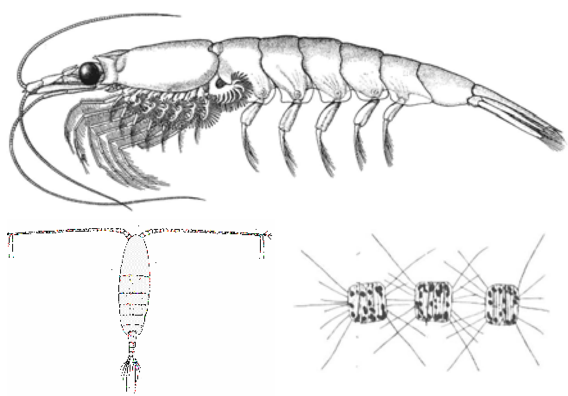
2005 STATE OF THE OCEAN: CHEMICAL AND BIOLOGICAL OCEANOGRAPHIC CONDITIONS IN THE GULF OF MAINE - BAY OF FUNDY, SCOTIAN SHELF, AND THE SOUTHERN GULF OF ST. LAWRENCE



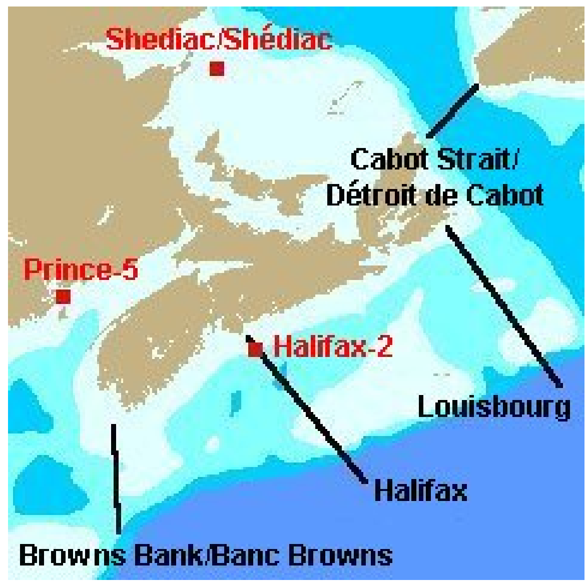


Figure 1. AZMP-Maritimes/Gulf fixed stations and shelf sections.

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, groundfish 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 surface nutrient concentrations in 2005 were lower off Halifax and in the Bay of Fundy than seen in the previous two years.
- The depth of summer nutrient depletion off Halifax in 2005 was the deepest observed since observations began in 1999.
- Deep water (>50m) nutrient concentrations off Halifax were the lowest on record, particularly in late spring.
- A strong spring bloom was observed off Halifax for the third consecutive year, however, its duration was the shortest on record. Record high chlorophyll levels were also observed along the Halifax line in spring.
- Background chlorophyll levels (outside of the spring bloom period) off Halifax have been declining since observations began in 1999.
- Continuous Plankton Recorder (CPR) colour index and species counts for 2004 showed that phytoplankton abundance on the Scotian Shelf continues to be well above levels observed in the 1960s/1970s.
- The contribution of *Calanus spp.* to the zooplankton community in Shediac Valley, off Halifax and in the Bay of Fundy has increased steadily since observations began in 1999.
- Zooplankton biomass and *Calanus finmarchicus* abundance increased dramatically in the Bay of Fundy late in the year in 2005, to levels well above the long term average, for the 2nd consecutive years.
- Zooplankton biomass and *C. finmarchicus* abundance were the lowest on record on the Scotian Shelf in spring and summer, 2005.
- *C. finmarchicus* abundance was the highest on record in Cabot Strait in spring 2005 and the highest on record on the central Scotian Shelf in fall.
- CPR counts for 2004 showed that the abundance of several important zooplankton species continues to be well below levels observed in the 1960s/1970s. Some species, however, (e.g. *C. finmarchicus* and *Paracalanus* / *Pseudocalanus spp.*) appear to be recovering and are now at levels close to or above the long term average.

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. Groundfish surveys and cross-shelf sections provide detailed regional geographic information but are limited in their seasonal coverage. Critically placed fixed stations (the Shediac Valley station in the Southern Gulf of St. Lawrence, 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. Rapid spring/early summer reduction in near surface nitrate concentrations was seen at all Maritimes/Gulf fixed station sites in 2005. Low surface values persisted throughout the summer/fall in Shediac Valley (evident despite limited sampling) and off Halifax; concentrations did not increase at the surface again until late fall (only observable off Halifax). The zone of nitrate depletion (i.e. defined as depths where concentrations were ≤1 μM) in summer is greater off Halifax-2 (~30 m) than in the Shediac Valley (~15 m). Summer nitrate depletion depths in 2005 off Halifax were the deepest on record (>40 m) since observations began in 1999. Near surface nitrate concentrations in the Bay of Fundy were never reduced below ~4 μM. Limited sampling in 2005 precluded an evaluation of the seasonal nutrient cycle at the Shediac Valley station. however, the few observations made during summer/fall suggested that surface concentrations may have been somewhat lower than in previous years. The seasonal evolution of the vertical nitrate structure off Halifax in 2005 was similar to that observed in previous years except that concentrations at depth (50-140 m) were the lowest on record. Of particular note were the low concentrations at depth in late spring/early summer. Nitrate anomaly plots showed that near surface concentrations in 2005 were comparable to the long term average but concentrations at depth were substantially below the long-term average (- 6 to –8 μM) and lower than concentrations observed since systematic observations began in 1999.

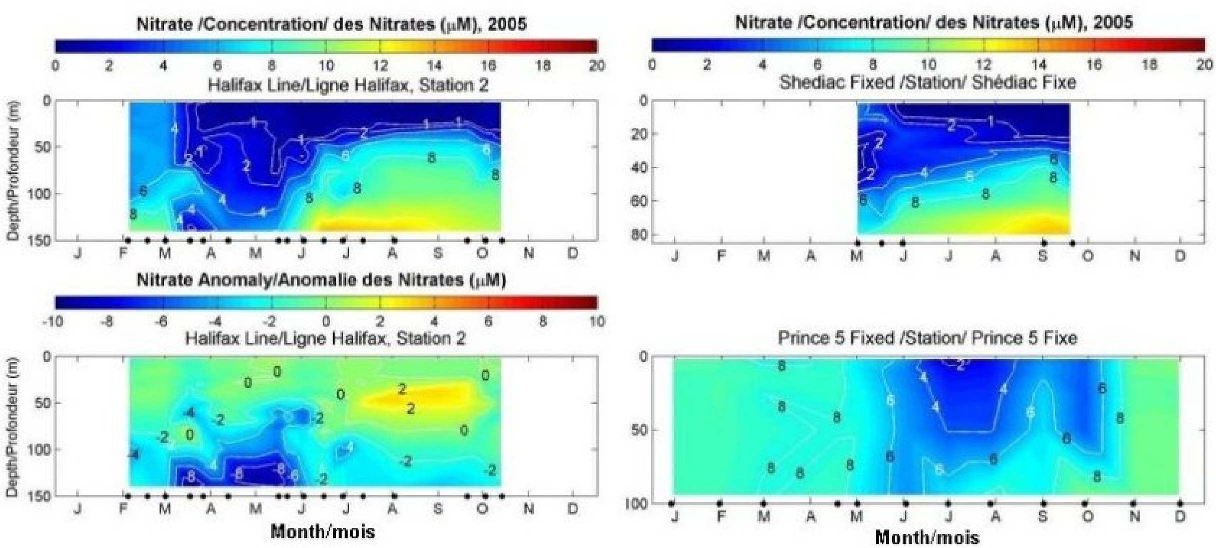


Figure 2. Vertical nitrate structure and nitrate anomalies (2005 minus long-term mean) at the AZMP-Maritimes/Gulf fixed stations in 2005.

