associated with a warm anomaly first observed in Cabot Strait in 2010 that is propagating toward the heads of channels.

Patterns of variation in biogeochemical variables appear dominated by short term fluctuations because the collection program for these elements was initiated only in 1999. The current state of the biogeochemical environment appears to demonstrate some spatial structuring, with conditions for the Scotian Shelf, Gulf of St. Lawrence and the southern Grand Banks having above normal nutrient inventories and near normal phytoplankton abundance, while conditions across much of the Newfoundland and Labrador Shelf being below average. The abundance of different groups of zooplankton also demonstrated strong spatial structure in the patterns of variation, with generally higher concentrations on the Newfoundland and Labrador Shelf and lower concentrations on the Scotian Shelf in recent years.

SOURCES OF INFORMATION

This Science Advisory Report is from the March 18-20, 2014 Sixteenth Annual Meeting of the Atlantic Zone Monitoring Program (AZMP). Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Colbourne, E., Holden, J., Craig, J., Senciall, D., Bailey, W., Stead, P., and Fitzpatrick, C. 2014. Physical oceanographic conditions on the Newfoundland and Labrador Shelf during 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/094. v + 38 p.

Galbraith, P.S., Chassé, J., Gilbert, D., Larouche, P., Brickman, D., Pettigrew, B., Devine, L., Gosselin, A., Pettipas, R.G. and Lafleur, C., 2014. Physical Oceanographic Conditions in the Gulf of St. Lawrence in 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/062.

Hebert, D., R. Pettipas, D, Brickman and M. Dever. 2014. Meteorological, Sea Ice and Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/070.

Johnson, C., Harrison, G., Casault, B., Spry, J., Li, W., and Head, E. 2013. Optical, chemical, and biological oceanographic conditions on the Scotian Shelf and in the eastern Gulf of Maine in 2012. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/070. v + 42 p.

Pepin, P., Maillet, G., Fraser, S., Shears, T., and Redmond, G. 2013. Optical, chemical, and biological oceanographic conditions on the Newfoundland and Labrador Shelf during 2011-12. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/051. v + 38 p.

Plourde, S., 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.

Therriault, J.-C., Petrie, B., Pepin, P., Gagnon, J., Gregory, D., Helbig, J., Herman, A., Lefaivre, D., Mitchell, M., Pelchat, B., Runge J. and D. Sameoto. 1998. Proposal for a northwest Atlantic zonal monitoring program. Can. Tech. Rep. Hydrogr. Ocean Sci. 194: vii+57p.

APPENDIX: FIGURES

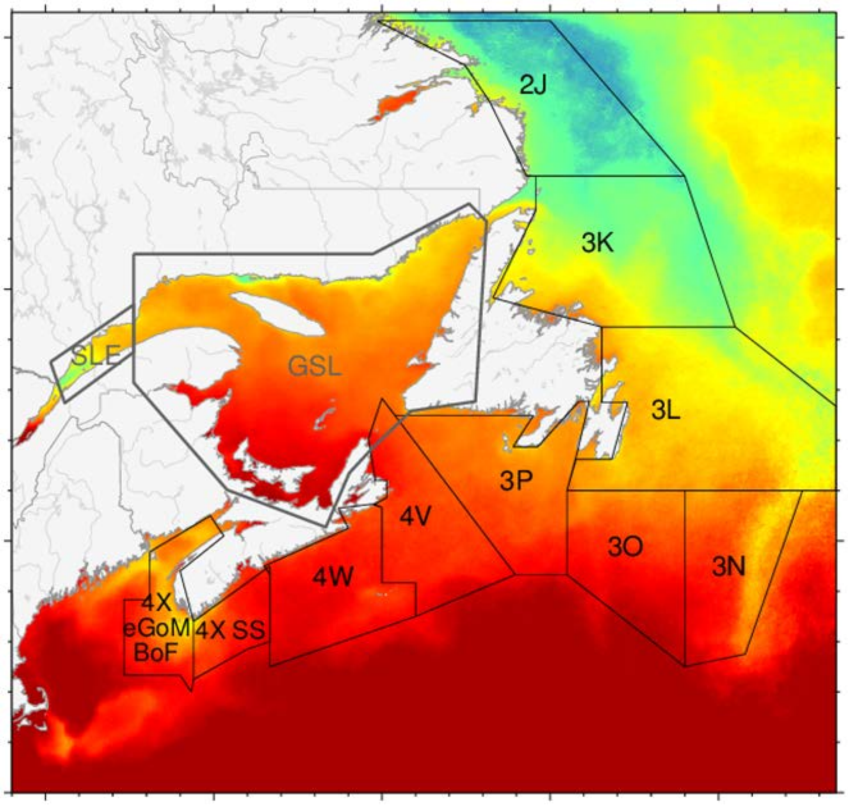

Figure 2. Reduced NAFO areas referenced in the text, and area used for SST averaging for the Gulf of St. Lawrence (GSL) and St. Lawrence Estuary (SLE). These reduced NAFO areas are cut off at the shelf break. Sea-surface temperatures are shown for July 2013'; see Figure 3 for colour palette.

