2002 State of the Ocean: Chemical and Biological Oceanographic Conditions in the Estuary and Gulf of St. Lawrence

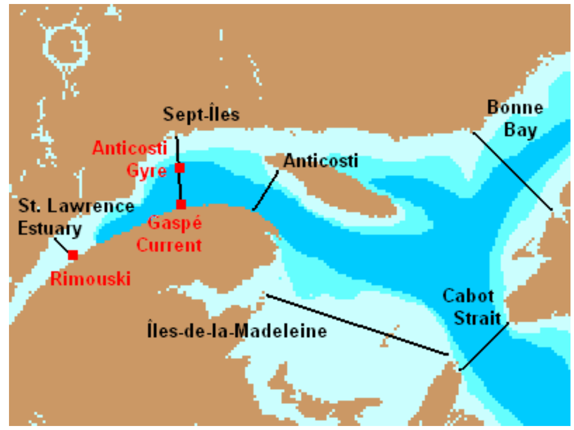

Figure 1. Atlantic Zone Monitoring Program (AZMP) sections (lines) and fixed stations (red squares).

Background

The Atlantic Zonal Monitoring Program (AZMP) was implemented in 1998 with the aim of: (1) increasing DFO's capacity to understand, describe, and forecast the state of the marine ecosystem and (2) quantifying the changes in physical, chemical, and biological oceanic properties and the predator-prey relationships of marine resources. A critical element in the AZMP observation program is an annual assessment of the distribution and variability of nutrients and the plankton they support.

A description of the distribution in time and space of nutrients (nitrate, silicate, phosphate) dissolved in seawater provides important information on water-mass movements and on the locations, timing, and magnitude of biological production cycles. A description of the distribution of phytoplankton and zooplankton provides important information on the organisms forming the base of the marine food-web. An understanding of the production cycles of plankton is an essential part of an ecosystems approach to fisheries management.

The AZMP derives its information on the state of the marine ecosystem from data collected at a network of sampling locations (fixed point stations, cross-shelf sections, groundfish surveys, satellite remote sensing) in each region (Québec, Maritimes, Newfoundland) sampled at a frequency of bi-weekly to once annually.

Summary

Seasonal patterns and regional differences were observed in the chemical and biological parameters in the Estuary and Gulf of St. Lawrence in 2002. Prominent events included:

- The initiation of the spring phytoplankton bloom in the Lower St. Lawrence Estuary occurred near the historical mean date for the first time since 1998.
- The phytoplankton biomass during spring-summer 2002 in the Lower St. Lawrence Estuary was, for a third consecutive year, much lower compared to the 1995-1999 period, but nevertheless has shown an increasing trend since 2000.
- On the basis of the nutrient evolution, phytoplankton production in the northwestern Gulf of St. Lawrence could have been higher in 2002 compared to the previous two years but much lower than for 1999.
- For a second consecutive year, we noted the massive presence of the diatom *Neodenticula seminae* in the Gulf of St. Lawrence; this phenomenon is unusual since this species is typically found in North Pacific waters.

- The mean integrated zooplankton biomass in the Anticosti Gyre was comparable with what we observed in 1999, 2000, and 2001 while in the Gaspé Current the zooplankton biomass was 1.5 times higher than in 2001 and 2000.
- The zooplankton biomasses observed in 2002 along all transects in both spring and fall were comparable to observations made in 2001 and 2000.
- In 2002, the overall abundance of zooplankton increased to the levels observed in 2000 in all regions and seasons except in fall in the southern Gulf (Magdalen Island transect), where the abundance continued to increase as compared to 2000 and 2001.
- In the Lower Estuary and the northwest Gulf of St. Lawrence, there was a slight increase in the mesozooplankton biomass in 2002 compared to 2001 and no changes in the macrozooplankton biomass.
- In the Lower Estuary and the northwest Gulf of St. Lawrence, the year 2002 was characterized by large increase in the abundance of chaetognaths and gelatinous zooplankton and a decrease in the abundance of mysids.
- In 2002, the abundance of the amphipod *Themisto libellula* was similar to that observed in 2001.

Introduction

Phytoplankton are microscopic plants that form the base of the aquatic food web, occupying a position in the marine environment analogous to terrestrial plants on land. They use light to synthesize organic matter from inorganic carbon and nutrients dissolved in marine waters. Thus, they are responsible for ocean productivity. The rate at which phytoplankton produce new organic matter in the marine environment is determined by nutrient availability (especially nitrogen compounds), light intensity, and temperature. The maximum potential level of primary productivity in a system also depends on additional factors such as the freshwater runoff and the stratification of the water column.

Zooplankton are animals that range in size from smaller than 1 mm (e.g., copepods) to about 4 cm (e.g., krill). Because zooplankton are the principal consumers of phytoplankton, they represent a critical link in the food web between phytoplankton and larger animals. Zooplankton are fed on by all species of fish at some time in the fishes' life cycle.

Nutrient concentrations and phytoplankton biomass

Lower St. Lawrence Estuary

In most marine waters, phytoplankton undergo spring-summer population explosions called blooms. In the Lower St. Lawrence Estuary, the primary phytoplankton bloom is a well-established seasonal event representing the major net input of carbon into the food web in the estuary. To follow the inter-annual variability in timing, duration, and magnitude of the spring phytoplankton bloom, Station Rimouski (Fig. 1) has been visited on a weekly basis from May to September since 1992.

In 2002, the standing stock of phytoplankton at Station Rimouski, as reflected by the amount of chlorophyll *a* (Fig. 2), showed a major pulse in June-July, with integrated values in the upper 50 m exceeding 400 mg of chlorophyll *a* per m^2 (Fig. 3). Outside of this period, chlorophyll levels remained relatively low except in mid May and mid August, when two small blooms of short duration were observed (Figs. 2 and 3). Phytoplankton species responsible for the June-July bloom were the diatoms *Thalassiosira gravida*, *T. nordenskioeldii*, *T. pacifica*, *Chaetoceros* spp. and *Skeletonema costatum*. These species were gradually replaced in September by

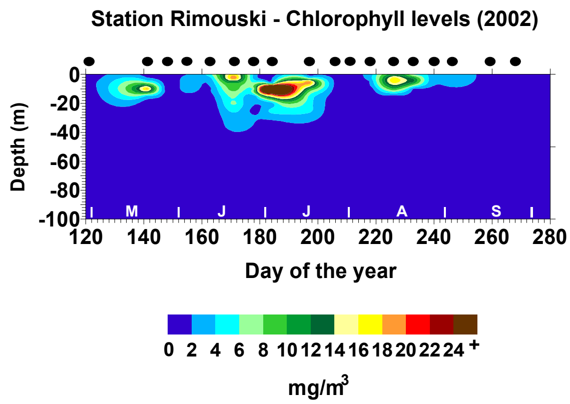

Figure 2. Chlorophyll a concentrations in the upper 100 m of the water column at Station Rimouski during spring-summer 2002. Dots : sampling periods.

