

PHYTOPLANKTON MONITORING PROGRAM: NOVA SCOTIA COMPONENT - 1989 TO 1994

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ABSTRACT

Keizer, P.D., T.G. Milligan, D.V. Subba Rao, P.M. Strain, and G. Bugden. 1996. Phytoplankton Monitoring Program: Nova Scotia component - 1989 to 1994. Can. Tech. Rep. Fish. Aquat. Sci. 2136: vi + 74 p.

In the fall of 1988, several deaths in eastern Canada were attributed to complications arising from consumption of cultured blue mussels that were contaminated with domoic acid. The Department of Fisheries and Oceans initiated an investigation of the domoic acid incident. Part of that investigation included a survey of Atlantic coastal waters to determine what potentially toxic species of phytoplankton were commonly present. In Nova Scotia this survey was conducted at five coastal sites over a period of three years. Approximately 26 times each year samples were collected from 3 depths at each of the sites in Whitehaven Harbour, Ship Harbour, St. Margaret's Bay, Woods Harbour and Annapolis Basin. A vertical profile of temperature, salinity and *in vivo* fluorescence was obtained and discrete samples were collected for determination of chlorophyll *a*, suspended particulate matter, ammonia, nitrate, phosphate and silicate. Phytoplankton in these samples were identified and counted and a vertical net tow was also analyzed. This technical report summarizes the information from that survey plus additional sampling at two of the sites, Ship Harbour and Annapolis Basin.

RÉSUMÉ

Keizer, P.D., T.G. Milligan, D.V. Subba Rao, P.M. Strain, and G. Bugden. 1996. Phytoplankton Monitoring Program: Nova Scotia component - 1989 to 1994. Can. Tech. Rep. Fish. Aquat. Sci. 2136: vi + 74 p.

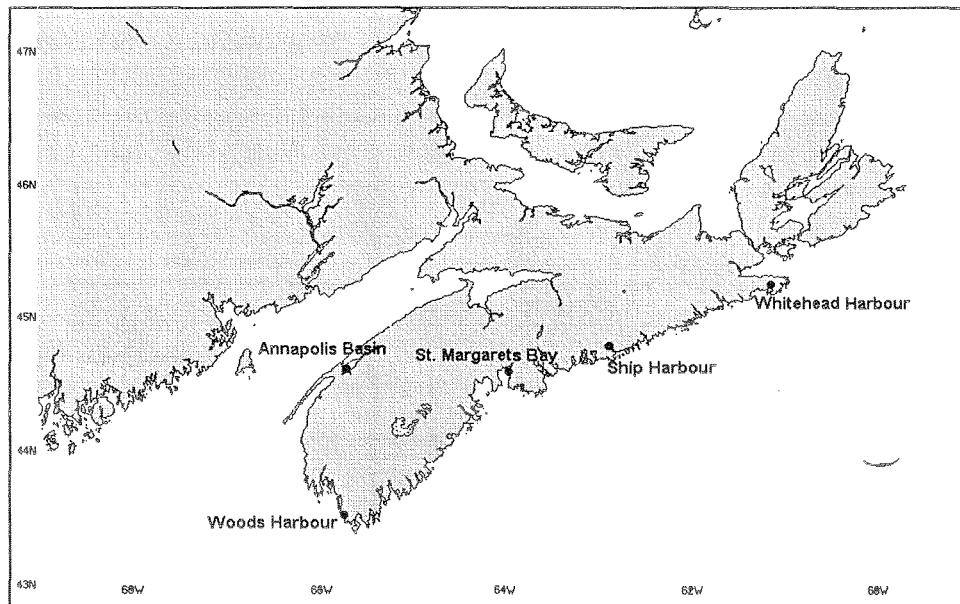
En automne 1988, plusieurs décès survenus dans l'est du Canada étaient attribués à des complications dues à la consommation de moules bleues d'élevage contaminées par l'acide domoïque. Le ministère des Pêches et des Océans entreprit alors une enquête à ce sujet, comprenant une étude des eaux côtières de l'Atlantique qui avait pour but de déterminer quelles espèces de phytoplancton à potentiel toxique y étaient communément présentes. En Nouvelle-Écosse, cette étude a été réalisée dans cinq sites côtiers, sur trois ans. Environ 26 fois par an, des échantillons ont été prélevés à trois profondeurs différentes dans chacun de ces sites, soit à Whitehaven Harbour, à Ship Harbour, dans la baie de St. Margaret, à Woods Harbour et dans le bassin d'Annapolis. L'étude en question a permis d'établir un profil vertical de la température, de la salinité et de la fluorescence *in vivo* et de recueillir des échantillons discrets pour déterminer les concentrations de chlorophylle *a*, de particules en suspension, d'ammoniaque, d'azote, de phosphates et de silicates. On a également identifié et dénombré le phytoplancton présent dans ces échantillons et analysé les résultats d'un trait vertical au filet. Le présent rapport résume les renseignements recueillis dans le cadre de cette étude et les données d'échantillonnages supplémentaires réalisés aux sites de Ship Harbour et du bassin d'Annapolis.

INTRODUCTION

In the fall of 1988, several deaths in eastern Canada were attributed to complications arising from consumption of cultured blue mussels that were contaminated with domoic acid. This shellfish toxin, also referred to as amnesic shellfish poison (ASP), was previously unknown. The pelagic diatom, *Nitzschia pungens* f. *multiseries* (later called *Pseudonitzschia multiseries*, Hasle 1995), was found to be the producer of the toxin (Subba Rao et al. 1989 and Bates et al. 1989). At that time it was uncertain if this phytoplankton species was normally found in Atlantic Canada coastal waters or if any other potential toxin-producing phytoplankton might be commonly present. In general there was little information on coastal phytoplankton and seasonal and annual variations in numbers and species. Until 1988 the only documented shellfish toxin in the area were the paralytic shellfish toxins(PSP) produced by *Alexandrium* spp. Since that time there have been additional shellfish harvesting area closures due to the presence of ASP and diarrhetic shellfish posioning (DSP) as well as the usual PSP closures in Atlantic Canada.

Fisheries and Oceans Canada initiated an investigation of the domoic acid incident with the following objectives:

- determine what areas and times are favourable or unfavourable for shellfish or finfish aquaculture with regards to the presence of toxins.
- indicate times when screening for toxins should be more or less frequent if a consistent species succession can be established.
- the program would also provide background information for gauging whether observed phytoplankton events are normal or whether changes in biomass and species diversity may be related to exceptional meteorological events or anthropogenic activity.



In Nova Scotia this survey was conducted at five coastal sites (see Fig. 1) over a period of 3 yr beginning in November 1988. This report summarizes the information from that survey plus additional sampling at two of the sites, Ship Harbour and near Digby in Annapolis Basin. Similar information has also been collected at a number of sites in the western part of Bay of Fundy (Martin 1995).

The purpose of this report is to document the type, amount and general characteristics of the information that has been collected. There is an obvious need for intensive analysis of the data but it was felt that it was important to bring the existence of this information to the attention of the scientific community. The authors encourage anyone interested in such analyses to contact them.

METHODS

SAMPLE/DATA COLLECTION

Discrete Water Samples

Samples were collected with a Niskin bottle from 1 m below the surface, mid-depth and 1 m above the bottom. The water was transferred to carboys and kept in a cooler until returned to the laboratory for processing. Duplicate subsamples were removed for salinity, plant nutrients, extracted chlorophyll, and suspended particulate matter (SPM) and single samples were taken for phytoplankton culture and phytoplankton analyses. Water temperatures were recorded also for the three samples.

Frequency of sampling varied from monthly during the winter to weekly during the summer. Detailed information is provided for each station as part of the site description below.

Depth Profiles

Starting in November 1989, a SeaBird Model 25 Profiling CTD was used to collect vertical profiles of temperature, salinity, and *in vivo* chlorophyll *a* fluorescence as a function of pressure (depth) at each site. The SeaBird was also not available during February and March 1990. Before the SeaBird was available, water temperatures were taken from the discrete water samples and therefore can only be considered rough estimates.

Phytoplankton Net Samples

A vertical plankton net tow was collected at each site using a 20 μm mesh, 0.5 or 0.25 m diameter net. The sample was then filtered through a 200 μm mesh sieve to remove the larger organisms and measured for volume in a graduated cylinder. The sample was stored in an opaque plastic bottle and preserved in 1% paraglutaraldehyde (1 mL/100 mL) for later identification and counting.

Additional Information

Temperature recorders were moored at all of the sites for various periods of time. Sensors for photosynthetically active radiation (PAR) and dissolved oxygen were added to the SeaBird profiler during the study period, but these data are not reported here. In addition, from July 1993 to March 1994 similar data are available for 3 additional sites in Annapolis Basin. This information is available by contacting any of the authors. Data from two additional sites on the Atlantic coast of Nova Scotia, Sambor and Indian Point, which continue to be sampled have already been published (Keizer et. al. 1996).

ANALYSIS

Plant Nutrients

Silicate, phosphate, ammonia, and nitrate (nitrite+nitrate) were determined using the standard methods for the Technicon Autoanalyzer II (ca. 1973), with modifications for phosphate.

Chlorophyll a

Chlorophyll was determined according to the method of Strickland and Parsons (1968).

Suspended Particulate Material

Samples were filtered using preweighed 47 mm, 8.0 μm pore size SCWP Millipore cellulose acetate filters for gravimetric analysis. These filters retain particle sizes well below their nominal pore size and show close agreement with 0.4 μm pore size Nucleopore filters in estuarine waters (Kranck and Milligan 1979). Cellulose acetate filters can also be ashed and the grain size distribution of the inorganic material in suspension analyzed. The filters were oven dried at $< 60^\circ\text{C}$ and then desiccated prior to reweighing on a Mettler AE163 balance (± 0.01 mg range) in accordance with the method described by Winneberger et al (1963) to obtain total SPM values in g m^{-3} .

Phytoplankton Analyses

A subsample of 500 mL was taken from each of the three water samples, put in opaque bottles, and preserved with 5 mL of 1% paraformaldehyde and kept for later identification and enumeration.

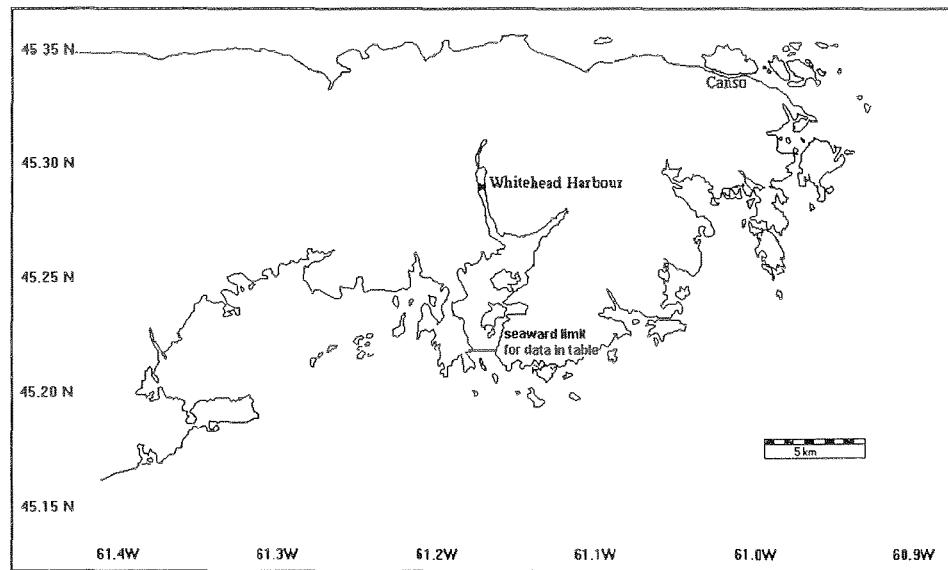
DATA MANAGEMENT

All data were tracked with an identification number assigned at the time of sample collection. Information was entered, maintained, and accessed using a relational database management system. Data for the three depths corresponding to the Niskin bottle samples collected were extracted from the SeaBird depth profile data. These data were stored with the data from the discrete samples in a relational database. The individual depth profiles from the SeaBird profiler are also stored, as is the information from the vertical plankton net tows. Only the data for the discrete sampling depths are presented here.

WHITEHAVEN HARBOUR

This site is located at the head of Whitehaven Harbour, Guysborough County, at 45.2943°N and 61.1710°W. Average depth of water at the site was 10 m above a very muddy bottom. There is very little residential and no industrial development in the area. Since 1990 there has been rapid growth of shellfish and salmon sea cage culture in Whitehaven Harbour proper. The following information is from Gregory et al. 1993.

Area (CD)	14.7 km ²	Area (HW)	16.1 km ²
Perimeter	46.7 km ²	Volume (CD)	133.0 10 ⁶ km ³
Axis Length	17.0 km	Maximum Depth	29.3 m
Tidal Range		Tidal Volume	
Mean	Large	Mean Tide	Tidal Current
1.30 m	1.80 m	20.0 10 ⁶ km ³	Mean Peak
			0.06 m s ⁻¹ 0.10 m s ⁻¹
Tidal/Freshwater volume	280.71		
Watershed area	78.1 km ²		



PHYSICAL PROPERTIES

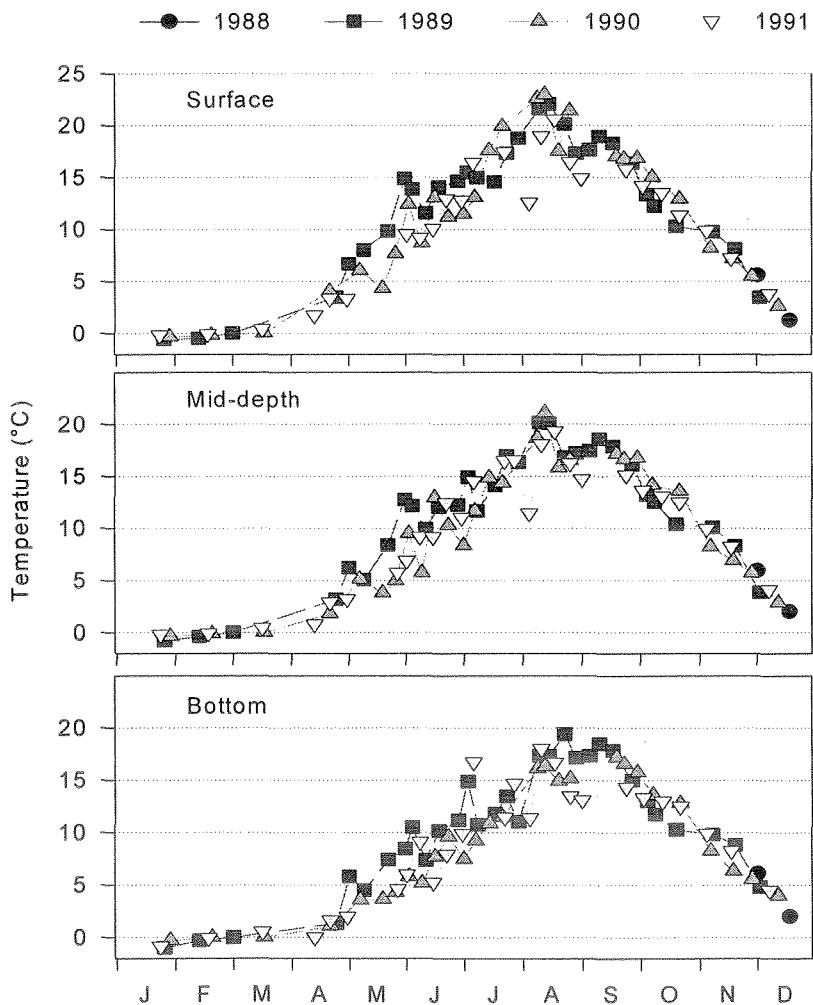
This site was sampled on 96 occasions from November 4, 1988, to December 16, 1991. Before November 9, 1989, data for the physical variables were collected from the discrete water samples. Starting on that date the information presented were extracted from the continuous depth profiles collected with the SeaBird Model 25.

Temperature

The minimum and maximum water temperatures observed at the site were -1.0 and 23.0 °C, respectively. Water temperatures were significantly different at all three depths every year. Surface water temperatures declined significantly over the study period from a median of 14.3°C in 1989, to 12.4°C in 1990 and 11.3°C in 1991. Mid-depth and bottom temperatures were lower in 1990 and 1991 than in the first year of the study.

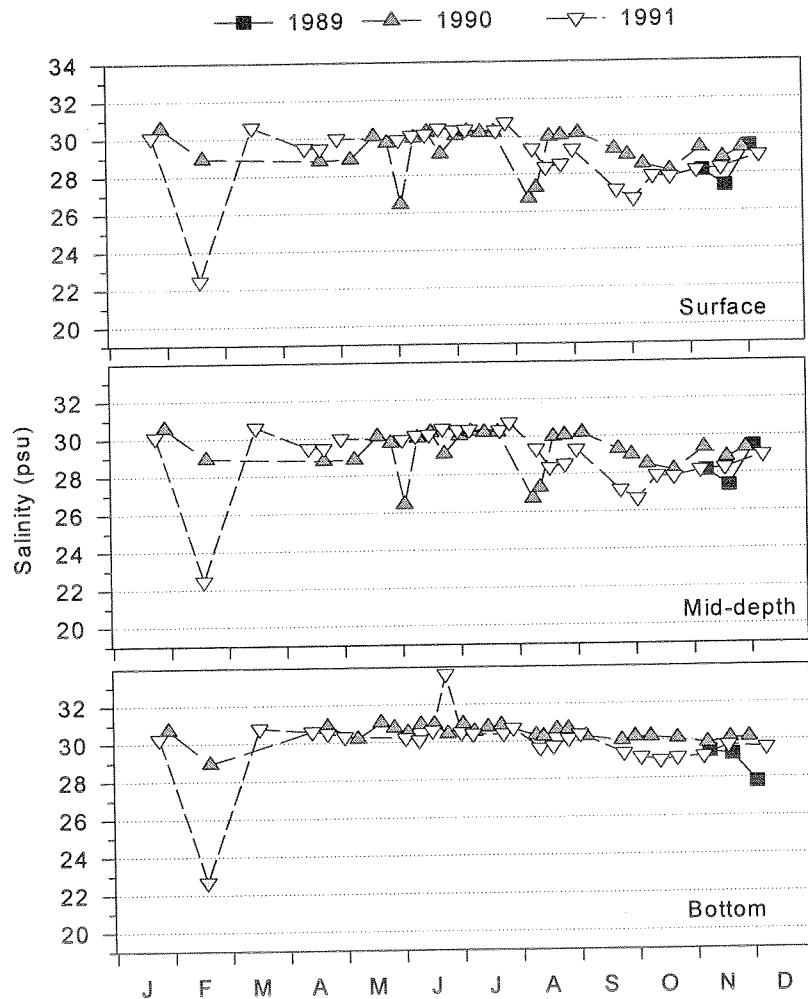
Table 6. Median (mean) water temperatures

	1989	1990	1991
Surface	14.3 (12.9)	12.4 (11.7)	11.3 (10.2)
Mid-depth	12.4 (11.9)	10.3 (10.2)	11.0 (9.8)
Bottom	10.9 (10.9)	8.2 (9.0)	9.9 (8.8)



Salinity

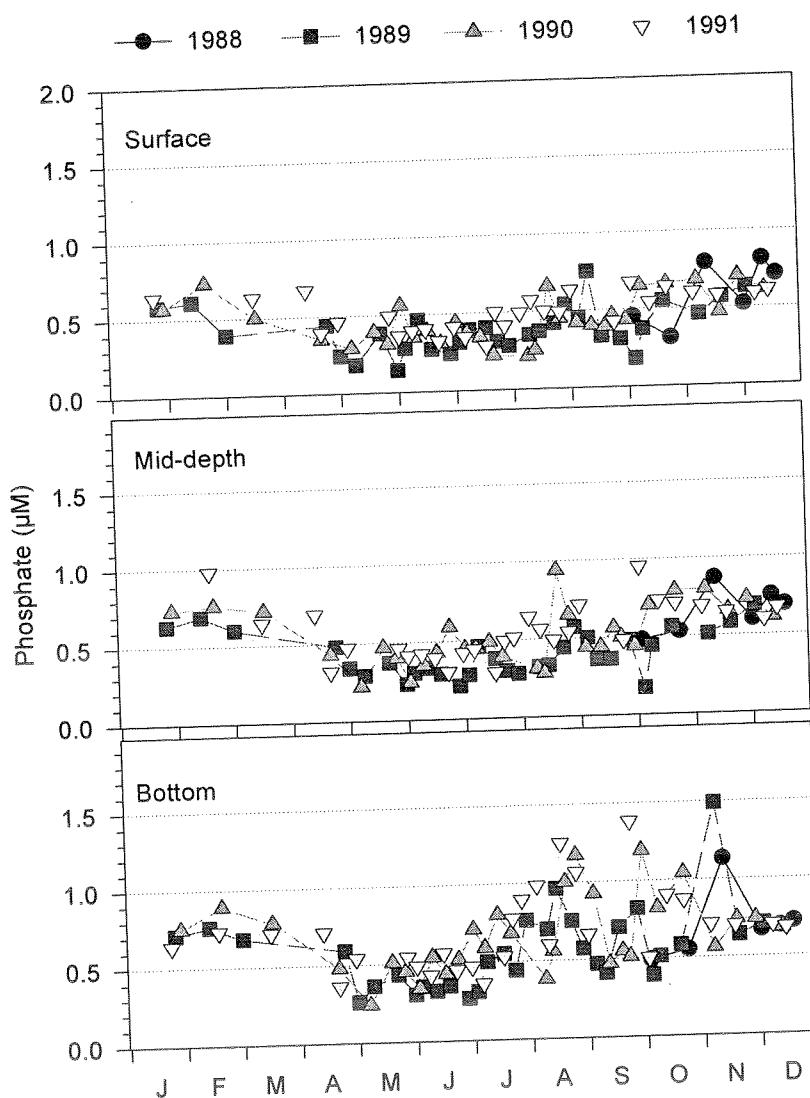
Salinity of the bottom water at this site remained relatively constant over the 3-yr study period; however, there were numerous low salinity events recorded in the surface and mid-depth samples. Salinity at all three depths was higher in the summer than in the fall.