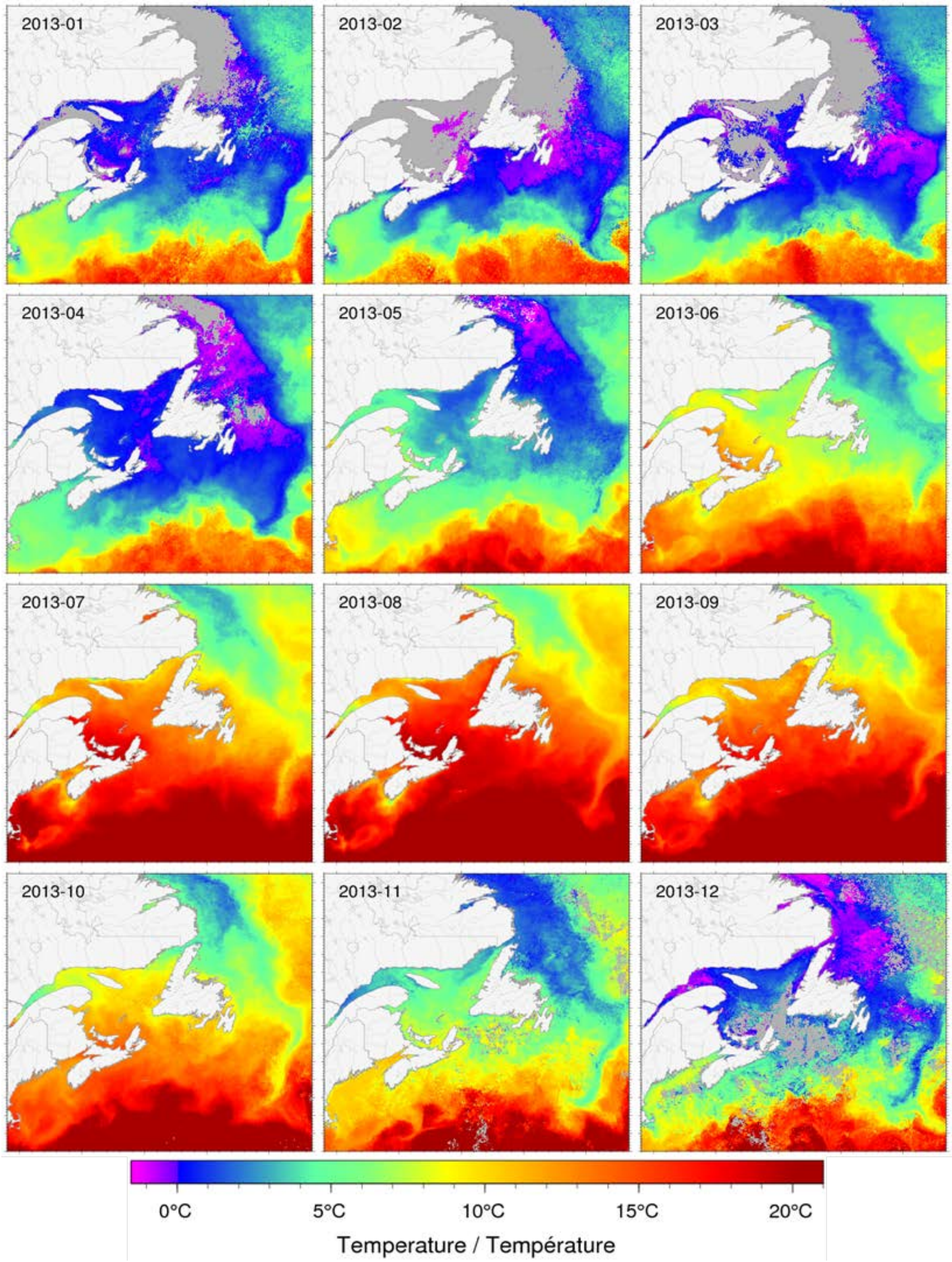

Figure 3. Sea-surface temperature monthly averages for 2013 in the AZMP region.

