Fisheries and Oceans Canada
Science

Pêches et Océans Canada
Sciences

Maritimes/Gulf Regions

Canadian Science Advisory Secretariat
Science Advisory Report 2007/047

2006 STATE OF THE OCEAN: CHEMICAL AND BIOLOGICAL OCEANOGRAPHIC CONDITIONS IN THE GULF OF MAINE - BAY OF FUNDY AND ON THE SCOTIAN SHELF

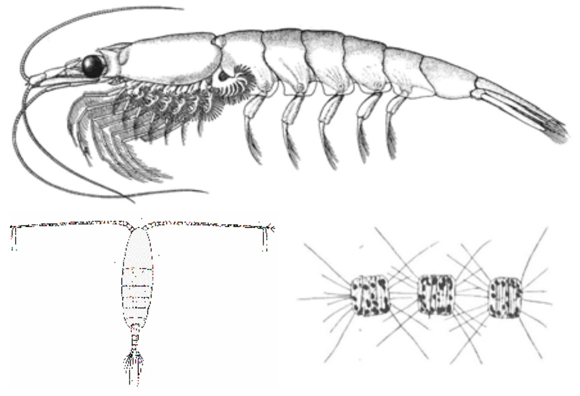

Figure 1. AZMP-Maritimes/Gulf fixed stations and shelf sections.

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.

January 2008

SUMMARY

- Winter nutrient levels at Halifax-2 continued to decline in 2006 while nutrient levels at Prince-5 continued to increase
- The summer nutrient depletion zone at Halifax-2 was the second deepest on record in 2006.The spring bloom at Halifax-2 in 2006 was weaker in magnitude and of shorter duration than the strong blooms of the previous 3 years and background chlorophyll levels (outside of the spring bloom period) continue to decline
- Maxiumum chlorophyll levels at Prince-5 in 2006 occurred much later (2 months) than seen previously
- The Continuous Plankton Recorder (CPR) colour index and species counts in 2005 showed that phytoplankton abundance on the Scotian Shelf continued to be at or above levels observed in the 1960s/1970s. *Calanus finmarchicus* abundance continued to increase at Prince-5 in 2006 while the abundance of younger developmental stages (CI-CIII) were lowest on record at both Maritimes fixed-stations
- Biomass and abundance of small zooplankton (e.g. *Pseudocalanus sp. and Oithona sp.),* relative to the larger forms (*Calanus sp., Metridia sp.),* were significantly lower at the Maritimes fixed stations in 2006 than seen in previous years
- Zooplankton biomass was the lowest on record on the eastern Scotian Shelf during the March Groundfish Survey in 2006 while *C. finmarchicus* abundance was the highest on record on the during the July Groundfish Survey
- CPR counts for 2005 showed that the abundance of several important zooplankton species continue to be at or below levels observed in the 1960s/1970s, however, some species (e.g. *C. finmarchicus*, *Paracalanus/Pseudocalanus sp.*, euphausiids) are 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. Ecosystem trawl (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: 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.

Rapid spring/early summer reduction in near surface nitrate concentrations was seen at both Maritimes fixed stations in 2006 (Fig. 2). Low surface values persisted throughout the summer/fall at Halifax-2; 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 2006 at Halifax-2 was shallower (33 m) than the record depth seen in 2005 (40 m) but similar to the long-term average. The seasonal evolution of the vertical nitrate structure at Halifax-2 in 2006 was similar to that observed in previous years. However, anomaly plots showed that nitrate concentrations in deep waters (>50 m) in 2006 were lower (-2 to -4 mmol m^{-3}) in summer and higher (+4 mmol m^{-3}) in fall than the climatological average. Near surface nitrate concentrations at Prince-5 in 2006 were never reduced below ~3 mmol m^{-3}. Anomaly plots for this station indicated that nitrate concentrations were higher (+1 to 2 mmol m^{-3}) than usual throughout the year, but most markedly in late summer/fall.

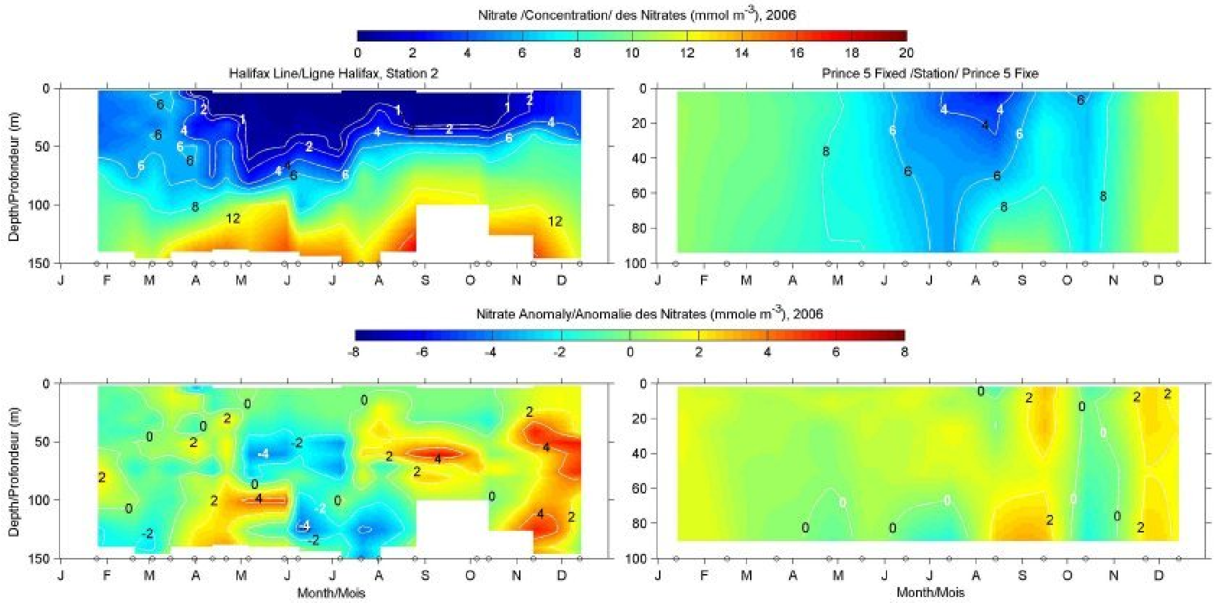

Figure 2. Vertical nitrate structure and nitrate anomalies (2006 minus long-term mean) at the AZMP-Maritime fixed stations in 2006.

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 (Fig. 3). Although the seasonal pattern of variability in nitrate at Halifax-2 in 2006 was similar to that observed in previous years, wintertime maximum inventories in 2006 (~260 mmol m^{-2}) were lower than seen in the previous years and continued a trend of declining concentrations following the record high inventories in 2003 (~400 mmol m^{-2}).

