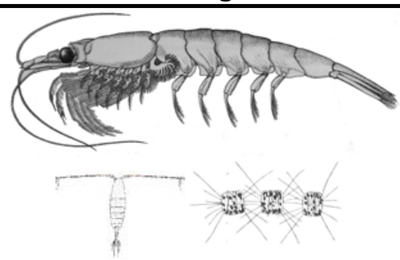

2001 State of the Ocean: Chemical and Biological Oceanographic Conditions in the Estuary and Gulf of St. Lawrence

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 ocean physical, chemical and biological properties and the predator-prey relationships of marine resources. A critical element in the observational program of AZMP 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 dissolved in seawater (nitrate, silicate, phosphate, oxygen) provides important information on the water-mass movements and on the locations, timing and magnitude of biological production cycles. A description of the distribution of phytoplankton and zooplankton provides important information on the organisms forming the base of the marine 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.

Figure 1. Atlantic Zonal Monitoring Program (AZMP) sections (lines) and fixed stations (dots).

Summary

Seasonal patterns and regional differences were observed in the chemical and biological parameters in the Estuary and Gulf of St. Lawrence in 2001. Prominent events included:

- The initiation of the spring phytoplankton bloom in the Lower St. Lawrence Estuary occurred, for a fourth consecutive year, 6-8 weeks earlier than usual.
- The phytoplankton biomass during spring-summer 2001 in the Lower St. Lawrence Estuary was, for a second consecutive year, much lower compared to the 1995-1999 period.
- The satellite data revealed for the first time, little spatial differences in the timing of the 2001 spring bloom in the Gulf of St. Lawrence.
- The first occurrence of the diatom *Neodenticula seminae* in the Estuary and Gulf of St. Lawrence; this

species is usually observed in North Pacific waters.

- The most important increase in abundance of the mean abundance of the hyperiid amphipod *Themisto libellula* in the last decade.
- While the zooplankton biomass observed in 2001 was similar to the previous year in both the lower Estuary and the Gulf of St. Lawrence, the overall abundance of zooplankton was 64 % and 41 % lower in spring and fall 2001 due to the lower abundance copepod and invertebrate eggs 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.

Lower St. Lawrence Estuary

Timing, duration, and magnitude of the primary bloom

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 (Figure 1) has been visited on a weekly basis from May to September since 1992.

In 2001, the standing stock of phytoplankton at Station Rimouski, as reflected by the amount of chlorophyll *a* (Figure 2), showed a major pulse in early May with integrated values in the upper 50 m exceeding 200 mg of chlorophyll *a* per m^2 (Figure 3). From late May to mid August, chlorophyll levels remained relatively low (<100 mg per m^2) whereas a second major pulse was observed in late August, with integrated values exceeding 300 mg of chlorophyll *a* per m^2 (Figures 2 and 3).

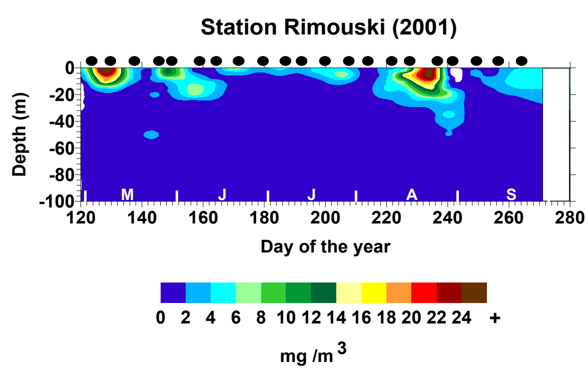

Figure 2. Chlorophyll a concentrations in upper 100 m of water column at Station Rimouski during spring-summer 2001. Dots : sampling periods.

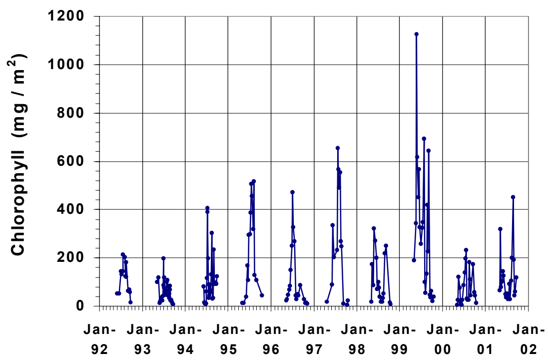

Figure 3. Chlorophyll a concentrations integrated over the upper 50 m at Station Rimouski during spring-summer 1992-2001.

Compared to our previous observations, the onset of the spring phytoplankton bloom at Station Rimouski in 2001 occurred about the same time as in 1998 and 1999 (early May; Figure 4), but 6-8 weeks earlier compared to the 1992-1997 period (mid-June). A comparison of these results with historical data on the phytoplankton biomass in the Lower St. Lawrence Estuary confirms the development of the primary bloom in early May as observed during the 1998-2001 period, is unusual for this region.