PLANT NUTRIENTS

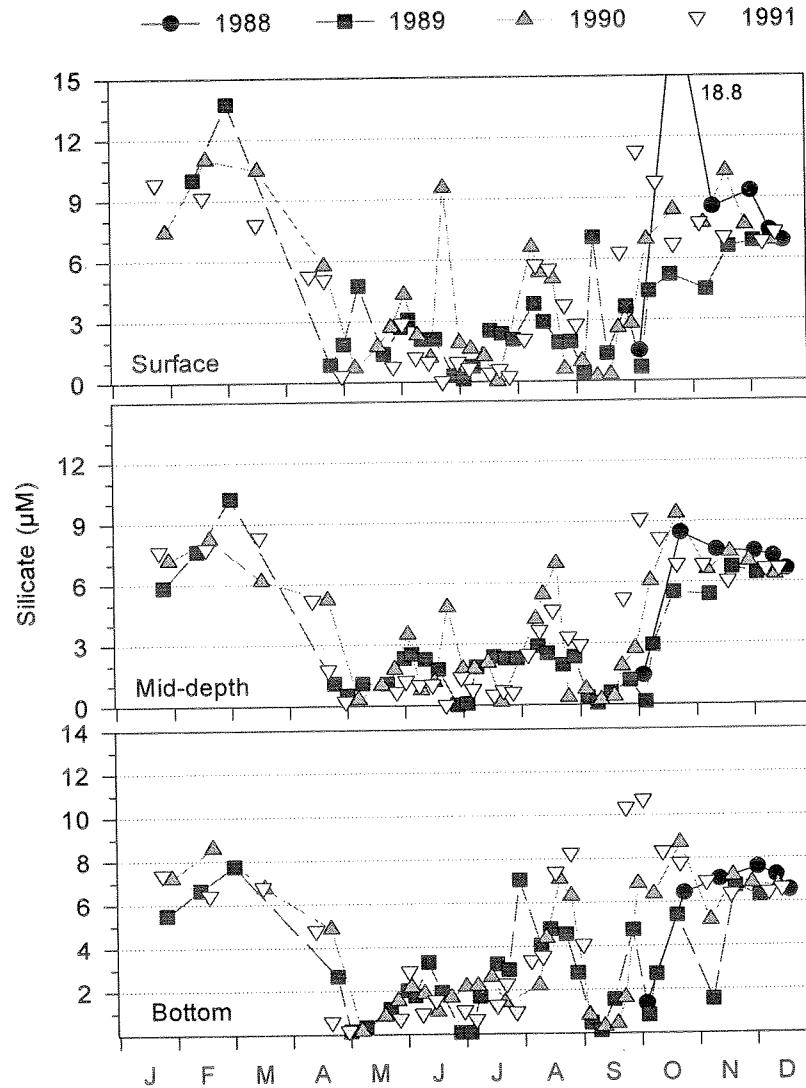
Phosphate

Phosphate concentrations in surface and mid-depth samples never exceeded 1.0 μM . In the summer, concentrations were generally lower, less than 0.5 μM , than during the spring and fall. In the bottom samples the same seasonal pattern was observed; however, concentrations were higher and, in the late summer and fall, were more variable.



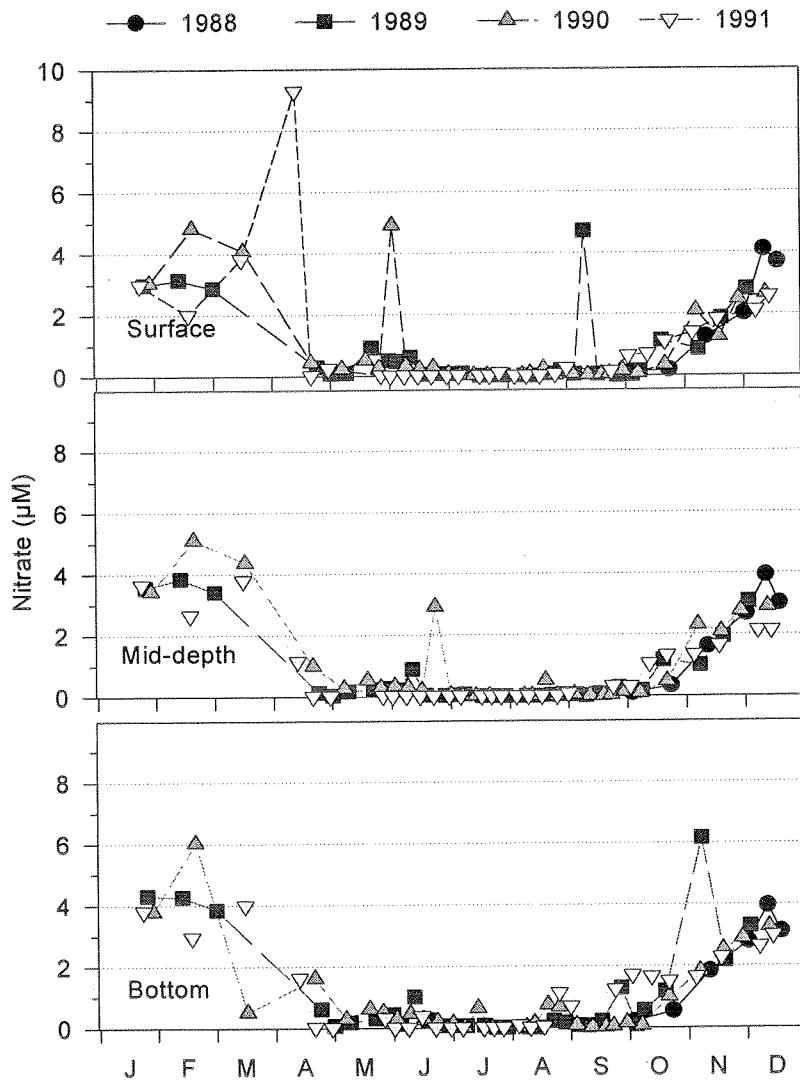
Silicate

Silicate concentrations varied seasonally. In the fall and winter, concentrations varied from 6 to 12 μM but dropped to less than 2 μM in the summer.



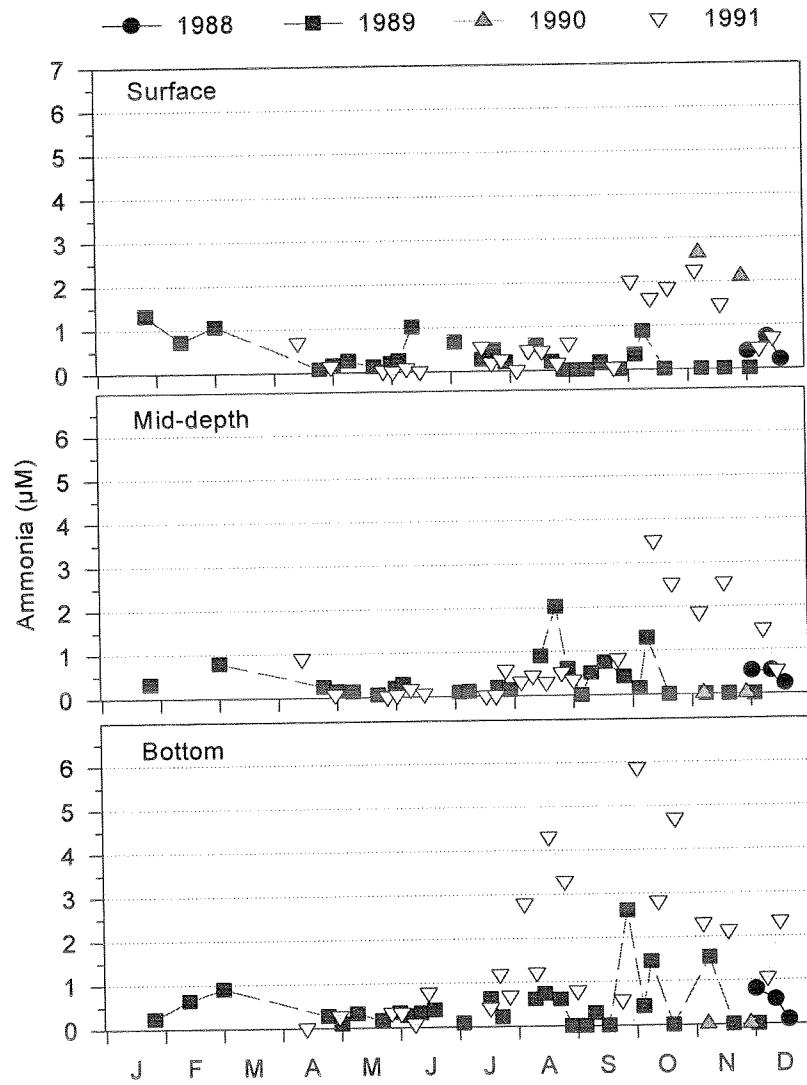
Nitrate

There was a strong seasonal pattern in the nitrate concentrations, with winter values of approximately 4 µM falling to near zero in summer.



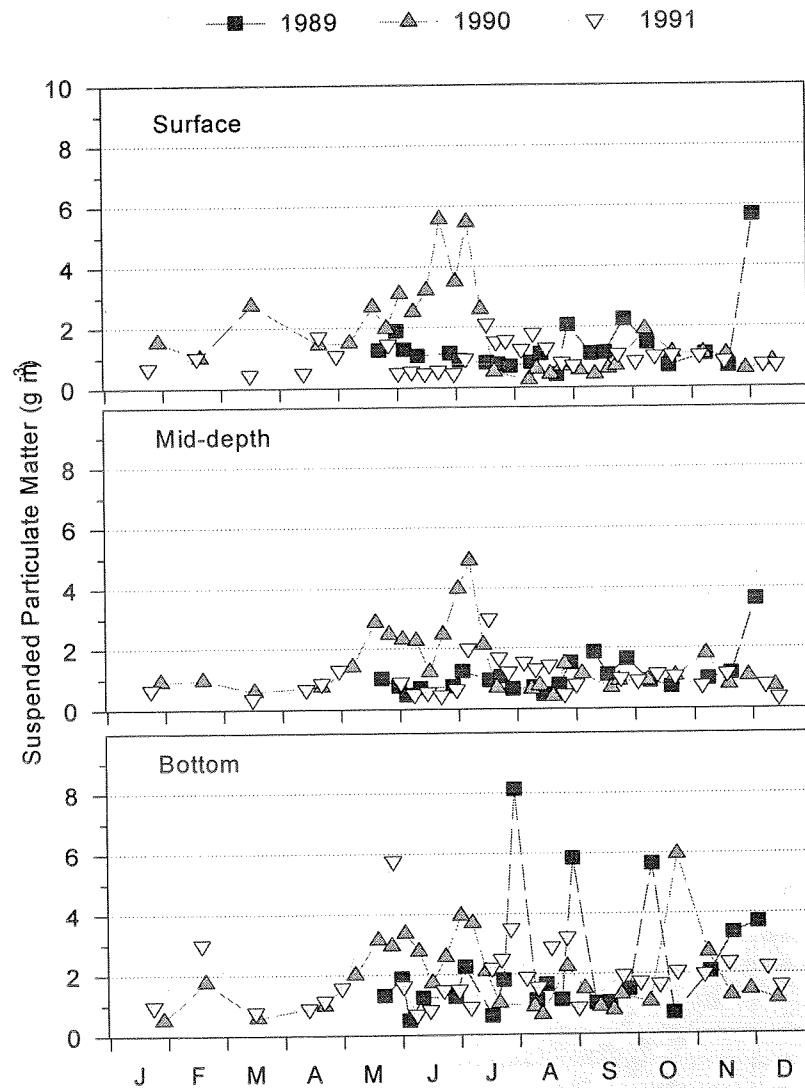
Ammonia

The data for ammonia are limited, but there appears to be a pattern of lower concentrations in the spring and early summer and higher and more variable concentrations in the fall.



Suspended Particulate Material

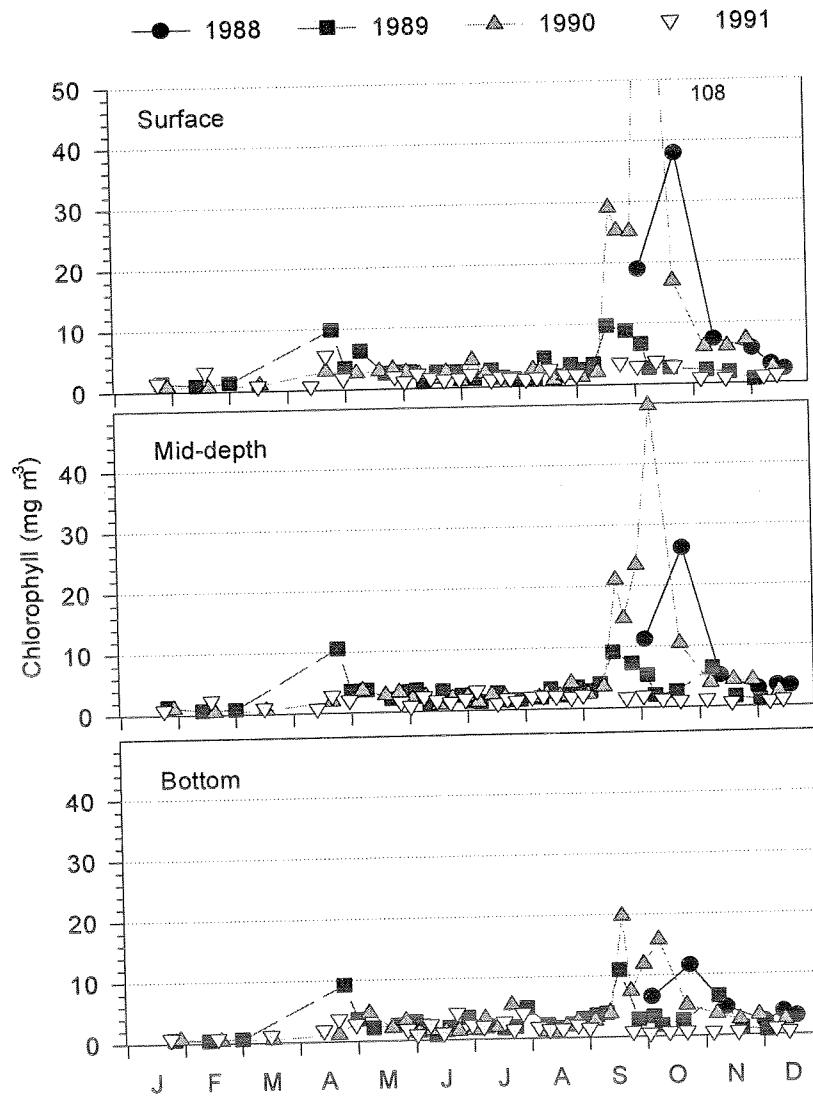
Concentrations of SPM ranged from less than 1 to more than 8 g m⁻³, with most sample concentrations below 2 g m⁻³.

