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State of phytoplankton in the Estuary and Gulf of St. Lawrence during 2003

État du phytoplancton dans l'estuaire et le golfe du Saint-Laurent en 2003

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ABSTRACT

We reviewed information concerning the seasonal and interannual variations in the concentrations of chlorophyll *a*, nitrates, and silicates as well as the abundance of the major species of phytoplankton measured at three fixed stations (Rimouski, Anticosti Gyre, and Gaspé Current) and six sections crossing the Estuary and Gulf of St. Lawrence. We concentrated on conditions prevailing in 2003 but also compared those observations with previous information from the 1992-2002 period.

In 2003, the initiation of the major phytoplankton bloom at Station Rimouski in the Lower St. Lawrence Estuary occurred in late May, which is one month earlier than usual. Excluding 2002, this continued a trend that began in 1998. This major shift in the timing of the phytoplankton cycle is believed to be due to the below-normal spring freshwater runoff that has been generally observed in the St. Lawrence basin since 1998. The average phytoplankton biomass during spring–summer 2003 at Station Rimouski was also higher compared to 1992-1994, 1996, 1998, and 2000-2002, but lower compared to 1995, 1997, and, more especially, to 1999. Spring–summer phytoplankton production measured at this station was also much higher in 2003 compared to the previous three years but lower than in 1999.

At the Anticosti Gyre and the Gaspé Current stations, nitrate and silicate concentrations were high in late fall–winter and low in late spring-summer due to biological consumption by phytoplankton. For both stations, the reduction of nutrients in the surface layer during spring–summer was much more pronounced in 2003 compared to the 2000-2002 period. Thus based on the evolution of nutrients, phytoplankton production in the northwestern Gulf of St. Lawrence could have been higher in 2003 compared to the previous three years. This is consistent with data from Station Rimouski in the Lower St. Lawrence Estuary.

Similarly, the surface nutrient levels in late winter 2003 were also higher in the southern and northeastern Gulf of St. Lawrence compared to the previous two years while levels were not markedly different for the late spring–summer period. This suggests again that the spring phytoplankton bloom in these regions was also more intense in 2003 compared to recent years.

For a third consecutive year, the analysis of the phytoplankton community composition in 2003 revealed the presence of the diatom *Neodenticula seminae* in many areas of the Gulf of St. Lawrence, with concentrations up to 197 X 10^2 cells per litre. This phenomenon is unusual since this species is typically found in North Pacific waters. In the Atlantic Ocean, this species has only been recorded in middle to high latitude Quaternary sediments, dating from between 0.84 and 1.2 million years ago. It is proposed 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 invasion of *N. seminae* on the Atlantic coast is consistent with recent observations suggesting a greater influx of Pacific waters into the Atlantic.

RÉSUMÉ

Ce document présente une synthèse des variations saisonnières et interannuelles des concentrations de chlorophylle *a*, de nitrates et de silicates ainsi que de l'abondance des principales espèces de phytoplancton à trois stations fixes (Rimouski, gyre d'Anticosti et courant de Gaspé), de même qu'aux stations situées le long de six sections qui traversent l'estuaire et le golfe du Saint-Laurent. Les auteurs ont analysés les conditions qui ont prévalue en 2003, mais ont aussi comparé ces données à celles obtenues au cours de la période s'échelonnant de 1992 à 2002.

En 2003, la principale prolifération de phytoplancton observée à la station de Rimouski, dans l'estuaire maritime du Saint-Laurent, s'est produite en mai, c'est-à-dire un mois plus tôt que la moyenne. À l'exception de 2002, ceci continue une tendance qui a débuté en 1998. Les auteurs pensent que cette variation dans la synchronisation du cycle de production primaire a été occasionnée par des apports printaniers en eau douce en dessus de la normale dans le bassin du Saint-Laurent. La biomasse moyenne estivale de phytoplancton en 2003 à la station Rimouski a été également plus élevée comparativement à 1992-1994, 1996, 1998, et à 2000-2002, mais inférieure à celle de 1995, 1997 et, à 1999 en particulier. Les taux de production primaire mesurés au printemps et à l'été à cette station ont été eux aussi beaucoup plus élevés en 2003 comparativement aux trois dernières années, mais inférieurs à ceux de 1999.

Aux stations de la Gyre d'Anticosti et du courant de Gaspé, les concentrations en nitrates et en silicates ont été élevées à la fin de l'hiver et faibles à la fin de l'été en raison d'une utilisation accrue par le phytoplancton. Pour ces deux stations, la réduction des éléments nutritifs dans la couche de surface au cours de la période estivale a été plus prononcée en 2003 par rapport à la période 2000-2002. Ainsi, d'après l'évolution des teneurs en sels nutritifs, la production de phytoplancton dans le nord-ouest du golfe du Saint-Laurent pourrait avoir été plus élevée en 2003 comparés aux trois années précédentes. Ceci est conforme aux données obtenues à la station Rimouski dans l'estuaire maritime du Saint-Laurent.

De même, les concentrations en sels nutritifs à la fin de l'hiver 2003 ont été également plus élevées dans le sud et le nord-est du golfe du Saint-Laurent par rapport aux deux années précédentes, tandis qu'elles n'ont pas été significativement différentes au cours de l'été. Ceci suggère une fois de plus que la floraison printanière de phytoplancton dans ces régions ait été également plus intense en 2003 comparativement aux années récentes.

Pour une troisième année consécutive, l'analyse de la composition de la communauté phytoplanctonique au cours de 2003 a permis de noter la présence de la diatomée *Neodenticula seminae* dans plusieurs secteurs du Golfe du Saint-Laurent, avec des concentrations pouvant atteindre jusqu'à 197 x 10^2 cellules par litre. Il est tout à fait exceptionnel que cette espèce soit retrouvée dans le golfe du Saint-Laurent car elle est généralement présente dans les eaux du Pacifiques Nord. Jusqu'à présent, cette espèce n'avait été signalée dans l'Atlantique que dans des sédiments datant du Quaternaire, il y a de cela 0.84 à 1.26 million d'années. Il est suggéré que cette espèce du Pacifique ait été introduite de façon naturelle dans le golfe du Saint-Laurent (en traversant l'Arctique et en descendant le courant du Labrador, pour ensuite emprunter le détroit de Belle-Isle) plutôt que par les eaux de ballast. L'invasion de *N. seminae* sur la côte atlantique est conforme aux observations récentes suggérant un plus grand apport des eaux du Pacifiques dans l'Océan Atlantique.

INTRODUCTION

This report presents the state of phytoplankton prevailing in the Estuary and Gulf of St. Lawrence in 2003. The information herein is essentially derived from AZMP (Atlantic Zone Monitoring Program) data collected at a network of stations (fixed-point stations and cross-shelf sections) sampled at a frequency of bimonthly to three times per year (Figures 1 and 2). Additional information from various research programs (Toxic Algae Monitoring Program, Station Rimouski, Helicopter Survey) are also used to complete this annual review.

METHODS

Sampling and standard measurements of nutrient and chlorophyll concentrations as well as the determination of phytoplankton composition are based on protocols outlined by the steering committee of the AZMP (Mitchell *et al.* 2002)

Primary production rates at Station Rimouski were determined using the ^{14}C uptake method as described in the Joint Global Ocean Flux Study (JGOFS) Protocols (JGOFS, 1994). Briefly, triplicate water samples were inoculated with the ^{14}C solution in 250-mL cell culture bottles. Inoculated samples were covered with filters reproducing the light intensity at the sampling depths (100, 75, 50, 25, and 1% of incident light) and incubated for 24 hours under natural light. Circulating surface seawater kept the temperature similar to *in situ* conditions. After the incubation, samples were filtered using a GFF Whatman filter. The filters were then placed in scintillation vials and acidified to remove inorganic carbon. Finally, 10 mL of CytoScint^{Tm} ES scintillation solution were added and the ^{14}C radioactivity was measured with an LKB liquid scintillation counter. Daily primary production rates were directly calculated from dpm counts.

RESULTS AND DISCUSSION

Lower St. Lawrence Estuary

The series of observations at Station Rimouski enable us to describe in more detail the interannual variability in the timing, duration, and magnitude of the spring phytoplankton bloom in the Lower St. Lawrence Estuary than at the other fixed stations. This station has been visited on a weekly basis from May to September since 1992.

In 2003, the standing stock of phytoplankton at Station Rimouski, as reflected by the amount of chlorophyll *a* (Figure 3), showed a major pulse in the period from mid May to mid July, with integrated values in the upper 50 m exceeding 400 mg of chlorophyll *a* m^{-2} (Figure 4). Outside of this period, chlorophyll levels remained relatively low except in early October, when a small bloom of short duration was observed (Figures 3 and 4). The phytoplankton species responsible for the late May – early July bloom were the diatoms *Thalassiosira nordenskioeldii*, *Skeletonema costatum*, *Chaetoceros furcellatus,* and *C. debilis*. These species were gradually replaced by several species of dinoflagellates and flagellates.

In contrast to our previous observations, the onset of the spring phytoplankton bloom at Station Rimouski in 2003 (late May) occurred somewhat later relative to the 1998-2001 period (early May), but 6 to 8 weeks earlier compared to 1992-1997 (mid-June, Figure 5 A). A comparison of these results with the historical data on the phytoplankton biomass in the Lower St. Lawrence Estuary confirms that the development of the primary bloom in May as observed in 2003, is unusual for this region. Data collected near Station Rimouski for 1969-1971 (Steven 1974), 1974 (Sinclair 1978), 1979-1980 (Levasseur *et al.* 1984), 1983-1984 (Starr *et al.* 1993), 1990 (Plourde and Runge 1993), and 1991 (Runge and Joly, unpubl. data) showed that the primary bloom in those years normally started between June and July.

Typically, the spring bloom in the lower St. Lawrence Estuary starts just after the spring-summer runoff peak (e.g., Levasseur *et al.* 1984, Therriault and Levasseur 1985, Zakardjian *et al.* 2000). The lower-than-normal spring freshwater runoff that has been observed since 1998 in the St. Lawrence basin (except for 2002) (Gilbert *et al.* 2004) could thus be responsible for the recent shift seen in the timing of phytoplankton cycle.

Overall, the average phytoplankton biomass during spring–summer 2003 at Station Rimouski was close to the historical mean (1992-2002), being higher compared to 1992-1994, 1996, 1998, and 2000-2002, but lower compared to 1995, 1997, and, more especially, to 1999 (Figure 5 B). Spring–summer phytoplankton production measured at Station Rimouski was also higher in 2003 compared to the previous three years but lower than in 1999 (Figure 6).

Northwestern 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 from the St. Lawrence Estuary along the Gaspé Peninsula. These two systems represent two distinct pelagic ecosystems. The biological and chemical properties of the Gaspé Current reflect the conditions developing in the Lower Estuary whereas those found in the Anticosti Gyre are more typical of the conditions prevailing over the rest of the Gulf of St. Lawrence (Levasseur *et al.* 1992). Within the AZMP, these two systems have been monitored at a frequency of 9 to 19 times per year.

In 2003, 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 (Figures 7 and 8). As it is typically observed, 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. At both stations, the spring decrease in nitrate and silicate occurred principally between late April and June.

The major increase in the chlorophyll concentration in the Gaspé Current's low salinity surface waters was observed in June and coincided with the major pulse of phytoplankton at Station Rimouski (Figures 3 and 7). Outside of this period, chlorophyll levels remained relatively low except in May and September, when small phytoplankton peaks of short duration were observed (Figures 7 and 8) that were similar those observed in the St. Lawrence Estuary. In the Anticosti Gyre, near-surface chlorophyll concentrations remained low throughout the sampling period except in June, when a subsurface chlorophyll peak was observed (Figure 7).

Compared to our previous observations, the chlorophyll *a* levels at the Gaspé Current station were generally lower in 2003 than in 1999 but comparable to the 2000-2002 period (Figure 8). In contrast, chlorophyll concentrations at the Anticosti Gyre station were somewhat lower compared to recent years. On the other hand, the late winter nutrient concentrations in the top 50 m were higher at both stations compared to the previous three years while the summer levels were comparable (i.e., Anticosti Gyre) or lower (i.e., Gaspé Current). Consequently, the amount of nutrients potentially used by phytoplankton in the surface layer during spring–summer at both stations was much more pronounced in 2003 compared to the 2000-2002 period. Thus based on this evolution of nutrients, phytoplankton production in the northwestern Gulf of St. Lawrence could have been higher in 2003 compared to the previous three years. This is consistent with data from Station Rimouski in the Lower St. Lawrence Estuary.

Other regions of the Gulf

AZMP Sections and winter helicopter survey. Chlorophyll and nutrient data were collected at 41 stations along six sections crossing the Estuary and the Gulf of St. Lawrence (Figure 1) to obtain quasi-synoptic information over a broader spatial scale. Sections were occupied during early spring (April), late spring (June), and mid–fall (November) 2003 (Figure 2). In addition, nutrient concentrations at the surface (2m) were collected at 64 stations covering the Gulf of St. Lawrence in late winter (March) 2003. Winter nutrient concentrations are play a key role in determining the intensity of the spring phytoplankton bloom.

Late winter nutrient concentrations in 2003 were extremely high for most regions of the Gulf of St. Lawrence (Figure 9). The highest nutrient concentrations were observed in the St. Lawrence Estuary, possibly due to upwellings at the head of the Laurentian Channel and the high tidal mixing in this area (Levasseur *et al.* 1984), and to some degree to anthropogenic sources. In early spring, surface (0-50m) nutrient concentrations were similar to those observed during the winter survey, except for the southern Gulf of St. Lawrence (Magdalen Island and Cabot Strait transects) (Figures 10-13), where the spring phytoplankton bloom had clearly already begun (Figures 14 and 15). In contrast, surface nitrate and silicate concentrations during the late spring survey were usually low for most regions of the Gulf of St. Lawrence due to utilization by phytoplankton (Figures 10-13). The depletion of nutrients in the surface layers was 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 (e.g., Steven 1974). During the 2003 fall survey, surface nitrate and silicate levels were comparable or somewhat lower than those measured during the late spring survey for most areas of the Gulf of St. Lawrence (Figures 10-13). This indicates that the autumnal turnover had not yet occurred.

