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State of phytoplankton in the Estuary and Gulf of St. Lawrence during 2001

État de phytoplancton dans l'estuaire et le golfe du Saint-Laurent en 2001

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Abstract

We review the 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 and six sections crossing the Estuary and Gulf of St. Lawrence. We focus on the conditions prevailing in 2001 but compare those observations with previous information from the period of 1992-2000.

In 2001, the initiation of the spring phytoplankton bloom at Station Rimouski in the Lower St. Lawrence Estuary occurred in early May, that is, 6-8 weeks earlier than usual. 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 observed in the St. Lawrence basin since 1998.

For the second consecutive year, the average phytoplankton biomass at Station Rimouski during spring-summer 2001 was much lower compared to the 1995-1999 period (except for 1998) but comparable to the 1992-1994 period. In particular, the 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.

In the Anticosti Gyre and the Gaspé Current, the reduction of nutrients in the surface layer during spring-summer-fall 2001 was much less pronounced compared to the 1996-1999 period (except for 1998). 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.

Satellite observations of sea surface chlorophyll concentrations indicate that the 2001 spring bloom occurred in late April for most areas of the Gulf of St. Lawrence. This contrasts with previous observations showing a greater spatial variability in the timing of the bloom.

The analysis of community composition showed that the 2001 spring bloom over most of the Gulf was principally dominated by the diatom *Neodenticula seminae*. This is the first occurrence of this species in the Gulf of St. Lawrence; this species is usually found in North Pacific waters. This unusual event is consistent with recent observations indicating a greater influx of Pacific waters into the Atlantic Ocean (via the Bering Strait) and with hydrographic evidence of a major intrusion of Labrador Slope Water into the Gulf of St. Lawrence in 2001.

In late spring 2001, the chlorophyll levels were extremely low for most areas of the Gulf of St. Lawrence. The highest levels were observed in the nutrient-rich waters of the St. Lawrence Estuary and Gaspé Current system. In the eastern and southern part of the Gulf, the chlorophyll and nitrate levels in the surface layer in late spring 2001 were not notably different than those observed in 1999-2000.

Résumé

Nous rapportons les variations saisonnières et interannuelles dans les concentrations de la chlorophylle *a*, les nitrates, et les silicates aussi bien qu'au niveau de la composition spécifique du phytoplancton dans l'estuaire et le golfe du Saint-Laurent. L'information présentée provient de données mesurées à trois stations fixes et de six sections situées dans les diverses régions du golfe et de l'estuaire du Saint-Laurent. Nous examinons plus particulièrement les conditions présentes en 2001 tout en les comparant aux observations pour la période de 1992-2000.

En 2001, l'initiation de la floraison printanière de phytoplancton à la station Rimouski dans l'estuaire maritime du Saint-Laurent s'est produite au début mai, soit 6-8 semaines plus tôt que la normale. Cette floraison printanière précoce poursuit la tendance initiée depuis 1998. Nous croyons que ce changement majeur dans le cycle du phytoplancton est dû aux débits d'eaux douces printaniers dans le Saint-Laurent qui ont été bien au-dessous de la normale depuis 1998.

Pour une deuxième année consécutive, la biomasse phytoplanctonique moyenne à la station Rimouski au cours du printemps et de l'été 2001 était beaucoup inférieure à celles observées au cours de la période 1995-1999 (excepté en 1998), mais néanmoins comparable à celles de la période 1992-1994. En particulier, la biomasse phytoplanctonique au mois de juillet 2001 était beaucoup inférieure à celles précédemment observées. Nous croyons que ceci a été occasionné par une période de mélange plus intense dans l'estuaire maritime du Saint-Laurent au cours du mois juillet 2001.

Dans la gyre d'Anticosti et le courant de Gaspé, la réduction des éléments nutritifs dans la couche de surface au cours de la période printemps-été-automne 2001 était beaucoup moins prononcée comparée à la période 1996-1999 (excepté 1998). De plus dans le courant de Gaspé, les niveaux de chlorophylle en surface étaient généralement plus bas en 2001 comparés aux deux années précédentes. D'autre part, les niveaux de chlorophylle estivale dans la gyre d'Anticosti étaient plus élevés en 2001 comparés à ceux observés en 1997-2000.

Les observations satellitaires en 2001 au niveau des concentrations en chlorophylle de surface indiquent que la floraison phytoplanctonique s'est produite à la fin d'avril pour la plupart des régions du golfe du Saint-Laurent. Ces observations diffèrent de celles acquises antérieurement qui démontrent une plus grande variabilité spatiale dans la période de la floraison phytoplanctonique.

L'analyse de la composition spécifique du phytoplancton a démontré que la floraison phytoplanctonique de 2001 a été dominée par la diatomée *Neodenticula seminae* dans la plupart des régions du Golfe. C'est la première occurrence de cette espèce dans le golfe du Saint-Laurent; cette espèce étant généralement retrouvée dans les eaux du Pacifique nord. Cet événement peu commun est consistant avec les observations récentes indiquant une plus grande intrusion des eaux du Pacifique nord dans l'océan Atlantique (par l'intermédiaire du détroit de Béring) et d'une intrusion importante des eaux du Labrador dans le golfe du Saint-Laurent en 2001.

Au printemps 2001, les niveaux de chlorophylle étaient extrêmement bas pour la plupart des secteurs du golfe du Saint-Laurent. Les niveaux les plus élevés ont été observés dans les eaux riches de l'estuaire du Saint-Laurent et du courant de Gaspé. Dans le nord-est et le sud du Golfe, les niveaux de chlorophylle et de nitrate dans la couche de surface n'étaient pas notamment différents au printemps 2001 que ceux observées au cours des deux dernières années.

Introduction

This report presents the state of phytoplankton prevailing in the Estuary and Gulf of St. Lawrence in 2001. 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 (Figure 1). Additional information from various research programs (SeaWIFS, cruises, 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 inter-annual 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 2).

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* / m^2 (Figure 3). From late May to mid August, chlorophyll levels remained relatively low (<100 mg / 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).

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; Figures 2 and 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. 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 below-normal spring freshwater runoff observed since 1998 in the St. Lawrence basin (not shown here) 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 1995-1999 period (Figure 2). 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 (not shown here).

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 are monitored at a frequency of 9 to 19 times per year.

In 2001, 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 (Figure 6). Typically, nutrient concentrations were somewhat higher in the Gaspé Current than in the Anticosti Gyre and more variable due to the dynamics of this coastal jet. The spring decrease in the surface nutrients occurred approximately 2-3 weeks earlier in the Anticosti Gyre than in the Gaspé Current (Figure 6), 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 6). From early June to late July, chlorophyll levels remained relatively low (<70 mg / m^2) 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* / m^2 (Figures 6 and 7). 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 in late April, when a small spring bloom of short duration was observed (Figure 6). A deep chlorophyll maximum layer was nevertheless observed at 35 m from late June to late August at the base of the nutricline (Figure 6). 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.

Overall, the chlorophyll *a* levels in the Gaspé Current were lower in 2001 than in 1999 and 2000 but comparable to 1996 and 1997 (Figure 7). In contrast, the subsurface chlorophyll levels during summer 2001 in the Anticosti Gyre were much higher compared to our previous observations (Figure 8). On the other hand, the nitrate concentrations in the near-surface waters in late winter 2001 at both stations were comparable to those observed in 2000 but lower than those in 1996-1999 (except for 1998) while the summer concentrations were comparable (Figures 7 and 8). Moreover, the reduction of nutrients during fall 2001 in the Anticosti Gyre was much less pronounced compared to 1999 and 2000 (Figure 8). Based on the seasonal reduction of nutrients, phytoplankton production in the northwestern part of the Gulf of St. Lawrence would probably have been lower in 2001 compared to the previous two years.

