Fisheries and Oceans Canada | Pêches et Océans Canada
Science | Sciences

**C S A S** | **S C C S**

**Canadian Science Advisory Secretariat** | **Secrétariat canadien de consultation scientifique**

**Research Document 2003/103** | **Document de recherche 2003/103**



# State of phytoplankton in the Estuary and Gulf of St. Lawrence during 2002.

# État du phytoplancton dans l'estuaire et le golfe du St-Laurent en 2002.

Michel Starr, Liliane St-Amand, Laure Devine, Lyse Bérard-Therriault

Institut Maurice-Lamontagne
Direction des Sciences Océaniques
Ministère des Pêches et Océans
CP 1000, Mont-Joli, Québec, Canada G5H 3Z4



ISSN 1499-3848 (Printed)

Canada

## ABSTRACT

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 from three fixed stations (Rimouski, Anticosti Gyre and Gaspé Current) and six sections crossing the Estuary and Gulf of St. Lawrence was reviewed. The authors concentrated on conditions prevailing in 2002 but also compared those observations with previous information from the 1992-2001 period.

In 2002, the initiation of the major phytoplankton bloom at Station Rimouski in the Lower St. Lawrence Estuary occurred in late June, which is near the historical mean date. This contrasts with observations made from 1998 to 2001, when the spring phytoplankton bloom began 6-8 weeks earlier than normal (mid to early May). 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.

In the Anticosti Gyre and the Gaspé Current, the depletion of nutrients in the surface layer (0-50 m) during spring occurred later in 2002 compared to the 1996-2001 period, suggesting that phytoplankton growth was also initiated later in 2002 compared to recent years in the northwestern part of the Gulf of St. Lawrence. This was particularly true for the Gaspé Current. The reduction of nutrients in the surface layer during spring-summer was also 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.

For a second consecutive year, the analysis of community composition in 2002 revealed the massive presence of the diatom *Neodenticula seminae* in most areas of the Gulf of St. Lawrence, with concentrations up to $1 \times 10^6$ cells per litre. 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 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 return of *N. seminae* to the Atlantic coast is consistent with recent observations indicating a greater influx of Pacific waters into the Atlantic and the freshening of the North Atlantic waters.

In late spring and early fall 2002, the chlorophyll levels were higher in the southern Gulf of St. Lawrence compared to the previous three years. In the eastern part of the Gulf, the chlorophyll and nitrate levels in the surface layer in late spring and fall 2002 were not notably different from those observed in 1999-2001.

## RÉSUMÉ

Ce document présente une synthèse des données sur les 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) et sur six transects qui traversent l'estuaire et le golfe du Saint-Laurent. Les auteurs se sont concentrés sur les conditions qui prévalaient en 2002, mais ont aussi comparé ces données à celles obtenues de 1992 à 2001.

En 2002, à la station Rimouski, dans le bas estuaire du Saint-Laurent, la principale prolifération de phytoplancton a débuté à la fin de juin, ce qui s'approche de la date moyenne historique. La situation était très différente de 1998 à 2001, lorsque la prolifération printanière a débuté de six à huit semaines plus tôt que la normale (du début à la fin de mai). À la station Rimouski, la biomasse moyenne du phytoplancton au printemps et à l'été 2002 était légèrement supérieure à celles observées de 1992 à 1994, en 1998 et en 2000 et 2001, mais de beaucoup inférieure à celles observées en 1995, en 1997 et en 1999.

Dans la gyre d'Anticosti et surtout dans le courant de Gaspé, l'appauvrissement printanier des éléments nutritifs dans la couche de surface (0-50 m) s'est produit plus tard en 2002 que de 1996 à 2001, ce qui porte à croire que la croissance du phytoplancton a débuté plus tard en 2002 que les années précédentes dans la partie nord-ouest du golfe du Saint-Laurent. L'appauvrissement printanier-estival de la couche de surface en éléments nutritifs était également un peu plus marqué en 2002 qu'en 2000 et en 2001, mais beaucoup moins qu'en 1999. Ainsi, l'évolution des concentrations d'éléments nutritifs indique que la production de phytoplancton dans le nord-ouest du golfe du Saint-Laurent pourrait avoir été plus forte en 2002 que lors des deux années précédentes, mais beaucoup plus faible qu'en 1999, ce qui est compatible avec les données de la station Rimouski dans le bas estuaire du Saint-Laurent.

Pour une deuxième année consécutive, l'analyse de la composition de la communauté en 2002 a montré que la diatomée *Neodenticula seminae* était présente en grand nombre (concentrations atteignant $1 \times 10^6$ cellules par litre) dans la plupart des régions du golfe du Saint-Laurent. Il s'agit d'un phénomène inhabituel puisque cette espèce occupe normalement le Pacifique Nord. Dans l'océan Atlantique, cet espèce n'a été observée que dans des sédiments quaternaires de moyenne à haute latitude datés de 0,84 à 1,2 million d'années. Il est proposé que cette espèce du Pacifique soit apparue de façon naturelle dans le golfe (en passant par l'océan Arctique, le courant du Labrador et le détroit de Belle Isle) plutôt qu'à la suite de son transport dans des eaux de ballast. Le retour de *N. seminae* près de la côte atlantique est compatible avec des observations récentes qui indiquent une pénétration accrue d'eaux du Pacifique dans l'Atlantique et un plus grand apport d'eau douce dans les eaux de l'Atlantique Nord.

En 2002, les concentrations de chlorophylle dans le sud du golfe du Saint-Laurent à la fin du printemps et au début de l'automne étaient plus élevées que les trois années précédentes. Par contre, dans l'est du golfe, les concentrations de chlorophylle et de nitrates dans la couche de surface à la fin du printemps et au début de l'automne 2002 ne différaient pas de façon marquée de celles observées aux mêmes périodes de 1999 à 2001.

## INTRODUCTION

This report presents the state of phytoplankton prevailing in the Estuary and Gulf of St. Lawrence in 2002. Information is essentially derived from AZMP (Atlantic Zonal Monitoring Program) data collected at a network of stations (fixed point stations and cross-shelf sections) sampled at a frequency of weekly to twice per year (Figures 1 and 2). Additional information from various research programs (Toxic Algae Monitoring Program, Station Rimouski) are also used to complete this annual review.

## METHODS

Collections 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 Atlantic Zonal Monitoring Program (www.meds-sdmm.dfo-mpo.gc.ca).

## 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 timing, duration, and magnitude of the spring phytoplankton bloom in the Lower St. Lawrence Estuary. This station has been visited on a weekly basis from May to September since 1992 (Figure 3).

In 2002, the standing stock of phytoplankton at Station Rimouski, as reflected by the amount of chlorophyll *a* (Figure 3), showed a major pulse in June-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 mid May and mid August, when two small blooms of short duration were observed (Figures 3 and 4). Phytoplankton species responsible for the June-July bloom were the diatoms *Thalassiosira gravida*, *T. nordenskioeldii*, *T. pacifica*, *Chaetoceros* spp., *Skeletonema costatum*. These species were gradually replaced in September by *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; Figures 4 and 5) but 6-8 weeks earlier 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. Data 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 the primary bloom starting 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 near-normal spring freshwater runoff in the St. Lawrence basin in 2002 compared to the 1998-2001 period (Gilbert and Lafleur 2003) 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 (Figure 6). In particular, phytoplankton biomass in July 2002 was much higher compared to the two previous years (Figure 4).

**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 identifiable 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 Gulf of St. Lawrence proper (Levasseur *et al.* 1992). Within the AZMP, these two systems have been monitored at a frequency of 9 to 19 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 (Figures 7 and 8). 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 (Figures 7 and 8). The spring decrease in the surface nutrients occurred approximately six weeks earlier in the Anticosti Gyre than in the Gaspé Current (Figure 8), 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 low salinity surface waters (Figures 3 and 7). 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 (Figures 7 and 8) that was 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 (Figures 7 and 8). A deep chlorophyll maximum layer was nevertheless observed at 35 m from late June to late August at the base of the nutricline (Figure 7), which is typical (Levasseur *et al.* 1992). 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 (not shown here).

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 (Figure 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.

**Other regions of the Gulf**

**Sections.** 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 on a broader spatial coverage. Sections were occupied during late spring (June) and mid-fall (November) 2001 (Figure 2). This sampling program has been in place since 1999.

Vertical distributions of nitrate and silicate were generally similar along the six seasonal sections in spring and fall 2002, i.e. concentrations increased with depth (Figures 9 and 10). 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 with depth but to a greater degree than did nitrate (Figure 10), which is typical for the Gulf of St. Lawrence (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 10). 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 2002 were comparable to those in 2001 (Starr *et al.* 2002).

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 (Figures 9 and 10). 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 (e.g., Steven 1974).

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 (Figures 9 and 11). This is also true for the silicate concentrations except for the estuarine portion of the Gulf where the fall silicate levels were lower compared to spring (Figures 10 and 12). This typical inversion for the St. Lawrence Estuary compared to the other regions is probably due to spring inputs of silicate from the river water.

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 (Figures 13 and 14). In contrast, the nitrate and silicate depletion during the spring 2002 was 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. In spite that, 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 (Figures 15 and 16).

Overall, chlorophyll levels in 2002 were higher during the spring survey than during the fall survey, which is typical (Figures 17 and 18). During the spring survey of 2002, higher chlorophyll levels were observed in the northwestern and southern parts of the Gulf of St. Lawrence (Figures 17 and 18). Inversely, 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 (Figure 19), 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 (Figure 20).

**Satellite observations.** 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 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.

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. 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.

**Toxic Algae Monitoring Program.** Within the toxic algae monitoring program, phytoplankton samples were collected from May to September at 10 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 Maurice Lamontagne Institute since 1989.

In 2002, the analysis of these samples revealed for a second consecutive year the massive presence 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 (Figures 21 and 22). This phenomenon is unusual (Starr *et al.* 2002; Bérard-Therriault *et al.* 2002) since this species

is usually 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 the 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). In fact, the past occurrence of *N. seminae* in the North Atlantic has principally been associated with the presence of low salinity surface waters in the Atlantic during the early Quaternary (Baldauf 1986). Impacts of this 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 the phytoplankton composition in the Estuary and Gulf of St. Lawrence in 2002. Prominent events in 2002 :

1) 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;

2) 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;

3) on the basis of the nutrient evolution, the phytoplankton production of phytoplankton 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;

4) in contrast to 2001, the field observations and satellite data revealed great differences in the timing of the 2002 spring bloom in the St. Lawrence basin;

5) 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.

## ACKNOWLEDGEMENTS

We thank Alain Gagné, Marie-Lyne Dubé, Yves Gagnon, Pierre Joly, and Esther Bonneau for their steadfast work on this project. The taxonomic expertise of Dr. Michel Poulin (Museum of the Nature, Ottawa) was crucial for the completion of this work. A special thanks goes to Dr. F. Akiba (JAPEX Research Center, Chiba, Japan) and Dr. Y. Yanagisawa (Geological Museum, Geological Survey of Japan, Tsukuba, Japan) for confirming the identification of *Neodenticula seminae*. This is a contribution to the Atlantic Zonal Monitoring Program, Fisheries and Oceans Canada.

## REFERENCES


Baldauf J.G. (1986). Diatom biostratigraphic and paleoceanographic interpretations for the middle to high latitude North Atlantic Ocean. In: Summerhayes C.P. and N.J. Shackleton (eds) North Atlantic Paleoceanography, Geological Society Special Publication No. 21, pp. 243-252.

