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Modern diatom assemblages in surface sediments from the Maritime Estuary and the Gulf of St. Lawrence, Québec (Canada)

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Abstract

The Gulf of St. Lawrence located in the northeastern part of North America is a transitional environment from estuarine to marine conditions. Diatom analysis of 41 surface sediments samples showed great diversity with the identification of 51 genera and 135 species. Diatom concentrations in surface sediments varied between 9×10^3 and 1.9×10^6 valves per gram of dry sediment, and mean diatom flux in the Gulf of St. Lawrence is about 53×10^3 frustules/cm^2/year. *Q*-mode factor analysis was performed upon 25 taxonomic categories that are defined by similar ecology. Eight factors that explain 93.8 percent of the variance were defined. From these, 6 diatom assemblage zones that were closely related to surface water hydrography could be delimited. The Saguenay Fjord assemblage (I) is mainly composed of fresh to brackish water species *Achnanthes* spp., *Tabellaria* spp., *Cocconeis placentula* var. *euglypta* and by a marine associated taxon *Thalassiosira* cf. *pacifica*. The Maritime Estuary assemblage (II) is principally dominated by estuarine taxa, including *Cyclotella meneghiniana*. The Northwestern Gulf assemblage (III) is characterized by *Aulacoseira* spp. The Northeastern and Central Gulf assemblage (IV) is dominated by the resting spores of *Thalassiosira antarctica*. The North Atlantic assemblage (V) is marked by vegetative cells of marine *Chaetoceros* spp. The last assemblage (VI) corresponds to nutrient rich and high productivity coastal areas with common *Paralia sulcata*. Attempts to calculate quantitative estimates or to generate paleoecological transfer functions, in order to characterize the relations between the modern diatom assemblages and the hydrographic conditions of the Gulf of St. Lawrence, were not successful, in part due to the limited number of samples analyzed in this study to represent the high variability of the whole area.

Le golfe du Saint-Laurent, situé au nord-est de l'Amérique du Nord, forme un milieu de transition complexe entre l'estuaire du Saint-Laurent et l'océan Atlantique. L'analyse diatomologique de 41 échantillons provenant des sédiments de surface a permis l'identification de 51 genres et de 135 espèces. La concentration des diatomées varie entre 9×10^3 et 1.9×10^6 frustules par gramme de sédiment sec, alors que le flux moyen dans le golfe du Saint-Laurent est de l'ordre de 53×10^3 frustules/cm^2/an. L'analyse factorielle (mode *Q*) de 25 groupes de taxa associés selon des affinités écologiques, a permis de définir 8 facteurs expliquant 93.8 pour cent de la variance. La distribution régionale de ces facteurs a permis de délimiter 6 zones étroitement liées aux conditions hydrographiques du milieu. Le Fjord du Saguenay (zone I) est principalement caractérisé par les taxa d'eau douce à saumâtre *Achnanthes* spp., *Tabellaria* spp., *Cocconeis placentula* var. *euglypta* et par un taxon marin *Thalassiosira* cf. *pacifica*. L'estuaire maritime (zone II) est marqué par l'abondance des espèces estuariennes, dont *Cyclotella meneghiniana*. Le nord-ouest du golfe (zone III) est dominé par différentes espèces du genre *Aulacoseira*. Le nord-est et le centre du golfe (zone IV) sont composés par une prédominance des spores de dormance de *Thalassiosira antarctica*. L'Atlantique Nord (zone V) est

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caractérisé par une abondance des cellules végétatives de plusieurs espèces marines de *Chaetoceros*. Finalement, la zone (VI) dominée par *Paralia sulcata*, est associée à des régions côtières, riches en éléments nutritifs et très productives. Malgré la définition de ces 6 zones régionales, caractérisées par un assemblage particulier de diatomées, aucune corrélation significative n'a pu être établie entre les facteurs résultants de l'analyse factorielle en mode *Q*, et les paramètres hydrographiques du milieu. Cette piètre performance est en grande partie reliée à un nombre insuffisant de sites de surface afin de représenter adéquatement la variabilité de toute la région. Ainsi, aucune fonction de transfert paléoécologique n'a pu être développée pour traduire quantitativement les relations entre les diatomées et le milieu.

Keywords: diatoms; surface sediments; hydrographic relation; diatom abundance; Gulf of St. Lawrence; *Q*-mode factor analysis

1. Introduction

The Gulf of St. Lawrence (Fig. 1), covering an area of about 250,000 km^2, is located in the northeastern part of North America. Defined as an highly stratified semi-enclosed sea, the region includes a great variety of environments of different salinity and temperature (Loring and Nota, 1973).

The hydrography is characterized by a strong summer horizontal gradient of salinity (11–34‰) and temperature (8–15°C) from the estuary to the ocean. Important seasonal variations influence the

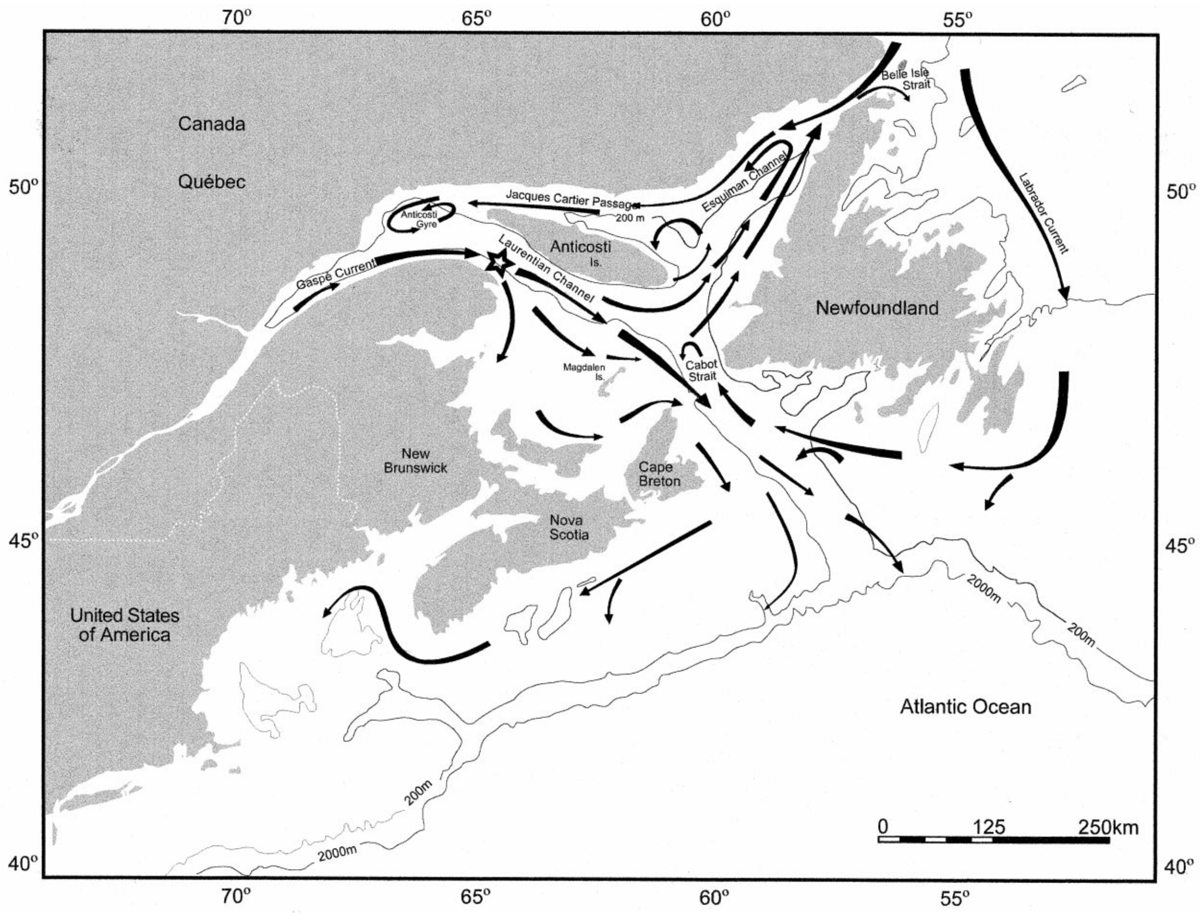


Fig. 1. Map of the Gulf of St. Lawrence showing the surface circulation and the location of the CTD (salinity and temperature) profile (☆) from site 90-031-028.

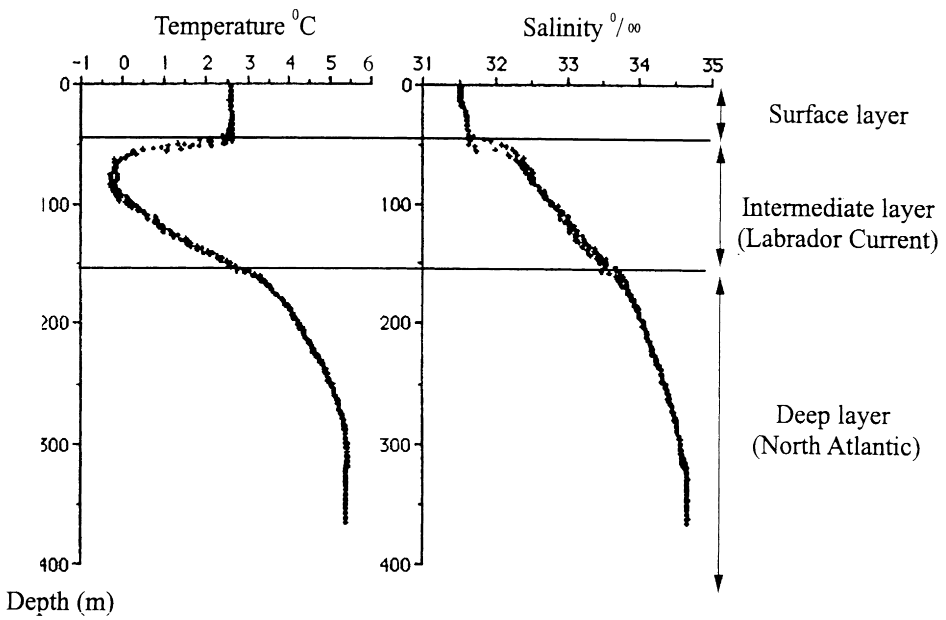


Fig. 2. Salinity and temperature profiles (November 1990) of the water column of the Gulf of St. Lawrence. This CTD profile is from site 90-031-028 (see location on Fig. 1), located southwest of Anticosti Island in the Laurentian Channel, at latitude: 48° 19,48′N. and longitude: 64° 23,54′W. (Unpublished data, GEOTOP, Université du Québec à Montréal).

region, with an average of 3.5 months of sea ice cover during the winter (Weiler and Keeley, 1980; Petrie, 1990).