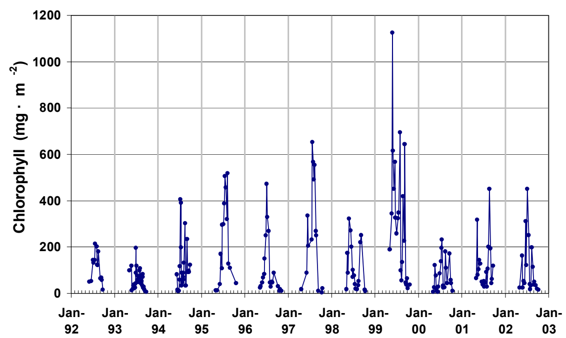

Figure 3. Chlorophyll a concentrations integrated over the upper 50 m at Station Rimouski during spring-summer 1992-2002.

Leptocylindrus minimus and several species of dinoflagellates and flagellates.

Compared to our previous observations, the onset of the major phytoplankton bloom at Station Rimouski in 2002 occurred about the same time as in 1992-1997 (late June to early July; Fig. 4) but 6-8 weeks later compared to the 1998-2001 period (early May). A comparison of these results with historical data on the phytoplankton biomass in the Lower St. Lawrence Estuary confirms that the development of the primary bloom in mid June as observed in 2002 is much more typical for this region.

Typically, the spring bloom in the lower St. Lawrence Estuary starts just after the

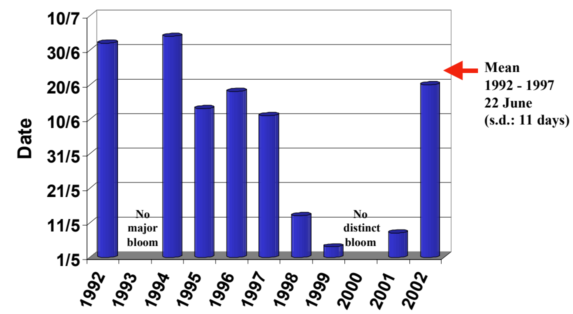

Figure 4. Date of onset of the primary bloom defined by the first incidence of chlorophyll concentrations greater than 100 mg of chlorophyll a per m² at Station Rimouski, 1992-2002.

spring-summer runoff peak. The near-normal spring freshwater runoff in the St. Lawrence basin in 2002 compared to the 1998-2001 period could thus be responsible for the return toward the normal phytoplankton cycle in the estuary in 2002.

Overall, the average phytoplankton biomass during spring-summer 2002 at Station Rimouski was also somewhat higher compared to 1992-1994, 1998 and 2000-2001, but much lower compared to 1995, 1997, and, more especially, to 1999 (Fig. 5). In particular, phytoplankton biomass in July 2002 was much higher compared to the two previous years (Fig. 3).

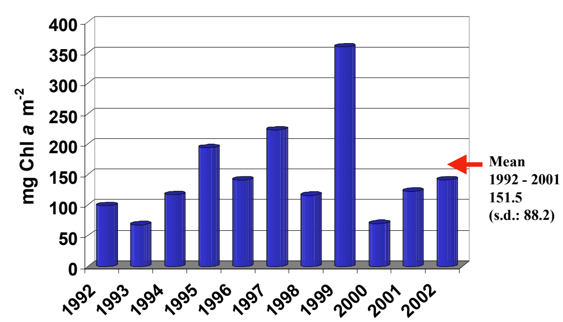

Figure 5. Mean integrated (surface to 50 m depth) chlorophyll a levels at Station Rimouski from May to August, 1992-2002.

Northwest Gulf of St. Lawrence

The northwestern Gulf of St. Lawrence is characterized by a quasi-permanent cyclonic gyre, the Anticosti Gyre. The Anticosti Gyre is separated from the Gaspé Current by a frontal system; the Gaspé Current is a coastal jet resulting from the seaward advection of the low salinity waters of the St. Lawrence estuary along the Gaspé Peninsula. These two systems represent two identifiable pelagic ecosystems. The biological and chemical properties of the Gaspé Current primarily reflect the conditions developing in the lower estuary whereas those found in the Anticosti Gyre are more typical of the conditions prevailing over the Gulf of St. Lawrence proper. Within the AZMP, these two systems are monitored at a frequency of 9 to 16 times per year.

In 2002, nutrient concentrations in the surface layer (top 50 m) followed a similar seasonal pattern at both stations in the northwestern Gulf of St. Lawrence: nitrate and silicate concentrations were high in late fall-winter and low in spring-summer due to biological consumption by phytoplankton (Fig. 6). Typically, nutrient concentrations were somewhat higher in the Gaspé Current than in the Anticosti Gyre and more variable due to the dynamics of this coastal jet. The spring decrease in the surface nutrients occurred approximately six weeks earlier in the Anticosti Gyre than in the Gaspé Current (Fig. 6), suggesting that phytoplankton growth may have been initiated much earlier in the Gyre.

In the Gaspé Current, the spring decrease of nitrate and silicate occurred principally in June and coincided with the major pulse of phytoplankton at Station Rimouski (mid June) and also with a major increase in the chlorophyll concentration in the Current's less saline surface waters (Fig. 6). Outside of this period, chlorophyll levels remained relatively low except in mid May and in late September, when two small phytoplankton peaks of short duration were observed that were similar to those observed in the St. Lawrence Estuary.