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 all of the

Maritimes/Gulf fixed stations. Nitrate levels in the Shediac Valley in 2005 were somewhat lower than levels observed previously, despite limited sampling. Although the seasonal pattern of variability in nitrate off Halifax in 2005 was similar to that observed in previous years, wintertime inventories in 2005 were lower than the previous two years (<300 mmol m^{-2}) and continued a trend of declining concentrations. Summer/fall inventories were among the lowest observed over the past seven years (<10 mmol m^{-2}). Winter maximum nitrate inventories (~400 mmol m^{-2}) in the Bay of Fundy in 2005 were significantly lower than the previous two years but similar to the long term average; summer levels were only slightly lower than the long term average (~200 mmol m^{-2}). Overall, annual nitrate inventories continue to be greatest in the Bay of Fundy and lowest off Halifax. Except for the anomalously low spring nitrate concentrations off Halifax, no discernible trend has been observed in the annual deep (>50 m) nitrate inventories at any of the fixed stations over the seven years of systematic observations.

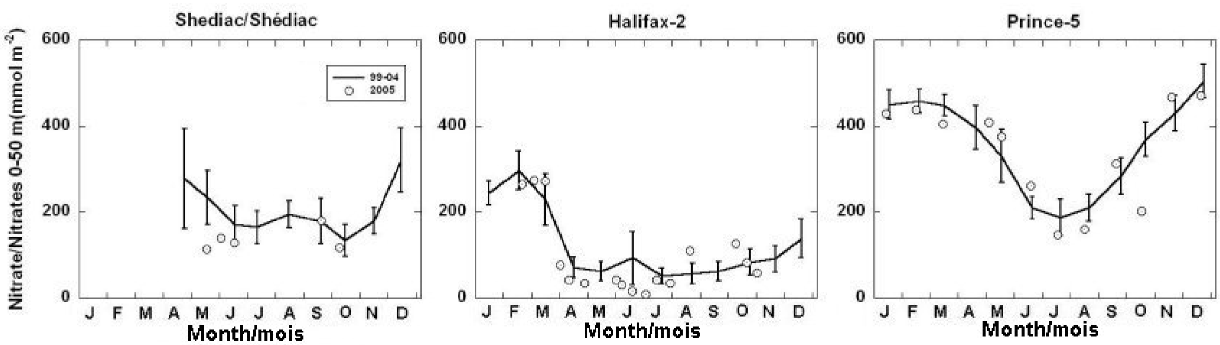


Figure 3. Nitrate inventories (surface to 50 m) at the AZMP-Maritimes/Gulf fixed stations in 2005.

Shelf Sections. Vertical distributions of nitrate in spring and fall were generally similar along the Scotian Shelf sections in 2005, i.e. concentrations were low (<1 μM) in near surface waters (<50 m), as a result of phytoplankton consumption, and increased with depth. Deep-water concentrations were highest in basins (>12 μM) and in slope waters off the edge of the shelf. As in the previous year, nitrate levels in surface waters were already significantly depleted at the time of the spring survey in early April (1 μM depth horizon: 20-40 m). Likewise, surface nitrate concentrations were still low during the fall survey in late October (1 μM depth horizon: 20-50 m), showing no evidence of seasonal mixing of nutrients from depth into surface waters. Nitrate inventories in the upper 50 m in 2005 were comparable to levels observed in previous years except during spring along the Cabot Strait line where levels were higher. Generally speaking, spring and fall surface nutrient inventories along the Cabot Strait and Brown's Bank lines are almost twice those found along the Louisbourg and Halifax lines.

Groundfish Surveys. Bottom water nitrate concentrations on the Scotian Shelf in the July, 2005 (Avg: 10.98 μM) were similar to levels observed in 2004 (Avg: 10.35 μM) and not statistically different from the longer term levels. 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 2005 (Avg: 78% sat) was slightly lower than saturation levels observed in 2004 (Avg: 81% sat) but not statistically different from the previous year nor the long-term mean; lowest saturations were found in deep basins and deep waters off the shelf edge where nutrients are highest.

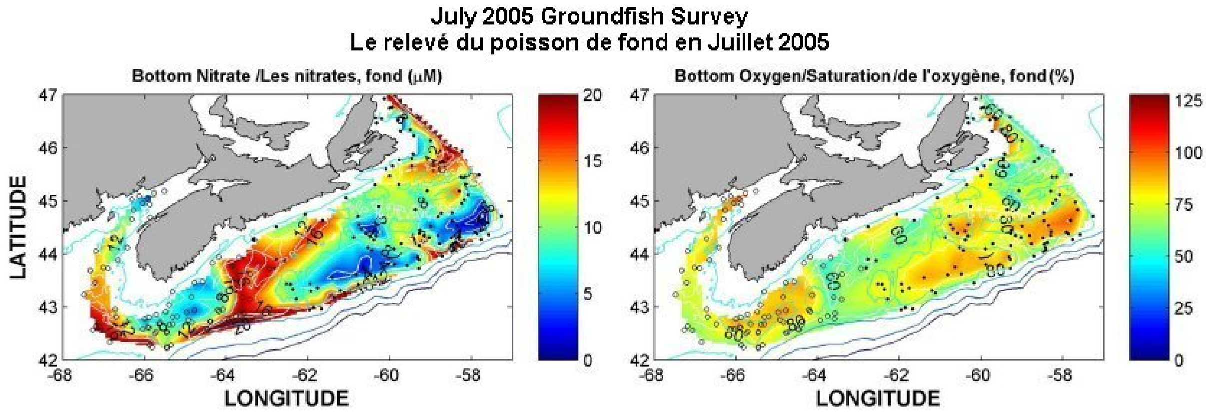


Figure 4. Bottom nitrate concentrations and oxygen saturation on the Scotian Shelf during the July 2005 groundfish survey.

Bottom water nitrate concentrations in the Southern Gulf in September were lower in 2005 (Avg: 8.90 μM) than in 200 (Avg: 9.73 μM). Highest concentrations were found in the western basin and in deep waters of the Laurentian Channel. Bottom water oxygen saturation in the Southern Gulf was virtually the same on average as levels observed in 2004 (Avg: 72% sat). Saturation levels in the Southern Gulf were minimal in the western basin and in the Laurentian Channel where nutrients were highest.

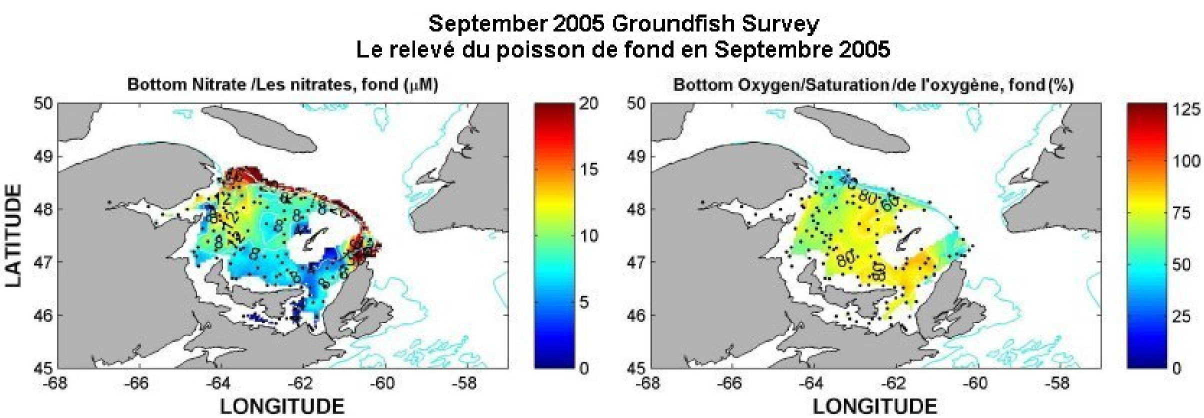


Figure 5. Bottom nitrate concentrations and oxygen saturation in the Southern Gulf of St. Lawrence during the September 2005 groundfish survey.