Bérard-Therriault L., Starr M., Poulin M. and S. Roy (2002). A very unusual spring bloom in the Gulf of St. Lawrence, eastern Canada: The rebirth of the diatom *Neodenticula seminae*. In Proceedings of the 17th International Diatom Symposium. Canadian Museum of Nature, Ottawa (Ont.), Canada, 25-31 August.

Coote A.R. and P.A. Yeats (1979). Distribution of nutrients in the Gulf of St. Lawrence. Journal of the Fisheries Research Board of Canada **36**: 122-131.

Dickson B. (1999). Oceanography: All change in the Arctic. Nature **397**: 389-391.

Dickson B., Yashayaev I., Meincke J., Turrelli B., Dye S. and J. Holfort (2002). Rapid freshening of the deep North Atlantic Ocean over the past four decades. Nature **416**: 832-837.

Gilbert D. and C. Lafleur (2003). Oceanographic conditions in the Gulf of St. Lawrence in 2002. DFO Science Stock Status Report (In press).

Levasseur M., Fortier L., Therriault J.-C. and P. Harrison (1992). Phytoplankton dynamics in a coastal jet frontal region. Marine Ecology Progress Series **86**: 283-295.

Levasseur M., Therriault J.-C. and L. Legendre (1984). Hierarchical control of phytoplankton succession by physical factors. Marine Ecology Progress Series **19**: 211-222.

Plourde S. and J.A. Runge (1993). Reproduction of the planktonic copepod *Calanus finmarchicus* in the Lower St. Lawrence Estuary: relation to the cycle of phytoplankton production and evidence for a Calanus pump. Marine Ecology Progress Series **102**: 217-227.

Savenkoff C., Vézina A.F., Smith P.C. and G. Han (2001). Summer transports of nutrients in the Gulf of St. Lawrence estimated by inverse modelling. Estuarine, Coastal and Shelf Science **52**: 565-587.

Sinclair M. (1978). Summer phytoplankton variability in the lower St. Lawrence Estuary. Journal of the Fisheries Research Board of Canada **35**: 1171-1185.

Starr M., Himmelman J.H. and J.-C. Therriault (1993). Environmental control of green sea urchin, *Strongylocentrotus droebachiensis*, spawning in the St. Lawrence Estuary. Canadian Journal of Fisheries and Aquatic Sciences **50**: 894-901.

Starr M., St-Amand L. and L. Bérard-Therriault (2002). State of phytoplankton in the Estuary and Gulf of St. Lawrence during 2001. DFO RES DOC **2002/046**, 29 p.

Steven D. M. (1974). Primary and secondary production in the Gulf of St. Lawrence. Mc Gill University Marine Science Center MS Report. **26**:116 p.

Therriault J.-C. and M. Levasseur (1985). Control of phytoplankton production in the Lower St. Lawrence Estuary: light and freshwater runoff. Naturaliste canadien **112**: 77-96.

Yanagisawa Y. and F. Akiba (1990). Taxonomy and phylogeny of three marine diatom genera, *Crucidenticula*, *Denticulopsis* and *Neodenticula*. Bulletin of the Geological Survey of Japan **41**: 197-301.

Zakardjian A.B., Gratton Y. and A. F. Vezina (2000). Late spring phytoplankton bloom in the Lower St. Lawrence Estuary: the flushing hypothesis revisited. Marine Ecology Progress Series **192**: 31-48.

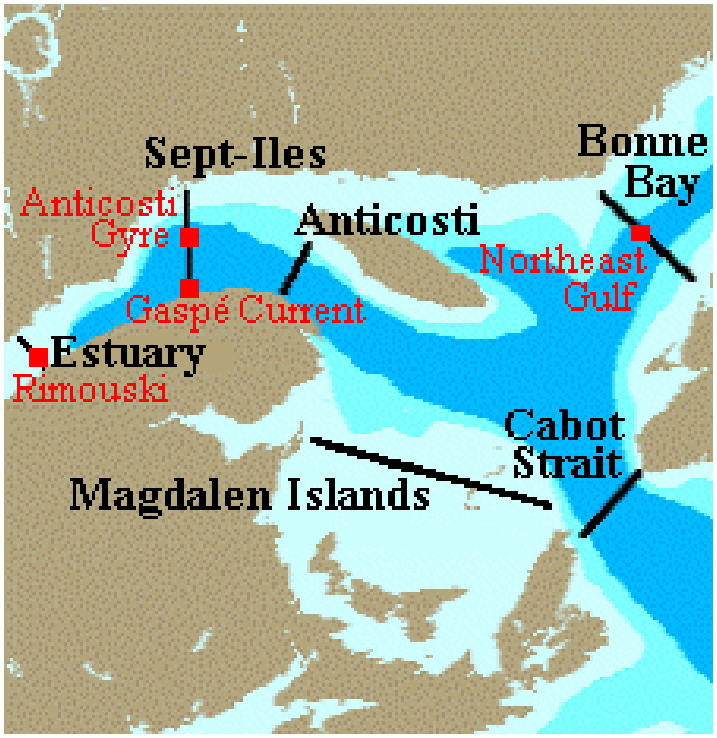


**Figure 1.** Atlantic Zonal Monitoring Program (AZMP) sections (black lines) and fixed stations (red squares).

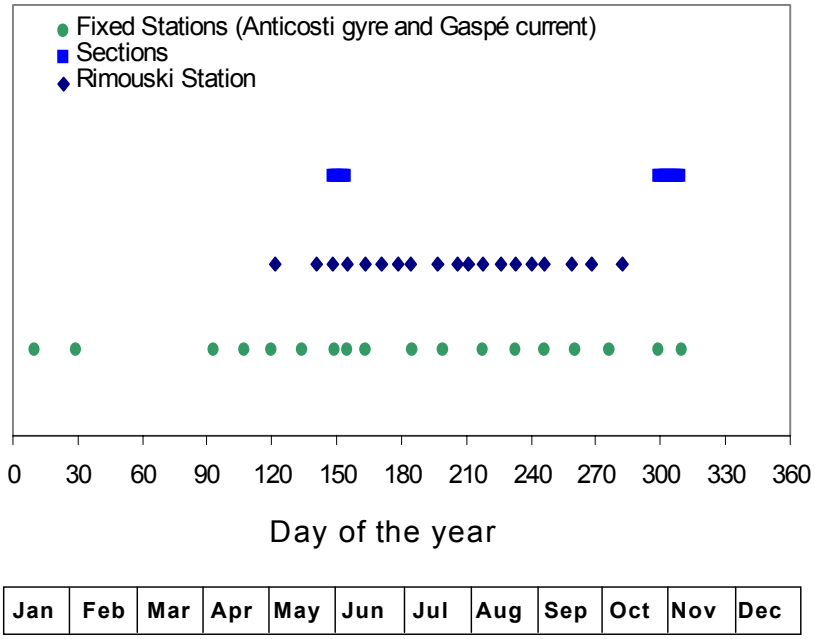


**Figure 2.** Sampling dates for fixed stations and sections for 2002.

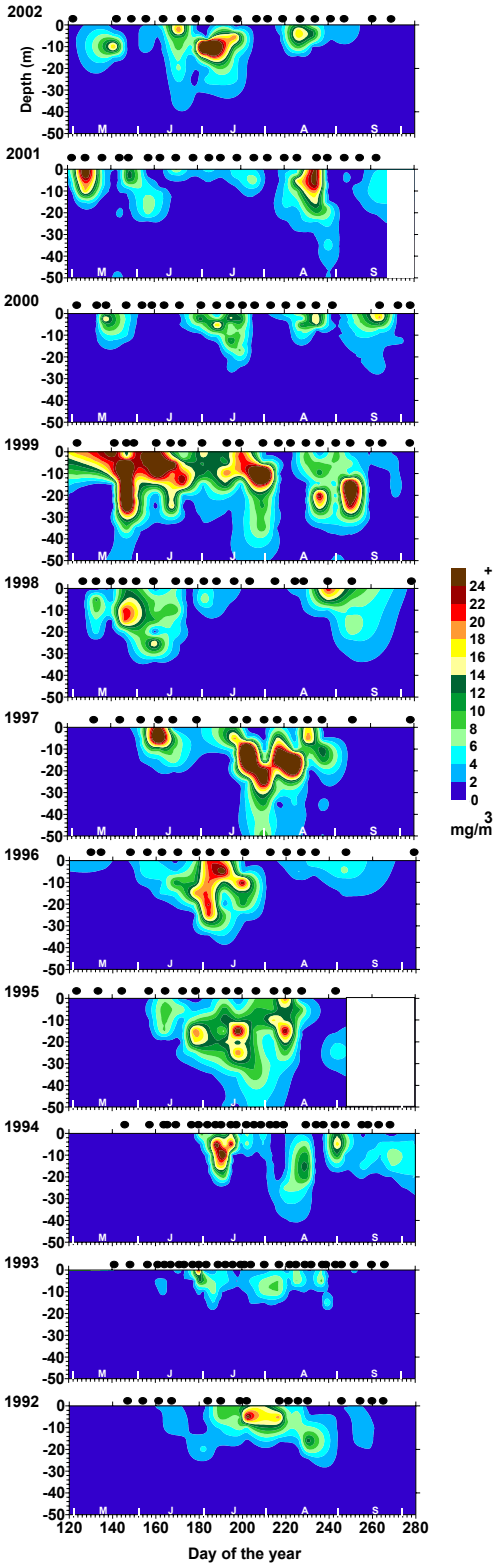


**Figure 3.** Chlorophyll *a* concentration (mg / $m^3$) at the Rimouski station from May to September between 1992 and 2002. The black dots over each graph indicate the precise sampling date.

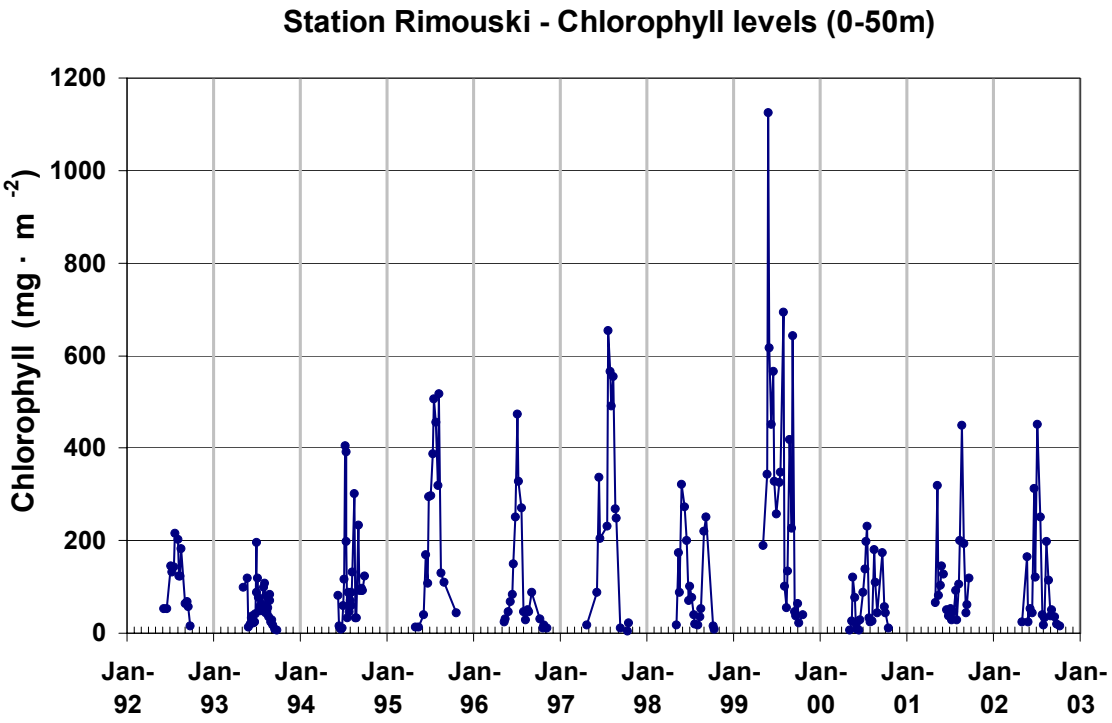


**Figure 4.** Chlorophyll *a* concentrations (mg / $m^2$) integrated over the upper 50 m at Station Rimouski during spring-summer 1992-2002.