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 9) to obtain quasi-synoptic information on a broader spatial coverage. Sections were occupied during late spring (June) and late fall (December) 2001 (Figure 1). This sampling program has been in place since 1999. Analysis of the 2001 fall samples is not yet completed.

Nitrate concentrations in the late spring 2001 increased with depth for the most areas of the Gulf of St. Lawrence (Figure 9). 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 (Coote & Yeats 1979, Savenkoff *et al.* 2001). Compared to previous years, nitrate concentrations in the deep layer in 2001 were comparable to those in 2000, but higher than in 1999 (not shown here).

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. 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 concentrations in the deep layer in the late spring 2001 were comparable to 2000 but lower than in 1999 (not shown here).

In the surface layer, spring nitrate and silicate concentrations were uniformly low in 2001 for most regions of the Gulf of St. Lawrence (Figures 9 and 10). 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 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).

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 (Figure 11). 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.

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 12), which is typical (e.g. Steven 1974). In 2001, the chlorophyll levels in the eastern and southern part of the Gulf were not markedly different from those in 1999-2000 (Figure 13).

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 scale. 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 humic substances) and must be used with caution.

Satellite data revealed that the 2001 spring bloom occurred in late April for most areas of the Gulf of St. Lawrence (not shown here). This contrasts with our previous observations, which showed a

greater spatial variability in the timing of the spring bloom. During late spring-summer, chlorophyll levels remained low for most areas of the Gulf (except for the estuarine portion), which is consistent with observations from the fixed stations and sections crossing the Gulf. Another smaller phytoplankton peak was observed in the fall for the most areas of the Gulf (October), which is usual.

Research cruise. During a research cruise in late April, 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 (Yanagisawa and Akiba 1990). In the Atlantic Ocean, this species has only been recorded in high-latitude Quaternary sediments between 0.84 and 1.26 Ma (Baldauf 1986). Because this unusual spring bloom coincided with a massive intrusion of Labrador Slope Waters into the Gulf of St. Lawrence (Gilbert 2002, Harvey *et al.* 2002), we suppose that this Pacific species was introduced naturally into the Gulf (across the Arctic and down the Labrador current), rather than via ballast waters. This is consistent with recent observations indicating a greater influx of Pacific waters into the North Atlantic and changes in the circulation and oceanographic conditions in the Arctic Ocean (Dickson 1999).

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 2001. Prominent events in 2001 included: 1) 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; 2) 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; 3) the satellite data revealed for the first time, little differences in the timing of the 2001 spring bloom in the Gulf of St. Lawrence and 4) the first occurrence of the diatom *Neodenticula seminae* in the region; this species is usually observed in North Pacific waters.

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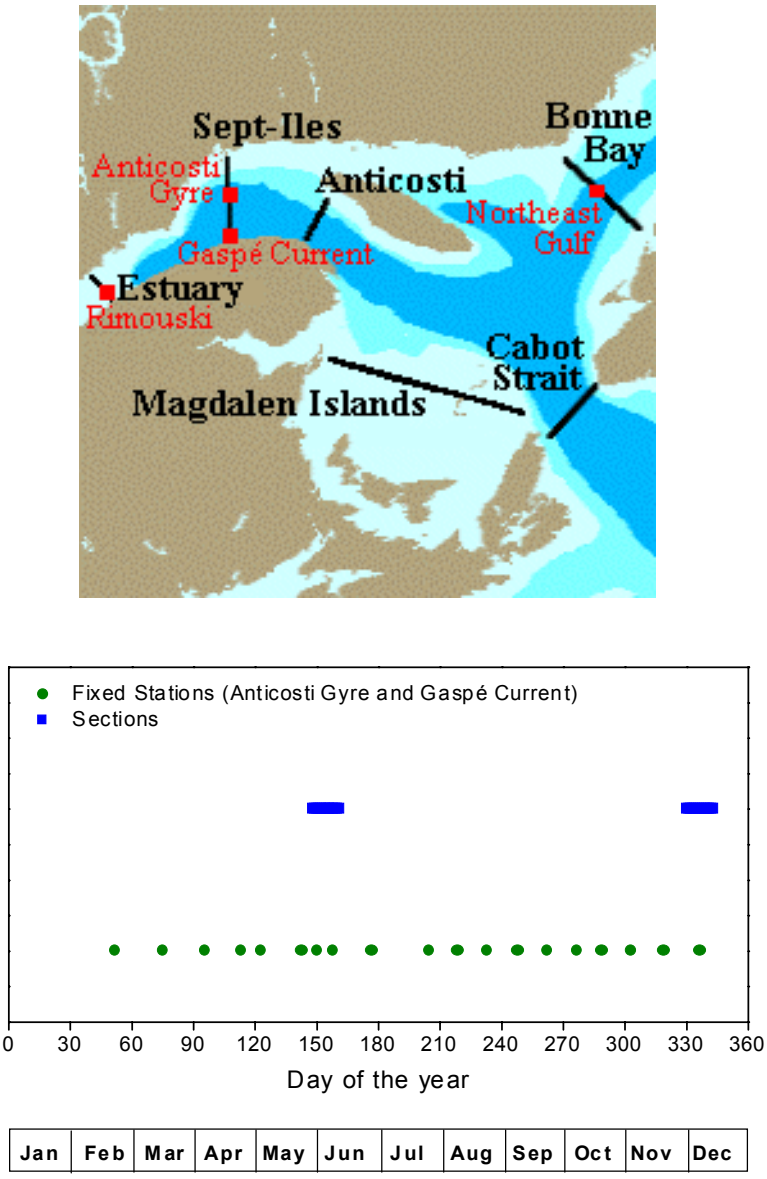

Figure 1. Dates of 2001 sampling at the Atlantic Zonal Monitoring Program (AZMP) sections (lines) and fixed stations (dots).

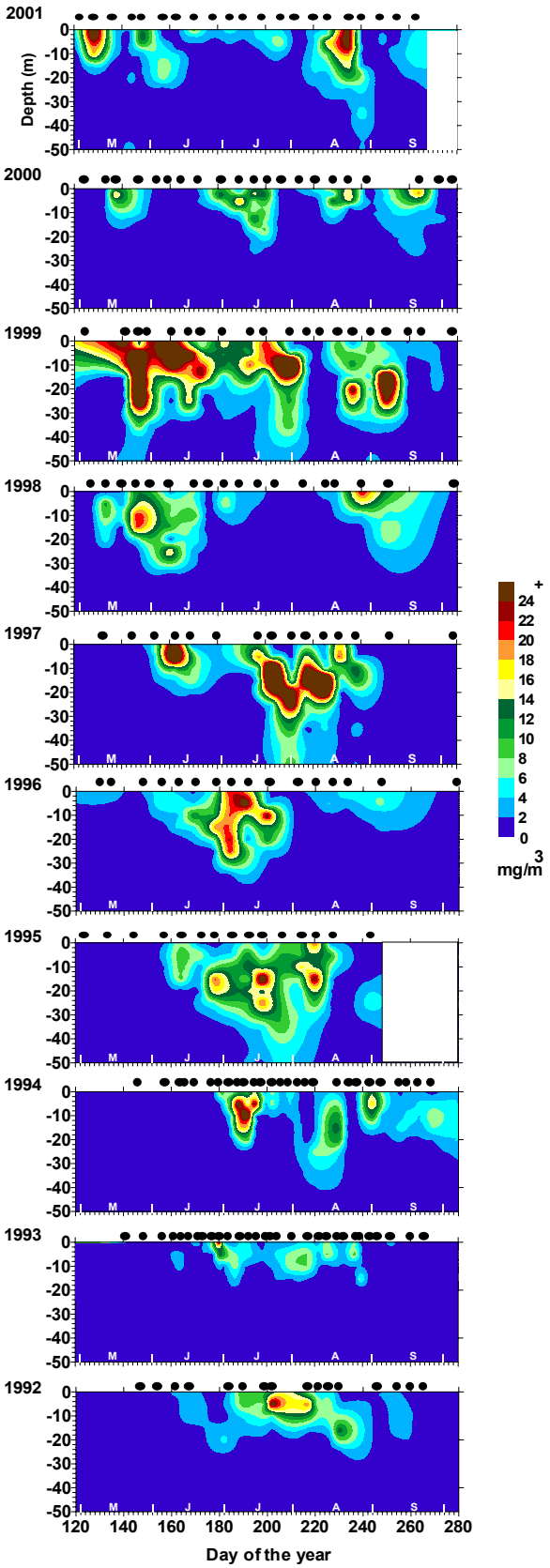

Figure 2. Chlorophyll *a* concentration (mg / m^2) at the Rimouski station during the period May September between 1992 and 2001. The black dots over each graph indicate the precise date of sampling.

