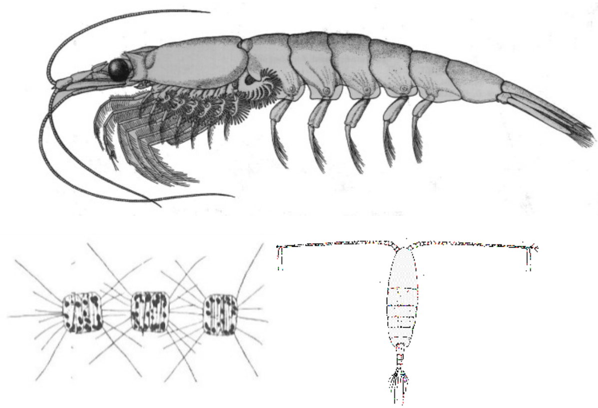
OCEANOGRAPHIC CONDITIONS IN THE ATLANTIC ZONE IN 2012



Key taxa of the pelagic food web: euphausids (top), phytoplankton (bottom right), and copepods (bottom left). Images: Fisheries and Oceans Canada

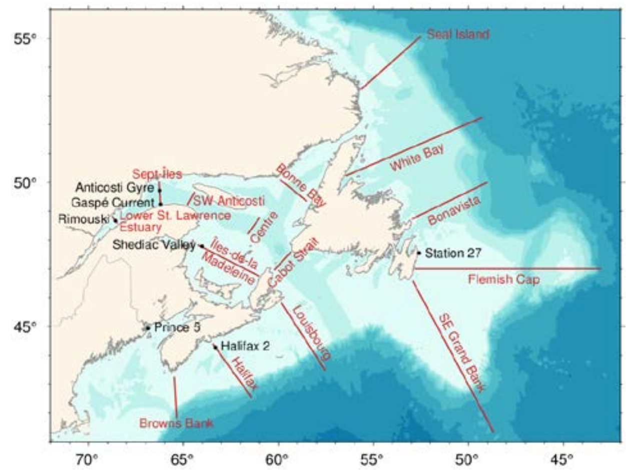


Figure 1. Atlantic Zone Monitoring Program fixed stations and selected sections.

Context:

The Atlantic Zone Monitoring Program (AZMP) was implemented in 1998 with the aim of increasing the Department of Fisheries and Oceans' (DFO) 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) provides important information about organisms that form the base of the marine foodweb. 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 or near-record highs during ice-free months across the zone, most notably on the Scotian Shelf and southern areas of Newfoundland.
- Sea ice volume remained very low in the Gulf of St. Lawrence but rebounded somewhat in the Newfoundland–Labrador (NL) Shelf where it was nevertheless still the 8th lowest of the series.

- In the Gulf of St. Lawrence the Cold Intermediate Layer (CIL) temperature index, CIL volume and the southern Gulf bottom area covered by cold water were at record warm levels, the Scotian Shelf CIL volume was at a record low and on the Newfoundland and Labrador Shelves the Bonavista and White Bay CIL cross-sectional area was below-normal while the Southern Labrador and Grand Bank CIL areas were near-normal.

- Bottom temperatures were generally above-normal across the zone, with record highs recorded in the northern Gulf as well as on the Scotian Shelf. Spring bottom temperatures in Division 3Ps on the southern Newfoundland Shelf were identical to the previous year both the highest since 1984.

- Nitrate inventories in both surface and near bottom waters were generally near the long-term average in the Gulf of St. Lawrence but remained below normal on the Newfoundland and Labrador Shelf.

- Since 2010, phytoplankton abundance has been near or below the long-term average throughout much of the Atlantic Zone, although overall abundance has been strongly below normal across much of the Newfoundland and Labrador Shelf in 2011 and 2012.

- The overall abundance of zooplankton was below average throughout most of the Atlantic Zone, although some groups (e.g. non-copepod zooplankton) demonstrated remarkably high abundance levels in some areas (e.g. Grand Banks) in 2012 and over much of the Gulf of St. Lawrence in 2011.

BACKGROUND

The AZMP was implemented in 1998 (Therriault et al.1998) with the aim of: (1) increasing 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, plankton 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 (fixed point stations, cross-shelf sections, ecosystem surveys) in each region (Quebec, Maritimes/Gulf, Newfoundland and Labrador) sampled at a frequency of bi-weekly to once annually (Fig. 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 (ecosystem) surveys and cross-shelf sections provide detailed geographic information, but are limited in their seasonal coverage. Strategically placed fixed stations 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 2012 for eastern Canadian oceanic waters (Fig. 1) as reported annually by the AZMP in three reports (Colbourne et al. 2013; Galbraith et al. 2013; Hebert et al. 2013). Air temperature set a record-high at many stations across the zone in August. It was at a record high in summer in the Gulf of St. Lawrence, at a record high annual average on the Scotian Shelf, and above average on the Newfoundland Shelf reaching a record high at St. John's. The effect on the ocean was dramatic with record or near-record high sea-surface temperature (SST) during ice-free months across the zone (Figs. 2-5), most notably on the Scotian Shelf where annual anomalies reached +1.6°C to +1.9°C and on the Newfoundland Shelf (region 3P) where the April-December anomaly reached +1.7°C. Record high anomalies in August (Fig. 4) occurring at the same time as the annual cycle peak led to the highest observed SSTs in over 100 years in most areas of the zone (Figs. 3 and 5)

A number of environmental (the North Atlantic Oscillation [NAO] index, freshwater runoff at Québec City) and oceanographic variables and indices are summarized as time series (1980–2012) values in matrix form in Fig. 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 ~0.5 salinity units more than the average for high runoff years in the 1970s, 1980s, and 1990s. This represents approximately an extra 17 km^3 of freshwater in the upper 20 m of the Shallows. The St. Lawrence River runoff has been decreasing since the early 1970s but appears to have been increasing again since 2001. However, the mean runoff was below normal (-0.8 SD) in 2012.