Inventories in fall, in contrast, were slightly higher than seen previously. Winter maximum nitrate inventories in the upper 50 m at Prince-5 in 2006 (~520 mmol m^{-2}) were significantly higher than seen in 2005 (~440 mmol m^{-2}) but similar to the long term average. In addition, summer levels (~240 mmol m^{-2}) were higher than the long term average (~210 mmol m^{-2}). Nitrate inventories in deep waters (>50 m) at Halifax-2 in 2006 were generally comparable with the long-term average (~800 mmol m^{-2}) although concentrations were slightly higher than the norm late in the year, October-December. At Prince-5, however, nitrate inventories in deep waters in 2006 were greater than average conditions (in all seasons) and continued a trend of increasing concentrations over time.

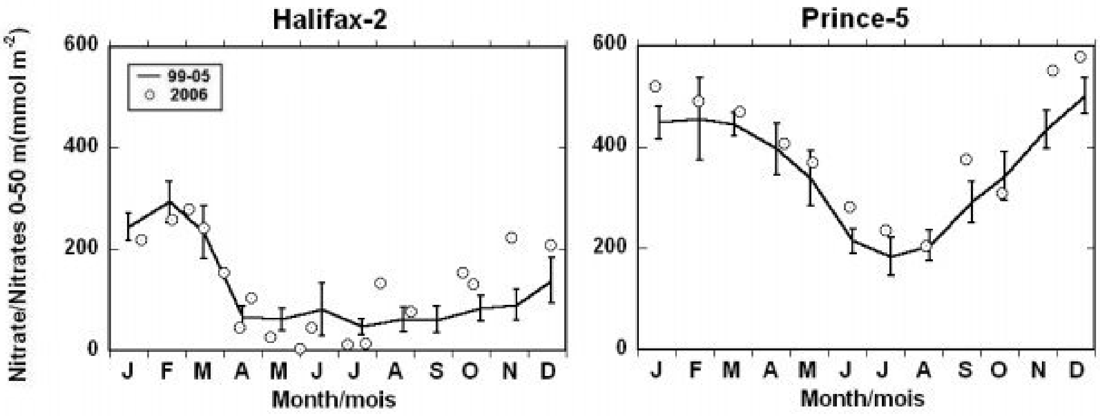

Figure 3. Nitrate inventories (surface to 50 m) at the AZMP-Maritimes fixed stations in 2006.

Shelf Sections: Vertical distributions of nitrate in spring and fall were generally similar along the Scotian Shelf sections in 2006, i.e. concentrations were low (<1 mmol m^{-3}) in near surface waters (<50 m), as a result of phytoplankton consumption, and increased with depth. Deep-water concentrations were highest in basins (>10 mmol m^{-3}) and in slope waters off the edge of the shelf. As in previous years, nitrate levels in surface waters were already depleted at the time of the spring survey in early April (1 mmol m^{-3} depth horizon: 20-40 m). Likewise, surface nitrate concentrations were still low during the fall survey in late October (1 mmol m^{-3} 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 2006 were comparable to levels observed in previous years except during spring along the Cabot Strait line where levels were lower than usual (~50 mmol m^{-3} versus the long-term average of ~100 mmol m^{-3}) and during fall along the Louisbourg line where levels were higher than the norm, ~90 mmol m^{-3} versus the long-term average of ~60 mmol m^{-3}. 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 July 2006 (average: 11.5 mmol m^{-3}) were similar to levels observed previously, long-term average = 11.6 mmol m^{-3-}. 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 (Fig. 4). Bottom water oxygen saturation on the Scotian Shelf in summer 2006 (average: 77% sat) was also similar to the long-term average (79% sat). The area of the bottom covered by waters with <60% saturation, however, was lower (14,000 km^2 or ~10% of the shelf area) than usual (16,600 km^2 or ~11% of the shelf area) but not statistically different. Lowest saturations were found in deep basins (e.g. Emerald Basin) and deep waters off the shelf edge where nutrients are highest.

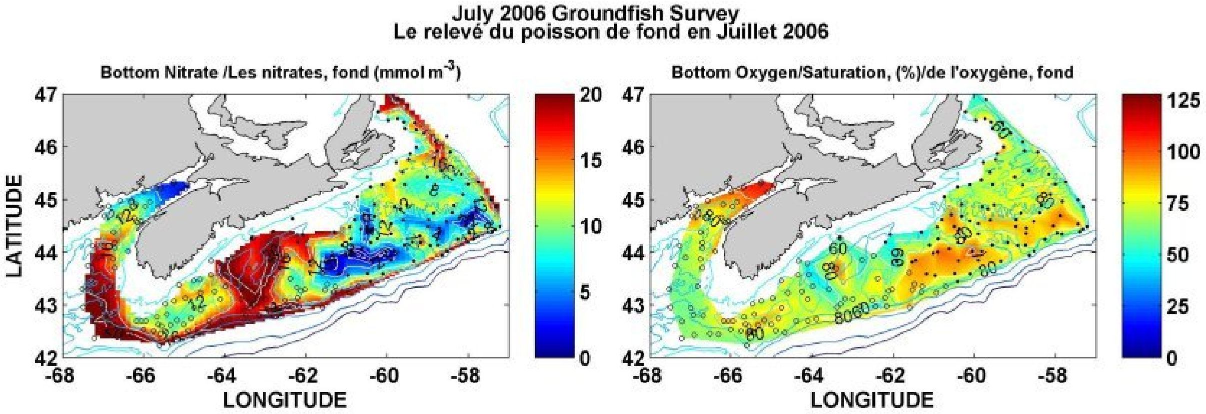

Figure 4. Bottom nitrate concentrations and oxygen saturation on the Scotian Shelf during the July 2006 groundfish survey.

Phytoplankton

Fixed Stations: Distinctly different seasonal phytoplankton growth cycles are evident at the two Maritimes fixed stations (Fig. 5, 6). The strong spring bloom observed at Halifax-2 between 2003 and 2005 (~650-700 mg m^{-2}) was absent in 2006 and levels (~250 mg m^{-2}) were the lowest seen since 1999. Anomaly plots suggested that the 2006 spring bloom started somewhat later and ended somewhat earlier than the norm. The evolution of the phytoplankton community composition at Halifax-2 in 2006 was 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 2006, total microplankton counts (~50,000 L^{-1}) were the lowest seen since AZMP observations began in 1999 and consistent with the low chlorophyll levels at this station.

