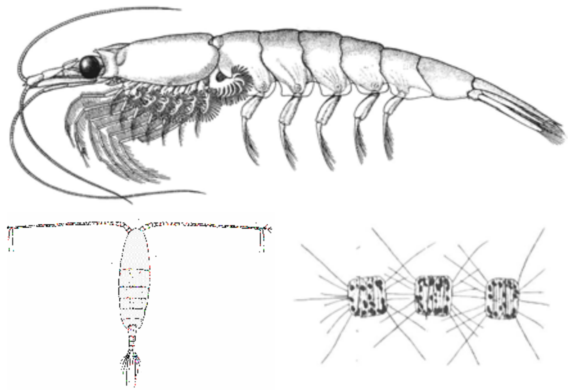
2008 STATE OF THE OCEAN: CHEMICAL AND BIOLOGICAL OCEANOGRAPHIC CONDITIONS IN THE GULF OF MAINE - BAY OF FUNDY AND ON THE SCOTIAN SHELF



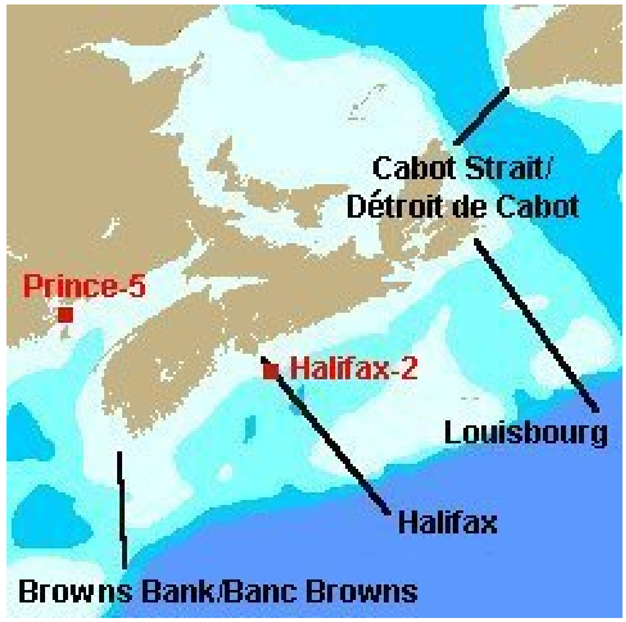


Figure 1. AZMP-Maritimes fixed stations and shelf sections.

Context:

The Atlantic Zone Monitoring Program (AZMP) was initiated in 1998 to: (1) increase DFO's capacity to understand, describe, and forecast the state of the marine ecosystem, and (2) quantify the changes in ocean physical, chemical and biological properties and predator-prey relationships of marine resources. A critical element of AZMP is an annual assessment of the distribution and variability of nutrients and the plankton that they support.

The AZMP uses data collected through a network of sampling locations (fixed point stations, cross-shelf sections, trawl surveys, satellite remote-sensing) in Quebec, Maritimes, Southern Gulf, and Newfoundland sampled from bi-weekly to annually. Information on the relative abundance and community structure of plankton is also collected from Iceland to the coast of Newfoundland and Newfoundland to the Gulf of Maine through commercial ship traffic instrumented with a Continuous Plankton Recorder (CPR).

A description of the distribution in time and space of nutrients dissolved in seawater (nitrate, silicate, phosphate, oxygen) provides important information on the water 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 food-web. An understanding of the production cycles of plankton is an essential part of an ecosystems approach to fisheries management.

SUMMARY

- Winter, spring and fall nutrient inventories in the Maritimes region were at or above normal levels in 2008 but summer inventories were lower than usual.
- The magnitude of the spring phytoplankton bloom was at or below average in 2008 and well below the 2007 record high level.
- Chlorophyll levels outside of the March-May bloom period have been declining since observations began in 1999.
- At Halifax-2, zooplankton biomass and *Calanus finmarchicus* abundance both exhibited late peaks of near-average magnitude, and both were above average in the summer. High *C. finmarchicus* abundance persisted in the fall.
- Cold water *Calanus* species were more abundant than average at Halifax-2, while warm water shelf species were less abundant than normal. However, these trends were reversed on the broader Scotian Shelf.
- Two numerically dominant small copepod species, *Pseudocalanus* spp. and *Oithona similis*, and the shallow water copepod *Temora longicornis* were more abundant than average on the eastern Scotian Shelf.
- At Prince-5, zooplankton biomass and copepod abundance exhibited an earlier than average peak, which was dominated by offshore species. The copepod community at Prince-5 was dominated by offshore species in 2008, especially in the summer.
- Observations from the Continuous Plankton Recorder indicate that, compared with the historical data record (starting in 1961), recent phytoplankton abundances on the Scotian Shelf have been at or above the long term average while zooplankton abundances have been at or below the norm.

INTRODUCTION / BACKGROUND

The production cycle of plankton is largely under the control of physical processes. Specifically, light and nutrients (e.g. nitrate, phosphate, silicate) are required for the growth of marine microscopic plants (phytoplankton). Of the major available nutrients, nitrogen is generally in shortest supply in coastal waters and is thought to limit the growth of phytoplankton, particularly in summer. A description of the cycle of nutrients on the continental shelf will aid in understanding and predicting the spatial and temporal variability in plankton populations.

Phytoplankton are the base of the marine food-web and the primary food source for the animal component of the plankton (zooplankton). Both phytoplankton and zooplankton, in turn, are food for larval fish and invertebrates and influence their survival rate. An understanding of plankton cycles will aid in assessing the state of the marine ecosystem and its capacity to sustain harvestable fisheries.

The AZMP provides basic information on the natural variability of physical, chemical and biological properties of the Northwest Atlantic continental shelf. Ecosystem trawl (groundfish) surveys and cross-shelf sections provide detailed regional geographic information but are limited in their seasonal coverage. Critically placed fixed stations (Station 2 along the Halifax section on the Scotian Shelf and the Prince 5 station in the Bay of Fundy) complement the geography-based sampling by providing more detailed information on seasonal changes in ecosystem properties. Satellite remote-sensing of sea-surface phytoplankton biomass (chlorophyll) provides a large scale, zonal perspective on important environmental and ecosystem variability. The CPR sections provide information on large scale, inter-regional, and long-term (yearly to decadal) variability in plankton abundance and community structure.

ASSESSMENT / ANALYSIS

Nutrients

Fixed Stations: Distributions of the primary dissolved inorganic nutrients (nitrate, silicate, phosphate) included in the observational program of AZMP strongly co-vary in space and time (Petrie et al. 1999). For that reason and because the availability of nitrogen is most likely to limit phytoplankton growth in our coastal waters (DFO, 2000), emphasis in this report will be placed on variability in nitrate concentrations.

A clear spring/early summer biologically-mediated reduction in near surface nitrate concentrations was seen at both Maritimes fixed stations in 2008 (Figure 2). Low surface values persisted throughout the summer/fall at Halifax-2 and concentrations did not increase at the surface again until late fall. The zone of nitrate depletion (i.e. defined as depths where concentrations were ≤1 mmol m^{-3}) in summer 2008 at Halifax-2 (33 m) was close to the long-term average (34 m). The seasonal evolution of the vertical nitrate structure at Halifax-2 in 2008 was similar to that observed in previous years although the period of most rapid draw-down appeared to occur later than usual (i.e. April rather than March). Near surface nitrate concentrations at Prince-5 in 2008 were never reduced below 2 mmol m^{-3}. The period of most rapid biological draw-down at Prince-5 in 2008 (May) was comparable to the long-term average.