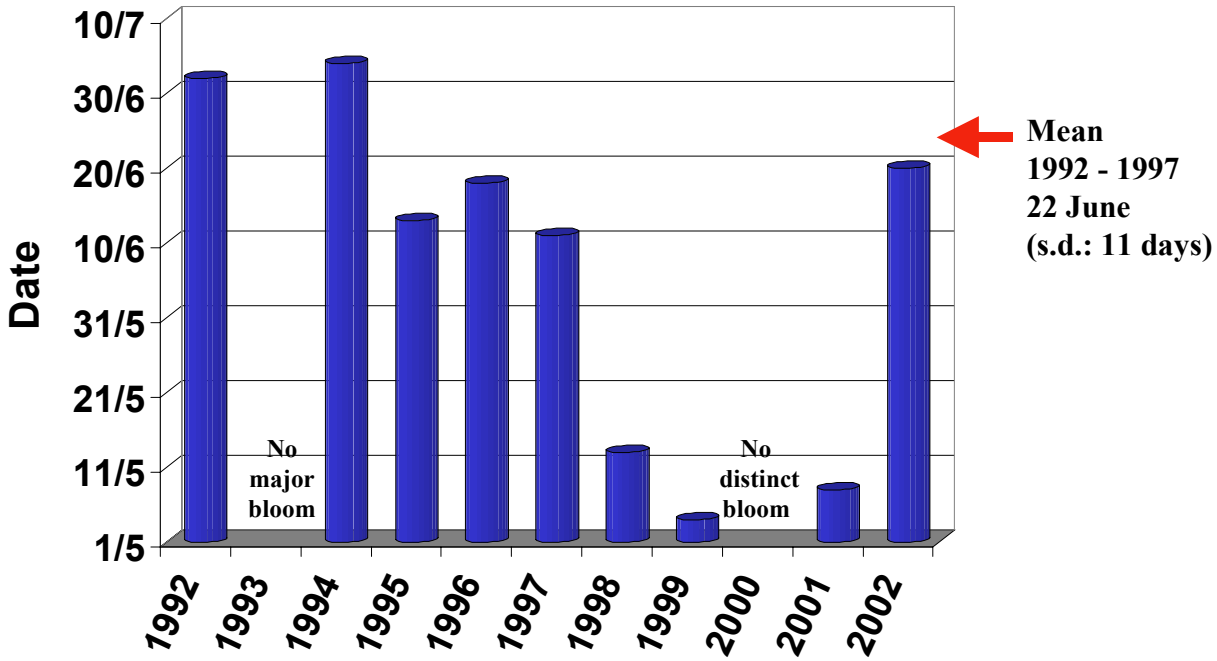


**Figure 5.** Date of onset of the primary bloom defined by the first incidence of chlorophyll concentrations greater than 100 mg of chlorophyll *a* per $m^2$ at Station Rimouski, 1992-2002.

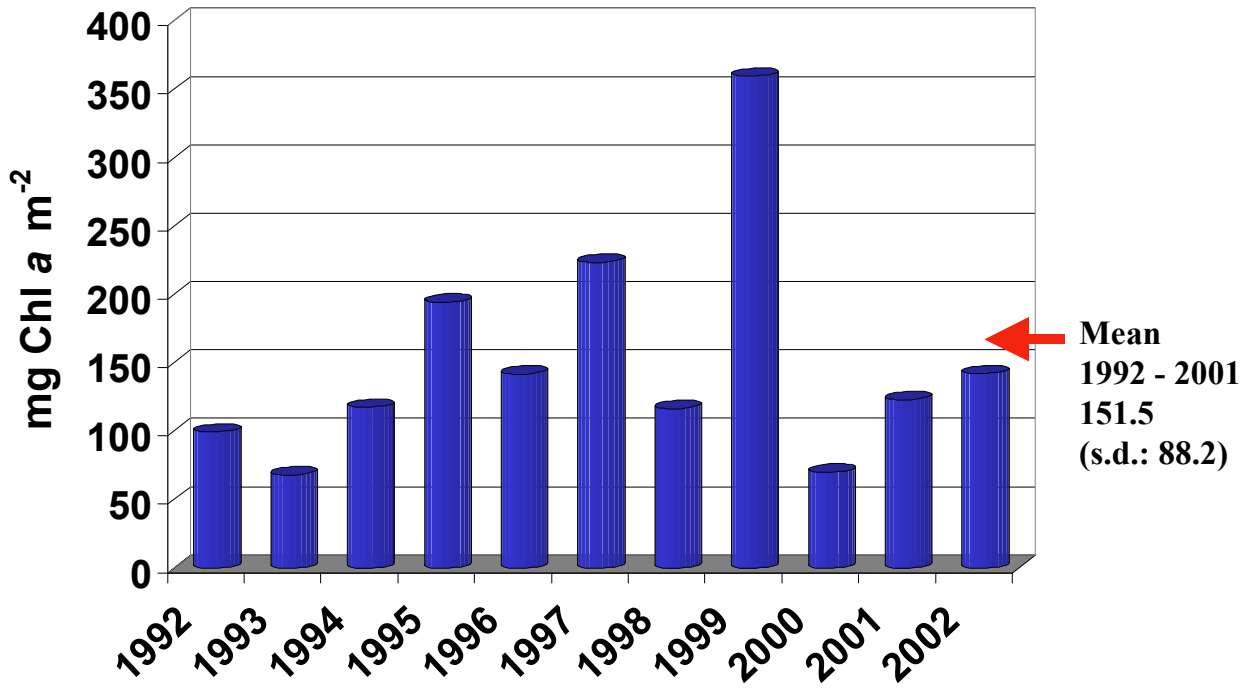


**Figure 6.** Mean integrated (surface to 50m depth) chlorophyll *a* levels at Station Rimouski from May to August, 1992-2002.

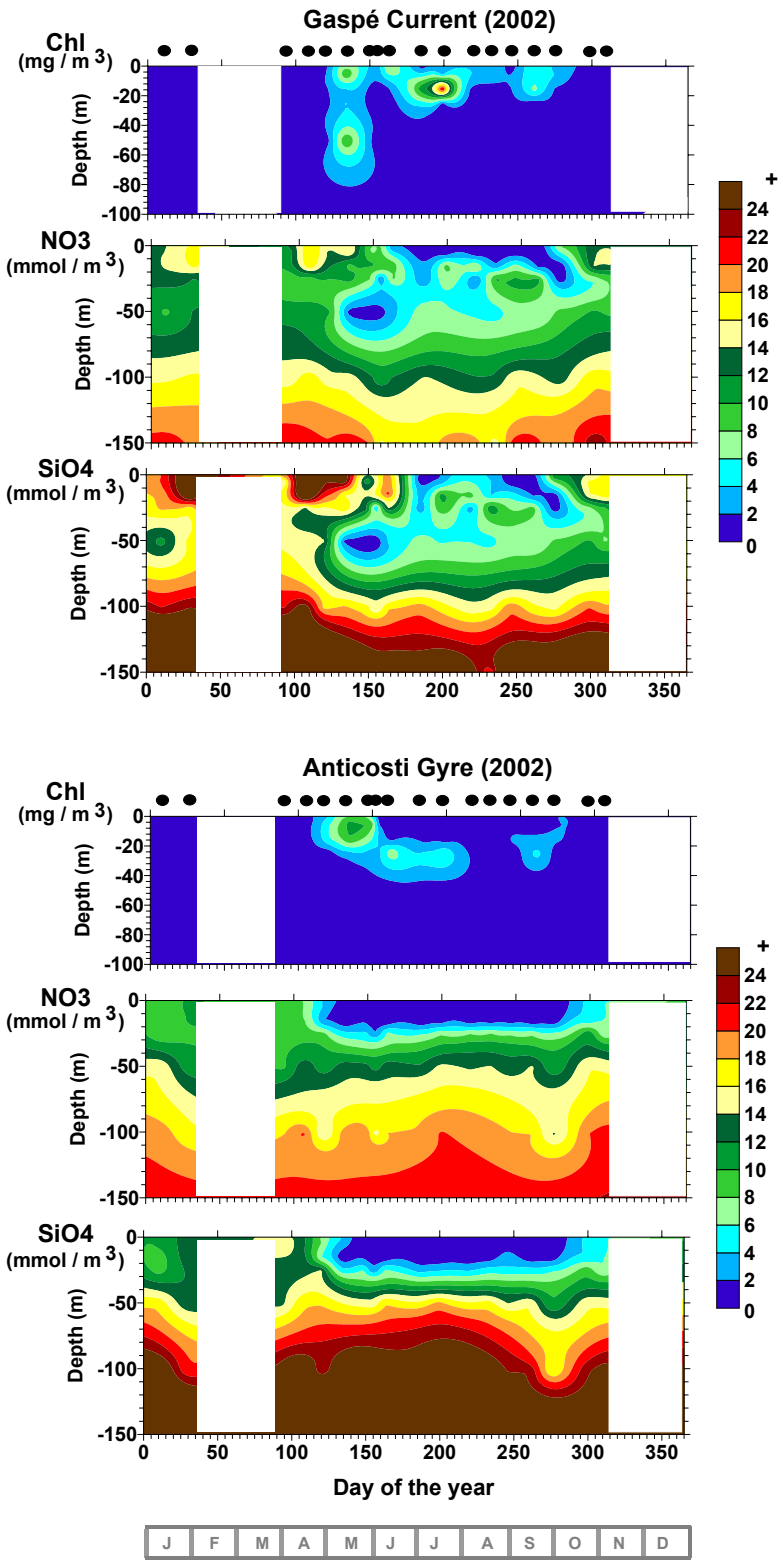


**Figure 7.** Vertical profiles of chlorophyll *a* (mg / $m^3$), nitrate (mmol / $m^3$) and silicate (mmol / $m^3$) concentrations in the Gaspé Current and Anticosti Gyre during 2002. The black dots above the graphs indicate the exact sampling dates.