In the Anticosti Gyre, near-surface chlorophyll concentrations remained low throughout the sampling period except in late May, when a small spring bloom of short duration was observed (Fig. 6). A deep chlorophyll maximum layer was

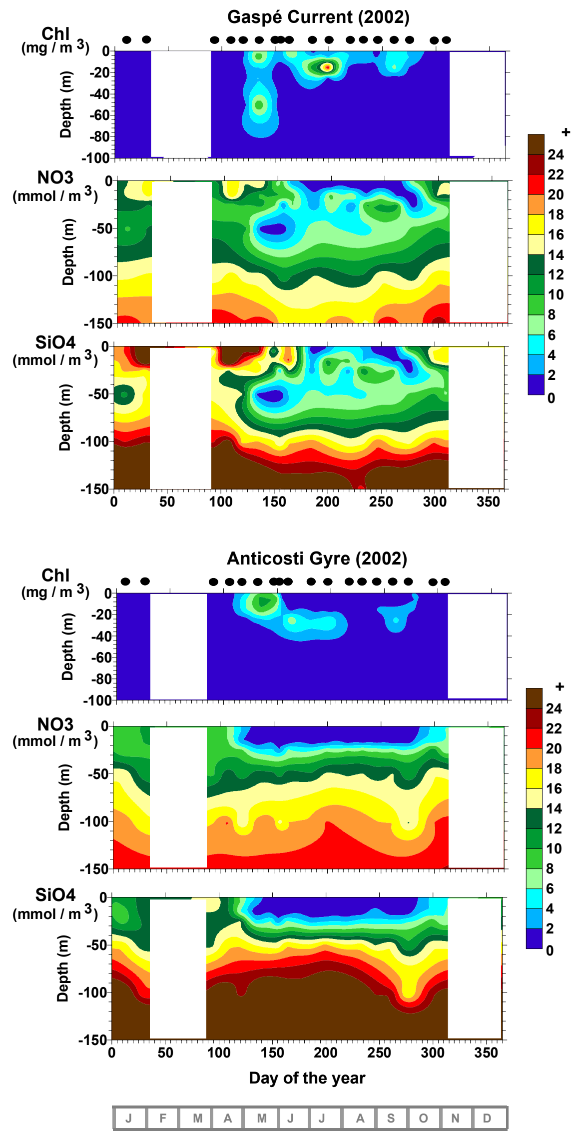

Figure 6. Chlorophyll a (mg per m^3), nitrate (mmol per m^3) and silicate (mmol per m^3) concentrations in upper 150 m of water column in the Gaspé Current and Anticosti Gyre during 2002. Dots : sampling periods.

nevertheless observed at 35 m from late June to late August at the base of the nutricline, which is typical. The activity of the phytoplankton assemblage in the deep chlorophyll maximum layer at this time would be limited due to irradiance levels approaching the 1% light level.

Compared to our previous observations, the chlorophyll *a* levels in the Gaspé Current and the Anticosti Gyre were generally lower in 2002 than in 1999 but relatively comparable to 2001 (Figs. 7 and 8). On the other hand, the reduction of nutrients in the surface layer during spring-summer in the Anticosti Gyre and Gaspé Current was somewhat more pronounced in 2002 compared to the 2000-2001 period but much less compared to 1999. Thus, based on the evolution of nutrients, phytoplankton production in the northwestern Gulf of St. Lawrence could have been higher in 2002 compared to the previous two years but much lower than for 1999. This is consistent with data from Station Rimouski in the Lower St. Lawrence Estuary. The depletion of nutrients in the surface layer (0-50 m) during spring also occurred later in 2002 compared to the 1996-2001 period at both stations, suggesting that phytoplankton growth was initiated later in 2002 compared to recent years in the northwestern part of the Gulf of St. Lawrence.

Sections

Biological and chemical data were collected at stations along six sections crossing the Estuary and the Gulf of St. Lawrence (Fig. 1) to obtain quasi-synoptic information on a broader spatial scale. Sections were occupied during late spring (June) and fall (November) 2002.

Vertical distributions of nitrate (Fig.9) and silicate (not shown) were generally similar along the six seasonal sections in spring and fall 2002, i.e., concentrations increased with depth. Deep concentrations of nitrate (> 200 m) increased from Cabot Strait toward the head of the Laurentian Channel

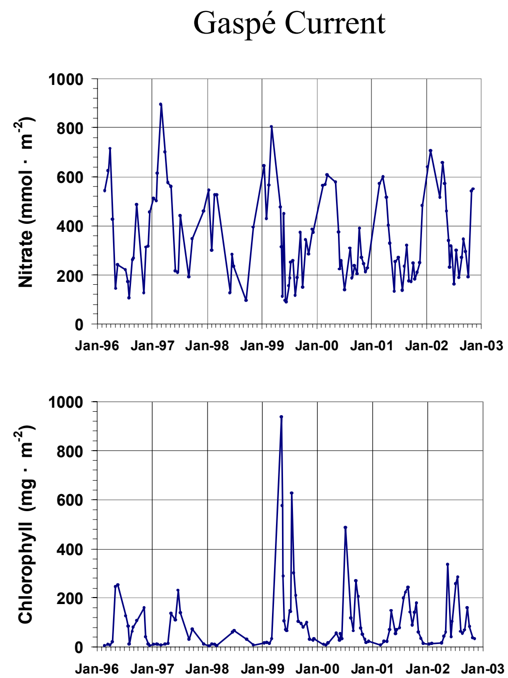

Figure 7. Nitrate (mmol per m^2) and chlorophyll a (mg per m^2) concentrations in the Gaspé Current, 1996-2002. Values are integrated over the upper 50 m of the water column.