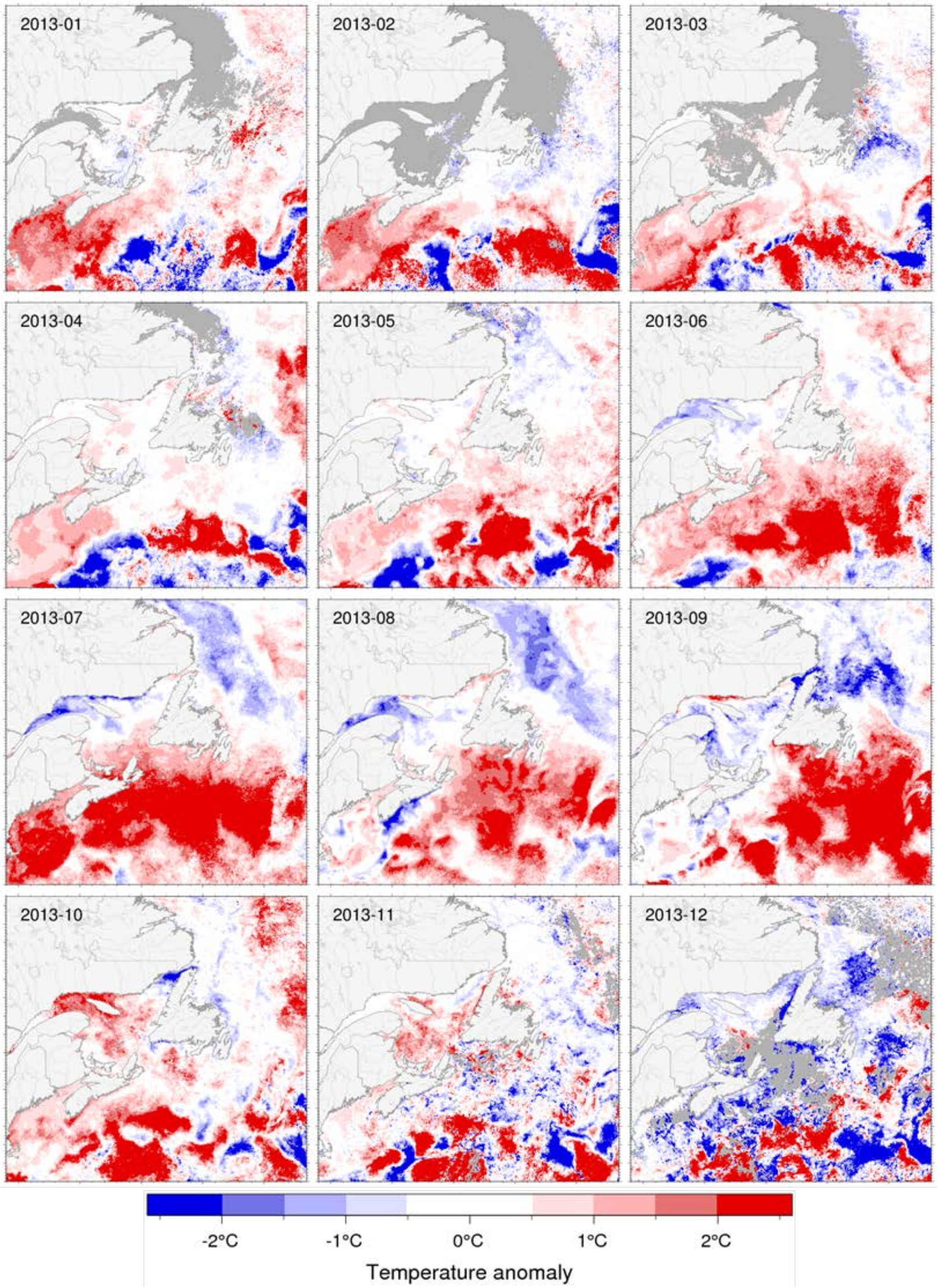

Figure 4. Sea-surface temperature anomalies for 2013 in the AZMP region. Temperature anomalies are based on a 1985–2010 climatology for January-August and on a 1999-2010 climatology for September-December.