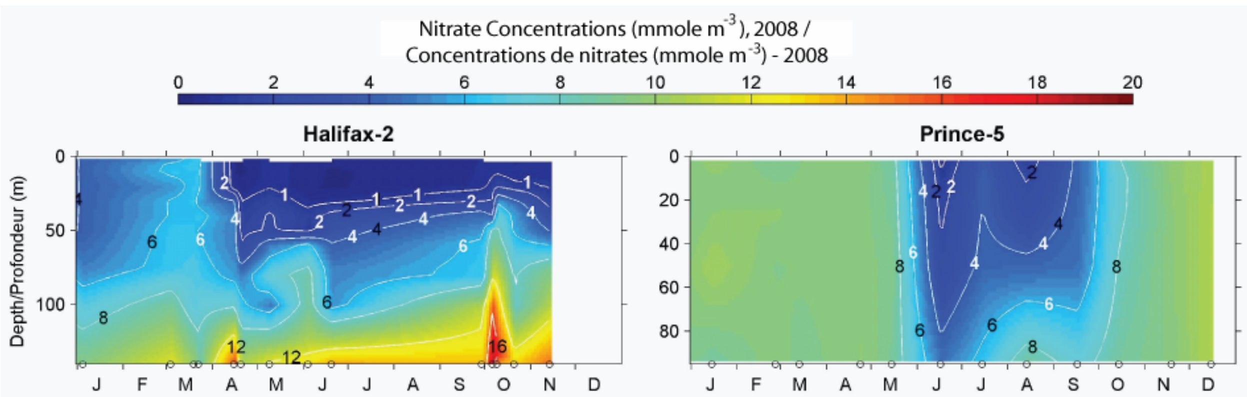


Figure 2. Vertical nitrate structure at the AZMP-Maritime fixed stations in 2008.

Strong seasonal variability in nitrate inventories of the upper 50 m (depth zone over which nutrient dynamics are strongly influenced by biological processes) is evident at both of the Maritimes fixed stations (Figure 3). Although the seasonal pattern of variability in nitrate at Halifax-2 in 2008 was similar to that observed in previous years, winter inventories were higher (by 30 mmol m^{-2}) than the norm (~250 mmol m^{-2}) and summer inventories were lower (by 35 mmol m^{-2}) than the norm (by 65 mmol m^{-2}). Winter nitrate inventories in the upper 50 m at Prince-5 in 2008 were similar to the long term average (~470 mmol m^{-2}) but, like Halifax-2, summer levels were lower (by 65 mmol m^{-2}) than the norm (~210 mmol m^{-2}). At both fixed stations, summer nitrate inventories in the upper 50 m were the lowest seen since observations began in 1999. Winter nitrate inventories in deep waters (>50 m) at Halifax-2 and Prince-5 in 2008 were generally comparable with the long-term averages: Halifax-2 (~720 mmol m^{-2}), Prince-5 (~470 mmol m^{-2}). However, summer inventories in deep waters were below (by 160 mmol m^{-2} at Halifax-2 and 30 mmol m^{-2} at Prince-5) the norm (~910 mmol m^{-2} at Halifax-2, ~ 270 mmol m^{-2}). Annual anomalies (departure from the average condition) of near surface nitrate suggest that inventories have been relatively steady and slightly above the norm for the past several years at Halifax-2 whereas annual anomalies of deep water nitrate have shown considerable interannual variation with levels slightly below the norm for the past two years;

lowest levels were see in 2005. Because of strong vertical mixing, annual surface and deep water nitrate anomalies show the same patterns of relatively high interannual variability at Prince-5; levels have been at or slightly above the average for the past three years. No long-term trend in nitrate inventories has been seen at either fixed station.

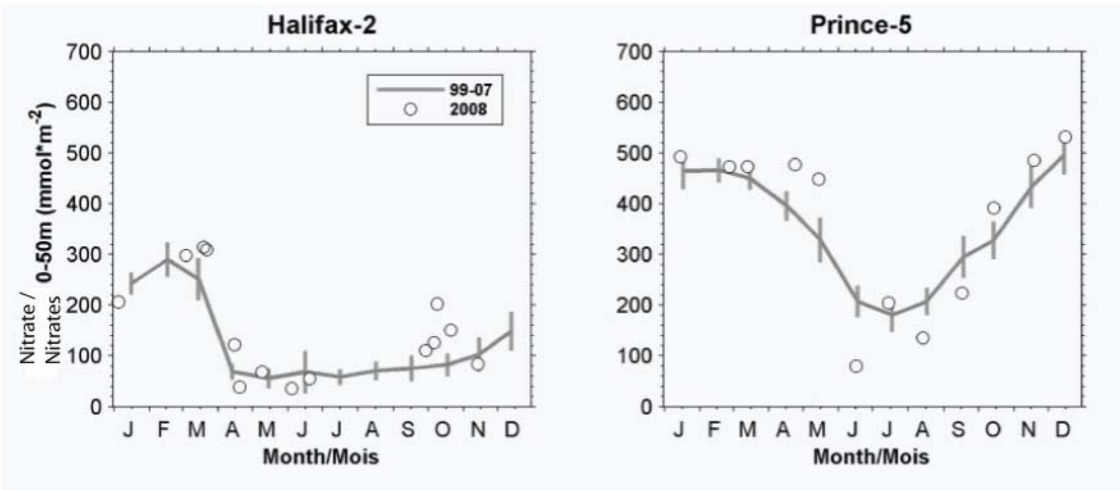


Figure 3. Nitrate inventories (surface to 50 m) at the AZMP-Maritimes fixed stations in 2008.

Shelf Sections: Vertical distributions of nitrate in spring were generally similar along the Scotian Shelf sections in 2008, i.e. concentrations were low (<2 mmol m^{-3}) in near surface waters (<50 m), as a result of phytoplankton consumption, and increased with depth; the exception was along the Cabot Strait line where surface concentrations generally exceeded 2 mmol m^{-3} except at the two northern-most stations. Deep-water (>50 m) concentrations were highest in basins (>20 mmol m^{-3}) and in slope waters off the edge of the shelf. As in previous years, nitrate levels in surface waters were already reduced at the time of the spring survey in April (1 mmol m^{-3} depth horizon: ~20-50 m). Likewise, surface nitrate concentrations were still low during the fall survey in October (1 mmol m^{-3} depth horizon: ~20-50 m), showing little evidence of seasonal mixing of nutrients from depth into surface waters. Despite similarities to the norm in vertical structure in 2008, nitrate inventories in the upper 50 m in 2008 were higher (by 50-60 mmol m^{-2}) along all lines in spring compared to previous years; levels were highest or second highest seen since observations began in 1999. Similarly, surface inventories were at record high levels (40-60 mmol m^{-2} above normal) in fall on the western shelf (Halifax and Browns Bank lines); fall surface inventories, however, were slightly lower (by 30 mmol m^{-2}) than the norm on the Louisbourg line in fall. Deep (>50 m) nitrate inventories were higher (by 70-100 mmol m^{-2}) than normal on the Louisbourg and Halifax lines in spring and Halifax line in fall; deep inventories on the Louisbourg line were below average (by 110 mmol m^{-2}) in fall. Deep nitrate inventories along the Cabot Strait and Browns Bank lines were at normal levels in spring and fall 2008. There is a suggestion of progressively increasing near surface inventories of nitrate on the Louisbourg and Halifax lines since ~2003 but not on the Cabot Strait and Browns Bank lines. There are no discernable trends in deep nitrate inventories for any of the lines over the 10 year time series.

Trawl (groundfish) Surveys: Bottom water nitrate concentrations on the Scotian Shelf in July 2008 (Avg: 10.3 mmol m^{-3}) were below the long-term average (11.4 mmol m^{-3}) and consistent with observed low summer deep water (>50 m) nitrate inventories at the Halifax-2 fixed station. Concentrations increased with water depth with highest levels observed in the deep basins on the shelf (e.g. Emerald Basin) and in slope waters off the shelf edge. Bottom water oxygen saturation on the Scotian Shelf in summer 2008 (Avg: 79% sat), in contrast, was comparable to the long-term average. However, the area of the bottom covered by waters with

<60% saturation was somewhat lower (11,800 km^2 or 7.8% of the shelf area) than the long term average (13,900 km^2 or 9.2% of the shelf area). As usual, lowest saturations were found in deep basins (e.g. Emerald Basin) and deep waters off the shelf edge where nutrients are highest. There is no discernable trend in bottom water nitrate concentrations nor oxygen content on the Scotian Shelf over the 10 year time series.