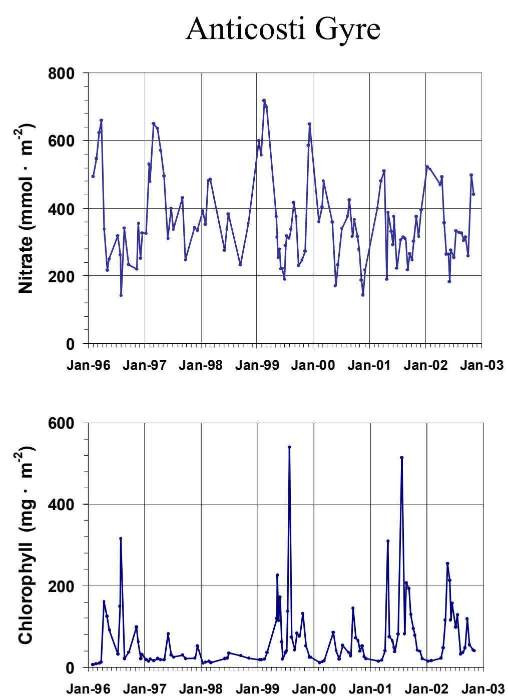

Figure 8. Nitrate (mmol per m^2) and chlorophyll a (mg per m^2) concentrations in the Anticosti Gyre, 1996-2002. Values are integrated over the upper 50 m of the water column.

in the Lower St. Lawrence Estuary, a gradient that probably results from the circulation and mineralization of organic matter that sinks into the deep layer. Compared to previous years, silicate as well as nitrate concentrations in the deep layer in spring and fall 2002 were comparable to those in 2001.

In the surface layer, spring nitrate and silicate concentrations were usually low in 2002 for most regions of the Gulf of St. Lawrence excluding the St. Lawrence Estuary (Fig. 9). There was a gradual decrease in the depth over which nutrient depletion occurred from Cabot Strait to the Estuary along the Laurentian Channel, indicating that nutrients moving from the Estuary toward Cabot Strait were gradually incorporated into plankton. The depletion of nutrients in the surface layers was also more pronounced in the eastern and southern part of the Gulf of St. Lawrence compared to the Estuary and northwestern part of the Gulf, which is typical.

Perhaps due to the autumnal turnover, surface nitrate levels during the fall survey 2002 were somewhat higher compared to those from the spring survey for most areas of the Gulf of St. Lawrence (Fig. 9).

Compared to our previous observations, the spring nitrate and silicate concentrations in the top 50 m were not markedly different in 2002 compared to 2001 for the northeastern part of the Gulf of St. Lawrence (not shown here). In contrast, the nitrate and silicate depletion during spring 2002 were generally less pronounced in the Estuary and the northwestern and southern parts of the Gulf compared to 2001. The fact that the spring bloom in the St. Lawrence Estuary and northwestern Gulf occurred later in 2002 than in 2001 may help explain this interannual nutrient variability. Nevertheless, fall nitrate and silicate concentrations were not markedly different in 2002 compared to our previous observations for most areas of the Gulf of St. Lawrence.

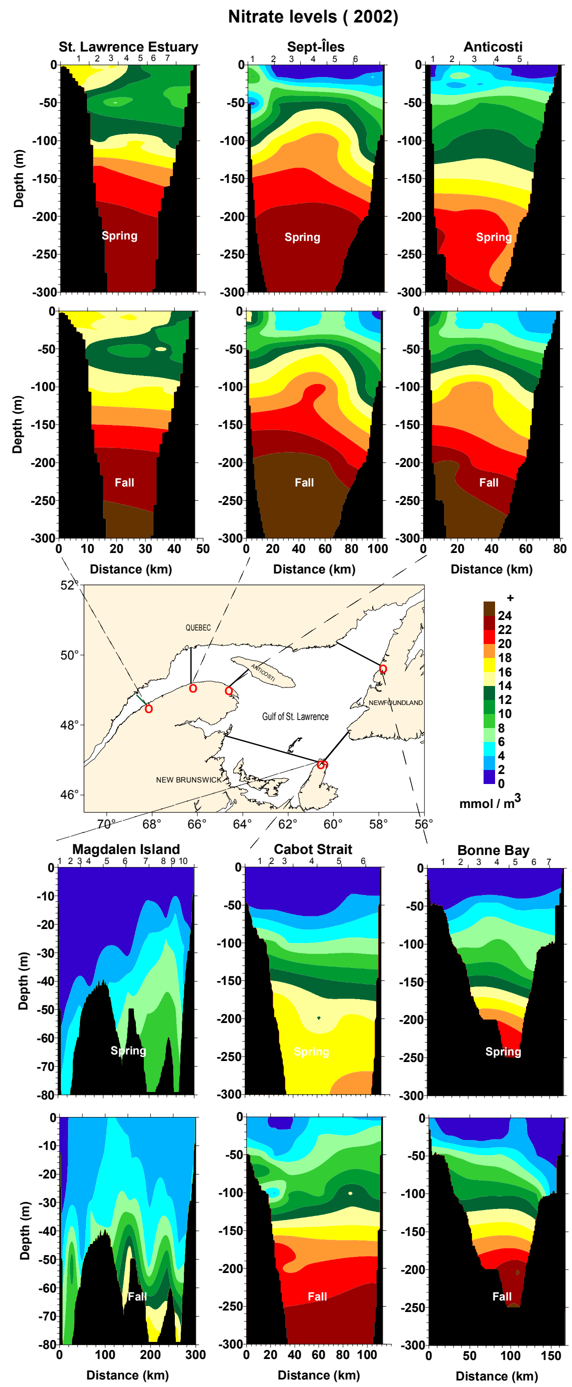

Figure 9. Concentrations of nitrate (mmol per m^3) with depth along the six sections sampled in late spring (June) and fall (November) 2002 in the Estuary and Gulf of St. Lawrence. The numbers over graphs indicate the location of sampling stations. Red circle on the map : station 1 of the transects.

Overall, chlorophyll levels in 2002 were higher during the spring survey than during the fall survey, which is typical (Fig. 10).

During the spring survey of 2002, higher chlorophyll levels were observed in the northwestern and southern parts of the Gulf of St. Lawrence. Conversely, chlorophyll levels during the fall survey were extremely low for most areas of the Gulf of St. Lawrence except for some stations situated in Cabot Strait and in the southern part of Gulf.

Compared to our previous observations, the chlorophyll levels during the fall of 2002 were overall somewhat higher than for the three previous years (not shown here), especially in the southern part of Gulf. Chlorophyll levels during the spring 2002 survey were also higher compared to the three previous years except for the St. Lawrence Estuary, where the spring bloom began later (not shown).