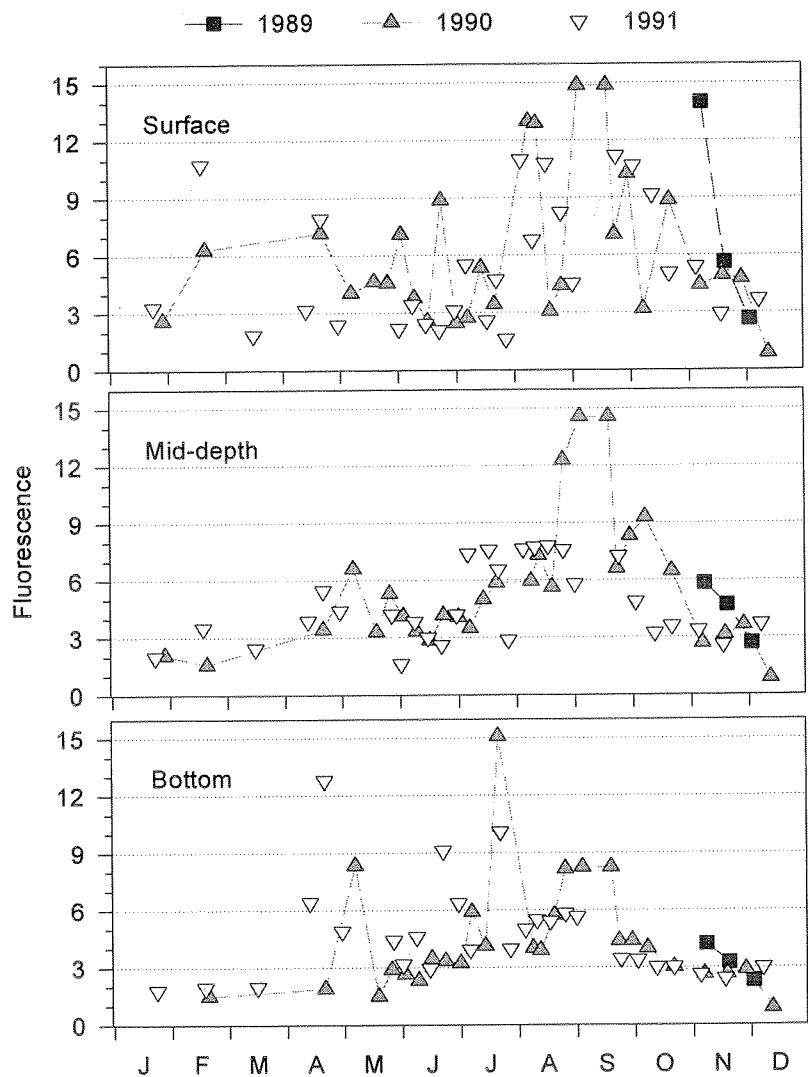


PLANT PIGMENTS

Chlorophyll (Extracted and *in vivo* Fluorescence)

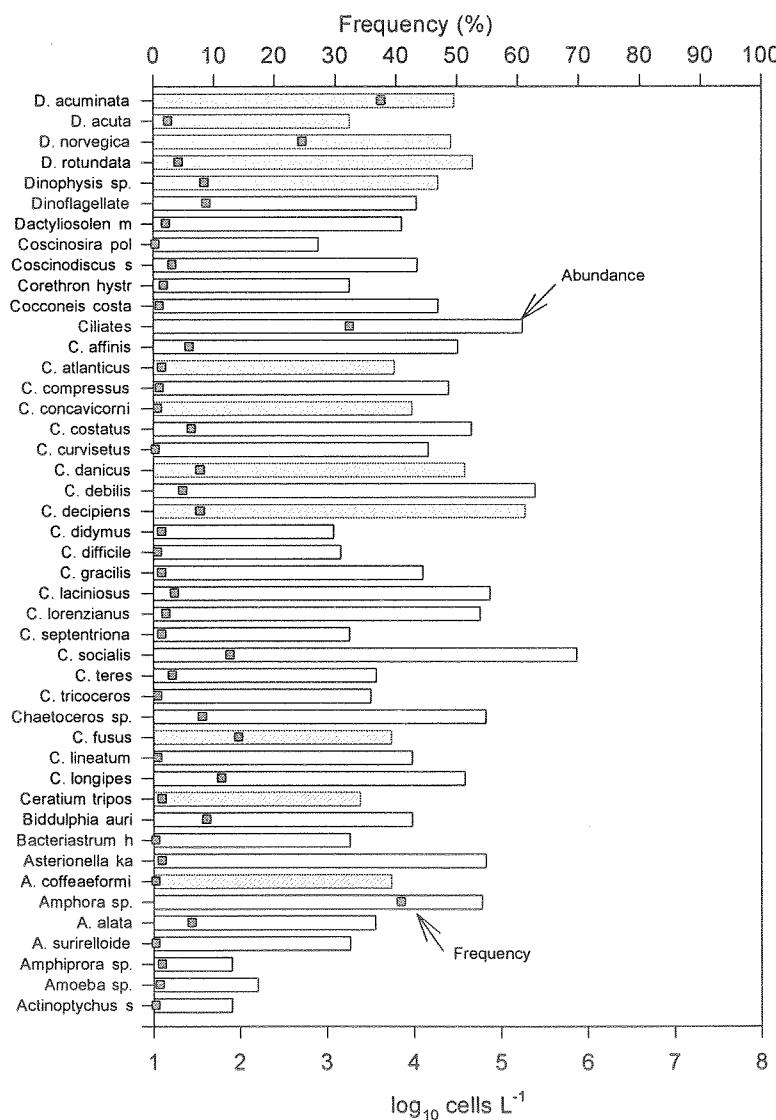
Chlorophyll concentrations exhibited maxima in both the spring (April and May) and in the fall (September and October). *In vivo* fluorescence data from the SeaBird CTD profiler are more variable than the extracted chlorophyll data but show the same general patterns.

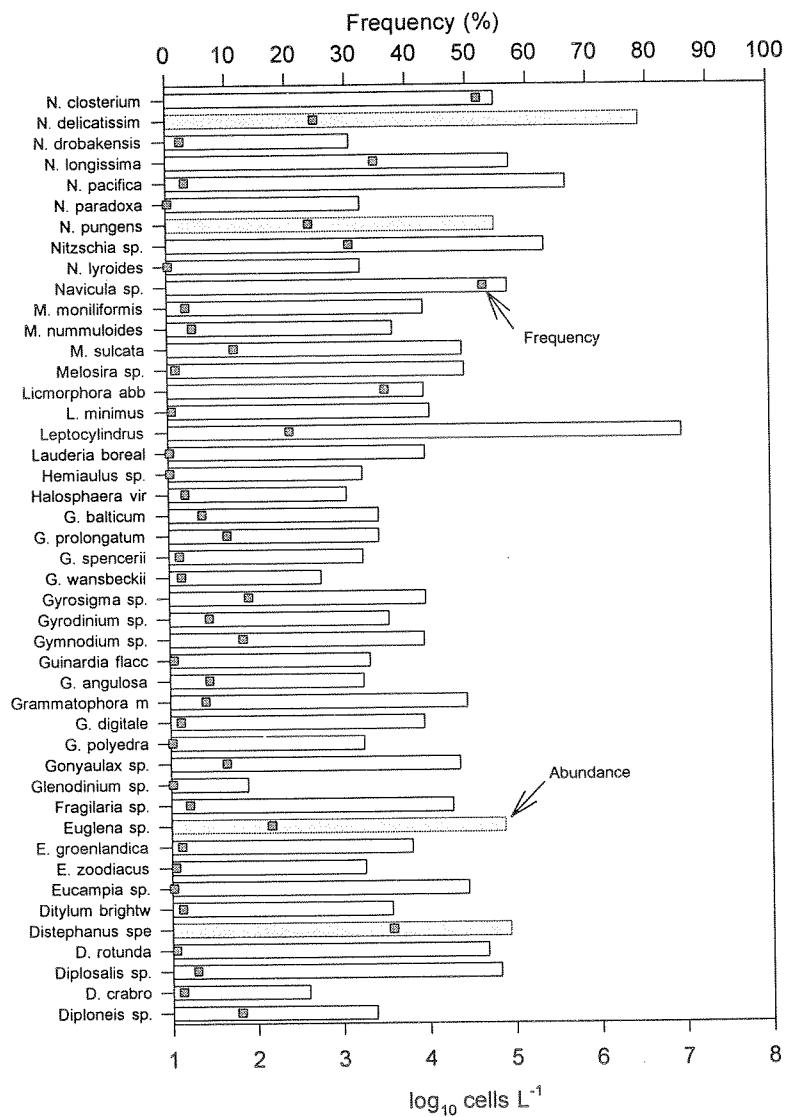


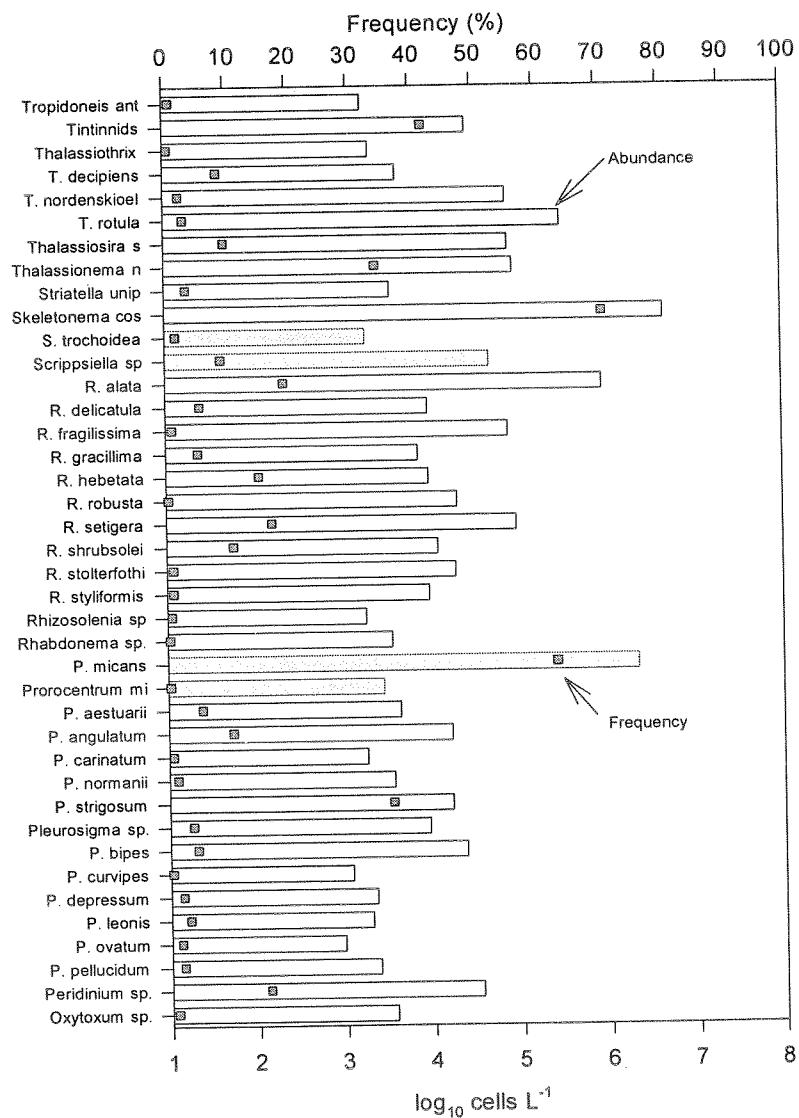


PHYTOPLANKTON - IDENTIFICATION AND ENUMERATION

A total of 132 phytoplankton species were found in samples at the Whitehaven Harbour site with numbers in individual samples ranging from 1 to 34 and averaging 13. Data for all depths for the entire sampling period are condensed to graphs which display for each species the fraction of samples from all years in which it was found (% frequency) and maximum cell density observed. The cell density bars for potentially harmful phytoplankton are shaded. Due to software limitations, species names are truncated in these plots; a complete list of species observed is in the Appendix.



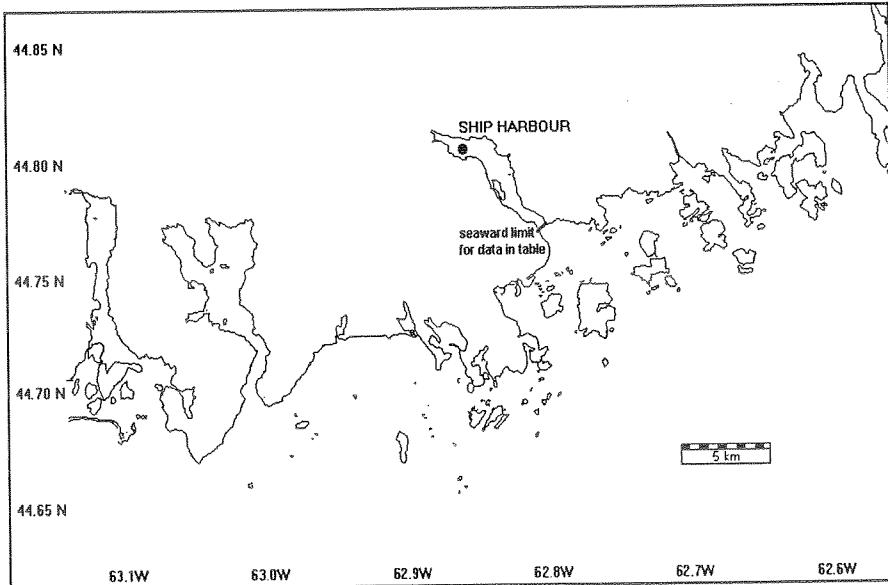




SHIP HARBOUR

Located in Halifax County, at 44.8093°N and 62.8548°W , in a lightly populated area, this Harbour has seen moderate development of shellfish, primarily blue mussel, culture over the past 10 yr. The sampling site was in the inner Harbour at a mussel culture site in 15 m of water where the bottom is quite muddy. The inner Harbour has a shallow sill separating it from the outer Harbour and the Atlantic coastal waters. The following information is from Gregory et al. 1993.

Area (CD)	6.6 km^2	Area (HW)	7.1 km^2
Perimeter	25.9 km^2	Volume (CD)	$47.0 \cdot 10^6 \text{ km}^3$
Axis Length	8.3 km	Maximum Depth	25.0 m
Tidal Range	Tidal Volume	Tidal Current	
Mean	Large	Mean Tide	Mean Peak
1.40 m	2.00 m	$9.6 \cdot 10^6 \text{ km}^3$	0.12 m s^{-1}
			0.19 m s^{-1}
Tidal/freshwater volume	23.87		
Watershed area	78.1 km^2		



PHYSICAL PROPERTIES

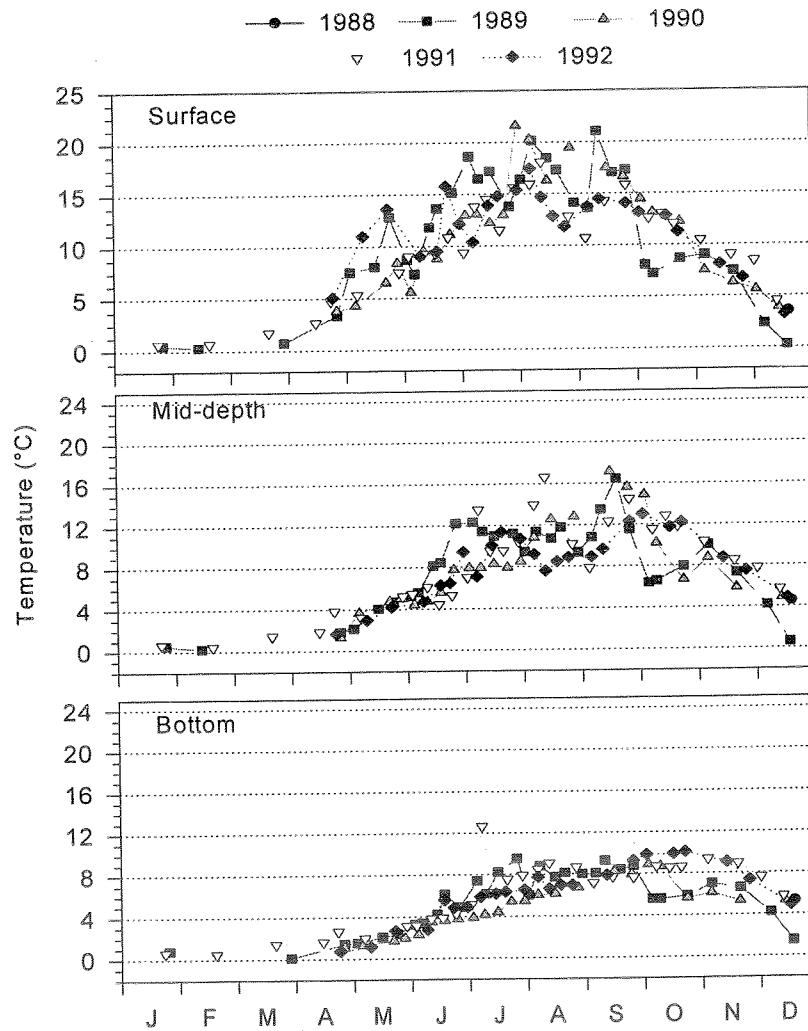
This site was first sampled from November 4, 1988 to December 16, 1991 on 123 occasions. Until November 9, 1989, data for the physical variables were collected from the discrete water samples. Starting on that date the information presented were extracted from the continuous depth profiles collected with the SeaBird Model 25.

Temperature

The minimum and maximum water temperatures observed at the site were 0.1 and 21.6°C, respectively. Water temperatures were significantly different at the three depths every year. Surface water temperatures declined over the study period from a median of 12.3°C in 1989, to 12.2°C in 1990, and 10.4°C in 1991. Mid-depth temperatures also declined over the study period.

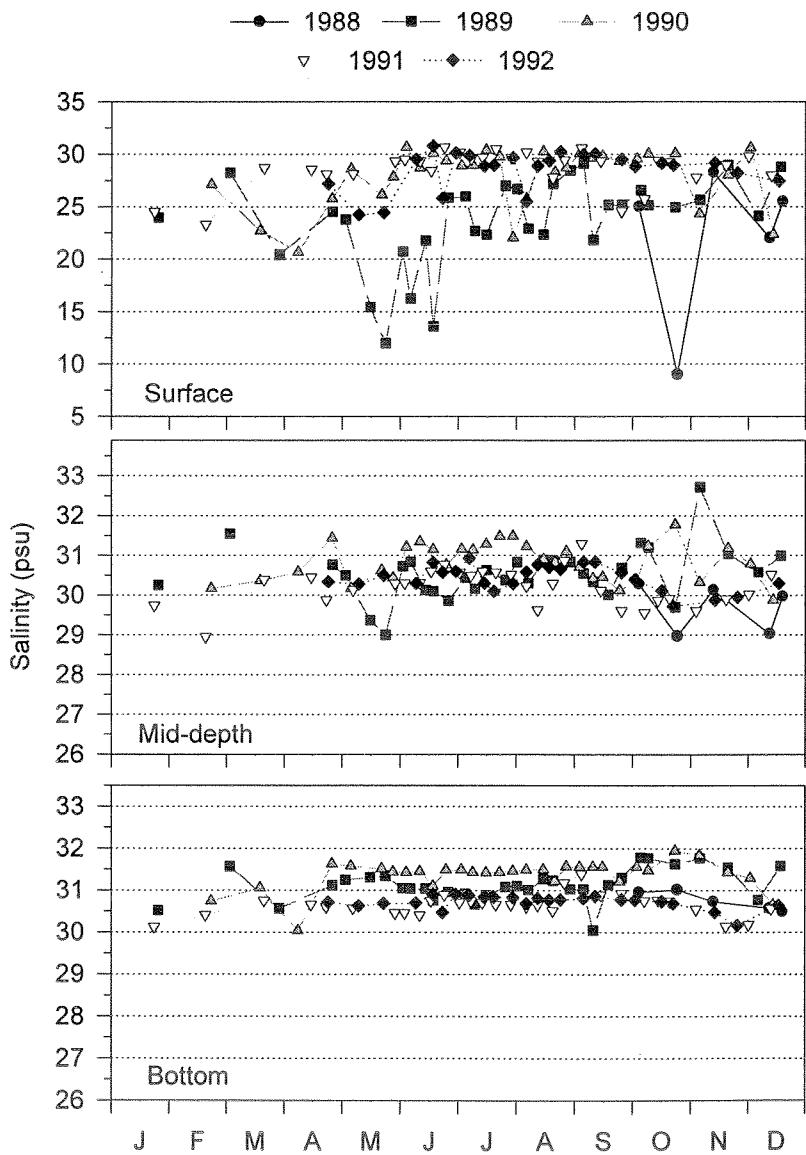
Table 6. Median (mean) water temperatures

	1989	1990	1991
Surface	12.3 (11.1)	12.2 (11.3)	10.4 (9.8)
Mid-depth	8.4 (7.9)	7.9 (8.2)	7.8 (8.0)
Bottom	6.0 (5.5)	5.3 (4.9)	7.1 (5.9)



Salinity

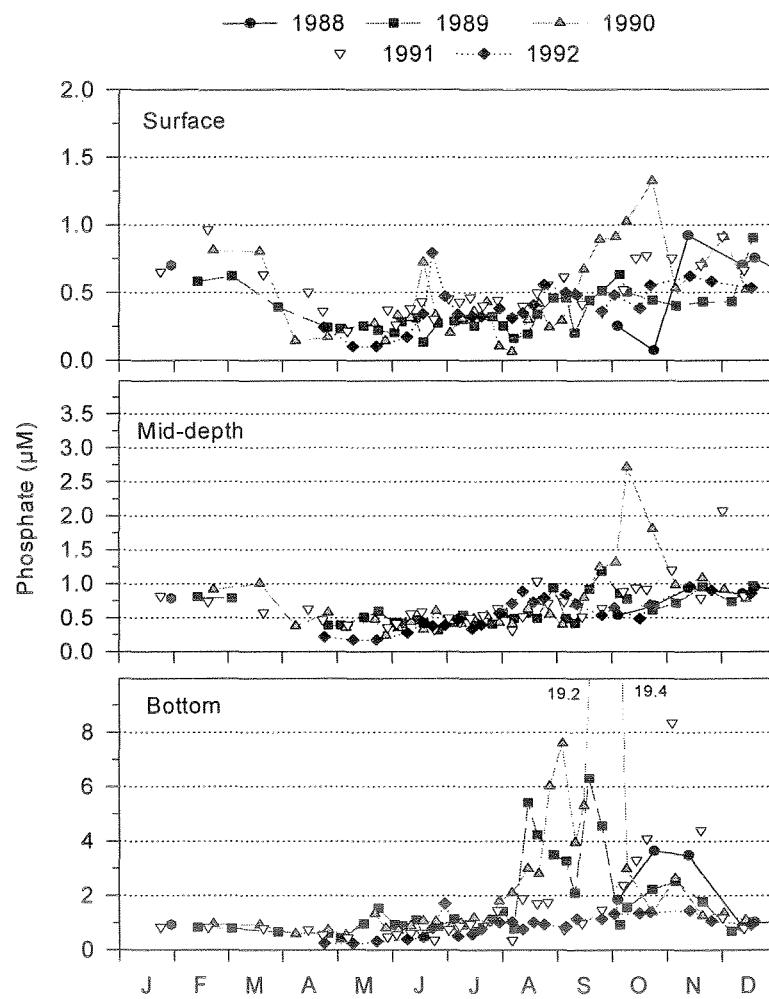
Salinity of the bottom water at this site remained relatively constant over the 3-yr study period; however, there were numerous low salinity events recorded in the surface and mid-depth samples.