Below the surface, nutrient concentrations did not vary with time but varied spatially (Figures 10 and 11). Deep concentrations of nitrate (> 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 (Coote and Yeats 1979, Savenkoff *et al.* 2001). Silicate concentrations also increased from Cabot Strait toward the head of the Laurentian Channel but to a greater degree than did nitrate, which is typical (Steven 1974, Savenkoff *et al.* 2001). The average silicate concentration in the deep water of Cabot Strait and the eastern part of the Gulf was 20 mmol m^{-3} while values exceeding 45 mmol m^{-3} occurred near the bottom in the Estuary (Figure 11). These unusually high values compared to adjacent waters are thought to be due to precipitation processes and sedimentation of silica from the river water. Compared to previous years, silicate as well as nitrate concentrations in the deep layer in spring and fall 2003 were comparable to those in 2001 and 2002 (Starr *et al.* 2002, 2003).

Compared to our previous observations (2000-2002), the late winter nitrate levels at the surface (0-50m) were much higher (Figures 16 and 17). In contrast, surface nitrate concentrations in the late spring (June) were not markedly different in 2003 compared to recent years (1999-2002) for most of the Gulf of St. Lawrence, except for the Anticosti section where levels were somewhat higher in 2003 (Figure 18). Based on this evolution of nitrate, phytoplankton production during spring could have been higher in 2003 compared to the previous three years for most areas of the Gulf of St. Lawrence. This is consistent with data from fixed stations in the Lower St. Lawrence Estuary and northwestern Gulf of St. Lawrence. In fall, nitrate and silicate concentrations were somewhat lower in 2003 compared to our previous observations for most areas (except for the northeastern part of the Gulf of St. Lawrence; Figures 19 and 20). This may suggest that the autumnal turnover was delayed in 2003 compared to recent years.

Overall, chlorophyll levels in 2003 were higher in early to late spring than during the fall survey, which is typical (Figures 14 and 15). During the early spring survey of 2003, higher chlorophyll levels were observed in the southern parts of the Gulf of St. Lawrence including Cabot Strait. Conversely, the late spring and fall chlorophyll levels were extremely low for most areas of the Gulf of St. Lawrence, except for the St. Lawrence Estuary. Compared to our previous observations, the chlorophyll levels in the late spring and fall of 2003 were not markedly different for most areas of the Gulf of St. Lawrence compared to recent years (Figures 21 and 22).

Satellite observations. Phytoplankton biomass was also assessed using ocean colour data collected by the Sea-viewing Wide Field-of-View Sensor (SeaWiFS) satellite 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 area. Composite images over two-week intervals for the Gulf of St. Lawrence can be found at the Bedford Institute of Oceanography Ocean Sciences Division website (http//www.mar.dfo-mpo.gc.ca/science/ocean/ias/seawifs_1.html). Note that data for the estuarine portion of the Gulf are uncertain (due to yellow substances) and must be used with caution.

Satellite data showed a great spatial variability in the timing of the spring bloom in the Gulf of St. Lawrence in 2003, which is potentially due to sub-regional differences in the timing of sea-ice melting (Le Fouest *et al.* 2003). 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. Overall, surface chlorophyll concentrations were somewhat higher during spring 2003 compared to the historical mean (1997-2002). During summer, chlorophyll levels remained low for most areas of the Gulf except for the estuarine portion. Another smaller phytoplankton peak was observed in fall 2003 for most areas of the Gulf, which is usual. This is consistent with observations from the fixed stations and sections crossing the Gulf.

Toxic Algae Monitoring Program. Within the Toxic Algae Monitoring Program, phytoplankton samples were collected from May to October at 11 coastal stations covering the Estuary and Gulf of St. Lawrence to determine the presence of harmful algae and toxic or invasive species. This sampling program has been in place at the Maurice Lamontagne Institute since 1989.

In 2003, no major toxic event was observed in the Estuary and Gulf of St. Lawrence. Nevertheless, the analysis of phytoplankton samples revealed for a third consecutive year the presence of the diatom *Neodenticula seminae* in many areas of the Gulf of St. Lawrence with concentrations up to 197 x 10^2 cells per litre (Figures 23 and 24). This phenomenon is unusual (Bérard-Therriault *et al.* 2002; Starr *et al.* 2002) since this species is typically found in North Pacific waters (Yanagisawa and Akiba 1990). In the Atlantic Ocean, this species has only been recorded in high latitude Quaternary sediments dating from between 0.84 and 1.26 Ma (Baldauf 1986). Since the presence of *N. seminae* was also detected in Labrador waters during spring–summer 2001, we propose 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 (Dickson 1999) and the freshening of the North Atlantic waters (Dickson *et al.* 2002). The impacts of this new invasive species on the productivity of the Gulf of St. Lawrence have not yet been determined.

CONCLUSIONS

Seasonal patterns and regional differences were observed in the concentrations of chlorophyll, nitrates, and silicates as well as in the phytoplankton composition in the Estuary and Gulf of St. Lawrence in 2003. In summary, the prominent 2003 events were as follows:

1. The initiation of the spring phytoplankton bloom in the Lower St. Lawrence Estuary occurred at least one month earlier than usual. Excluding 2002, this continued a trend that began in 1998.

2. The average phytoplankton biomass and primary production during spring–summer 2003 in the Lower St. Lawrence Estuary were much higher compared to the previous three years but lower compared to 1999.

3. Surface nutrient levels in late winter 2003 were higher in most areas of the Gulf of St. Lawrence compared to the previous three years while levels were not markedly different for the late spring–summer period, suggesting that the spring phytoplankton bloom in the Gulf was also more intense in 2003 compared to the previous three years.

4. Field observations and satellite data revealed large differences in the timing of the 2003 spring bloom in the St. Lawrence basin.

5. For a third consecutive year, we noted the presence of the diatom *Neodenticula*

seminae in many parts of the Gulf of St. Lawrence. This phenomenon is unusual since this species is typically only found in North Pacific waters.

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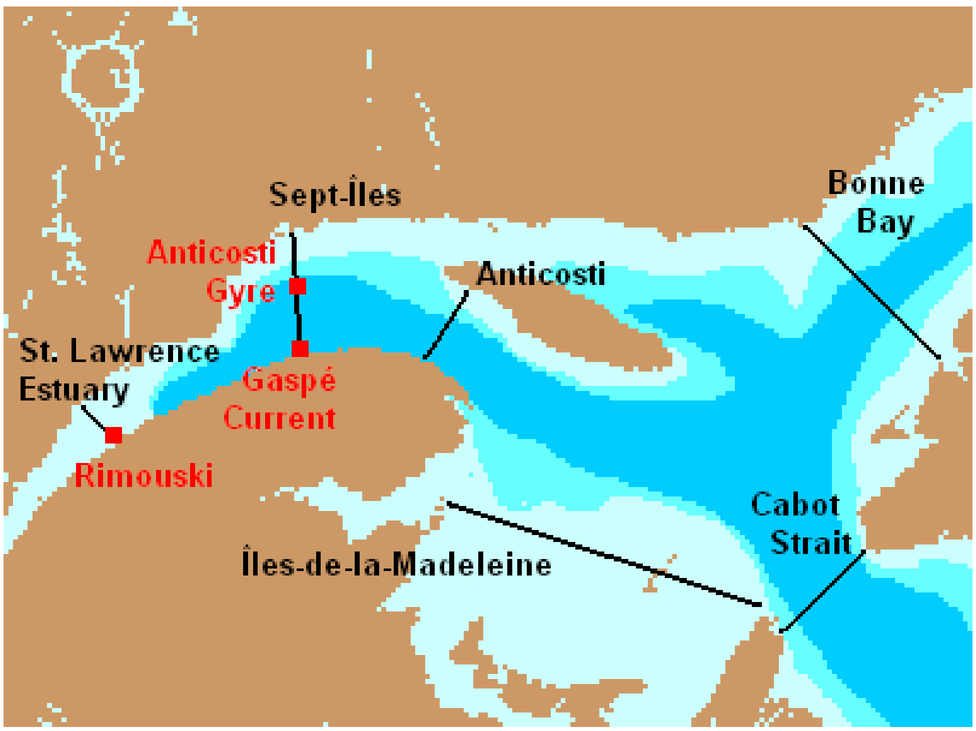


Figure 1. Atlantic Zone Monitoring Program (AZMP) sections (black lines) and fixed stations (red squares).

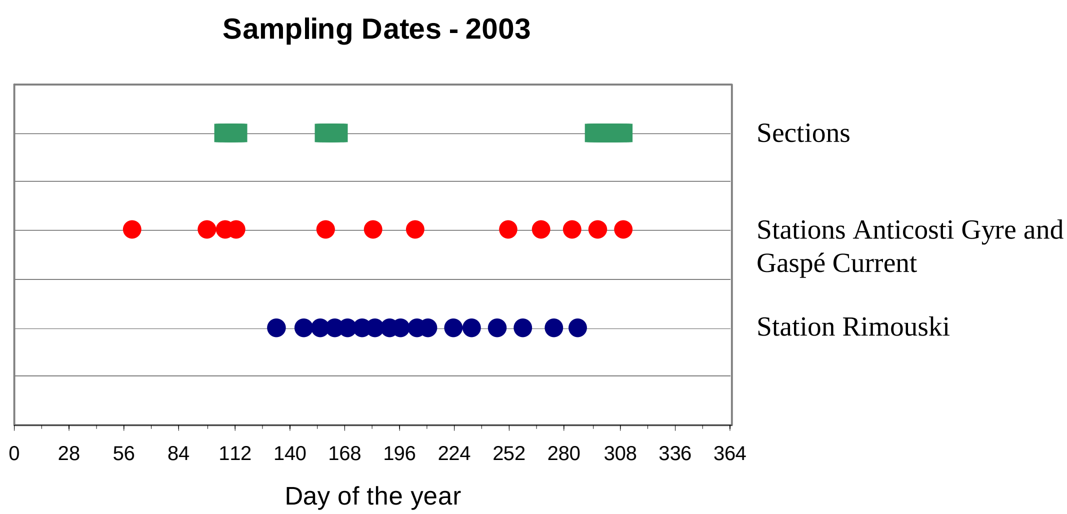


Figure 2. Sampling dates for fixed stations and sections for 2003.

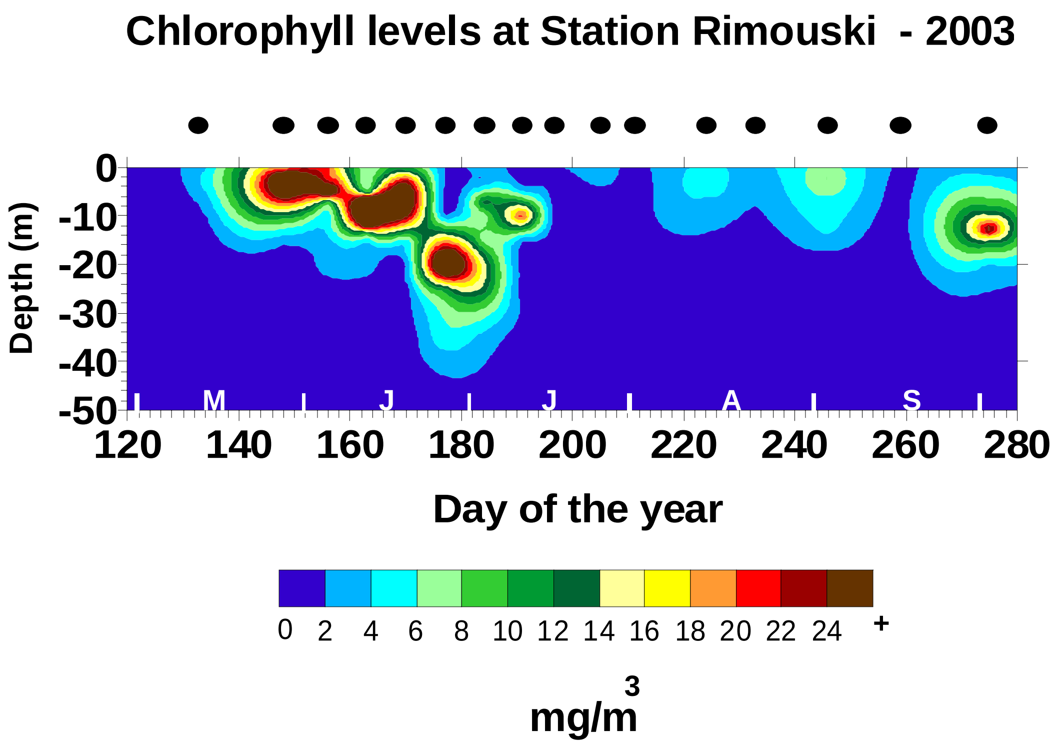


Figure 3. Chlorophyll *a* concentration (mg m^{-3}) at the Rimouski station from May to September in 2003. The black dots above the graph indicate the exact sampling dates.