Phytoplankton

Fixed Stations: Distinctly different seasonal phytoplankton growth cycles are evident at the two Maritimes fixed stations (Figures 4, 5). The record high spring bloom observed at Halifax-2 in 2007 (>900 mg m^{-3}) was not seen in 2008; indeed, the 2008 bloom (267 mg m^{-3}) was significantly smaller then the long term average (~500 mg m^{-3}). Annual chlorophyll anomalies at Halifax-2 have been relatively stable over the past 10 years and show no discernable trend. The evolution of the phytoplankton community composition at Halifax-2 in 2008 was broadly similar to that seen previously, i.e. diatoms dominated in the winter/spring, i.e. >75% of the total count, and flagellates and dinoflagellates dominated (>60% of the total count) the rest of the year. In 2008, however, the contribution of diatoms to the microplankton community at the peak of the spring bloom comprised almost 100% of the community (usually ~90%) but immediately following the bloom, fell to <10% (normally ~30%) and increased again in the fall to >60% (normally ~30%). During the post-bloom period in 2008, flagellates accounted for >80% of the microplankton (normally 60%) with low percentages in the fall (~20% as opposed to the normal 40-60%).

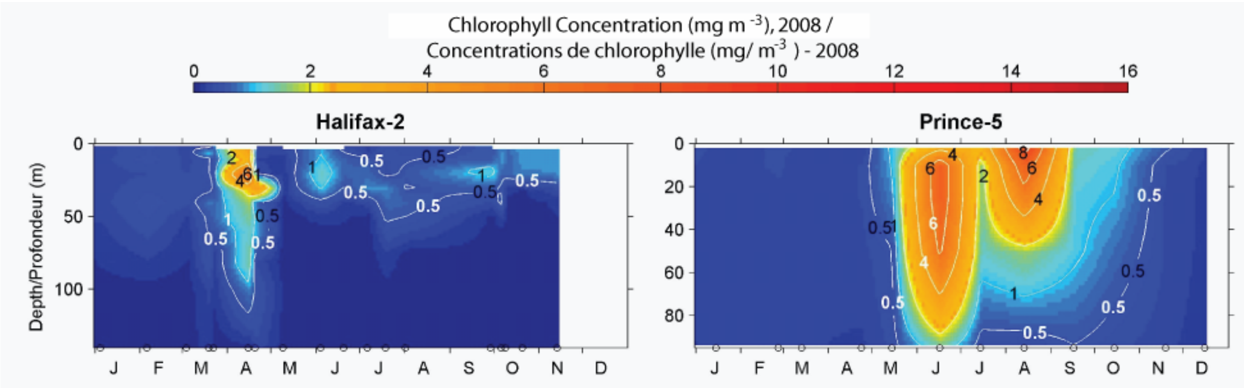


Figure 4. Vertical chlorophyll structure at the AZMP-Maritimes fixed stations in 2008.

The phytoplankton growth cycle at Prince-5, in contrast to Halifax-2; is characterized by a primary burst of growth in summer (June) with secondary peaks in late summer or fall (August-September) (Figures 4, 5). Annual chlorophyll anomalies at Prince-5, as is also the case for Halifax-2, have been relatively stable over the past 10 years and show no discernable trend. As has been noted previously, the phytoplankton community at Prince-5 is comprised almost exclusively of diatoms (>95%) year-round. On an annual basis, Prince-5 sustains the larger chlorophyll inventories of the two Maritimes fixed stations (Prince-5: 107 mg m^{-2}, Halifax-2: 79 mg m^{-2}).

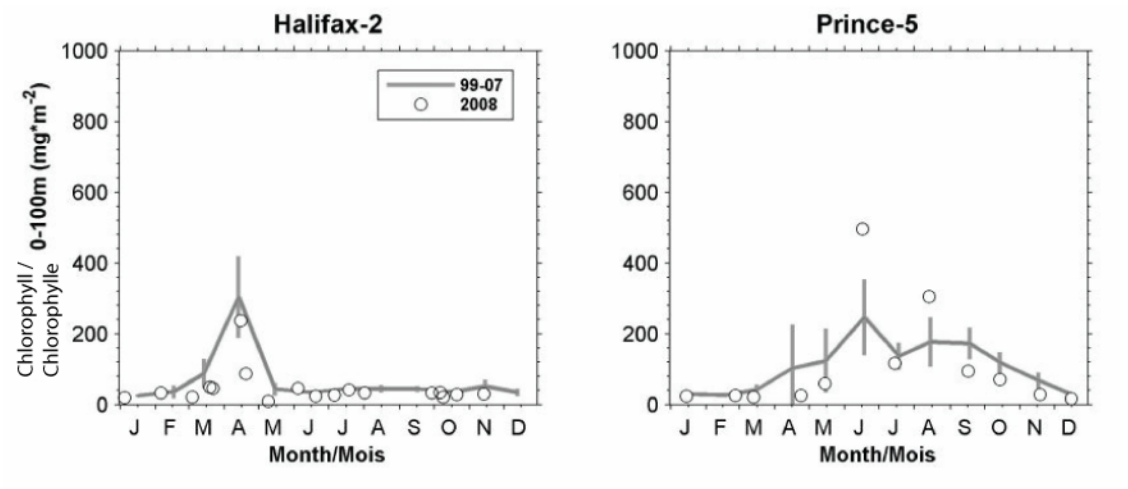


Figure 5. Chlorophyll inventories (surface to 100 m) at the AZMP-Maritimes fixed stations in 2008.

A more detailed analysis of the bloom at Halifax-2 suggested that the timing in 2008 (YD 106) was 11 days later than normal (peak at YD 95) (Figure 6). In addition, the duration of the bloom was somewhat shorter (32 days) than the long-term average (45 days). Besides changes in bloom dynamics, the "background" chlorophyll levels (outside the bloom period) have been declining over the past 10 years, from ~40 mg m^{-2} in 1999 to ~30 mg m^{-2} in 2007 and 2008. In contrast to the bloom at Halifax-2, the peak chlorophyll concentration (496 mg m^{-2}) at Prince-5 occurred on YD 162 and was comparable in magnitude (426 mg m^{-2}) and timing (YD 162) with the long term average. However, the duration of the primary bloom (61 days) was shorter than the long term average (72 days).