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. The tendency of the ocean currents to move from north to south spreads the NAO's influence into the Gulf of St. Lawrence and onto the Scotian Shelf where record or near-record ocean temperatures dominated in 2012, corresponding to the negative NAO index the two years preceding. Direct effects occur predominantly in waters of the Labrador Sea and the Newfoundland–Labrador Shelf, where the positive NAO index in 2012 (+1.3 SD) led to deeper winter convection in the Labrador Sea and a significant cooling of ocean temperatures on the NL Shelf compared to the previous year.

For the past decade, ice volumes on the Newfoundland–Labrador Shelf and the Gulf of St. Lawrence–Scotian Shelf have generally been lower than normal and reached a record-low value in the Gulf of St. Lawrence in 2010, with sea-ice almost absent due to the record-high winter air temperatures, and reached a record-low in 2011 on the Newfoundland–Labrador Shelf. In 2012, sea ice volume remained very low in the Gulf of St. Lawrence (3rd lowest Dec.-Feb. average volume and 4th lowest seasonal peak volume) but rebounded somewhat in the Newfoundland–Labrador Shelf where it was nevertheless still the 8th lowest of the series.

A number of indexes 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 indexes from the southern Labrador and northeast (NE) Newfoundland Shelf and the northern Grand Bank, followed by similarities between the Gulf of Lawrence and the Scotian Shelf. In 2012, the Gulf CIL temperature index, CIL volume and the southern Gulf bottom area covered by cold water (T <1°C) were at record low (e.g. warm) levels since the early 1980s. The Scotian Shelf CIL volume (T <4°C), which is influenced by Gulf of St. Lawrence outflow, was also at a series record low. On the Newfoundland and Labrador Shelves, the White Bay and Bonavista CIL (T <0°C) cross-sectional area was below-normal; the Seal Island and 47°N CIL cross-sectional areas were near-normal.

Bottom temperatures were above-normal across the zone except for the Northwest Atlantic Fisheries Organization (NAFO) Divisions 3LNO in the fall. Record highs were recorded in the northern Gulf in both shallow (less than 100 m, +3.0 SD) and greater depths (+1.9 SD) as well as in Divisions 4W (+2.4 SD) and 4X (+3.0 SD) of the Scotian Shelf. Spring bottom temperatures in Division 3Ps on the southern Newfoundland Shelf were identical to the previous year both the highest (+1.8 SD) since 1984. In 2J and 3K bottom temperatures were lower than the previous year, but still +1 SD above normal.

In 2012, annually averaged temperatures at fixed AZMP stations reached a 33-year record high of +3.7 SD at Halifax 2 and +3.5 at Prince 5, and were above-normal at all other stations (Fig. 6). The annual 0–50 m salinity anomalies did not display a consistent pattern across the region. They were above-normal at Rimouski station, Gaspé Current station and Prince 5, normal at the others. The annual 0–50 m stratification index also did not display a consistent pattern, but was at a record-high at Anticosti Gyre station. Since 1950, 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 0.36 kg m^3 over 50 years. This change in mean stratification is due mainly to a freshening of the surface waters. Stratification on the Scotian Shelf strengthened significantly in 2012 compared to 2011 and was the fourth strongest stratification of the series.

A total of 40 indices listed in Figs. 5 and 6 describe ocean conditions within the AZMP area (SST; ice; summer CIL areas, volumes, and minimum temperature; bottom temperature; 0–100 m average temperature). Of these, four were within normal values and thirty six were above normal, indicating how out-of-the-ordinary oceanographic conditions were in 2012.

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, with the largest species being members of a group called diatoms while smaller species are members of a group called flagellates. They use light to produce organic matter from 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. 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. 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.

A number of environmental variables (e.g. nitrate inventories, phytoplankton and zooplankton standing stocks) and indices are summarized as time series (1999–2012) of annual values in matrix form in Figs. 7-9. 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 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 ~2 SD, with the magnitude of the average maximum year-to-year change increasing slightly as we move from nutrients to phytoplankton to zooplankton. There is a degree of synchrony in the patterns of variation of individual biogeochemical variables within regions, with the sign of anomalies tending to persist for several years, although in some instances there may also be considerable variability among locations within a region.

Following a two year period (2010-11) when nutrient inventories in both surface (0-50 m) and subsurface (50-150 m) (Fig. 7) were below normal throughout much of the Atlantic zone, nitrate concentration anomalies became positive in 2012 in most parts of the Scotian Shelf, Gulf of St. Lawrence and southeast Shoal whereas they have remained below normal through much of the Newfoundland–Labrador Shelf. There was considerable variability in the size of the anomalies among neighboring areas.

Chlorophyll inventories (0-100 m; Fig. 8), 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. Phytoplankton abundance has been near the long-term average throughout much of the Atlantic Zone, within approximately ± 0.5 SD units of the 1999-2010 average, although overall abundance has been strongly below normal across much of the Newfoundland & Labrador Shelf in 2011 and 2012. 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, 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 includes estuarine to oceanic environments.