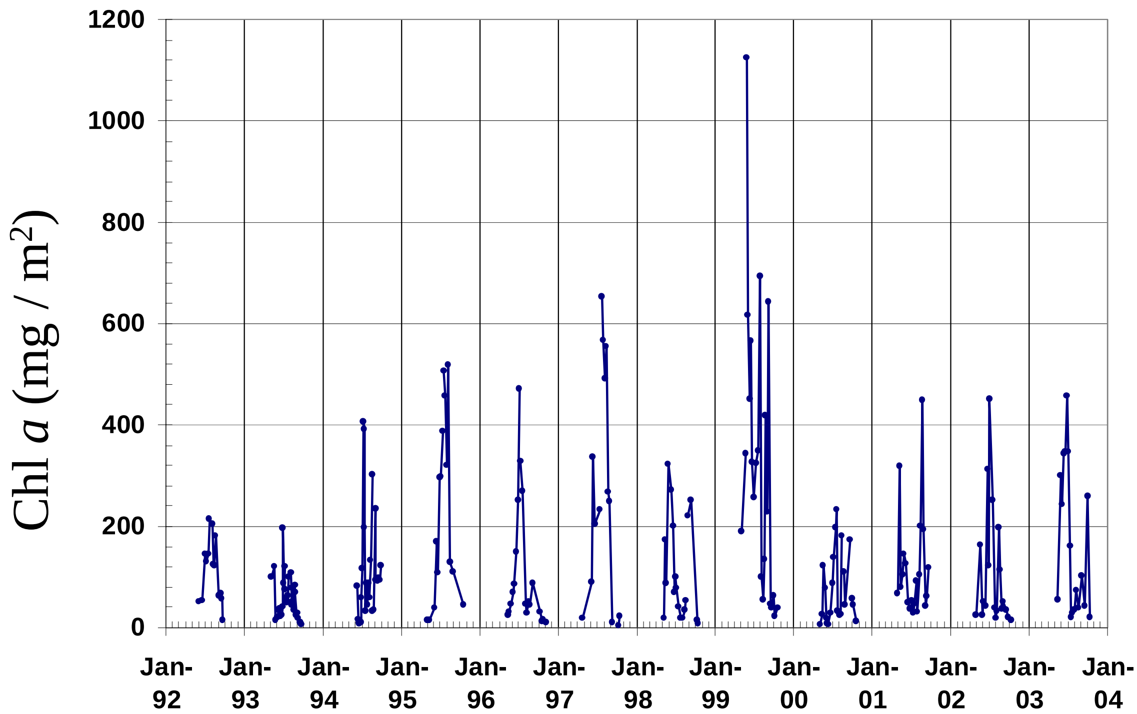
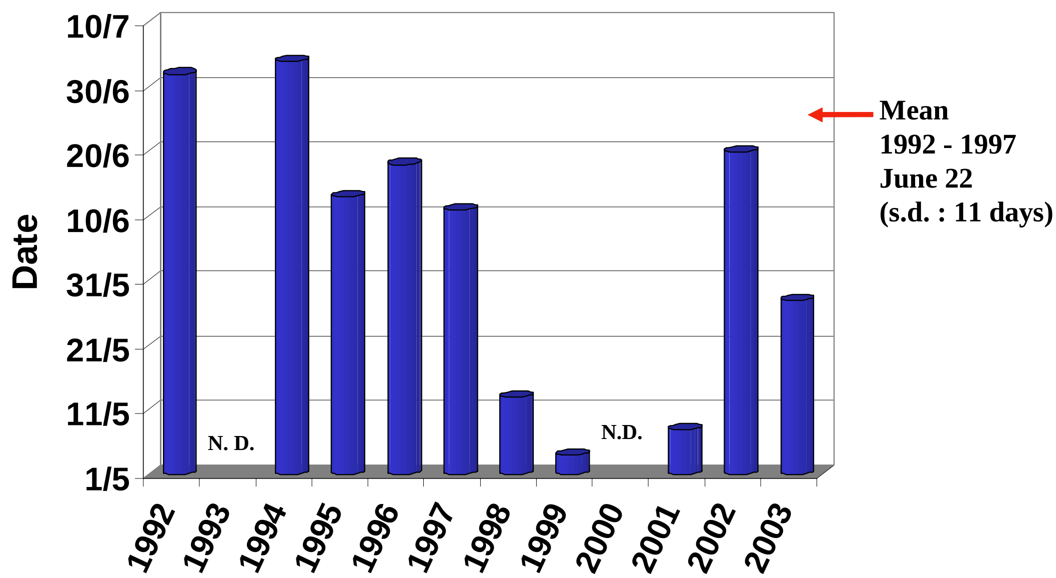


Figure 4. Chlorophyll *a* concentrations (mg m^{-2}) integrated over the upper 50 m at Station Rimouski during spring–summer 1992-2003.

A)



B)

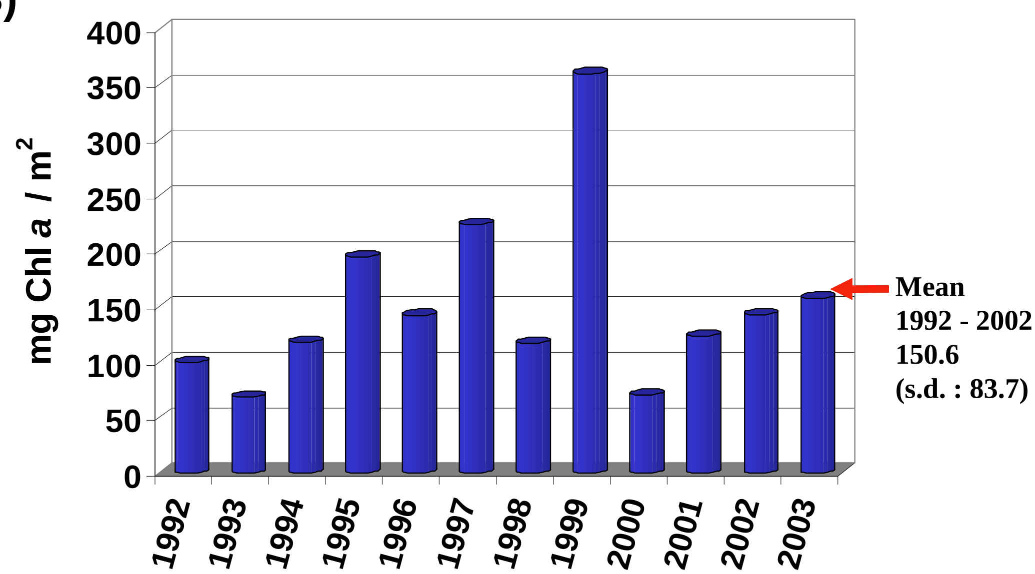
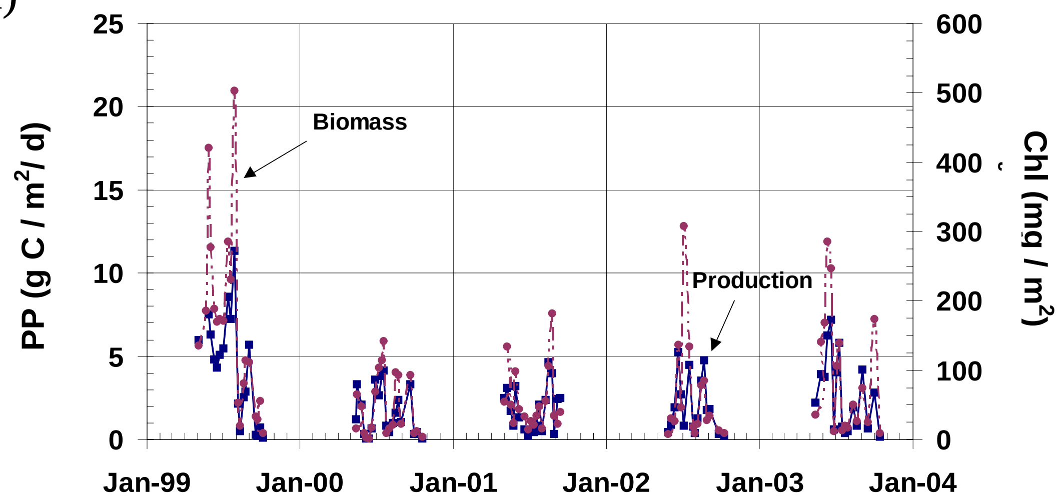


Figure 5. Station Rimouski. A) Date of onset of the primary bloom, defined as the first incidence of chlorophyll *a* concentrations greater than 100 mg m^{-2}, 1992-2003. N.D.: no distinct bloom. B) Mean integrated (surface to 50 m) chlorophyll *a* concentrations from May to August, 1992-2003.

A)



B)

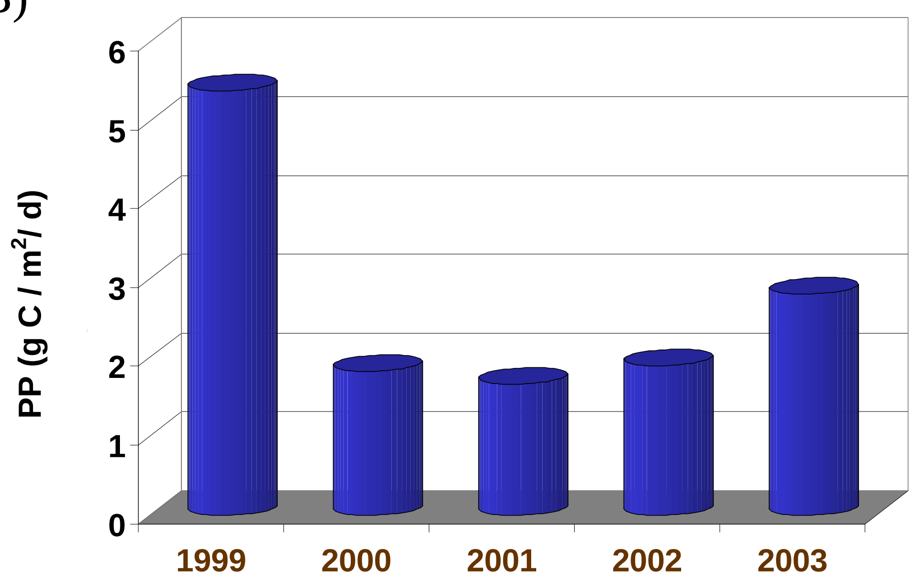


Figure 6. Station Rimouski. A) Phytoplankton production (PP) and biomass (Chl *a*) integrated over the euphotic zone during spring–summer 1999-2003. B) Mean phytoplankton production (g C m^{-2} d^{-1}) from May to August, 1999-2003.

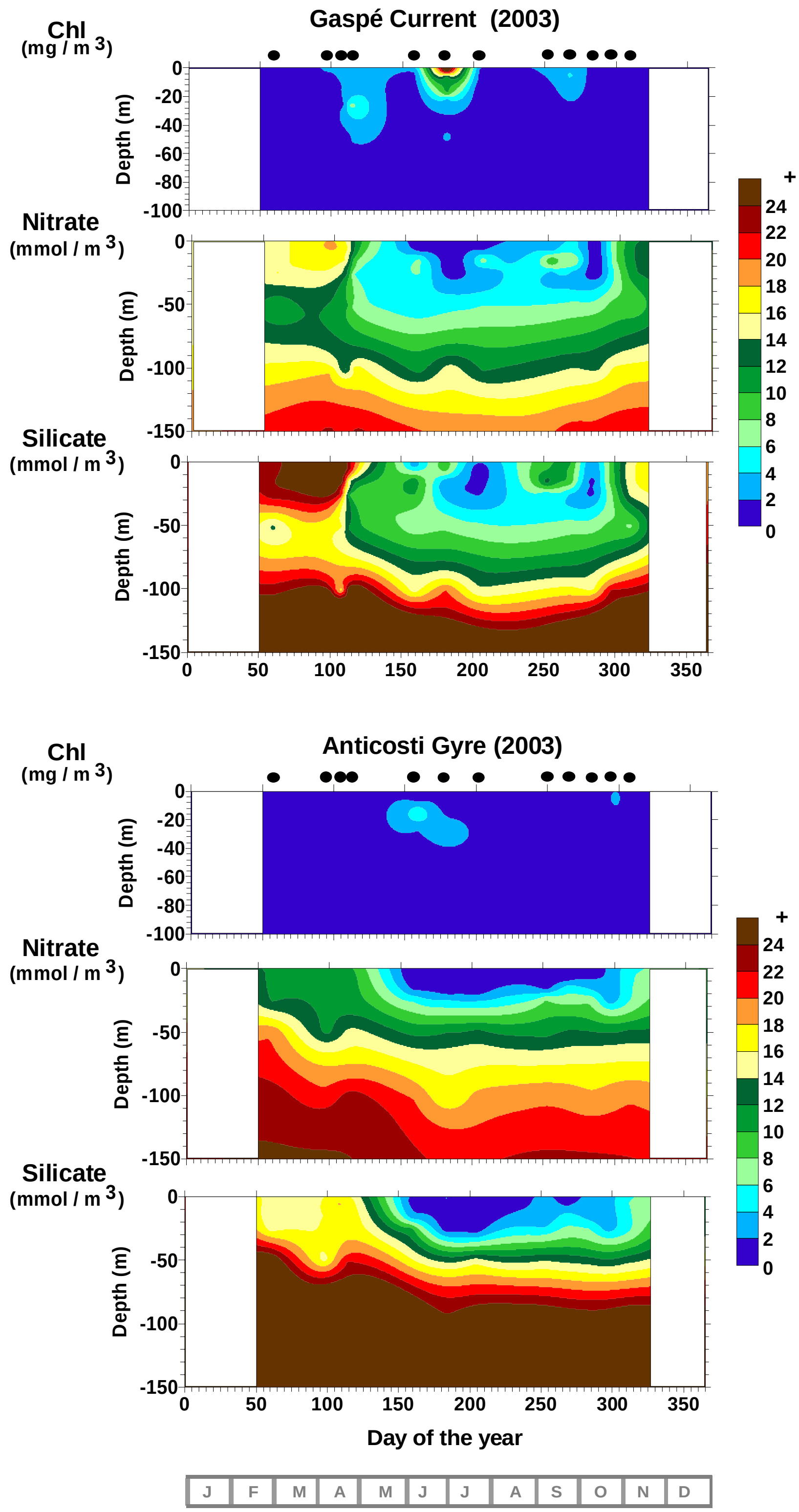


Figure 7. Vertical profiles of chlorophyll *a* (mg m^{-3}), nitrate (mmol m^{-3}) and silicate (mmol m^{-3}) concentrations in the Gaspé Current and Anticosti Gyre during 2003. The black dots above the graphs indicate the exact sampling dates.