The focus of this study is to develop a regional diatom data base in order to characterize the regional hydrographic variations of the Maritime Estuary and the Gulf of St. Lawrence based on the analysis of 41 surface sediment samples.

The main goals are as follows:

1. evaluate surface sediment concentrations and fluxes of the preserved diatoms;
2. document the regional distribution of the diatom assemblages;
3. define the relationship between diatom assemblages and the hydrographic parameters.

2. The Gulf of St. Lawrence and the Maritime Estuary

2.1. Hydrography

Freshwater runoff from the St. Lawrence River drainage basin and the Atlantic marine water entering through Belle Isle and Cabot Straits, are mixed together in the Gulf of St. Lawrence to generate a complex, highly-stratified hydrographic system (Fig. 1) (Koutitonsky and Bugden, 1991).

In summer, surface water heating induces the formation of a surface layer (seasonal thermocline) of less than 50 m in depth, with temperature varying from 12 to 18°C and salinity of 27–32‰. Throughout the year, the intermediate water mass, at a depth of 60–125 m, originating from the Labrador Current, is characterized by colder temperatures −1 to 2°C and salinities of 32–33‰ (Fig. 2). The bottom water mass lying at 200–400 m, comes from the Atlantic Ocean and is characterized by temperatures of 2–5°C and higher salinities, from 33 to 35‰ (Steven, 1974; Dunbar et al., 1980).

Surface circulation patterns in the Gulf of St. Lawrence (Fig. 1) are dominated by a density current forced by freshwater runoff, and is strongly influenced by atmospheric conditions (winds, tides, Coriolis effect) and topography (El-Sabh, 1976; Dunbar et al., 1980; Mertz et al., 1988a,b; Centre Saint-Laurent, 1996a). The main features of the circulation (Fig. 1)

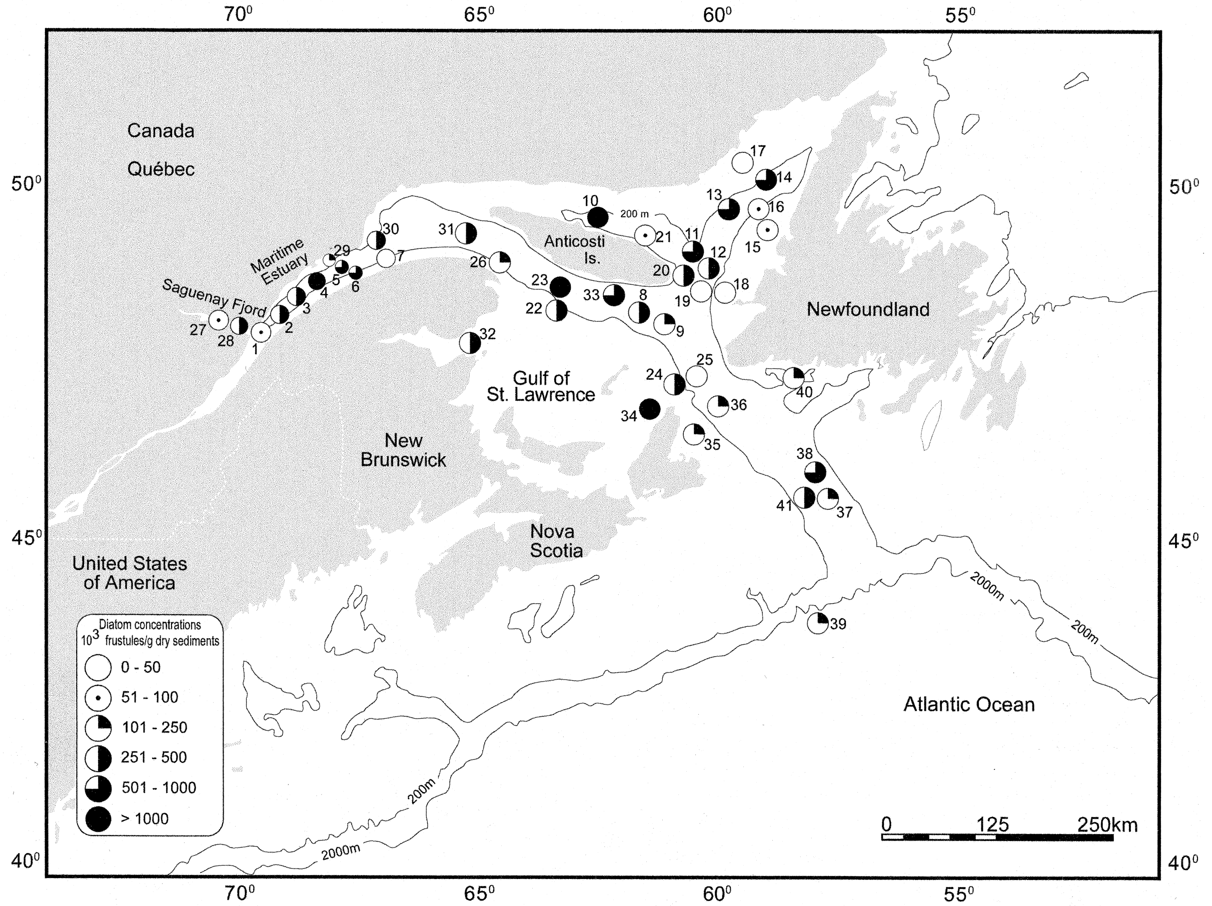


Fig. 3. Distribution of diatom concentrations in surface sediments and sample numbers from the Maritime Estuary and the Gulf of St. Lawrence.

are represented by the general two-way flow in all openings of the Gulf, the Gaspé, Cape Breton and Labrador currents, the anticlockwise circulation in the interior part of the Gulf and in Anticosti Gyre (Trites, 1971; El-Sabh, 1976), and the subcurrent from the Atlantic Ocean in Cabot Strait (Steven, 1974). Water exchange via the Belle Isle Strait was studied amongst others by Petrie et al. (1988) and has only minor influence on overall circulation in the Gulf of St. Lawrence (Steven, 1974).

2.2. Primary production

The controlling factors for primary production in the Maritime Estuary and the Gulf of St. Lawrence are defined by: air-ocean heat exchanges, freshwater runoff, winds, tides, stability of the water column and turbidity (Sinclair, 1978; Legendre and Demers, 1985; Therriault and Levasseur, 1985; Gratton et al., 1988; Wang et al., 1991).

Generally, the amount of phytoplankton is not limited by the nutrients, which are quite abundant (Levasseur et al., 1984), except for two regions, the Anticosti Gyre (Sevigny et al., 1979) and the northeastern region (Steven, 1974). Both regions present stable environments with particularly low nitrate and silicate concentrations, resulting in lower productivities.

Primary producers in the area are documented by several authors (Brunel, 1970; Steven, 1974; Sevigny et al., 1979; Dunbar et al., 1980; Therriault and Levasseur, 1985; Bérard-Therriault et al., 1999). Moreover, Centre Saint-Laurent (1996a,b) published

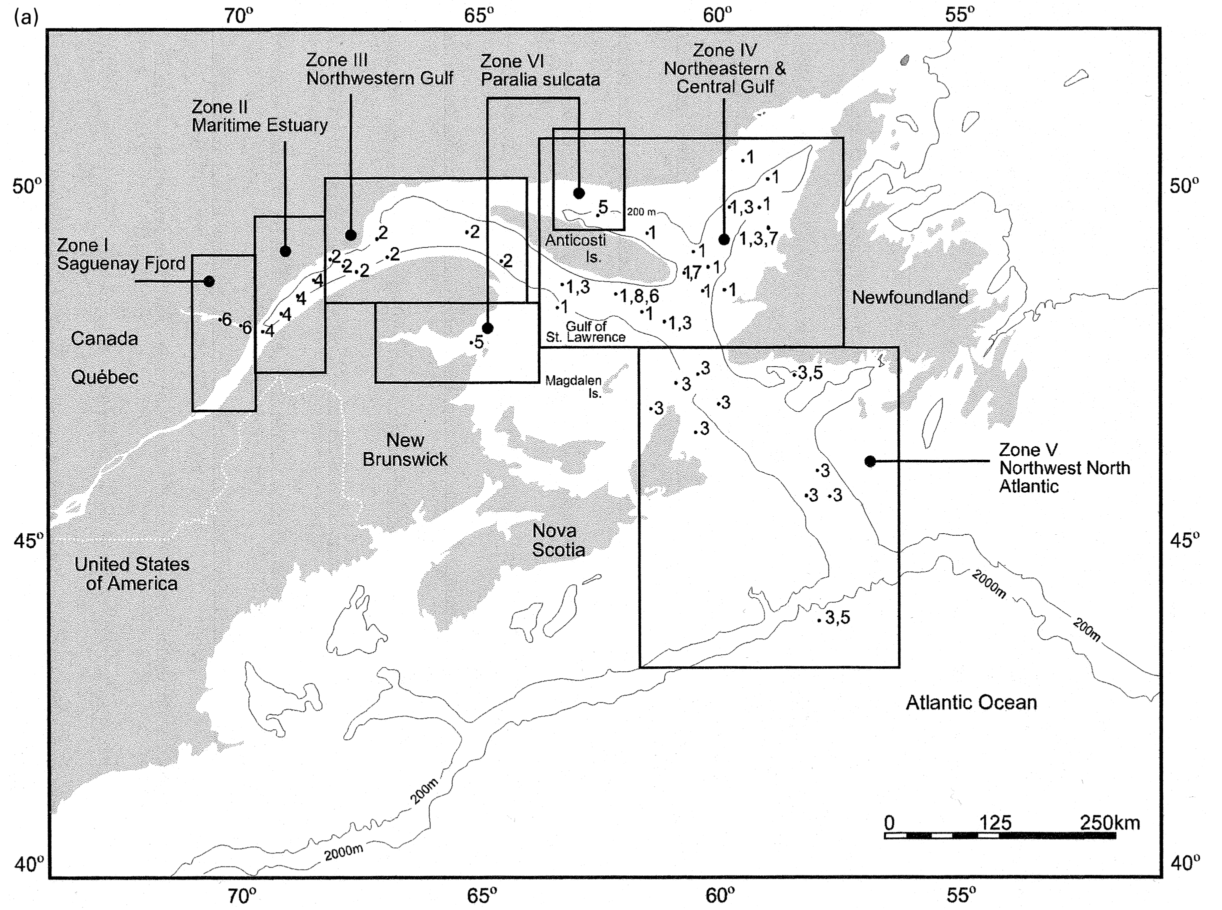


Fig. 4. (a) Diatom assemblage factor (*Q*-mode analysis) distributions and recent diatom zonations in surface sediments from the Maritime Estuary and the Gulf of St. Lawrence and (b) Diatom species related to the *Q*-mode factors.

a complete synthesis on the environmental state of the St. Lawrence River, which refers to the most recent studies available on hydrography, biology, ecology and socio-economy. These studies reported that the primary producers were dominated by diatoms and microflagellates.