Zooplankton indices of abundance tended to demonstrate a greater degree of temporal consistency within regions than was apparent in the case of chlorophyll abundance. The mesozooplankton (0.2-20 mm in size) sampled by the AZMP generally consist of taxa with life cycles of one or more years, with the populations in one region having potentially a high degree of connectivity with adjacent areas because these organisms are greatly influenced by the effects of ocean currents.

In 2012, most indices of zooplankton abundance were within ± 1 SD of the 1999-2010 average (Fig. 9). Copepod abundance on the Central Scotian Shelf (Halifax section and fixed site) and in the Lower St. Lawrence Estuary and Gaspé Current was below average in 2012. In the case of *Pseudocalanus* spp., an important prey for many species of young fish, their abundance was about normal across almost the entire Atlantic Zone, which represent a shift from a three year period (2009-11) during which abundance levels had been generally above normal throughout much of the Newfoundland and Labrador Shelf and the Gulf of St. Lawrence and below normal on the Scotian Shelf. The abundance of *Calanus finmarchicus*, a key species in most ecosystems of the North Atlantic, has been below normal in both the Gulf of St. Lawrence and Scotian Shelf since 2009 whereas abundance levels have generally been above normal across most the of the Newfoundland and Labrador Shelf during the same period.

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 2012 this group was highly abundant on the Grand Banks, on the Magdelan Shallows and in the Bay of Fundy. 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 21% 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 Fig. 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 (Fig. 10). 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 a general decrease in the abundance of zooplankton throughout much of the Atlantic Zone in 2012.

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, oxygen) 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 fixed 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 locations (fixed sites) 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). Also, reductions in vessel scheduling within regions have also reduced the number of full observations at some sites.

CONCLUSIONS

While a shift to warmer conditions occurred prior the implementation of the AZMP, the last few years have seen a further increase in water temperatures. Sea-surface temperatures reached record values across the zone in summer, and record or near-record values during ice-free months. Sea-ice cover has been low for three consecutive winters and summertime CIL conditions at record warm levels since the early 1980s or longer in the Gulf of St. Lawrence and on the Scotian Shelf. Bottom temperatures were above-normal across almost the entire zone with record highs recorded in the northern Gulf, regions of the Scotian Shelf (NAFO Divisions 4X and 4W) and southern Newfoundland Shelf (Division 3P).

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–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– Labrador Shelf and lower concentrations on the Scotian Shelf in recent years.

SOURCES OF INFORMATION

This Science Advisory Report is from the March 18-21, 2013 Fifteenth 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., Craig, J., Fitzpatrick, C., Senciall, D., Stead, P., and Bailey, W. 2013. An assessment of the physical oceanographic environment on the Newfoundland and Labrador Shelf during 2012. DFO Can. Sci. Advis. Sec. Res. Doc., 2013/052. vi+35p.

Galbraith, P.S., Chassé, J., Larouche, P., Gilbert, D., Brickman, D., Pettigrew, B., Devine, L., and Lafleur, C., 2012. Physical oceanographic conditions in the Gulf of St. Lawrence in 2012. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/026. v+89p.

Hebert, D., Pettipas, R., Brickman, D. and Dever, M. 2013. Meteorological, sea ice and physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine during 2012. DFO Can. Sci. Advis. Sec. Res. Doc., 2013/058. iv+46p.

Pepin, P., Maillet, G., Fraser, S., and Redmond, G.. 2013. Optical, chemical, and biological oceanographic conditions on the Newfoundland and Labrador Shelf during 2011-2012. DFO Can. Sci. Advis. Sec. Res. Doc., 2013/051, iv+39p.

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

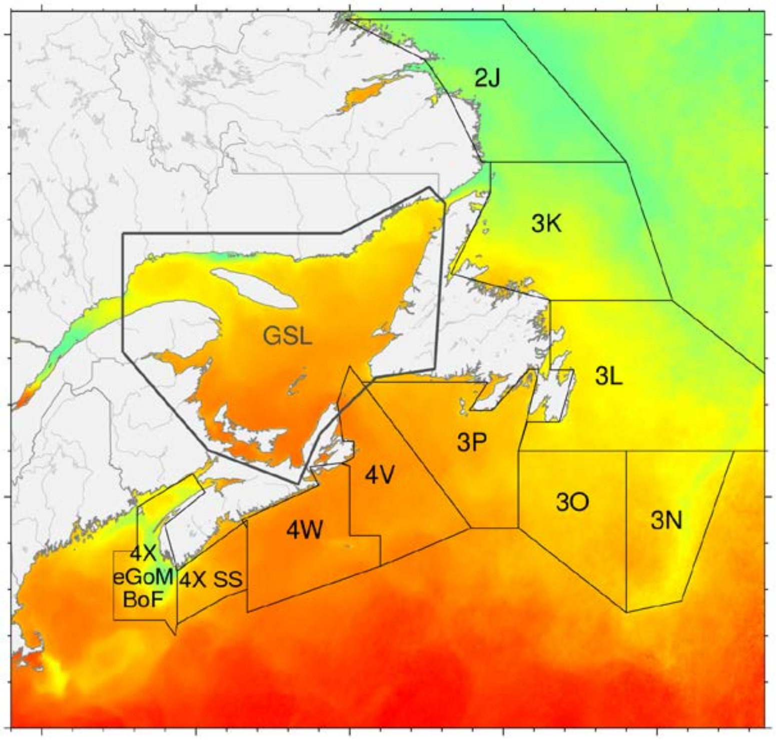


Figure 2. Reduced NAFO areas referenced in the text, and area used for SST averaging for the Gulf of St. Lawrence (GSL). These reduced NAFO areas are cut off at the shelf break.