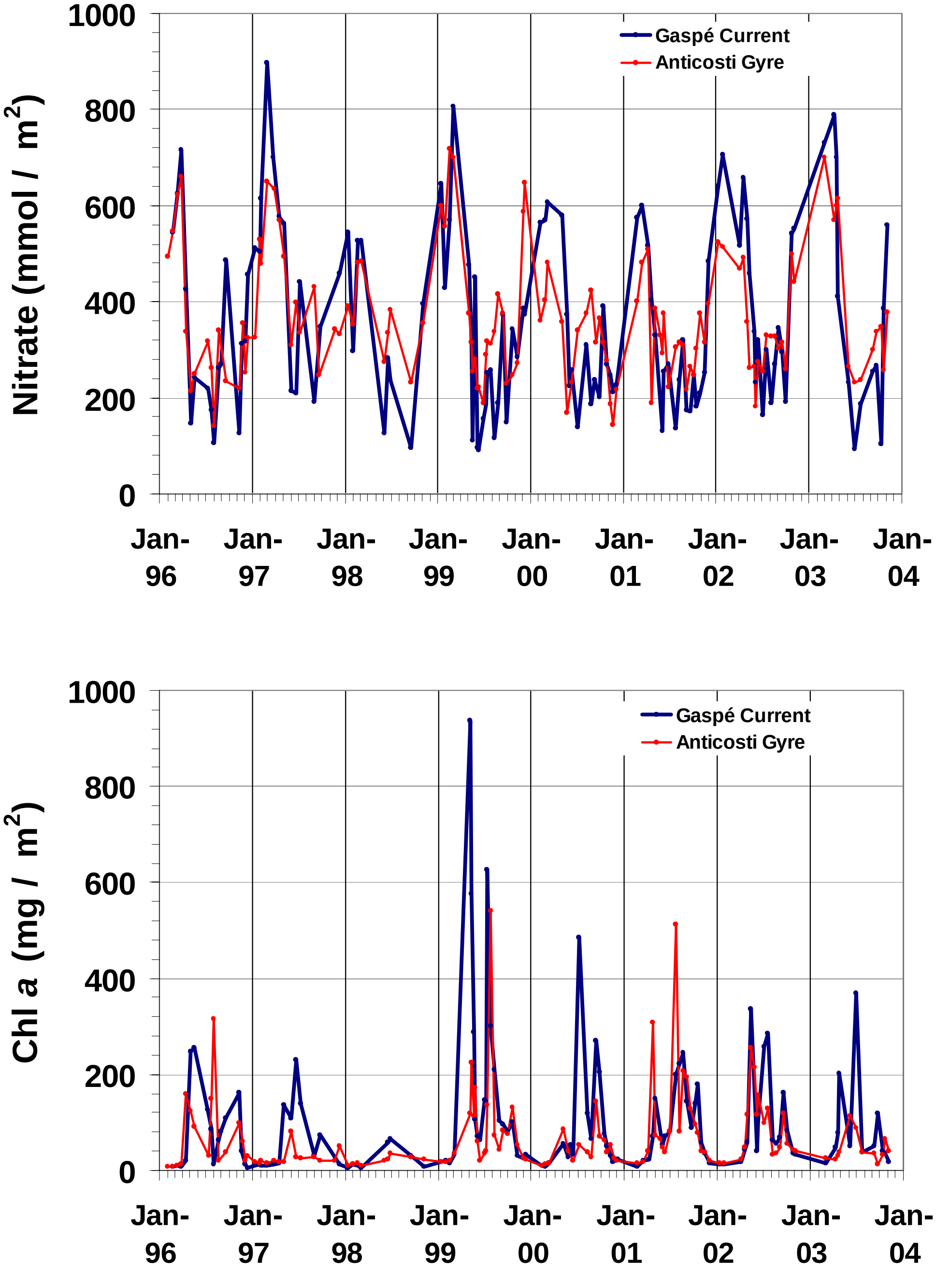


Figure 8. Nitrate (mmol m^{-2}) and chlorophyll *a* (mg m^{-2}) concentrations in the Gaspé Current and Anticosti Gyre, 1996-2003. Values are integrated over the upper 50 m of the water column.

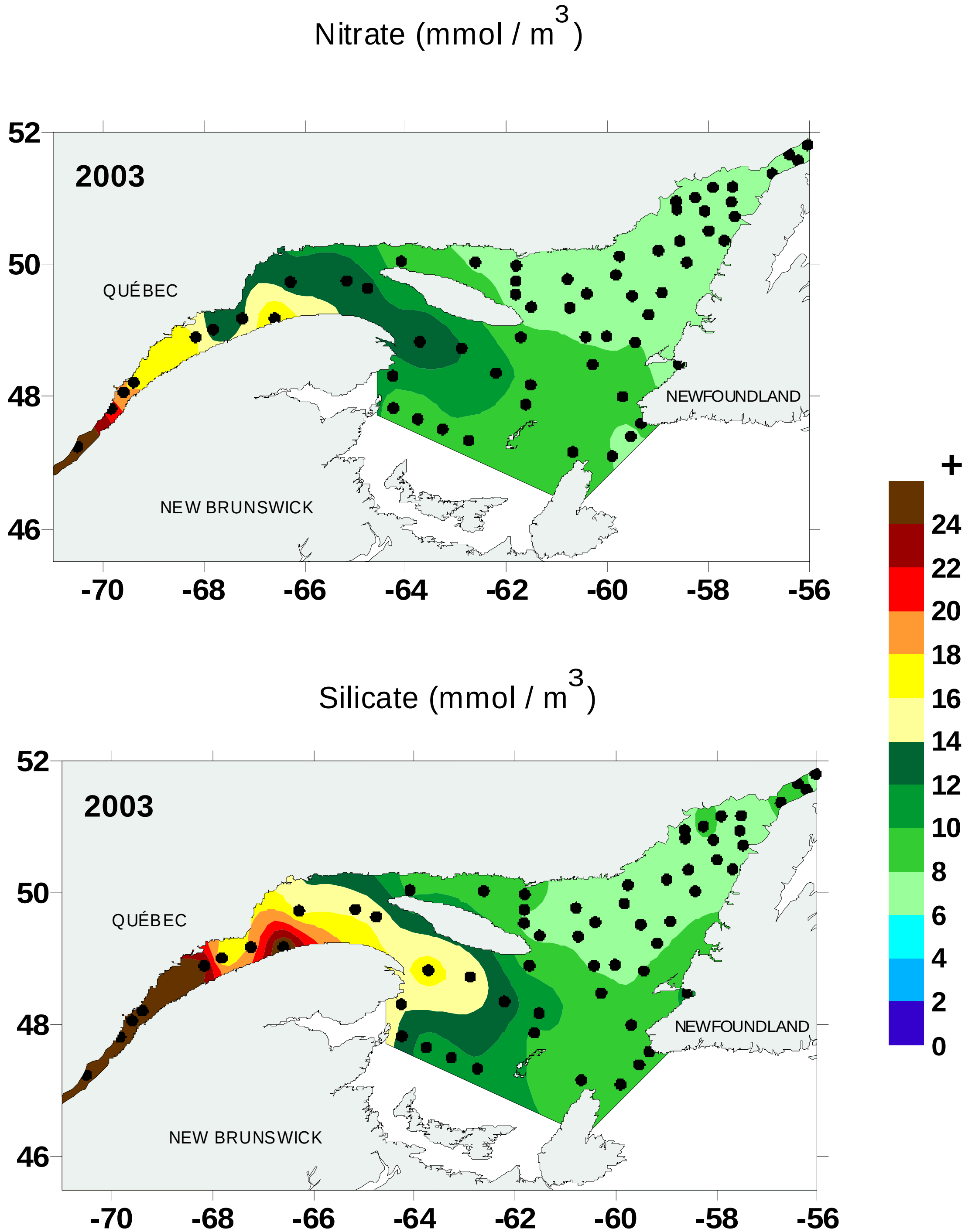


Figure 9. Concentrations of nitrate (mmol m^{-3}) and silicate (mmol m^{-3}) at 2 m collected at 64 stations covering the Gulf of St. Lawrence in late winter (March) 2003. Dots indicate the location of sampling stations.

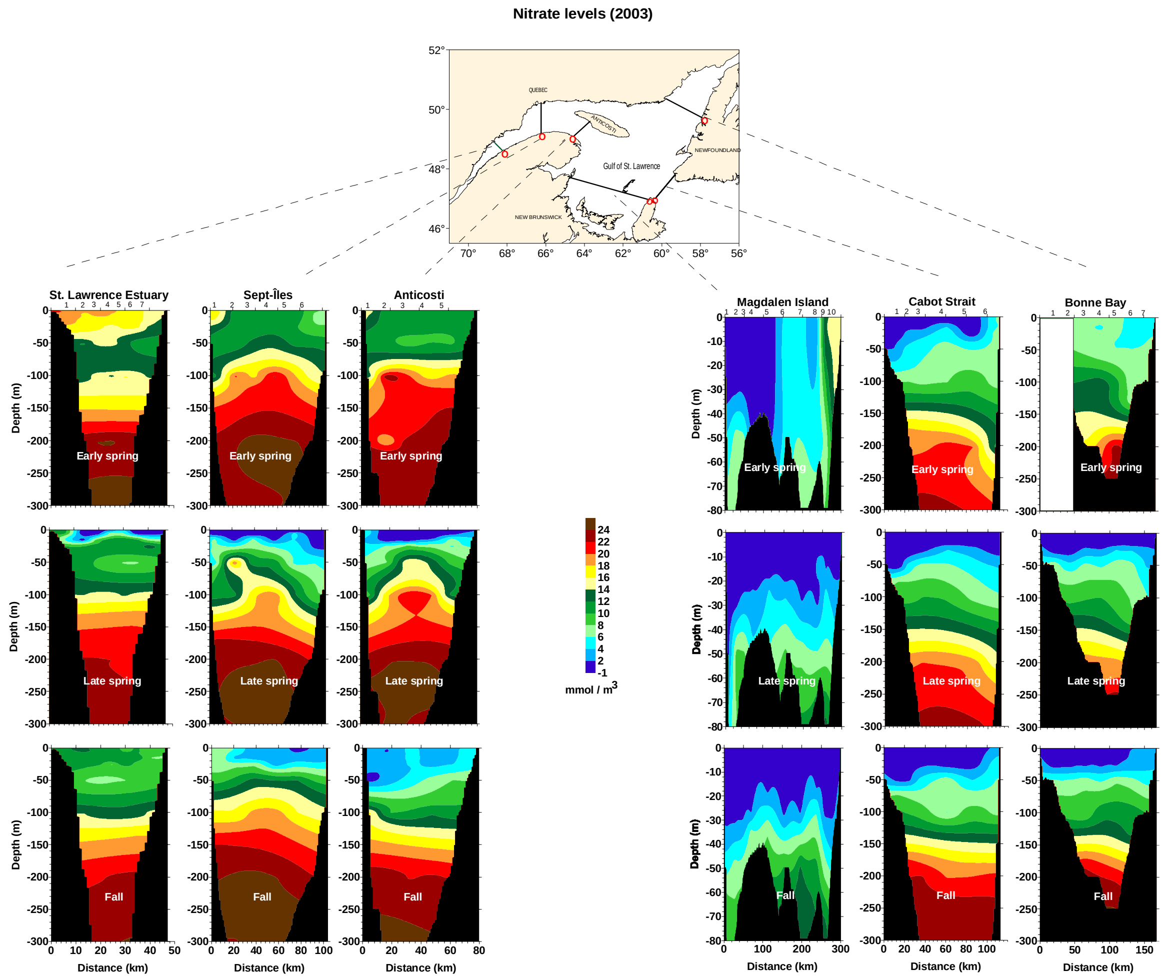


Figure 10. Concentrations of nitrate (mmol m^{-3}) versus depth along the six sections sampled in early spring (April), late spring (June), and fall (November) 2003 in the Estuary and Gulf of St. Lawrence. The numbers over graphs indicate the location of sampling stations. Red circles: starting points.