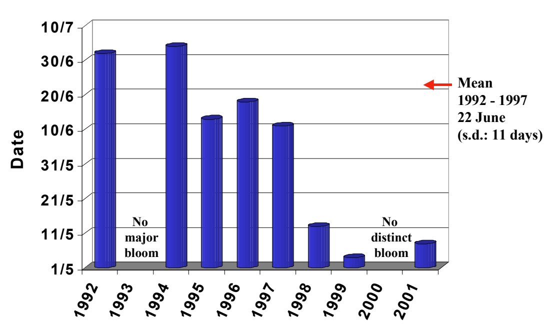

Figure 4. Date of onset of the primary bloom defined by the first incidence of chlorophyll concentrations greater than 100 mg of chlorophyll a per m^2 at Station Rimouski, 1992-2001.

Typically, the spring bloom in the Lower St. Lawrence Estuary starts just after the spring-summer runoff peak. The below-normal spring freshwater runoff observed since 1998 in the St. Lawrence basin could thus be responsible for the recent shift seen in the timing of phytoplankton cycle.

Compared to our previous observations, the spring bloom duration at Station Rimouski was also shorter and less intense in 2001 compared to the 1997-1999 period (Figure 3). In contrast, the second phytoplankton bloom in late August was more intense in 2001 compared to our previous observations. Nevertheless, for the entire sampling period, the average chlorophyll levels in the Lower St. Lawrence Estuary during 2001 were, for the second consecutive year, much lower compared to the 1995-1999 period but comparable to the 1992-1994 period (Figure. 5). In particular, phytoplankton biomass in July 2001 was much lower compared to our previous observations. This is believed to be due to a more intense mixing period in the Lower St. Lawrence Estuary in July 2001, as indicated by CTD data and satellite images of temperature.

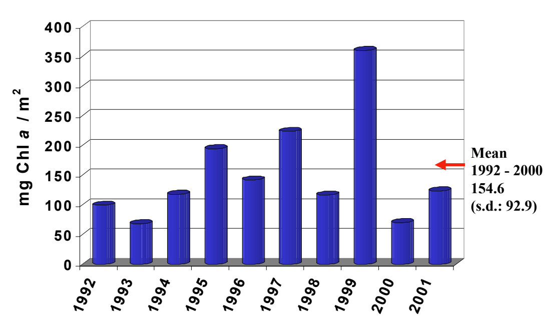

Figure 5. Mean integrated (surface to 50 m depth) chlorophyll a levels at Station Rimouski from May to August, 1992-2001.

Zooplankton biomass

An annual zooplankton survey was initiated in 1994 to follow the variability in zooplankton abundance in the Lower

St. Lawrence Estuary. This survey is conducted in September and involves sampling at up to 44 stations along 8 transects covering the lower Estuary from Les Escoumins to Sept-Îles.

The total mesozooplankton biomass observed in September 2001 in the Lower St. Lawrence Estuary and in the northwest GSL is comparable to the September 1996 measurements, slightly lower than the 1995, 1997, 1998, 1999, and 2000 observations, and significantly lower than in 1994. Likewise, the total macrozooplankton biomass observed in September 2001 was comparable to the 1997 measurements, slightly higher than the 1996, 1997, 1998, 1999, and 2000 observations, and significantly lower than in 1995 and 1994 (Figure 6).

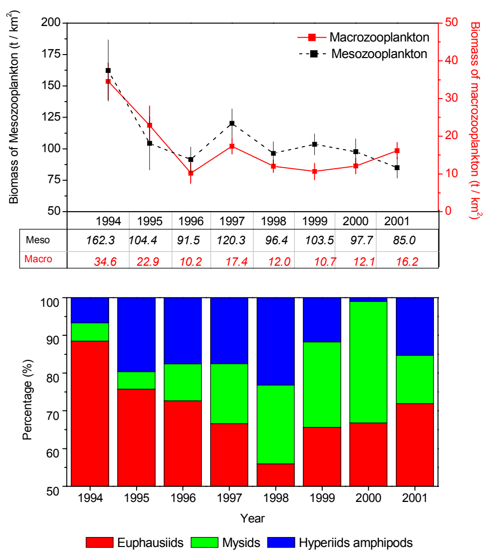

Figure 6. Mean biomass of mesozooplankton and macrozooplankton in the Lower St. Lawrence Estuary and the northwest Gulf of St. Lawrence from 1994 to 2001 (upper panel) and relative abundance of the three most important macrozooplankton groups in terms of biomass (lower panel).