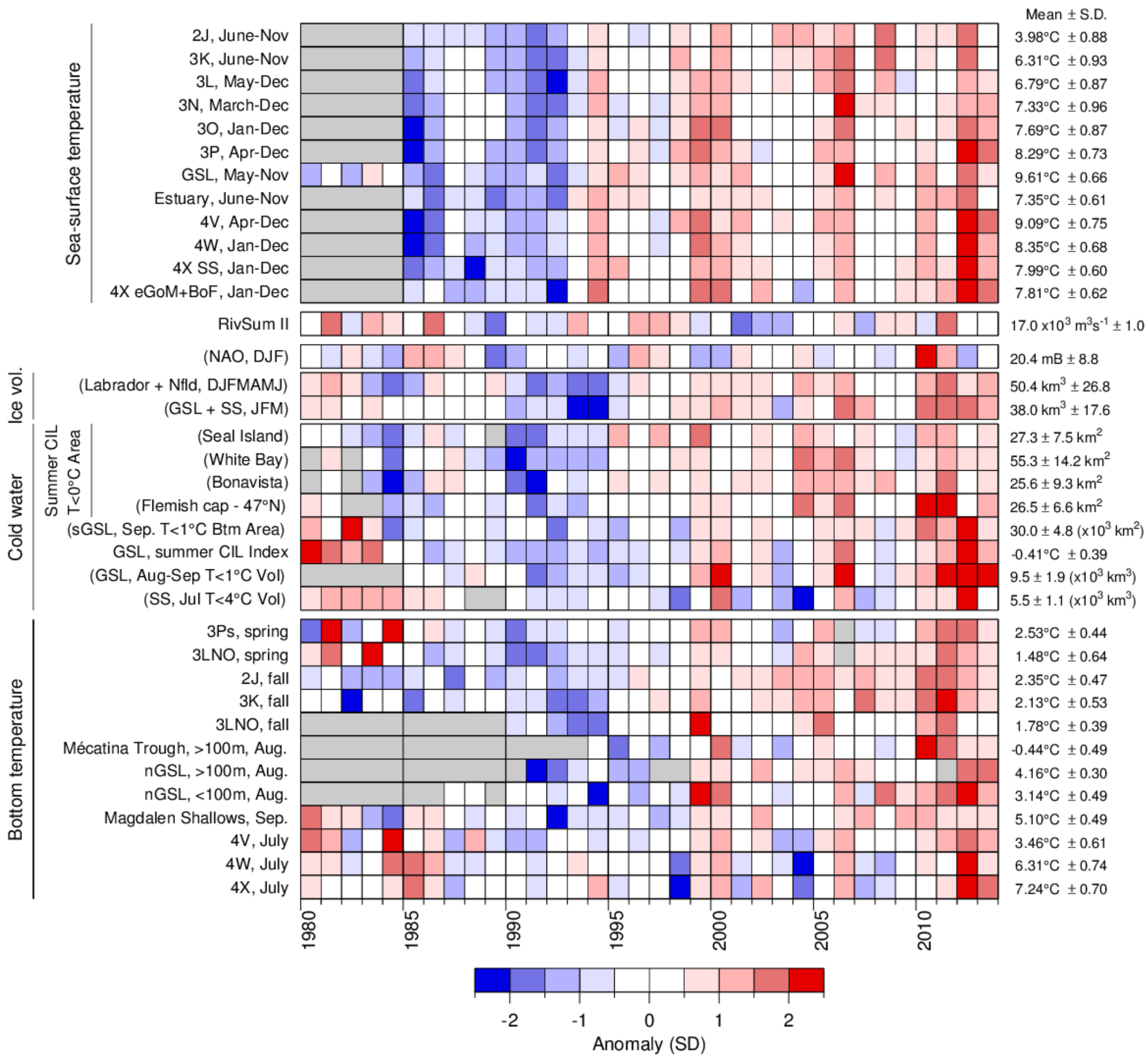

Figure 5. Time series of oceanographic variables, 1981–2013. A grey cell indicates missing data, a white cell is a value within 0.5 standard deviation of the long-term mean based on data from 1981–2010 when possible; a red cell indicates above-normal conditions, and a blue cell below-normal. Parameters whose names appear in parentheses have reversed colour coding, whereby reds are lower than normal values that correspond to warm conditions. More intense colours indicate larger anomalies. Long-term means and standard deviations are shown on the right-hand side of the figure. Sea-surface temperature for the GSL for 1980-1984 is based on an air temperature proxy. RivSum II is the combined runoff flowing into the St. Lawrence Estuary. (North Atlantic Oscillation [NAO], GSL [Gulf of St. Lawrence], SS [Scotian Shelf], sGSL [southern Gulf of St. Lawrence], nGSL [northern Gulf of St. Lawrence], cold intermediate layer [CIL]).