Phytoplankton

Fixed Stations. Distinctly different seasonal phytoplankton growth cycles are evident at the three Maritimes/Gulf fixed stations. Because of the presence of ice in the Southern Gulf in the spring, only the latter phase of the spring bloom can be observed at the Shediac Valley station. This, in addition to limited sampling during the ice-free period, meant that little could be said about the magnitude and variability of phytoplankton biomass (chlorophyll), vertical distribution and community composition in 2005. The strong spring bloom observed off Halifax-2 in 2003 and 2004 was again evident in 2005. Anomaly plots suggested that the 2005 spring bloom, as was the case in 2003 and 2004, was higher than historical levels, however, its termination was earlier than seen previously. The phytoplankton growth cycle in the Bay of Fundy in 2005, in contrast to Shediac Valley and off Halifax; was characterized, after a late start, by a relatively sustained burst of growth beginning in early summer and lasting until fall and characterize by two peaks.

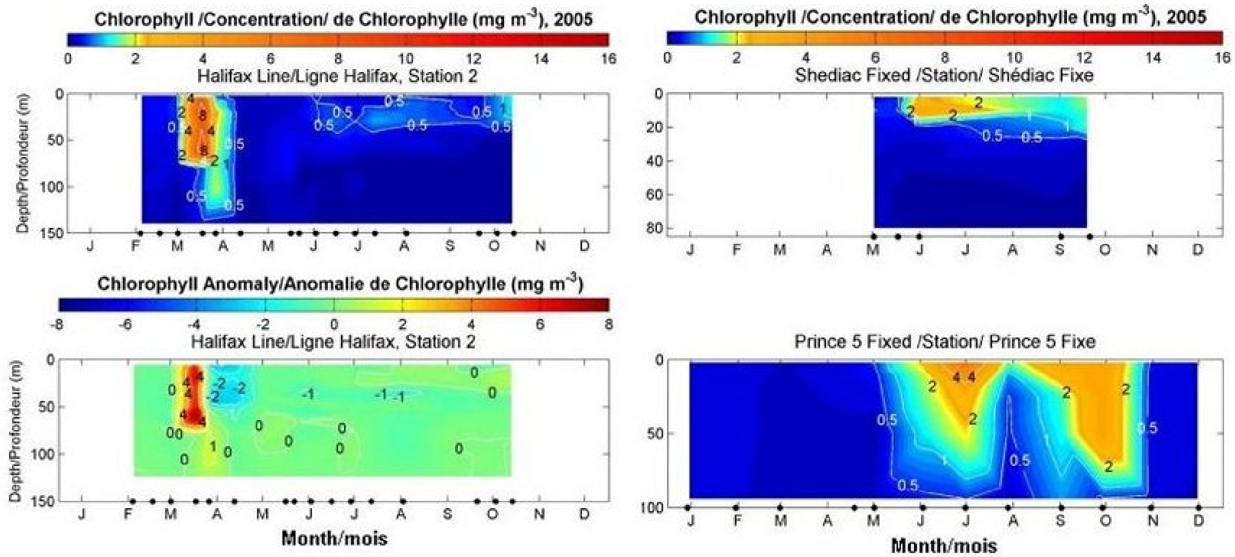


Figure 6. Vertical chlorophyll structure and chlorophyll anomalies (2005 minus long-term mean) at the AZMP-Maritimes/Gulf fixed stations in 2005.

Chlorophyll inventories of the upper 100 m in Shediac Valley during the limited sampling in 2005 were lower than levels observed previously. Similarly, evolution of the phytoplankton community composition at this site in 2005 was consistent with observations from earlier years, i.e. a shift from diatom to flagellate back to diatom dominated populations as the year progressed. Chlorophyll inventories off Halifax showed the strong spring bloom in 2005, similar in magnitude to the strong blooms observed in 2003 and 2004. Year-round dominance of the phytoplankton community by flagellates at this site seen in 2004 was not seen in 2005, i.e. a more typical seasonal evolution of community composition was observed with winter, spring and late fall dominance by diatoms and post-bloom and summer dominance by flagellates. Annual chlorophyll inventories in the Bay of Fundy were the lowest on record and the biomass maxima were later in the year than usual. As has been noted previously, the phytoplankton community in the Bay of Fundy is almost exclusively comprised of diatoms (>90%), year-round. On an annual basis, the Bay of Fundy site sustains the largest chlorophyll inventories of the three Maritimes/Gulf fixed station sites.

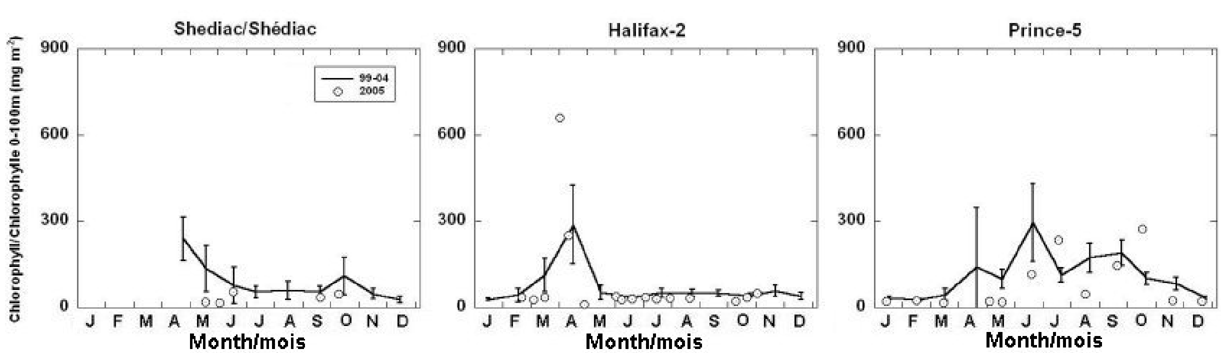


Figure 7. Chlorophyll inventories (surface to 100 m) at the AZMP-Maritimes/Gulf fixed stations in 2005.

A more detailed analysis of the timing of the start and end of the spring bloom off Halifax revealed that the 2005 bloom was the shortest on record, lasting 25 days compared to 36-67 in previous years. In addition to changes in spring bloom dynamics the "background" chlorophyll inventories (outside the bloom period) have been declining over the past seven years, from ~40 mg m^{-2} in 1999 to ~30 mg m^{-2} in 2005, likely linked to lower summer nutrient reserves in near surface waters in recent years.

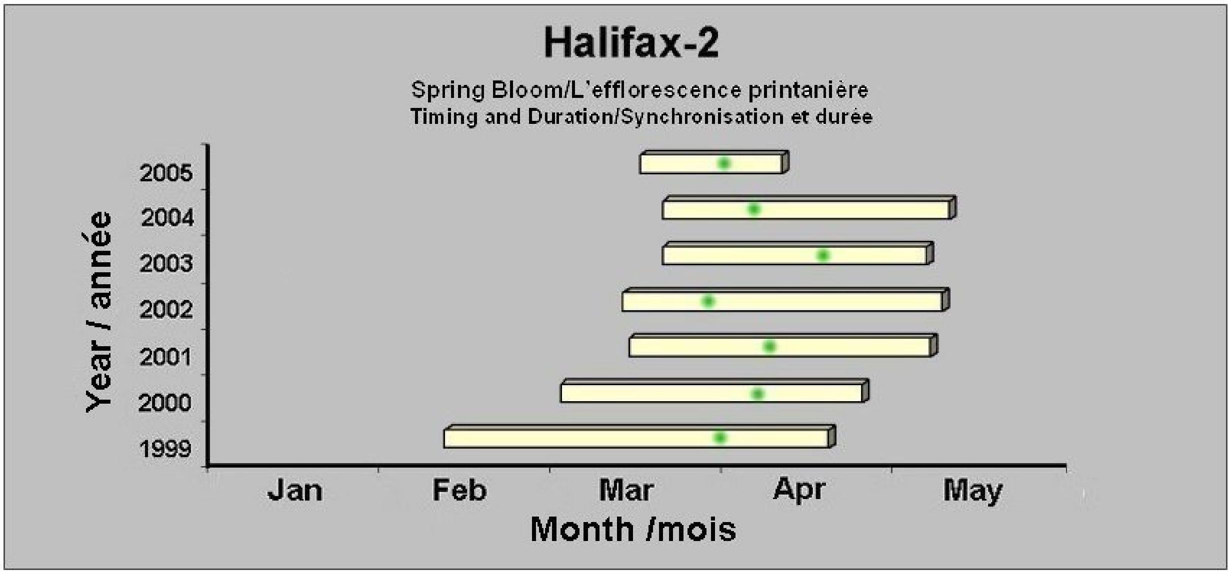


Figure 8. Duration (horizontal bars) and timing of maximum chlorophyll concentration (circle) of the spring phytoplankton bloom at the Halifax fixed station, 1999-2005.