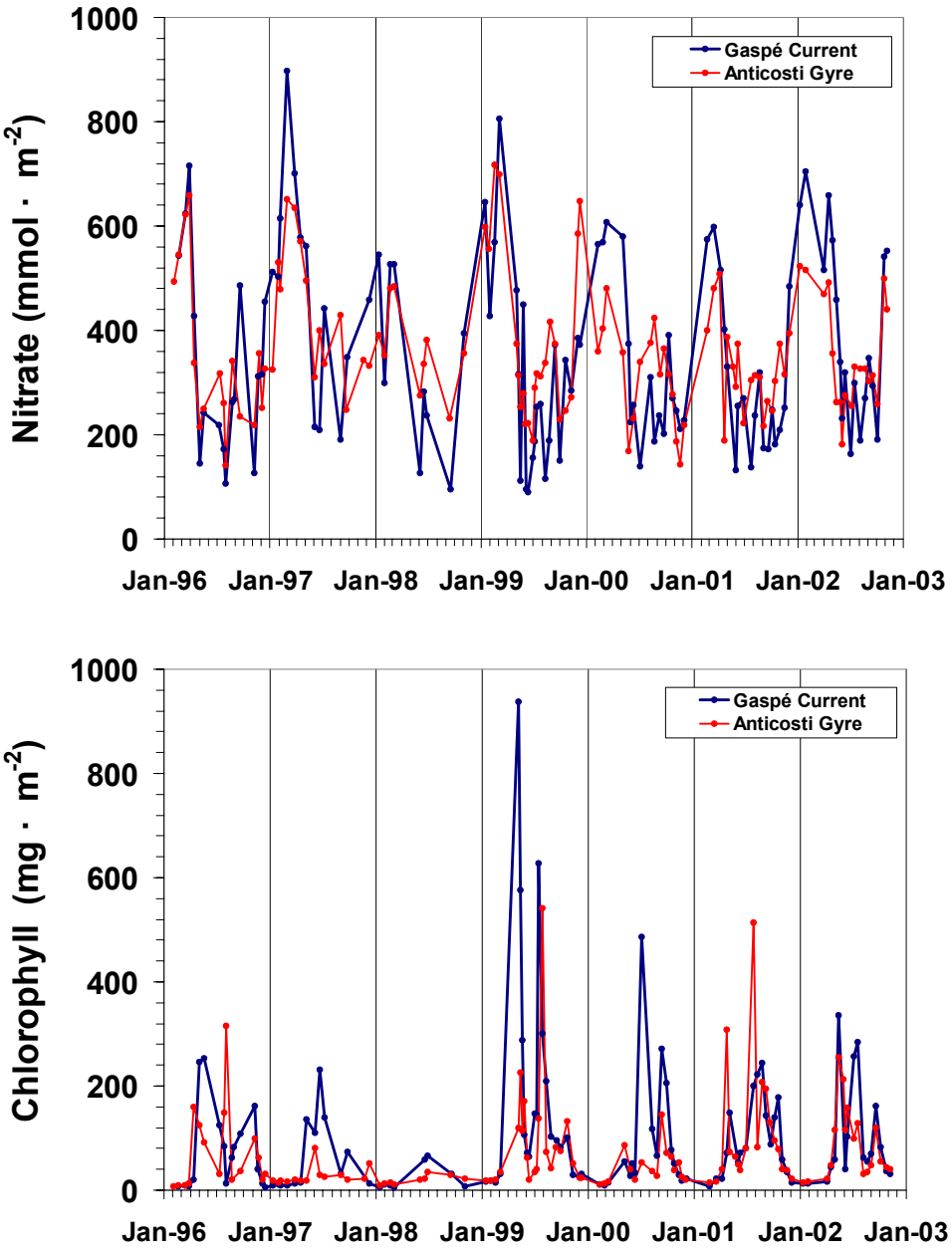


**Figure 8.** Nitrate (mmol / $m^2$) and chlorophyll *a* (mg / $m^2$) concentrations in the Gaspé Current and Anticosti Gyre, 1996-2002. Values are integrated over the upper 50 m of the water column.

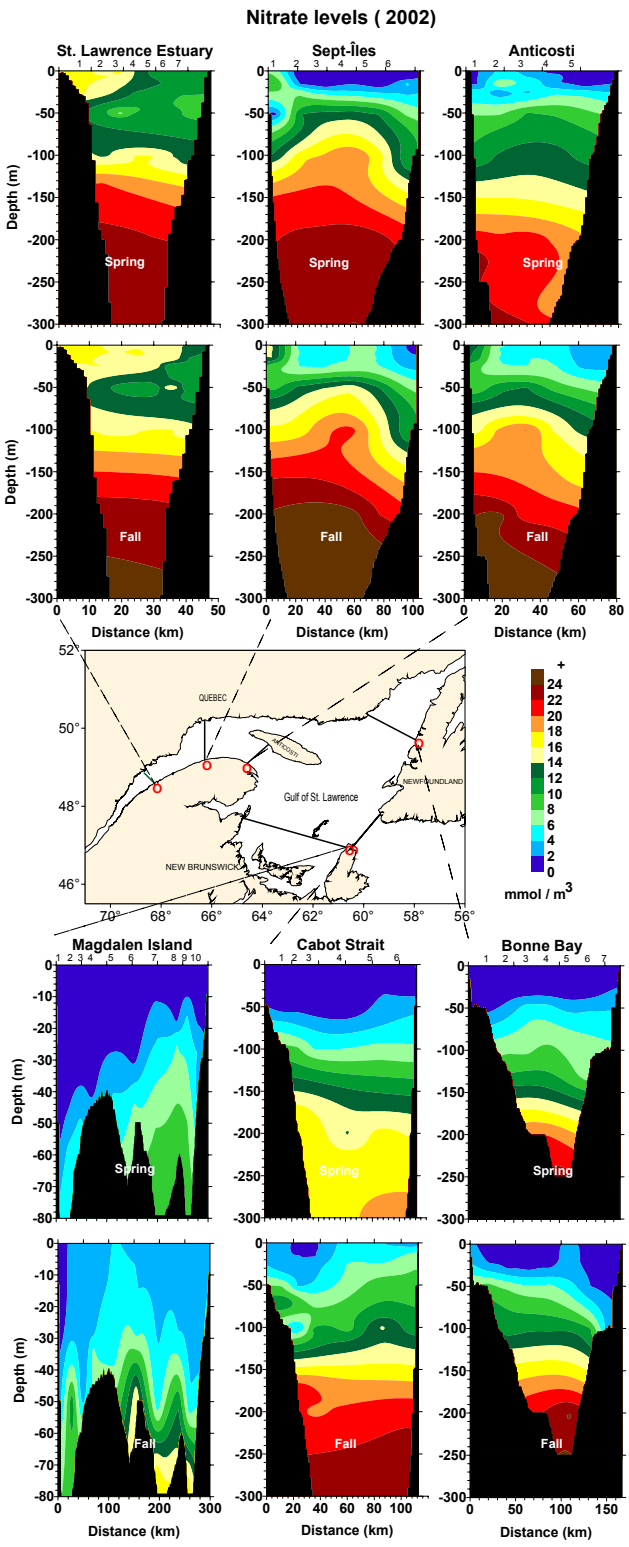


**Figure 9.** Concentrations of nitrate (mmol / $m^3$) versus depth along the six sections sampled in late spring (June) and fall (November) 2002 in the Estuary and Gulf of St. Lawrence. The numbers over graphs indicate the location of sampling stations. Red circle: starting point.

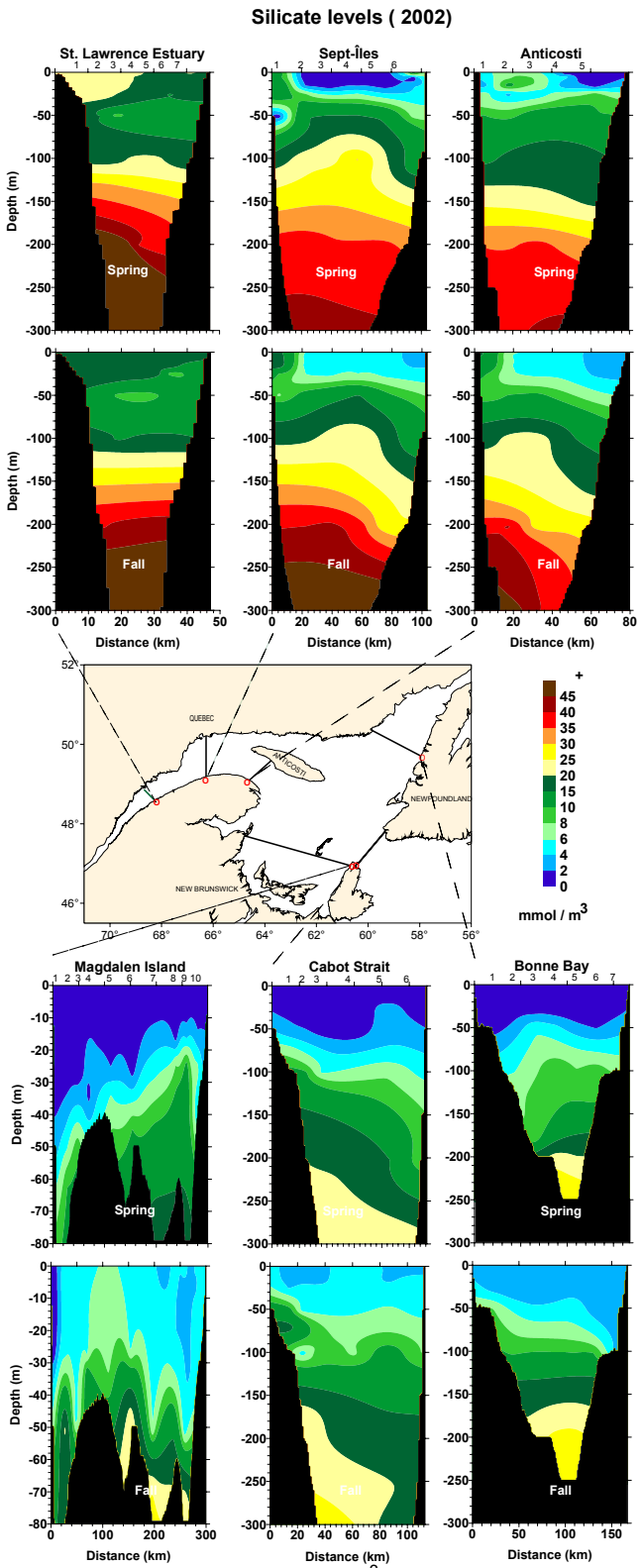


**Figure 10.** Concentrations of silicate (mmol / $m^3$) versus depth along the six sections sampled in late spring (June) and fall (November) 2002 in the Estuary and Gulf of St. Lawrence. The numbers over graphs indicate the location of sampling stations. Red circle: starting point.