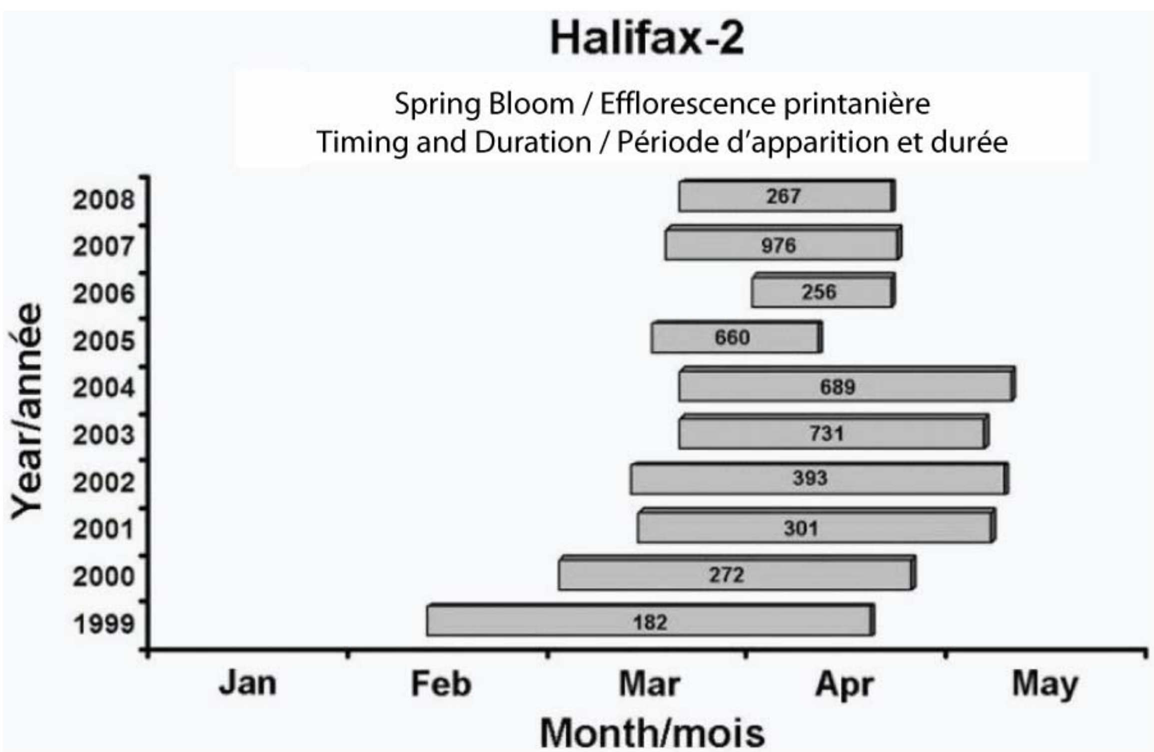


Figure 6. Timing, duration (horizontal bars) and magnitude (numbers in bars, mg CHL m^{-2}) of the spring phytoplankton bloom at the Halifax-2 fixed station, 1999-2008.

Shelf Sections: Chlorophyll levels along all the shelf sections are always considerably higher in spring than in fall. Particularly noteworthy during the spring 2008 survey was the overall low chlorophyll levels at the southern stations of the Cabot Strait line and the low surface values at the inner Louisbourg line stations (Figure 7). Levels were also lower then usual along the Browns Bank line. Although chlorophyll levels >6 mg m^{-3} in near surface waters were observed during spring 2008 survey, inventories (0-100 m) were considerably lower (by 100-190 mg m^{-2}) than normal (~250-370 mg m^{-2}) along three of the four lines (Cabot Strait, Louisbourg and Browns Bank). In contrast, chlorophyll inventories during the fall surveys were above (by 40-60 mg m^{-2}) average levels (~30-50 mg m^{-2}) on the western shelf (Halifax and Browns Bank lines). High interannual variability has characterized spring chlorophyll inventories along all lines and no clear trend has been discernable. In contrast, fall inventories have been much less variable and have been trending downward over the past 10 years.

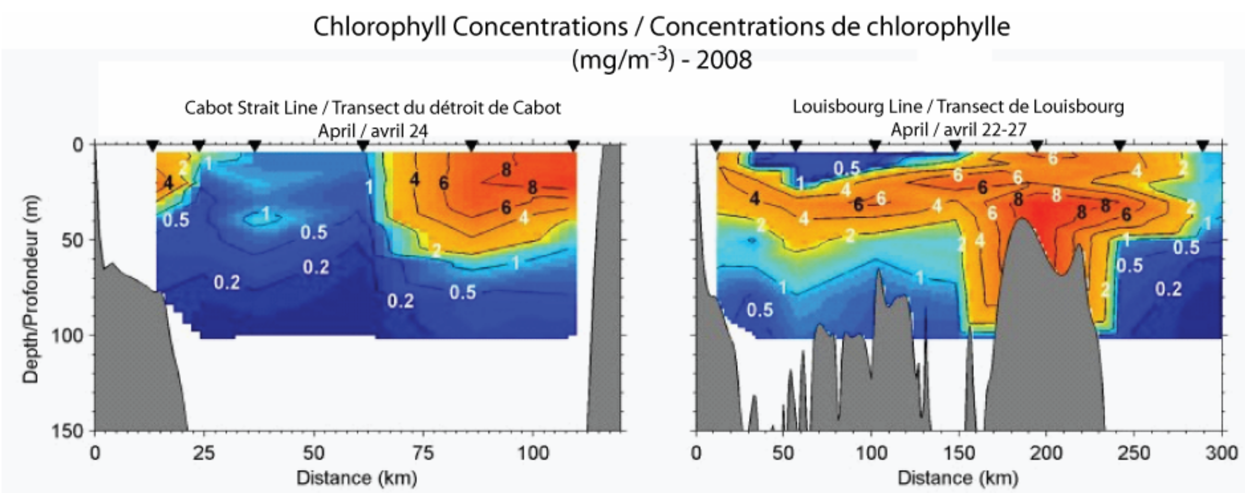


Figure 7. Vertical chlorophyll structure along the Cabot Strait and Louisbourg sections in spring 2008.

Trawl (Groundfish) Surveys: Near-surface chlorophyll levels during the 2008 spring survey on the eastern Scotian Shelf showed a distributional pattern similar to that seen in previous years, i.e. high concentrations were seen off-shelf (>4 mg m^{-3}) and distributed generally west of Sable Island. Surface chlorophyll levels during the summer Scotian Shelf survey, on the other hand, were uniformly low (<1 mg m^{-3}) over the central and eastern shelf. Elevated concentrations (>1 mg m^{-3}) were only observed near the coast off SW Nova Scotia and approaches to the Bay of Fundy, as observed in previous years. These areas are generally characterized by strong vertical mixing, cold temperatures and elevated near surface nutrient concentrations. Overall, summer surface chlorophyll concentrations on the Scotian Shelf in 2008 (0.64 mg m^{-3}) were similar to the long-term average (0.68 mg m^{-3}). There is no discernable trend in shelf-wide chlorophyll concentrations over the 10 year time series.

Satellite Remote-Sensing: Satellite ocean colour (SeaWiFS and MODIS) data provide a valuable alternative means of assessing surface phytoplankton biomass (chlorophyll) at the AZMP fixed stations, along the seasonal sections, and at larger scales (Northwest Atlantic) and have the potential to provide temporal data and synoptic spatial coverage not possible from conventional sampling. Two-week composite images of the Maritimes region covering the major periods of the shelf section surveys and trawl surveys put those operations into a larger geographic context and reveal features that supplement/corroborate ship-based observations or provide information not otherwise attainable (Figures 8, 9). For example, the off-shelf maximum in surface chlorophyll observed during the early March Eastern Scotian Shelf trawl survey was seen in the satellite imagery. In a similar way, the imagery shows the contrast in surface chlorophyll levels between annual spring (April) and fall (October) AZMP shelf surveys.

Noteworthy also was the uncharacteristically low chlorophyll levels on the southern end of the Cabot Strait line observed during the spring survey. Similarly, the images show the overall low shelf-wide surface chlorophyll levels and enhanced levels off Yarmouth and the mouth of the Bay of Fundy observed during the July trawl survey.