3. Material and methods

Forty-one surface samples collected during cruises of the *CSS Dawson* (89-007), *CSS Hudson* (90-028 and 90-031) and *Petrel V* (88-007), were selected for diatom analysis (Figs. 3 and 4). Sample location, core type, water depth and diatom concentration are given in Tables 1 and 2.

Surface sediment was sampled from the cores at interval depths of 0–1 cm. Depending on the sedimentation rates, which vary from a mean value of 0.9 cm/year in the Saguenay Fjord, 0.37 cm/year in the Maritime Estuary and 0.18 cm/year in the Gulf (Sylverberg et al., 1986; Jennane, 1992), they represent, respectively, and approximately 1, 3 and 5 years of accumulation. Surface temperature and salinity data in the research area were provided by the Environment Canada and represent mean values of data collected up to 1989. Data compilation is archived at the Université du Québec à Montréal.

One gram of dry sediment was subsampled and chemically treated to clean and concentrate the

(b)

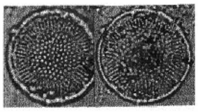
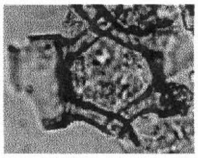
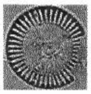
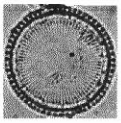
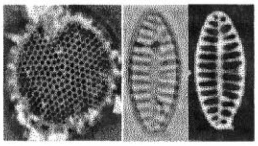
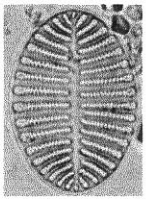
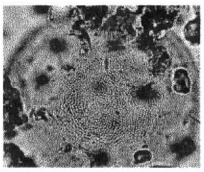
	Q-mode Factors	Diatom species
	1.	*Thalassiosira antarctica* resting spores
	2.	*Aulacoseira distans*, *A. italica*, *A.* cf. *granulata* and *A. islandica*
	3.	*Chaetoceros* spp.
	4.	*Cyclotella meneghiniana*
	5.	*Paralia sulcata*
	6.	*Fragilaria* spp., *Achnanthes* spp., *Tabellaria* spp., *Cocconeis placentula* var. *euglypta*, *Tabularia* spp., *Thalassiosira* cf *pacifica* and *Rhoicosphenia curvata*
	7.	*Cocconeis costata*, *C. scutellum* var. *scutellum*, *C. scutellum* var. *parva*, *Diploneis smithii*, *Grammatophora arctica*, *G. arcuata, G. oceanica*, *G. angulosa*, *Rhabdonema arcuatum* and *R. minutum*
	8.	*Coscinodiscus asteromphalus*, *Coscinodiscus oculus-iridis* and *Porosira glacialis*

Fig. 4. (*continued*)

Table 1
Location and water depth of surface sediment samples from the Maritime Estuary and the Gulf of St. Lawrence

Sample and laboratory numbers	Cruise and site numbers	Latitude North	Longitude West	Water depth (m)
1. E003	*Petrel V* 88-007 E2	48° 10.26′	69° 31.81′	190
2. E006	*Petrel V* 88-007 F2	48° 16.90′	69° 20.86′	329
3. E013	*Petrel V* 88-007 H2	48° 45.25′	68° 33.91′	351
4. E016	*Petrel V* 88-007 I2	48° 54.92′	68° 14.52′	336
5. E019	*Petrel V* 88-007 J2	49° 09.86′	67° 42.07′	284
6. E021	*Petrel V* 88-007 K2	49° 09.42′	67° 14.55′	327
7. E023	*Petrel V* 88-007 L2	49° 16.69′	66° 16.50′	330
8. G052	*Dawson* 89-007 003	48° 30.60′	60° 38.09′	391
9. G053	*Dawson* 89-007 008	48° 20.02′	60° 14.53′	427
10. G055	*Dawson* 89-007 018	49° 42.80′	61° 57.00′	258
11. G056	*Dawson* 89-007 023	49° 31.09′	60° 47.96′	281
12. G057	*Dawson* 89-007 028	49° 19.81′	59° 46.85′	274
13. G060	*Dawson* 89-007 033	49° 47.90′	59° 27.70′	261
14. G061	*Dawson* 89-007 038	50° 06.92′	58° 43.59′	300
15. G996	*Dawson* 89-007 042	49° 45.00′	58° 16.98′	70
16. G995	*Dawson* 89-007 043	49° 47.59′	58° 20.80′	100
17. G994	*Dawson* 89-007 050	50° 11.53′	58° 56.87′	150
18. G992	*Dawson* 89-007 062	49° 15.52′	59° 39.76′	250
19. G991	*Dawson* 89-007 070	48° 50.83′	59° 28.63′	146
20. G990	*Dawson* 89-007 072	48° 51.56′	59° 39.28′	250
21. G989	*Dawson* 89-007 075	48° 56.12′	60° 26.58′	250
22. G062	*Dawson* 89-007 095	48° 31.45′	62° 37.48′	395
23. G064	*Dawson* 89-007 100	48° 38.36′	62° 32.61′	420
24. G065	*Dawson* 89-007 108	47° 21.00′	60° 01.66′	420
25. G066	*Dawson* 89-007 113	47° 31.04′	59° 53.05′	503
26. G998	*Hudson* 90-028 019	49° 06.49′	63° 47.58′	382
27. G997	*Hudson* 90-028 039	48° 21.16′	70° 23.04′	258
28. G993	*Hudson* 90-028 056	48° 15.14′	70° 10.53′	196
29. G067	*Hudson* 90-031 009	49° 05.24′	67° 26.22′	311
30. G999	*Hudson* 90-031 013	49° 25.42′	66° 19.45′	322
31. G068	*Hudson* 90-031 017	49° 17.44′	63° 59.57′	373
32. G069	*Hudson* 90-031 021	47° 55.43′	65° 12.31′	73
33. G070	*Hudson* 90-031 029	48° 32.00′	61° 10.20′	408
34. G071	*Hudson* 90-031 034	47° 09.15′	60° 32.54′	174
35. G072	*Hudson* 90-031 038	46° 43.47′	60° 13.16′	154
36. G073	*Hudson* 90-031 041	46° 59.56′	59° 04.56′	448
37. G075	*Hudson* 90-031 045	45° 51.17′	57° 35.51′	473
38. G076	*Hudson* 90-031 049	46° 11.21′	57° 56.17′	468
39. G077	*Hudson* 90-031 052	43° 30.56′	56° 22.15′	355
40. G078	*Hudson* 90-031 056	47° 04.37′	57° 03.07′	333
41. G079	*Hudson* 90-031 059	45° 50.36′	58° 34.19′	268

diatoms. Calcium carbonate component was removed by adding concentrated HCl (10%), and organic matter was oxidized using hydrogen peroxide H_2O_2 (30%). The sample was then sieved using a 10 μm mesh to remove fine silt and clay. Both smaller and larger fractions were diluted in 25 ml of distilled water and an average of 0.2 and 0.5 ml, respectively, were pipetted onto a glass slide, using Hyrax as the mounting medium. The finer fraction was examined to make sure that the loss of diatom valves due to the sieving procedure was not important enough to affect the flora assemblages.

A light microscope (Leitz Aristoplan) with phase contrast optics and a magnification of up to 1600× was used for the diatom identification, using the fraction larger than 10 μm. A minimum of 300 diatoms

Table 2
Diatom concentrations in surface sediment samples from the Maritime Estuary and the Gulf of St. Lawrence

Sample, laboratory and site numbers	Core type	No. valves/g dry sediment	No. frustules/g dry sediment
1. E003 E2	Dredge	126,972	63,486
2. E006 F2	Boxcore	513,334	256,667
3. E013 H2	Boxcore	847,000	423,500
4. E016 I2	Boxcore	3,263,334	1,631,667
5. E019 J2	Boxcore	1,235,666	617,833
6. E021 K2	Boxcore	1,276,000	638,000
7. E023 L2	Boxcore	1,122,000	561,000
8. G052 003	Boxcore	871,200	435,600
9. G053 008	Boxcore	454,666	227,333
10. G055 018	Boxcore	2,280,666	1,140,333
11. G056 023	Boxcore	1,535,112	767,556
12. G057 028	Boxcore	919,112	459,556
13. G060 033	Boxcore	1,133,000	566,500
14. G061 038	Boxcore	1,029,600	514,800
15. G996 042	Van Veen Grab	175,454	87,727
16. G995 043	Van Veen Grab	192,350	96,175
17. G994 050	Van Veen Grab	35,650	17,825
18. G992 062	Van Veen Grab	18,064	9,032
19. G991 070	Van Veen Grab	50,066	25,033
20. G990 072	Van Veen Grab	542,666	271,333
21. G989 075	Van Veen Grab	169,400	84,700
22. G062 095	Boxcore	682,880	341,440
23. G064 100	Boxcore	2,293,500	1,146,750
24. G065 108	Boxcore	850,080	425,040
25. G066 113	Boxcore	1,988,800	994,400
26. G998 019	Boxcore	211,200	105,600
27. G997 039	Boxcore	158,400	79,200
28. G993 056	Boxcore	880,000	440,000
29. G067 009	Boxcore	366,300	183,150
30. G999 013	Boxcore	965,250	482,625
31. G068 017	Boxcore	909,333	454,667
32. G069 021	Boxcore	1,276,000	638,000
33. G070 029	Boxcore	3,818,375	1,909,188
34. G071 034	Boxcore	360,800	180,400
35. G072 038	Van Veen Grab	457,600	228,800
36. G073 041	Boxcore	459,066	229,533
37. G075 045	Boxcore	1,199,000	599,500
38. G076 049	Boxcore	259,926	129,963
39. G077 052	Boxcore	335,500	167,750
40. G078 056	Boxcore	504,534	252,267
41. G079 059	Boxcore	943,250	471,625

was counted per sample, along random transect lines, for statistical treatments.