On the other hand, the relative abundance of the three most important macrozooplankton groups in terms of biomass (euphausiids, mysids and hyperiid amphipods) varied significantly as a function of the year (Figure 6). The relative abundance of the euphausiids decreased between 1994 and 1998 and then increased slightly every year since 1998. The relative abundance of the mysid *Boreomysis artica* increased from 1994 to 2000 and decreased again in 2001 (Figure 6). Finally, the relative abundance of the hyperiid amphipods increased from 8 % in 1994 to 18 % in 1995, stayed around 20 % from 1995 to 1998, significantly decreased from 23 % to 1 % between 1998 and 2000, and significantly increased again from 1 % to 16 % in 2001 (Figure 6).

The most notable feature of the mean annual abundance of the various macrozooplankton species in 2001, was the highly significant increase of the abundance of the hyperiid amphipod *Themisto libellula* from 0.17 ind. per m^2 in 2000 to 10 ind. per m^2 in 2001 (Figure7).

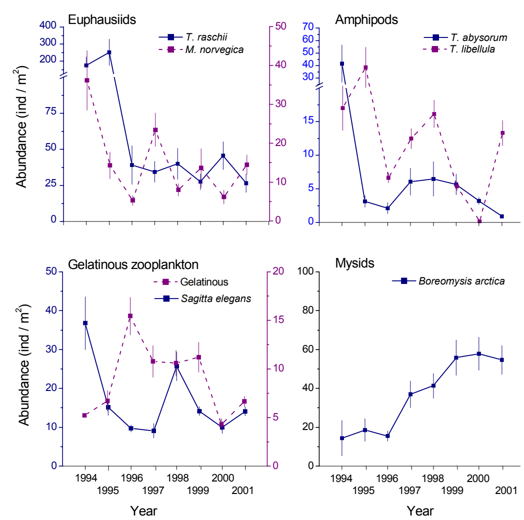

Figure 7. Mean abundance of the most important species of macrozooplankton in the Lower St. Lawrence Estuary and the northwest Gulf of St. Lawrence from 1994 to 2001.

We hypothesize that this significant increase in the abundance of T. libellula in 2001 is associated with the intrusion of the cold Labrador Current water into the Gulf of St. Lawrence via the Strait of Belle-Isle. This hypothesis is supported by: 1) the low value of the CIL core temperature index observed in 2001 suggesting that there was an important intrusion of the cold Labrador Current water into the Gulf of St. Lawrence via the Strait of Belle-Isle during the winter of 2001 (Gilbert, 2002), 2) the fact that T. libellula is only present within the CIL and lives in water with temperatures lower than 4 ºC (not shown), and 3) the highly significant negative relationship between the annual CIL core temperature index and the mean annual abundance of T. libellula sampled since 1994 in the Lower St. Lawrence Estuary and the northwest Gulf of St. Lawrence (Figure 8).

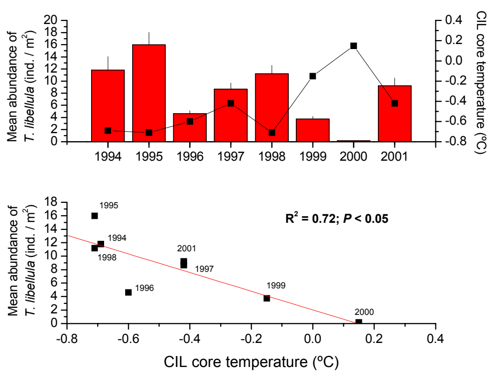

Figure 8. Relationship between the annual CIL core temperarure index and the annual mean abundance of the hyperiid amphipod Themisto libellula in the Lower St. Lawrence Estuary and the northwest Gulf of St. Lawrence from 1994 to 2001.

Based on those observations, the hyperiid amphipod *Themisto libellula* could be considered as an index of the intrusion of cold Labrador Current into the Gulf of St. Lawrence and the lower Estuary. If this hypothesis is true, 2001, 1998, and 1995 would be years where important intrusions of Labrador Current waters occurred (Figure 8). Bousfield (1951), who studied the pelagic amphipods of the Belle Isle Strait region suggested that the presence and the mean abundance of *T. libellula* there could be considered as an index species of the cold Labrador Current in that area. The present results extend this conclusion to the northern Gulf and the lower Estuary.

The hyperiid amphipod *Themisto libellula* is a very efficient predator species and consequently the episodic invasions of this species in the Gulf of St. Lawrence and the lower Estuary could have an impact on the zooplankton standing stock biomass by direct predation or on the survival and recruitment of fish larvae through predation, and through competition with the larvae for copepod preys. On the other hand, between 1994 and 2000, there was a highly significant positive correlation between the abundance of *Themisto libellula* sampled in the in the lower Estuary and the northwest Gulf of St. Lawrence and their relative abundance in cod stomachs (not shown). This suggests that cod eat *T. libellula* in proportion to its availability in the field. The impacts on cod growth and productivity are unknown.