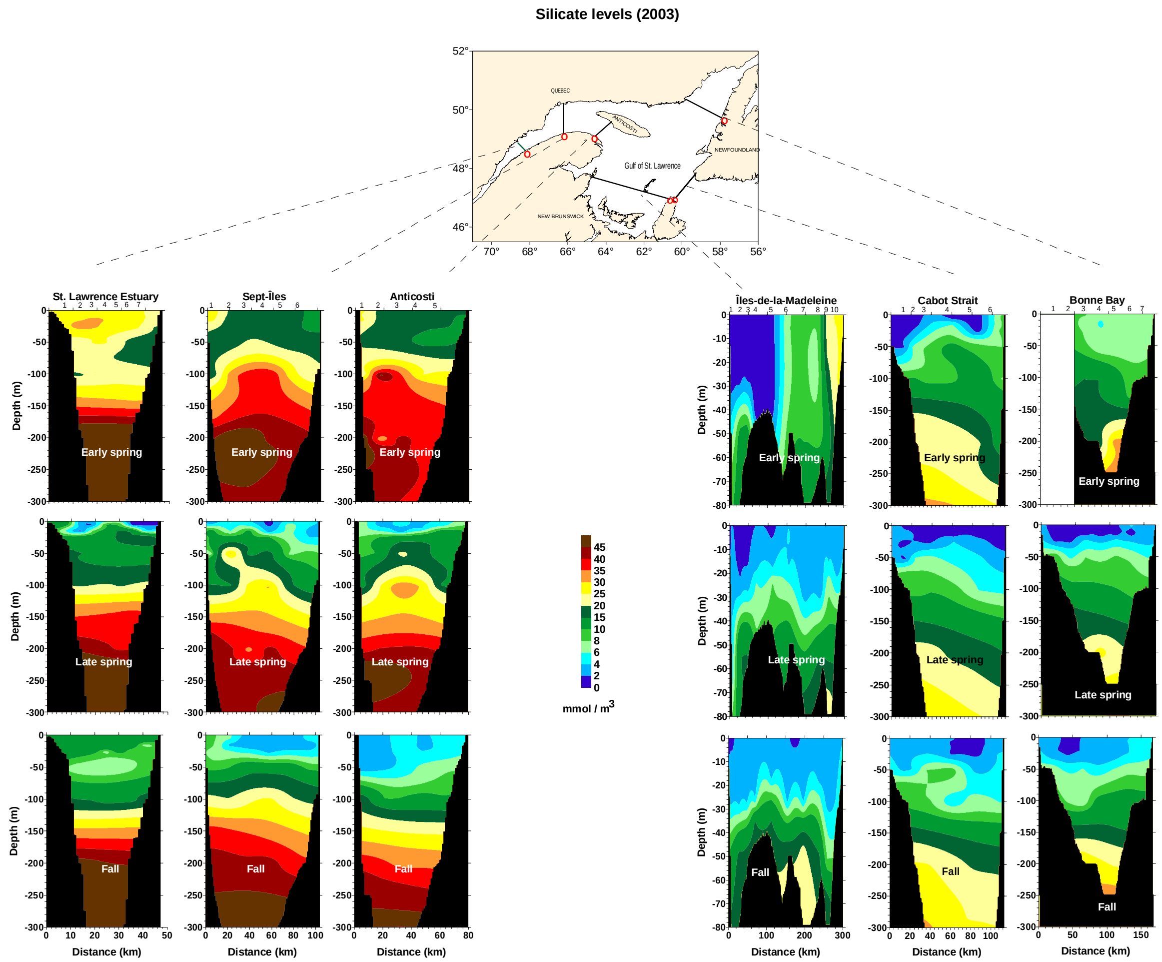


Figure 11. Concentrations of silicate (mmol m^{-3}) versus depth along the six sections sampled in early spring (April), late spring (June), and fall (November) 2003 in the Estuary and Gulf of St. Lawrence. The numbers over graphs indicate the location of sampling stations. Red circles: starting points.

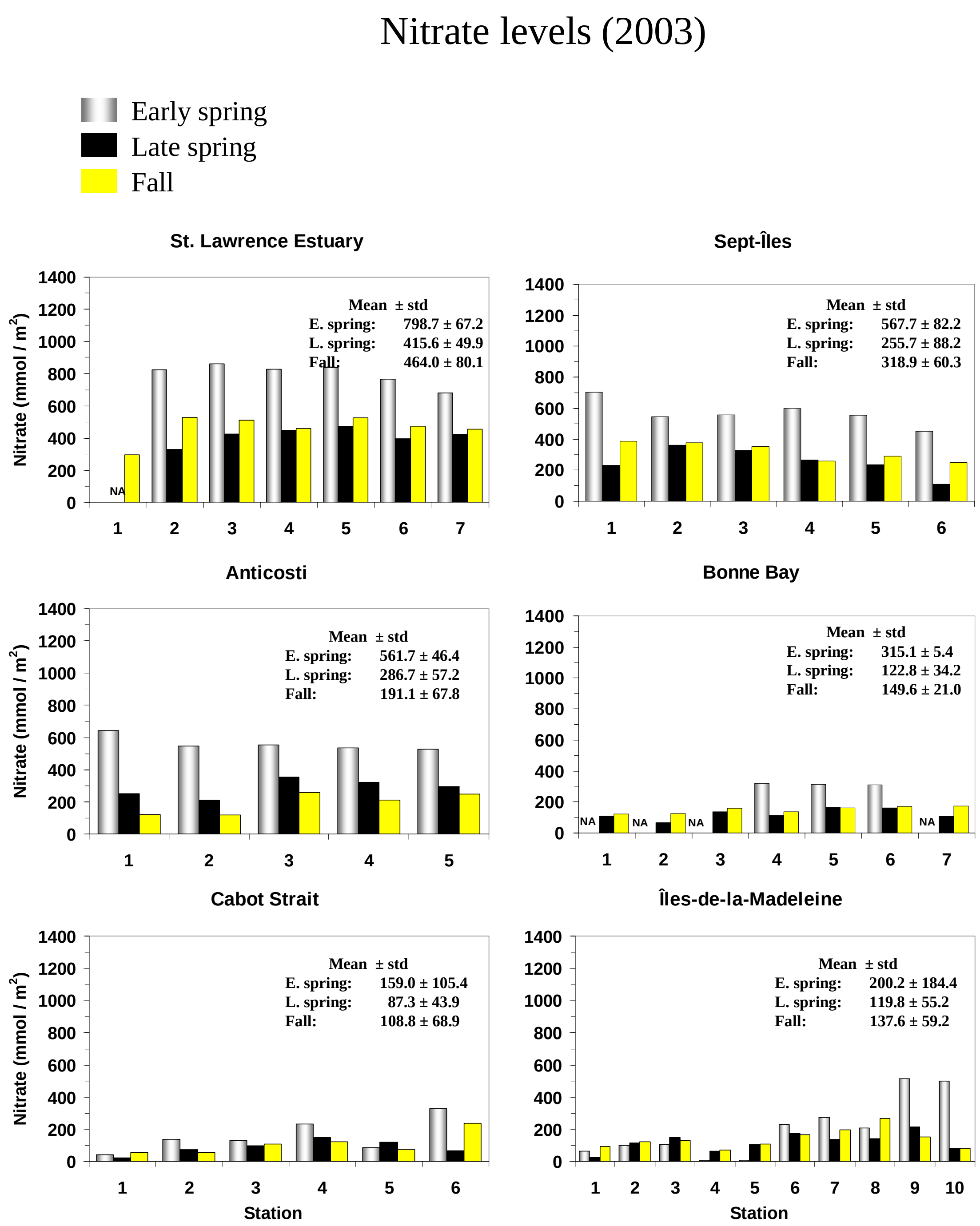


Figure 12. Nitrate concentrations (mmol m^{-2}) along the six sections sampled in early spring (April), late spring (June), and fall (November) 2003 in the Estuary and Gulf of St. Lawrence. Values are integrated over the upper 50 m of the water column.

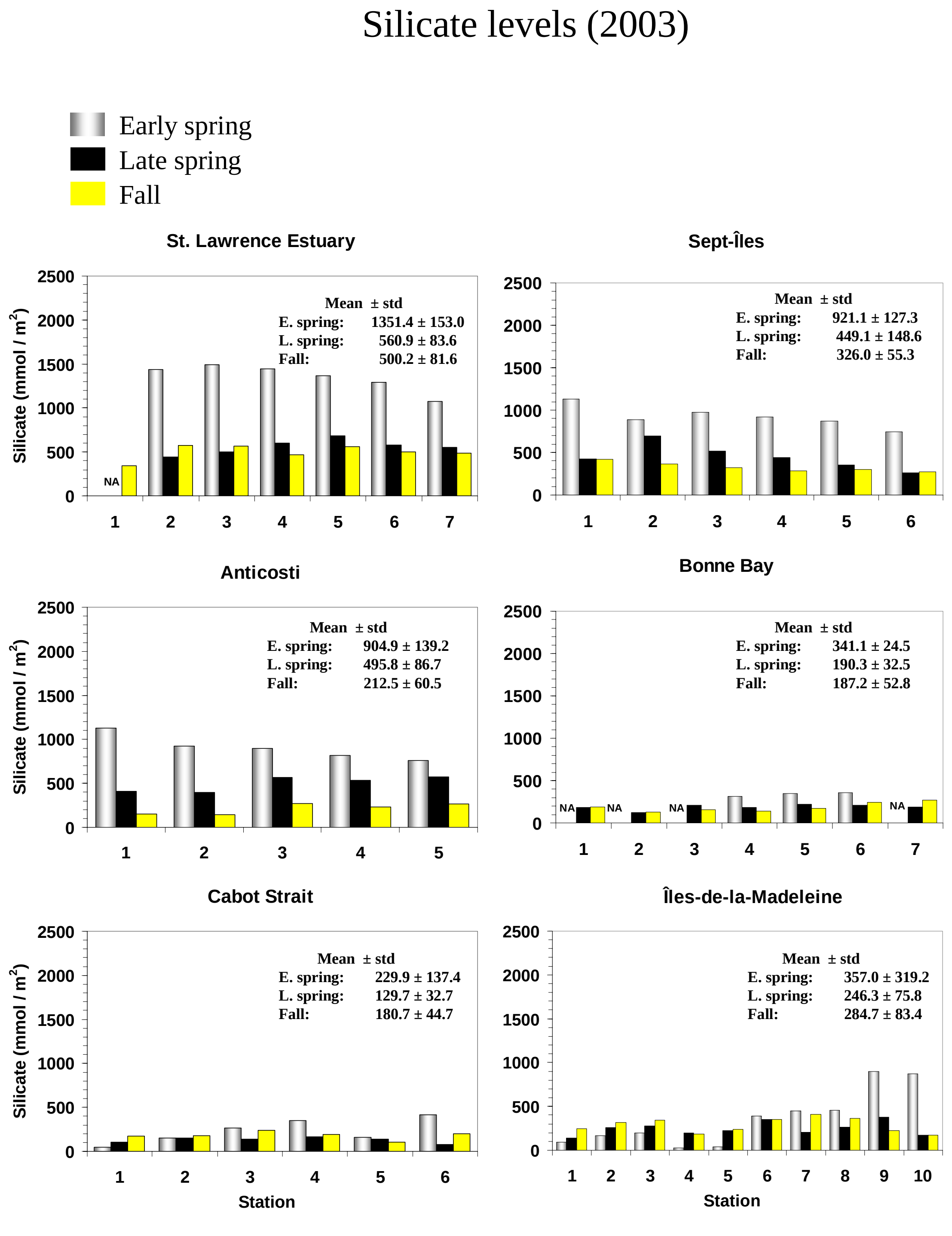


Figure 13. Silicate concentrations (mmol m^{-2}) along the six sections sampled in early spring (April), late spring (June), and fall (November) 2003 in the Estuary and Gulf of St. Lawrence. Values are integrated over the upper 50 m of the water column.

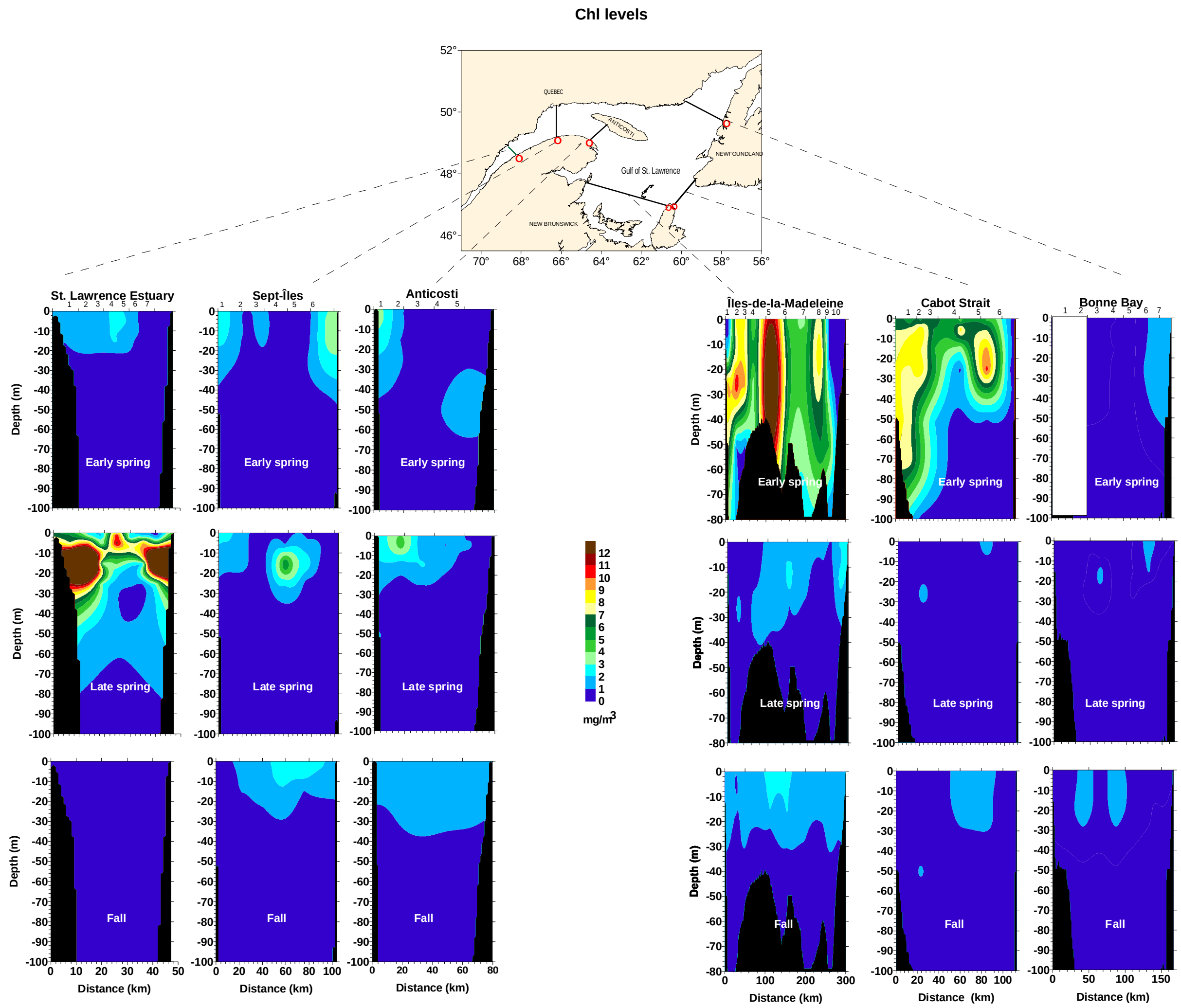


Figure 14. Concentrations of chlorophyll *a* (mg m^{-3}) versus depth along the six sections sampled in early spring (April), late spring (June), and fall (November) 2003 in the Estuary and Gulf of St. Lawrence. The numbers over graphs indicate the locations of sampling stations. Red circles: starting points.