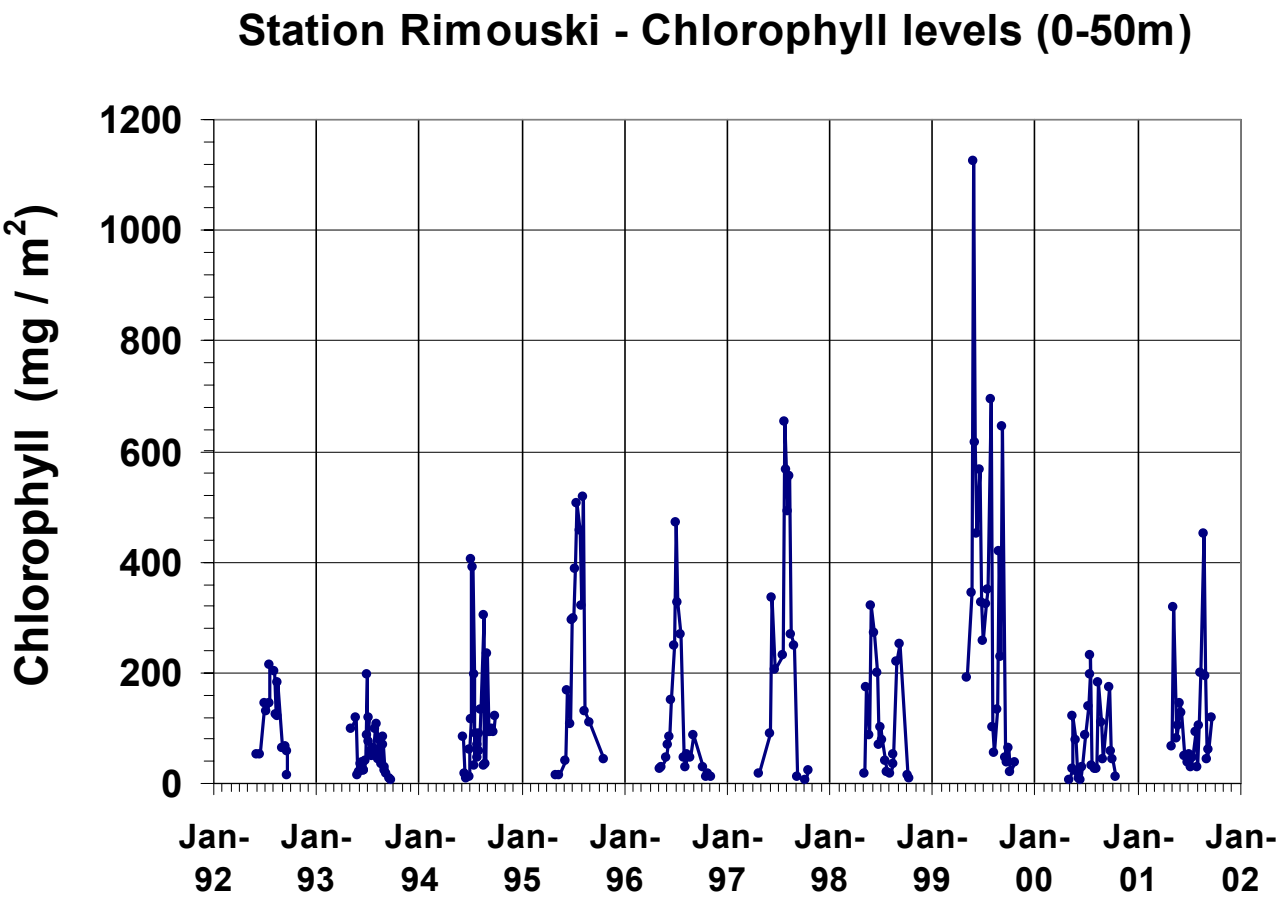

Figure 3. Chlorophyll *a* concentrations (mg / m^2) integrated over the upper 50 m at Station Rimouski during spring-summer 1992-2001.

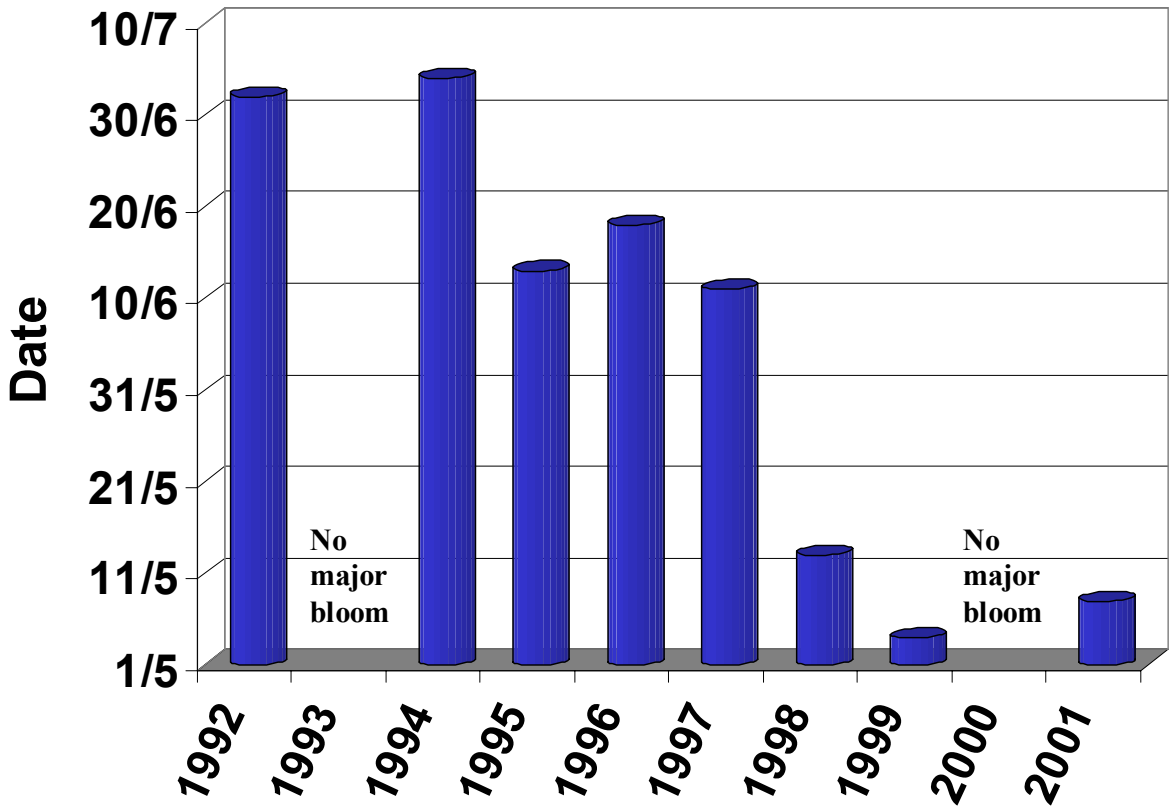

Figure 4. Date of onset of the primary bloom defined by the first incidence of chlorophyll concentrations greater than 100 mg of chlorophyll *a* per m^2 at Station Rimouski, 1992-2001.