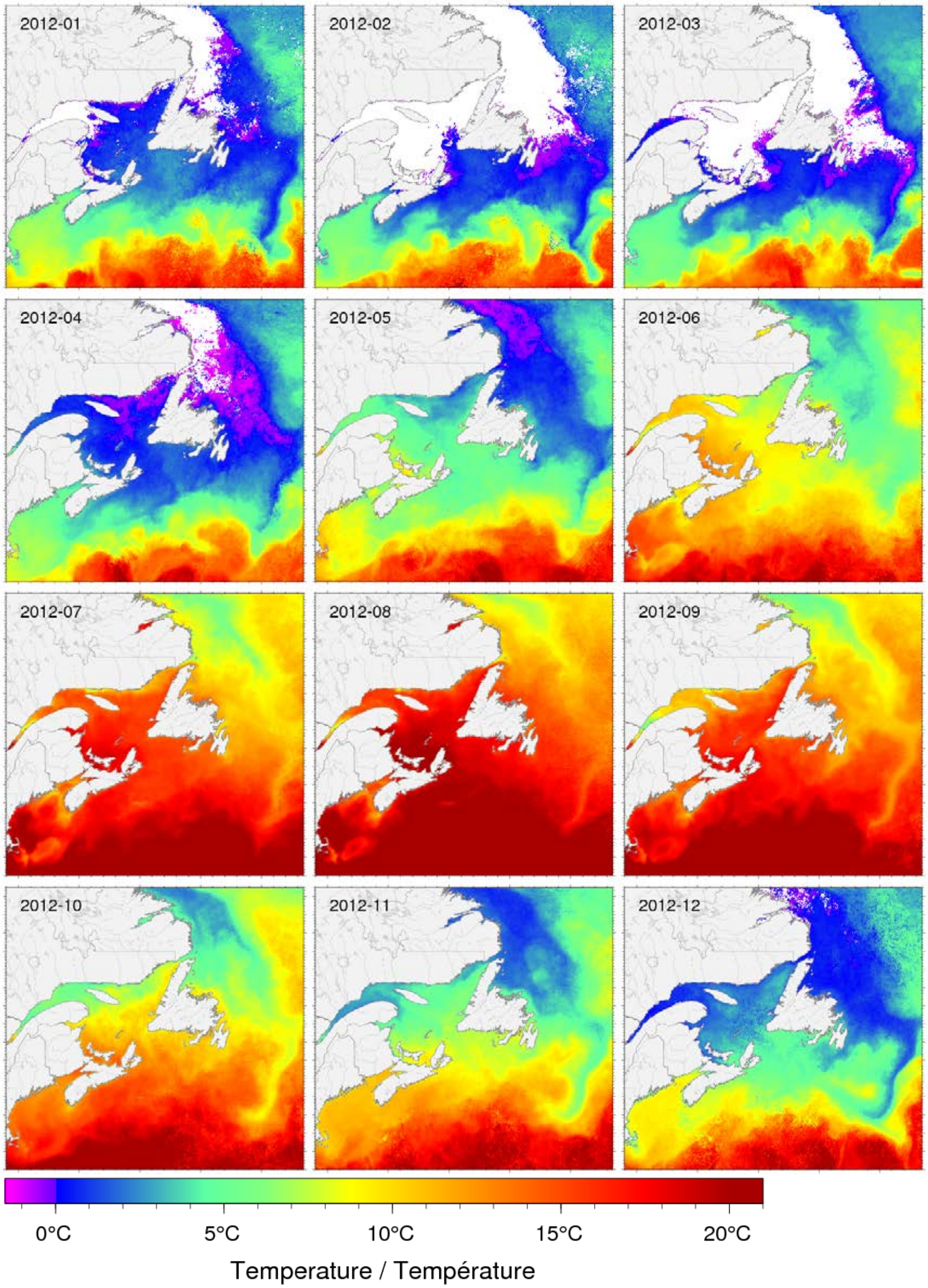


Figure 3. Sea-surface temperature monthly averages for 2012 in the AZMP region.