Diatom valve concentrations (n_{vc}) were estimated using the general equation

$$(N_{vtot}/Vol_p)(Vol_{tot}/P_{tot}) = n_{vc}(C_{tot}/C_c)$$

where N_{vtot} is the total amount of counted valves, Vol_p the volume of sample in ml, Vol_{tot} the volume of total dilution in ml, P_{tot} the total weight in gram, n_{vc} the number of specific valves, C_{tot} the total number of fields, and C_c the number of counted fields.

Both the resting spores and the vegetative cells were included in the computation of diatom

Table 3
Mean diatom fluxes in surface sediment samples from the Maritime Estuary and the Gulf of St. Lawrence (References: (a) Jennane, 1992; (b) Sylverberg et al., 1986

Location	Sample, Laboratory and Site numbers	Number of frustules/g	Mean density/g of dry sediment (cm^3)	Diatom concentrations (No. frustules/cm^3)	Mean sedimentation rates (cm/yr)	Mean diatom fluxes (No. of frustules/cm^2/yr)
Saguenay Fjord	27. G997 039	79,200	1.50	52,800	0.9a	47,520
	28. G993 056	440,000		293,333		264,000
Maritime Estuary	1. E003 E2	63,486		42,324		15,660
	2. E006 F2	256,667	1.50	171,111	0.37a, b	63,311
	3. E013 H2	423,500		282,333		104,463
	4. E016 I2	1,631,667		1,087,778		402,478
Northwest Gulf	5. E019 J2	617,833		411,889	0.37a, b	152,399
	6. E021 K2	638,000		425,333	0.37a, b	157,373
	7. E023 L2	561,000	1.50	374,000	0.18a, b	138,380
	26. G998 019	105,600		70,400	0.18a, b	12,672
	29. G067 009	183,150		122,100	0.18a, b	21,978
	30. G999 013	482,625		321,750	0.18a, b	57,915
	31. G068 017	454,667		303,111	0.18a, b	54,560
Northeast and Central Gulf	8. G052 003	435,600		290,400	0.18a, b	52,272
	9. G053 008	227,333		151,555		27,280
	10. G055 018	1,140,333		760,222		136,840
	11. G056 023	767,556		511,704		92,107
	12. G057 028	459,556		306,371		55,147
	13. G060 033	566,500		377,667		67,980
	14. G061 038	514,800		343,200		61,776
	15. G996 042	87,727		58,485		10,527
	16. G995 043	96,175	1.50	64,117		11,541
	17. G994 050	17,825		11,883		2,139
	18. G992 062	9,032		6,021		1,084
	19. G991 070	25,033		16,689		3,004
	20. G990 072	271,333		180,889		32,560
	21. G989 075	84,700		56,467		10,164
	22. G062 095	341,440		227,627		40,973
	23. G064 100	1,146,750		764,500		137,610
	33. G070 029	1,909,188		1,272,792		229,103
Baie des Chaleurs	32. G069 021	638,000	1.50	425,333	0.18a, b	76,560
Northwest North Atlantic	24. G065 108	425,040		283,360	0.18a, b	51,005
	25. G066 113	994,400		662,933		119,328
	34. G071 034	180,400		120,267		21,648
	35. G072 038	228,800		152,533		27,456
	36. G073 041	229,533	1.50	153,022		27,544
	37. G075 045	599,500		399,667		71,940
	38. G076 049	129,963		86,642		15,596
	39. G077 052	167,750		111,833		20,130
	40. G078 056	252,267		168,178		30,272
	41. G079 059	471,625		314,417		56,595

percentages and concentrations. Diatom concentrations are given in number of valves or frustules per gram of dry sediment. Calculation of the number of frustules per gram of dry sediment is obtained by a simple division of the valves concentrations in half.

3.1. Taxonomy

Species identification were primarily based on Hustedt (1927–1933, 1937, 1959, 1976: reprint of 1930), Hendey (1964), Patrick and Reimer (1966, 1975), Cleve-Euler (1968: reprint of 1951–1955), Germain (1981), Van Heurck (1981: reprint of 1885) and Hartley et al. (1996). Details and further information about methodology, species description, illustration and taxonomy can be found in Lapointe (1998).

4. Results

4.1. Diatom concentration and fluxes in surface sediment samples

Diatom concentrations in surface sediments varied between 9×10^3 and 1.9×10^6 with a median value of 0.4×10^6 frustules/g (Table 2, Fig. 3). In order to establish a relationship between surface water and surface sediments diatom abundance, mean diatom fluxes were estimated using the mean values of sedimentation rates for the Saguenay Fjord (0.9 cm/year), the Maritime Estuary (0.37 cm/year) and the Gulf of St. Lawrence (0.18 cm/year), based on Sylverberg et al. (1986) and Jennane (1992). Results are listed in Table 3.

4.2. Diatom analysis

Diatom analysis of surface sediments from the Maritime Estuary and the Gulf of St. Lawrence reveals generally well preserved frustules and high diversity with the identifications of 51 genera and 135 species. The most abundant Centrales, in alphabetical order, were identified as: *Aulacoseira* spp., *Bacterosira bathyomphala* resting spores, *Chaetoceros* spp. resting spores (including *C. affinis*, *C. debilis*, *C. diadema*, *C. furcellatus* and *C. mitra*), *Chaetoceros* spp., *Coscinodiscus asteromphalus*, *Coscinodiscus divisus*, *Coscinodiscus marginatus*, *Coscinodiscus oculus-iridis*, *Cyclotella meneghiniana*, *Paralia sulcata*, *Porosira glacialis*, *Stephanodiscus rotula*, *Thalassiosira antarctica* resting spores, *Thalassiosira decipiens*, *Thalassiosira* cf. *eccentrica*, *Thalassiosira hyalina*, *Thalassiosira nordenskioeldii* and *Thalassiosira* cf. *pacifica*. The most abundant Pennales, in alphabetical order, are: *Achnanthes delicatula* spp. *hauckiana*, *Cocconeis costata*, *Fragilaria* spp., *Fragilariopsis cylindrus*, *Nitzschia* aff. *arctica*, *Tabellaria flocculosa* var. *linearis* and *Thalassiothrix longissima*.

4.3. Q-Mode factor analysis

For the purpose of statistical analysis, the numerous taxa were gathered into 25 groups, which include three different types: (1) dominant taxon; (2) associated species of the same genus living in similar environments; and (3) gathering of different species showing comparable ecology and distribution (marine, brackish, benthic, sea ice associated, etc.). Composition of these groups is given as following:

1. FRAG: represents benthic and fresh to brackish water species: *Fragilaria* spp., *Achnanthes* spp., *Tabellaria* spp., *Rhoicosphenia curvata*, *Cocconeis placentula* var. *euglypta* and *Tabularia* spp.
2. NAVI: is a group composed mainly by marine coastal species: *Navicula* cf. *distans*, *N. directa*, *N.* spp. and *Lyrella lyra*.
3. ACTI: represents marine centrics: *Actinocyclus octonarius* var. *crassus*, *A. ehrenbergii*, *Coscinodiscus curvatulus* and *C.* aff. *granulosus*.
4. CODI: groups together benthic marine coastal species: *Cocconeis costata*, *C. scutellum* var. *scutellum*, *C. scutellum* var. *parva*, *Diploneis smithii*, *Grammatophora arctica*, *G. arcuata*, *G. oceanica*, *G. angulosa*, *Rhabdonema arcuatum* and *R. minutum*.
5. AULA: is defined by all the species of the same genus *Aulacoseira* that is found in fresh to brackish water: *Aulacoseira distans*, *A. italica*, *A.* cf. *granulata* and *A. islandica*.
6. BACT: *Bacterosira bathyomphala* (vegetative cells and resting spores).
7. CHAE: *Chaetoceros* spp. vegetative cells.
8. CHSP: *Chaetoceros* spp. resting spores. The vegetative cells and the resting spores of the genus *Chaetoceros* were divided into two separate groups in order to find out if the hydrographic conditions of the area had some influence on their distribution.
9. COSD: *Coscinodiscus divisus*.
10. COSM: *Coscinodiscus marginatus* and *C. radiatus*. Although *C. marginatus* is far more abundant than *C. radiatus*, both species are heavily silicified and were encountered in the same samples.
11. COSA: *Coscinodiscus asteromphalus* and *C. oculus-iridis*.

Table 4
Varimax factor score matrix for groups of species from the Maritime Estuary and the Gulf of St. Lawrence

Species group names[a]	F1	F2	F3	F4	F5	F6	F7	F8
1. FRAG	−0.007	−0.032	−0.032	0.285	0.004	0.588	0.005	−0.234
2. NAVI	0.012	0.008	0.017	0.038	0.025	0.086	0.100	−0.105
3. ACTI	0.009	0.000	−0.003	0.005	0.001	−0.002	−0.007	0.004
4. CODI	0.121	0.140	−0.062	0.149	0.094	−0.093	0.774	−0.163
5. AULA	−0.102	0.908	−0.112	−0.073	−0.003	0.132	−0.063	−0.196
6. BACT	0.188	−0.001	0.005	−0.007	0.044	0.024	0.071	0.016
7. CHAE	0.168	0.091	0.953	0.043	−0.120	0.036	−0.017	−0.155
8. CHSP	−0.001	0.040	0.042	0.001	0.016	0.051	0.002	0.020
9. COSD	0.065	0.013	0.013	0.017	0.027	0.047	0.020	0.142
10. COSM	0.051	0.109	0.063	−0.032	0.248	−0.057	−0.219	0.165
11. COSA	0.014	0.291	0.076	−0.004	−0.011	−0.157	−0.178	0.548
12. CYCL	−0.010	0.026	−0.032	0.917	−0.020	−0.128	−0.127	0.104
13. PORO	0.162	0.067	0.088	−0.032	0.219	0.020	0.395	0.503
14. PARA	−0.022	−0.050	0.079	0.015	0.885	−0.020	−0.168	−0.197
15. ODON	0.000	0.021	0.003	−0.004	0.042	0.008	0.018	0.024
16. FCYL	0.041	0.061	0.027	−0.002	0.052	0.002	0.176	−0.095
17. THLX	0.091	−0.002	0.008	0.019	0.141	0.018	0.050	0.029
18. THNM	−0.016	0.009	0.054	−0.016	0.005	0.070	0.053	0.087
19. TECC	−0.035	0.041	0.048	0.121	0.047	0.019	0.119	0.260
20. TANT	0.925	0.026	−0.193	−0.024	−0.050	−0.004	−0.181	−0.088
21. TDEC	0.077	0.159	−0.053	0.153	0.029	0.107	−0.117	0.030
22. TLEP	0.007	0.008	0.041	−0.003	−0.029	0.007	0.053	−0.011
23. TNOR	0.010	−0.018	0.008	−0.027	0.219	0.153	0.018	0.060
24. TPAC	0.011	−0.080	−0.002	−0.065	−0.017	0.727	0.000	0.310
25. HYAS	0.071	0.039	−0.012	−0.005	−0.016	−0.002	0.015	−0.015