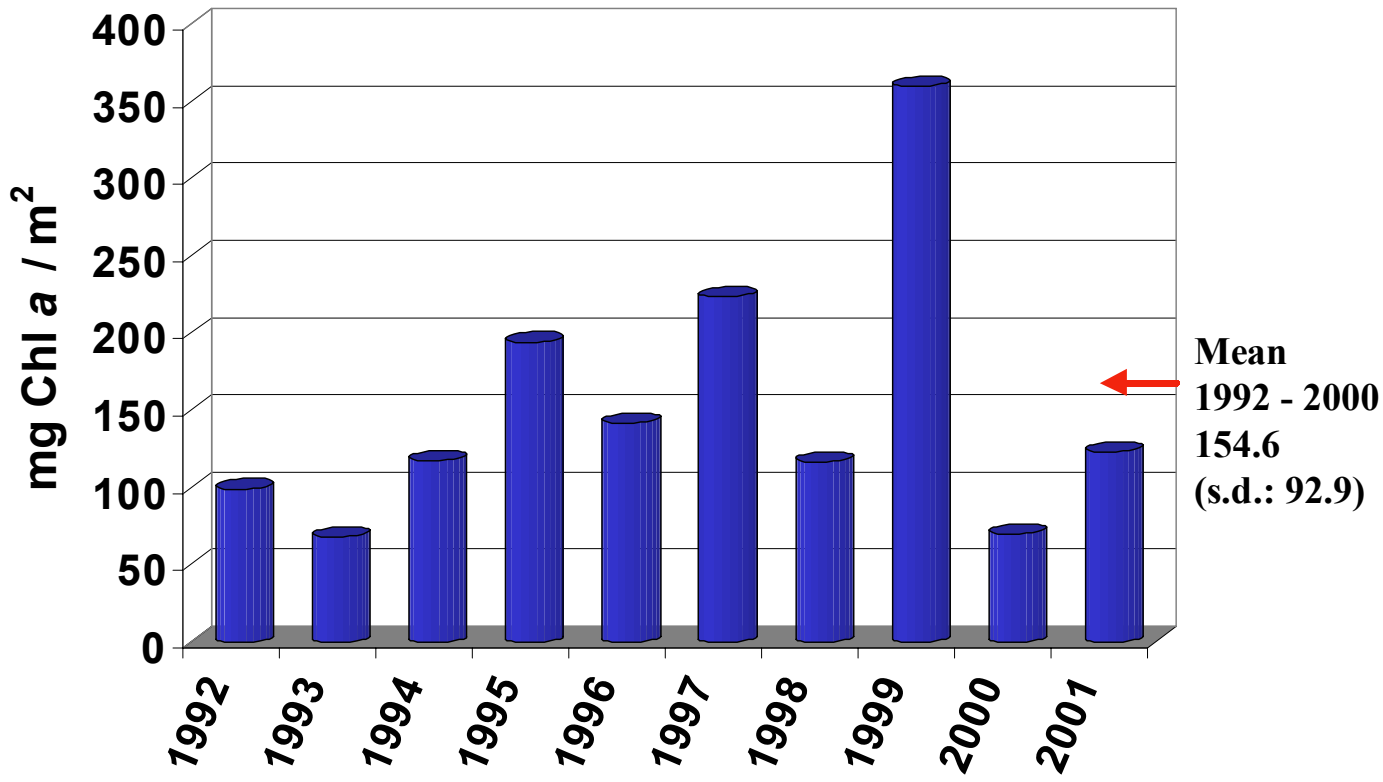

Figure 5. Mean integrated (surface to 50m depth) chlorophyll *a* levels at Station Rimouski from May to August, 1992-2001.

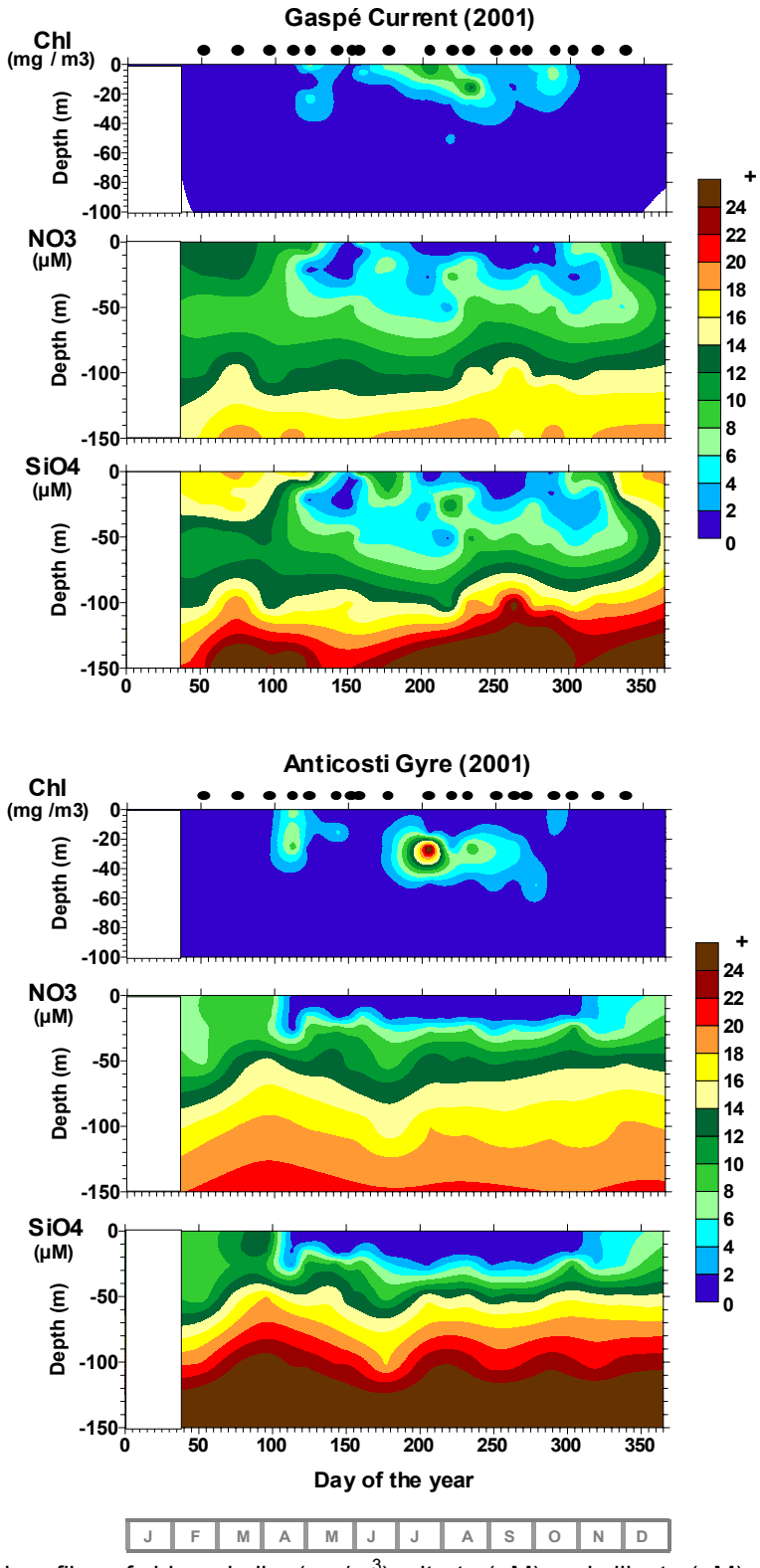

Figure 6. Vertical profiles of chlorophyll *a* (mg/m^3), nitrate (µM) and silicate (µM) concentrations in the Gaspé Current and Anticosti Gyre during 2001. The black dots over each graph indicate the precise data of sampling.