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.

Variations in phytoplankton biomass and nutrients in the northwestern Gulf of St. Lawrence

In 2001, nutrient concentrations in the surface layer (top 50m) 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 (Figure 9). 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 2-3 weeks earlier in the Anticosti Gyre than in the Gaspé Current (Figure 9), suggesting that phytoplankton growth may have been initiated somewhat earlier in the Gyre.

In the Gaspé Current, the spring decrease of nitrate and silicate coincided with the first pulse of phytoplankton at Station Rimouski (early May) and also with the small increase in the chlorophyll concentration in the Current's low salinity surface waters (Figures 2 and 9). From early June to late July, chlorophyll levels remained relatively low whereas a second major pulse was observed in August (i.e. about same time as the one observed at Station Rimouski), with integrated values exceeding 200 mg of chlorophyll *a* per m^2 (Figures 9 and 10). Finally, a third smaller phytoplankton peak was observed during fall 2001 (mid October), which is typical.

In the Anticosti Gyre, near-surface chlorophyll concentrations remained low throughout the sampling period except

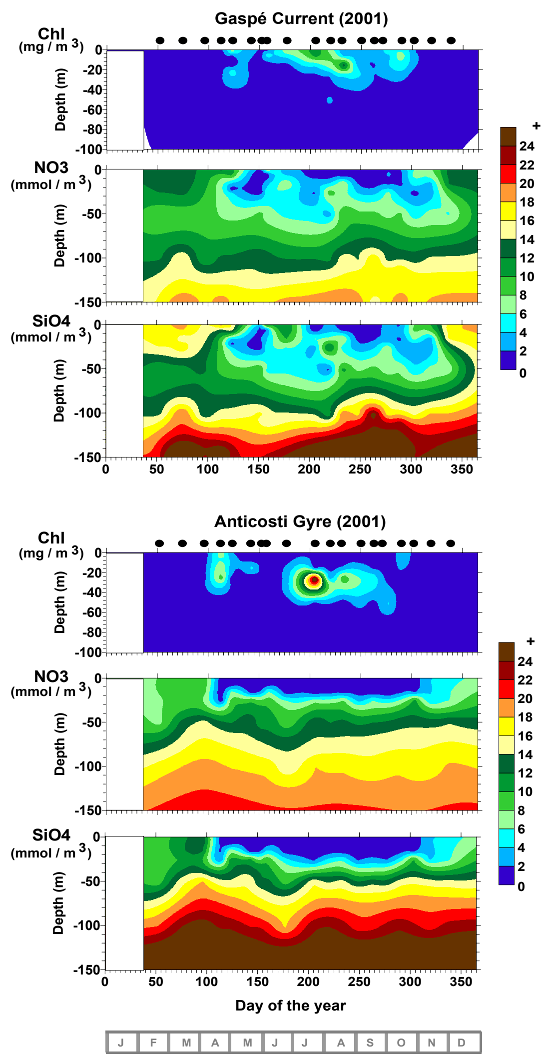

Figure 9. Chlorophyll a (mg/m^3), nitrate (mmol per m^3) and silicate (mmol per m^3) concentrations in upper 150 m of water column in the Gaspé Current and Anticosti Gyre during 2001. Dots : sampling periods.

in late April, when a small spring bloom of short duration was observed (Figure 9). A deep chlorophyll maximum layer was nevertheless observed at 35 m from late June to late August at the base of the nutricline (Figure 9). 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 reduction of nutrients in the surface layer during spring-summer-fall 2001 was much less pronounced at both stations compared to the 1996-1999 period (except for 1998) (Figures 10 and 11). In the Gaspé Current, near-surface chlorophyll levels were also generally lower in 2001 compared to the previous two years. On the other hand, summertime chlorophyll levels in the Anticosti Gyre were higher in 2001 compared to those observed in 1997-2000.

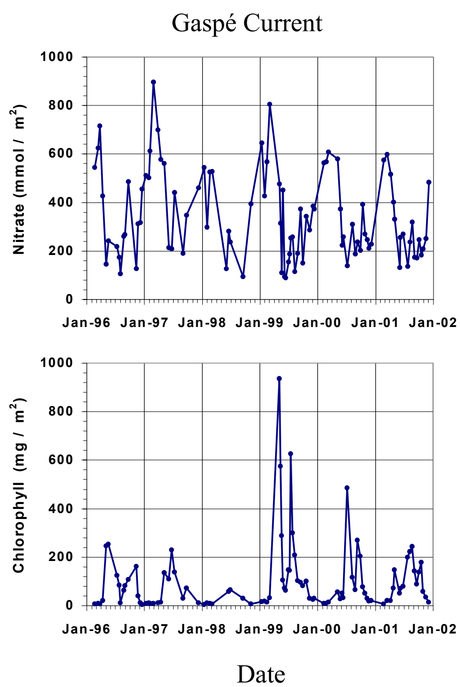

Figure 10. Nitrate (mmol per m^2) and chlorophyll a (mg per m^2) concentrations in the Gaspé Current; 1996-2001. Values are integrated over the upper 50 m of the water column.