[a] 1. FRAG: *Fragilaria* spp., *Achnanthes* spp., *Tabellaria* spp., *Rhoicosphenia curvata*, *Cocconeis placentula* var. *euglypta* and *Tabularia* spp. 2. NAVI: *Navicula* cf. *distans*, *N. directa*, *N.* spp. and *Lyrella lyra*. 3. ACTI: *Actinocyclus octonarius* var. *crassus*, *A. ehrenbergii*, *Coscinodiscus curvatulus* and *C.* aff. *granulosus*. 4. CODI: *Cocconeis costata*, *C. scutellum* var. *scutellum*, *C. scutellum* var. *parva*, *Diploneis smithii*, *Grammatophora arctica*, *G. arcuata*, *G. oceanica*, *G. angulosa*, *Rhabdonema arcuatum* and *R. minutum*. 5. AULA: *Aulacoseira* spp. 6. BACT: *Bacterosira bathyomphala* (veg. cells and resting spores). 7. CHAE: *Chaetoceros* spp. (veg. cells). 8. CHSP: *Chaetoceros* spp. (resting spores). 9. COSD: *Coscinodiscus divisus*. 10. COSM: *Coscinodiscus marginatus* and *C. radiatus*. 11. COSA: *Coscinodiscus asteromphalus* and *C. oculus-iridis*. 12: CYCL: *Cyclotella bodanica* var. *affinis*, *C. meneghiniana* and *Stephanodiscus rotula*. 13. PORO: *Porosira glacialis*, *Thalassiosira hyalina* and *T. hyperborea*. 14. PARA: *Paralia sulcata*. 15. ODON: *Odontella aurita* var. *aurita* and *O. aurita* var. *obtusa*. 16. FCYL: *Fragilariopsis cylindrus* and *F. curta*. 17. THLX: *Thalassiothrix longissima*. 18. THNM: *Thalassionema nitzschioides*. 19. TECC: *Thalassiosira eccentrica*. 20. TANT: *Thalassiosira antarctica* (resting spores). 21. TDEC: *Thalassiosira decipiens*. 22. TLEP: *Thalassiosira leptopus*. 23. TNOR: *Thalassiosira nordenskioeldii*. 24. TPAC: *Thalassiosira* cf. *pacifica* and 25. HYAS: *Hyalodiscus scoticus*.

12. CYCL: groups toghether fresh to brackish planktonic species *Cyclotella bodanica* var. *affinis*, *C. meneghiniana* and *Stephanodiscus rotula*.
13. PORO: is composed of ice associated species: *Porosira glacialis*, *Thalassiosira hyalina* and *T. hyperborea*.
14. PARA: *Paralia sulcata*.
15. ODON: *Odontella aurita* var. *aurita* and *O. aurita* var. *obtusa*.
16. FCYL: *Fragilariopsis cylindrus* and *F. curta*.
17. THLX: *Thalassiothrix longissima*.
18. THNM: *Thalassionema nitzschioides*.
19. TECC: *Thalassiosira* cf. *eccentrica*.
20. TANT: *Thalassiosira antarctica* (resting spores).
21. TDEC: *Thalassiosira decipiens*.
22. TLEP: *Thalassiosira leptopus*.
23. TNOR: *Thalassiosira nordenskioeldii*.
24. TPAC: *Thalassiosira* cf. *pacifica*.
25. HYAS: *Hyalodiscus scoticus*.

A *Q*-mode factor analysis, using CABFAC (Imbrie and Kipp, 1971) was performed on the

Table 5
Varimax factor components matrix for surface sediment samples from the Maritime Estuary and the Gulf of St. Lawrence

Site number	Communality	*F*1	*F*2	*F*3	*F*4	*F*5	*F*6	*F*7	*F*8
E003 88007E2	0.917	0.018	0.027	−0.048	0.932	0.034	0.203	−0.001	−0.051
E006 88007F2	0.957	0.053	0.123	0.050	0.959	0.112	0.047	−0.041	−0.003
E013 88007H2	0.910	0.034	0.334	0.055	0.887	0.042	−0.029	−0.067	0.007
E016 88007I2	0.918	0.082	0.139	0.280	0.884	0.022	0.103	0.137	0.047
E019 88007J2	0.925	0.075	0.718	0.368	0.451	0.161	0.138	0.102	0.098
E021 88007K2	0.924	0.089	0.872	0.133	0.300	0.080	0.022	−0.058	0.194
E023 88007L2	0.919	0.313	0.845	0.112	0.074	0.126	0.020	−0.065	0.262
G052 8907003	0.950	0.914	0.137	0.199	0.042	0.224	0.044	−0.035	−0.031
G053 8907008	0.943	0.603	0.111	0.619	0.057	0.380	0.029	−0.045	−0.183
G055 8907018	0.937	0.358	0.096	0.397	0.070	0.784	0.002	0.143	−0.052
G056 8907023	0.966	0.809	0.121	0.542	0.030	−0.012	0.045	0.004	−0.022
G057 8907028	0.967	0.926	0.113	0.274	0.010	0.145	0.026	0.005	0.023
G060 8907033	0.940	0.680	0.189	0.650	0.069	0.035	0.042	0.075	−0.070
G061 8907038	0.877	0.705	0.144	0.420	0.097	0.259	−0.002	0.249	−0.210
G996 8907042	0.905	0.627	0.180	0.436	0.087	0.177	0.066	0.481	0.121
G995 8907043	0.982	0.947	0.143	0.214	0.034	0.077	0.013	0.100	0.031
G994 8907050	0.869	0.808	0.139	0.336	0.089	0.063	0.061	0.193	−0.178
G992 8907062	0.967	0.947	0.133	0.116	0.006	0.108	−0.011	−0.161	0.025
G991 8907070	0.955	0.928	0.127	0.087	0.012	0.211	0.073	0.026	0.140
G990 8907072	0.946	0.683	0.157	−0.098	0.107	0.190	−0.035	0.628	−0.044
G989 8907075	0.970	0.949	0.123	0.191	0.013	0.067	0.020	0.058	0.094
G062 8907095	0.936	0.756	0.194	0.535	0.050	0.096	0.051	0.147	0.070
G064 8907100	0.963	0.616	0.141	0.726	0.065	−0.009	0.077	0.152	−0.050
G065 8907108	0.928	0.796	0.129	0.401	0.026	0.334	0.042	−0.042	−0.039
G066 8907113	0.955	0.322	0.311	0.855	0.056	0.070	0.071	0.024	−0.101
G998 9028019	0.961	0.376	0.771	0.402	0.058	0.114	0.167	0.102	−0.094
G997 9028039	0.872	−0.014	0.409	−0.047	0.339	0.017	0.736	0.023	−0.214
G993 9028056	0.911	0.047	0.288	0.136	0.194	0.091	0.868	−0.027	0.087
G067 9031009	0.943	0.009	0.925	0.140	0.144	0.041	0.154	−0.043	−0.140
G068 9031017	0.951	0.175	0.923	0.114	0.021	0.087	0.152	0.086	−0.135
G069 9031021	0.938	0.219	0.116	0.194	0.087	0.895	0.036	0.132	0.111
G070 9031029	0.860	0.551	0.052	0.315	−0.009	0.148	0.516	0.069	0.401
G071 9031034	0.975	0.261	0.083	0.816	0.059	0.454	0.064	0.011	−0.145
G072 9031038	0.945	0.333	0.100	0.773	0.046	0.462	0.083	0.033	−0.057
G073 9031041	0.959	0.248	0.205	0.915	0.053	0.102	0.049	−0.023	0.041
G075 9031045	0.953	0.265	0.271	0.854	0.045	0.202	0.006	0.043	0.187
G076 9031049	0.949	0.286	0.261	0.860	0.017	0.108	−0.009	−0.039	0.214
G077 9031052	0.979	0.322	0.077	0.664	0.030	0.641	0.033	−0.044	−0.116
G078 9031056	0.947	0.195	0.116	0.674	0.057	0.638	0.054	0.123	0.109
G079 9031059	0.940	0.077	0.037	0.109	0.051	0.948	0.079	−0.105	−0.047
G999 9031013	0.950	0.355	0.805	0.341	0.119	0.044	0.151	0.110	−0.094
Variance		28.952	14.672	21.624	9.599	10.443	4.382	2.374	1.760
Cumulative Variance		28.952	43.623	65.247	74.846	85.289	89.671	92.044	93.804

surface samples in order to define representative diatom assemblages. Results of the varimax factor scores matrix and varimax component scores matrix are listed in Tables 4 and 5, respectively. A total of 8 factors explained 93.8 percent of the data variance. High communalities of the samples (Table 5) associated with these factors are concordant with this good performance. Details about variance, diatom content and environmental conditions of all factors are elaborated in Table 6. These factors were used to define the recent regional surface distribution of diatom zones.

Table 6
Q-mode factor descriptions of surface sediment samples from the Gulf of St. Lawrence with respect to their diatom content and hydrographic conditions

Factors (names of grouped taxa)	Variance (%)	Diatoms	Environments (mean summer temperatures and salinities)
*F*1 (TANT)	28.9	*Thalassiosira antarctica* resting spores	(10–11°C and 30–31‰) Labrador current
*F*2 (AULA)	14.6	*Aulacoseira distans*, *A. italica A.* cf. *granulata*, and *A. islandica*	(11–12°C and 28–29‰) Northwest Gulf
*F*3 (CHAE)	21.6	*Chaetoceros* spp. vegetative cells	(12–14°C and 31–32‰) Atlantic ocean
*F*4 (CYCL)	9.6	*Cyclotella meneghiniana*, *Cyclotella bodanica* var. *affinis* and *Stephanodiscus rotula*	(8–11°C and 23–26‰) Maritime Estuary
*F*5 (PARA)	10.4	*Paralia sulcata*	(10–12°C and 26–29‰) Coastal and nutrient rich waters
*F*6 (FRAG and TPAC)	4.3	FRAG: *Fragilaria* spp., *Achnanthes* spp., *Tabellaria* spp., *Rhoicosphenia curvata*, *Cocconeis placentula* var. *euglypta*, *Tabularia* spp. and TPAC: *Thalassiosira pacifica*	(11–13°C and 12–18‰) Saguenay Fjord (FRAG) mixed with a marine component (TPAC)
*F*7 (CODI)	2.3	*Cocconeis costata*, *C. scutellum* var. *scutellum*, *C. scutellum* var. *parva*, *Diploneis smithii*, *Grammatophora arctica*, *G. arcuata*, *G. oceanica*, *G. angulosa*, *Rhabdonema arcuatum* and *R. minutum*	(10–11°C and 30–31‰) Epicontinental, marine and benthic
*F*8 (COSA and PORO)	1.8	COSA: *Coscinodiscus asteromphalus*, *Coscinodiscus oculus-iridis* and PORO: *Porosira glacialis*, *T. hyperborea* and *Thalassiosira hyalina*	(10–11°C and 30–31‰) Marine water (COSA) and associated sea ice environment (PORO)

4.4. Diatom assemblages from recent surface sediment samples

Regional distribution of the *Q*-mode factor assemblages are shown in Fig. 4a. The most important diatom species for each factor are illustrated (Fig. 4b) in association with the map keys for helpful visual recognition of the taxa involved.