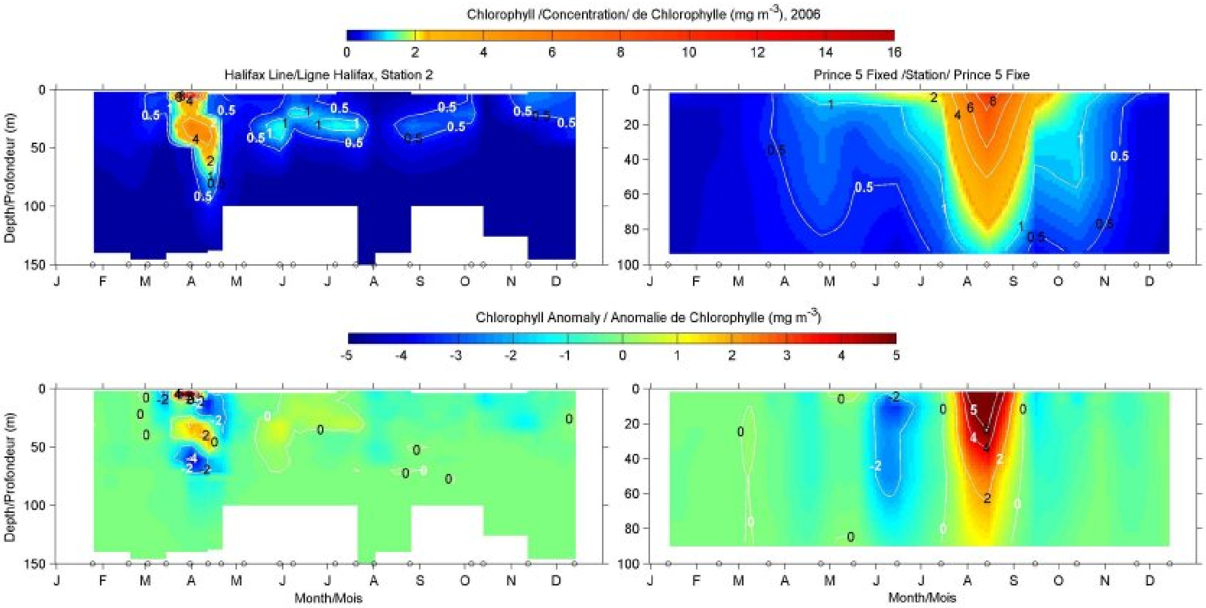

Figure 5. Vertical chlorophyll structure and chlorophyll anomalies (2006 minus long-term mean) at the AZMP-Maritimes fixed stations in 2006.

The phytoplankton growth cycle at Prince-5 in 2006, in contrast to Halifax-2; was characterized by a burst of growth in late summer (August) with a peak concentration (~450 mg m^{-2}) higher than seen since the record high in 2000 (~780 mg m^{-2}). In previous years, multiple growths events were evident at this station, the dominant one occurring much earlier (June) than in 2006. This was clearly evident in the anomaly plot which shows the absence (-2 mg m^{-3}) of the normal June chlorophyll peak and appearance (+5 mg m^{-3}) of a two month later (August) peak. As has been noted previously, the phytoplankton community at Prince-5 are 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.

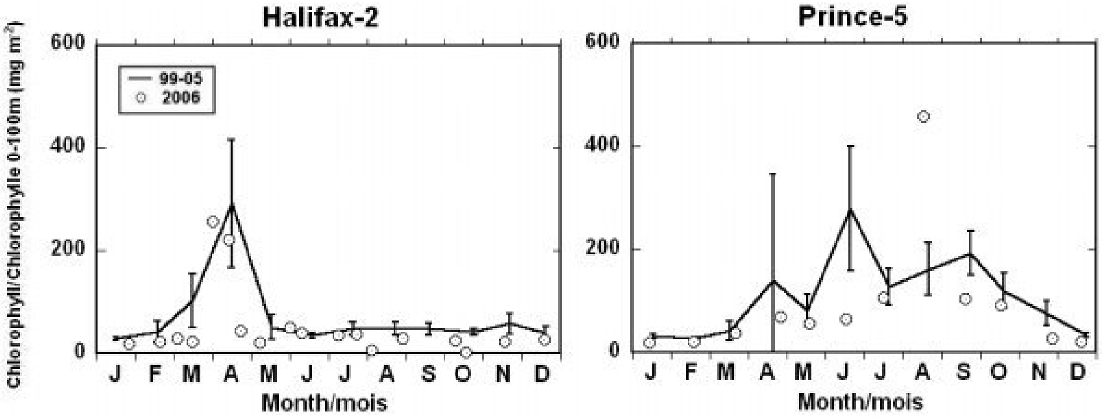

Figure 6. Chlorophyll inventories (surface to 100 m) at the AZMP-Maritimes fixed stations in 2006.

A more detailed analysis of the timing of the bloom at Halifax-2 revealed that the 2006 bloom continued a trend of later initiation, earlier termination and shorter duration (29 days) than seen previously (Fig. 7). In addition to changes in bloom dynamics, the "background" chlorophyll levels (outside the bloom period) have been declining over the past eight years, from ~40 mg m^{-2} in 1999 to ~30 mg m^{-2} in 2006.

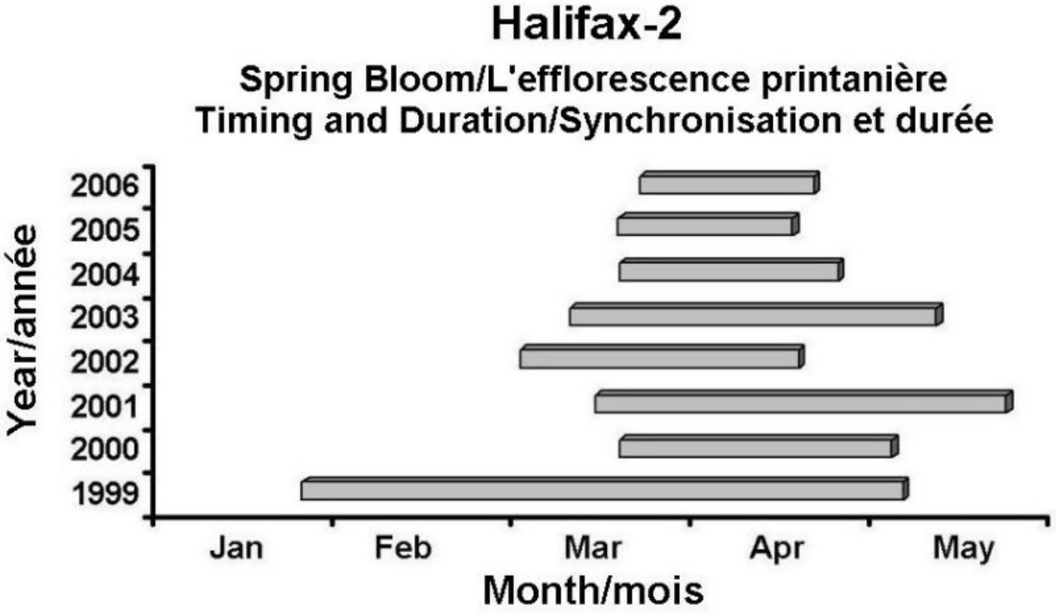

Figure 7. Duration (horizontal bars) and timing and duration of the spring phytoplankton bloom at the Halifax-2 fixed station, 1999-2006.