Chlorophyll levels (2003)

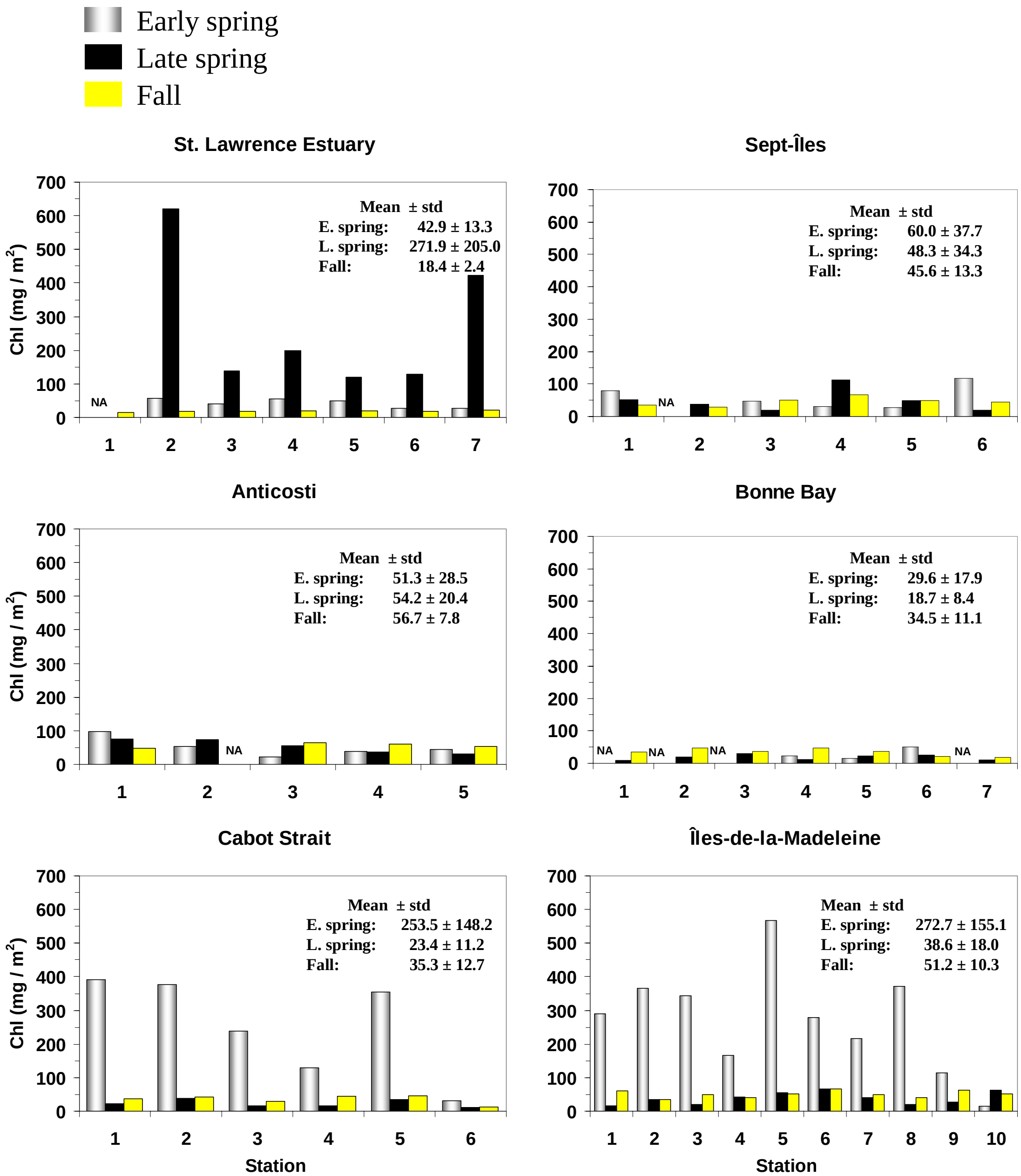


Figure 15. Chlorophyll concentrations (mg m^{-2}) along the six sections sampled in early spring (April), late spring (June), and fall (November) 2003 in the Estuary and Gulf of St. Lawrence. Values are integrated over the upper 50 m of the water column. NA: not available.

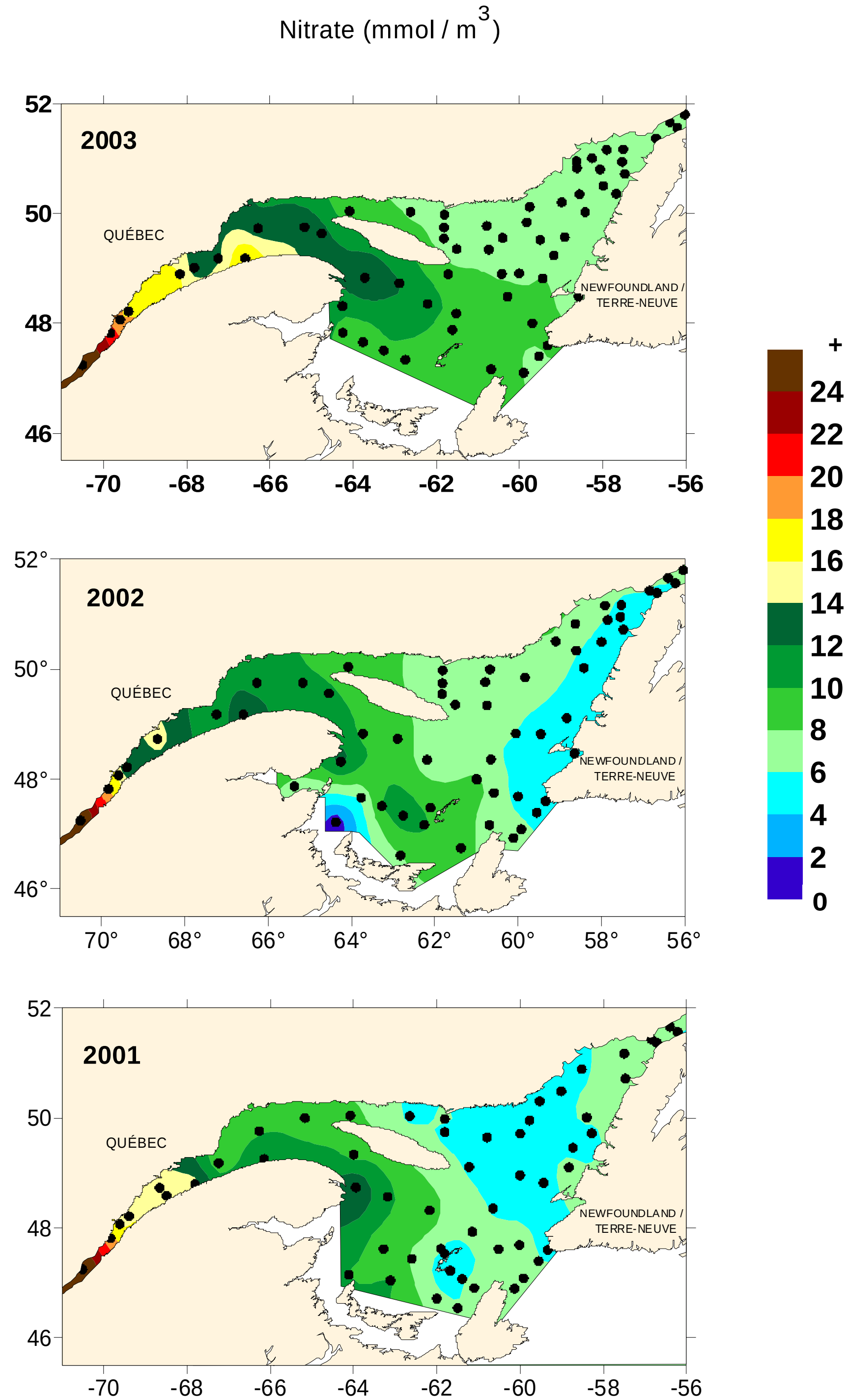
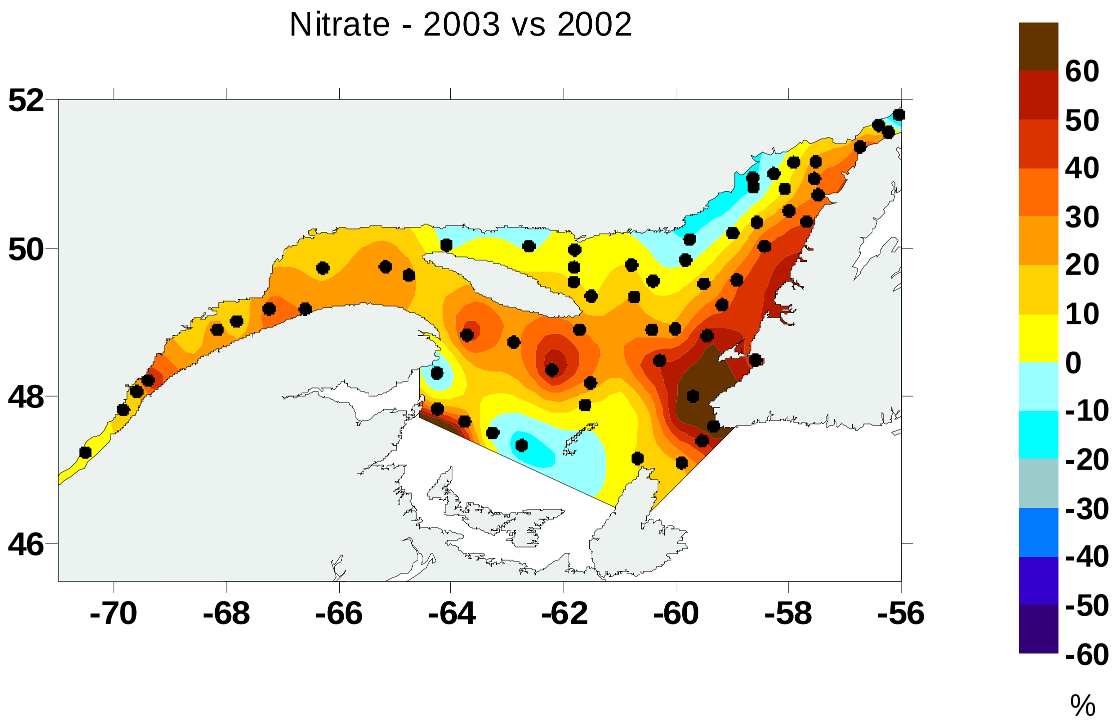


Figure 16. Late winter (March) concentrations of nitrate (mmol m^{-3}) at 2 m collected at 64 stations covering the Gulf of St. Lawrence, 2001-2003. Dots indicate the location of sampling stations.



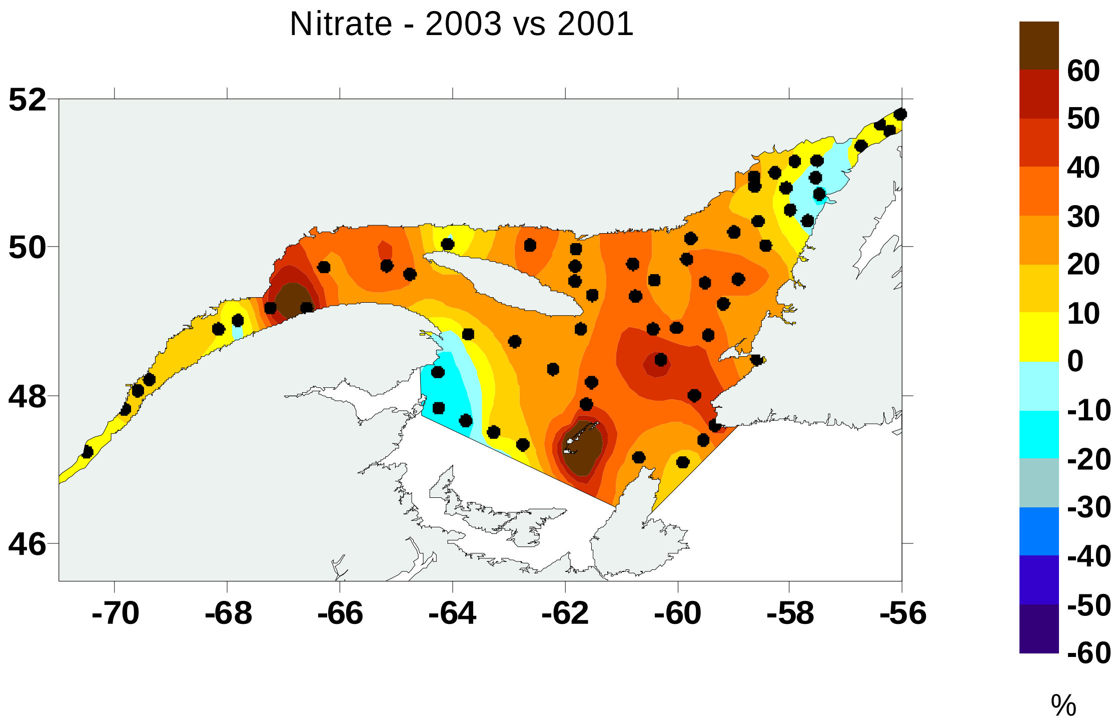


Figure 17. Percentage of change in the late winter nitrate concentrations at 2 m between 2003 and 2002, and 2003 and 2001. Dots indicate the location of sampling stations.