Coefficient of correlations between *Q*-mode factors and monthly mean temperatures and salinities were calculated, to identify controlling environmental parameters upon factors distributions. The results were not significant because they presented low correlations or poor diffusional patterns of their distribution (annexe 3, Lapointe, 1998). This is mainly due to the fact that the number of analyzed sites is not sufficiently large to represent the high variability of the whole area.

5. Discussion

5.1. Frustule densities and primary production

Pattern of diatom accumulations and fluxes in bottom sediments generally agree with measurements of surface, in situ, primary production as published by Steven (1971, 1974) and Dunbar et al. (1980) and for the North Atlantic by Colebrook (1982). Highest diatom concentrations (Fig. 3) and fluxes (Table 3) are closely associated with Gaspé (samples 4, 5, 6, 7, 23 and 33) and Cape Breton (sample 34) currents, while lowest values are mostly found in the northeastern part of the Gulf along the Newfoundland coast, following the path of the cold Labrador Current (samples 15–19 and 21) and in Saguenay Fjord (sample 27).

Moreover, significant differences are well recognized between productive south shore Gaspé Current (samples 4–7) and the less productive north shore of the Maritime Estuary and the Northwestern Gulf (samples 1–3, 26 and 29–31). While sample 10, located in the western part of Jacques Cartier Passage (northwest shore of Anticosti Island) and sample 25 from Cabot Strait, with particularly high diatom concentrations and fluxes, correspond with the unusual higher July and August production zones described by Steven (1974). High correlation between distribution of diatom concentrations in surface sediments with the overlying pattern of primary productivity was also recognized in the Atlantic Ocean by Maynard (1976).

However, significantly higher values (even

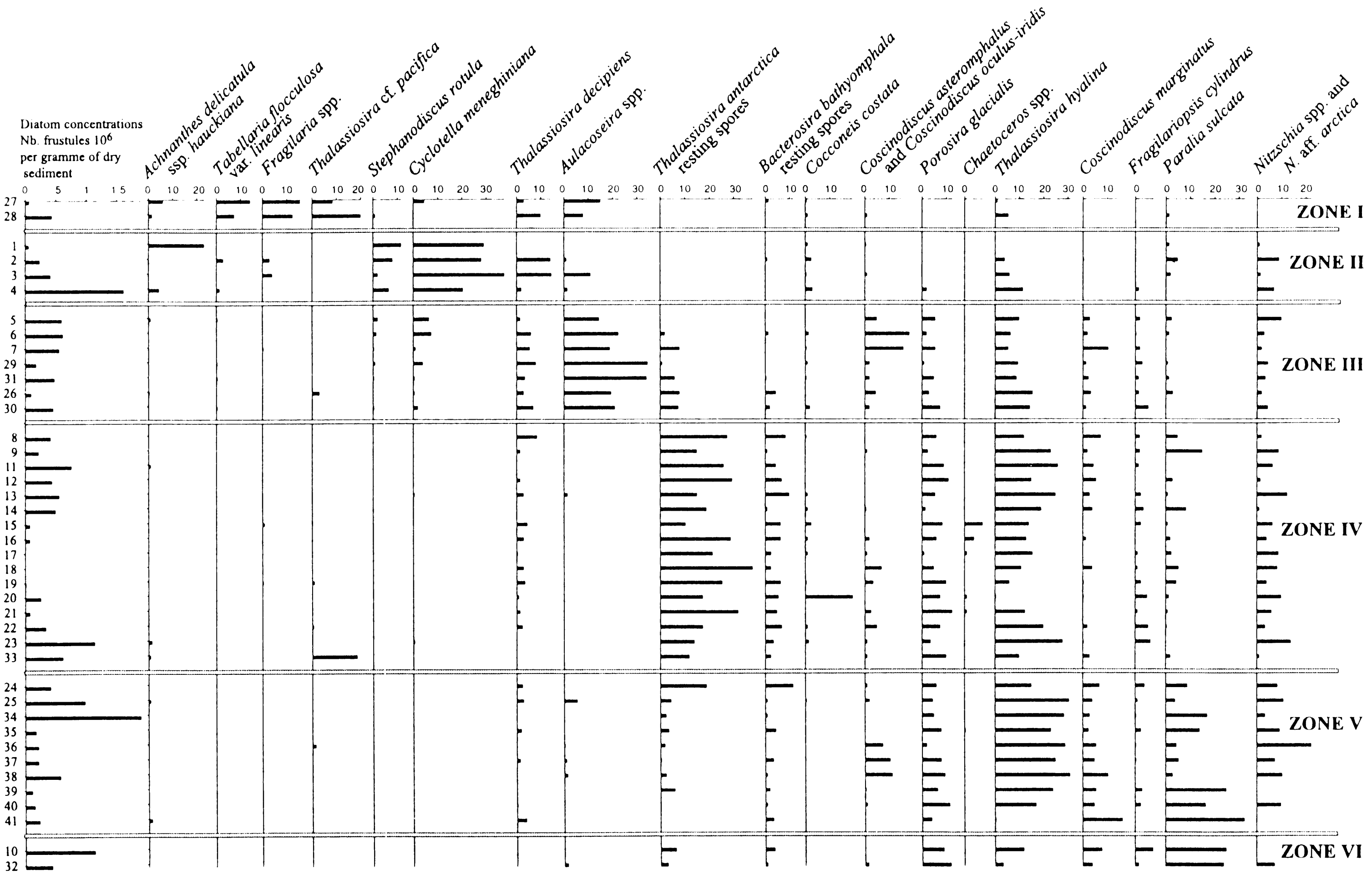


Fig. 5. Summary diatom percentages diagram of surface sediment samples with diatom zonations, (ZONE I) Saguenay Fjord, (ZONE II) Maritime Estuary, (ZONE III) Northwestern Gulf, (ZONE IV) Northeastern and Central Gulf, (ZONE V) Northwest North Atlantic and (ZONE VI) *Paralia sulcata*.

exceeding the mean value in the Gulf) were found in some samples (numbers 11, 13, and 14) within Esquiman Channel surface sediments. Those differences could reflect favorable bottom conditions enabling accumulation and settling of transported diatom frustules.

5.2. Diatom zonations in recent surface sediments

Based on the *Q*-mode factorial analysis of the recent diatom distributions, a total of six zones are defined, from northwest to southeast in the Gulf of St. Lawrence (Fig. 4a): (I) Saguenay Fjord, (II) Maritime Estuary, (III) Northwestern Gulf, (IV) Northeastern and Central Gulf, (V) Northwest North Atlantic and (VI) *Paralia sulcata* zone. A summary diagram of diatom species percentages characterizing these zonations is shown in Fig. 5.

5.2.1. Zone I. Saguenay Fjord (Factor 6)

Environmental description: fresh to brackish waters mixed with a marine influence. Mean summer temperature 11–13°C and salinity 12–18‰.

Only 2 samples were taken in the area, and since the diatom abundance of sample 28 is significantly higher, the factor analysis (*Q*-mode) combined equally both group of species (brackish and marine affinities) to form the factor. The Saguenay Fjord zone is mainly composed of fresh to brackish water species *Fragilaria* spp., *Achnanthes* spp., *Tabellaria* spp. (including *T. fenestrata*, *T. flocculosa* var. *flocculosa* and *T. flocculosa* var. *linearis*), *Rhoicosphenia curvata*, *Cocconeis placentula* var. *euglypta*, *Tabularia* spp. Sample 28, located at the mouth of the Saguenay, also presented a high concentration of marine species *Thalassiosira* cf. *pacifica*.

5.2.2. Zone II. Maritime Estuary (Factor 4)

Environmental description: estuarine conditions with brackish water.

Mean summer temperature 8–11°C and salinity 23–26‰.

Four samples cover the whole area of this zone. *Cyclotella meneghiniana*, *Cyclotella bodanica* var. *affinis* and *Stephanodiscus rotula* were the major diatom species found in the surface sediments. Reported by Vickers (1980) in the spring diatom communities of the St. Lawrence Estuary, these species are typical of shallow, coastal, fresh, brackish and inland saline waters (Germain, 1981; Håkansson and Kling, 1994).

5.2.3. Zone III. Northwestern Gulf (Factor 2)

Environmental description: mixing zone of mainly marine and estuarine conditions.

Mean summer temperature 11–12°C and salinity 28–29‰.

This region is characterized by the presence and abundance of *Aulacoseira distans*, *A. italica*, *A.* cf. *granulata* and *A. islandica*. These are coastal freshwater species (Germain, 1981). *A.* cf. *granulata* and *A. islandica* were identified in the spring diatom assemblages of the St. Lawrence Estuary by Vickers (1980) and *A. granulata* was observed in only one rock sample in the St. Lawrence River by Reavie and Smol (1998). Because of the composition of this surface assemblage, mainly represented by fresh water associated species, it could be argued whether it is a result of in situ accumulation or more likely from a lateral transportation of diatom living in lower salinity waters upstream the estuary. In this case, the importance of the in situ accumulation could not be neglected because the presence of *A. islandica* in the living plankton of the Northwestern Gulf (Zone III) area was recently described by Bérard-Therriault et al. (1999). Further, the brackish-water affinity of *A. islandica* was also reported from the Baltic Sea by Snoeijs and Vilbaste (1994).

5.2.4. Zone IV. Northeastern and Central Gulf (Factors 1, 7 and 8)

Environmental description: cold marine water associated with Labrador Current.