Satellite derived estimates of surface chlorophyll

Phytoplankton biomass was also assessed from ocean color data collected by the Sea-viewing Wide Field-of-View (SeaWiFS) satellite sensor launched by NASA in late summer 1997. While satellite data do not give information for the water column, they provide high-resolution (1.5 km) data on the geographical distribution of phytoplankton in surface waters over a large scale. In contrast to 2001, satellite data showed a greater spatial variability in the timing of the spring bloom in the Gulf of St. Lawrence in 2002 (not shown). The spring phytoplankton bloom occurred between April and June depending on the region and started earlier in the southern part of the Gulf (early April), which is typical. During late spring-summer, chlorophyll levels remained low for most areas of the Gulf except for the estuarine portion and, to a lesser degree, the southern part of the Gulf. This is consistent with observations from the fixed stations and sections crossing the Gulf. Another smaller phytoplankton peak was observed in fall 2002 for most areas of the Gulf, which is usual.

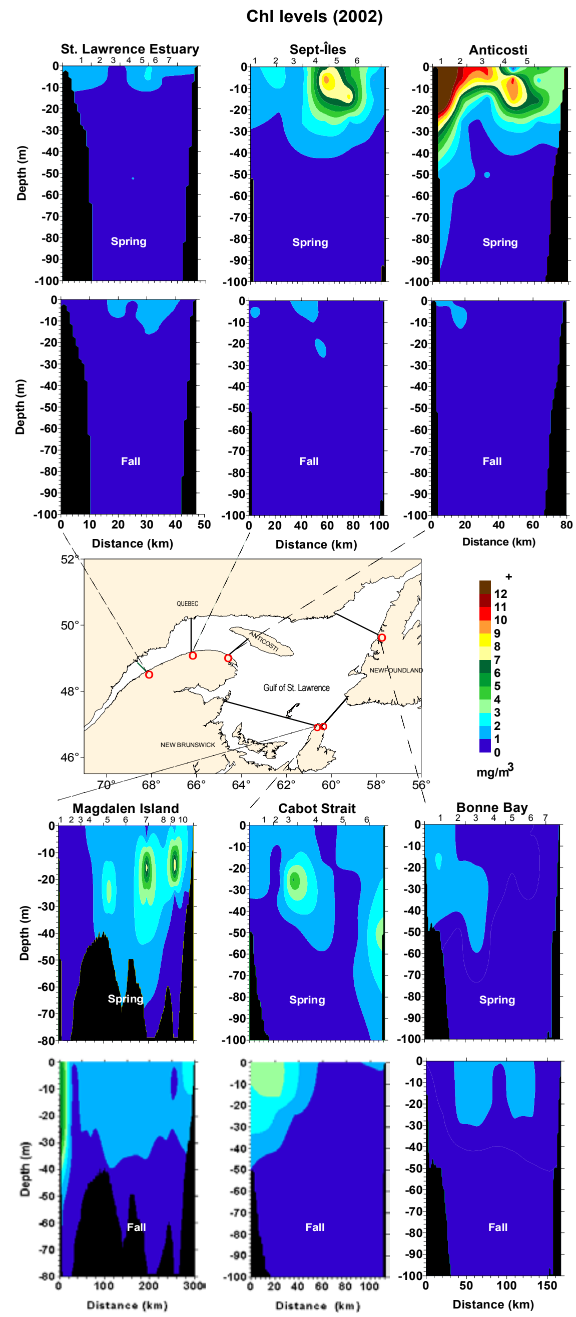

Figure 10. Concentrations of chlorophyll a (mg per m^3) with depth along the six sections sampled in late spring (June) and fall (November) 2002 in the Estuary and Gulf of St. Lawrence. The numbers over graphs indicate the locations of sampling stations. Red circle on the map : station 1 of the transects.

Coastal stations

Within the toxic algae monitoring program, phytoplankton samples were collected from May to September at ten coastal stations covering the Estuary and Gulf of St. Lawrence (Fig. 11) to determine the presence of harmful algae and toxic or invasive species. This sampling program has been in place at Maurice-Lamontagne Institute since 1989.

In 2002, the analysis of these samples revealed for a second consecutive year the presence in significant numbers of the diatom *Neodenticula seminae* in most areas of the Gulf of St. Lawrence, with concentrations up to 1 x 10^6 cells per litre (Figs. 11 and 12). This phenomenon is unusual since this species is usually found in North Pacific waters. In the Atlantic Ocean, this species has only been recorded in high-latitude Quaternary sediments dating from between 0.84 and 1.26 million years ago. Since the presence of *N. seminae* was also detected in the Labrador waters during spring-summer 2001, we suppose that this Pacific species was introduced naturally into the Gulf (across the Arctic, down the Labrador Current, and through Strait of Belle-Isle) rather than via ballast waters. The return of *N. seminae* to the Atlantic coast is consistent with recent observations indicating a greater influx of Pacific waters into the Atlantic. Impacts of this invasive species on the productivity of the Gulf of St. Lawrence have not yet been determined.

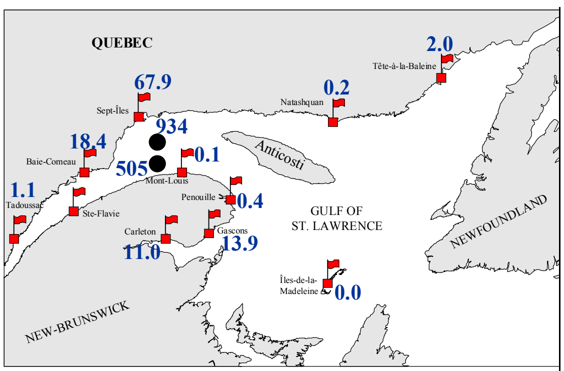

Figure 11. Maximum abundance of the diatom Neodenticula seminae *(x 10^3 cells per litre) in 2002 at fixed stations of the Toxic Algae Monitoring Program (red flags) and of the Atlantic Zone Monitoring Program (black dots). Depth = 0-15 m.*

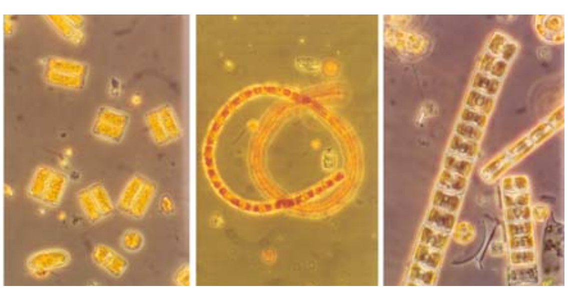

Figure 12. Light photomicrographs of the diatom Neodenticula seminae confirming its presence in the Gulf of St. Lawrence.