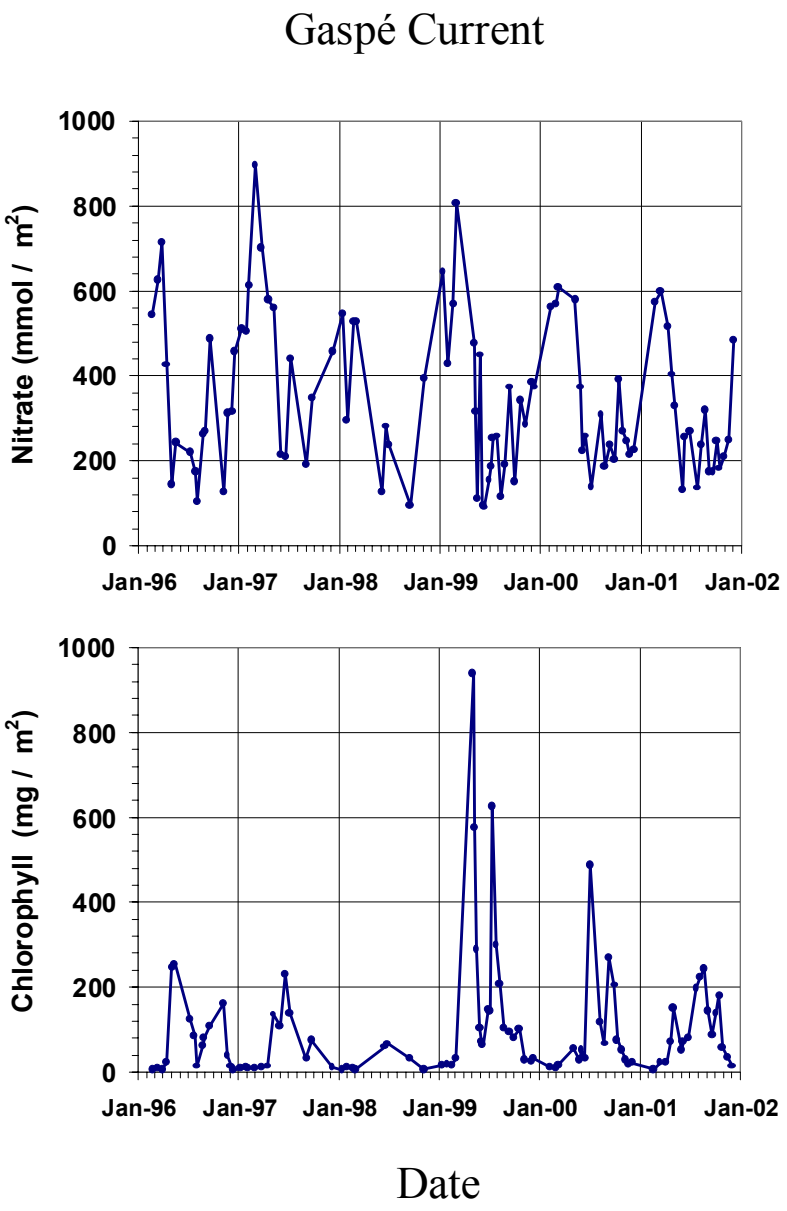

Figure 7. Nitrate (mmol / m^2) and chlorophyll *a* (mg / m^2) concentrations in the Gaspé Current, 1996-2001. Values are integrated over the upper 50 m of the water column.

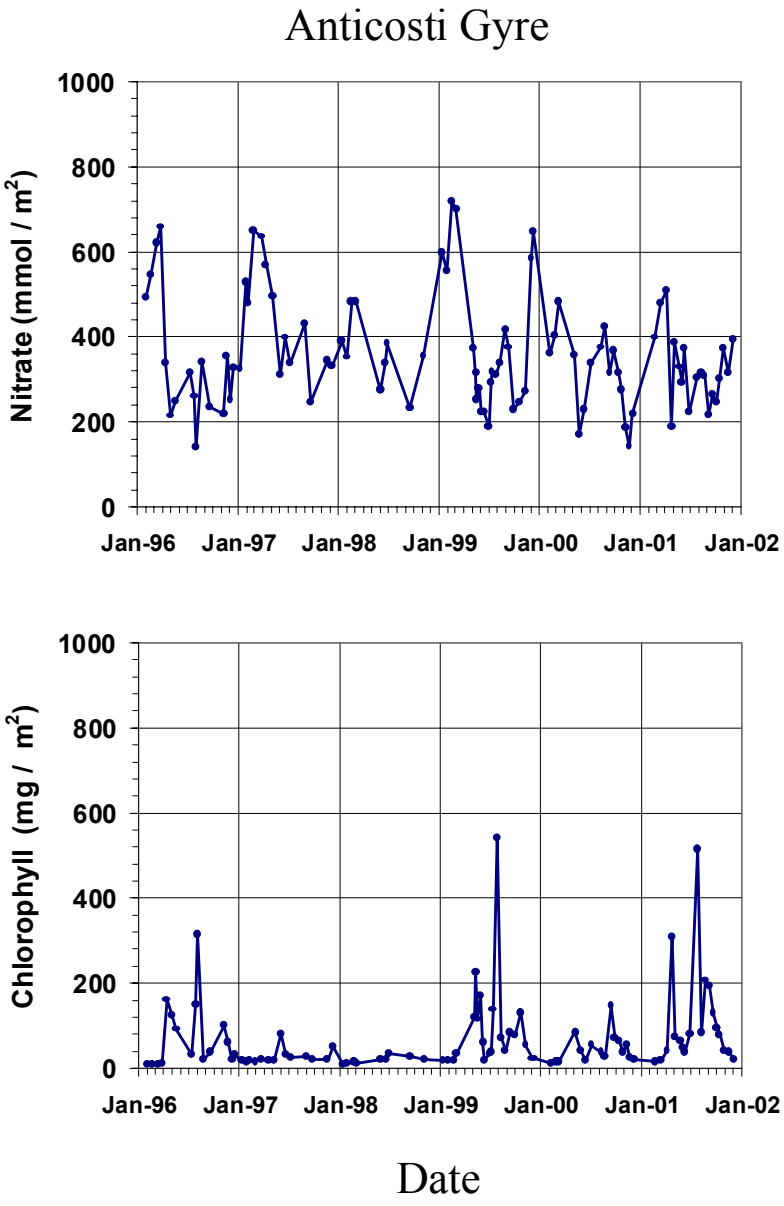

Figure 8. Nitrate (mmol / m^2) and chlorophyll *a* (mg / m^2) concentrations in the Anticosti Gyre, 1996-2001. Values are integrated over the upper 50 m of the water column.