Mean summer temperature 10–11°C and salinity 30–31‰.

Covering the main portion of the center and the northeastern regions of the Gulf of St. Lawrence, this zone is principally represented by *Thalassiosira antarctica* resting spores and some patches of *Chaetoceros* spp. vegetative cells. Both are associated with the Atlantic cold waters coming from Belle Isle and Cabot Straits partly as the Labrador Current and the Atlantic subsurface current. Similar surface sediments assemblages associated with subarctic to arctic environments (identified as *Thalassiosira gravida*) were also reported from North and Northeast Atlantic

Ocean by Maynard (1976) and Barde (1981), from the Arctic Seas by Polyakova (1997), from Greenland, Iceland and Norwegian Sea by Koc Karpuz and Schrader (1990), from Western North Atlantic Ocean by Palmer (1984), from Western Baffin Bay by Williams (1988 and 1990) and from the Gulf of Maine by Jorgensen (1984), Schnitker and Jorgensen (1990) and Popek (1993).

On the other hand, two samples (15 and 20) located close to the shore of Newfoundland and within the Esquiman Channel, respectively, presented a significant amount of *Cocconeis costata* and *Cocconeis scutellum* var. *scutellum*. Those coastal, benthic and marine species are also common and well known in Greenland, Davis Strait and Spitzbergen areas (Cleve, 1873).

Only sample 33 contradicts the general dominant trend of *Thalassiosira antarctica* resting spores of this zone, with the presence of high concentrations of ice associated diatoms *Porosira glacialis*, *Thalassiosira hyperborea* and marine diatom species *Thalassiosira* cf. *pacifica*. The noticeable differences of this sample lies with its unique location, on the southeastern side of Anticosti Island, where open pack ice occurs as early as the beginning of March (Dunbar et al., 1980).

5.2.5. Zone V. Northwest North Atlantic (Factor 3)

Environmental description: marine.

Mean summer temperature 12–14°C and salinity 31–32‰.

Samples from this zone extend from Cabot Strait toward the northwest North Atlantic Ocean. The most abundant species found in the area are *Chaetoceros* spp. vegetative cells. This genus is common in neritic temperate to cold seas (Brunel, 1970). Two samples (40 and 41) also had a major percentages of *Paralia sulcata*, which is abundant in coastal, nutrient rich waters (Sancetta, 1982).

5.2.6. Zone VI. Paralia Sulcata (Factor 5)

Two epicontinental samples located in productive areas in the Gulf of St. Lawrence, the Baie des Chaleurs and the north shore of Anticosti Island, were defined by a high abundance of *Paralia sulcata*. Their location agrees with the description of this taxon as an important indicator of nutrient rich and productive coastal waters (Sancetta, 1982). Similar environmental assemblages were also described, amongst other, from Basin Head Harbour (Prince Edward Island) by Palmer (1974), from San Francisco Bay by Laws (1988) and from Greenland, Iceland and Norwegian Sea by Koc Karpuz and Schrader (1990).

6. Conclusions

The distribution of the diatom assemblages from surface sediments of the St. Lawrence Estuary and the Gulf of St. Lawrence, based on the *Q*-mode factorial analysis, defined a total of six zones closely related to surface water hydrography. From northwest to southeast in the Gulf of St. Lawrence, the zones are listed as followed: (I) Saguenay Fjord, fresh to brackish waters mixed with a marine influence, (II) Maritime Estuary, estuarine conditions with brackish water, (III) Northwestern Gulf, mixing zone of mainly marine and estuarine conditions, (IV) Northeastern and Central Gulf, cold marine water associated with Labrador Current, (V) Northwest North Atlantic, marine environment and (VI) *Paralia sulcata* zone, nutrient rich and productive coastal waters.

Unfortunately, poor correlations between these diatom *Q*-mode factors and environmental parameters such as temperature and salinity, due in part to the insufficient number of analyzed sites, prevent the calculation of a paleoecological transfer function, in order to establish a quantitative relationship. An extended diatom sampling in surface sediments of a broader area, including the western part of the North Atlantic as well as the Labrador Sea, is certainly needed to eventually create a database large enough to enable the calculations of paleoecological transfer functions, which would adequately describe quantitatively the regional complexity of such a diversified environment.

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Appendix A. Taxonomic appendix

Division BACILLARIOPHYTA Engler and Gild
CLASS COSCINODISCOPHYCEAE Round and Crawford *in* Round et al.
Family AULACOSEIRACEAE Crawford *in* Round et al.
Genus *Aulacoseira* Thwaites
Aulacoseira distans (Ehrenberg) Simonsen.
Reference: (*Melosira distans*) Cleve-Euler, 1951 (reprint 1968), Figs. 11a–c, p. 20.
Aulacoseira cf. ***granulata*** (Ehrenberg) Simonsen.
Reference: (*Melosira granulata*) Germain, 1981, pl. 3, Fig. 1, p. 24.
Aulacoseira italica (Ehrenberg) Simonsen.
Reference: (*Melosira italica*) Germain, 1981, pl. 3, Fig. 7, pp. 24–25.
Aulacoseira islandica (O Müller) Simonsen.
Syn.: *Melosira islandica* Müller
Reference: Snoeijs and Vilbaste (eds.), 1994, pl. 113, p. 25.
Family CHAETOCEROTACEAE Ralfs *in* Pritchard
Genus *Chaetoceros* Ehrenberg
***Chaetoceros* spp.**: the vegetative cells were poorly preserved, the original setae were partly or totally broken, negating the identification to the species level.
***Chaetoceros* spp. resting spores**: this group is represented by the resting spores of five different species:
Chaetoceros affinis Lauder: because of the great variability found in *Chaetoceros affinis*, Brunel (1970) described it as a central type of a complex group. He included a total of 13 synonyms in *Chaetoceros affinis* such as *C. ralfsii* Cleve, *C. willei* Gran, *C. javanicus* Cleve. Only the resting spores of that species were found in this study.
Reference: Brunel, 1970, pl. 27, Fig. 1, pp. 114–116.
Chaetoceros debilis Cleve.
Reference: Brunel, 1970, pl. 32, Fig. 6, pp. 130–132.
Chaetoceros diadema (Ehrenberg) Gran.
Reference: Hendey, 1964, pl. X, Fig. 1a, pp. 122–125.
Chaetoceros furcellatus Bailey.
Reference: Brunel, 1970, pl. 34, Fig. 3, pl. 35, Figs. 1–3, pp. 134–135.
Chaetoceros mitra (Bailey) Cleve.
Reference: Brunel, 1970, pl. 17, Figs. 1–2, pp. 102–104.
Family COSCINODISCACEAE Kützing
Genus *Coscinodiscus* Ehrenberg
Coscinodiscus asteromphalus Ehrenberg: with the light microscope, this species was differentiated from *Coscinodiscus oculus-iridis* Ehrenberg by the fact that their frustules were not as heavily silicified and their areolae became finer at the margin of the valve. Both species were counted together.
Reference: Hasle and Lange, 1992, Figs. 10–14, pp. 42–45.
Coscinodiscus curvatulus Grunow *in* Schmidt.
References: Lohman, 1941, pl. 15, Fig. 8, p. 74; Hendey, 1964, p. 81.
Coscinodiscus divisus Grunow.
Reference: Cleve-Euler, 1951 (reprint 1968), Fig. 80a and b, p. 58.
Coscinodiscus* aff. *granulosus Grunow *in* Cleve and Grunow: our specimen were poorly preserved which made the identification very difficult. The closest taxon was described in Cleve-Euler (1951: reprint 1968).
Reference: Cleve-Euler, 1951 (reprint 1968), Fig. 112, p. 70.
Coscinodiscus marginatus Ehrenberg.
References: Lohman, 1941, pl. 14, Figs. 1, 6, p. 71; Cleve-Euler, 1951 (reprint 1968), p. 65.
Coscinodiscus oculus-iridis Ehrenberg.
Reference: Hendey, 1964, pl. XXIV, Fig. 1, p. 78.
Coscinodiscus radiatus Ehrenberg.
Reference: Brunel, 1970, pl. 3, Fig. 1, p. 55, 232.

Family HEMIDISCACEAE Hendey *emend.* Simonsen

Genus *Actinocyclus* Ehrenberg

Actinocyclus ehrenbergii Ralfs in Pritchard.

Reference: Van Heurck, 1885 (reprint 1981), pl. CXXIII, Fig. 7, p. 215.

Actinocyclus octonarius var. ***crassus*** (Wm Smith) Hendey.

Syn.: *Actinocyclus crassus* (Wm Schmidt) Ralfs *in* Pritchard

References: Hendey, 1964, p. 83; Snoeijs and Potapova (eds.), 1995, pl. 206, p. 18.

Family HYALODISCACEAE Crawford *in* Round et al.

Genus *Hyalodiscus* Ehrenberg

Hyalodiscus scoticus (Kützing) Grunow.

References: Bérard-Therriault et al., 1987, p. 93; Snoeijs and Vilbaste (eds.), 1994, pl. 147, p.59.

Family PARALIACEAE Crawford

Genus *Paralia* Heiberg

Paralia sulcata (Ehrenberg) Cleve.

Syn.: *Melosira sulcata* (Ehrenberg) Kützing

Reference: Crawford, 1979, Figs. 1–31, p. 209.

Family STEPHANODISCACEAE Glezer and Makarova

Genus *Cyclotella* Kützing *ex* Brébisson

Cyclotella bodanica* var. *affinis Grunow *in* Schneider: in the literature there was much confusion with the interpretation of *Cyclotella comta* (Ehrenberg) Kützing. Håkansson (1988) was used for the identification of this species. The centre of these specimens showed a distinct uplift or depression. Together with the distinct striations, these features are similar to *C. bodanica* var. *affinis*.

References: Cleve-Euler, 1951 (reprint 1968), Fig. 56i–l, p. 46; Håkansson, 1988, pp. 334–336.

Cyclotella meneghiniana Kützing.

References: Germain, 1981, pl. 7, Figs. 1–5, p. 32; Håkansson, 1990, pp. 21–22.

Genus *Stephanodiscus* Ehrenberg

Stephanodiscus rotula (Kützing) Hendey: the name *Stephanodiscus astraea* Kützing was changed to *Stephanodiscus rotula* as suggested by Hendey (1964). This species could also be *S. neoastraea* Håkansson and Hickel, since it is almost impossible to distinguish them with a light microscope (Snoeijs and Potapova, 1995).

References: Lohman, 1941, pl. 12, Fig. 2, p. 67; Hendey, 1964, p. 75.