Shelf Sections. Chlorophyll levels during the spring 2005 survey were relatively high (>6 mg m^{-3} or ~200-300 mg m^{-2}). In previous years, chlorophyll inventories were generally higher on the eastern shelf than on the western shelf in spring but levels where high along all lines in 2005. Levels along the Halifax line were the highest seen (>300 mg m^{-2}) since the surveys began in 1999 but low relative to levels previously seen in Cabot Strait. Concentrations during the fall 2005 survey, in contrast, were an order of magnitude lower (<1 mg m^{-3} or ~25-35 mg m^{-2}) and typical for that time of year. Generally, a pronounced subsurface chlorophyll maximum layer is observed at stations along the Scotian Shelf sections in fall, however, highest concentrations in 2005 survey appeared to be confined to surface waters, as observed in 2004. Chlorophyll inventories in fall 2005 were comparable along all sections except the Louisbourg line where levels were somewhat lower than seen previously.

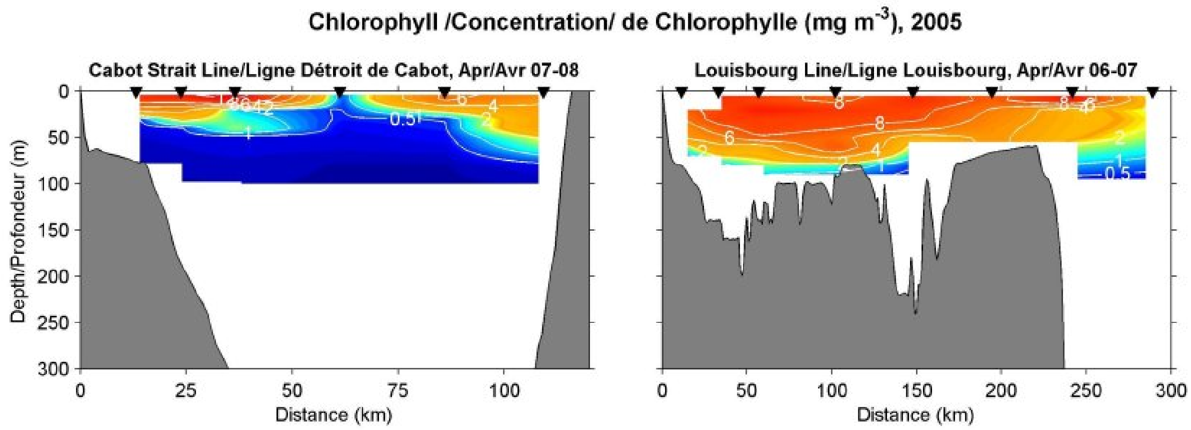


Figure 9. Vertical chlorophyll structure along the Cabot Strait and Louisbourg Shelf sections in spring 2005.

Groundfish Surveys. Near-surface chlorophyll levels during the 2005 spring survey on the eastern Scotian Shelf showed a distributional pattern seen in previous years, i.e. concentrations were highest off-shelf (>8 mg m^{-3}) indicating that the spring bloom was well underway in that region but had not yet begun on the inner shelf. Surface chlorophyll levels during the 2005 summer Scotian Shelf survey, on the other hand, were uniformly low (<1 mg m^{-3}) over most of the central and eastern shelf. Elevated concentrations (>2 mg m^{-3}) were 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. Overall, summer surface chlorophyll concentrations on the Scotian Shelf in 2005 (Avg: 0.56 mg m^{-3}) were the same as concentrations observed in 2004. Surface chlorophyll concentrations observed during the fall 2005 groundfish survey in the Southern Gulf (Avg: 1.17 mg m^{-3}) were lower than values observed in 2004 (Avg: 1.89 mg m^{-3}) but not statistically different from the long term average. Concentrations tended to be highest in the western basin as has been observed in previous years.

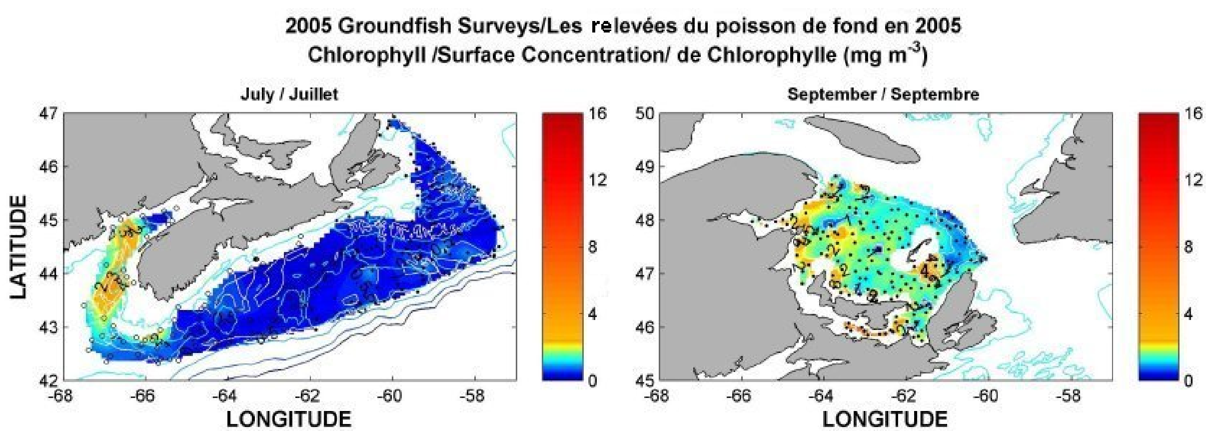


Figure 10. Near-surface chlorophyll concentrations on the Scotian Shelf and in the Southern Gulf of St. Lawrence during the July and September groundfish surveys, respectively.

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. An equally informative application of the satellite-based chlorophyll fields is to generate graphical representations of the seasonal chlorophyll dynamics along the shelf sections. It is evident from the satellite-data, for example, that surface chlorophyll concentrations are generally higher on the eastern Scotian Shelf (e.g. Louisbourg line) than on the central and western shelf (e.g. Halifax line). The dynamics of the onset, duration and termination of the spring and fall blooms are also revealed in this type of graphical presentation as well as spatial (across-shelf) relationships. Spring blooms on the Scotian Shelf can be viewed as discrete, intense and short-lived events whereas the fall blooms appear to be much weaker in magnitude, more diffuse and time-varying. This graphical representation also shows, for example, that the spring blooms along the Louisbourg and Halifax lines were weaker in 2005 than in 2004 and that the bloom along the Halifax line was shorter-lived in 2005 than in 2004, consistent with the fixed station observations off Halifax.