Shelf Sections: Chlorophyll levels along all the shelf sections are always considerably higher in spring than in fall and especially so along the Cabot Strait and Louisbourg lines in 2006 (Fig. 8). Despite this, chlorophyll levels during the spring 2006 survey were below normal. Indeed, chlorophyll inventories on the Halifax and Louisbourg lines were the lowest on record, i.e. ~40-150 mg m^{-2} in 2006 versus the long-term average of ~200-400 mg m^{-2}. Furthermore, a clear trend of decreasing spring inventories over the last four years of observations was evident along the Brown's Bank and Louisbourg lines. Chlorophyll levels were also below normal along all lines during the fall 2006 survey. Fall chlorophyll inventories, as in spring, were lowest on record but in this case, along the Cabot Strait as well as Halifax and Louisbourg lines, i.e. ~ 10-30 mg m^{-2} in 2006 versus the long-term average of ~30-40 mg m^{-2}. A clear trend of decreasing fall chlorophyll inventories was evident along all lines for the eight years of AZMP observations.

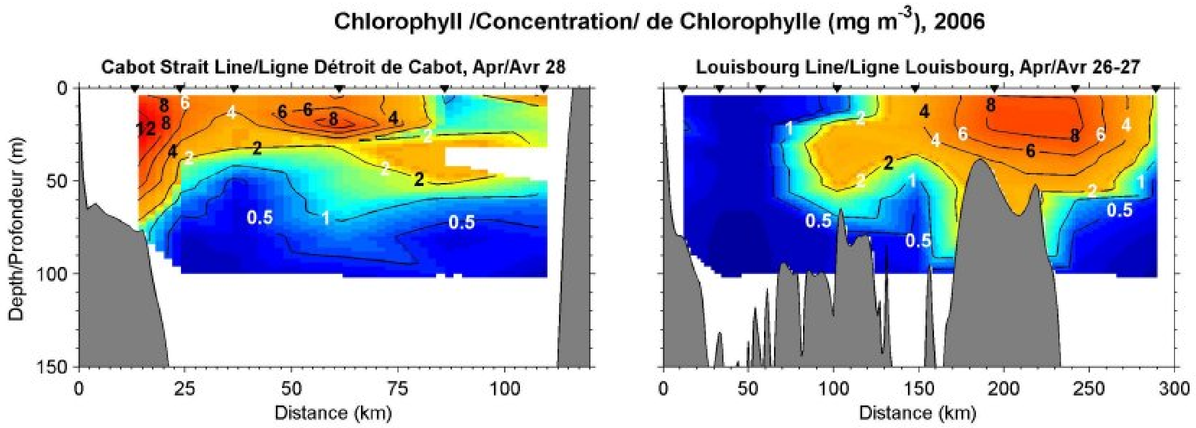

Figure 8. Vertical chlorophyll structure along the Cabot Strait and Louisbourg Shelf sections in spring 2006.

Groundfish Surveys: Near-surface chlorophyll levels during the 2006 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 (Fig. 9). 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 (>2 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. Overall, summer surface chlorophyll concentrations on the Scotian Shelf in 2006 (Avg: 0.69 mg m^{-3}) were similar to the long-term average of 0.68 mg m^{-3}.

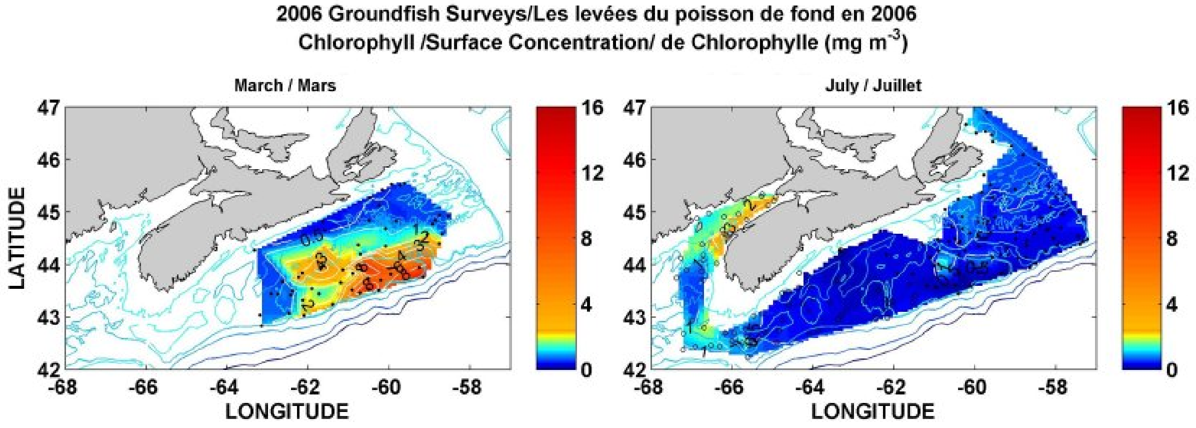

Figure 9. Near-surface chlorophyll concentrations on the Scotian Shelf during the March and July 2006 groundfish surveys.

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 Maritime Region covering the major periods of the shelf section surveys and groundfish surveys put those operations into a larger geographic context and reveal features that supplement/corroborate ship-based observations or provide information not otherwise attainable. For example, the off-shelf maximum in surface chlorophyll observed during the March Eastern Scotian Shelf groundfish survey was confirmed by MODIS data and the latter indicated the spatial extent of that offshore bloom. In a similar way, the MODIS composites indicated that the major spring bloom event was already in decline when the April/May shelf section survey was done. As well, the composites showed the overall low surface chlorophyll levels, shelf-wide, observed during the July groundfish survey and surface chlorophyll levels during October shelf section survey where highest levels were seen on the eastern shelf.

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) (Fig. 10). 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. For example, the earlier appearance of the spring bloom off the edge of the central Scotian Shelf (Halifax line) compared to the bloom on the inner shelf is clearly evident. Generally speaking, 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.