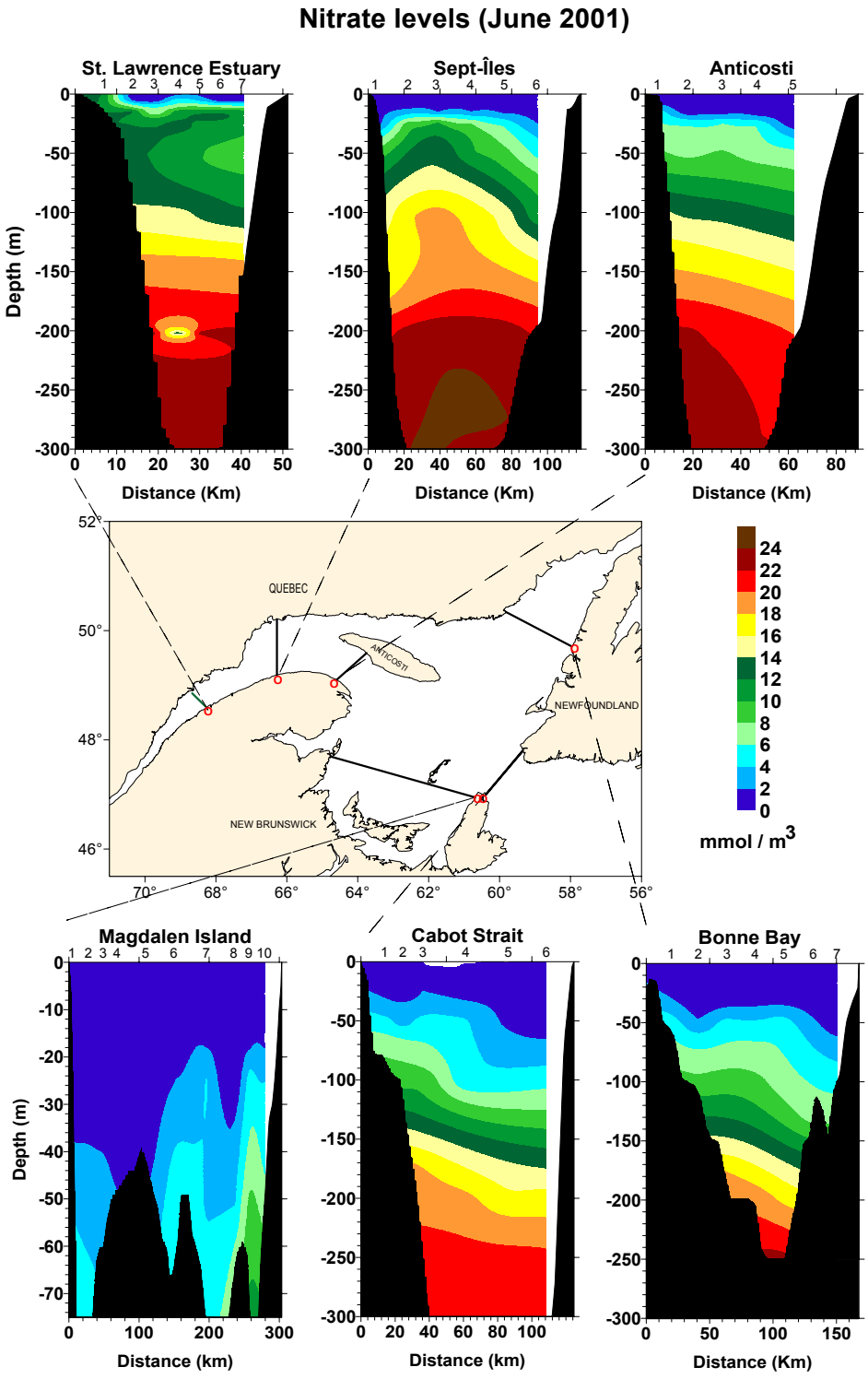

Figure 9. Concentrations of nitrate (mmol / m^3) versus depth along the six sections sampled in June 2001 in the Estuary and Gulf of St. Lawrence. The numbers over each graph indicate the location of sampling stations. Red circle : starting point.

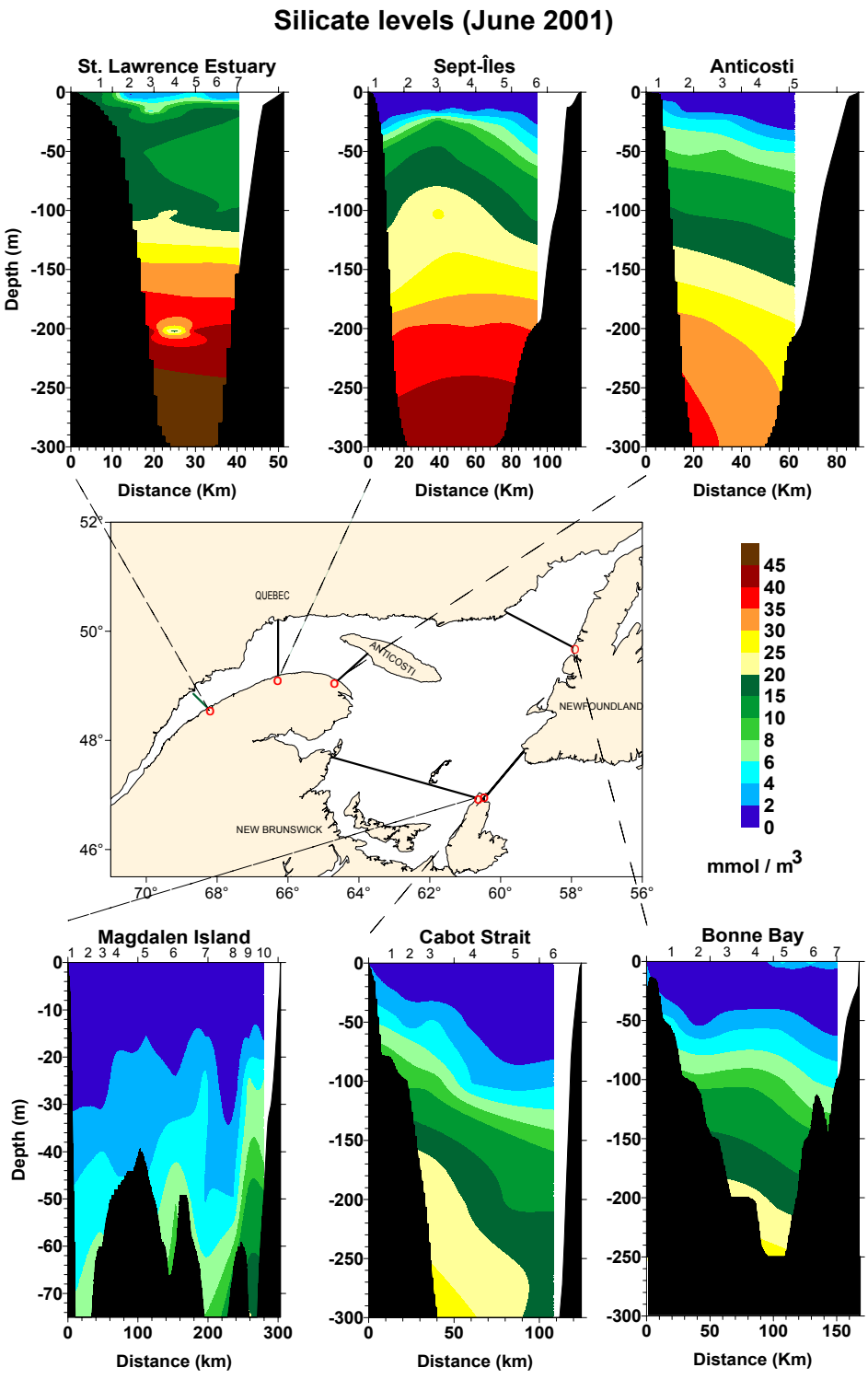

Figure 10. Concentrations of silicate (mmol / m^3) versus depth along the six sections sampled in June 2001 in the Estuary and Gulf of St. Lawrence. The numbers over each graph indicate the location of sampling stations. Red circle : starting point.