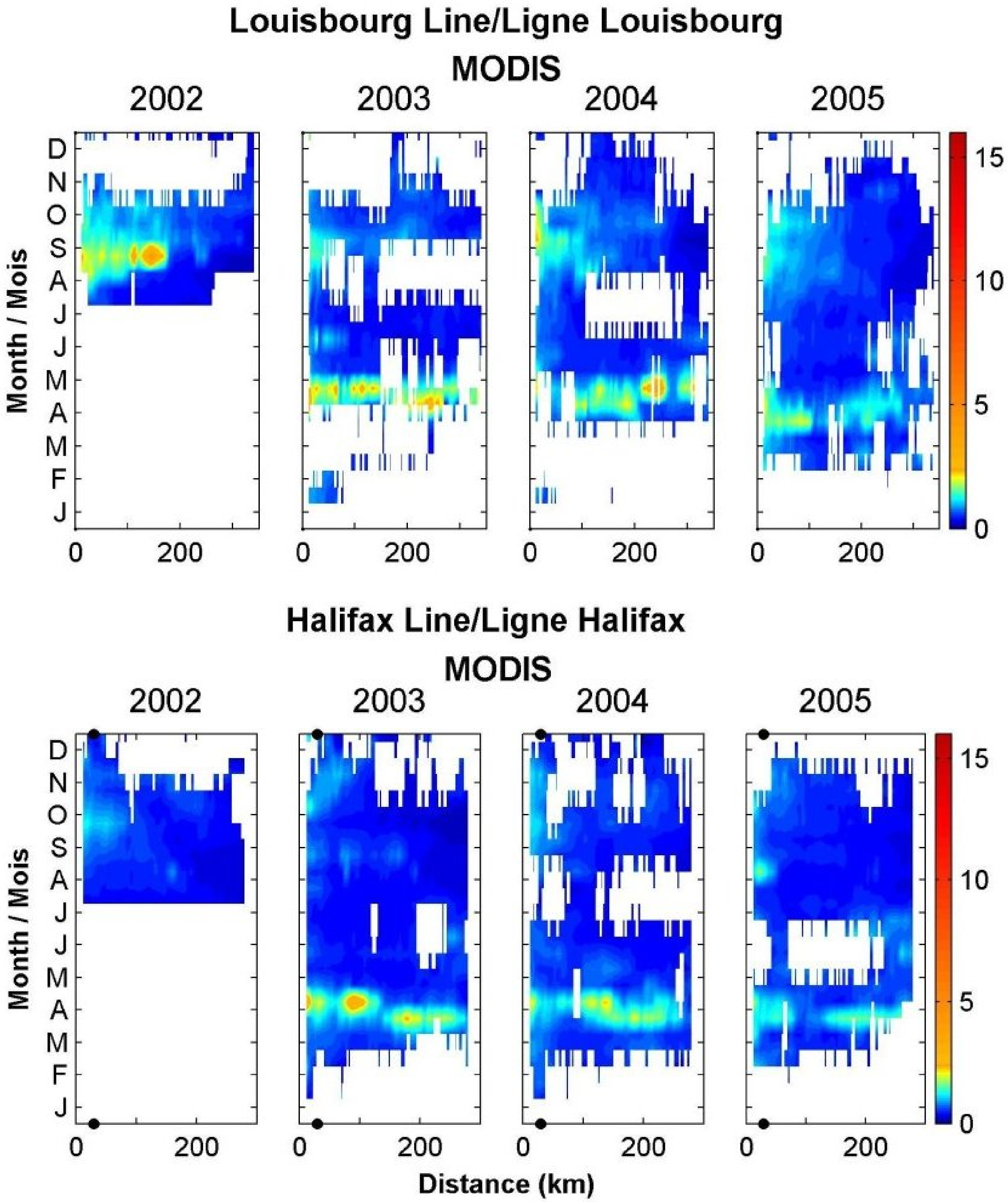


Figure 11. Surface chlorophyll concentrations (2002-2005) along the Louisbourg and Halifax shelf sections from MODIS ocean colour satellite sensor.

At the larger scale (i.e. statistical sub-regions in the Maritimes/Gulf area), the magnitude of the spring bloom in 2005 was noticeably lower in all Maritimes/Gulf locations than in 2004, this was particularly evident for the Scotian Shelf and Georges Bank. However, chlorophyll observations from the Halifax fixed station revealed a much stronger spring bloom in 2005 than suggested by the satellite data for the Central Scotian Shelf.

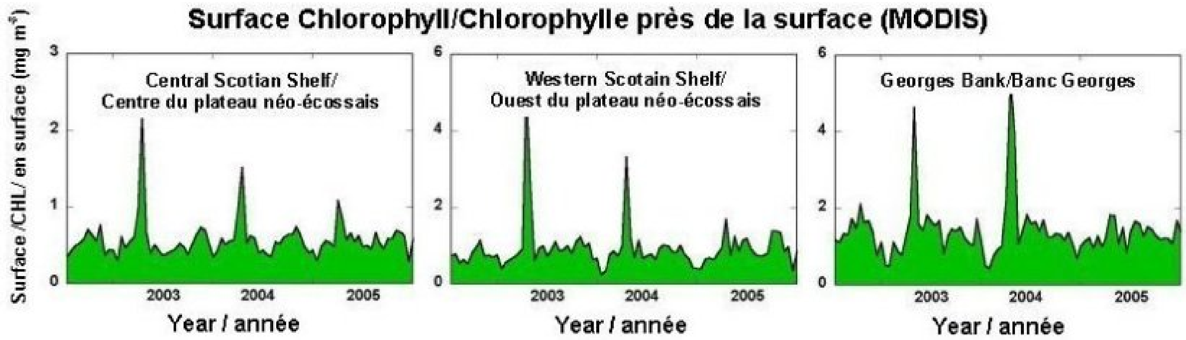


Figure 12. Surface chlorophyll concentrations on the central and western Scotian Shelf and on Georges Bank from MODIS ocean colour satellite sensor.

<u>Continuous Plankton Recorder</u>. The CPR is the longest data record available on plankton in the Northwest Atlantic. CPR data analysis lags AZMP reporting by one year; thus, only data up to 2004 are currently available. Nonetheless, the phytoplankton colour index and abundance of large diatoms and dinoflagellates on the Scotian Shelf (57º-66ºW) have been dramatically higher, starting in the early 1990s and continuing into the 2000s, than levels observed in the 1960s/1970s. On the shorter time scale, the phytoplankton colour index on the Scotian Shelf has been relatively stable (and above the long-term mean) over the past few years. Diatoms increased slightly in 2004 and dinoflagellate abundances, in contrast, continued to decline with levels in 2003 and 2004 below the long term average. The somewhat inconsistent patterns seen between the color index and diatom/dinoflagellate counts could be accounted for by the fact that the color index may also include phytoplankton species smaller than are routinely counted, i.e. the CPR retains particles smaller than the nominal 260 μm mesh of the silk gauze.

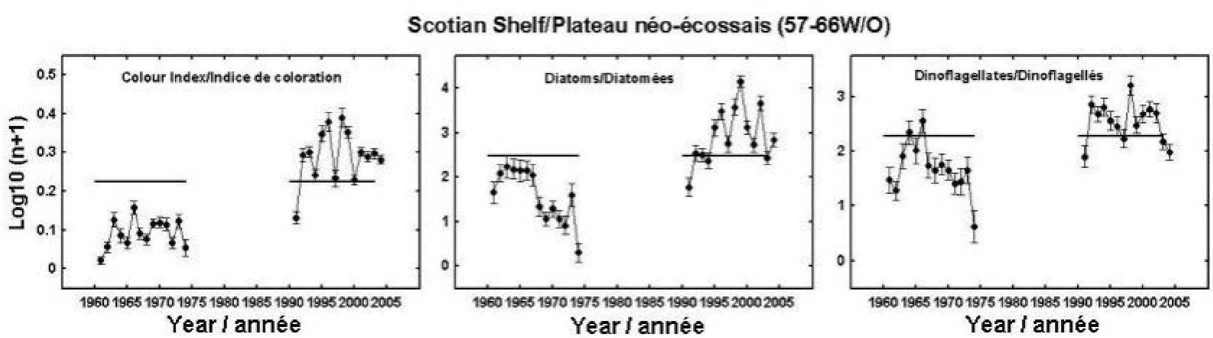


Figure 13. Time-series (1961-2004) of annual mean phytoplankton abundance on the Scotian Shelf and the Continuous Plankton Recorder (CPR).