Zooplankton biomass and abundance

Lower Estuary and northwest gulf of St. Lawrence

The total mesozooplankton biomass observed in September 2002 in the Lower St. Lawrence Estuary and in the northwest GSL was slightly higher than the September 1995, 1996, 2000, and 2001 observations, comparable to the September 1997, 1998, and 1999 measurements, and lower than those in September 1994 (Fig. 13). Likewise, the total macrozooplankton biomass observed in September 2002 is comparable to the 1996, 1998, 1999, 2000, and 2001 measurements, slightly lower than the September 1997 observations, and 3.1 and 3.3 times lower than those in September 1995 and 1994, respectively.

On the other hand, the relative abundance of the three most important macrozooplankton groups in terms of biomass (euphausiids, mysids, hyperiid amphipods) varied significantly as a function of the year (Fig. 13). The relative abundance of the euphausiids decreased steadily between 1994 and 1995 and stayed stable at ca. 50% of the macrozooplankton

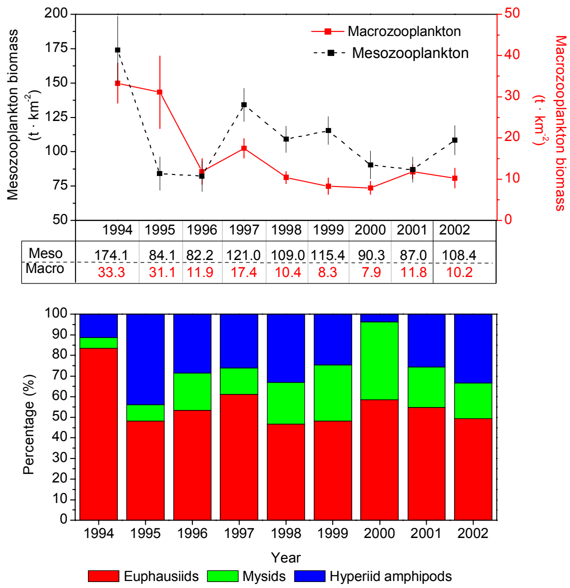

Figure 13. Mean biomass of mesozooplankton and macrozooplankton in the Lower St. Lawrence Estuary and the Northwest Gulf of St. Lawrence from 1994 to 2002 (upper panel) and relative abundance the three most important macrozooplankton groups in terms of biomass (lower panel).

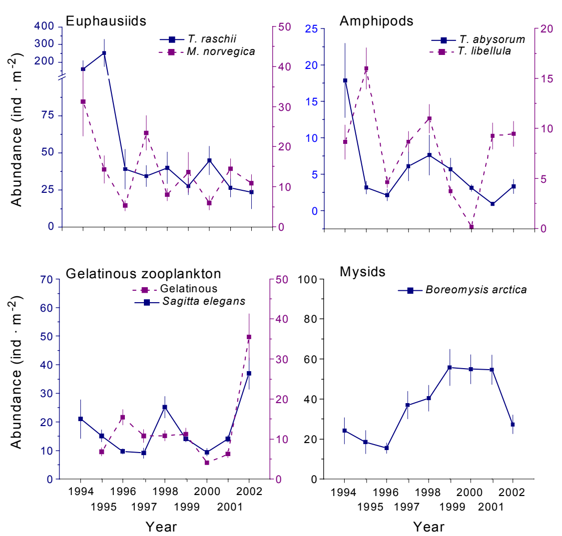

Figure 14. Mean abundance of the most important species of macrozooplankton in the Lower St. Lawrence Estuary and the northwest Gulf of St. Lawrence from 1994 to 2002.

assemblage between 1995 and 2002. The relative abundance of the mysid Boreomysis artica increased from 1994 to 2000 and decreased again 2001 and 2002 (Fig. 13). Finally, the relative abundance of the hyperiid amphipods increased from 1994 to 1995, stayed around 20% from 1996 to 1999, decreased to 1% in 2000, and increased again to the 1998 value in 2001 and 2002 (Fig. 13).

The most notable feature of the mean annual abundance of the various macrozooplankton species in 2002 was a large increase in the abundance of chaetognaths and gelatinous zooplankton and a decrease in the abundance of mysids (Fig. 14). The mean abundance of both gelatinous zooplankton and chaetognaths increased from 10 ind. per m^2 in 2001 to 35 ind. per m^2 in 2002 while the mean abundance of the mysids was two times lower in 2002 than in 2001.

Fixed stations

In 2002, the monthly variations in zooplankton biomass observed in the Anticosti Gyre was comparable with an average of our 1999, 2000, and 2001 observations while in the Gaspé Current the overall zooplankton biomass was slightly higher than in 2001 and 2000 (Fig. 15). The maximum and the minimum biomasses occurred in March and April respectively at the Anticosti Gyre (AG) station while the minimum and the maximum biomasses were observed in December and April respectively in the Gaspé Current (CG). The annual minimum (AG) and maximum (CG) zooplankton biomasses occurring in April seem to be typical since the same situation was observed in 1999, 2000, and 2001 (Fig. 15).