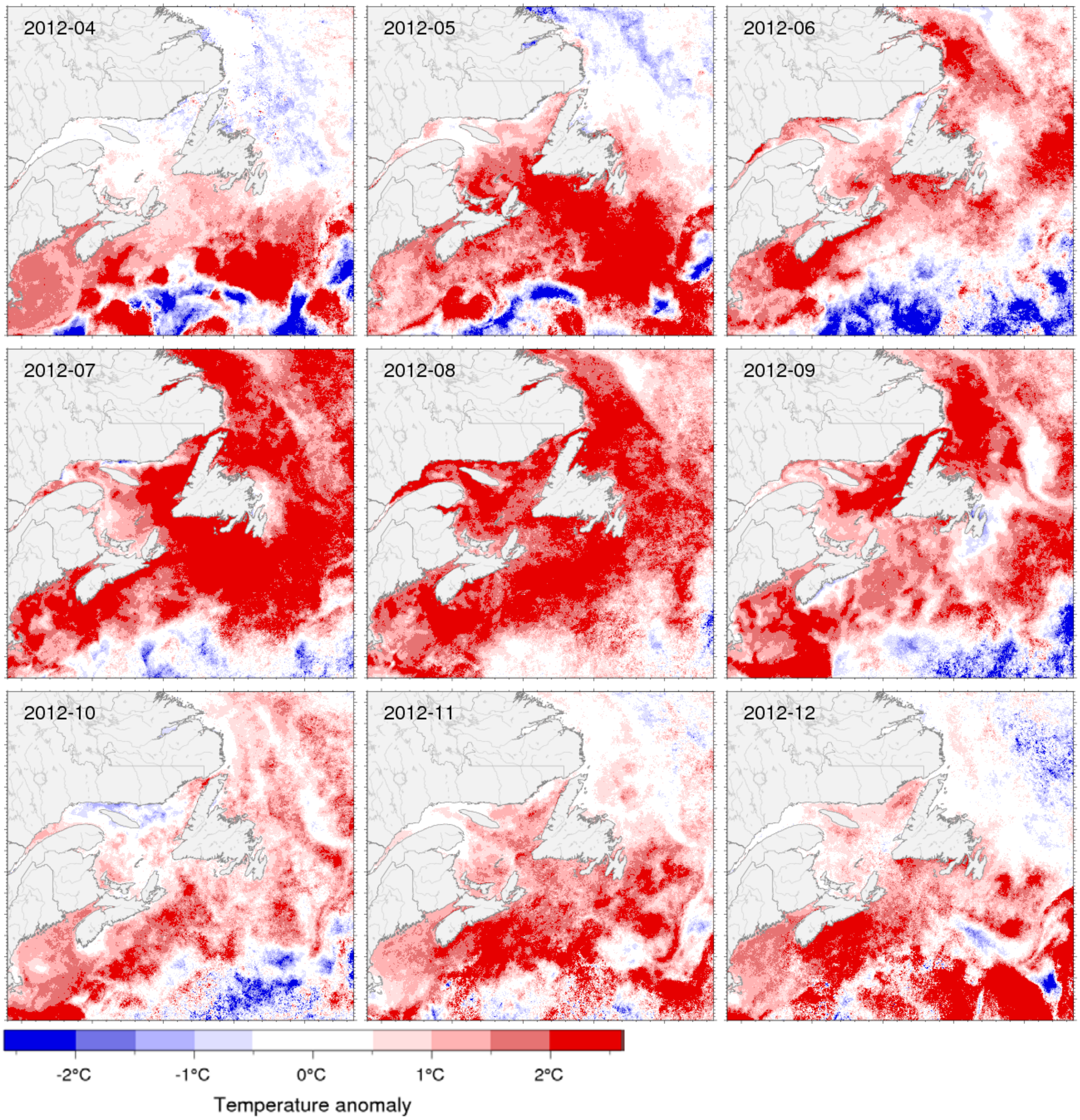


Figure 4. Sea-surface temperature anomalies from April to December 2012 in the AZMP region. Temperature anomalies are based on a 1985–2010 climatology.