In 2004, the magnitude and seasonal cycle of phytoplankton (diatom) abundances aligned more closely with the pattern observed in the 1990s/2000s than in the 1960s/1970s. There appeared to be a shift in phytoplankton abundance in more recent years to earlier months compared with the 1960s/1970s. Although the timing of peak abundance (April) did not change, much higher levels, particularly of diatoms, were observed in Januray-March in 2004 compared to levels observed during the 1960s/1970s.

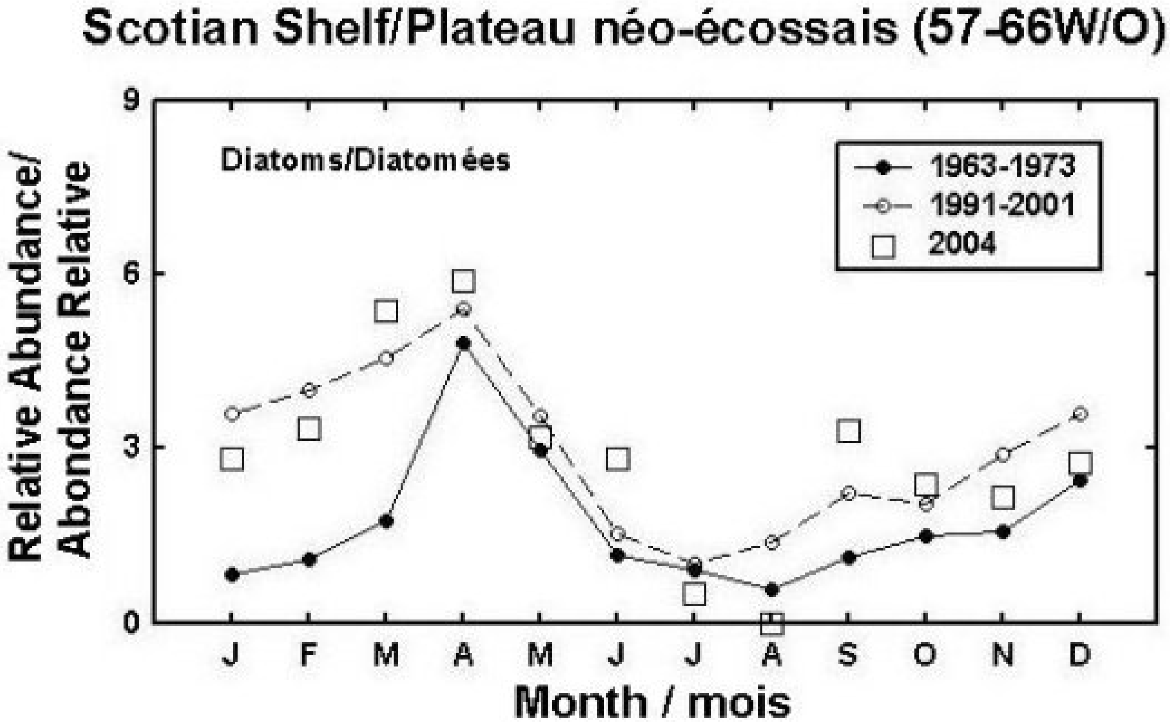


Figure 14. Monthly mean phytoplankton (diatom) abundance on the Scotian Shelf from the Continuous Plankton Recorder (CPR).

Zooplankton

Fixed Stations. Zooplankton biomass at all of the Maritimes/Gulf fixed stations was comparable to or lower in 2005 than levels observed in previous years. The record high biomass observed at the Shediac Valley station in 2003 was not observed in 2005, although sampling in 2005 was limited. Biomass off Halifax in 2005 was significantly lower than the high levels seen in 2004 and somewhat lower than the long term average, exhibiting a broad peak of ~30 g wet wt m^{-2} during spring/summer. Similarly, zooplankton biomass in the Bay of Fundy in 2005 was lower than in 2004 and lower than the historical levels, <10 g wet wt m^{-2}. There was, however, a dramatic increase in biomass in late fall, to almost 40 g wet wt m^{-2}. Zooplankton biomass in the Bay of Fundy is typically only a small fraction (10-20%) of the biomass at the other fixed station sites and peak levels occur later in the year than at the other sites.

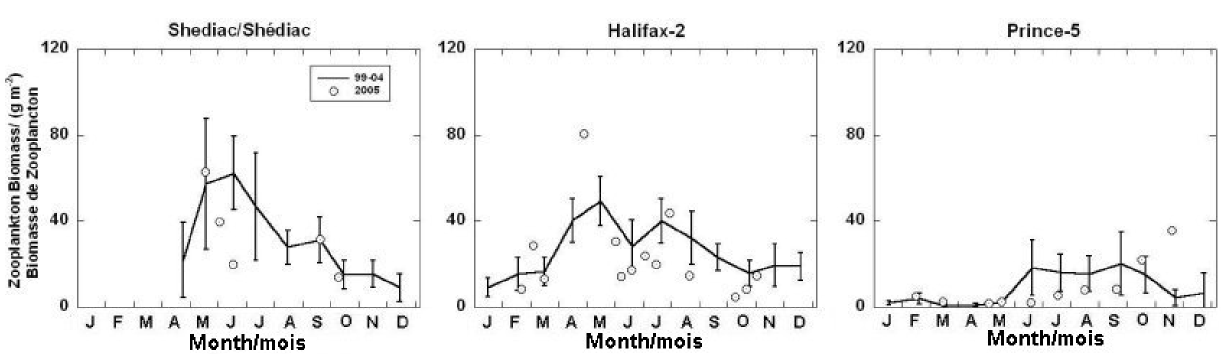


Figure 15. Zooplankton biomass at the AZMP-Maritimes/Gulf fixed stations in 2005.

As was the case for zooplankton biomass, *Calanus finmarchicus* abundance at all the fixed station sites in 2005 was comparable to or lower than levels seen previously. *C. finmarchicus* abundance in Shediac Valley in 2005 reverted from the record peak abundance observed in 2003 (>500,000 Ind m^{-2}) to levels more typical of the region (~25,000 Ind m^{-2}). Off Halifax-2, *C. finmarchicus* abundance in 2005 was comparable to levels seen the previous two years; levels in late summer/fall were somewhat lower than the long term average, however. *C. finmarchicus* abundance in the Bay of Fundy was lower than levels seen in 2004 and lower than the long term average for most of the year, however, as seen for zooplankton biomass, *C. finmarchicus* numbers increased dramatically during late fall, from <5,000 Ind m^{-2} to almost 60,000 Ind m^{-2}. *C. finmarchicus* abundance in the Bay of Fundy continues to be only a small fraction of the counts of that species at the other fixed station sites.

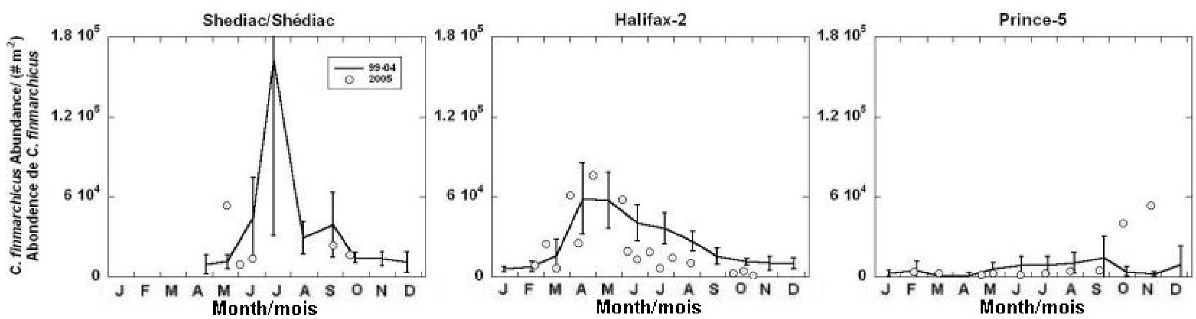


Figure 16. Calanus finmarchicus abundance at the AZMP-Maritimes/Gulf fixed stations in 2005.