At both stations, the total abundance of zooplankton observed in 2002 were consistent with previous observations. Copepod eggs, juveniles, and adults were clearly dominant, accounting for more than 80% of the zooplankton community for all

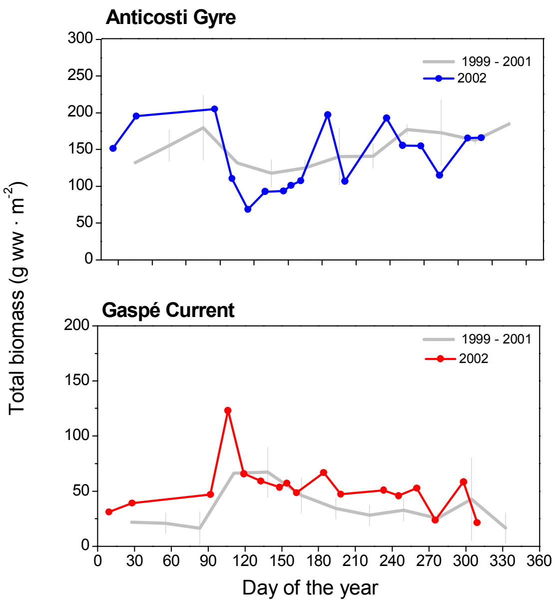

Figure 15. Monthly variations of the zooplankton biomass in the Anticosti Gyre and the Gaspé Current in 2002.

sampling dates at the Anticosti Gyre and the Gaspé Current. At the Anticosti Gyre, ostracoda were present at all sampling dates from April to July. In July and August, larvacea accounted for 10% of the zooplankton assemblage at both stations. All other zooplankters (mollusc larvae, euphausiids, jellies, chaetognaths, polychaetes) represented less than 5% of the zooplankton community for all sampling dates at both stations. They mostly occurred during the summer season at both stations (not shown).

Likewise, the total abundance of copepods observed in 2002 was consistent with observations made in 2000 and 2001 at both stations. In the Gaspé Current, the minimum and maximum copepod abundances occurred in June and late October respectively and were synchronized with the minimum and the maximum values observed in 2001; the maximum and the minimum copepod abundances were observed in April and June in the Anticosti Gyre (Fig. 16). This

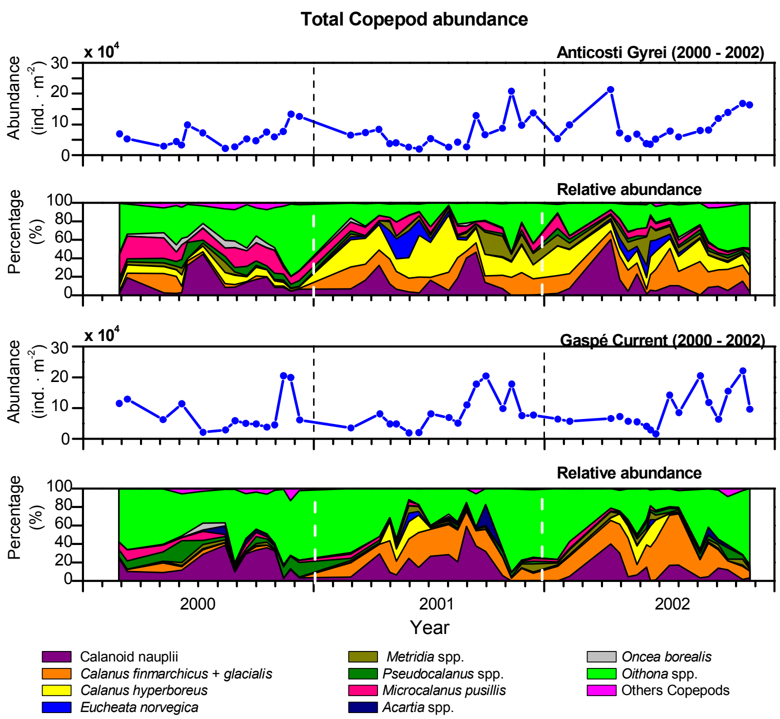

Figure 16. Monthly variations in the integrated copepod abundance and community structure for the Anticosti Gyre and the Gaspé Current fixed stations in 2000, 2001, and 2002.

maximum in April is not usual for this station and was due to the high abundance of Calanoid nauplii, which represented more than 60% of the copepod assemblage in the Anticosti Gyre in April.

Close examination of the monthly variations in the copepod community structure reveals that large copepod species (*Calanus finmarchicus* and *C. hyperboreus*) were dominant for all sampling dates in the Anticosti Gyre except in summer, when *Eucheata norvegica* and *Metridia* spp. were more abundant, and in fall, when the small species *Oithona similis* was more abundant (Fig. 16). On the other hand, the small copepod *Oithona similis* was dominant for all sampling dates in the Gaspé Current except in July, when larger species such as *Calanus finmarchicus* and *C. hyperboreus* were more abundant (Fig. 16). The same situation was observed in 2001 and 2000 at both stations.

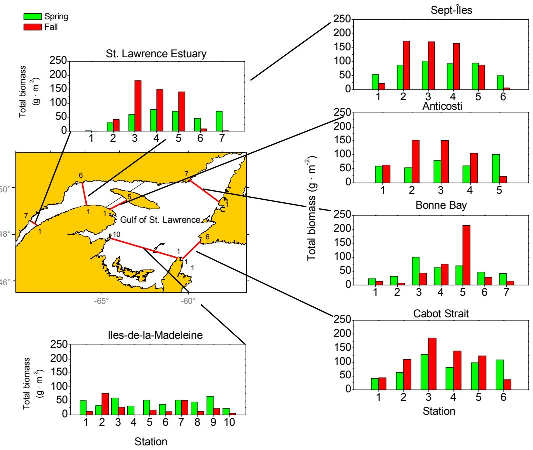

Figure 17. Total zooplankton biomass along the six sections sampled in late spring (June) and fall (November) 2002 in the Estuary and Gulf of St. Lawrence.