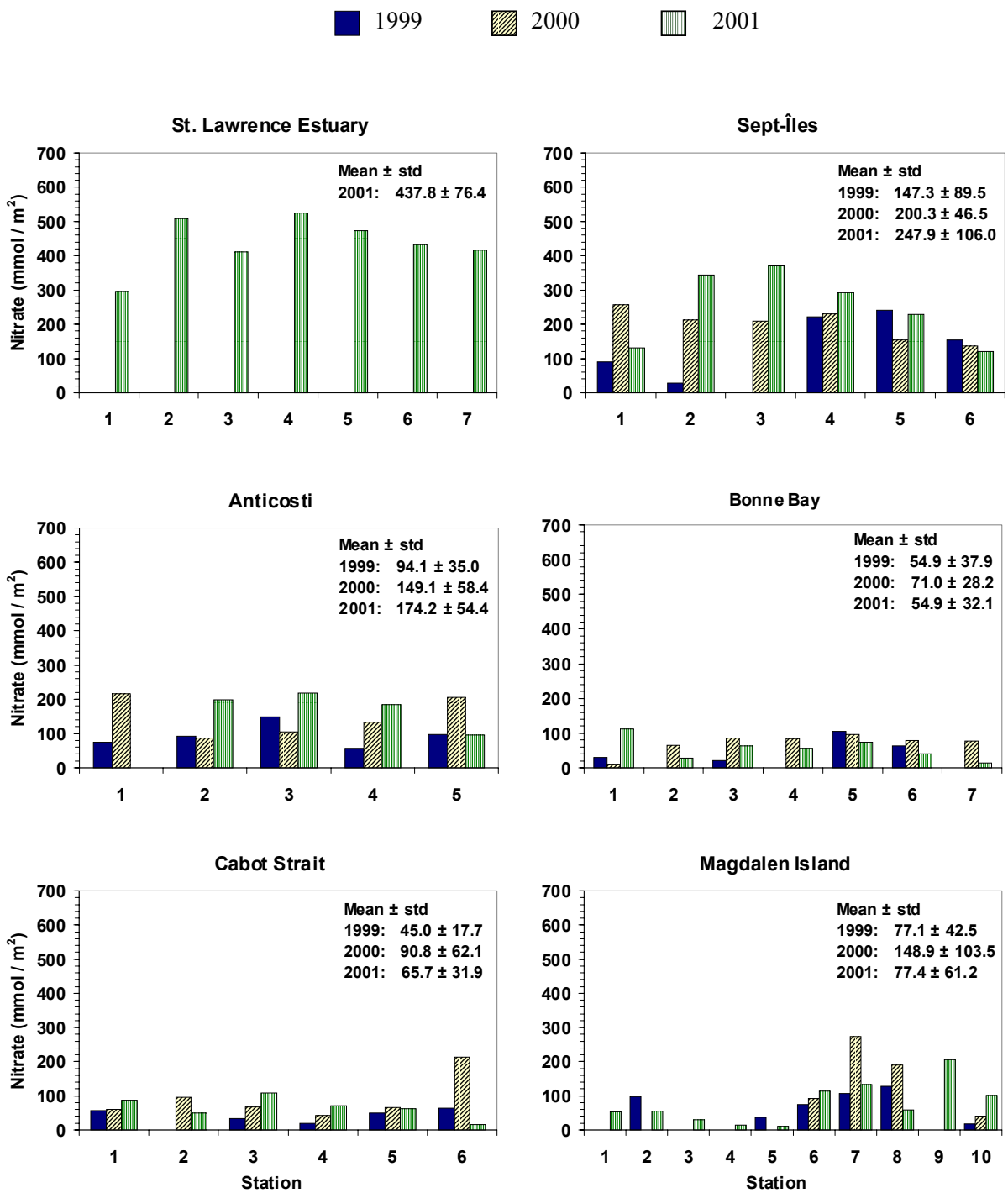

Figure 11. Nitrate concentrations (mmol / m^2) along the six sections sampled in June in the Estuary and Gulf of St. Lawrence, 1999-2001. Values are integrated over the upper 50 m of the water column.

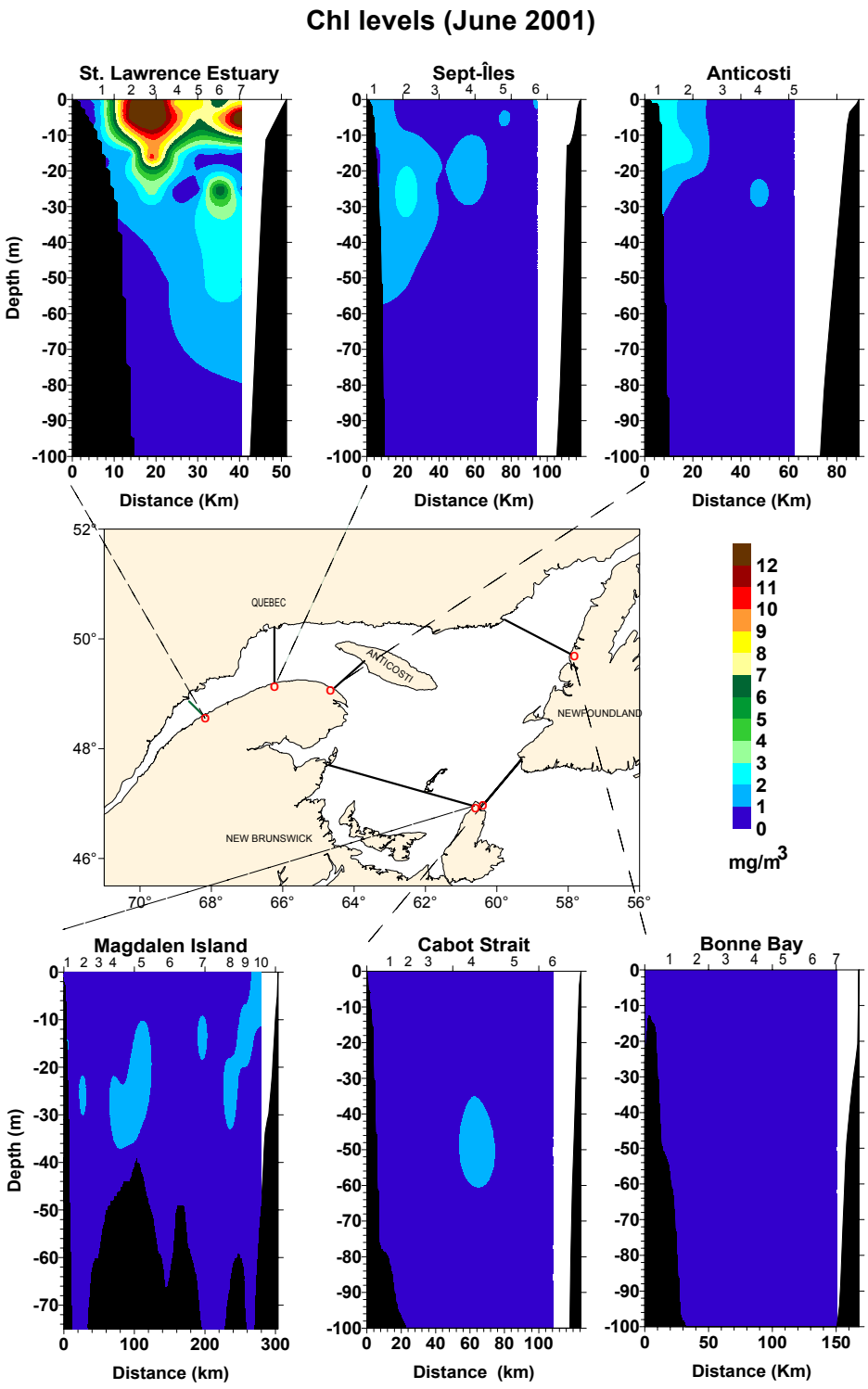

Figure 12. Concentrations of chlorophyll *a* (mg / m^3) versus depth along the six sections sampled in June 2001 in the Estuary and Gulf of St. Lawrence. The numbers over each graph indicate the location of sampling stations. Red circle : starting point.