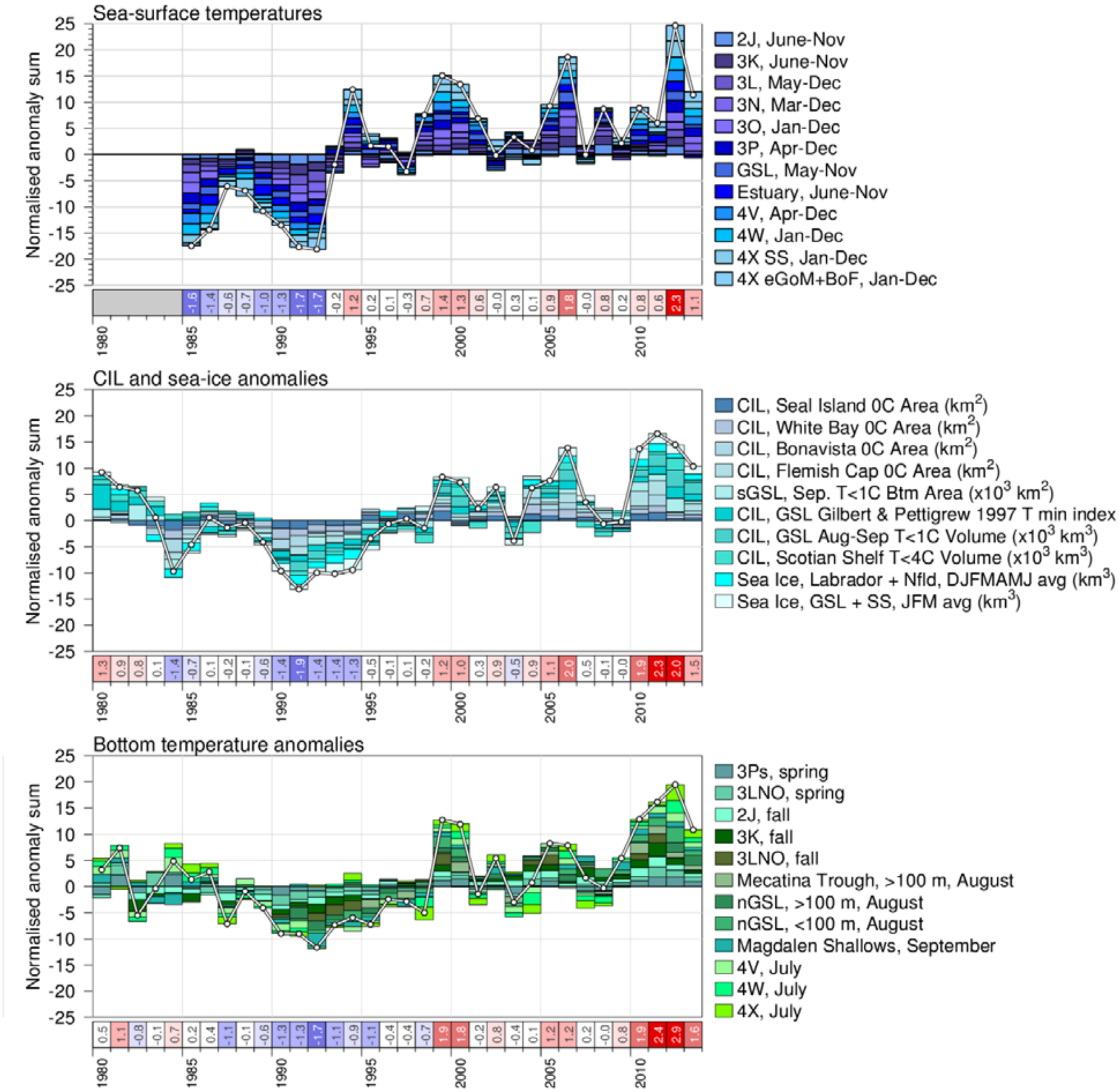

Figure 6. Composite climate indices (white lines and dots) derived by summing various standardized anomalies from different parts of the environment (colored boxes stacked above the abscissa are positive anomalies, and below are negative). Top panel sums sea-surface temperature anomalies, middle panel sums cold intermediate layer and sea-ice anomalies with areas and volumes in reversed scale (positive anomalies are warm conditions) and bottom panel sums bottom temperature anomalies.

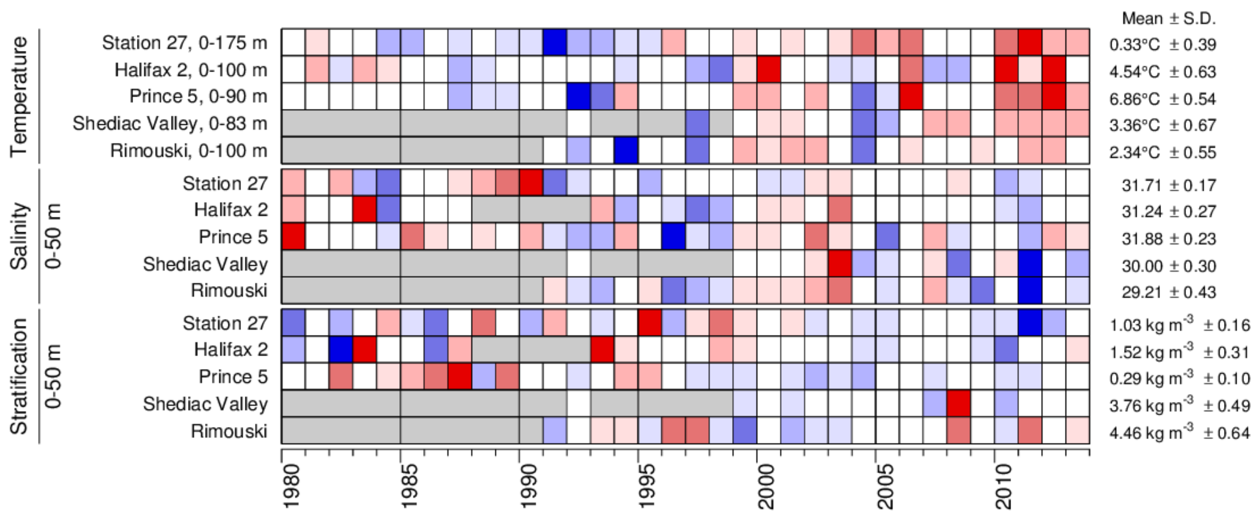

Figure 7. Time series of oceanographic variables at AZMP high-frequency sampling stations, 1981–2013. A grey cell indicates missing data, a white cell is a value within 0.5 standard deviation of the long-term mean based on data from 1981–2010 when possible; for high-frequency station depth-averaged temperature, a red cell indicates warmer-than-normal conditions, a blue cell colder than normal. More intense colours indicate larger anomalies. For salinity and stratification, red corresponds to above-normal conditions. Long-term means and standard deviations are shown on the right-hand side of the figure. see palette in Figure 5.