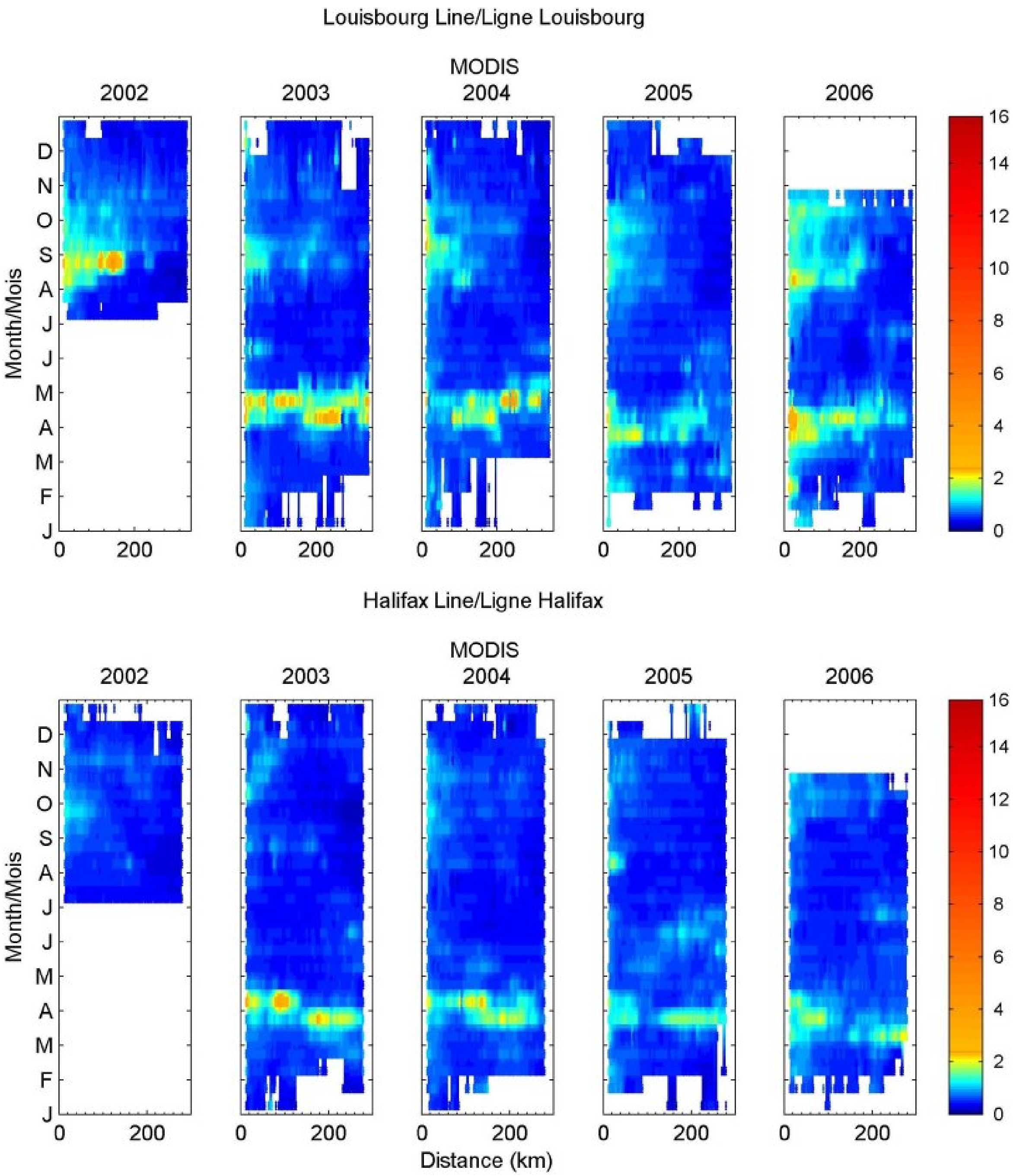

Figure 10. Surface chlorophyll concentrations (2002-2006) along the Louisbourg and Halifax shelf sections from MODIS ocean colour satellite sensor.

At the larger scale (i.e. statistical sub-regions in the Maritimes region), the timing and magnitude of the spring bloom in 2006 compared with previous years (Fig 11). The timing of peak spring chlorophyll, for example, was YD (year-day) 94-98 on the eastern shelf and somewhat earlier (YD 82-91) on the central and western shelf. Peak chlorophyll at the Halifax-2 fixed station was at YD 95. Contrary to the Halifax-2 results, the satellite data did not indicate that the magnitude of the spring bloom in 2006 was notably lower than seen in previous years, with the exception of Georges Bank where no spring bloom was evident above the high background chlorophyll concentrations.

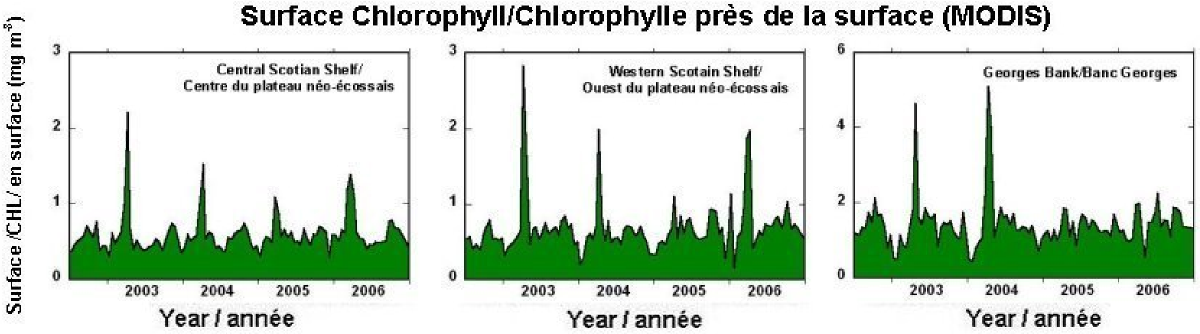

Figure 11. Surface chlorophyll concentrations on the central and western Scotian Shelf and on Georges Bank from MODIS ocean colour satellite sensor.

<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 2005 are currently available. Nonetheless, the phytoplankton colour index and abundance of large diatoms and dinoflagellates on the Scotian Shelf (57º-66ºW) have been notably higher, starting in the early 1990s and continuing into the 2000s, than levels observed in the 1960s/1970s (Fig. 12). On the shorter time scale, the phytoplankton colour index on the Scotian Shelf has been declining over the past few years although levels are still above the long-term average. Diatoms remained unchanged in 2005 and dinoflagellates showed a dramatic increase from low levels in 2003 and 2004, returning to levels above 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.