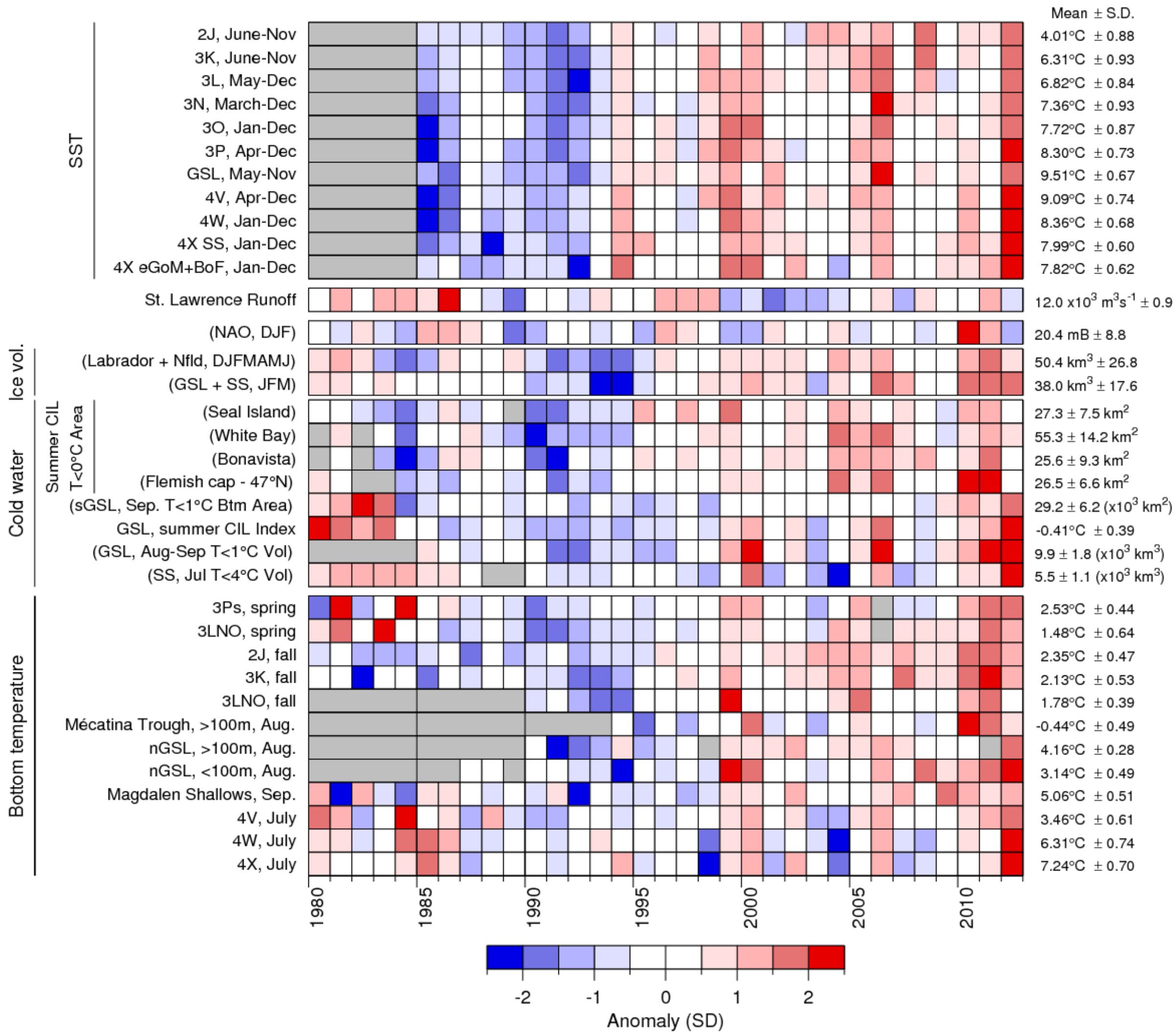


Figure 5. Time series of oceanographic variables, 1981–2012. A grey cell indicates missing data, a white cell is a value within 0.5 standard deviation of the long-term mean based on data from 1981–2010 when possible; a red cell indicates above-normal conditions, and a blue cell below-normal. Parameters 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. (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], December to February [DJF], December to June [DJFMAMJ], January to March [JFM], Bottom [Btm]).

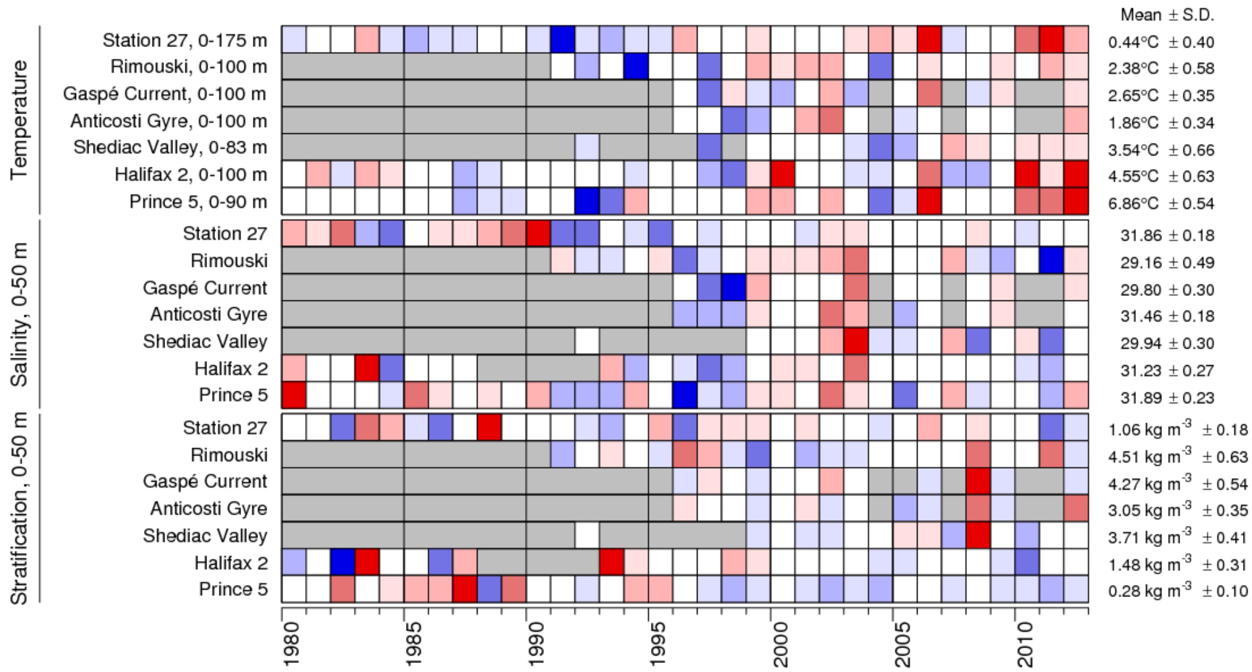


Figure 6. Time series of oceanographic variables at AZMP fixed stations, 1981–2012. A grey cell indicates missing data, a white cell is a value within 0.5 standard deviation of the long-term mean based on data from 1981–2010 when possible; for fixed station depth-averaged temperature, a red cell indicates 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.