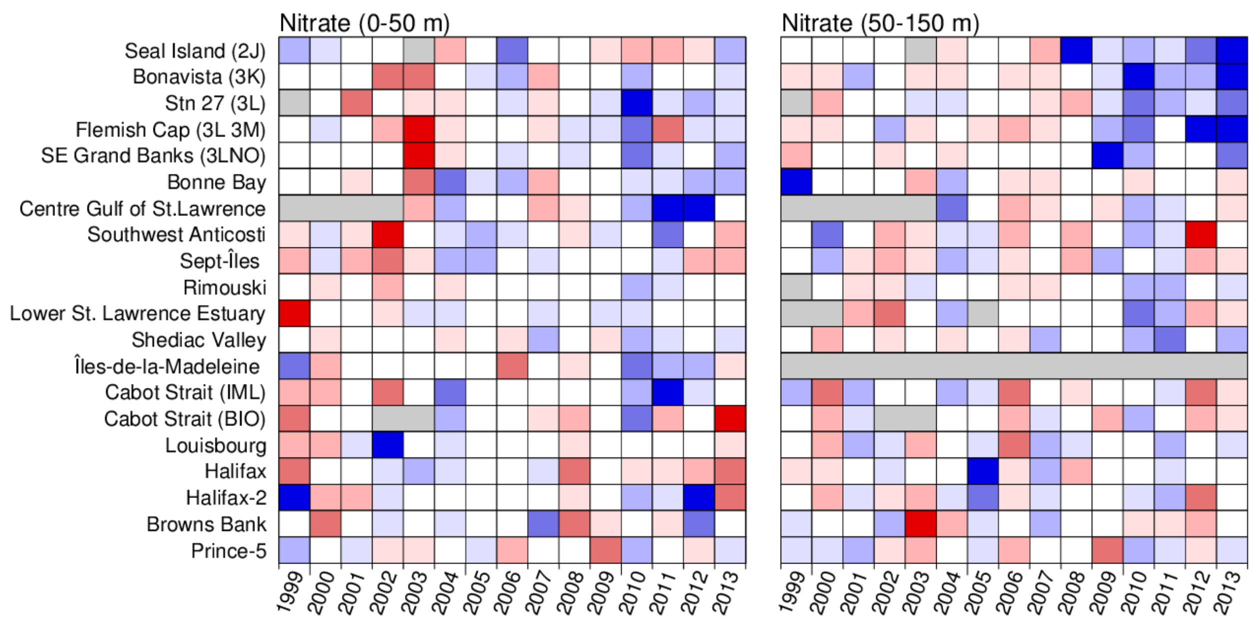

Figure 8. Time series of nitrate inventories for the surface (0-50 m) and subsurface (50-150 m) layers at AZMP sections and high-frequency sampling stations, 1999–2013. Cabot Strait was sampled both by Maurice Lamontagne Institute (IML) and by the Bedford Institute of Oceanography (BIO) at different times of the year and results are shown separately. A grey cell indicates missing data, a white cell is a value within 0.5 standard deviation of the long-term mean based on data from 1999–2010; a red cell indicates above normal inventories, a blue cell below normal. More intense colours indicate larger anomalies; see palette in Figure 5.