Hierarchical community analysis revealed that copepods continued to numerically dominate the zooplankton year-round at all of the Maritimes/Gulf fixed stations in 2005. Despite limited sampling, the appearance of euphauiids and decapod larvae was more prominent in Shediac Valley than seen previously. The recurring pulse of echinoderm and barnacle larvae and euphausiids observed during the spring and summer In the Bay of Fundy was observed again in 2005, however, the pulse of jellies and appendicularia seen in 2004 was absent. The copepods were dominated (>50% much of the year) at all the fixed stations by small species (*Oithona*, *Pseudocalanus*, *Paracalanus*, *Clausocalanus*, *Centropoges* and *Temora* sp.) in 2005 as in previous years. The relative importance of the larger *Calanus sp* appears to have been increasing in the Bay of Fundy since AZMP sampling began in 1999. Also at that site, “other” copepod species (e.g. *Acartia sp*., harpacticoids) comprise a significant fraction (up to >60%) of the copepods in summer whereas they play a minor role (<10%) at the other two sites. Stage distribution of *C. finmarchicus* in 2005 revealed that reproduction (indicated by presence of early developmental stages) was generally confined to the spring/early summer period in Shediac Valley and off Halifax but was spread more broadly over the year in the Bay of Fundy. However, the major reproductive activity appeared to occur in spring at all stations as in previous years. The timing of reproduction off Halifax (as judged by the early stage first emergence) appeared to start later in 2005 than in 2004 but closer to the long term average, i.e. early March.

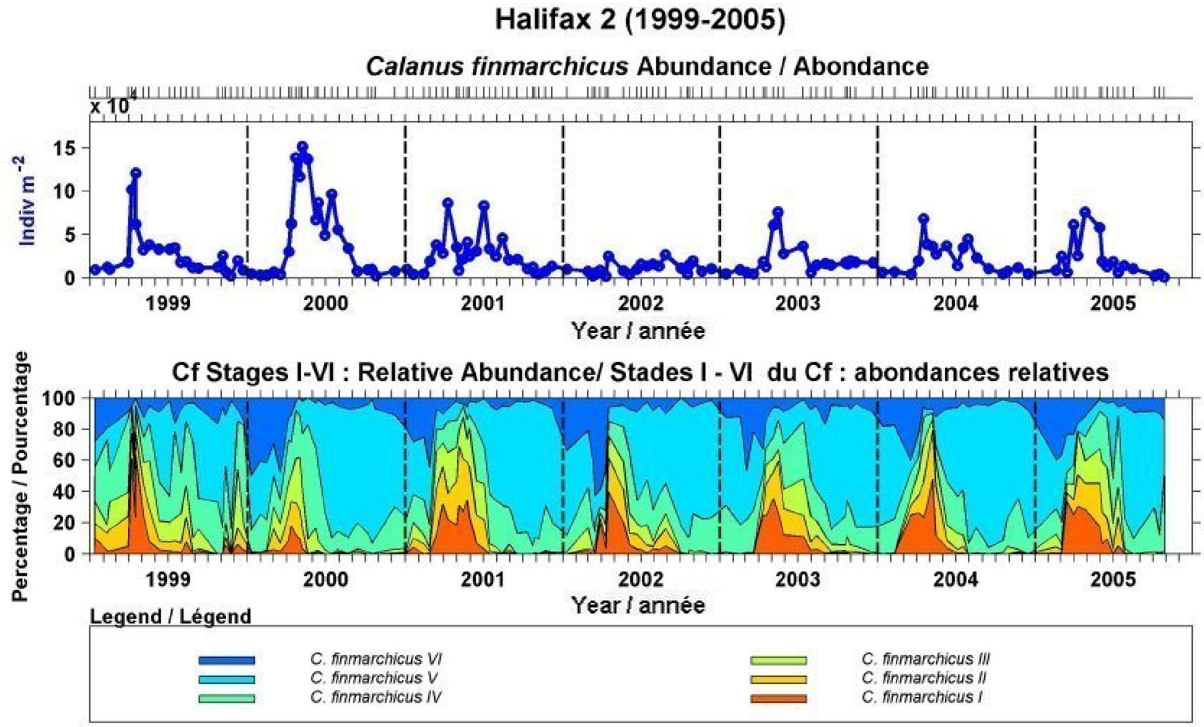


Figure 17. Time-series (1999-2005) of Calanus finmarchicus abundance and developmental stages at the Halifax fixed station.

Shelf Sections. Zooplankton biomass and *C. finmarchicus* abundance were generally higher in spring 2005 than during the fall shelf sections survey, as observed in previous years. Biomass levels increased from west (~30 g wet wt m^{-2} along the Browns Bank line) to east (~70 g wet wt m^{-2} along the Cabot Strait line) in spring while *C. finmarchicus* was generally more abundant on the western shelf; 26,000-56,000 Ind m^{-2} along the Brown's/Halifax lines compared with 18,000-21,000 Ind m^{-2} along the Louisbourg/Cabot lines. *C. finmarchicus* abundance was notably lower along the Brown's Bank line while considerably higher along the Cabot Strait line in spring 2005 than seen in previous years. In fall 2005, zooplankton biomass (17-28 g wet wt m^{-2}) and *C. finmarchicus* abundance (5,000-10,000 Ind m^{-2}) were fairly similar along the Brown's Bank, Halifax and Louisbourg lines, however, both biomass (47 g wet wt m^{-2}) and species abundance (~22,000 Ind m^{-2}) were considerably higher along the Cabot Strait line. In spring 2005, *C. finmarchicus* abundance was lower on the Browns Bank line than seen previously. In contrast, record high levels were seen in along the Cabot Strait line (~18,000 Ind m^{-2}) compared with the long term average in spring (~9,000 Ind m^{-2}). In fall 2005, zooplankton biomass was lower along the Brown's Bank line and record low *C. finmarchicus* abundances were observed along the Cabot Strait line (22,000 Ind m^{-2} compared with the long term average of 34,000 Ind m^{-2}). On the other hand, record high *C. finmarchicus* abundances were seen along the Halifax line in fall (11,000 Ind m^{-2} compared with the long term average of 8,000 Ind m^{-2}).

Groundfish Surveys. Zooplankton biomass distribution observed during the major winter/spring and summer/fall groundfish surveys can be characterized as highly variable in space and time. Generally, however, biomass is highest in deep basins and deep waters off the edge of the shelf or in channels (e.g. Northeast Channel off Georges Bank, Laurentian Channel bounding the Southern Gulf). Additionally, during the summer surveys, biomass has consistently been higher on the western Scotian Shelf than on the eastern shelf. This is in contrast to the east-west uniformity in biomass observed during the spring and fall surveys. In 2005, survey mean zooplankton biomass in February on Georges Bank (~10 g wet wt m^{-2}) was lower than the mean biomass in 2004 (~27 g wet wt m^{-2}) but not statistically different from the long term average. Zooplankton biomass during the eastern Scotian Shelf March survey, however, was the lowest on record (16 g wet wt m^{-2} compared with the long term average of 56 g wet wt m^{-2}). Similarly, zooplankton biomass, as well as *C. finmarchicus* abundance, were at record low levels during the July Scotian Shelf survey; biomass was ~18 g wet wt m^{-2} in 2005 compared with the long term average of ~36 g wet wt m^{-2} and *C. finmarchicus* abundance was ~19,000 Ind m^{-2} compared with the long term average of ~31,000 Ind m^{-2}). Zooplankton biomass was lower in 2005 than in 2004 during the September Southern Gulf of St Lawrence survey but not significantly different from the long term average. Zooplankton species data for most of the groundfish surveys have been processed but not yet interpreted.