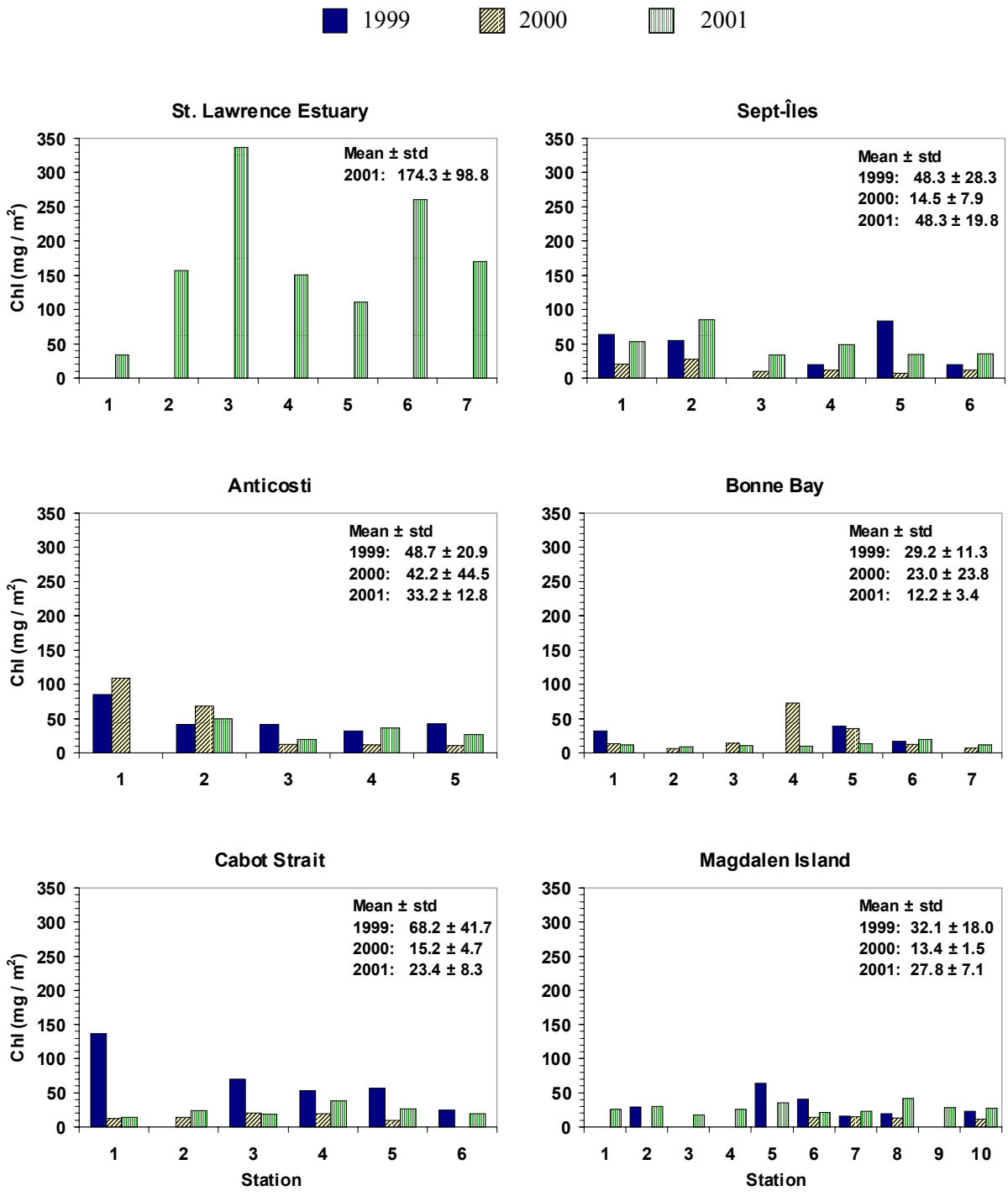

Figure 13. Chlorophyll *a* concentrations (mg / m^2) along the six sections sampled in June in the Estuary and Gulf of St. Lawrence, 1999-2001. Values are integrated over the upper 50 m of the water column.

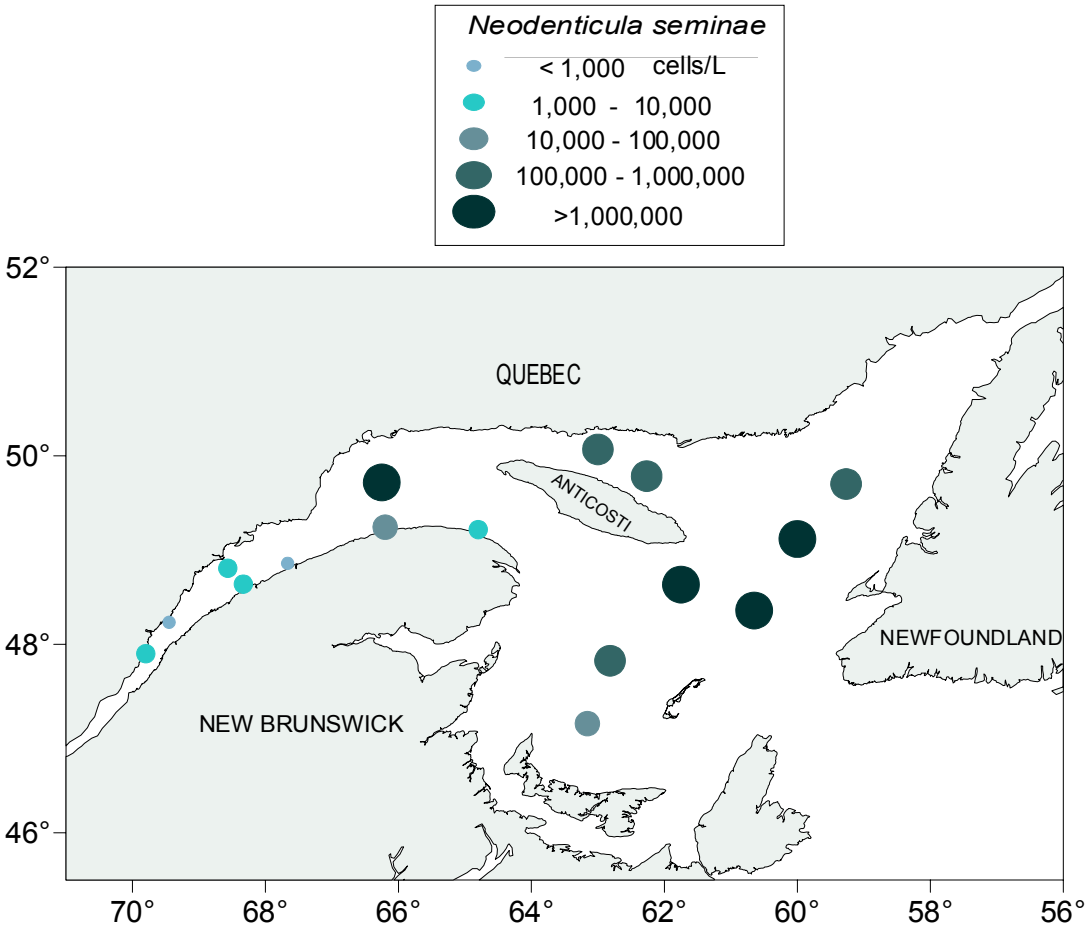

Figure 14. Abundances (cells/L) of the diatom *Neodenticula seminae* in late April 2001 in the Estuary and Gulf of St. Lawrence.