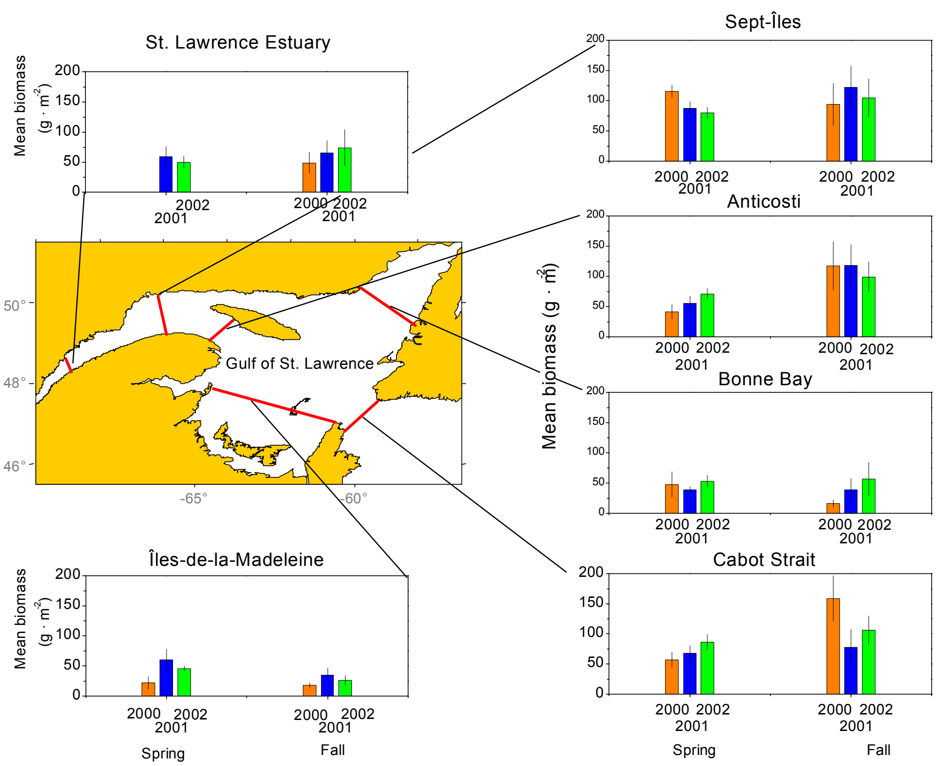

Figure 18. Mean zooplankton biomass (wet weight) along the six sections sampled in late spring and fall 2000, 2001, and 2002 in the Estuary and Gulf of St. Lawrence.

Sections

The zooplankton biomasses observed in 2002 along all sections in spring and fall were comparable with observations made in 2001 and 2000 (not shown). The biomass increased with depth along all sections during the two sampling periods. The highest biomasses were found along the transects located over the Laurentian Channel (St. Lawrence Estuary, Sept-Îles, Anticosti, and Cabot Strait) and the lowest were in the northern (Bonne Bay) and the southern (Îles-de-la-Madeleine) regions. The zooplankton biomass was higher in November than in June along all sections except at the shallow stations on both ends of each transect and in the southern region (Îles-de-la-Madeleine), where the inverse was true (Fig.17).

The zooplankton biomasses observed in 2002 along all transects at both seasons were comparable with observations made in 2001 and 2000 (Fig. 18).

Juvenile and adult copepods were clearly dominant along all sections, accounting for an average of 85% and 91% of the assemblage in June and November respectively (not shown). The overall copepod abundance varied between 1,928 and 234,410 ind. per m^2 for all sections in June and between 4,133 and 665,081 ind. per m^2 in November (Fig. 19). The highest copepod abundances were observed along the Îles-de-la-Madeleine, Bonne Bay and Cabot Strait sections in fall (Fig. 19). A closer examination of the abundance and the spatial distribution of the most important copepod species showed different patterns of distribution in the Lower species (C. finmarchicus, C. hyperboreus, M. longa) were more abundant (Fig. 19).

Estuary and the Gulf of St. Lawrence (Fig. 19). In June, a group composed of large copepod species (*Calanus finmarchicus*, *C. hyperboreus*, *Metridia longa*) dominated in abundance in all regions. In November, the small species

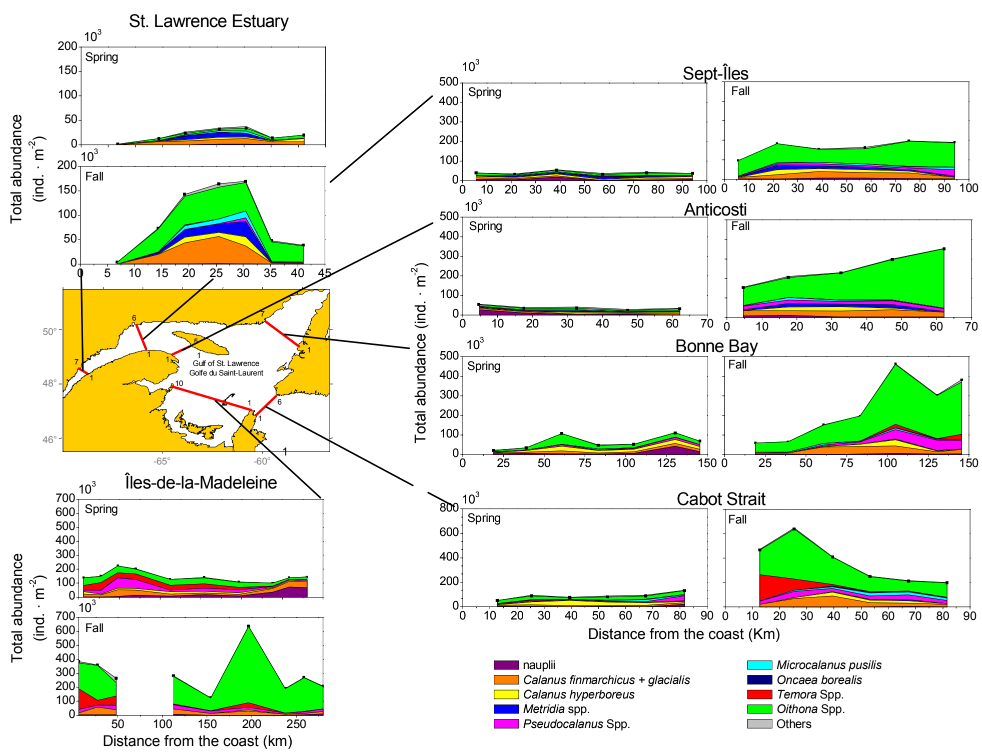

Figure 19. Integrated copepod abundance and community structure along the six transects sampled in June and November 2002 in the Lower Estuary and the Gulf of St. Lawrence.

Oithona spp. dominated in abundance in all regions except in the St. Lawrence estuary, where the large copepod species (*C. finmarchicus, C. hyperboreus, M. longa*) were more abundant (Fig. 19).

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