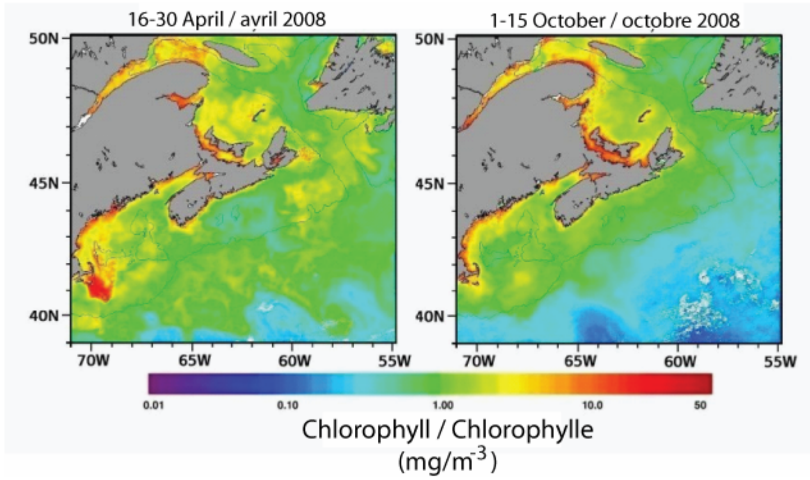


Figure 8. MODIS twice monthly composite images of surface chlorophyll in the Maritimes/Gulf regions: during the spring (April) and fall (October) shelf surveys in 2008.

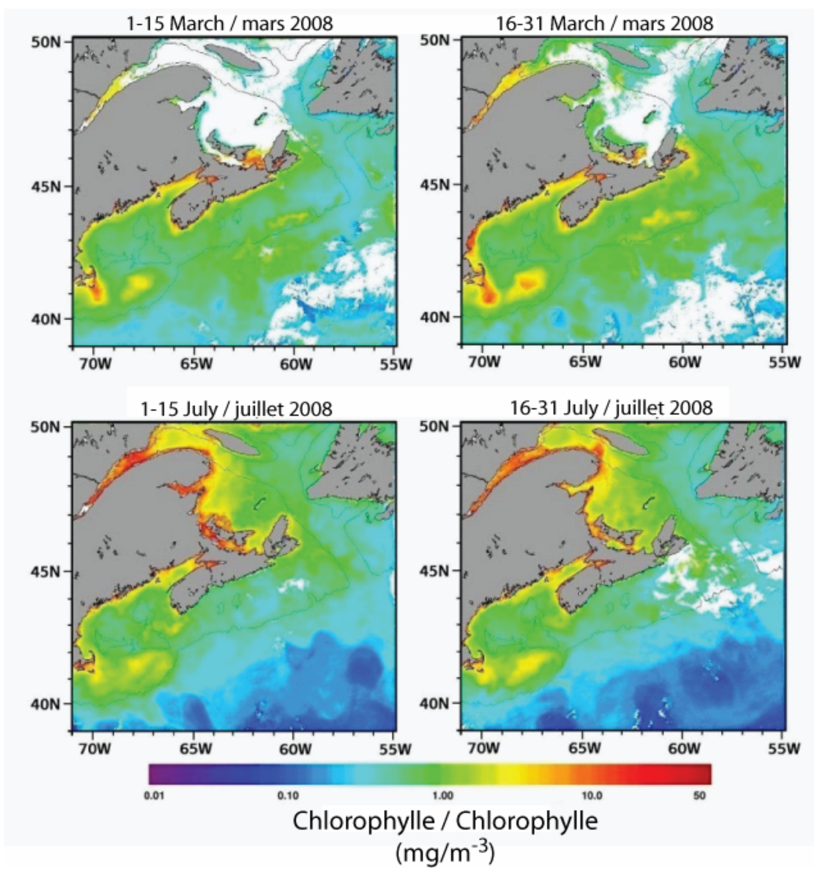


Figure 9. MODIS twice monthly composite images of surface chlorophyll in the Maritimes/Gulf regions during the winter (February), spring (March) and summer (July) trawl (groundfish) surveys in 2008.

At the larger scale, the timing and duration of the spring bloom in 2008 compared with previous years in most regions. One noteworthy exception was the absence of a spring bloom in Cabot

Strait as noted previously. Also, the satellite data suggested slightly higher levels of surface chlorophyll in the fall on the western Scotian Shelf than seen previously, consistent with the AZMP survey data. On an annual basis, no clear trend has been detected in any of the satellite products over the time period of observations (1998-2008).

Continuous Plankton Recorder (CPR): The CPR is the longest data record available on plankton for the NW Atlantic continental shelf, starting in 1961. CPR data analysis lags AZMP reporting by one year; thus, the most recent data available are for 2007 the winter/spring (January-May) of 2007. Nonetheless, the phytoplankton colour index and abundance of large diatoms and dinoflagellates on the Scotian Shelf have been notably higher, starting in the early 1990s, peaking in the mid 1990s and continuing into the 2000s, than levels observed in the 1960s-1970s (Head and Pepin, 2009). The increases in phytoplankton abundance in the 1990s were mainly in winter and in 2007 diatom abundance remained high in winter, while the PCI and dinoflagellate abundance decreased. Overall, phytoplankton abundances on the Scotian Shelf have been at or slightly above the long term average in recent years.

Zooplankton

Fixed Stations: The climatological seasonal cycles of zooplankton biomass and abundance are different at the Halifax-2 and Prince-5 fixed stations. At Halifax-2, the annual peak in abundance and biomass occurs in April to May, and zooplankton abundance and biomass remains relatively high during the fall and winter (Figure 10). At Prince-5, zooplankton abundance is about an order of magnitude lower in the late fall and winter than at Halifax-2, and biomass exhibits a similar but less extreme pattern. In 2008, zooplankton biomass at Halifax-2 peaked in early July, about two months later than usual. The magnitude of the zooplankton biomass peak in 2008 was similar to average levels during the climatological peak in April and May. Annually averaged zooplankton biomass at Halifax-2 in 2008 was similar to the lowest observed value in the ten-year time series, primarily driven by anomalously low spring-time values. At Prince-5, the 2008 zooplankton biomass peak occurred in June, about one month earlier than normal, and its magnitude was about average (Figure 10). Zooplankton biomass was about average in the winter and early spring of 2008, and it was lower than average in summer and fall. Annually averaged zooplankton biomass was lower than normal at Prince-5 in 2008.

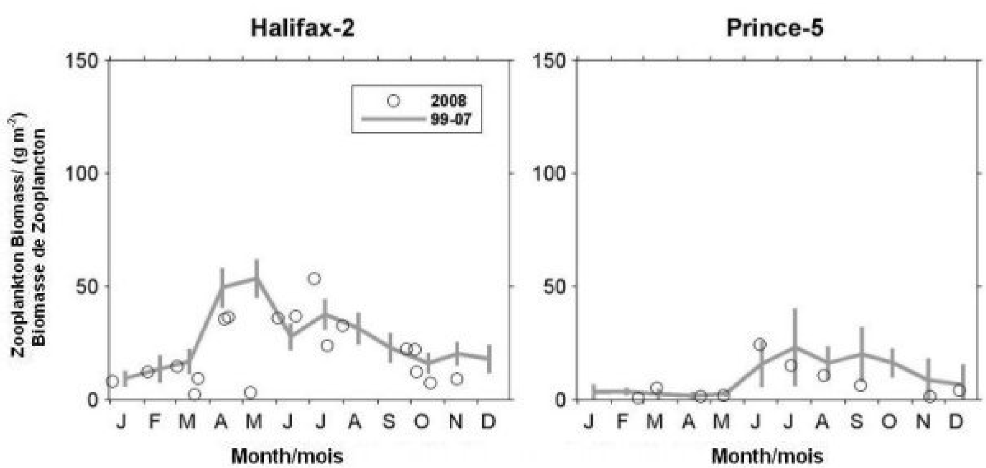


Figure 10. Zooplankton biomass at the AZMP-Maritimes fixed stations in 2008.

At Halifax-2, the spring increase in *Calanus finmarchicus* abundance started late and peaked about one month later than normal, in June rather than May (Figure 11). The peak abundance of *C. finmarchicus* was slightly higher than the climatological peak value but about average compared to peak values in other years. High *C. finmarchicus* abundance persisted in the summer and early fall of 2008 at Halifax-2. The annually averaged *C. finmarchicus* abundance was slightly higher than normal at Halifax-2 in 2008, primarily driven by higher than normal abundances in June and the second half for the year.