# Nitrate levels (Spring & Fall 2002)

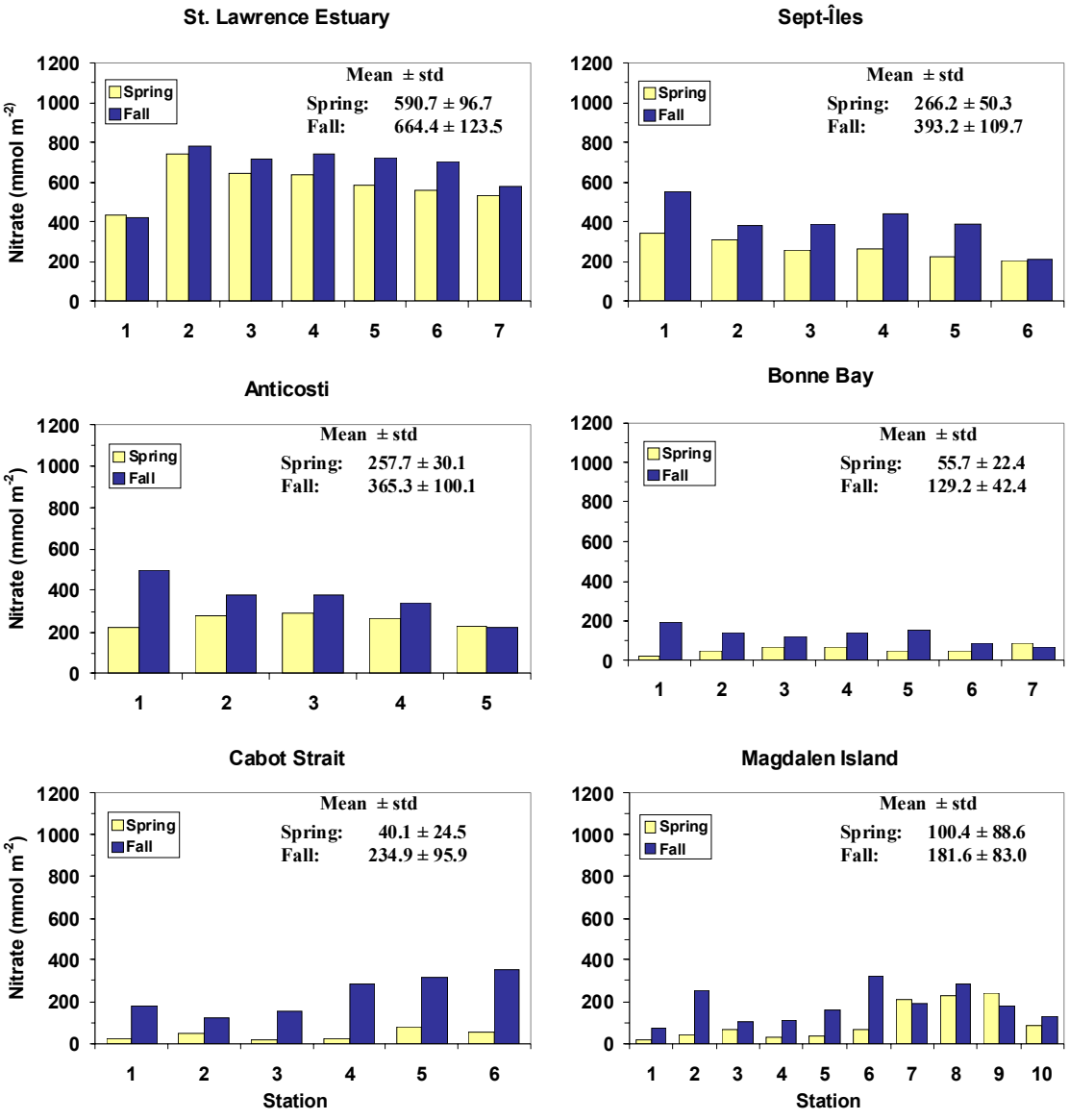


**Figure 11.** Nitrate concentrations (mmol / $m^2$) along the six sections sampled in late spring (June) and fall (November) 2002 in the Estuary and Gulf of St. Lawrence. Values are integrated over the upper 50 m of the water column.

# Silicate levels (Spring & Fall 2002)

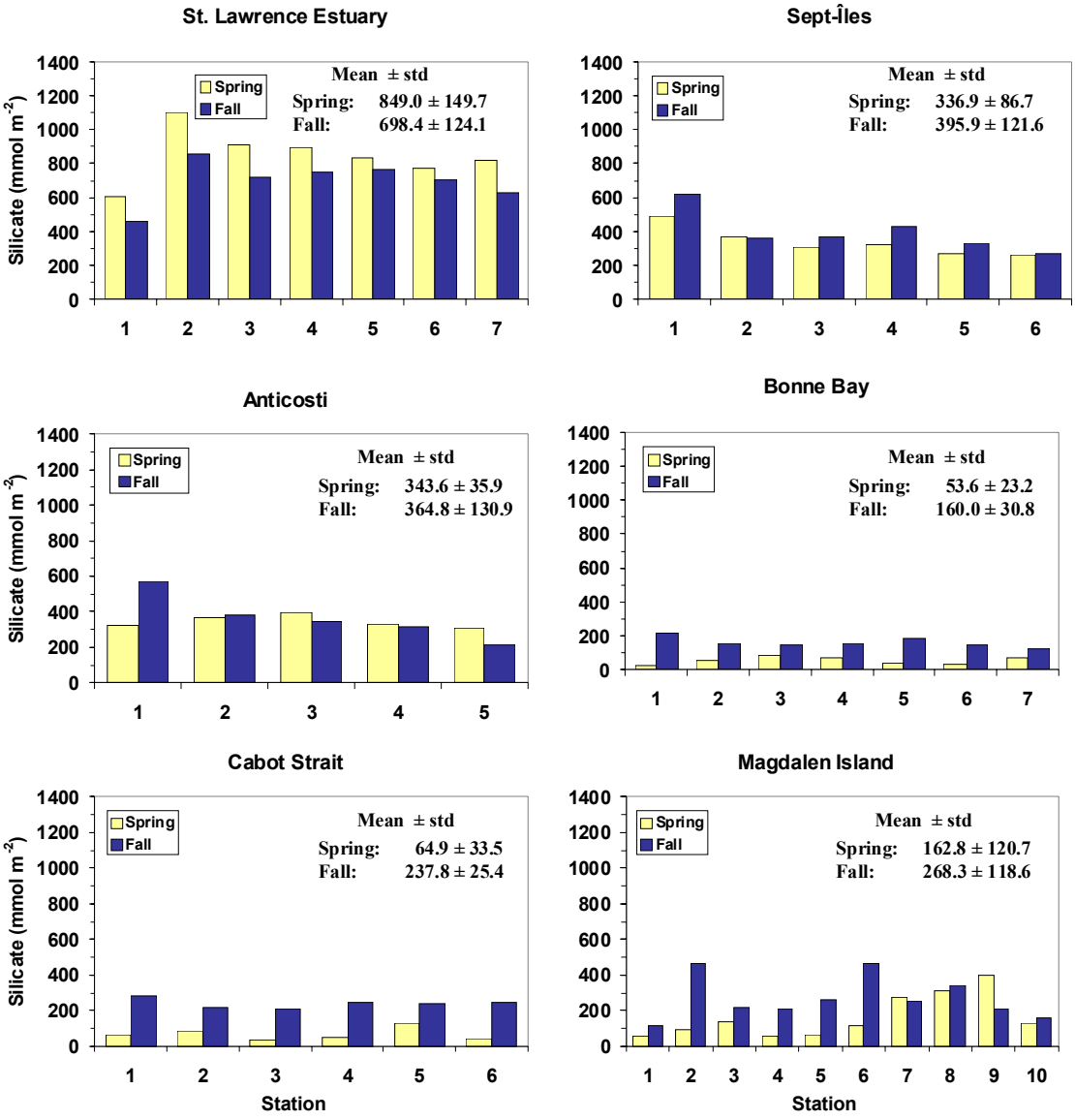


**Figure 12.** Silicate concentrations (mmol / $m^2$) along the six sections sampled in late spring (June) and fall (November) 2002 in the Estuary and Gulf of St. Lawrence. Values are integrated over the upper 50 m of the water column.

# Spring nitrate concentrations (2002 vs 1999-2001)

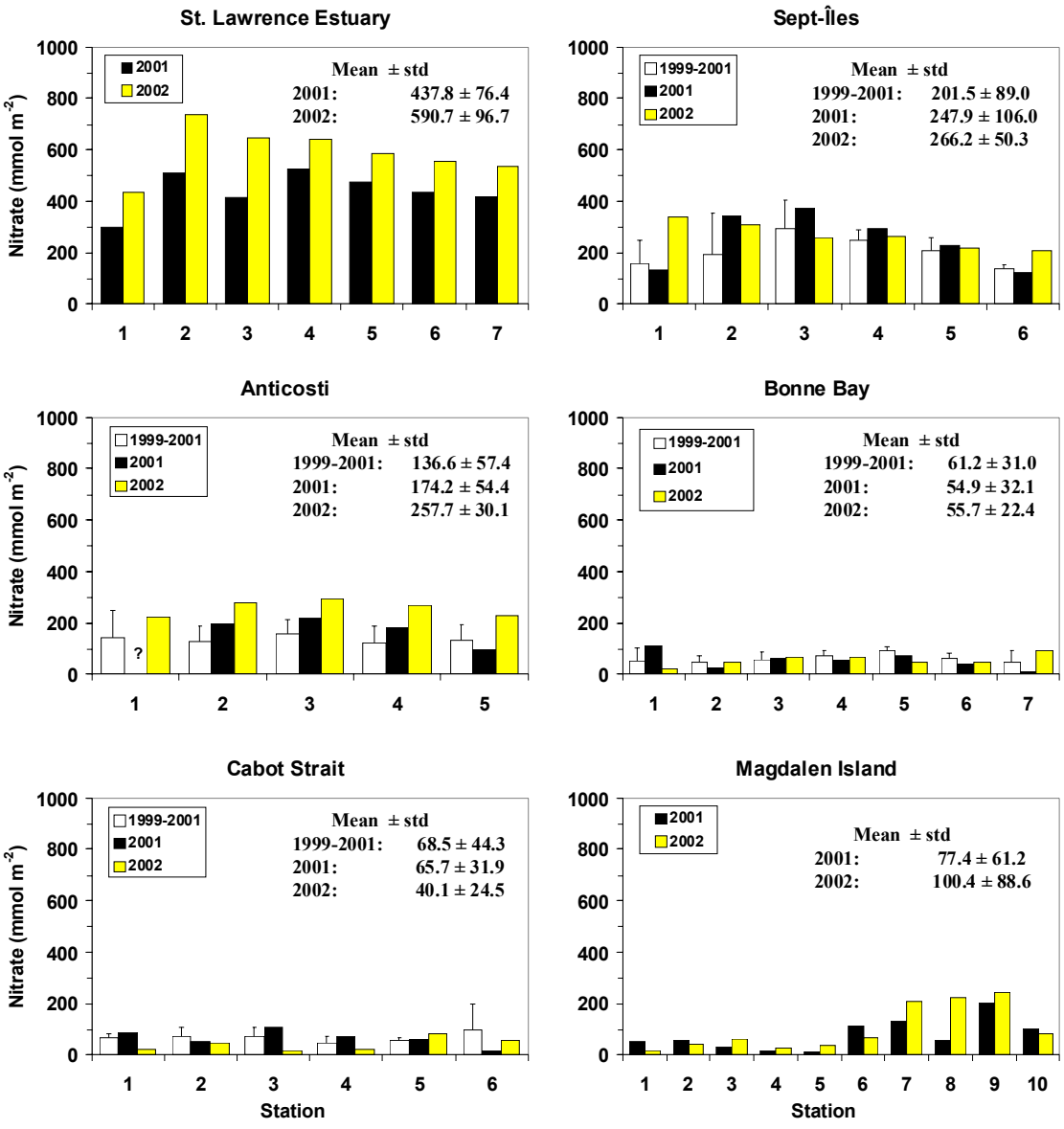


**Figure 13.** Nitrate concentrations (mmol / $m^2$) along the six sections sampled in late spring (June) in the Estuary and Gulf of St. Lawrence, 1999-2002. Values are integrated over the upper 50 m of the water column.