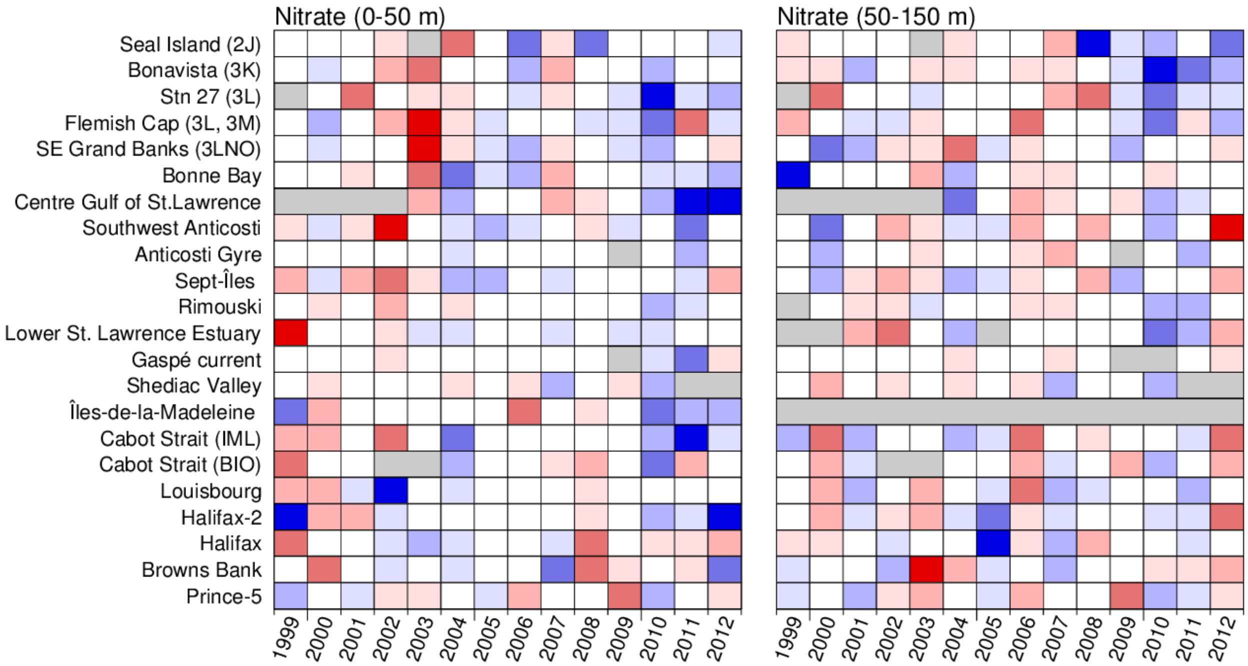


Figure 7. Time series of nitrate inventories for the surface (0-50 m) and subsurface (50-150 m) layers at AZMP sections and fixed stations, 1999–2012. Cabot Strait was sampled both by Maurice Lamontagne Institute (IML) and by the Bedford Institute of Oceanography (BIO) at different times of the year 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 Fig. 5.

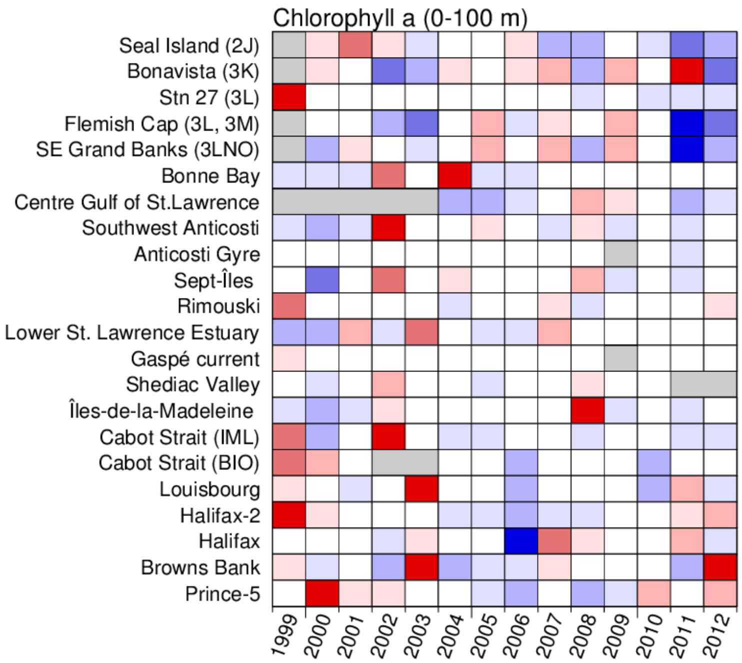


Figure 8. Time series of phytoplankton standing stocks (0-100 m), 1999–2012. A grey cell indicates missing data, a white cell is a value within 0.5 standard deviation of the long-term mean based on data from 1999–2010; a red cell indicates above normal inventories, a blue cell below normal. More intense colours indicate larger anomalies; see palette in Fig. 5.