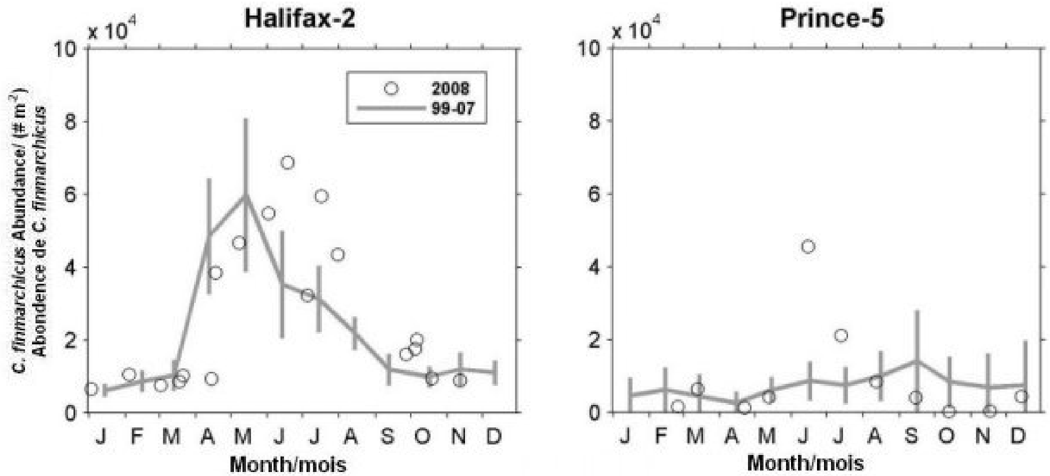


Figure 11. Calanus finmarchicus abundance at the AZMP-Maritimes fixed stations in 2008.

In 2008, emergence from dormancy, as indicated by an increase in the proportion of adults compared to fifth copepodite stages in the population, began in January at Halifax-2, slightly later than usual, but early copepodite stages began to appear in February, similar to previous years (Figure 12). Early copepodite stages persisted later in summer and fall in 2008 than in most previous years, suggesting late entry into dormancy and favourable conditions for production and development of young *C. finmarchicus* stages in the summer.

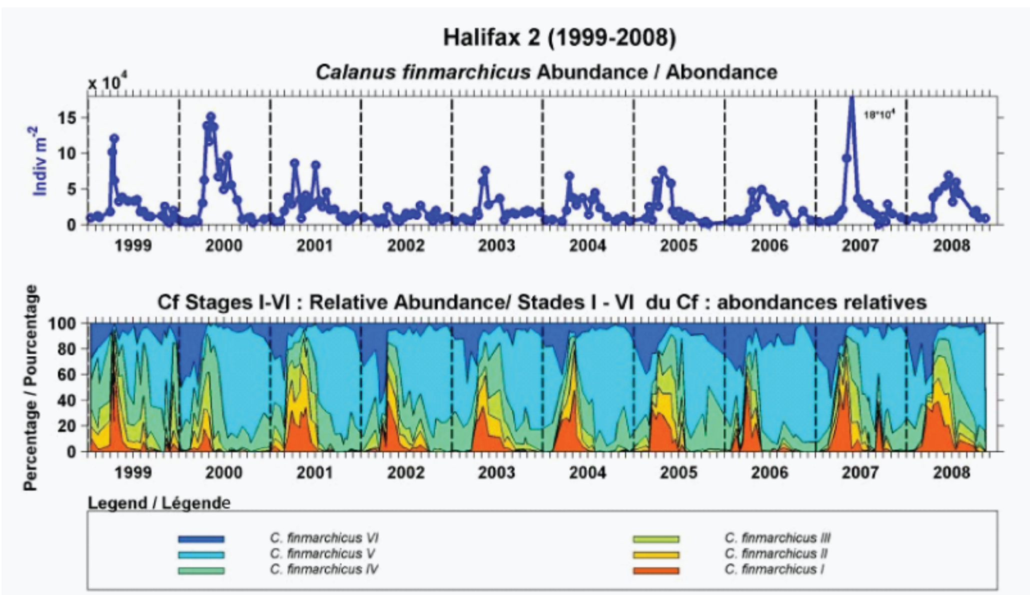


Figure 12. Time-series (1999-2008) of Calanus finmarchicus abundance and developmental stages at the Halifax-2 fixed station.

At Prince-5, the timing of the *C. finmarchicus* abundance peak is variable, but on average it occurs in September (Figure 11). In 2008, the peak abundance of *C. finmarchicus* occurred in June, about three months earlier than normal, and the magnitude of the peak was higher than normal. However, in the winter, early spring, and fall, *C. finmarchicus* abundance at Prince-5 was lower than normal. The annually averaged abundance of *C. finmarchicus* was slightly higher than normal at Prince-5, primarily due to higher than average abundance in June and July. The timing of emergence of dormancy cannot be inferred at Prince-5, due to a gap in sampling in the winter, but early copepodite stages began to appear at the station in March – April, similar to normal.

The seasonal variability pattern in copepod abundance at Halifax-2 in 2008 was similar to the climatological average, although copepod abundance was slightly lower than normal from January to May and from October to November, and higher than normal from June to August (Figure 13). *Calanus finmarchicus* and *Pseudocalanus* spp. contributed to the higher than average abundance of copepods in June through August, although their abundance was relatively low in the first five months of the year. The large, cold-water copepod species *Calanus hyperboreus* and *C. glacialis* were more abundant than average in the late spring, continuing a trend of relatively high peak abundance during recent years. The abundance of the warm water copepod species *Centropages typicus* and *Paracalanus* spp. was lower than average at Halifax-2 in the summer of 2008, and *Centropages typicus* continued to be less abundant than normal in the fall.

The copepod community at Prince-5 is highly variable from year to year, and the seasonal cycle of copepod abundance and community composition at Prince-5 in 2008 was very different from the climatological average cycle (Figure 29). Copepod abundance was lower than normal in the winter and early spring months of 2008 at Prince-5, but in June, copepod abundance increased rapidly to levels more than twice the climatological average for June. The dominant copepod in June, by abundance, was *Pseudocalanus*, while *Calanus finmarchicus*, *Oithona similis*, and *Centropages* spp. were also higher than normal (Figure 13). Both *Pseudocalanus* spp. and copepod nauplii exhibited their highest peak abundance of the time series in 2008. Nearshore copepod species, including *Acartia clausi* and *Eurytemora herdmani*, were less abundant than average at Prince-5 in 2008, and the community was dominated by offshore species for most of the year.