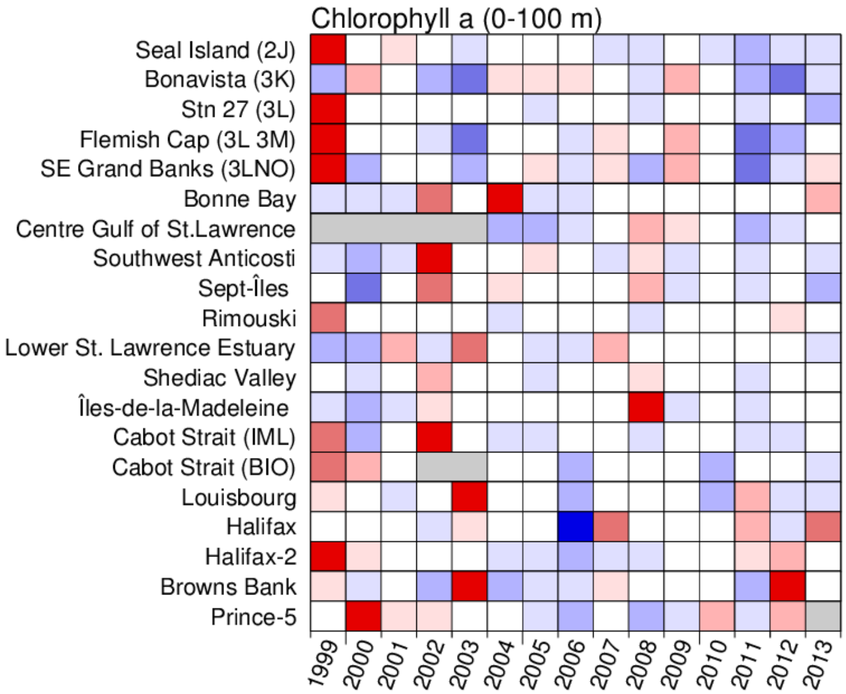

Figure 9. Time series of phytoplankton standing stocks (0-100 m), 1999–2013. A grey cell indicates missing data, a white cell is a value within 0.5 standard deviation of the long-term mean based on data from 1999–2010; a red cell indicates above normal inventories, a blue cell below normal. More intense colours indicate larger anomalies; see palette in Figure 5.