PLANT NUTRIENTS

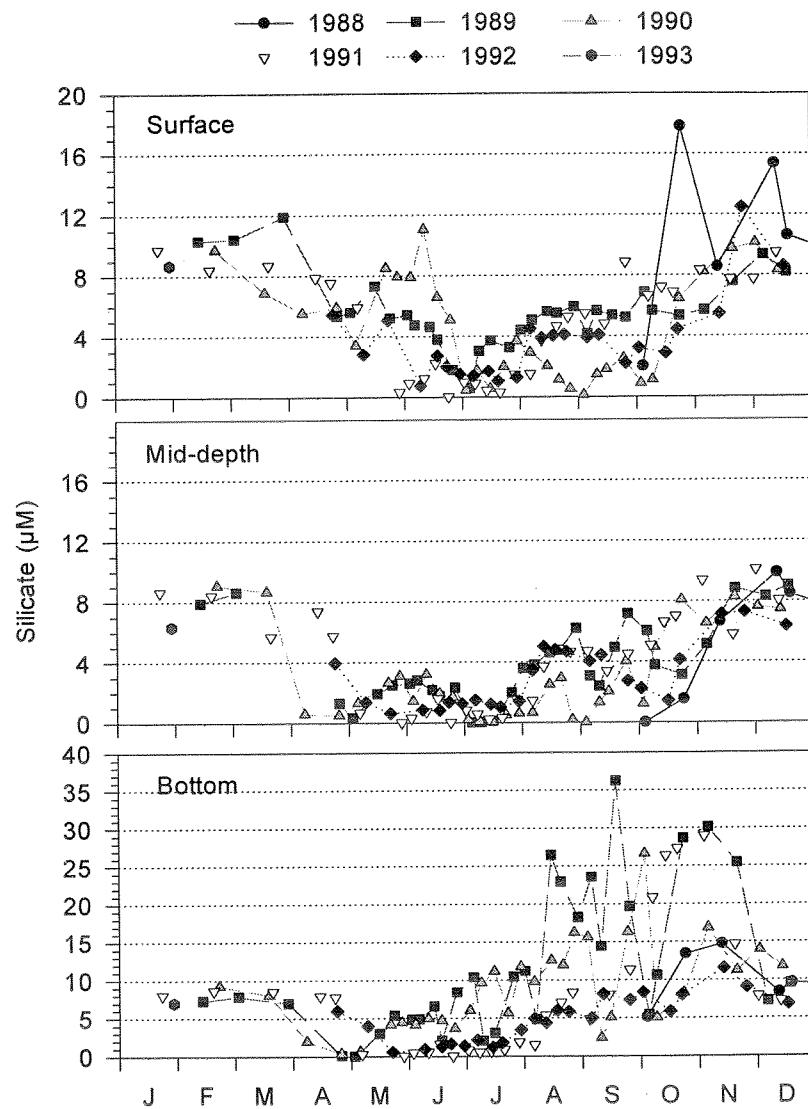
Phosphate

Phosphate concentrations in surface and mid-depth samples seldom exceeded 1.0 μM . In the summer, concentrations were generally lower than during the spring and fall. Concentrations in bottom samples were below 1 μM from January through April and were somewhat elevated, approaching 2 μM from May to July. From August to November very high concentrations, from 2 to 19 μM , were frequently observed. These unusually high concentrations are due to regeneration processes in the deep water of the inner basin of the Harbour. Renewal of this deep water is inhibited by the shallow sill in the inlet.



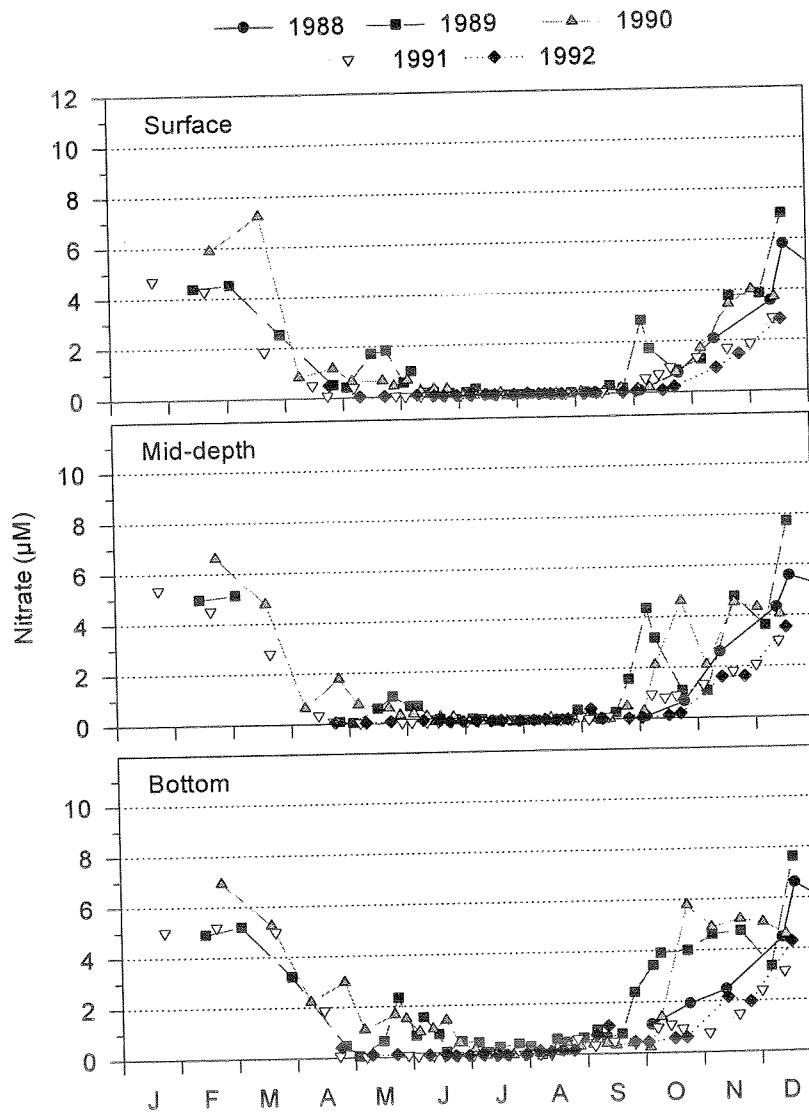
Silicate

Silicate concentrations also changed seasonally; from August through November very high concentrations, 15 to 30 μM , were frequently observed in the bottom water samples.



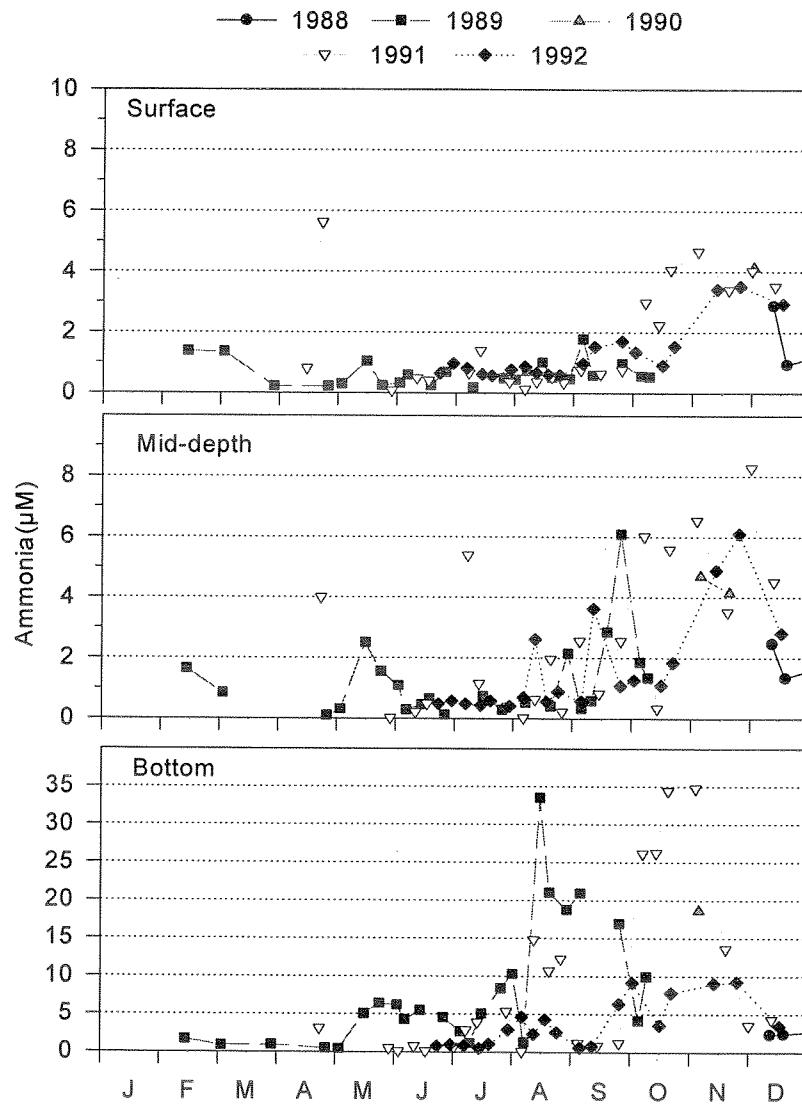
Nitrate

There was a strong seasonal pattern in the nitrate concentrations, with winter values of approximately 6 μM falling to near zero in summer. Nitrate concentrations in bottom samples increased in late summer and fall but were not abnormally high nor highly variable like the phosphate, silicate, and ammonia concentrations.



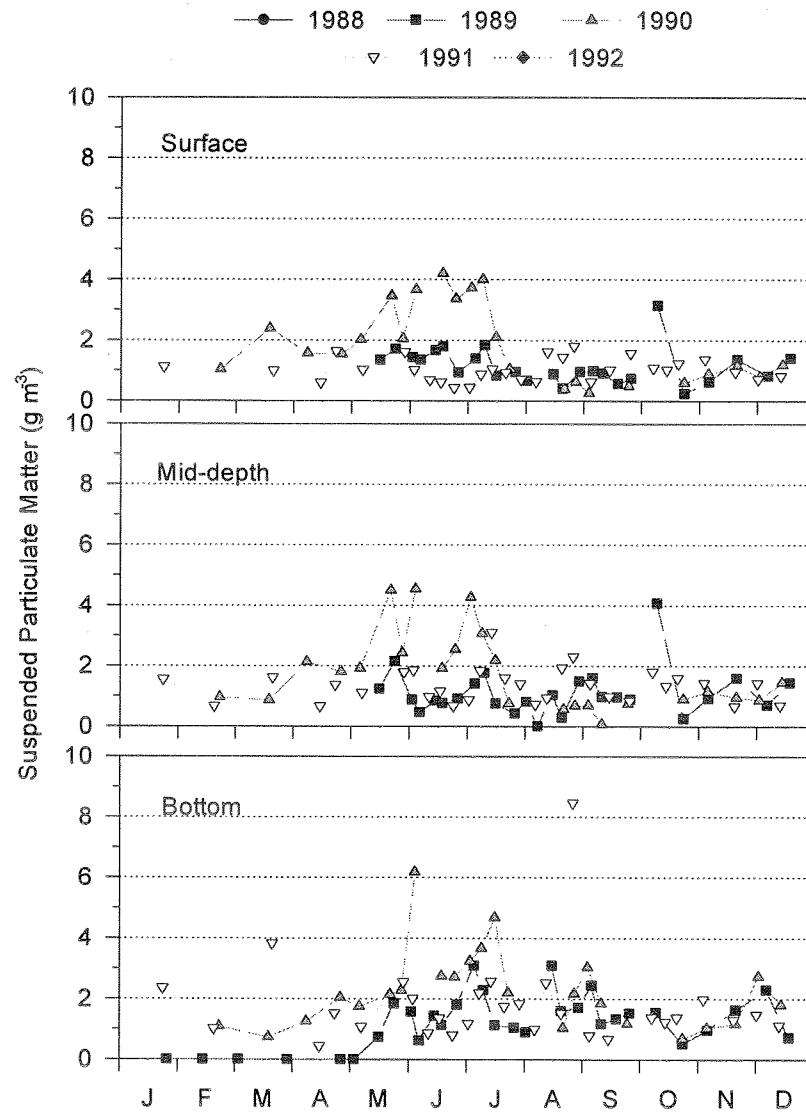
Ammonia

Unusually high ammonia concentrations, particularly in the near bottom samples, were observed at this location with the highest concentrations, $> 30 \mu\text{M}$, occurring in the late summer and fall.



Suspended Particulate Material

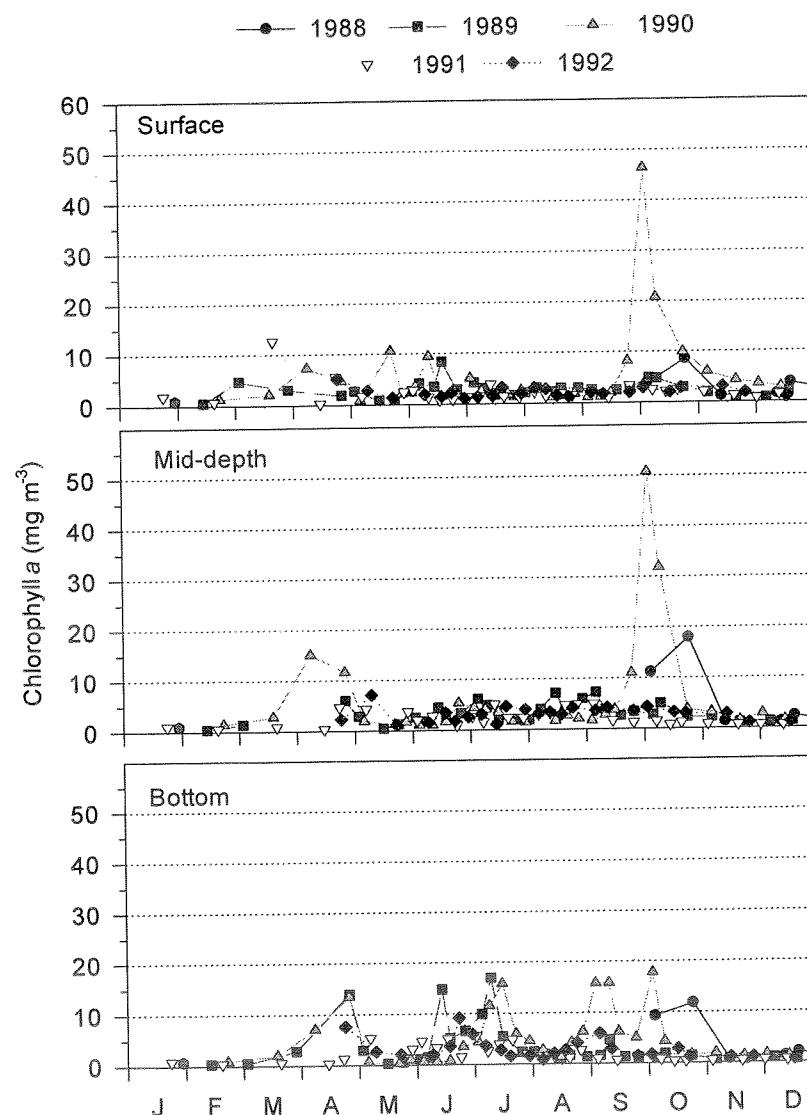
Concentrations of SPM ranged from less than 1 to more than 8 g m^{-3} , with most sample concentrations below 2 g m^{-3} .

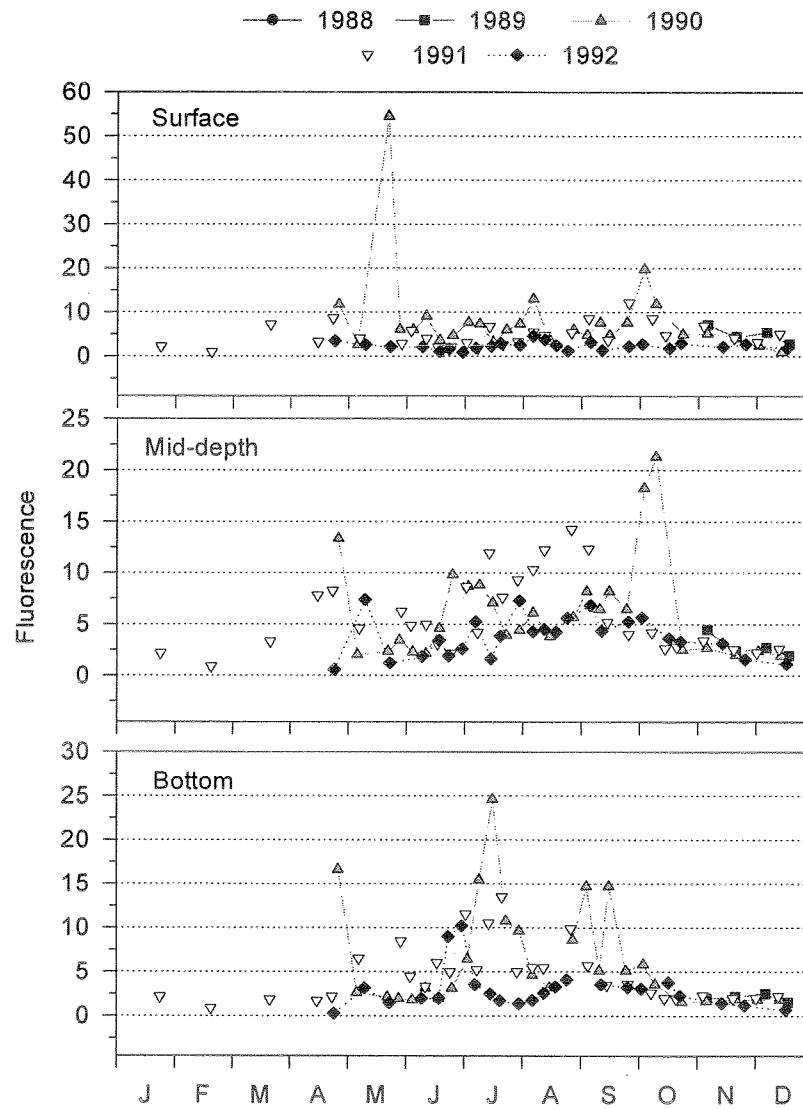


PLANT PIGMENTS

Chlorophyll (Extracted and *in vivo* Fluorescence)