Based on the evolution of nutrients, phytoplankton production in the northwestern part of the Gulf of St. Lawrence could have been lower in 2001 compared to the previous two years.

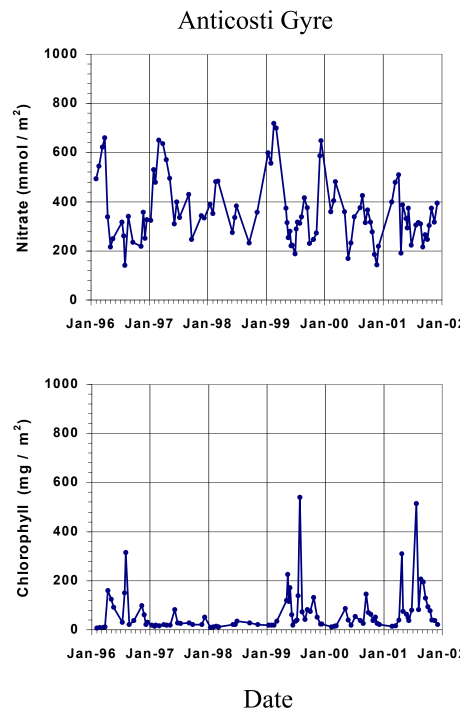

Figure 11. Nitrate (mmol per m^2) and chlorophyll a (mg per m^2) concentrations in the Anticosti Gyre, 1996-2001. Values are integrated over the upper 50 m of the water column.

Zooplankton

In 2001, the overall biomass of zooplankton observed in the Anticosti Gyre and the Gaspé Current were on par with what we observed in 1999 and 2000 (Figure. 12). The minimum and the maximum biomasses occurred in April and September respectively at the Anticosti Gyre station while the minimum and the maximum biomasses were observed in February and April respectively in the Gaspé Current. The annual minimum (AG) and maximum (CG) zooplankton biomasses occurring in April seem to be typical since the same situation was observed in 1999 and 2000 (Figure. 12). The macrozooplankton biomass varied little with time and represented less than 5 % of the total zooplankton biomass at both stations.

At both stations, the total abundance of zooplankton observed in 2001 were consistent with previous observations. Copepod eggs, juveniles, and adults were clearly dominant, accounting for more than 80 % of the zooplankton community for all sampling dates in the

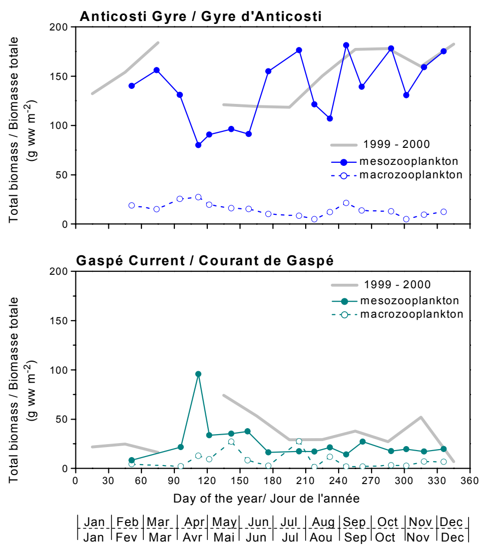

Figure 12. Monthly variations of the zooplankton biomass in the Anticosti Gyre and the Gaspé Current in 2001.

Anticosti Gyre and the Gaspé Current except in May and July in the Gaspé Current, where the invertebrate larvae (mostly echinoderm larvae) accounted for 30 % (May) and 80 % (July) of the zooplankton assemblage (not shown).

Likewise, the total abundance of copepods observed in 2001 were consistent with observations made in 2000 at both stations. In the Anticosti Gyre, the minimum and the maximum copepod abundance occurred in May and November respectively and were similar to the minimum and the maximum values observed in 2000; the minimum and the maximum copepod abundances were observed in June and September in the Gaspé Current, ca. 1.5 months earlier than in 2000 (Figure 13).

Close examination of the monthly variations of 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 May, when the predator species *Eucheata norvegica* was the dominant species (25 % of the assemblage), and in November, when smaller species (*Metridia longa*, *Oithona similis*, *Microcalanus pusillis*) were more abundant (Figure 13). On the other hand, the small copepod *O. similis* was dominant for all sampling dates in the Gaspé Current except in July, when larger species such as *C. finmarchicus* and *C. hyperboreus* were more abundant (Figure 13).