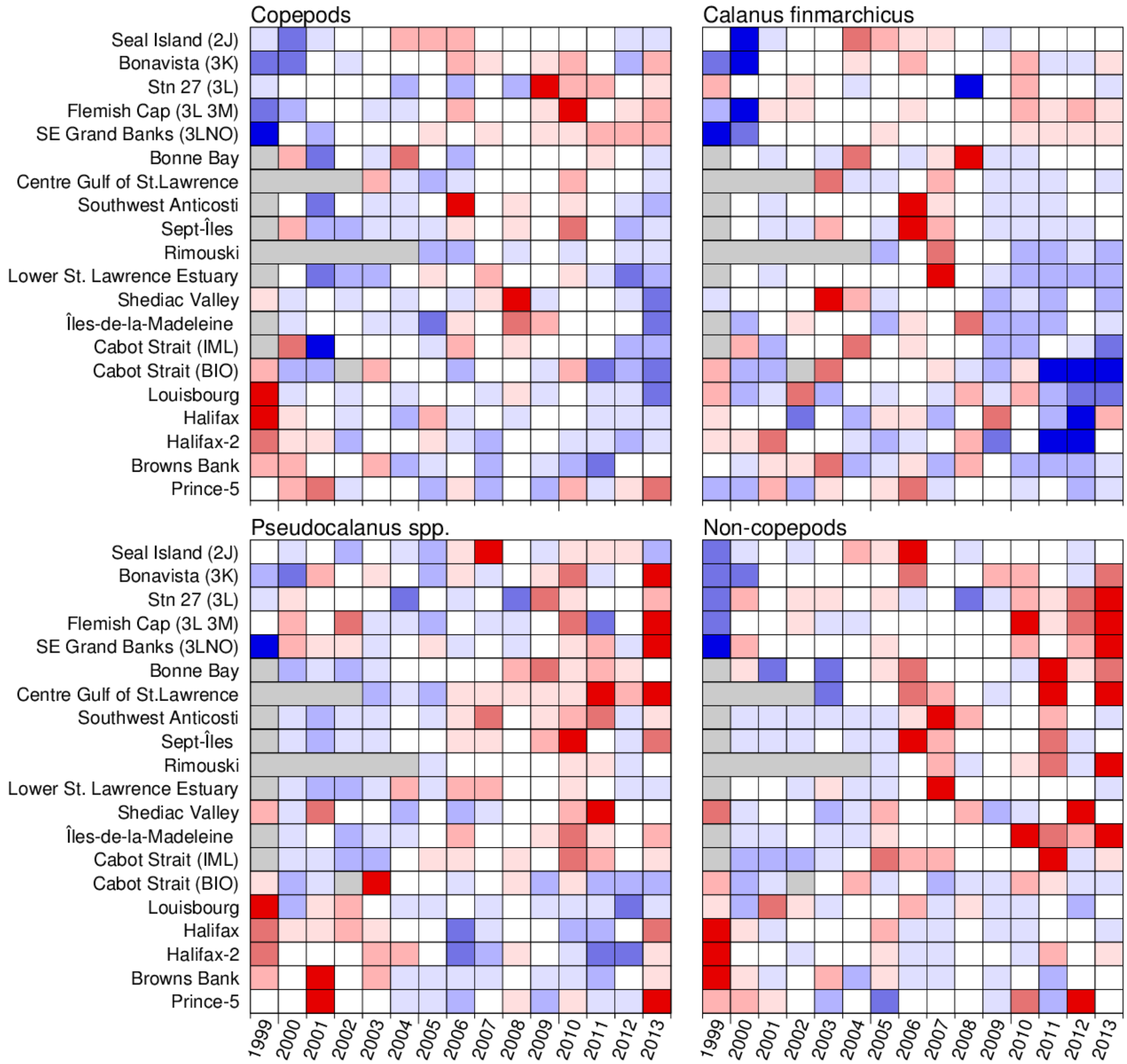

Figure 10. Time series of the standing stocks of total copepods, Calanus finmarchicus, Pseudocalanus spp., and non-copepod zooplankton, 1999–2013. A grey cell indicates missing data, a white cell is a value within 0.5 standard deviation of the long-term mean based on data from 1999–2010; a red cell indicates above normal inventories, a blue cell below normal. More intense colours indicate larger anomalies; see palette in Figure 5.

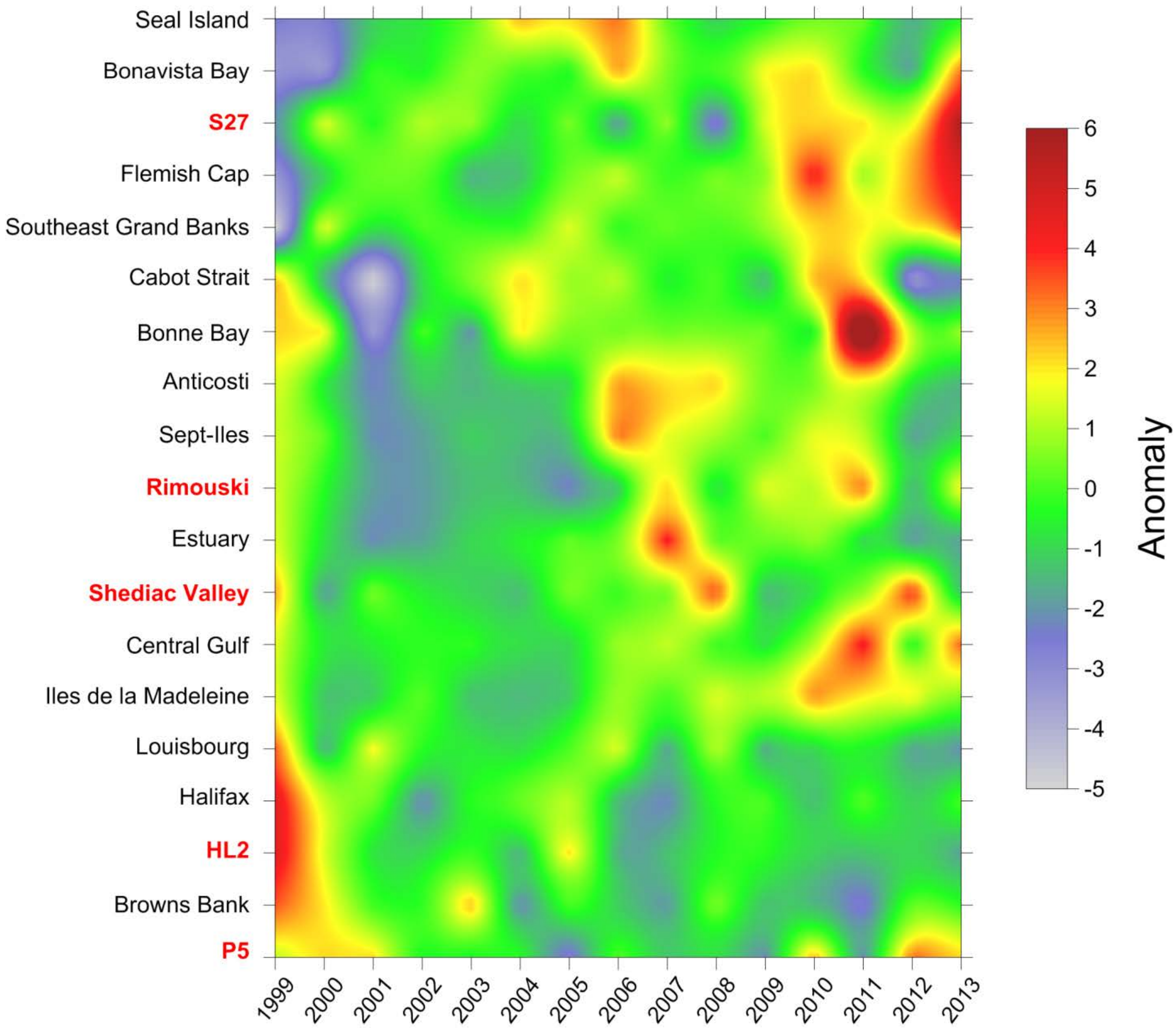

Figure 11. Schematic heat map of the summed copepod and non-copepod abundance anomalies along oceanographic sections and at high frequency sampling stations (highlighted in red on the left); blue indicates below average abundance while red indicate above average abundance.

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