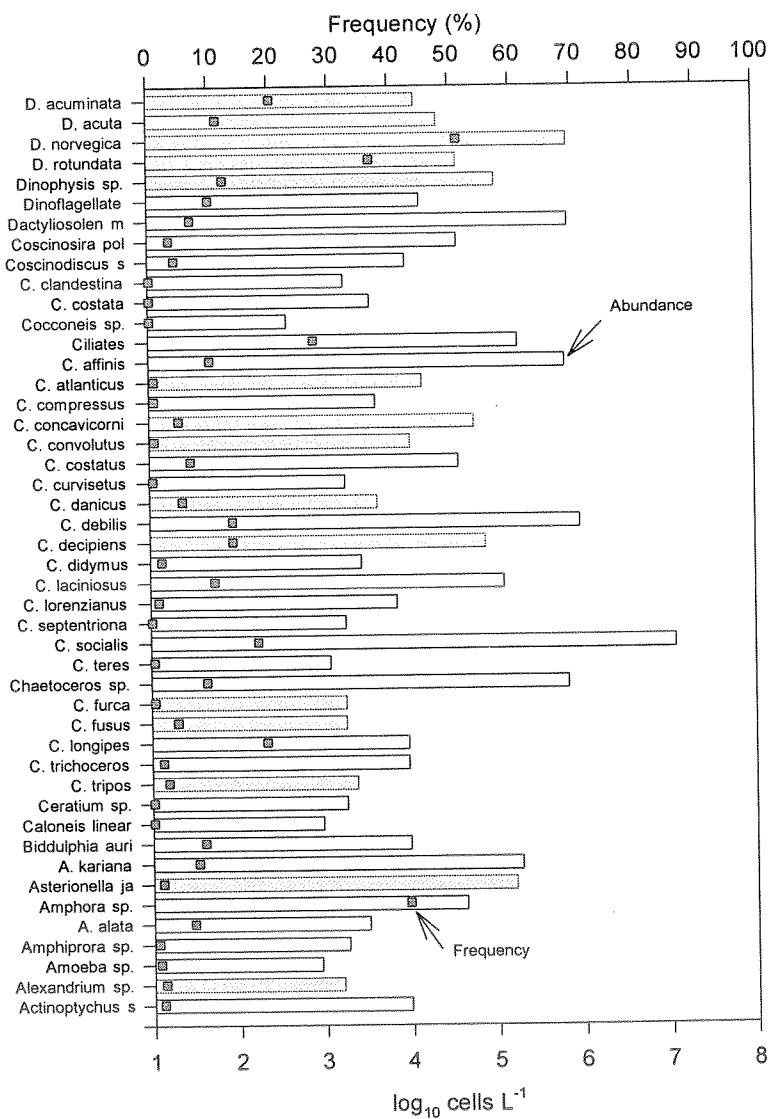
Chlorophyll concentrations exhibited maxima in both the spring (April and May) and in the fall (September and October). Concentrations in the bottom waters were high from April through October with values frequently above 5 mg m^{-3} and occasionally greater than 10 mg m^{-3} . *In vivo* fluorescence data from the SeaBird CTD profiler are more variable than the extracted chlorophyll data but show the same general pattern.

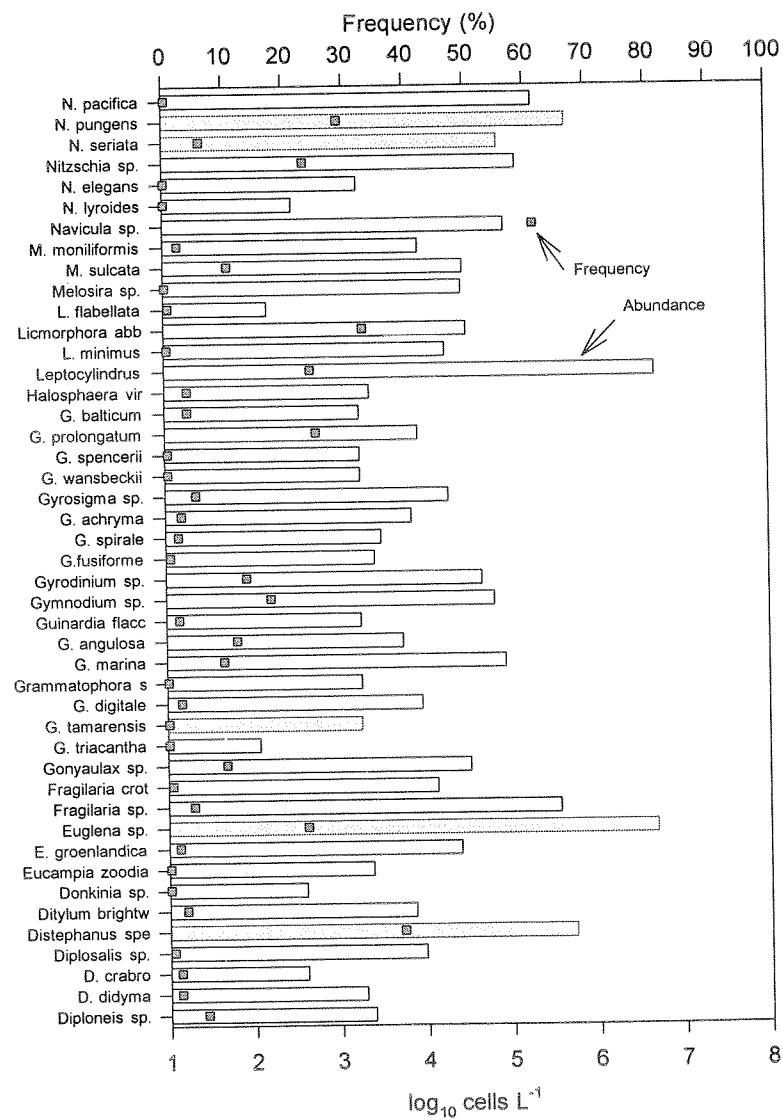


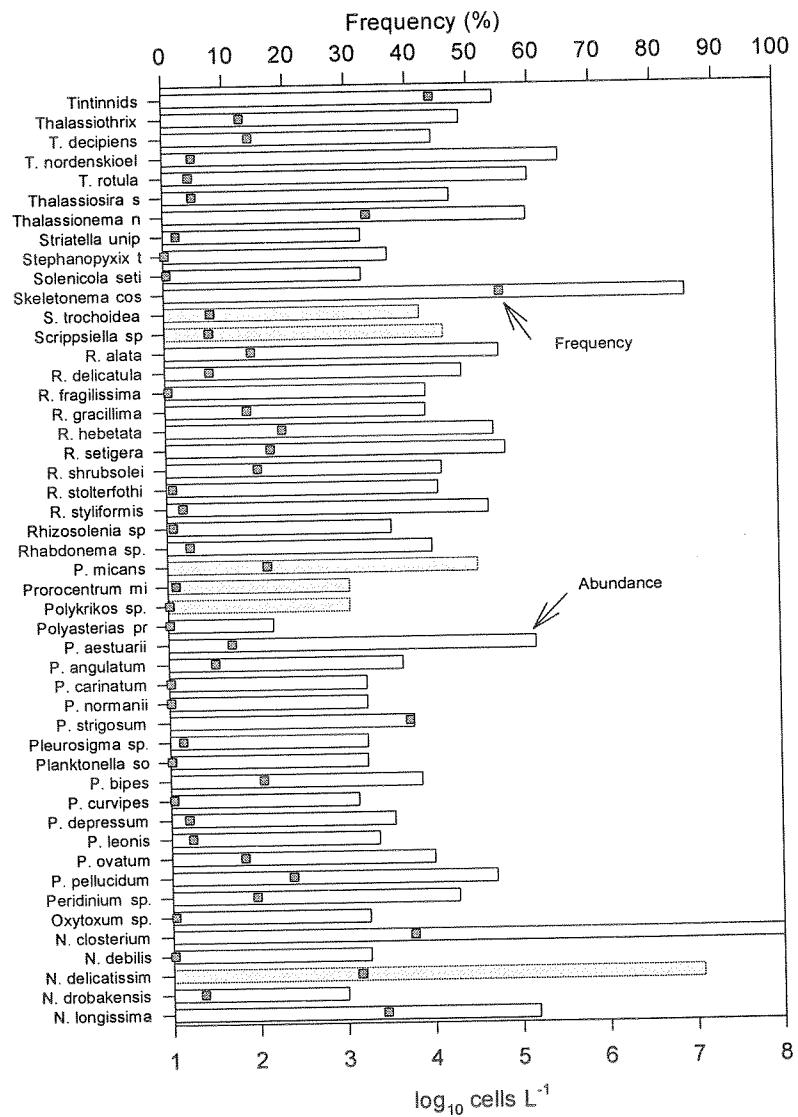


PHYTOPLANKTON - IDENTIFICATION AND ENUMERATION

A total of 141 phytoplankton species were found in samples at the Ship Harbour site, with numbers in individual samples ranging from 1 to 38 and averaging 14. Data for all depths for the entire sampling period are condensed to graphs which display for each species the fraction of samples from all years in which it was found (% frequency) and maximum cell density observed. The cell density bars for potentially harmful phytoplankton are shaded. Due to software limitations, species names are truncated in these plots; a complete list of species observed is in the Appendix.



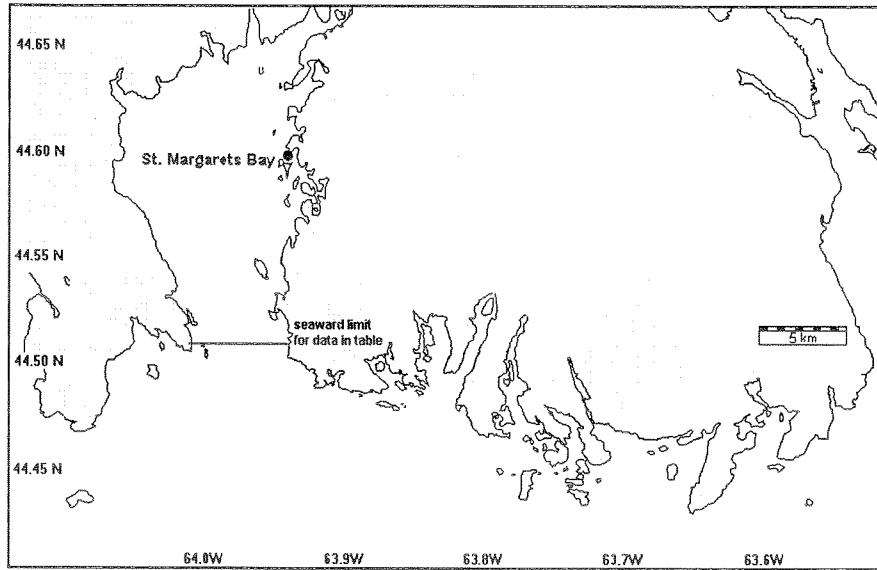




ST. MARGARETS BAY

Located on the eastern shore of St. Maragarets Bay just east of Halifax, at 44.5982°N and 63.9388°W, the sampling location was on a mussel line of a privately owned aquaculture site. Depth of water at low tide was 12 m above a soft silty bottom. There is extensive residential development but sparse industrial development in the area which is just to the west of the major urban centre of Halifax County. The following information is from Gregory et al. 1993.

Area (CD)	138.0 km ²	Area (HW)	141.7 km ²
Perimeter	123.6 km ²	Volume (CD)	5191.0 10 ⁶ km ³
Axis Length	23.7 km	Maximum Depth	91.4 m
Tidal Range		Tidal Volume	
Mean	Large	Mean Tide	
1.60 m	2.30 m	223.8 10 ⁶ km ³	Mean
			0.04 m s ⁻¹
			Peak
			0.06 m s ⁻¹
Tidal/Freshwater volume	416.32		
Watershed area	819.1 km ²		



PHYSICAL PROPERTIES

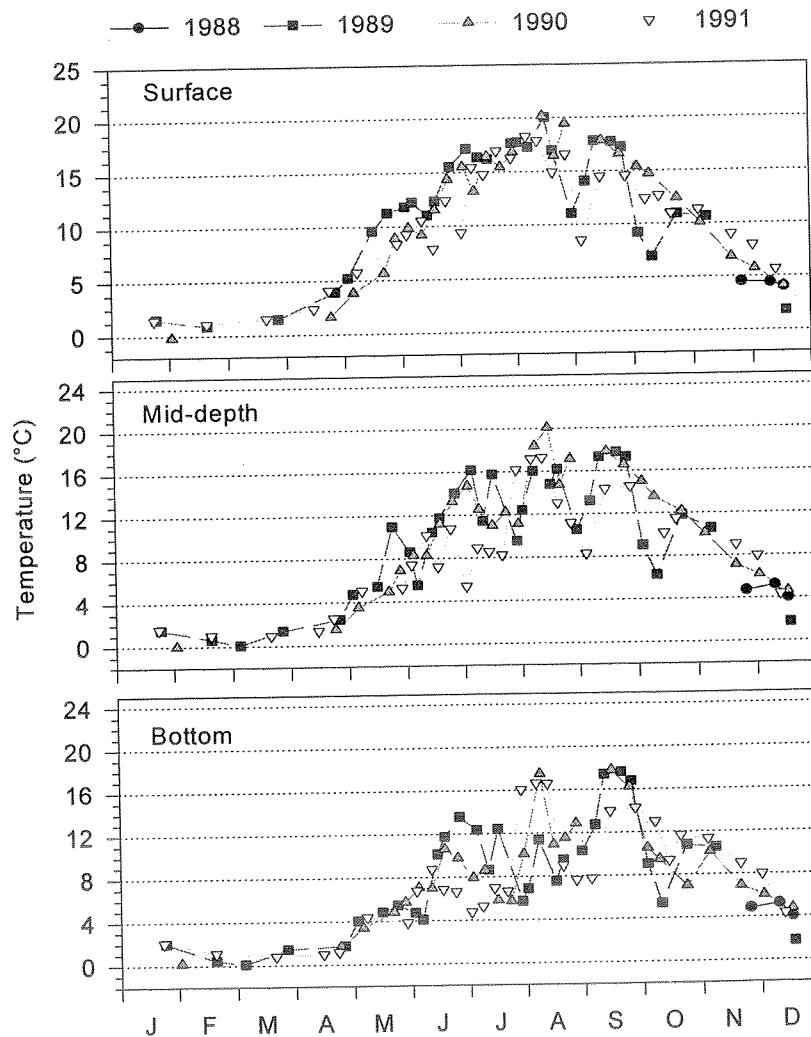
This site was sampled from November 6, 1988, to December 14, 1991, on 101 occasions. Until November 9, 1989, data for the physical variables were collected from the discrete water samples. Starting on that date the information presented were extracted from the continuous depth profiles collected with the SeaBird Model 25.

Temperature

The minimum and maximum water temperatures observed at the site were 0.2 and 20.2°C, respectively. Surface water was warmer than the deeper water. From July to October there were two or three deep cold water intrusion events each year of the study, resulting in surface water temperature changes of greater than 5°C in less than 1 wk.

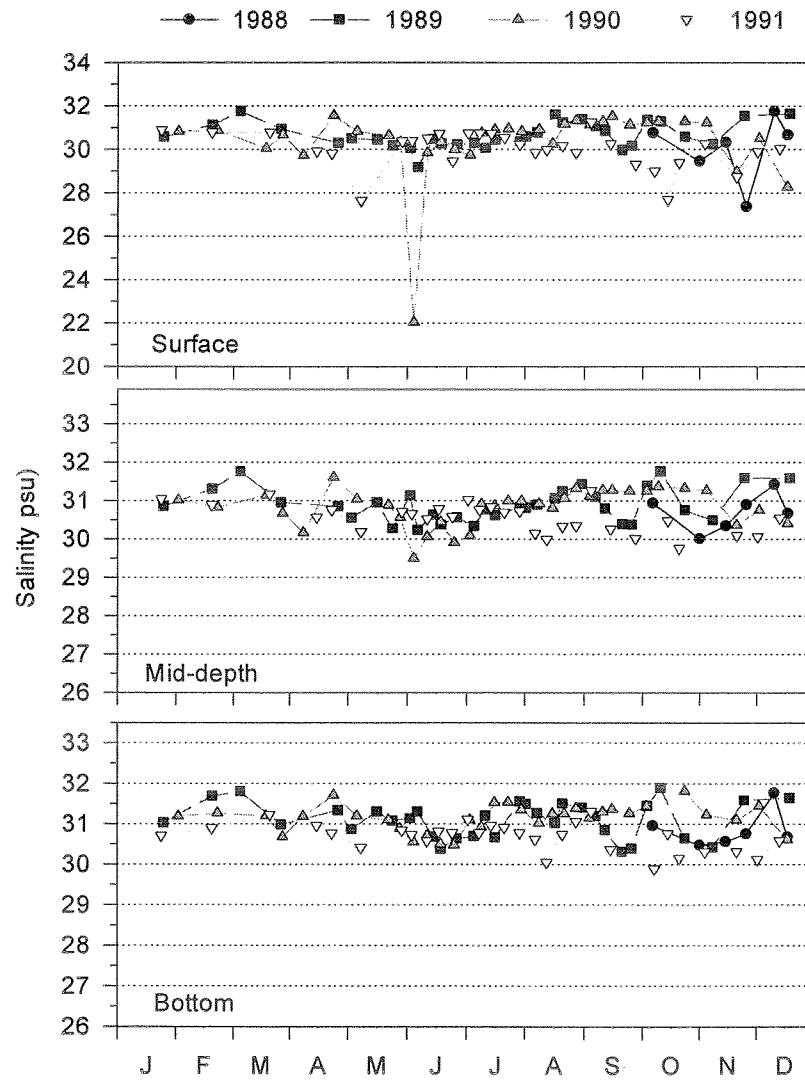
Table 6. Median (mean) water temperatures

	1989	1990	1991
Surface	12.0 (11.8)	12.8 (11.6)	10.7 (10.4)
Mid-depth	10.5 (9.8)	11.2 (10.8)	8.4 (8.5)
Bottom	8.6 (8.1)	7.9 (8.5)	7.3 (7.8)



Salinity

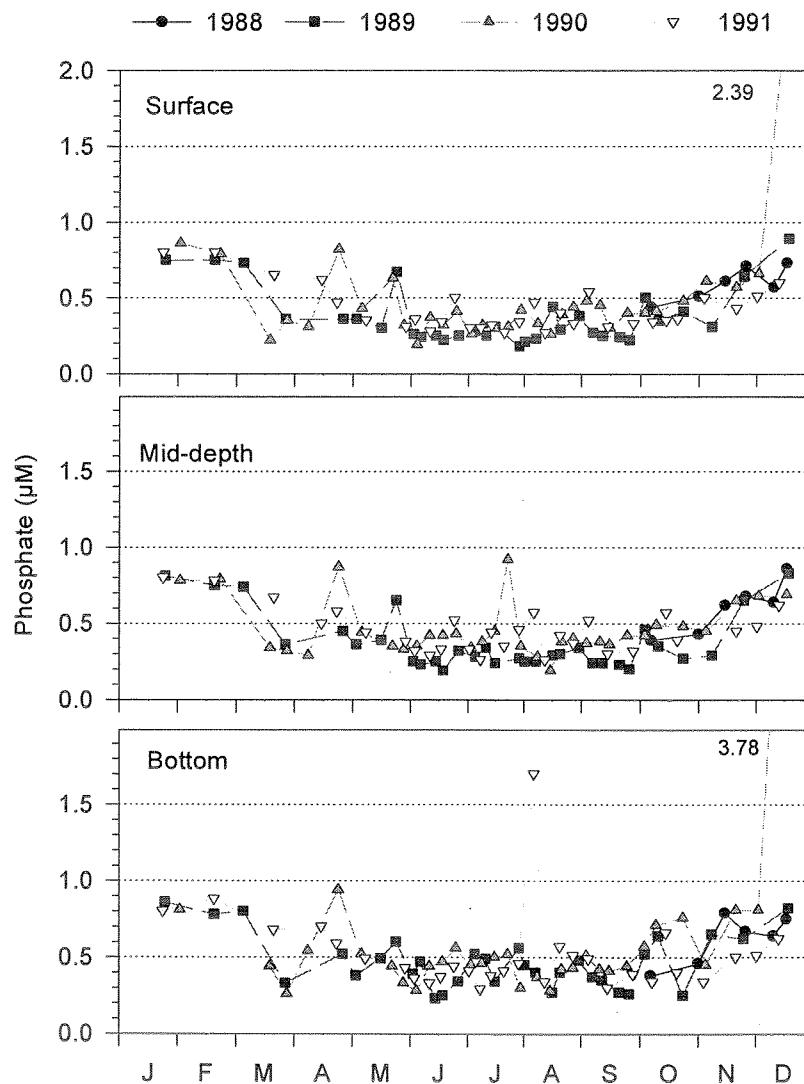
Salinity at this site was influenced by freshwater input to the surface and deep water intrusions, so salinity at all depths was quite variable.