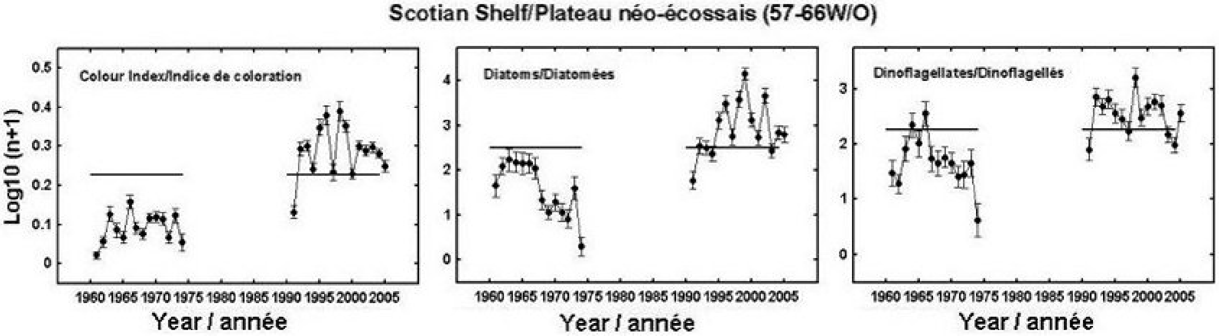

Figure 12. Time-series (1961-2005) of annual mean phytoplankton abundance on the Scotian Shelf from the Continuous Plankton Recorder (CPR).

In 2005, the magnitude and seasonal cycle of phytoplankton abundance aligned more closely with the pattern observed in the 1990s/2000s than in the 1960s/1970s (Fig.13). Although the timing of peak abundance (April) has not changed, much higher levels, particularly of diatoms, are now observed in January-March than observed during the 1960s/1970s.

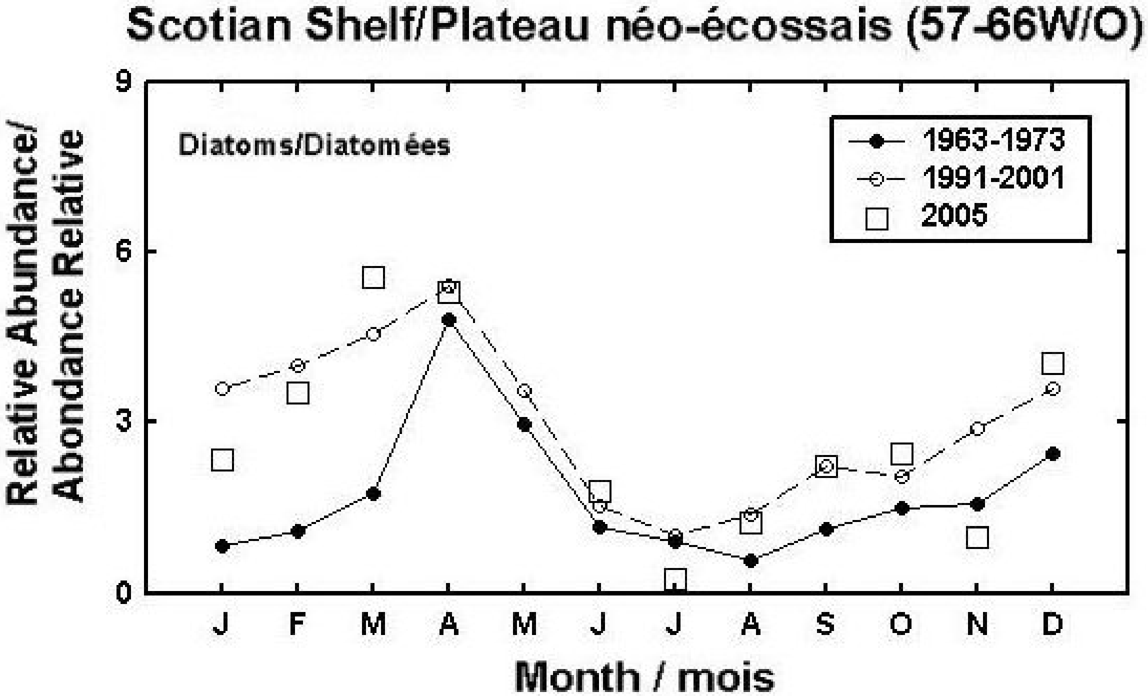

Figure 13. Monthly mean phytoplankton (diatom) abundance on the Scotian Shelf from the Continuous Plankton Recorder (CPR).

Zooplankton

Fixed Stations: Average zooplankton biomass over the year at both of the Maritimes fixed stations in 2006 was comparable to or somewhat higher than levels observed previously (Fig. 14). Biomass at Halifax-2 in 2006 was lower, however, than the long-term average late in the year (October-December). In contrast, zooplankton biomass at Prince-5 in 2006 was notably higher early in the year (January-April) than the long-term average. This was likely a carry-over from the high biomass levels observed late in 2005. Zooplankton biomass at Prince-5 is typically only a small fraction (10-20%) of the biomass observed at Halifax-2 and maximum levels are generally broader and occur much later in the year.

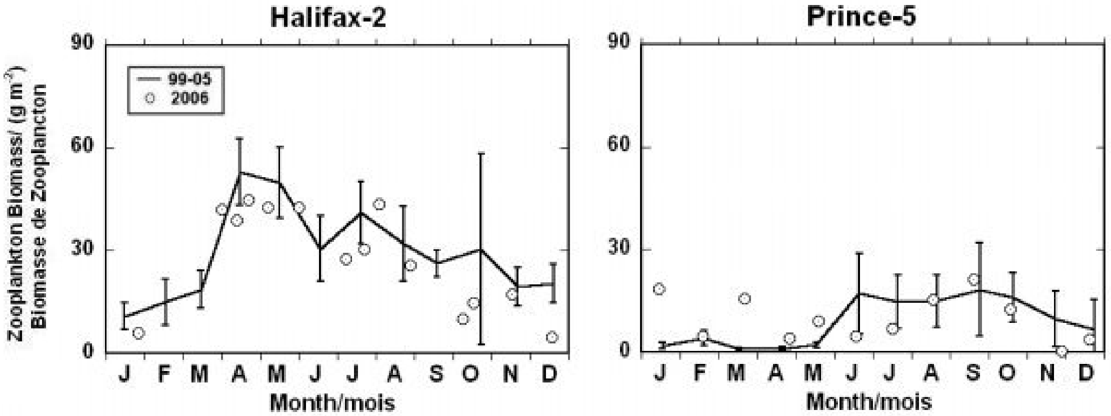

Figure 14. Zooplankton biomass at the AZMP-Maritimes fixed stations in 2006.

As was the case for zooplankton biomass, *Calanus finmarchicus* abundance at both of the fixed stations in 2006 was comparable to or higher than levels seen previously (Fig. 15). At Halifax-2, *C. finmarchicus* abundance was somewhat lower, however, early in the year (March-May) and thus peak abundance occurred later than the long-term average (April-May). *C. finmarchicus* abundance at Prince-5 in 2006 (average: ~14,000 m^{-2}) was the highest seen since the record abundance of 2001 (~15,000 m^{-2}). As was the case with zooplankton biomass, *C. finmarchicus* abundance was significantly higher than the norm early in the year (January-April) and likely a carry-over from the high levels seen late in 2005. Prince-5 continues to be only a small fraction of the *C. finmarchicus* counts seen at Halifax-2.