There were 2 peaks of abundance of calanoid nauplii caught by the 202 µm mesh net at the Anticosti Gyre station (Figure 13). They occurred in April and September and coincide with the reproductive period of *Calanus hyperboreus* and *Metridia longa* respectively. Likewise, the abundance of calanoid nauplii caught by the 202 µm mesh net at the Gaspé Current station showed a first peak of abundance in early April coinciding with the reproductive period of *C. hyperboreus*.

Contrary to the situation at the Anticosti Gyre station, the abundance of calanoid nauplii remained relatively high during the summer and the fall periods in the Gaspé Current (between 20 and 58 % of the copepod assemblage). This probably coincides with the reproductive period of *C. finmarchicus* in summer and *Acartia* sp. at the end of August.

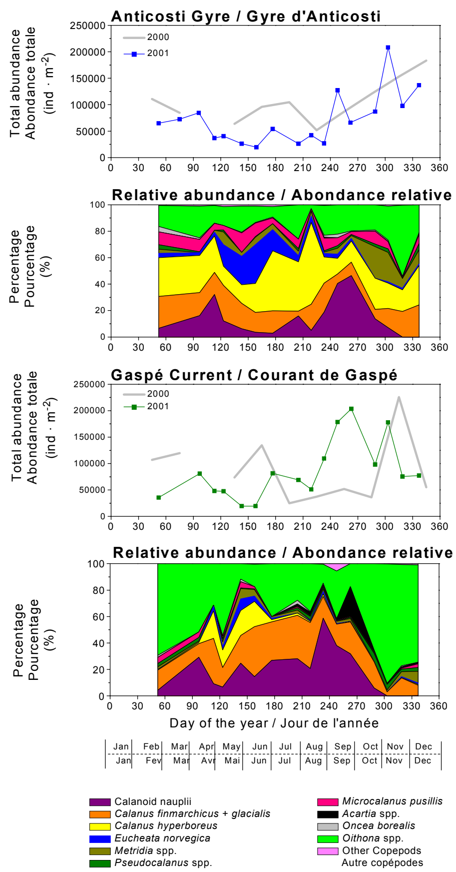

Figure 13. Monthly variations in the integrated copepod abundance and community structure for the Anticosti Gyre and the Gaspé Current fixed stations in 2001.

Others regions

Satellite observations and the phytoplankton composition

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. Satellite data do not give information for the water column but provide high-resolution (1.5 km) data on the geographical distribution of phytoplankton in surface waters over a large scale. In 2001, satellite data revealed that the 2001 spring bloom occurred in late April for most areas of the Gulf of St. Lawrence. This contrasts with our previous observations, which showed a greater spatial variability in the timing of the spring bloom.

At that time, phytoplankton samples were collected at 16 stations covering the Estuary and Gulf of St. Lawrence. The analysis of these samples revealed that the 2001 spring bloom in the Gulf of St. Lawrence was essentially dominated by the diatom *Neodenticula seminae* (Figure 14). This is the first occurrence of this species in the Gulf of St. Lawrence; this species is usually found in North Pacific waters. Because this unusual spring bloom coincided with a massive intrusion of Labrador Slope waters into the Gulf of St. Lawrence, we suspect that this Pacific species was introduced naturally into the Gulf (across the Arctic and down the Labrador Current), rather than via ballast waters. In support of this, the presence of *N. seminae* was also detected in the Labrador Slope waters during spring-summer 2001. This event is consistent with recent observations indicating a greater influx of Pacific waters into the Atlantic (via the Bering Strait) and changes in the circulation and oceanographic conditions in the Arctic Ocean.

Sections

Biological and chemical data were collected at stations along six sections crossing the Estuary and the Gulf of St. Lawrence (Figure 1) to obtain quasi-synoptic information on a broader spatial scale. Sections were occupied during late spring (June) and fall (December) 2001. Analysis of the 2001 fall samples for nutrients is not yet completed.

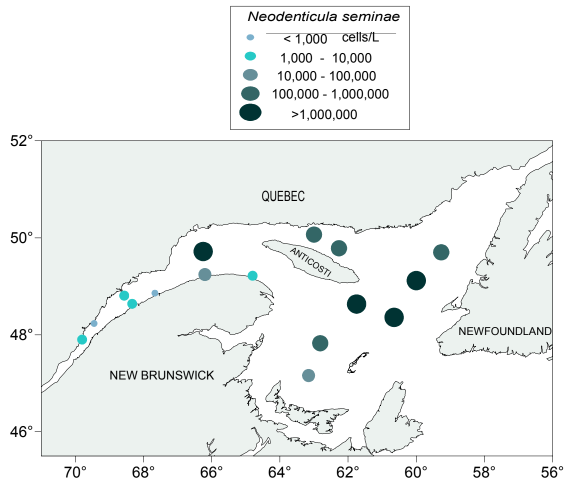

Figure 14. Abundances (cells per liter) of the diatom Neodenticula seminae in late April 2001 in the Estuary and Gulf of St. Lawrence.