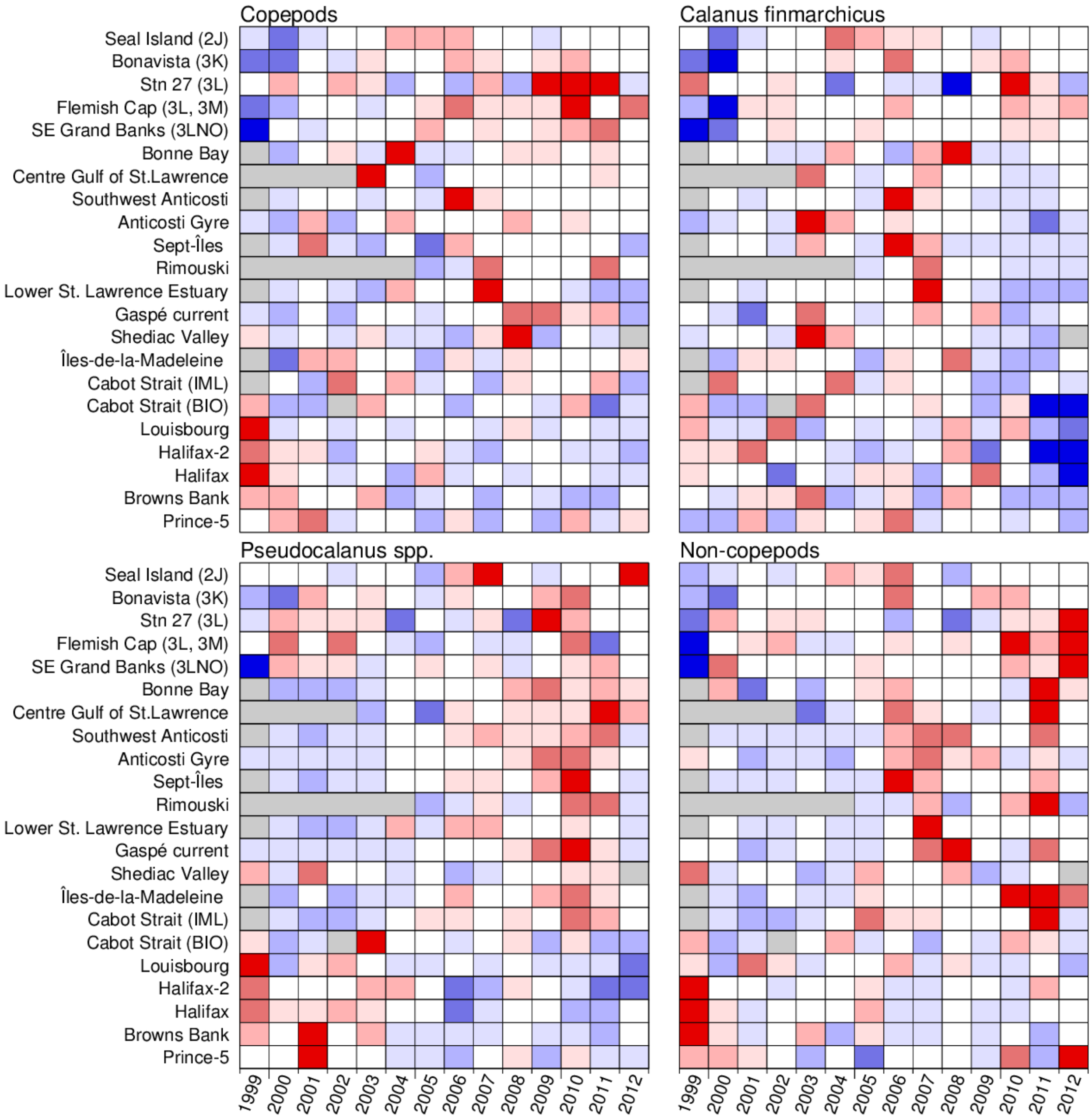


Figure 9. Time series of the standing stocks of total copepods, Calanus finmarchicus, Pseudocalanus spp., and non-copepod zooplankton, 1999–2012. A grey cell indicates missing data, a white cell is a value within 0.5 standard deviation of the long-term mean based on data from 1999–2010; a red cell indicates above normal inventories, a blue cell below normal. More intense colours indicate larger anomalies; see palette in Fig. 5

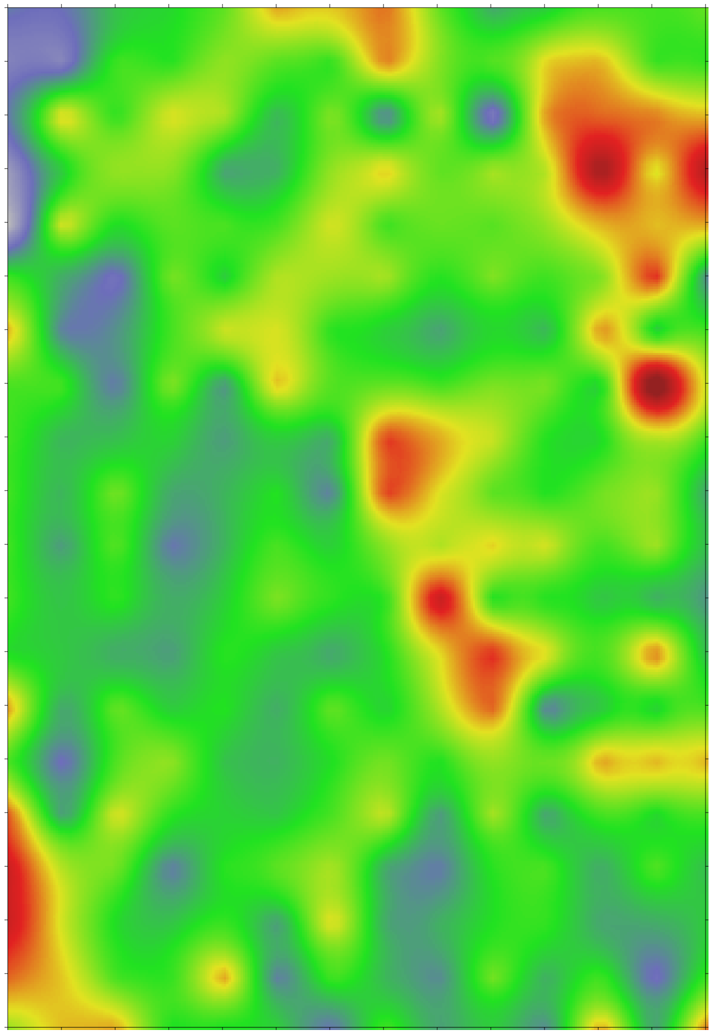


Figure 10. Schematic heat map of the summed copepod and non-copepod abundance anomalies along oceanographic sections and at high frequency fixed stations (highlighted in red on the left); blue indicates below average abundance while red indicate above average abundance.

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