# Spring silicate concentrations (2002 vs 1999-2001)

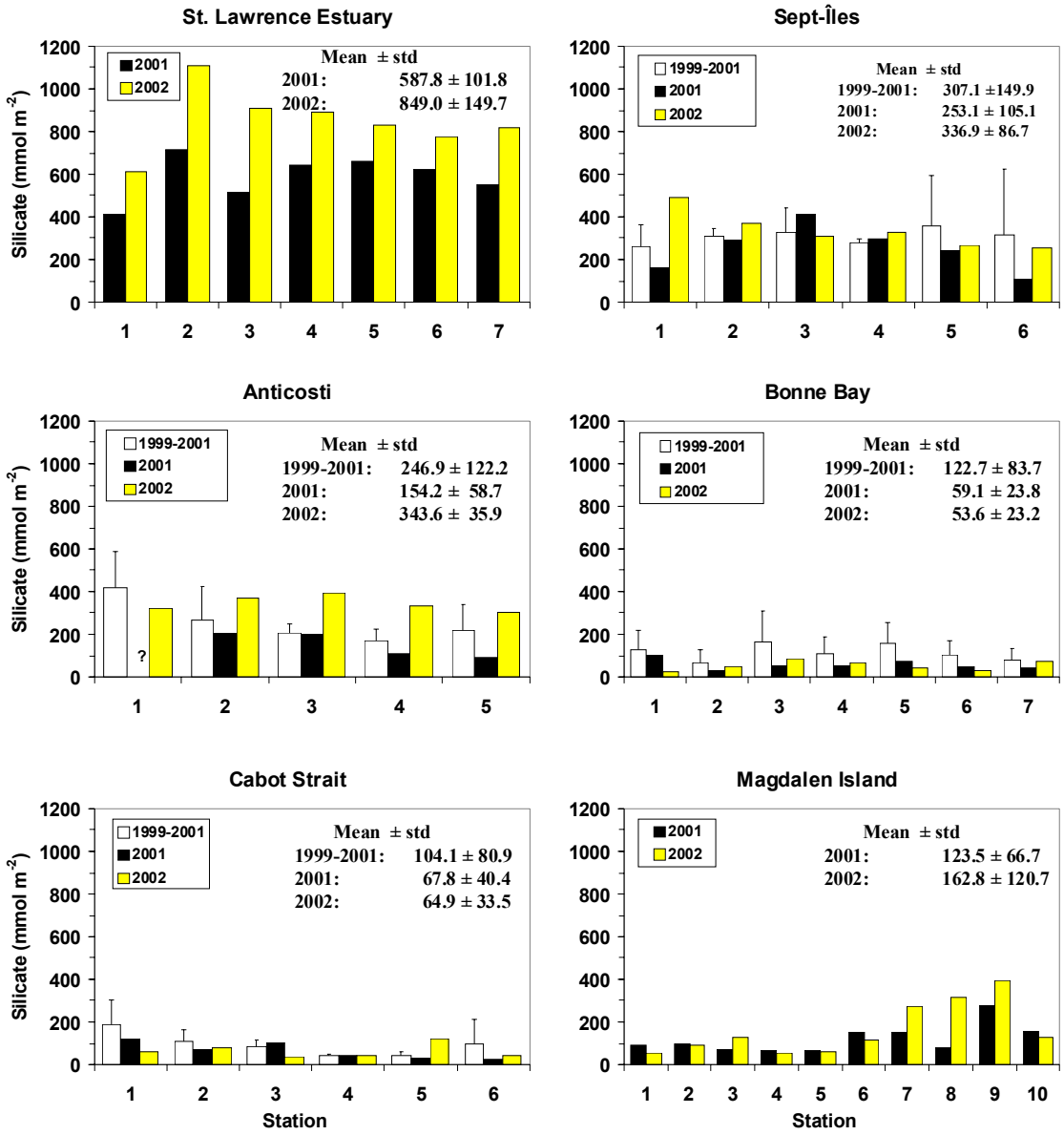


**Figure 14.** Silicate concentrations (mmol / $m^2$) along the six sections sampled in late spring (June) in the Estuary and Gulf of St. Lawrence, 1999-2002. Values are integrated over the upper 50 m of the water column.

# Fall nitrate concentrations (2002 vs 1999-2001)

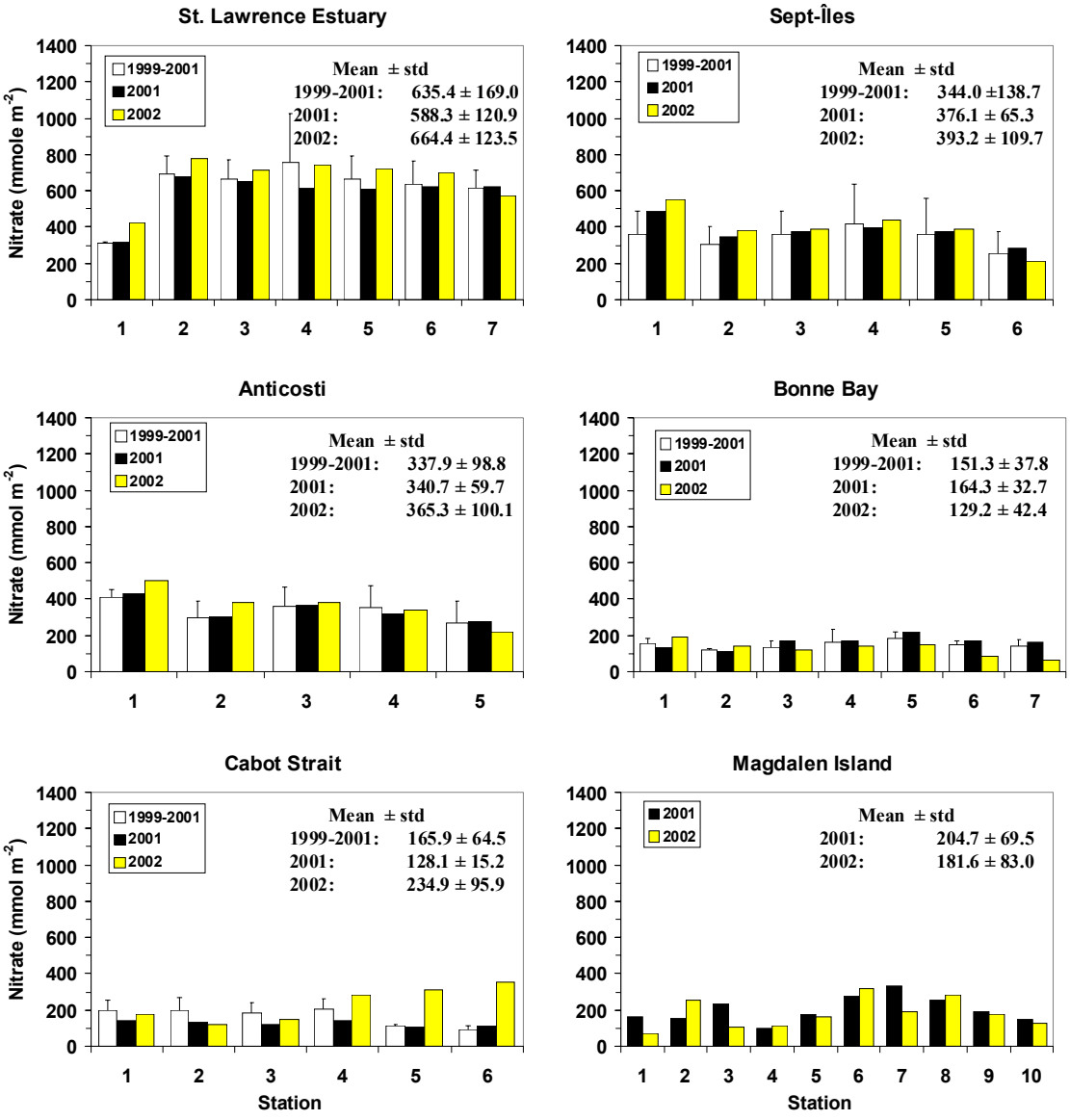


**Figure 15.** Nitrate concentrations (mmol / $m^2$) along the six sections sampled in fall in the Estuary and Gulf of St. Lawrence, 1999-2002. Values are integrated over the upper 50 m of the water column.

# Fall silicate concentrations (2002 vs 1999-2001)

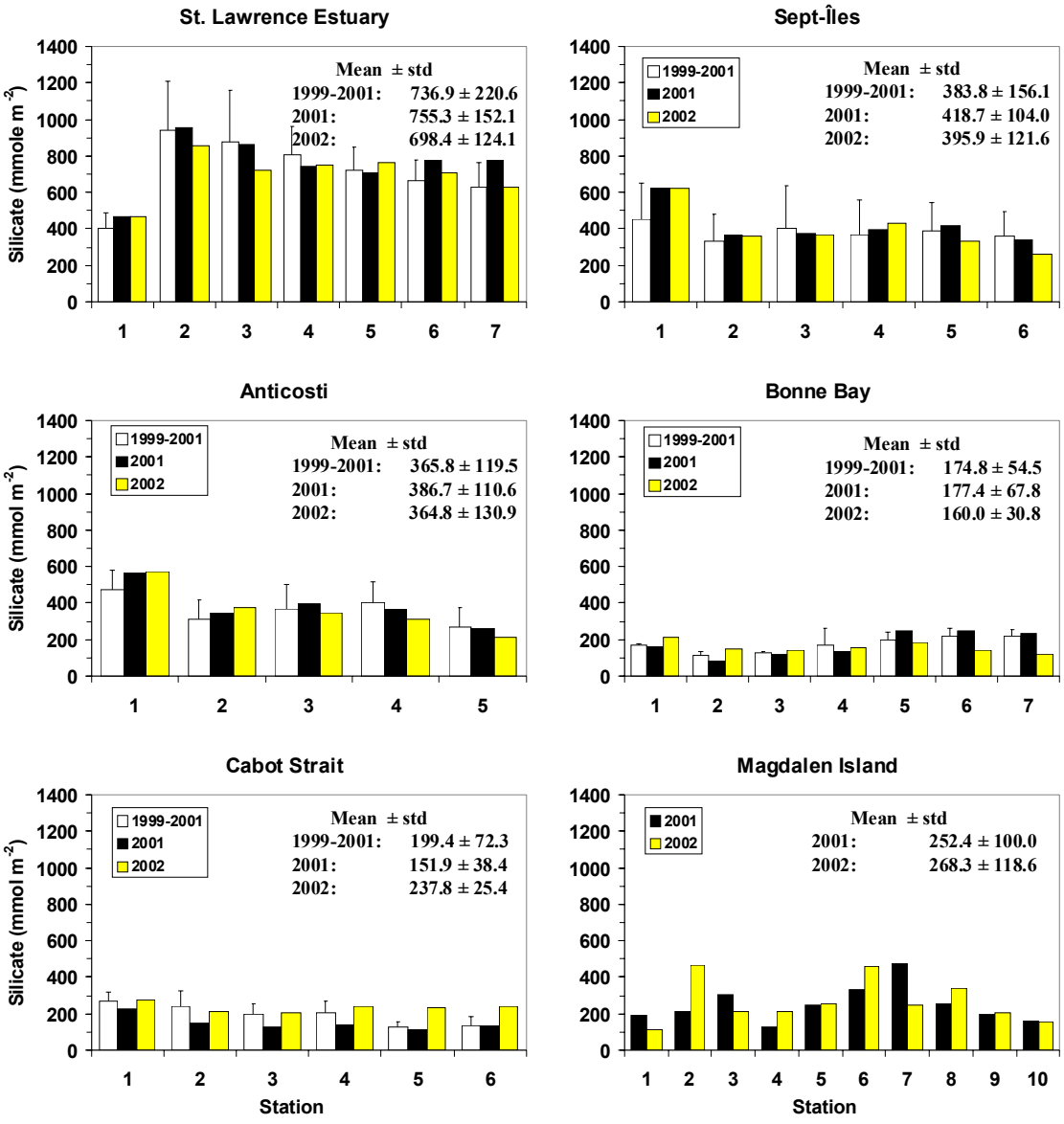


**Figure 16.** Silicate concentrations (mmol / $m^2$) along the six sections sampled in fall in the Estuary and Gulf of St. Lawrence, 1999-2002. Values are integrated over the upper 50 m of the water column.