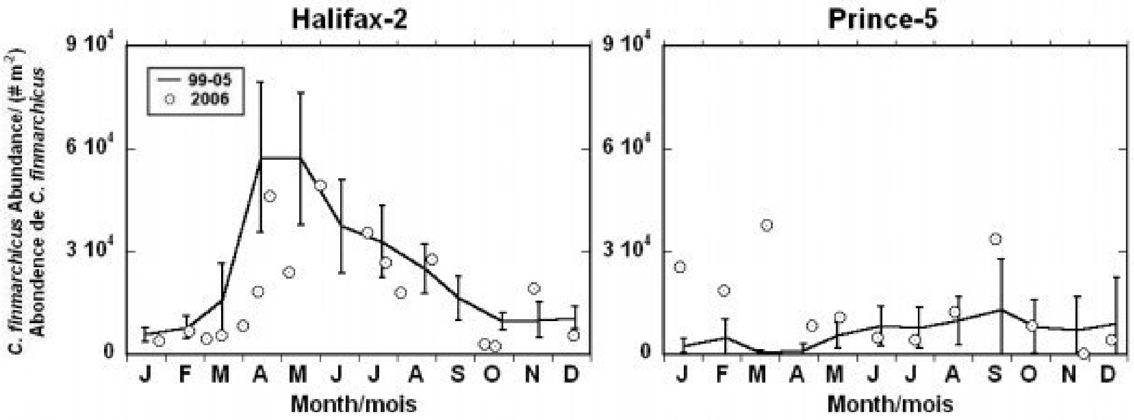

Figure 15. Calanus finmarchicus abundance at the AZMP-Maritimes fixed stations in 2006.

Hierarchical community analysis revealed that copepods continued to numerically dominate (~70-90%) the mesozooplankton year-round at both of the Maritimes fixed stations in 2006. The recurring pulse of echinoderm and barnacle larvae and euphausiids observed during the spring and summer at Prince-5 was observed again in 2006 as well as a pulse of bivalve larvae in late summer. The copepods were dominated (>50% much of the year) at both fixed stations by small species (*Oithona sp.*, *Pseudocalanus sp.*, *Paracalanus sp.*, *Clausocalanus sp.*, *Centropoges* sp. and *Temora sp.*) in 2006 as in previous years although counts were lower than usual. *Oithona sp.* abundance was the lowest on record at Prince-5 and *Pseudo/Paracalanus sp.* were lowest since 2002 at both fixed stations. The relative importance of the larger species (*Calanus sp., Metridia sp.),* on the other hand, increased at both stations. At Prince-5, “other” copepod species (e.g. *Acartia sp*., harpacticoids) comprise a significant fraction (~40-60%) of the copepods in summer whereas they play a minor role (<10%) at Halifax-2. Overall, total copepod abundance at Halifax-2 was the lowest seen since the 2002 record low. An analysis of the biomass (as opposed to numerical abundance) distribution of the dominant copepods at Halifax-2 showed that the contribution of the smaller forms (*Pseudocalanus sp., Oithona sp*.) was the least (~1-2%) seen in 2006 since observations began in 1999. In addition, biomass of the cold-water calanoid, *C. glacialis,* was the lowest on record at this station in 2006. Stage distribution of *C. finmarchicus* in 2006 revealed that reproduction (indicated by presence of early developmental stages, I-III) was generally confined to the single spring/early summer peak at Halifax-2 (Fig. 16). Reproduction at both stations appeared to be of shorter duration than seen previously. The production potential of *C. finmarchicus* at Halifax-2 in 2006 (as judged by abundance of the developmental stages) would be assessed as “poor” due to the low counts of CI-CIII, almost as low as the record low counts seen in 2002. The abundance of CIV-CVI, however, was comparable to the long-term average.

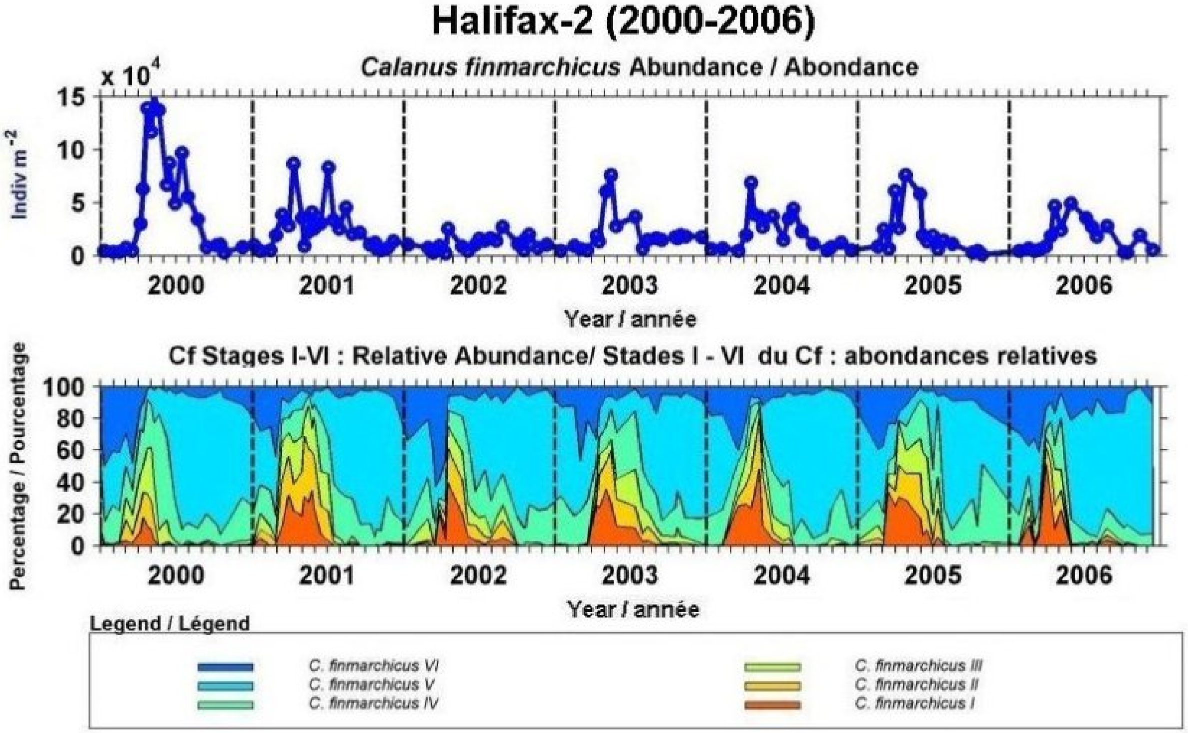

Figure 16. Time-series (2000-2006) of Calanus finmarchicus abundance and developmental stages at the Halifax-2 fixed station.