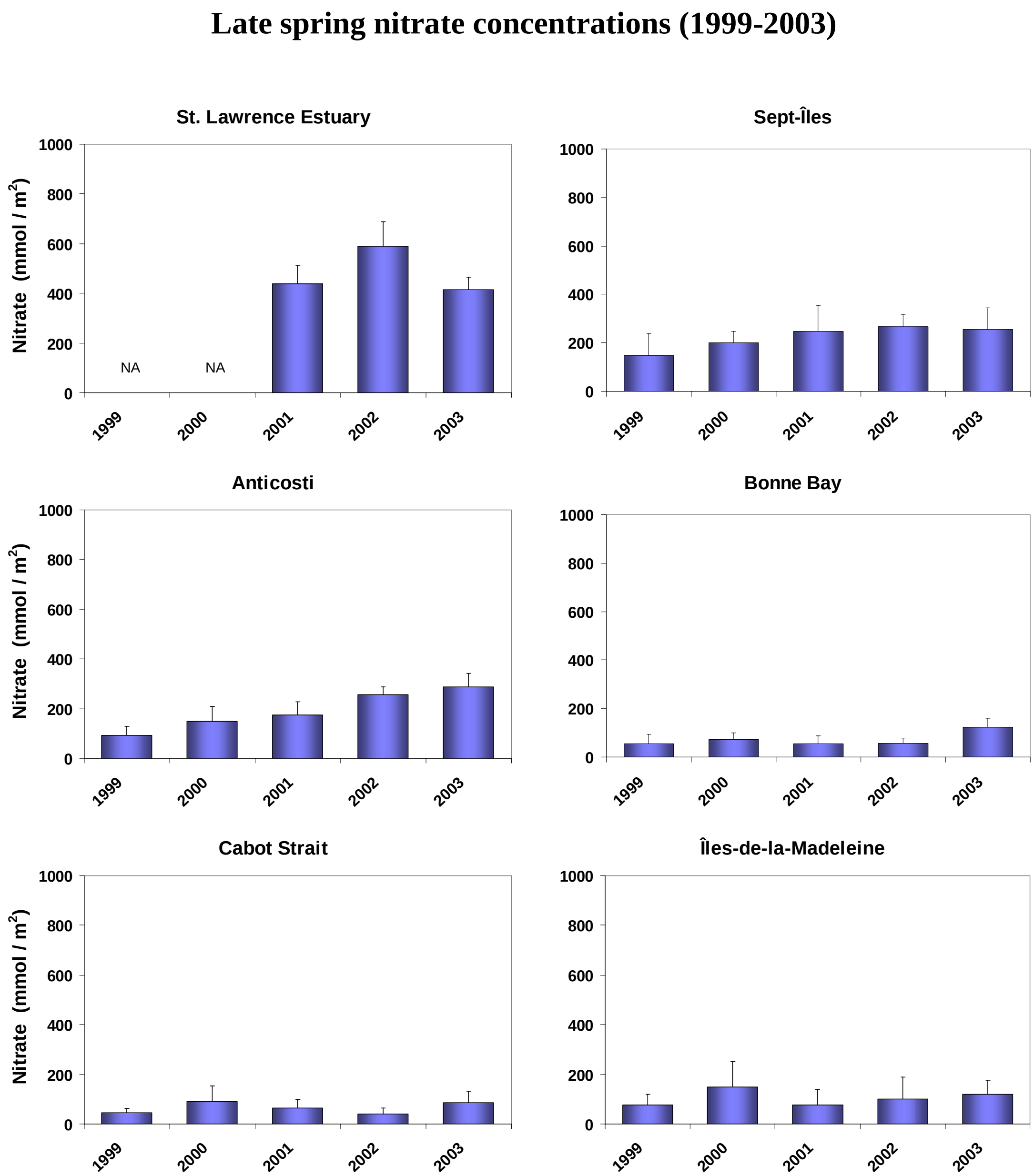


Figure 18. Nitrate concentrations (mmol m^{-2}) along the six sections sampled in late spring (June) in the Estuary and Gulf of St. Lawrence, 1999-2003. Values are integrated over the upper 50 m of the water column. NA: not available.

Fall nitrate concentrations (1999-2003)

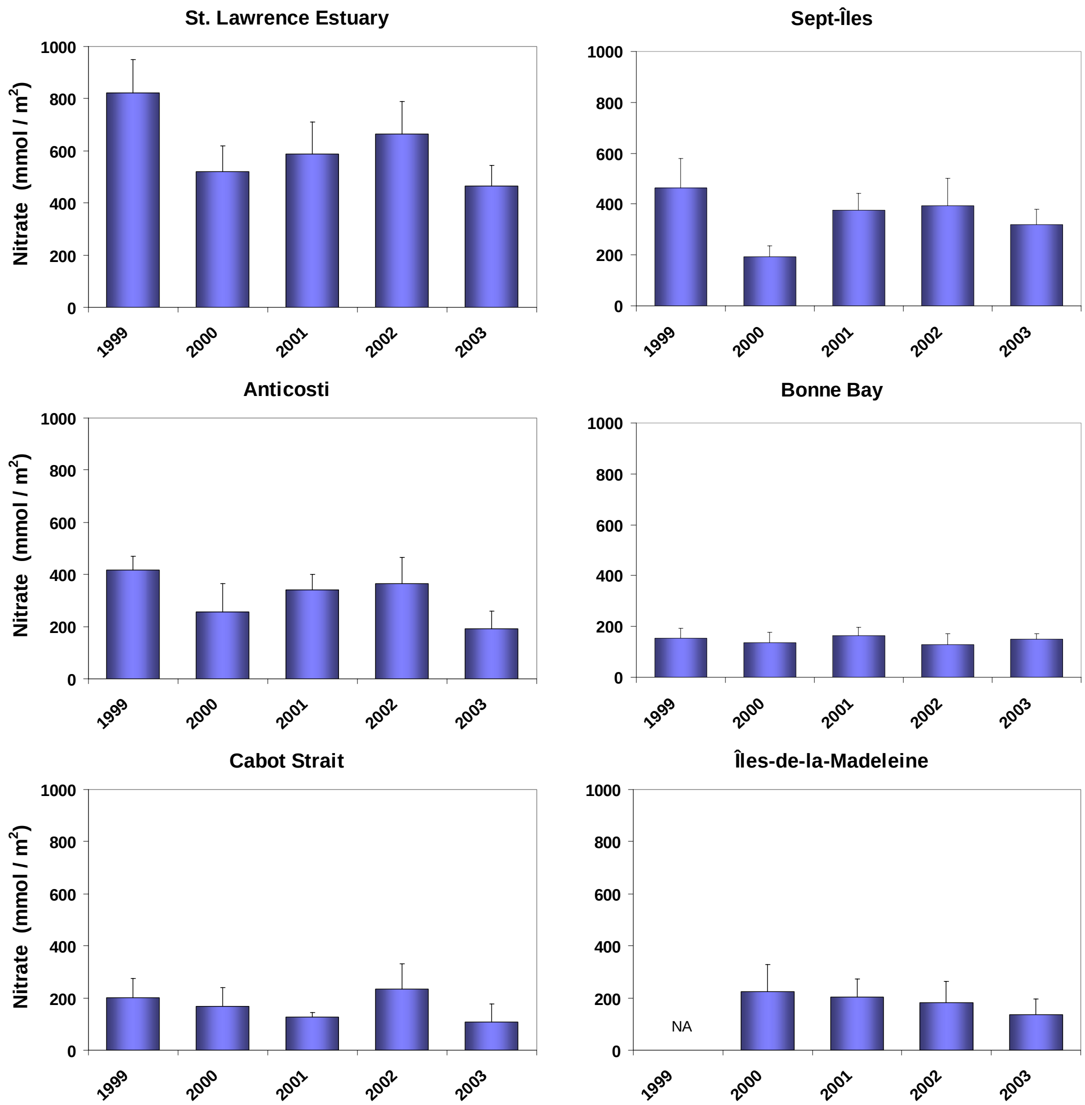


Figure 19. Nitrate concentrations (mmol m^{-2}) along the six sections sampled in fall in the Estuary and Gulf of St. Lawrence, 1999-2003. Values are integrated over the upper 50 m of the water column. NA: not available.

Fall silicate concentrations (1999-2003)

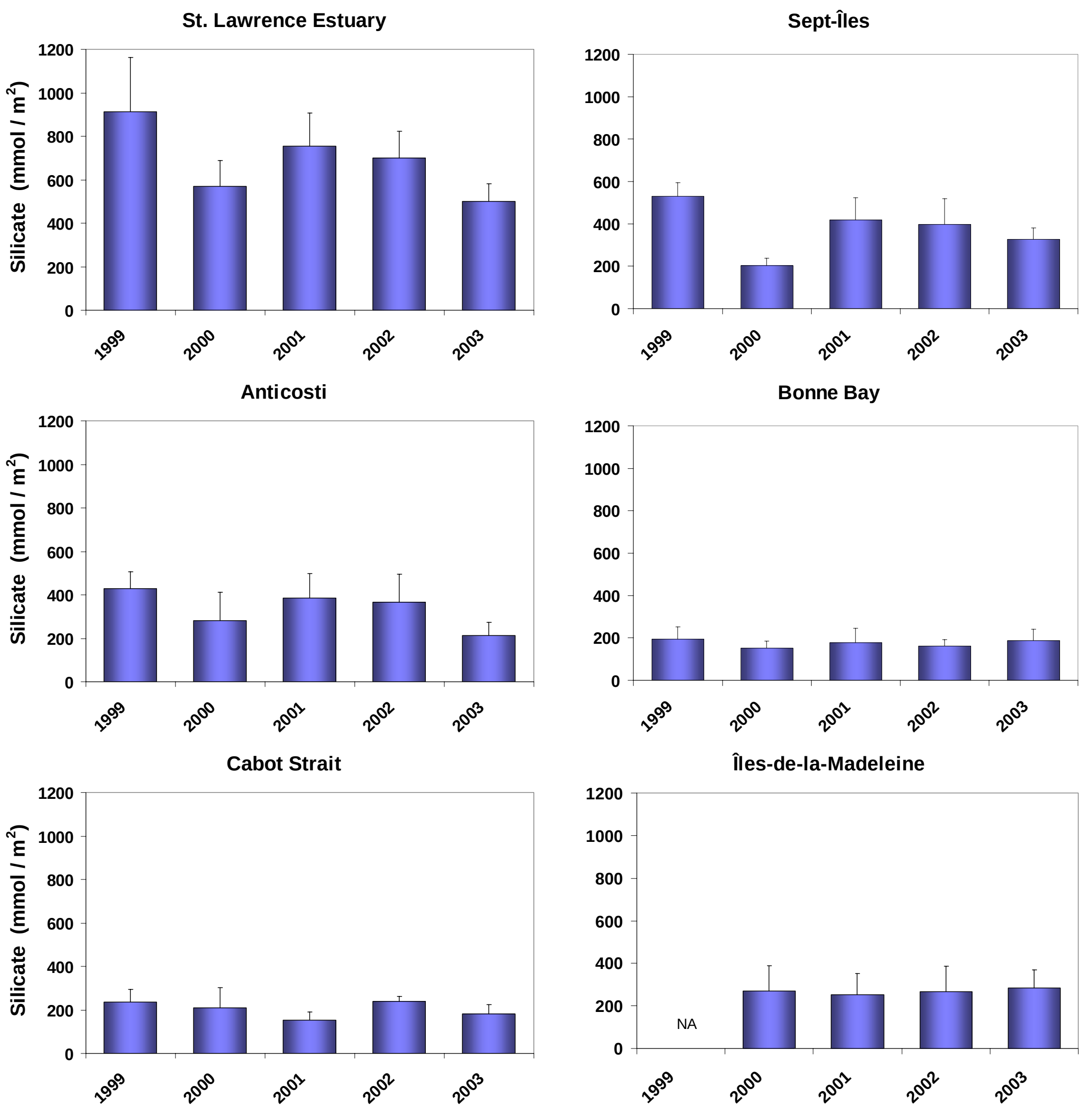


Figure 20. Silicate concentrations (mmol m^{-2}) along the six sections sampled in fall in the Estuary and Gulf of St. Lawrence, 1999-2003. Values are integrated over the upper 50 m of the water column. NA: not available.