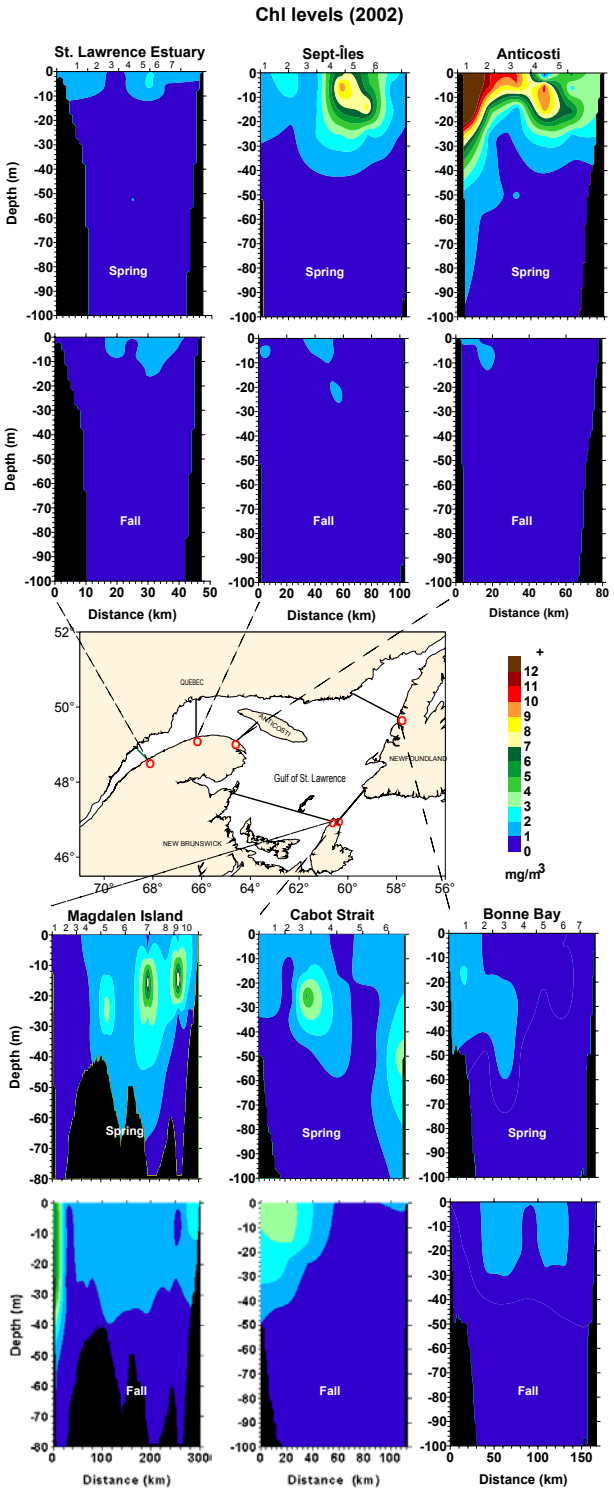


**Figure 17.** Concentrations of chlorophyll *a* (mg / $m^3$) versus depth along the six sections sampled in late spring (June) and fall (November) 2002 in the Estuary and Gulf of St. Lawrence. The numbers over graphs indicate the locations of sampling stations. Red circle : starting point.

# Chlorophyll levels (Spring & Fall 2002)

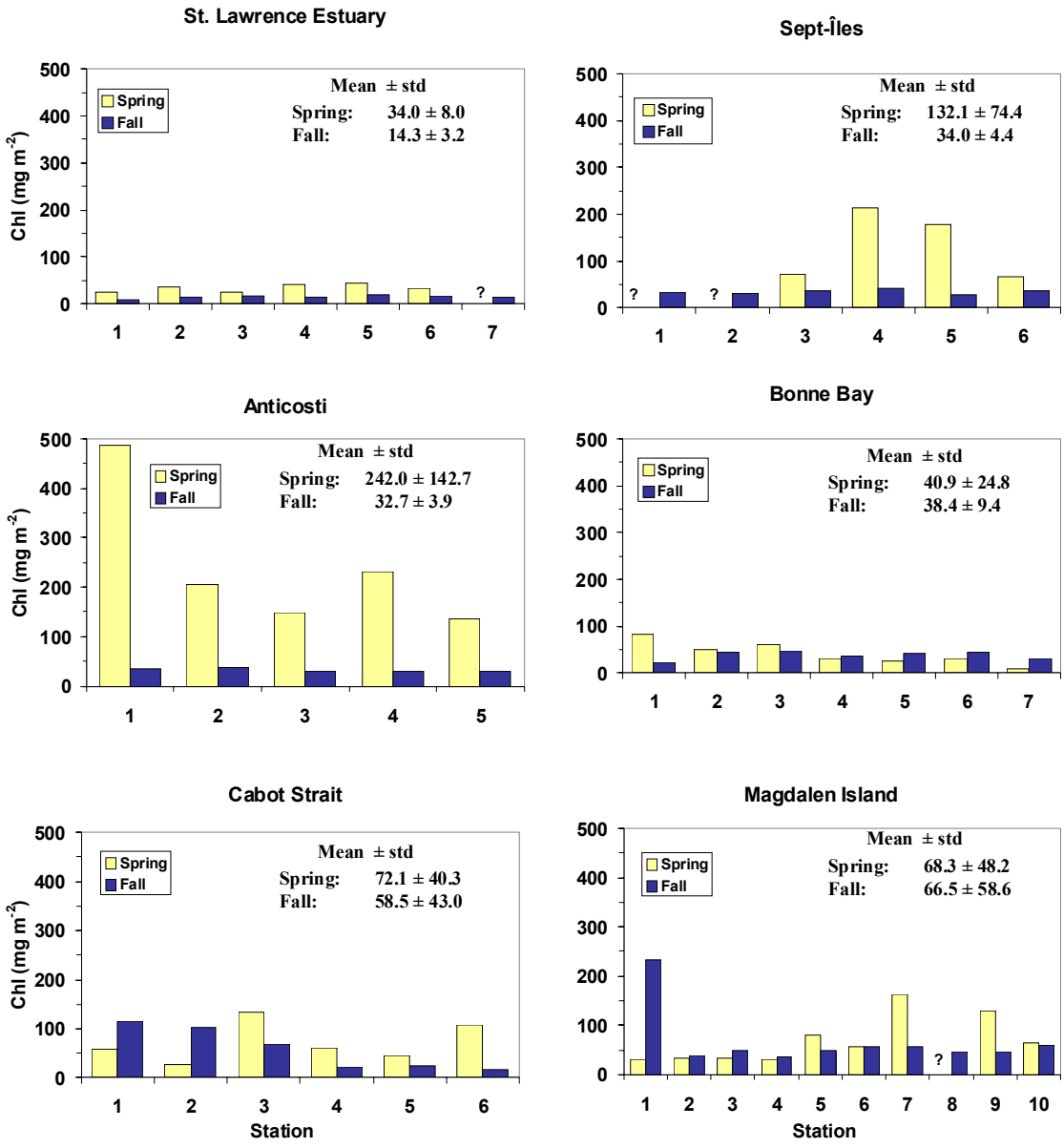


**Figure 18.** Chlorophyll concentrations (mg / $m^2$) along the six sections sampled in late spring (June) and fall (November) 2002 in the Estuary and Gulf of St. Lawrence. Values are integrated over the upper 50 m of the water column.