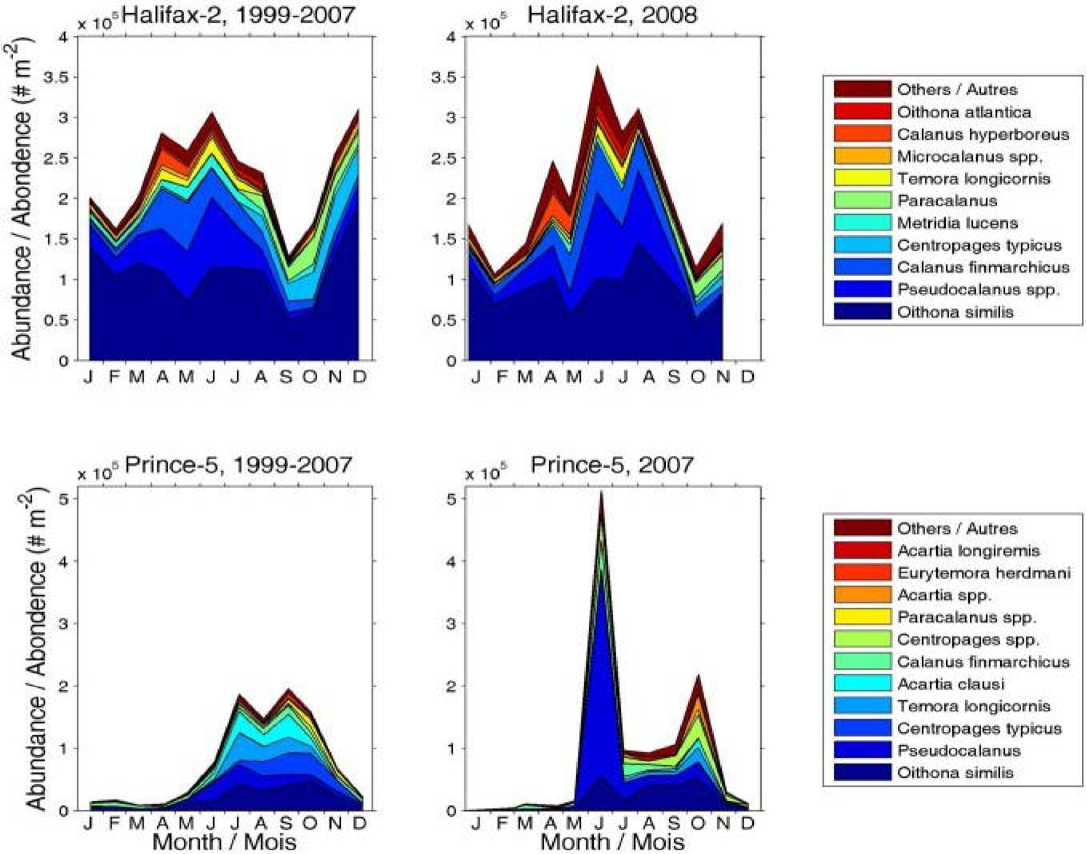


Figure 13. Seasonal variability of dominant copepods at Halifax-2 and Prince-5. The top 95% of copepod taxa by abundance are shown individually; other taxa are grouped as 'others.' Left-hand panels are based on average abundance of monthly mean abundance from 1999-2007. Right-hand panels are monthly mean abundance in 2008.

Shelf Sections: Springtime zooplankton biomass measured on the AZMP broadscale survey cruises in 2008 was similar to average on both the eastern and western Scotian Shelf. Springtime zooplankton biomass was highest at the Cabot Strait stations, the offshore Louisbourg line stations, the inshore and offshore Browns Bank line stations, and in Emerald Basin, while zooplankton biomass at the inshore Halifax line stations, including Halifax-2, was low relative to the rest of the region. Fall zooplankton biomass in 2008 was similar to the average for past years on the western Scotian Shelf but lower than normal on the eastern Scotian Shelf. The highest fall zooplankton biomass values in 2008 were observed at deep stations in the Cabot Strait, at the shelf break, and in Emerald Basin.

In 2008, springtime *Calanus finmarchicus* abundance was close to average on both the eastern and western Scotian Shelf. High abundances were observed in offshore water of the Louisbourg section and in Emerald Basin, and extremely high abundances were observed on the offshore end of the Browns Bank line. Fall *C. finmarchicus* abundance values in 2008 were higher than average on the eastern Scotian Shelf compared to past years, mainly driven by high abundance on the central part of the Louisbourg line. They were also higher than average on the western Scotian Shelf, primarily due to high abundances observed in the Emerald Basin.

Trawl (Groundfish) Surveys. The zooplankton biomass distribution in 2008 generally followed the normal pattern of higher biomass in deep waters, including deep basins, channels, and the shelf edge. In 2008, the average zooplankton biomass on Georges Bank was the highest yet observed, following a year of very low zooplankton biomass in 2007. Zooplankton biomass on the eastern Scotian Shelf in March 2008 was nearly the lowest observed, similar to the three previous years. The zooplankton biomass on the Scotian Shelf and eastern Gulf of Maine in July 2008 was the highest observed throughout the time series. *Calanus finmarchicus* abundance on Georges Bank was very high in February 2008. *C. finmarchicus* abundance was similar to the highest values observed on the eastern Scotian Shelf in March 2008. In July 2008, it was higher than previously observed on the Scotian Shelf and in the eastern Gulf of Maine.

Interannual variability in the abundance of several dominant copepod taxa was assessed using data from both shelf sections and groundfish surveys. The cold-water *Calanus* species *C. hyperboreus* and *C. glacialis* were both lower than average on the Scotian Shelf in 2008, in contrast to their higher than average abundance at Halifax-2. The abundance of warm shelf species was slightly higher than average on the Scotian Shelf, also in contrast to their lower than average abundance at Halifax-2. Two numerically dominant small copepod species, *Pseudocalanus* spp. and *Oithona similis*, and the shallow water copepod *Temora longicornis* were more abundant than average on the eastern Scotian Shelf.

Continuous Plankton Recorder (CPR): On the Scotian Shelf, the abundances of young stage *Calanus finmarchicus* were relatively high in the 1960s or 1970s and low in the 1990s, returning to relatively high values after 2004; the patterns are similar for late stage *C. finmarchicus* abundances. The peak in young stage abundance has occurred earlier in the year since the 1990s, perhaps because high phytoplankton concentrations have also occurred earlier in the year. The arctic species *Calanus glacialis* and *Calanus hyperboreus* are both most abundant in the regions like the Scotian Shelf, influenced by arctic waters. Both are only found early in the year and have shown increases in abundance since the 1990s, which were sustained in 2007. Since 2000, small copepods and copepod nauplii have shown decreases in abundance on the shelf. In 2007 sampling was too early in the year to make a good assessment as to the consistency of the data with that from previous years. Over time, euphausiid abundance has decreased on the shelf. Hyperiid abundance has increased in most regions since the 1990s. For both groups there were no obvious changes in abundance early in 2007 compared with the previous few years. Overall, zooplankton abundances on the Scotian Shelf have been at or slightly below the long term average in recent years.

Zonal Summary

To provide a summary among variables for the entire Atlantic Zone, we summarize the data as differences (anomalies) relative to 1999-2006 average values; furthermore, because these series have different units, each anomaly time series is normalized by dividing by its standard deviation (SD), which is also calculated using data from 1999-2006 (Figure 14).