<u>Continuous Plankton Recorder</u>. While phytoplankton were high on the Scotian Shelf in the 1990s/2000s compared with the 1960s/1970s, zooplankton were generally the reverse (i.e. lower in the 1990s/2000s than in the 1960s/1970s), particularly during the early to mid-1990s. During the last several years, zooplankton numbers have recovered from the mid-1990s lows for some species, however, counts for other species are still down. Of particular note was the dramatic increase in *C. finmarchicus*, particularly the elevated numbers of stages 1-4, in 2004; for the first time in a decade abundances of stages 1-4 were above the long term average. *Paracalanus/Pseudocalanus spp.* were also on the increase but levels still remained below the long term average. Euphausiid numbers in 2004 were down from the increase seen in 2003 and back below the long term average.

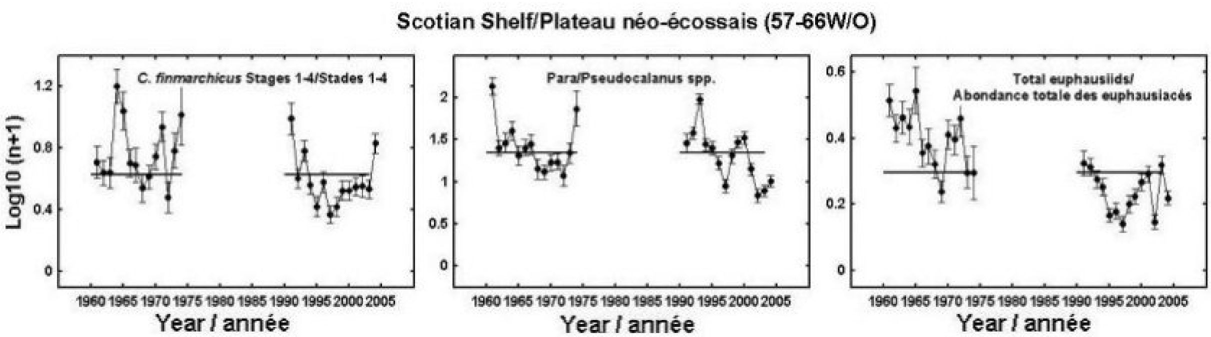


Figure 18. Time-series (1961-2004) of annual mean zooplankton abundance on the Scotian Shelf from the Continuous Plankton Recorder (CPR).

The seasonal abundance cycles for zooplankton species in 2004 could not as easily be aligned with the patterns of the 1960s/1970s and 1990s as was the case for phytoplankton.

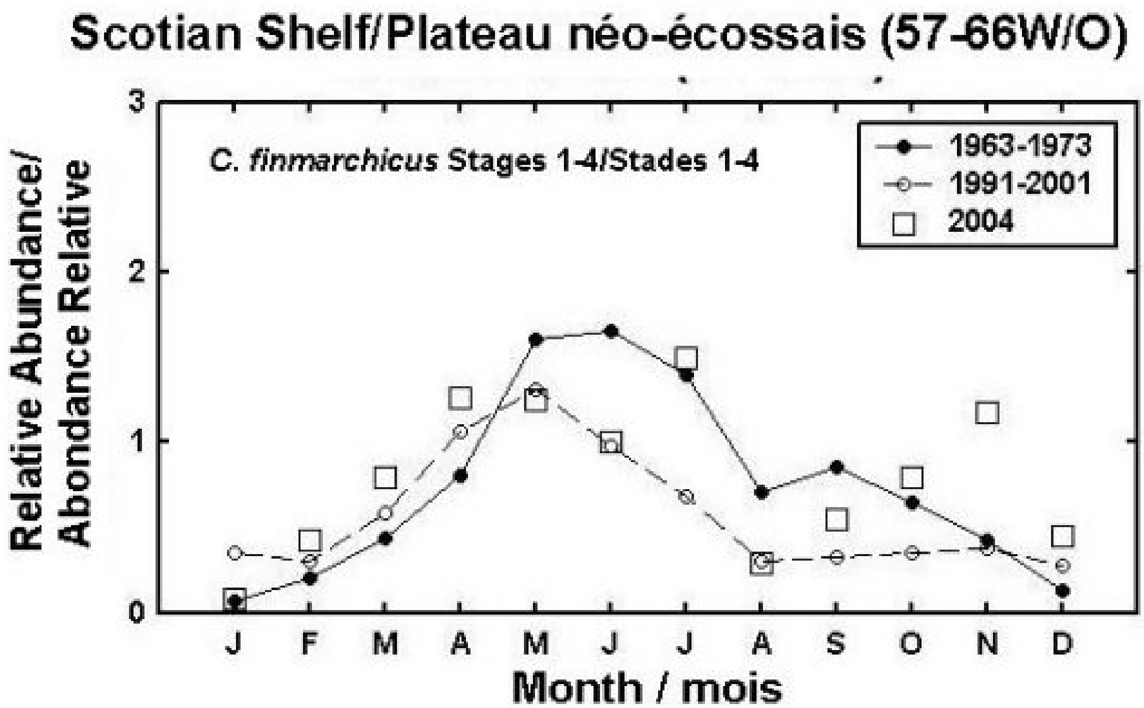


Figure 19. Monthly mean zooplankton (C. finmarchicus, stages 1-4) abundance on the Scotian Shelf from the Continuous Plankton Recorder (CPR).

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 region, seasonal sampling at the Shediac Valley fixed-station in the Southern Gulf has been significantly impacted by unavailability of ship-time; only 4-5 of the target ~15 sampling dates have been achieved for the past 2-3 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 groundfish 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 for CPR, and therefore quantitative estimates of biomass, abundance and inter-annual variability are not available.

CONCLUSION AND ADVICE

Winter-time surface nutrient concentrations and some deep water reserves were lower in the Maritime/Gulf regions in 2005 than seen previously. Likely linked with the low winter nutrient reserves was a spring bloom off Halifax that was strong in magnitude but was the shortest-lived since systematic observations began in 1999. Strong bloom conditions were observed on the central Scotian Shelf during the spring section survey. Low winter nutrients likely also contributed to the lower magnitude and delayed spring/summer bloom in the Bay of Fundy. Background phytoplankton levels (outside of bloom periods) have been systematically declining off Halifax for the past seven years; this could be linked to lower summer-time nutrients reserves in near surface waters. Longer-term observations of phytoplankton on the Scotian Shelf from CPR show that population levels continue to be well above levels observed in the 1960s/1970s when observations began.

Record low zooplankton biomass and abundances of the principal copepod, *C. finmarchicus*, were observed on the Scotian Shelf during the spring and summer groundfish surveys. On the other hand, record high levels were observed in fall on the central shelf, possibly related to the strong spring bloom seen there in April. Long term trends in zooplankton abundance from CPR show that counts continue to be well below levels seen in the 1960s/1970s for several important species, however some species, e.g. *C. finmarchicus,* appear to be recovering from record low levels seen in the early 1990s.

SOURCES OF INFORMATION

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

Harrison, G., D. Sameoto, J. Spry, K. Pauley, H. Maass, and V. Soukhovtsev. 2006. Optical, chemical and biological oceanographic conditions in the Maritimes/Gulf Regions in 2005. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/081.

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.

FOR MORE INFORMATION

Contact: Dr. G. Harrison
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia

Tel: (902) 426-3879
Fax: (902) 426-9388
E-Mail: harrisong@mar.dfo-mpo.gc.ca
Web Site: http://www.meds-sdmm.dfo-mpo.gc.ca/zmp/main_zmp_e.html

This report is available from the:

Centre for Science Advice,
Maritimes Region and Gulf Region
Department of Fisheries and Oceans
P.O. Box 1006, Stn. B203
Dartmouth, Nova Scotia
Canada B2Y 4A2

Phone number: 902-426-7070
Fax: 902-426-5435
e-mail address: XMARMRAP@mar.dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas

ISSN 1480-4913 (Printed)

La version française est disponible à l'adresse ci-dessus.

CORRECT CITATION FOR THIS PUBLICATION

DFO, 2006. 2005 State of the Ocean: Chemical and Biological Oceanographic Conditions in the Gulf of Maine - Bay of Fundy, Scotian Shelf, and the Southern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/048.