Shelf Sections: Zooplankton biomass and *C. finmarchicus* abundance are generally higher in spring than during fall along the shelf section surveys, except along the Cabot Strait line where the levels are higher in fall. In addition, biomass tends to increase west to east while *C. finmarchicus* abundance is the reverse. These same patterns of zooplankton distribution were generally seen in 2006 as well. Biomass levels in spring and fall in 2006 were similar to levels seen in the past along all lines, i.e. ~30-60 g wet wt m^{-2} in spring versus ~20-80 g wet wt m^{-2} in fall. In contrast to zooplankton biomass, *C. finmarchicus* abundance was higher than usual in spring 2006 along the Brown's Bank line (~65,000 m^{-2} versus the long-term average of ~45,000 m^{-2}) while spring abundance was lower along the Halifax line (~25,000 m^{-2} versus the long-term average of ~50,000 m^{-2}). During the fall survey, abundance was the highest on record along the Halifax line (~15,000 m^{-2} versus the long-term average of ~10,000 m^{-2}), the second year of record high counts.

Groundfish Surveys: Zooplankton biomass distribution observed during the major winter/spring and summer 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). Additionally, during the summer survey, biomass has consistently been higher on the western Scotian Shelf than on the eastern shelf. This is in contrast to the west-east increase in biomass observed during the spring and fall section surveys, the differences likely being season-related. In 2006, survey average zooplankton biomass in February on Georges Bank (~10 g wet wt m^{-2}) was lower than the long-term average biomass (~20 g wet wt m^{-2}). Zooplankton biomass during the eastern Scotian Shelf March survey was the lowest on record (~10 g wet wt m^{-2} compared with the long term average of ~50 g wet wt m^{-2}). Similarly, zooplankton biomass was below normal levels during the July Scotian Shelf survey, i.e. ~30 g wet wt m^{-2} in 2006 compared with the long term average of ~35 g wet wt m^{-2}. For all three surveys there appears to be a trend of decreasing zooplankton biomass with time and this is particularly evident from the year-by-year decrease on the July survey. Zooplankton species data for most of the groundfish surveys have been processed but not yet interpreted, however, *C. finmarchicus* abundance for the July survey have been done and in contrast to zooplankton biomass, counts were at record levels in 2006 (>40,000 m^{-2}).

Continuous Plankton Recorder: While phytoplankton were high on the Scotian Shelf and the Northwest Atlantic in the 1990s/2000s compared with the 1960s/1970s, zooplankton were generally the reverse (i.e. lower in more recent years), particularly during the early to mid-1990s (Fig. 17). During the last several years, zooplankton numbers have been recovering from the mid-1990s lows on the Scotian Shelf, however, counts for some species in the Northwest Atlantic are still down. Of particular note is the dramatic increase in the younger development stages (CI-CIV) of *C. finmarchicus* and *Paracalanus/Pseudocalanus sp.* on the Scotian Shelf; levels are now at or above the long-term average. Euphausiid numbers in 2005 also increased and are approaching long-term average levels. The seasonal abundance cycles for zooplankton species in 2005 could not as easily be aligned with the patterns of the 1960s/1970s or 1990s, as was the case for phytoplankton, because of the smaller difference in zooplankton abundance between decades and higher seasonal variability.

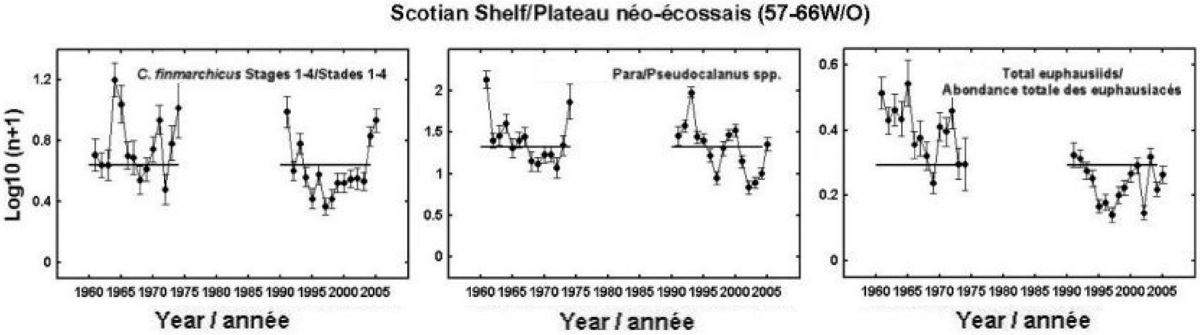

Figure 17. Time-series (1961-2005) of annual mean zooplankton abundance on the Scotian Shelf from the Continuous Plankton Recorder (CPR).

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 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 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 by CPR, and therefore quantitative estimates of biomass, abundance and inter-annual variability are not available.

CONCLUSION AND ADVICE

Winter maximum and summer minimum surface nutrient concentrations continued to decline at Halifax-2 in 2006 and the decrease in nutrient inventory may have contributed to the weak and short-lived spring bloom and declining background chlorophyll levels at that site. On the longer time scale (decadal), it appears from CPR data that the spring phytoplankton bloom on the Scotian Shelf has been much larger and started earlier in the year than blooms during the first decade of observations beginning some 30 years ago.

Near record low abundances of young developmental stages (CI-CIII) of the principal copepod, *C. finmarchicus*, and a shorter than normal reproduction period in 2006 at Halifax-2 may been linked to the diminished spring bloom there. In addition, the relative importance of smaller species (e.g. *Pseudocalanus sp.* and *Oithona sp.),* relative to larger species (e.g. *Calanus sp.* and *Metridia sp.),* decreased in 2006. Zooplankton biomass continued to decline on the groundfish surveys as well. Long term trends in zooplankton abundance from CPR data show that counts of several important species continue to be at or below levels observed in the 1960s/1970s, however, some species (e.g. *C. finmarchicus*, *Paracalanus*/*Pseudocalanus sp.,* euphausiids) are recovering and are now at levels close to or above the long term average.

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, C. Porter, and V. Soukhovtsev. 2007. Optical, chemical, and biological oceanographic conditions in the Maritimes Region in 2006. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/050.

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 (CSA)
Maritimes 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, 2007. 2006 State of the Ocean: Chemical and Biological Oceanographic Conditions in the Gulf of Maine - Bay of Fundy and on the Scotian Shelf. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/047.