PLANT NUTRIENTS

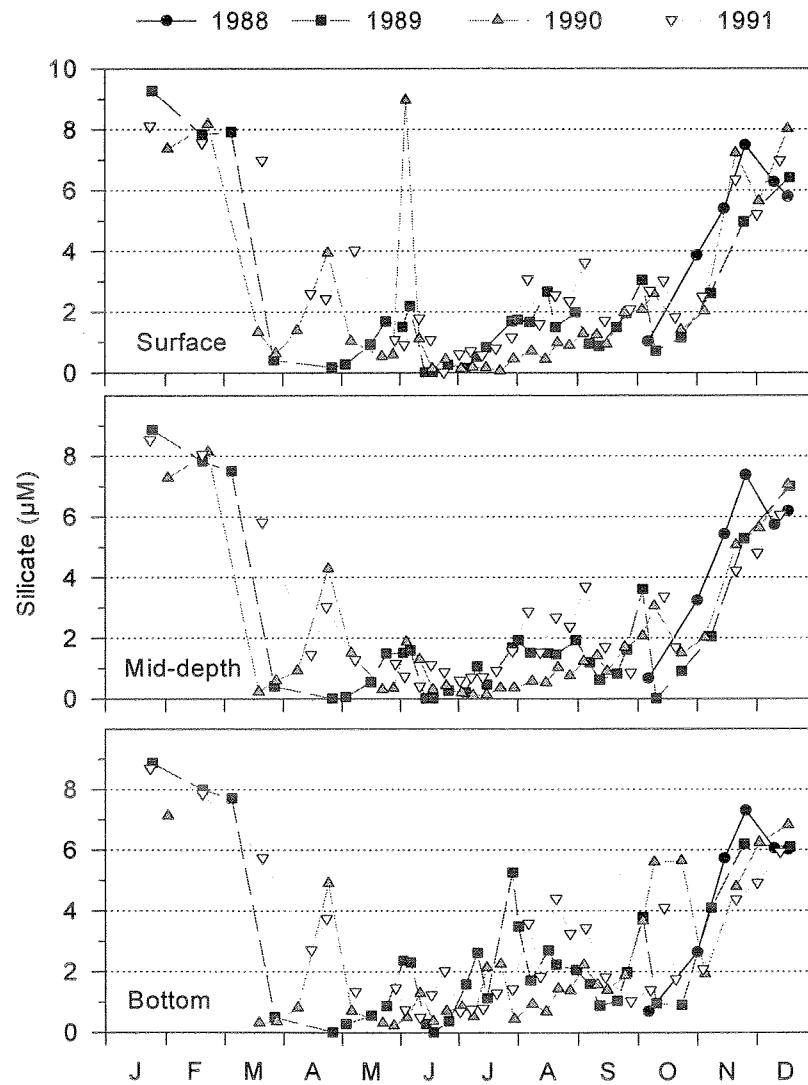
Phosphate

Phosphate concentrations ranged from 0.2 to 3.78 μM and had a strong seasonal pattern with higher concentrations in the spring, fall, and winter and lower concentrations in the summer.



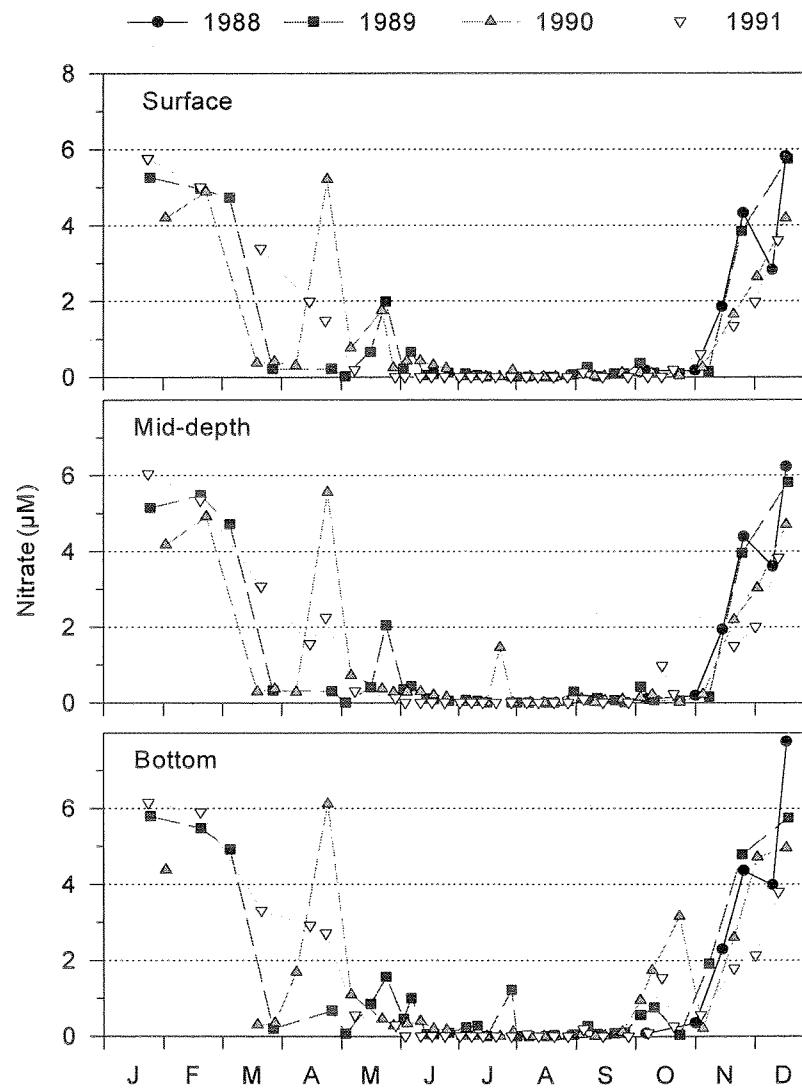
Silicate

Silicate concentrations also varied seasonally, ranging from a high of 8 to 9 μM in the spring and winter to a low of 0 μM in the summer.



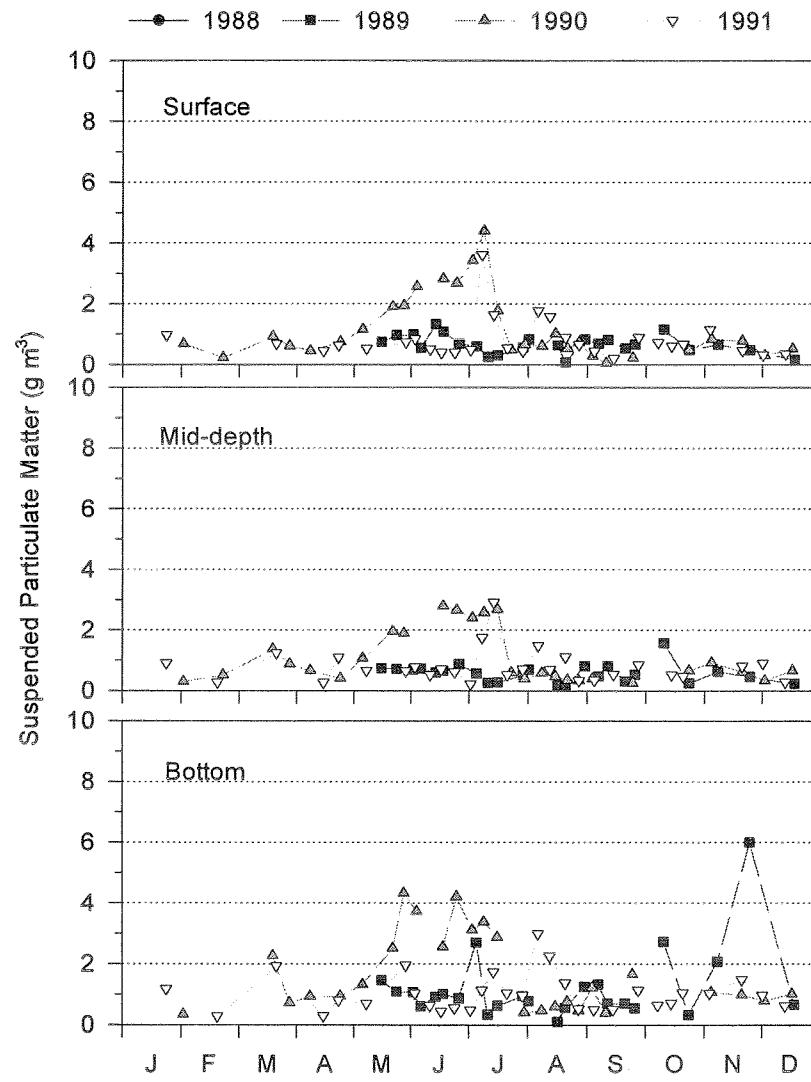
Nitrate

There was a strong seasonal pattern in the nitrate concentrations, with winter values of approximately 6 μM falling to 0 in summer.



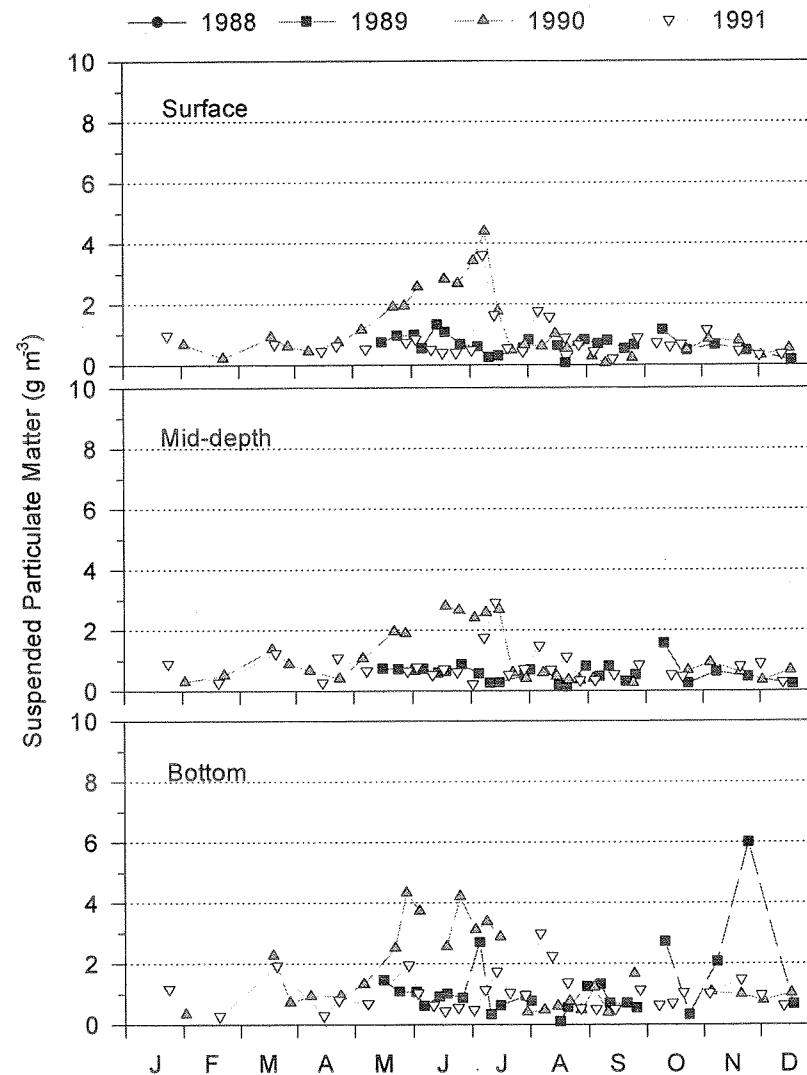
Ammonia

Ammonia concentrations were quite variable, ranging from 0 to 11.5 μM with no apparent seasonal pattern.



Suspended Particulate Material

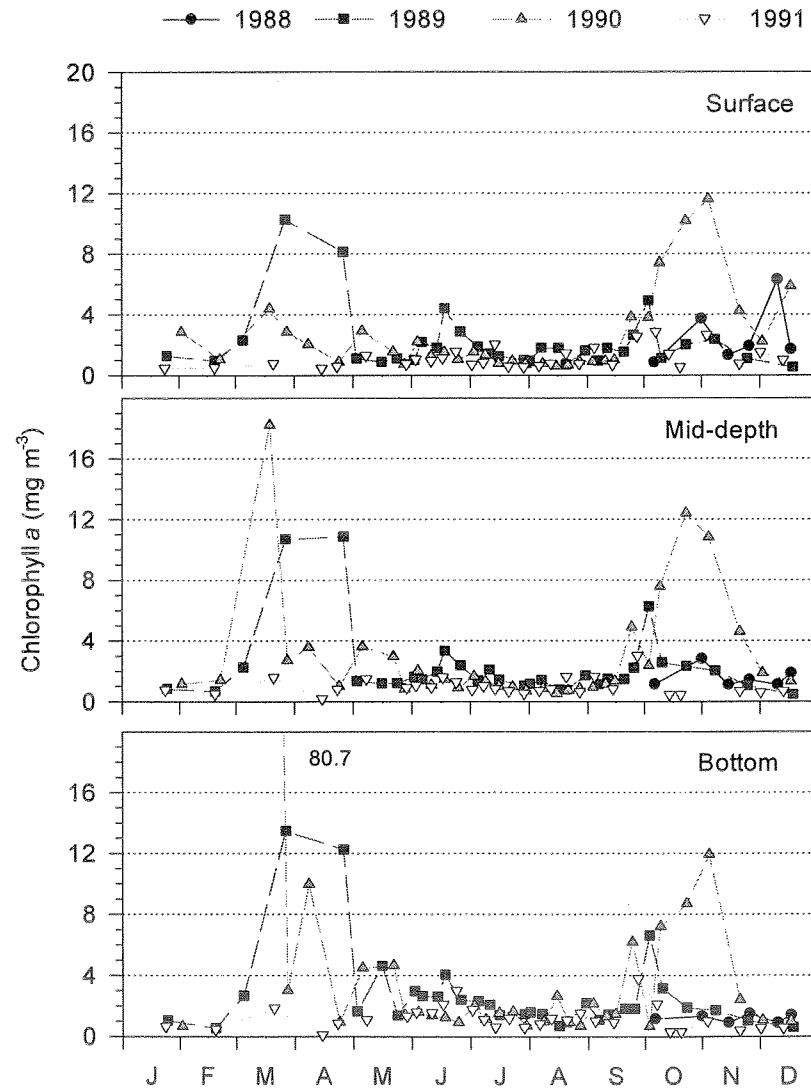
Concentrations of SPM ranged from less than 1 to 6 g m⁻³, with most sample concentrations below 2 g m⁻³.

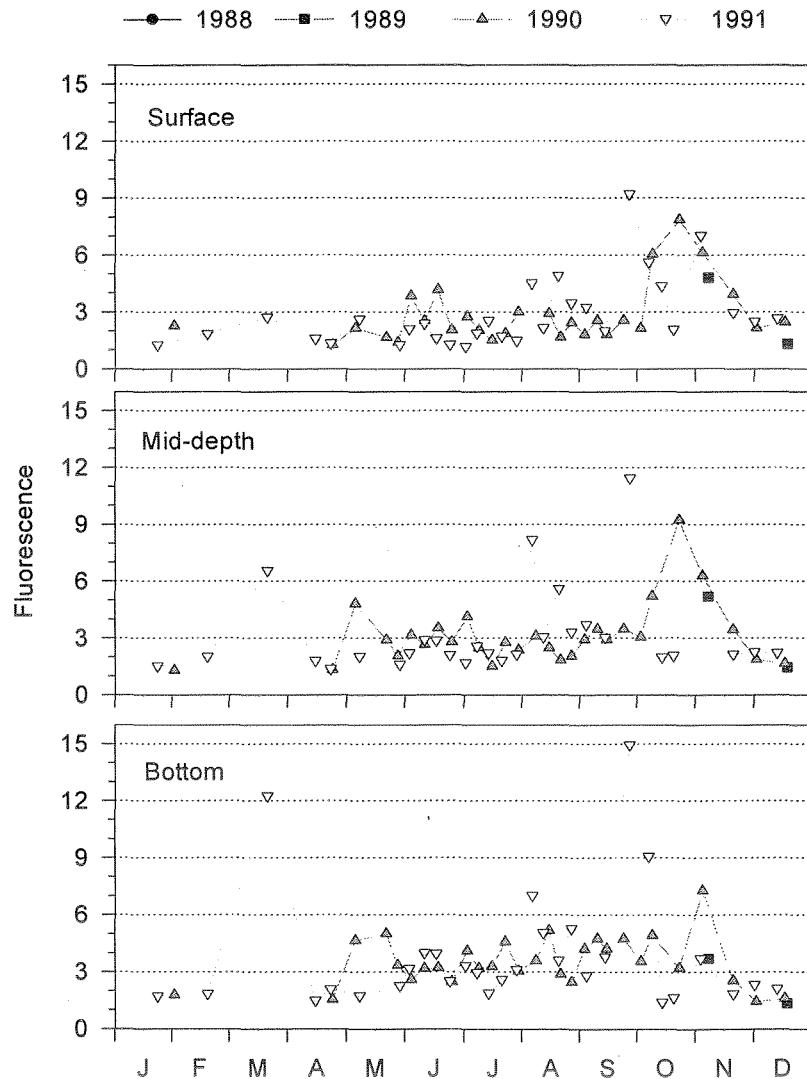


PLANT PIGMENTS

Chlorophyll (Extracted and *in vivo* Fluorescence)

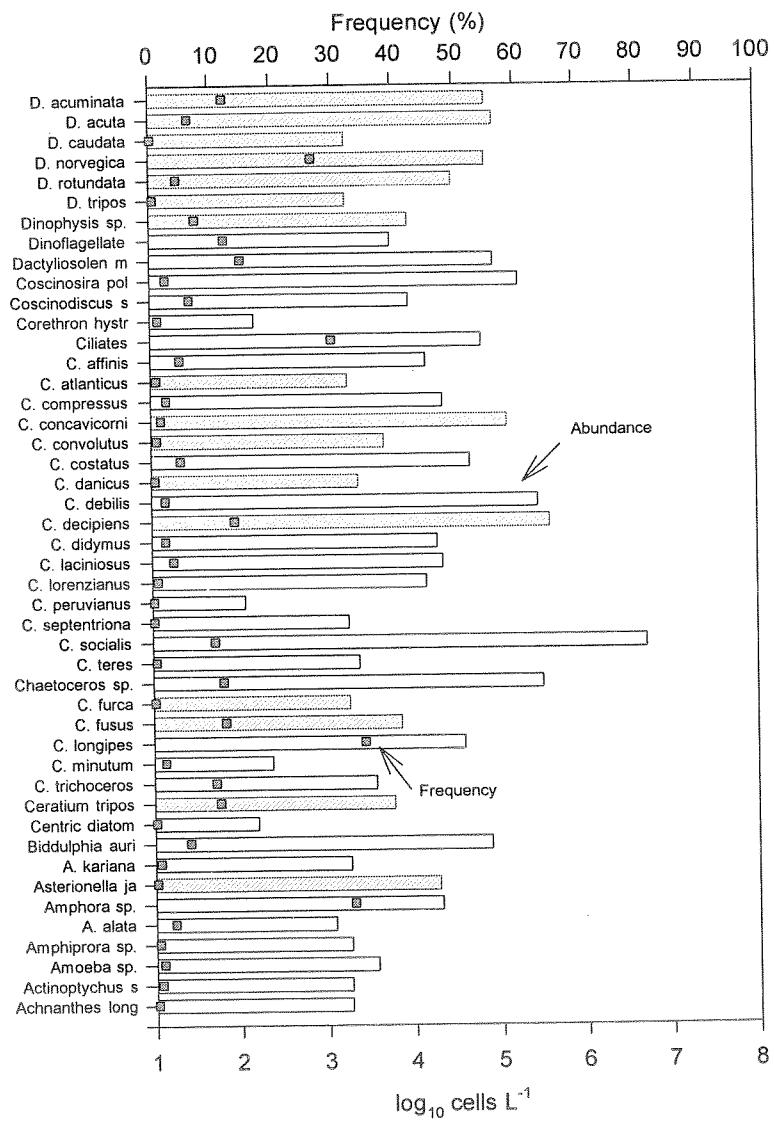
Chlorophyll concentrations exhibited maxima in both the spring (March to May) and in the fall (September and October). This same pattern was present in the SeaBird *in vivo* fluorescence data from 1990 and 1991.