Family THALASSIOSIRACEAE Lebour

Genus *Bacterosira* Gran

Bacterosira bathyomphala (P.T. Cleve) Syvertsen and Hasle *in* Hasle and Syvertsen:*B. bathyomphala* is an active producer of resting spores. Its weakly silicified vegetative valves are rarely seen while its resting spores in sediments (Stabell and Lange *in* Hasle and Syvertsen, 1993) and in ice samples are more common (Hasle and Syvertsen, 1993). In this study, the resting spores were also more abundant than the vegetative cells. The characteristic central depression with its numerous strutted processes, surrounded by an irregular, silicified border were helpful for the identification.

Syn.: *Bacterosira fragilis* Gran, *Coscinodiscus bathyomphalus* Cleve.

Reference: Hasle and Syvertsen, 1993, Fig. 3, pp. 298–303.

Genus *Porosira* Jörgensen

Porosira glacialis (Grunow) Jörgensen *emend.* Hasle

Reference: Hasle, 1973, pl. 3, Figs. 13–18, pl. 4, Figs. 19–25, pl. 5, Figs. 26–29, pp. 6–10, 39.

Genus *Thalassiosira* Cleve

Thalassiosira antarctica Comber *emend.* Hasle and Heimal **resting spores**: the resting spores of *T. antarctica* could be easily confused with *Thalassiosira gravida* Cleve. According to Syvertsen (1979), the difference lies in part in the number of areolae in 10 μm, which is 10–14 for the spore and about 20 for *T. gravida*. However, only *T. antarctica* produced resting spores in cultural experiments. To avoid confusion, although in the literature of the area the name of *T. gravida* is used (amongst other by Jorgensen, 1984; Palmer, 1984; Williams, 1988, 1990; Schnitker and Jorgensen, 1990; Popek, 1993), herein this morphological form was identified as being the resting spore of *T. antarctica*.

Reference: Syvertsen, 1979, pl.4, Figs. 44, 45, pp. 52–54.

Thalassiosira decipiens (Grunow) Jörgensen.

Reference: Hasle, 1979, pl. 4, Figs. 20–25, pl. 5, Figs. 26–29, pp. 85–108.

Thalassiosira* cf. *eccentrica (Ehrenberg) Cleve: the central areolae showed an irregular pattern due to the presence of a strutted tubulus (not directly observed in our sample, under the light microscope). In our material, the central areolae never presented the fasciculated structure that could be found on some valves of this species.

Reference: Fryxell and Hasle, 1972, pl. II, Figs. 4a, 8–9, pl. III, Fig. 15, pp. 300–304.

Thalassiosira hyalina (Grunow) Gran.

References: Hendey, 1964, p. 86; Bérard-Therriault et al., 1987, Figs. 38, 42, p. 89.

T. hyperborea (Grunow) Hasle *in* Hasle and Lange: the distinction between some of the different varieties of this species is not always obvious. The environmental factors have been known to affect the plasticity of the areolae size in the genus of *Thalassiosira*.

Reference: Hasle and Lange, 1989, Figs. 20–22, pp. 125–127.

Thalassiosira leptopus (Grunow) Hasle and Fryxell: Hasle and Syvertsen (1984) grouped *Coscinodiscus pseudolineatus* Pant. and *C. praelineatus* Jousé as synonyms of *T. leptopus*. Identification was not always obvious using the light microscope and occasionally the valves were poorly preserved. *Thalassiosira* with similar linear areolar arrays were grouped together with this species.

References: Lohman, 1941, pl. 12, Fig. 10, p. 68; Hasle and Fryxell, 1977, pp. 20–22.

Thalassiosira nordenskioeldii Cleve.

References: Hendey, 1964, pl. I, Fig. 8, p. 85; Hasle, 1978, pp. 79–83.

Thalassiosira* cf. *pacifica Gran and Angst.

Reference: Hasle, 1978, pp. 88–93.

Family TRICERATIACEAE (Schütt) Lemmermann

Genus *Odontella* Agardh

Odontella aurita* var. *aurita (Lyngbye) Agardh *emend*. Simonsen.

Reference: (*Biddulphia aurita*) Brunel, 1970, pp. 144–145.

Odontella aurita* var. *obtusa (Kützing) Hustedt.

Reference: (*Biddulphia aurita* var. *obtusa*) Brunel, 1970, pl. 7, Fig. 3, pp. 145, 240.

Class FRAGILARIOPHYCEAE Round and Crawford *in* Round et al.

Family FRAGILARIACEAE Greville

Genus *Fragilaria* Lyngbye

***Fragilaria* spp.**: due to their tiny size and since they were never found in great abundance, this taxon was not investigated to the species level.

Reference to the genus: Williams and Round, 1987, pp. 267–268.

Genus *Tabularia* (Kützing) Williams and Round

***Tabularia* spp.**: because they were not abundant in this study and mainly located in the Saguenay Fjord, this taxon was not investigated to the species level.

Reference to the genus: Round et al., 1990, p. 376.

Family RHABDONEMATACEAE Greville

Genus *Rhabdonema* Kützing

Rhabdonema arcuatum (Lyngbye) Kützing.

Reference: Hendey, 1964, pl. XXXV, Figs. 10–12, p. 172.

Rhabdonema minutum Kützing.

Reference: Hendey, 1964, p. 172.

Family STRIATELLACEAE Kützing

Genus *Grammatophora* Ehrenberg

Grammatophora angulosa Ehrenberg.

Reference: Hendey, 1964, p. 171.

Grammatophora arctica Cleve.

Reference: Poulin et al., 1984, Figs. 16–17, p. 278.

Grammatophora arcuata Ehrenberg.

Reference: Poulin et al., 1984, Figs. 2–3, 5, p. 278.

Grammatophora oceanica Ehrenberg.

References: Hendey, 1964, p. 170; Poulin et al., 1984, Figs. 10–12, p. 278.

Family TABELLARIACEAE Kützing

Genus *Tabellaria* Ehrenberg *ex* Kützing

Tabellaria fenestrata (Lyngbye) Kützing.

Reference: Germain, 1981, pl. 12, Figs. 2, 4, 5, 7, p. 50.

Tabellaria flocculosa* var. *flocculosa (Lyngbye) Kützing.

Reference: Germain, 1981, pl. 12, Figs. 10–12, p. 50.

Tabellaria flocculosa* var. *linearis Koppen

Reference: Poulin et al., 1984, Figs. 76–78, p. 290.

Family THALASSIONEMATACEAE Round *in* Round et al.

Genus *Thalassionema* Grunow *ex* Hustedt

Thalassionema nitzschioides (Grunow) Hustedt.
References: Hallegraeff, 1986, pp. 58–60; Snoeijs and Vilbaste (eds.), 1994, pl. 194, p. 106.
Genus *Thalassiothrix* Cleve and Grunow
Thalassiothrix longissima Cleve and Grunow.
Reference: Hasle and Semina, 1987, Figs. 1–13, pp. 177–181.
Class BACILLARIOPHYCEAE Haeckel *sensu emend.* Round et al.
Family ACHNANTHACEAE Kützing *sensu emend.* Round et al.
Genus *Achnanthes* Bory
Achnanthes delicatula* ssp. *hauckiana (Grunow) Lange-Bertalot and Ruppel.
Syn.: *Achnanthes hauckiana* ssp. *hauckiana* Grunow *in* Cleve and Grunow
Reference: Cooper, 1995, Fig. 34a and b, 51, pp. 63–64.
***Achnanthes* spp.**: due to their tiny size and since they were never found in great abundance, this taxon was not investigated to the species level.
Reference to the genus: Patrick and Reimer, 1966, pp. 245–250.
Family BACILLARIACEAE Gmelin *in* Linneaus
Genus *Fragilariopsis* Hustedt *in* A. Schmidt
Fragilariopsis cylindrus (Grunow) Krieger *in* Helmcke and Krieger.
Reference: (*Nitzschia cylindrus*), Hasle and Medlin *in* Medlin and Priddle (eds.), 1990, pl. 24.6, Figs. 6–11, pp. 181–182.
Fragilariopsis curta (Van Heurck) Hustedt.
Syn.: *Fragilariopsis linearis* var. *linearis* Frenguelli *in* Grenguelli and Orlando, *Nitzschia curta* (Van Heurck) Hasle.
Reference: Hustedt, 1958, pl. 11, Figs. 140–144, p. 160.
Genus *Nitzschia* Hassall
Nitzschia* aff. *arctica Cleve: striation was very fine and impossible to evaluate under the light microscope. The central nodule was not always obvious to observe.
Reference: Medlin and Hasle *in* Medlin and Priddle (eds.), 1990, pl. 21.1, Fig. 8, p. 160.
Family COCCONEIDACEAE Kützing
Genus *Cocconeis* Ehrenberg
Cocconeis costata Gregory.
Reference: Wasell and Håkansson, 1992, Figs. 24, 26–27, p. 171.
Cocconeis placentula* var. *euglypta (Ehrenberg) Cleve.
Reference: Patrick and Reimer, 1966, pl. 15, Fig. 8, pp. 241–242.
Cocconeis scutellum* var. *scutellum Ehrenberg.
Cocconeis scutellum* var. *parva Grunow ex Cleve.
Reference to both species: Hendey, 1964, pl. XXVII, Fig. 8, p. 181.
Family DIPLONEIDACEAE Mann *in* Round et al.
Genus *Diploneis* Ehrenberg *ex* Cleve
Diploneis smithii (Brébisson *ex* Wm Smith) Cleve.
Reference: Patrick and Reimer, 1966, pl. 38, Fig. 2, p. 410.
Family LYRELLACEAE Mann *in* Round et al.
Genus *Lyrella* Karajeva
Lyrella lyra (Ehrenberg) Karajeva.
Reference: Patrick and Reimer, 1966, pl. 39, Figs. 5–6, p. 443.
Family NAVICULACEAE Kützing
Genus *Navicula* Bory
Navicula directa (Wm Smith) Ralfs *in* Pritchard.
Reference: Hendey, 1964, p. 202.
Navicula* cf. *distans (Wm Smith) Ralfs *in* Pritchard.
Reference: Cleve-Euler, 1953 (reprint 1968), Fig. 768a, p. 133.
***Navicula* spp.**: the different species of *Navicula* that were not well enough preserved to be adequately identified were grouped together.
Family RHOICOSPENIACEAE Chen and Zhu
Genus *Rhoicosphenia* Grunow
Rhoicosphenia curvata (Kützing) Grunow.
Germain, 1981, pl. 44, Figs. 22–23, p. 118; Mann, 1982, pp. 162–176; Mann, 1984, pp. 544–555.

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