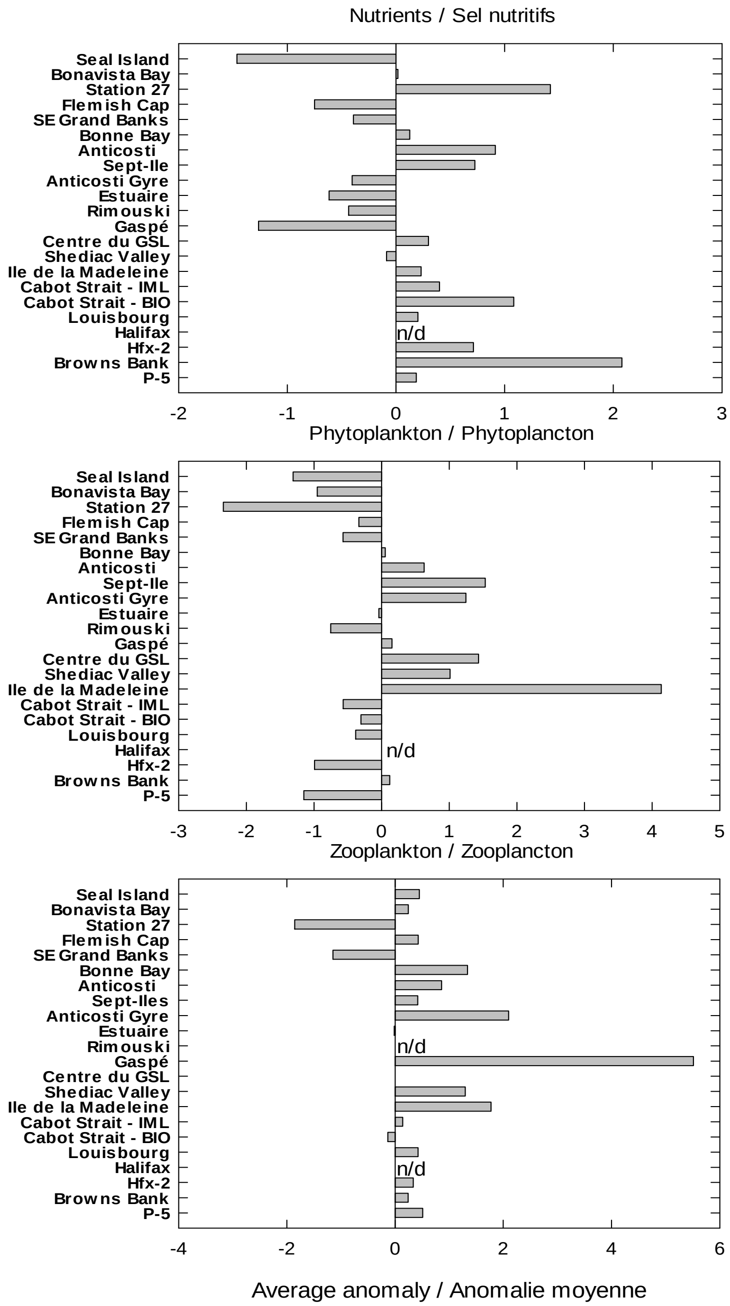


Figure 14. Zonal summary of the average anomaly of abundance indices for nutrients, phytoplankton and zooplankton for 2008.

The 2008 spring through fall nutrient inventories on the Newfoundland-Labrador and Grand Banks Shelf and in the northwest parts of the Gulf of St. Lawrence were below the 1999-2006 average, whereas nutrient inventories were generally well above normal throughout much of the northeast and southern Gulf of St. Lawrence as well the Scotian Shelf. The decline in the Newfoundland region and the increase on the Scotian Shelf are in marked contrast to conditions that occurred in 2007. However, winter maximum nutrients inventories (0-50 m) were well below normal at all coastal fixed stations (not shown). Phytoplankton demonstrated considerable spatial variability, with below average indices of abundance on the Newfoundland-Labrador Shelf and on the Scotian Shelf, and above average indices of abundance throughout much of the Gulf of St. Lawrence. Trends in average zooplankton abundance indices showed the greatest spatial coherence. Zooplankton abundance was well above throughout much of the region, with the largest positive anomalies occurring in the Gulf of St. Lawrence. The only exception to this trend occurred at the fixed site off St. John's Newfoundland and on the southeast Grand Banks, where average abundance indices were well below normal, possible as a result of the low abundance of large calanoid copepods in these areas.

When average among all taxa, sections and fixed sites within a region, inter-annual variations zooplankton abundance indices are greatest in the Gulf of St. Lawrence and smallest on the Newfoundland Shelf. Since 2001, there is an increasing trend in abundance in the Gulf of St. Lawrence. The pattern of variation on the Newfoundland and Scotian Shelves are in opposite phase to one another, with zooplankton abundance being relatively high on the Newfoundland Shelf when it is low on the Scotian Shelf, and vice versa. This inverse relationship is statistically significant.

Sources of Uncertainties

The general patterns in the spatial distribution of physical, chemical and biological oceanographic variables in the Northwest Atlantic zone monitored by AZMP has remained relatively constant during the period 1999-2005. 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 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. In an attempt to be conservative in our description of the long-term changes in chemical variables, we restrict our conclusions to deep water inventories 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 temporal coverage due to 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 the region and in relation to our 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 because of their longer generation times. 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 the Maritimes/Gulf regions, seasonal sampling at the Shediac Valley fixed-station in the Southern Gulf has been significantly impacted by unavailability of ship-time; only 4-6 of the target ~15 sampling dates have been achieved for the past 3-4 years. Another important data gap exists for the Canadian portion of the Gulf of Maine and Georges Bank. This significant geographic component of the Maritimes Region is not systematically sampled by AZMP, except for some modest sampling during the February and July trawl surveys and satellite coverage, and thus seasonal to inter-annual variations of key variables are not available for this area. With regard to ecosystem components, macrozooplankton particularly krill, are not systematically sampled in the Maritimes/Gulf regions, except by CPR, and therefore quantitative estimates of biomass, abundance and inter-annual variability are not available.

CONCLUSION AND ADVICE

The 2008 spring phytoplankton bloom in the Maritimes region was considerably lower than the record bloom in 2007 and chlorophyll levels were, in general, at or below the long term average. Nutrients inventories, on the other hand, were higher than usual in winter, spring and fall but lower in summer, 2008.

The most notable trend in the Scotian Shelf zooplankton in 2008 was a late peak in zooplankton biomass and in the abundance *C. finmarchicus*, the biomass dominant copepod on the shelf. Higher-than-average abundance of *C. finmarchicus* persisted into the summer and early fall months. The late development of the zooplankton biomass and *C. finmarchicus* peaks at Halifax-2 were also observed in their seasonal anomalies on the broadscale survey cruises in spring, summer, and fall. The late abundance and biomass peaks may have been related to colder than usual conditions at Halifax-2 in 2008. This interpretation is consistent with higher than normal abundances of the spring/summer species *Pseudocalanus* spp., the cold-water species *C. hyperboreus*, and of euphausiids eggs at Halifax-2. It is also consistent with lower than normal abundances of the warm water species *Centropages typicus* and *Paracalanus* spp. at Halifax-2 in summer 2008. Despite the consistency in annual trends between Halifax-2 and the broader Scotian Shelf observed in zooplankton and *C. finmarchicus,* the cold water *Calanus* species were less abundant than average on the eastern and western Scotian Shelves, in contrast to Halifax-2. Warm-water shelf copepod species were more abundant than normal on the Scotian Shelf in 2008, in contrast to conditions at Halifax-2, and offshore copepod species were less abundant than average on the Scotian Shelf. The difference in abundance anomalies of cold water and warm water species between Halifax-2 and the rest of the Scotian Shelf is consistent with differences between the temperature anomalies between Halifax-2, where the average water temperature was colder than normal, and the Scotian Shelf, where the average water temperature was slightly higher than normal.

It seems likely that the differences in decadal patterns of change in annual abundance and seasonal cycles in the plankton on the Canadian continental shelf reflect the changes in environmental conditions over the years. Thus, for example, the shelf regions were subjected to an increased contribution of fresh arctic water during the 1990s which had a dramatic impact on the plankton community. This appears to have been relaxing to some extent during the 2000s, but there may lags in the system, so that, for example, the while *Calanus finmarchicus* abundance appears to be returning to pre-1990s levels on the Scotian Shelf, the abundance of the arctic *Calanus* species continues to rise or remains high. The factors that may be influencing the plankton community beyond the shelf yet to be examined, although the rising temperatures in the mid-2000s do appear to have had effects on the abundance of small zooplankton forms.

SOURCES OF INFORMATION

DFO SeaWiFS/MODIS website: http://www.mar.dfo-mpo.gc.ca/science/ ocean/ias/remotesensing.html

Harrision, G., C. Johnson, E. Head, J. Spry, K. Pauley, H. Maass, M. Kennedy, C. Porter, and V. Soukhovtsev. 2009. Optical, Chemical, and Biological Oceanographic Conditions in the Maritimes Region in 2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/054.

Petrie, B., P. Yeats, and P. Strain. 1999. Nitrate, Silicate, and Phosphate Atlas for the Scotian Shelf and the Gulf of Maine. Can. Tech. Report of Hydrography and Ocean Sci. 203: 96pp.

Therriault, J.C., et al. (11 co-authors). 1998. Proposal for a Northwest Atlantic Zonal Monitoring Program. Can. Tech. Report of Hydrography and Ocean Sci. 194, 57pp.

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