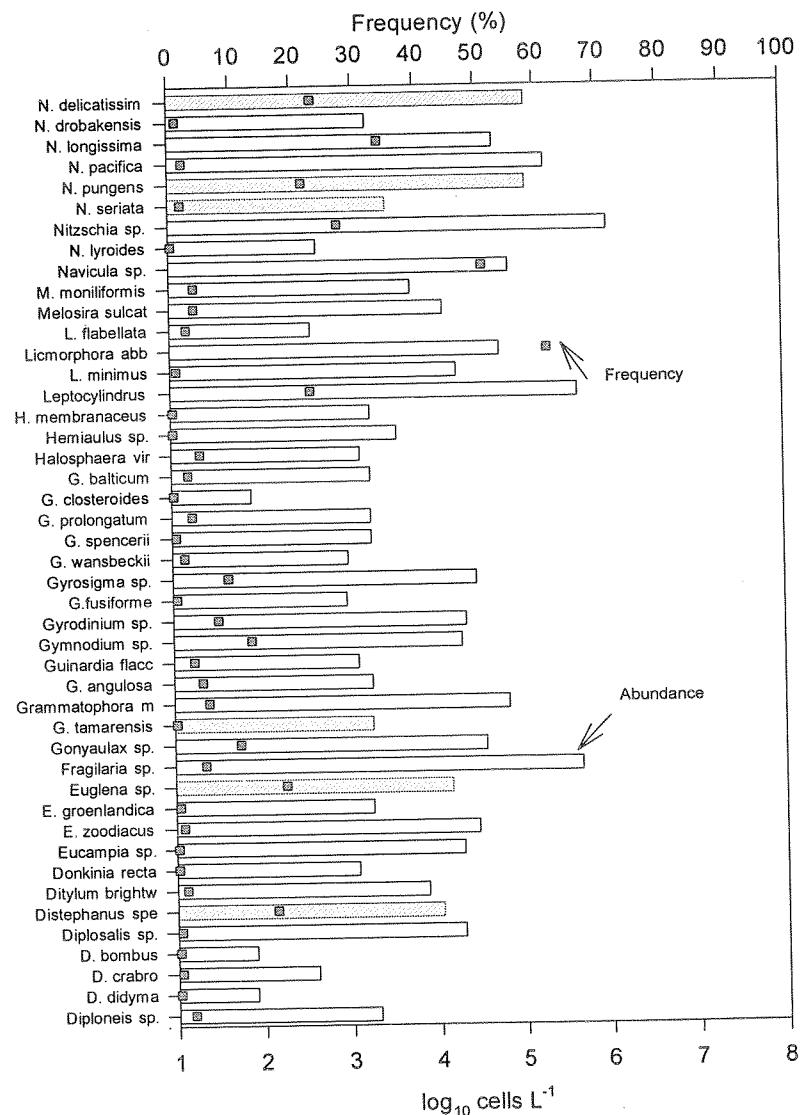


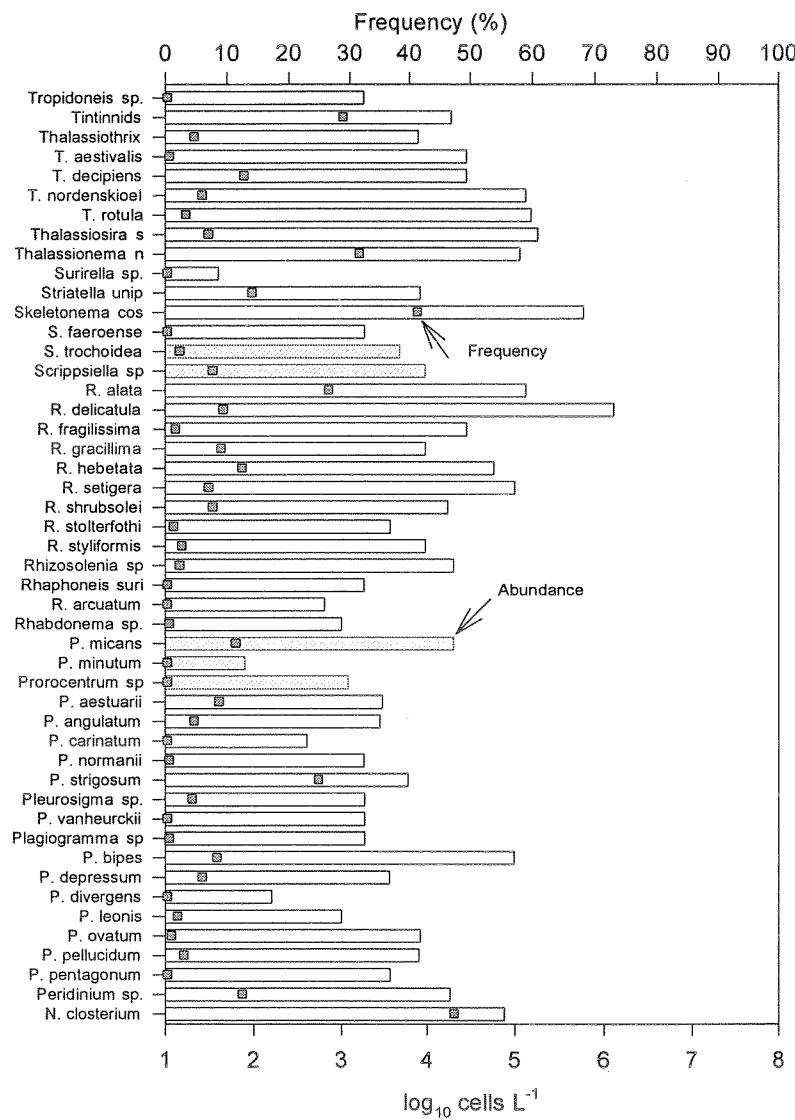


PHYTOPLANKTON - IDENTIFICATION AND ENUMERATION

A total of 141 phytoplankton species were found in samples at the St. Margarets Bay site, with numbers in individual samples ranging from 1 to 38 and averaging 12. Data for all depths for the entire sampling period are condensed to graphs which display for each species the fraction of samples for all years in which it was found (% frequency) and maximum cell density observed. The cell density bars for potentially harmful phytoplankton are shaded. Due to software limitations species names are truncated in these plots; a complete list of species observed is in the Appendix.

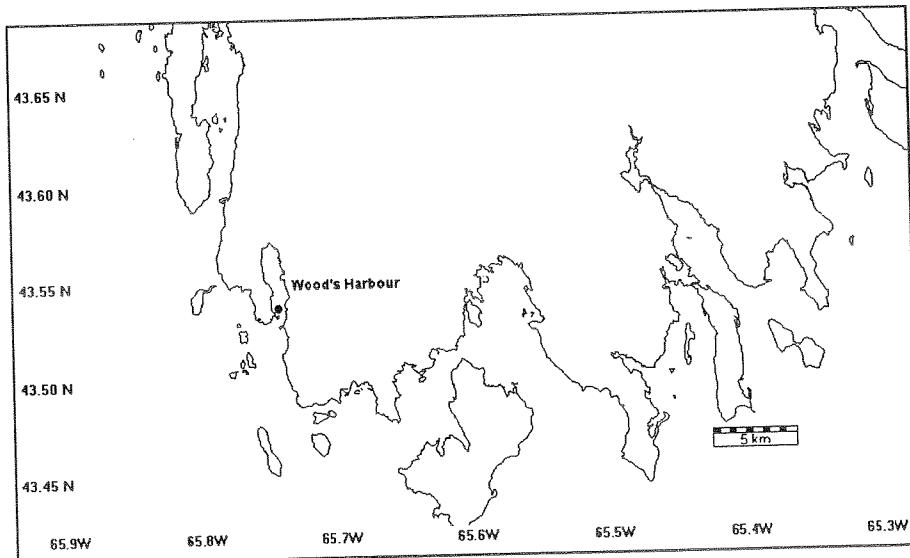






WOODS HARBOUR

This site is in a small inlet located in southwestern Nova Scotia to the south of Pubnico Harbour at 43.5405°N and 65.7408°W . Due to logistical problems there were two sampling locations, the first at John's Island and the second at the channel marker at the northern end of Cockerwit Passage. At the first location samples were taken over a mussel-holding area in 4-5 m of water. The bottom was mixed gravel covered with kelp. The second location had a similar bottom but was slightly deeper, 7 m. There is very little residential and no industrial development in the area.



PHYSICAL PROPERTIES

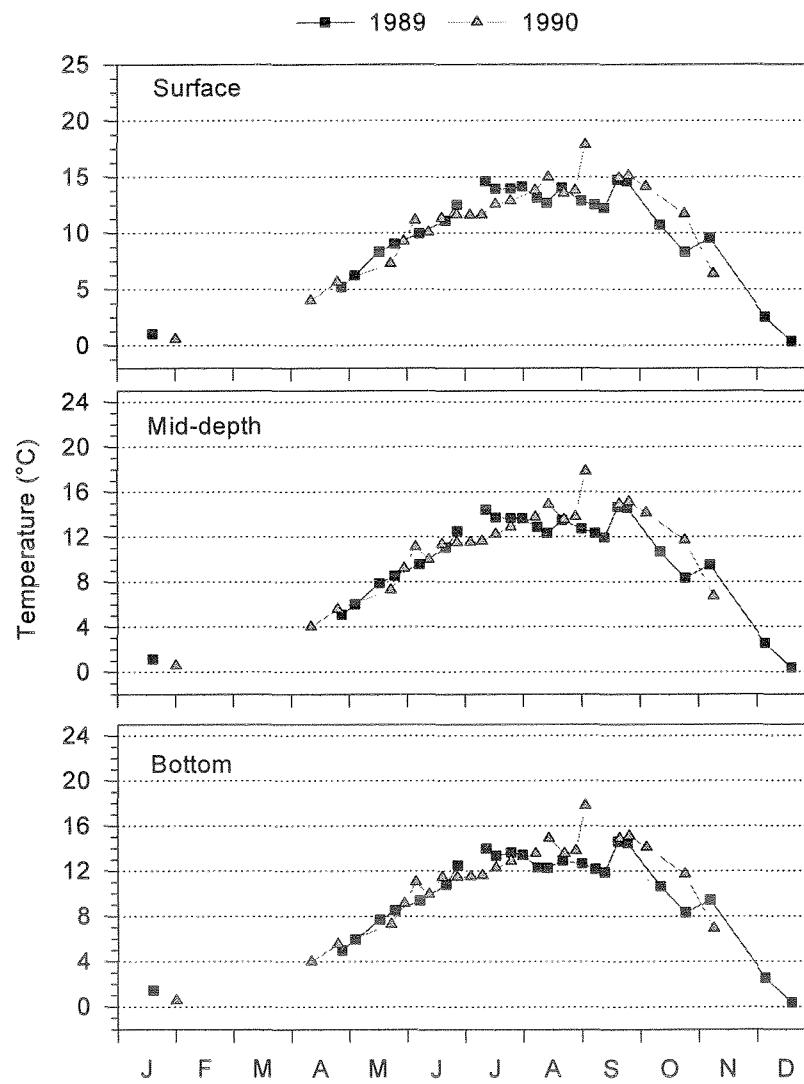
This site was sampled from January 19, 1989, to November 9, 1990, on 54 occasions. Until November 9, 1989, data for the physical variables were collected from the discrete water samples. Starting on that date the information presented were extracted from the continuous depth profiles collected with the SeaBird Model 25.

Temperature

The minimum and maximum water temperatures observed at the site were 0.0 and 17.8°C, respectively.

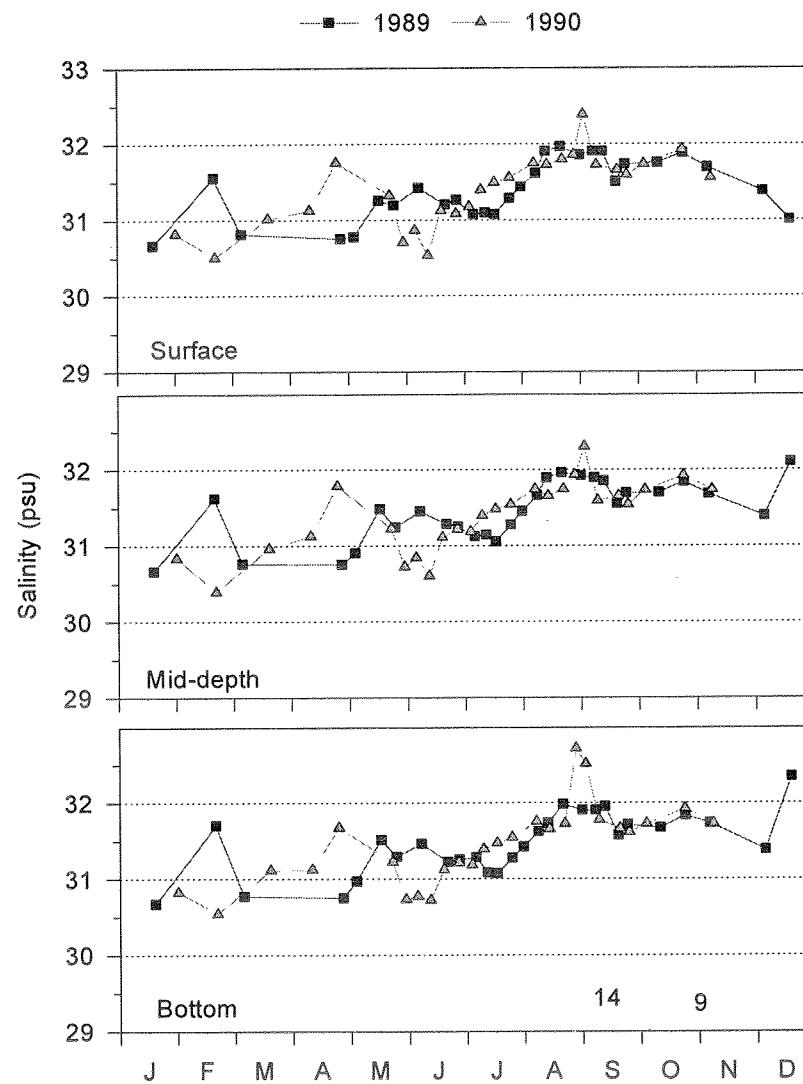
Table 6. Median (mean) water temperatures

	1989	1990
Surface	12.2 (10.3)	11.6 (11.1)
Mid-depth	11.8 (10.1)	11.6 (11.1)
Bottom	11.8 (10.0)	11.6 (11.1)



Salinity

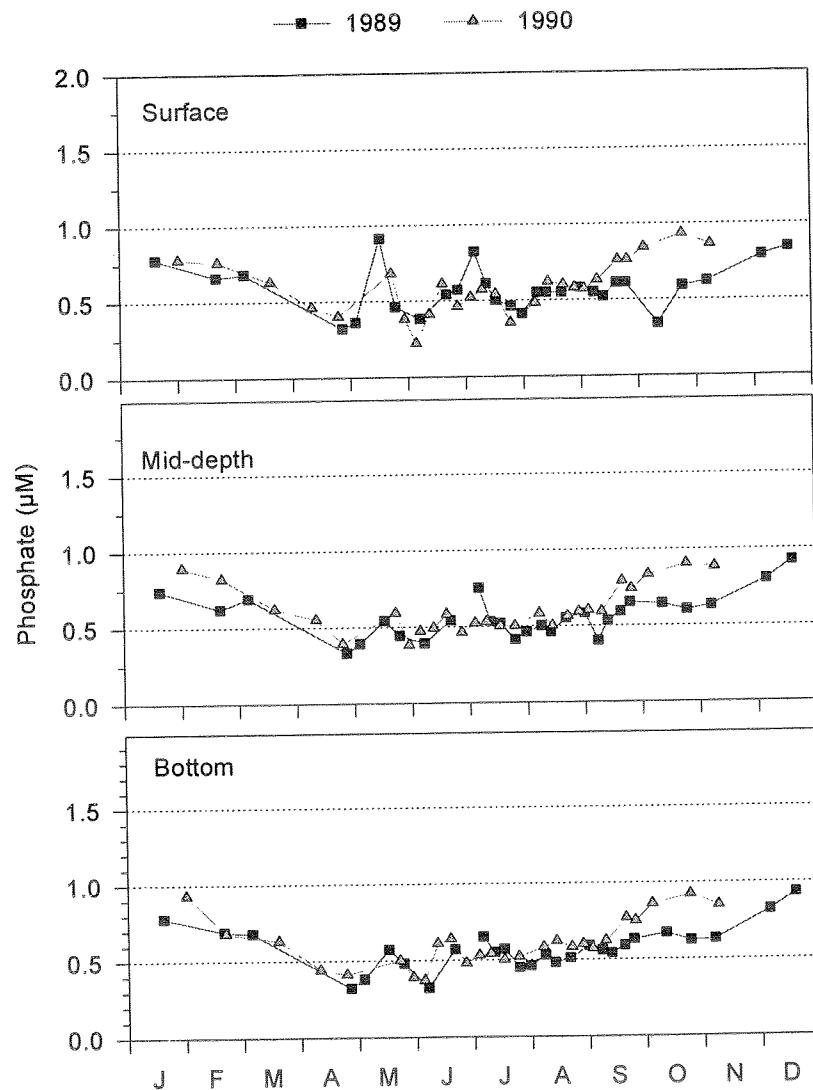
Salinity at this site was relatively constant over the study period, ranging only 1.34 psu from 30.53 to 31.87.