Late spring chlorophyll *a* concentrations (1999-2003)

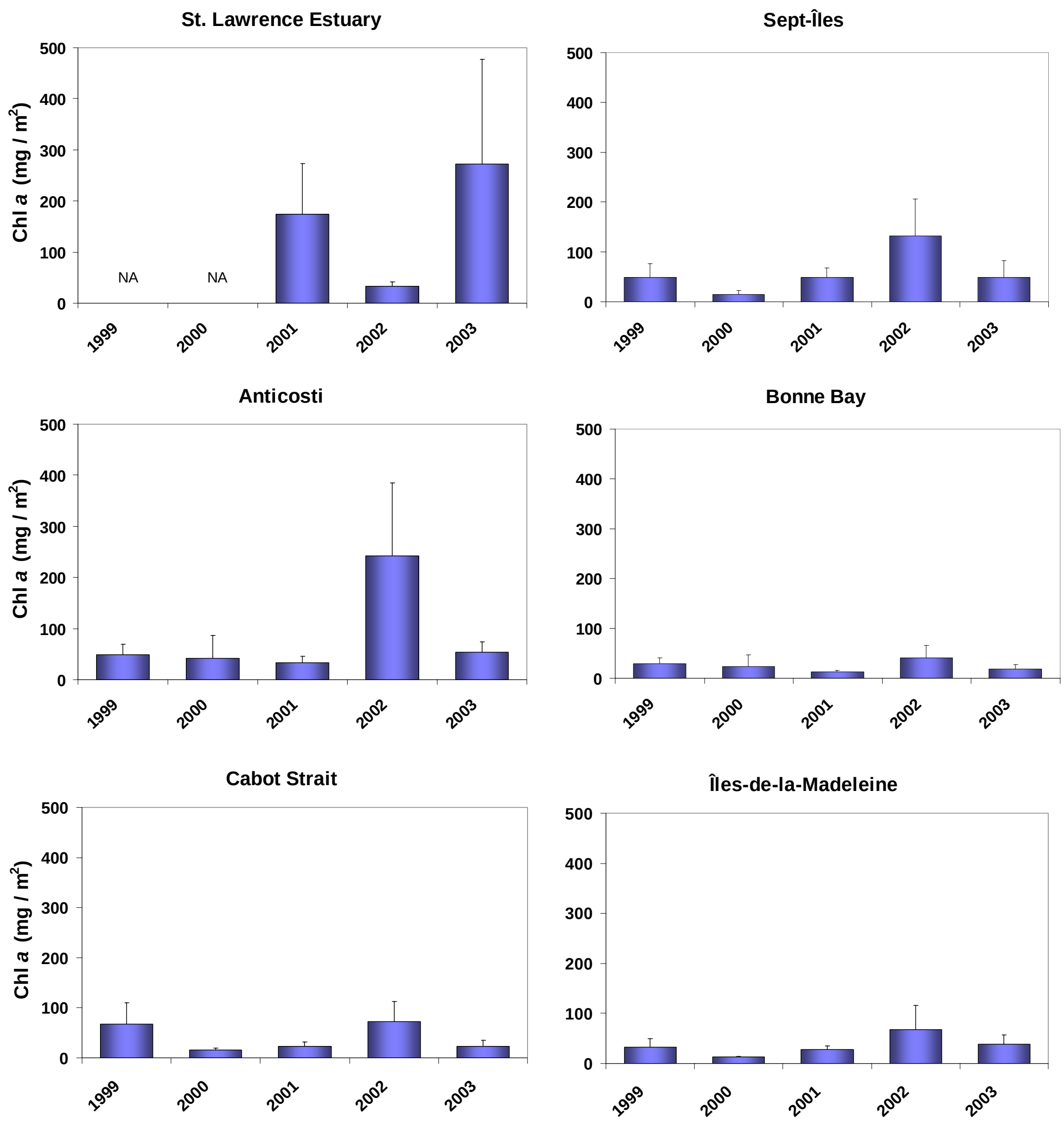


Figure 21. Chlorophyll *a* concentrations (mg m^{-2}) along the six sections sampled in late spring (June) in the Estuary and Gulf of St. Lawrence, 1999-2003. Values are integrated over the upper 50 m of the water column. NA: not available.

Fall chlorophyll concentrations (1999-2003)

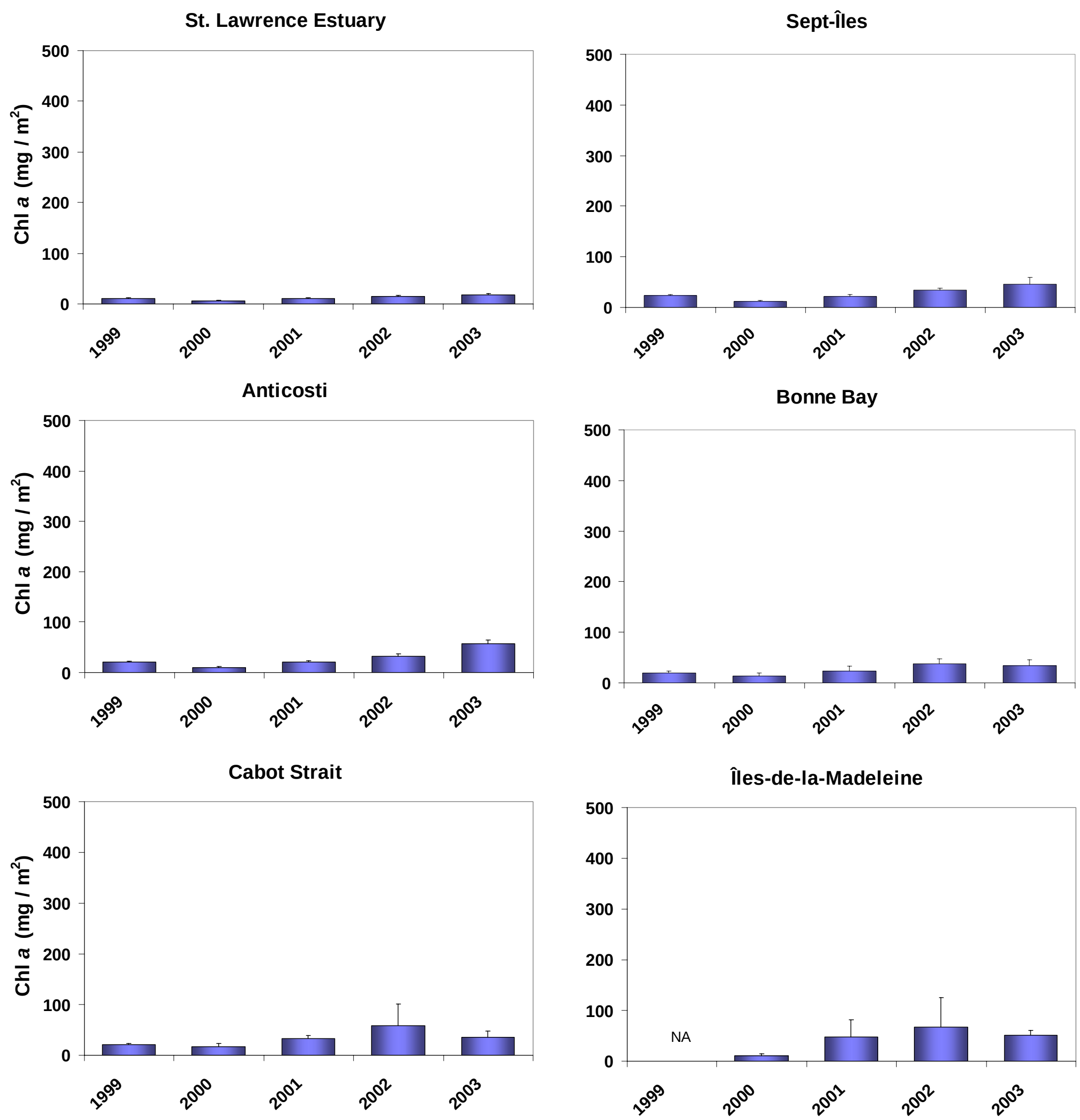


Figure 22. Chlorophyll *a* concentrations (mg m^{-2}) along the six sections sampled in fall in the Estuary and Gulf of St. Lawrence, 1999-2003. Values are integrated over the upper 50 m of the water column. NA: not available.

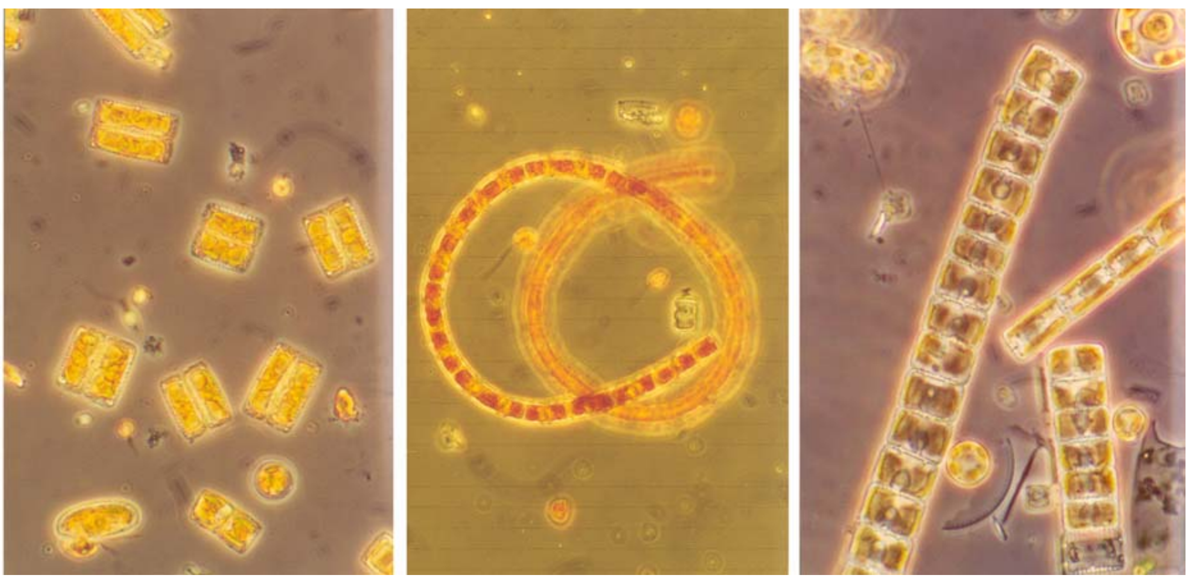


Figure 23. Light photomicrographs of the diatom *Neodenticula seminae* confirming its presence in the St. Lawrence and Labrador Shelf waters, NW Atlantic. This species is a small pennate diatom that belongs to the family Bacillariaceae. It can occur singly or in chains that are sometimes quite long and curved. The frustule is rectangular with rounded corners. The cells are 9–31.5 µm in length (mean: 20.6 µm) and 7–15 µm in width (mean: 10.2 µm).

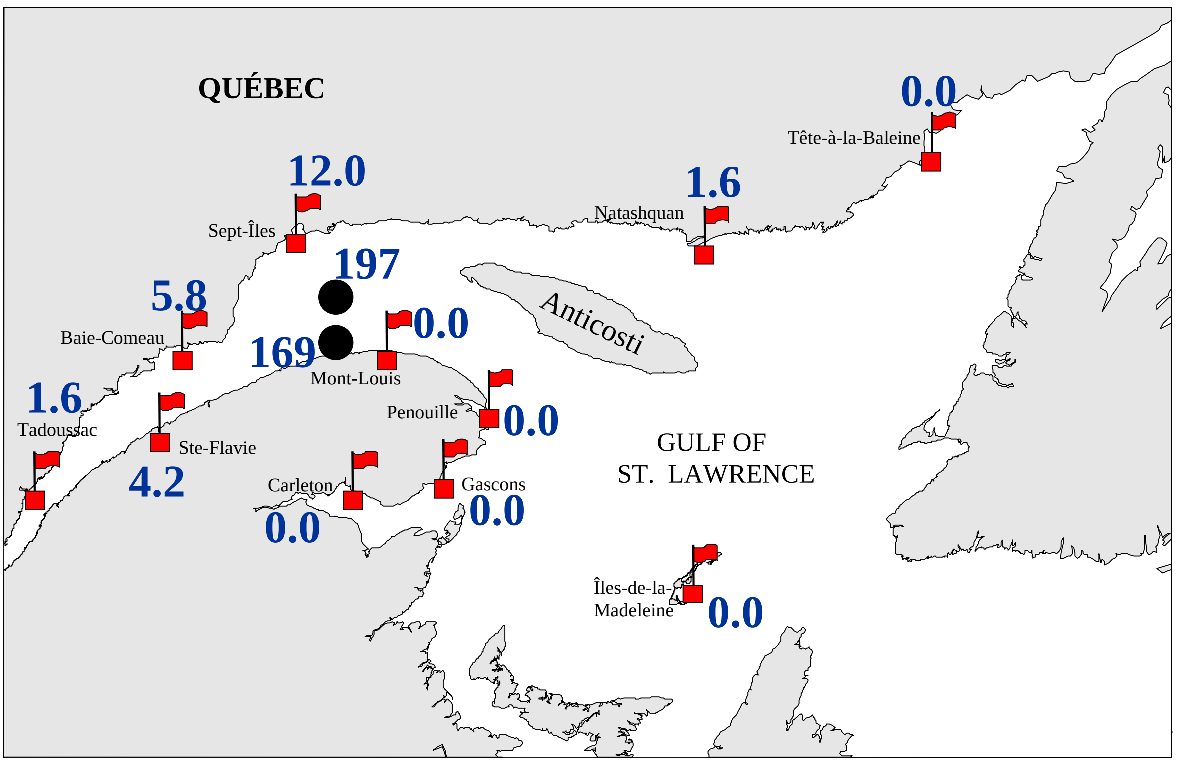


Figure 24. Maximum abundance of the diatom *Neodenticula seminae* (x 10^2 cells litre^{-1}) in 2003 at fixed stations of the Toxic Algae Monitoring Program (red flags) and of the Atlantic Zone Monitoring Program (black dots). Sampling = 0-15 m.