Nutrients and phytoplankton biomass

Nitrate (Figure 15) and silicate (not shown) concentrations in the late spring 2001 increased with depth for the most areas of the Gulf of St. Lawrence. The concentrations at depth (> 200 m) increased from Cabot Strait toward the head of the Laurentian Channel 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, nitrate and silicate concentrations in the deep layer in 2001 were comparable to those in 2000, but higher than in 1999 (not shown).

In the surface layer, spring nitrate and silicate concentrations were uniformly low in 2001 for most regions of the Gulf of St. Lawrence (Figure 15). Nevertheless, 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

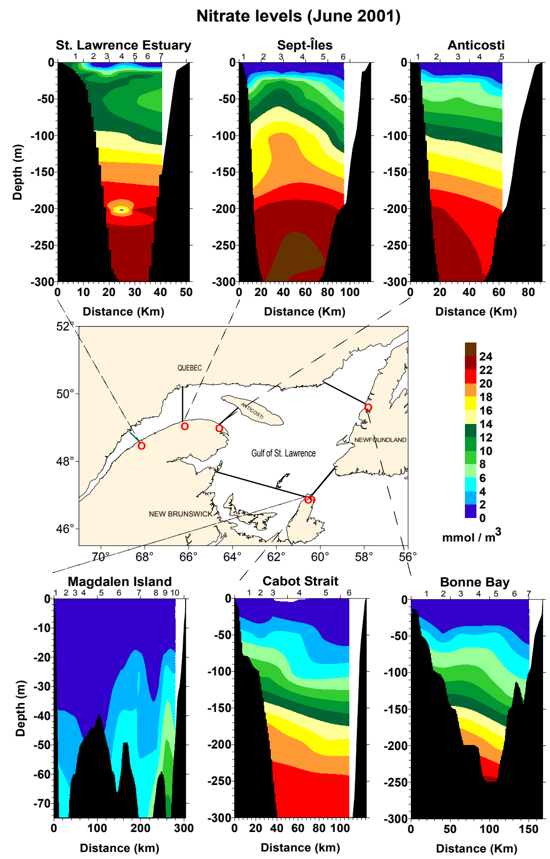

Figure 15. Concentrations of nitrate (mmol per m^3) versus depth along the six sections sampled in June 2001 in the Estuary and Gulf of St. Lawrence. The numbers over each graph indicate the location of sampling stations. Red circle: starting point.

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.

Compared to our previous observations, the amounts of nitrate in the top 50 m in the southern and eastern Gulf were not markedly different during the spring 2001 than in 1999-2000 (not shown). In contrast, the nitrate depletion in the surface layers was generally less pronounced in the northwestern Gulf during late spring 2001 than in 1999 and 2000.

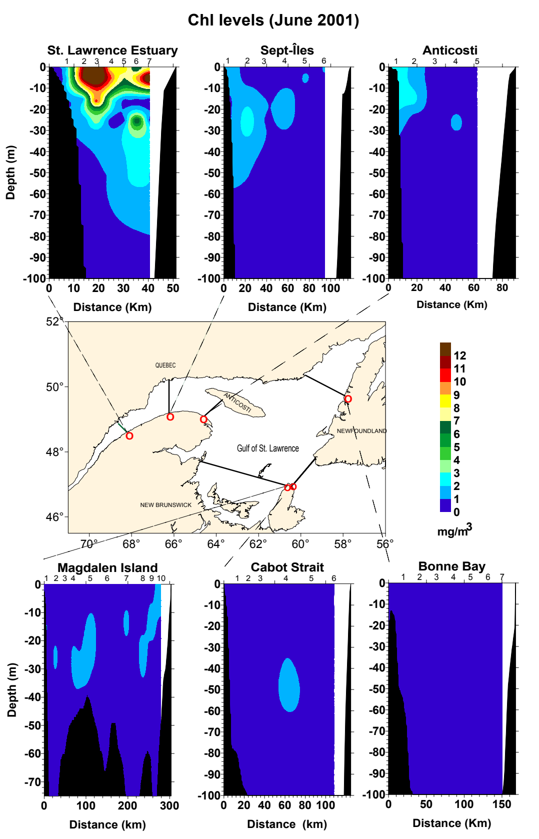

Figure 16. Concentrations of chlorophyll (mg per m^3) versus depth along the six sections sampled in June 2001 in the Estuary and Gulf of St. Lawrence. The numbers over each graph indicate the location of sampling stations. Red circle; starting point.