# Fall chlorophyll concentrations (2002 vs 1999-2001)

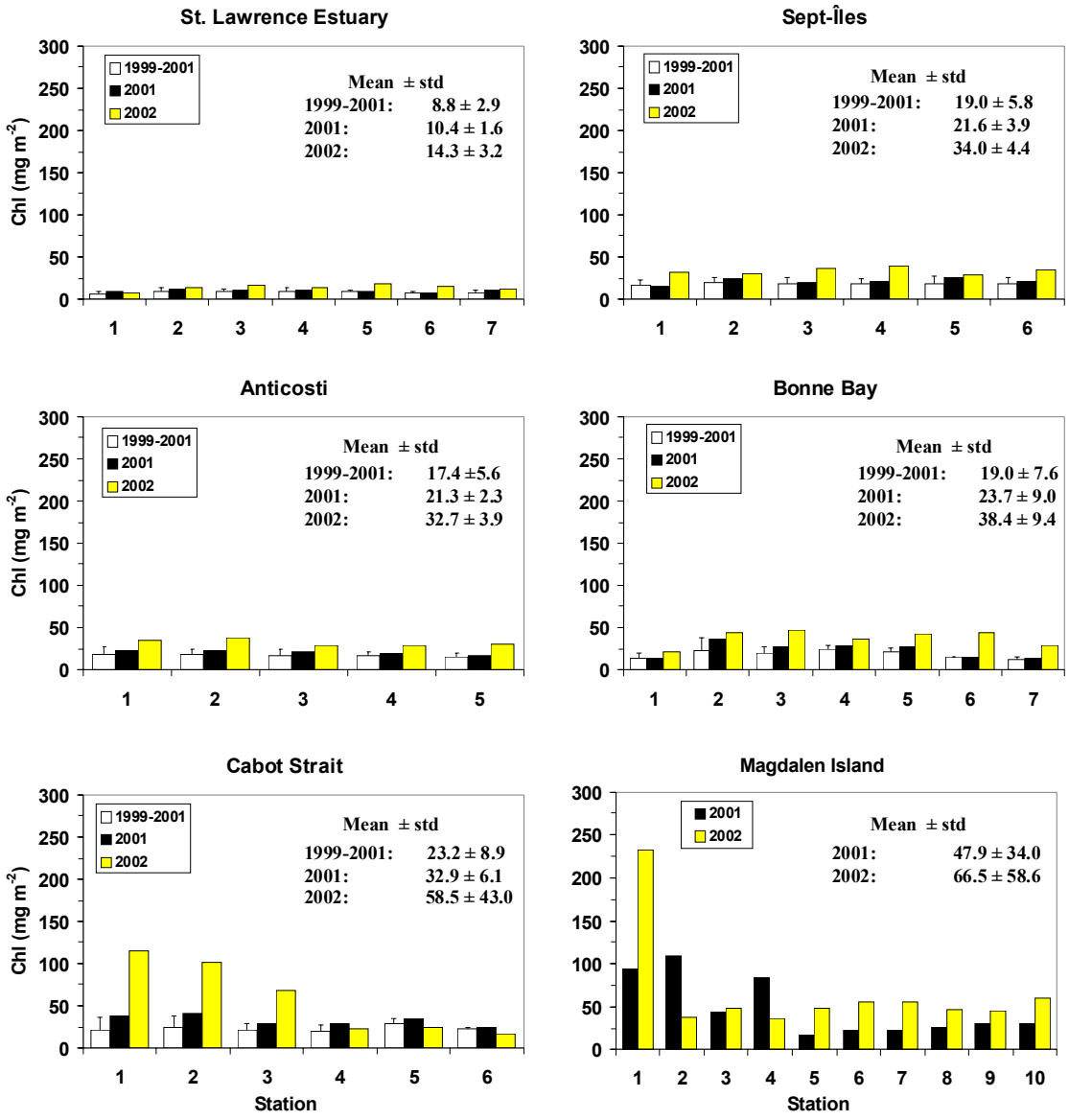


**Figure 19.** Chlorophyll concentrations (mg / $m^2$) along the six sections sampled in fall in the Estuary and Gulf of St. Lawrence, 1999-2002. Values are integrated over the upper 50 m of the water column.

# Spring chlorophyll concentrations (2002 vs 1999-2001)

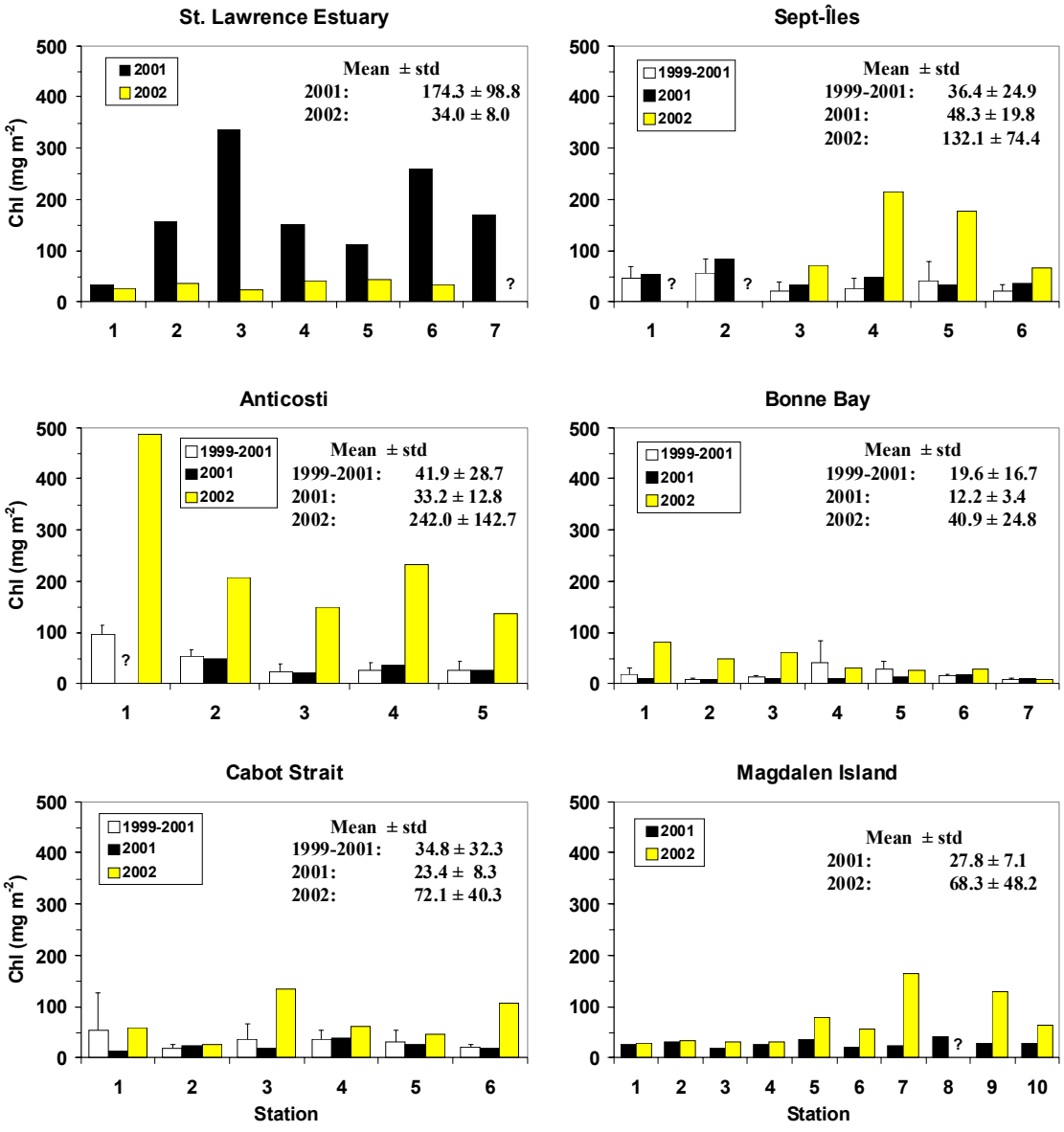


**Figure 20.** Chlorophyll concentrations (mg / $m^2$) along the six sections sampled in late spring (June) in the Estuary and Gulf of St. Lawrence, 1999-2002. Values are integrated over the upper 50 m of the water column.

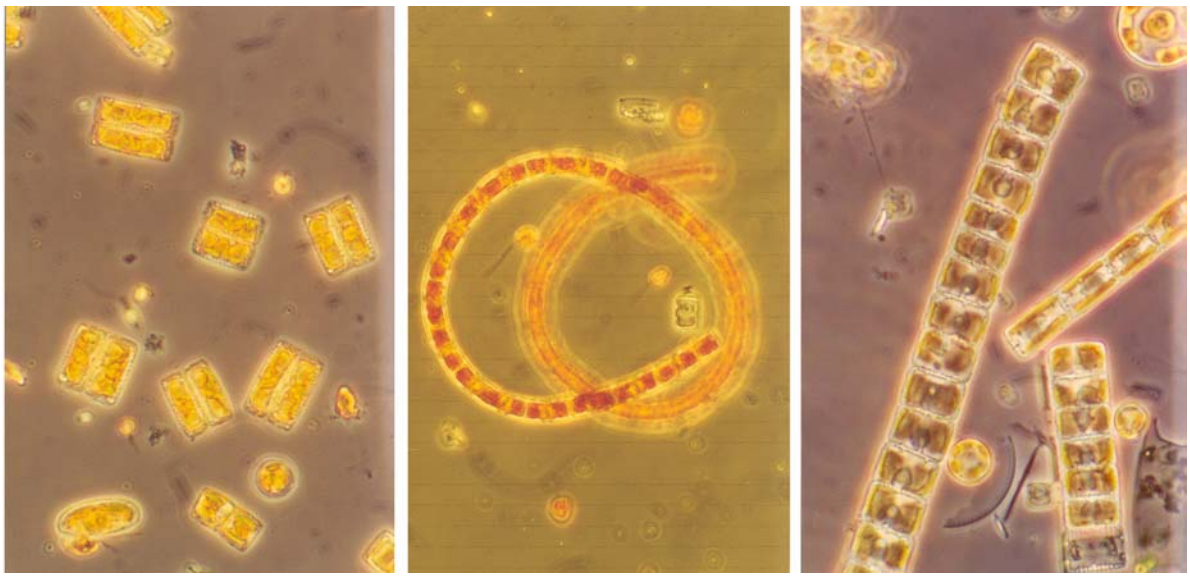

**Figure 21.** Light photomicrographs of the diatom *Neodenticula seminae* confirming its presence in the Gulf of St. Lawrence and Labrador Shelf waters, NW Atlantic. This species is a small pennate diatom that belongs to the family Bacillariaceae. It can occur singly or in chains that are sometimes 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).

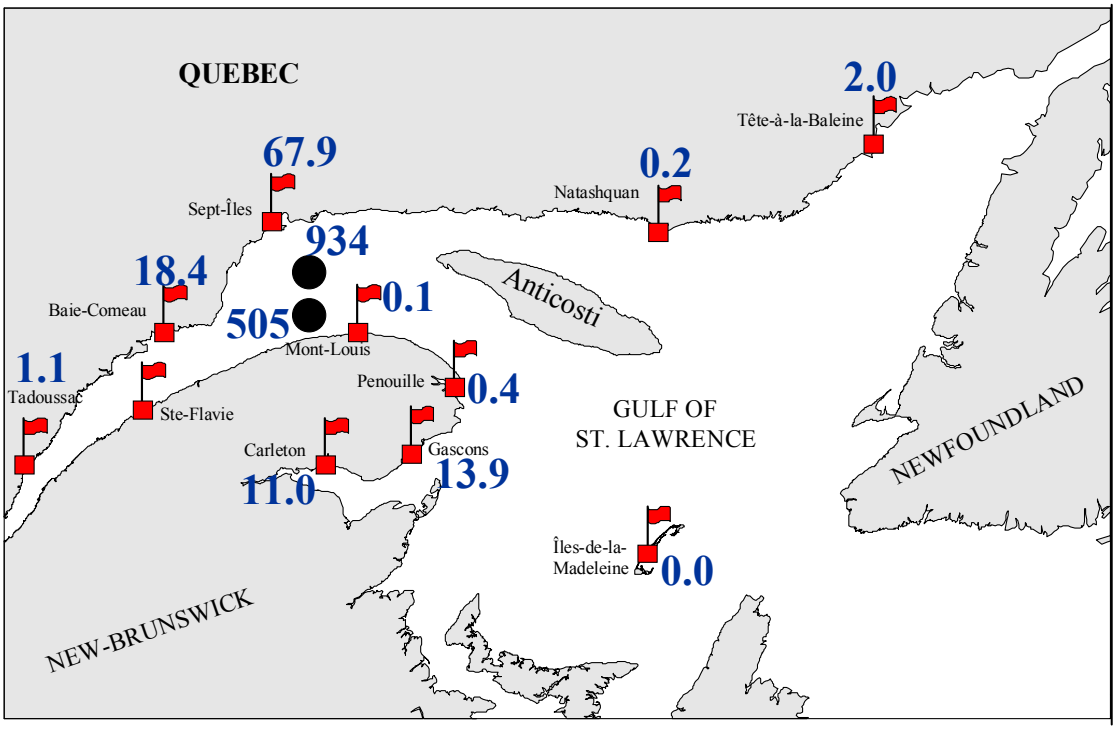


**Figure 22.** Maximum abundance of the diatom *Neodenticula seminae* (x $10^3$ cells per litre) in 2002 at fixed stations of the Toxic Algae Monitoring Program (red flags) and of the Atlantic Zone Monitoring Program (black dots). Depth = 0-15 m.