Chlorophyll levels during the spring of 2001 were low except for the estuarine portion of Gulf including the St. Lawrence Estuary and Gaspé Current system (Figure 16), which is typical. In 2001, the chlorophyll levels in the eastern and southern part of the Gulf were not markedly different from those in 1999-2000 (not shown).

Zooplankton abundance and biomass

The zooplankton biomass observed in 2001 along all transects at both seasons was on par with observations made in 2000 except along the Magdalen Island transect, where the biomass was three and two times higher in spring and fall 2001 than in spring and fall 2000, and along the Cabot Strait transect where, the biomass was two times lower in fall 2001 than in fall 2000 (not shown). The biomass increased with the depth along all transects during the two sampling periods (Figure 17). The highest biomass was found along the transect located over the Laurentian Channel (St. Lawrence Estuary, Sept-Îles, Anticosti, and Cabot Strait) and the lowest was in the northern (Bonne Bay) and the southern (Magdalen Island) regions. The zooplankton biomass was higher in December than in June along all transects except at the shallow stations on both ends of each transect, where the inverse was true (Figure 17).

The overall abundance of zooplankton was generally lower in 2001 than in 2000 in all regions for both seasons except in fall in the southern Gulf (Magdalen Island transect), where the inverse was true (Figure 18). Globally, in the lower Estuary and the Gulf of St. Lawrence, the overall abundance of zooplankton was 64 % and 41 % lower in spring and fall 2001 than in 2000. This difference in abundance between the two years was due to the lower abundance of both copepod and invertebrate eggs in 2001.

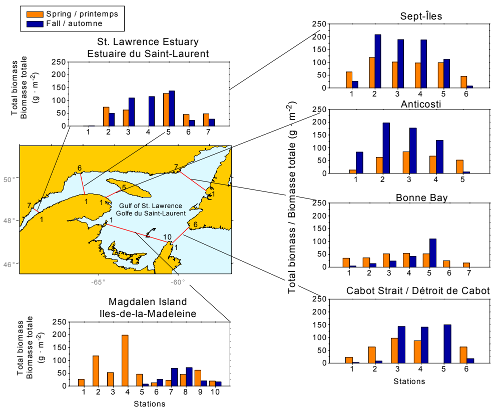

Figure 17. Total zooplankton biomass along the six transects sampled in June and November 2001 in the Lower Estuary and the Gulf of St. Lawrence.

Juvenile and adult copepods were clearly dominant along all transects, accounting for more than 65 % and 85 % of the assemblage in June and December respectively (not shown). The overall abundance of copepods integrated over the water column varied between 4,505 and 220,054 ind. per m^2 along all transects in June and between 10,425 and 295,669 ind. per m^2 in December (Figure 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 Estuary and the Gulf of St. Lawrence (Figure 19). In June, a group composed of large copepod species (Calanus finmarchicus, C. hyperboreus, Metridia longa) dominated in abundance in all regions except in the northern part of the Cabot Strait transect, where the small species Oithona spp. was more abundant. In December, Oithona spp. dominated in abundance in all regions (Figure 19).

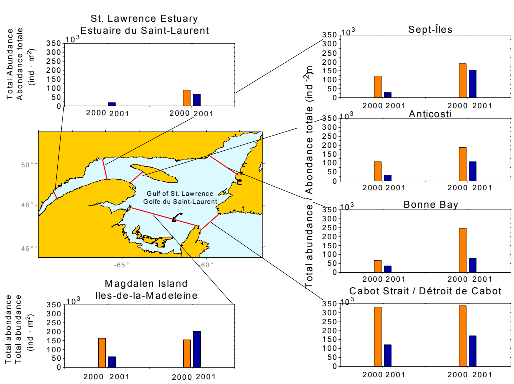

Figure 18. Integrated zooplankton abundance along the six transects sampled in spring and fall 2000 and 2001 in the lower Estuary and the Gulf of St. Lawrence .

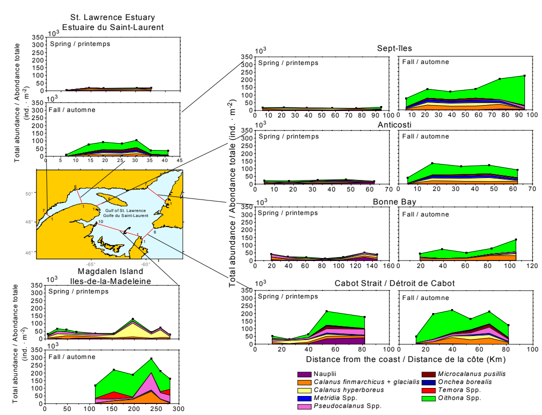

Figure 19. Integrated copepod abundance and community structure along the six transects sampled in June and December 2001 in the Lower Estuary and the Gulf of St. Lawrence.

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