PLANT NUTRIENTS

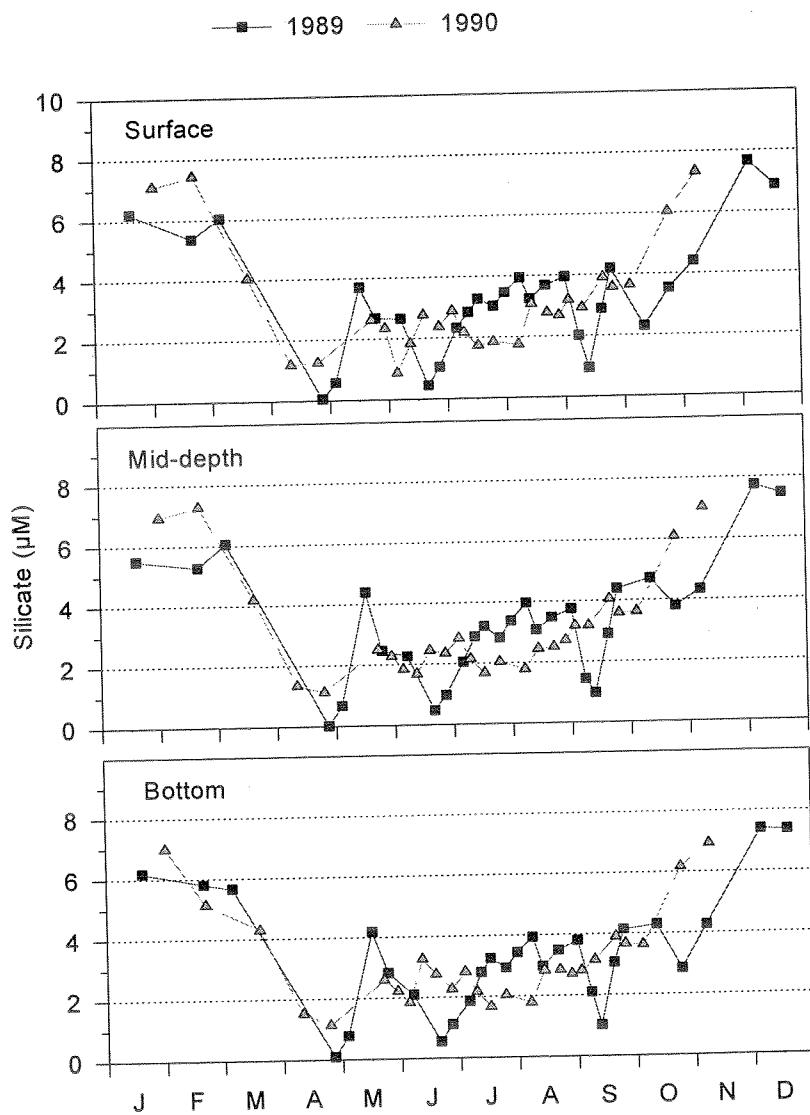
Phosphate

Phosphate concentrations varied from 0.22 μM to 0.93 μM , with lower values occurring in late spring and summer and higher values in the winter.



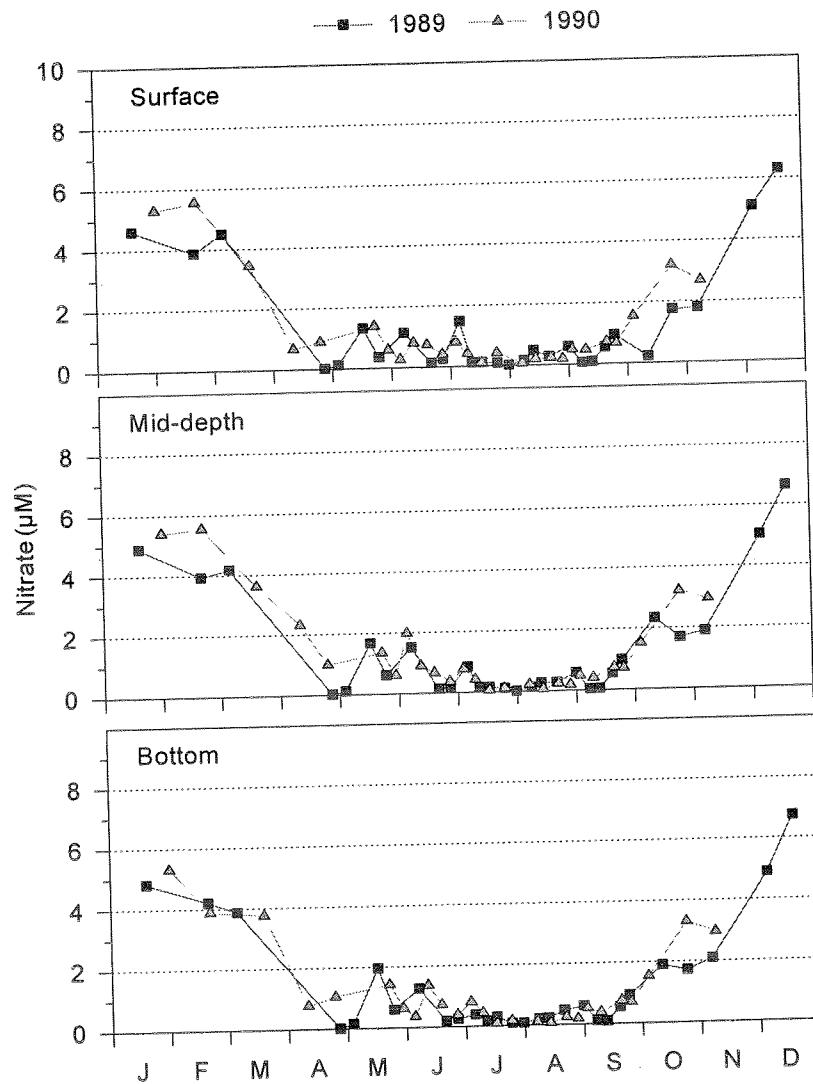
Silicate

Silicate concentrations varied seasonally. The highest values, 6-8 μM , occurred in the winter while the values during the late spring and summer were less than 4 μM .



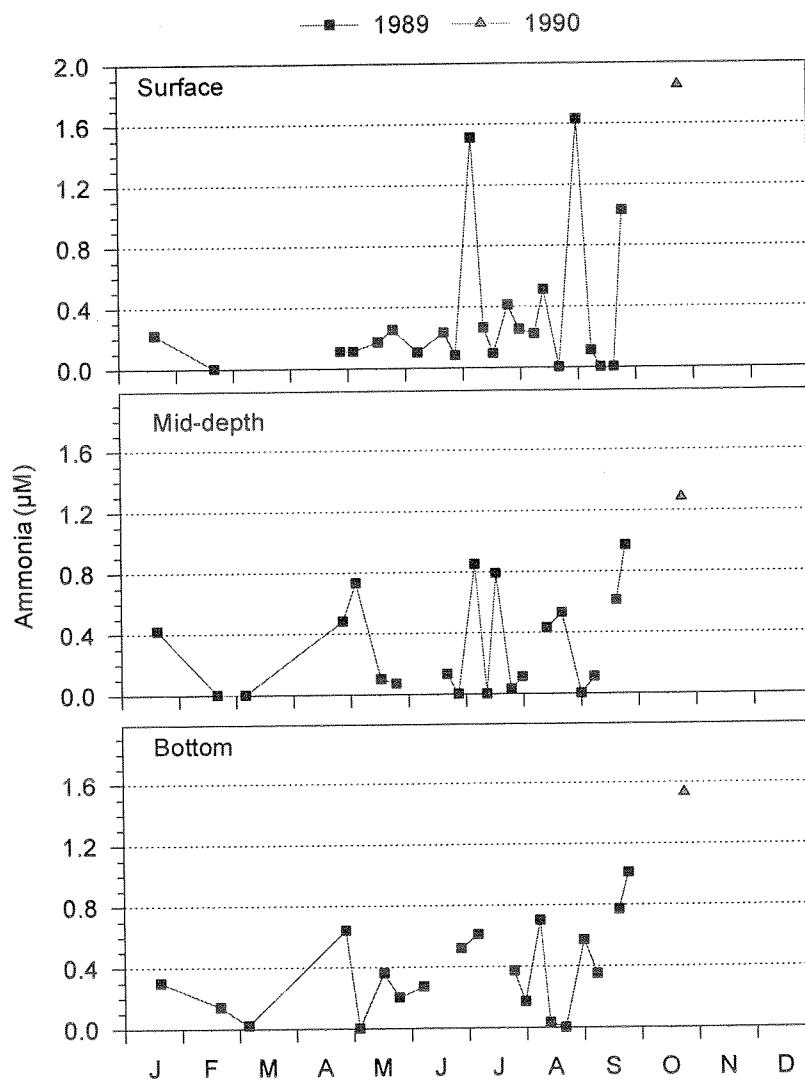
Nitrate

There was a strong seasonal pattern in the nitrate concentrations, with winter values of approximately 6 μM falling to or approaching 0 in the summer.



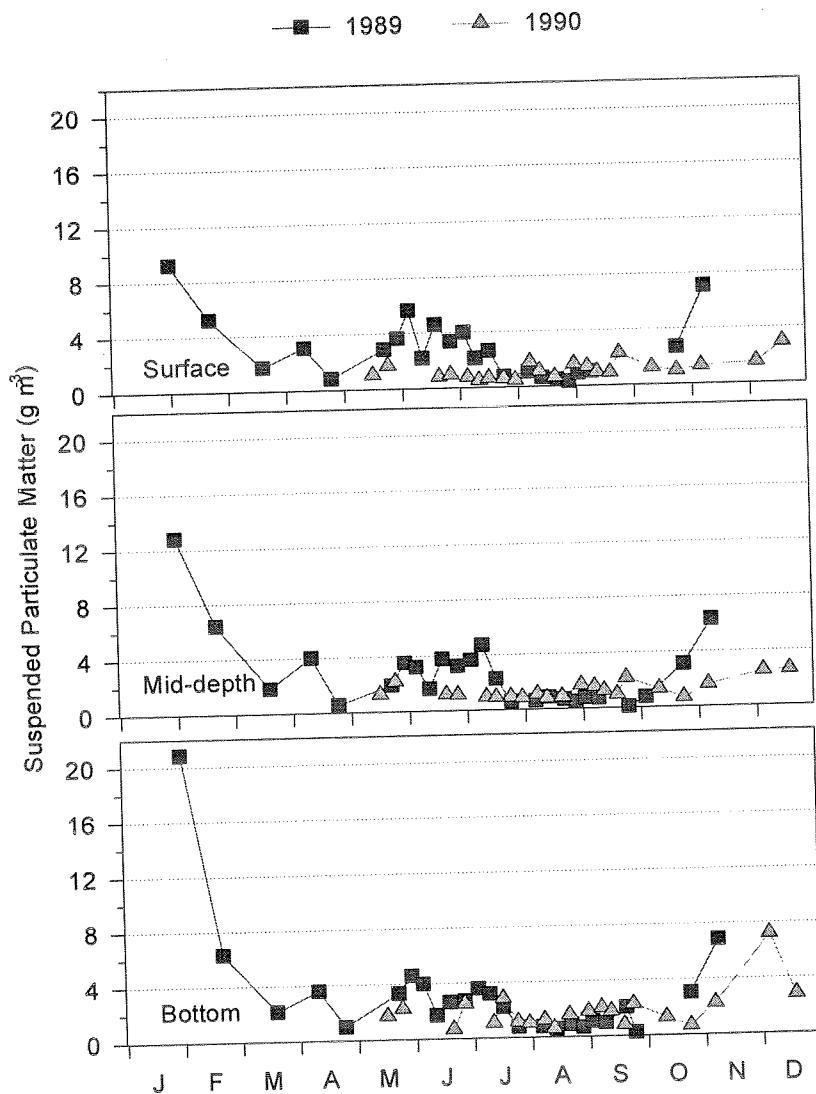
Ammonia

There are limited ammonia data available for this site. Concentrations ranged from 0 to 1.85 μM .



Suspended Particulate Material

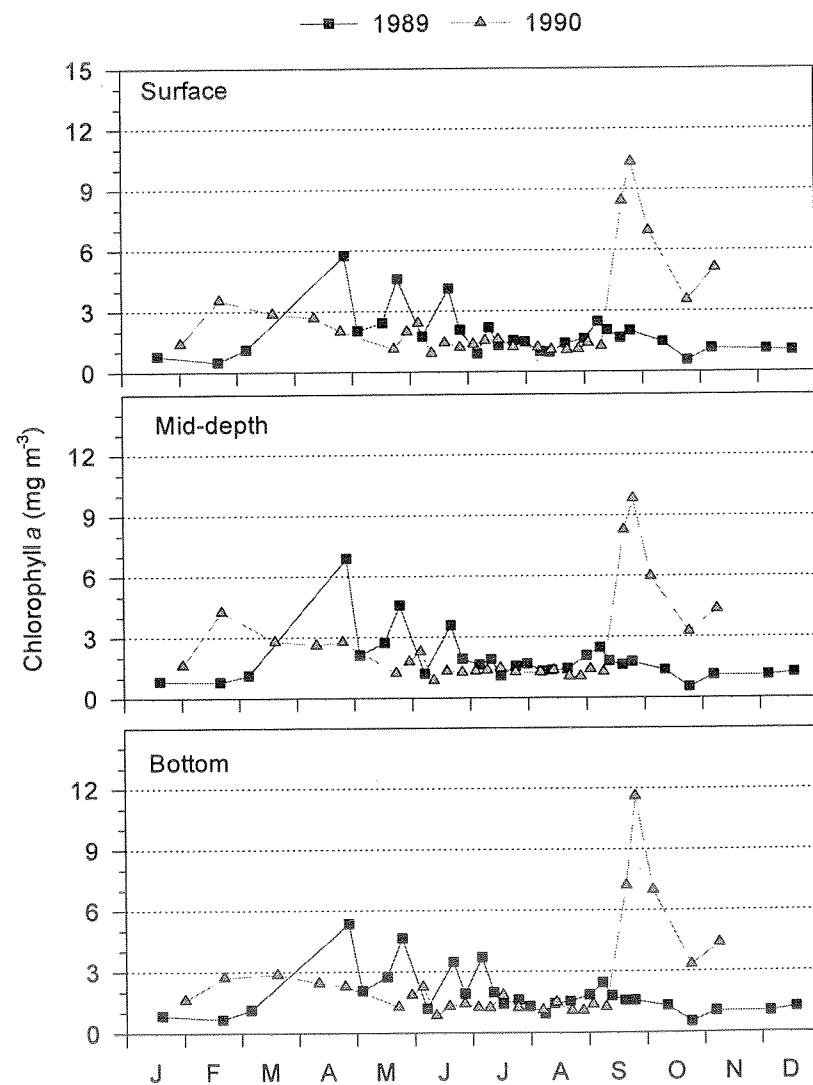
Concentrations of SPM ranged from less than 1 to more than 20 g m⁻³, with higher concentrations occurring in the bottom samples.

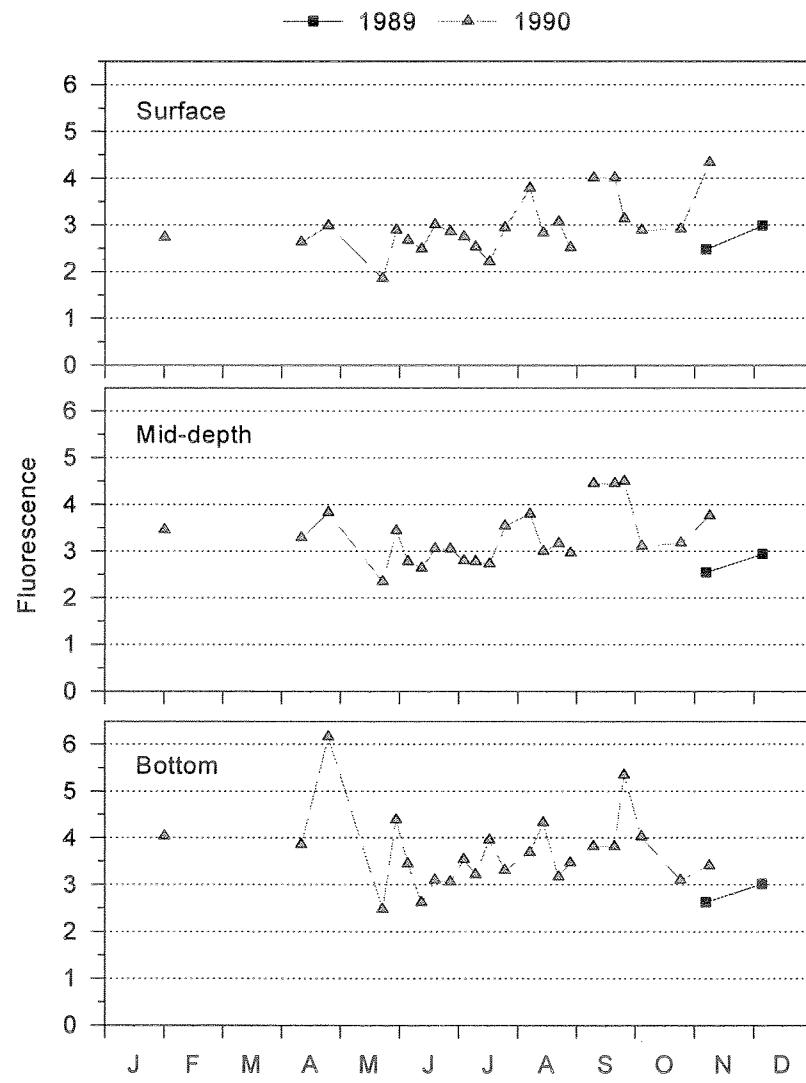


PLANT PIGMENTS

Chlorophyll (Extracted and *in vivo* Fluorescence)

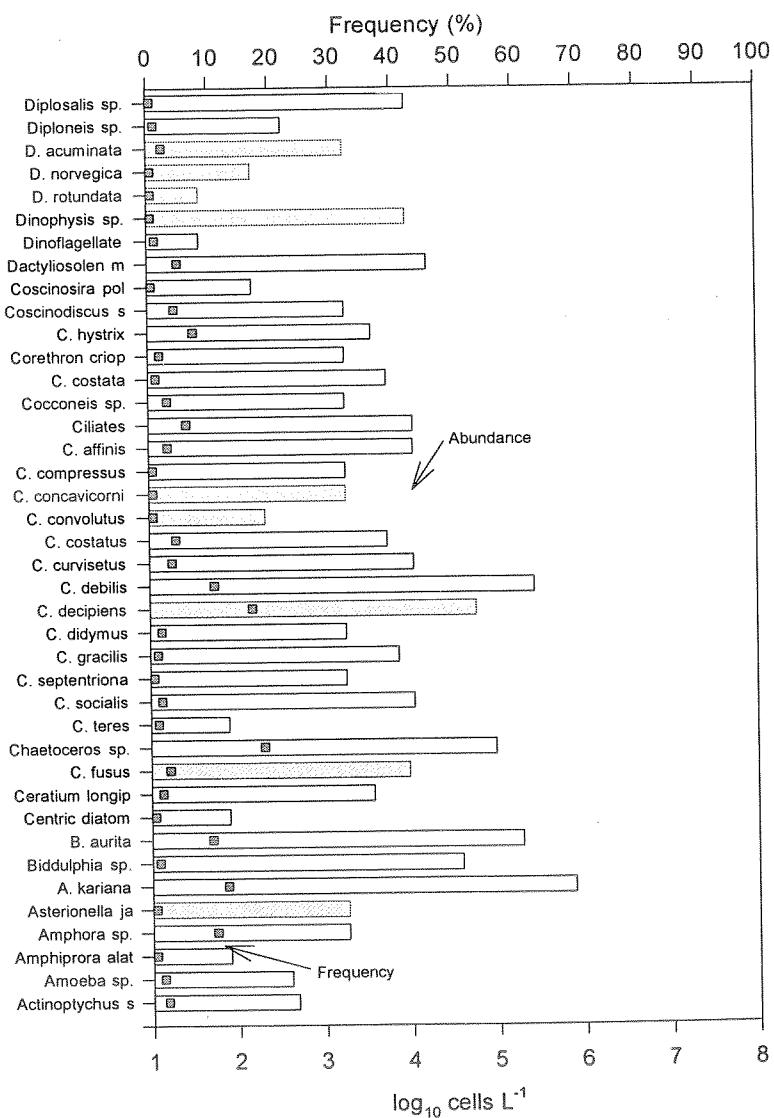
Chlorophyll concentrations exhibited maxima in both the spring (March to May) and in the fall (September and October). There are limited *in vivo* fluorescence data for this site.

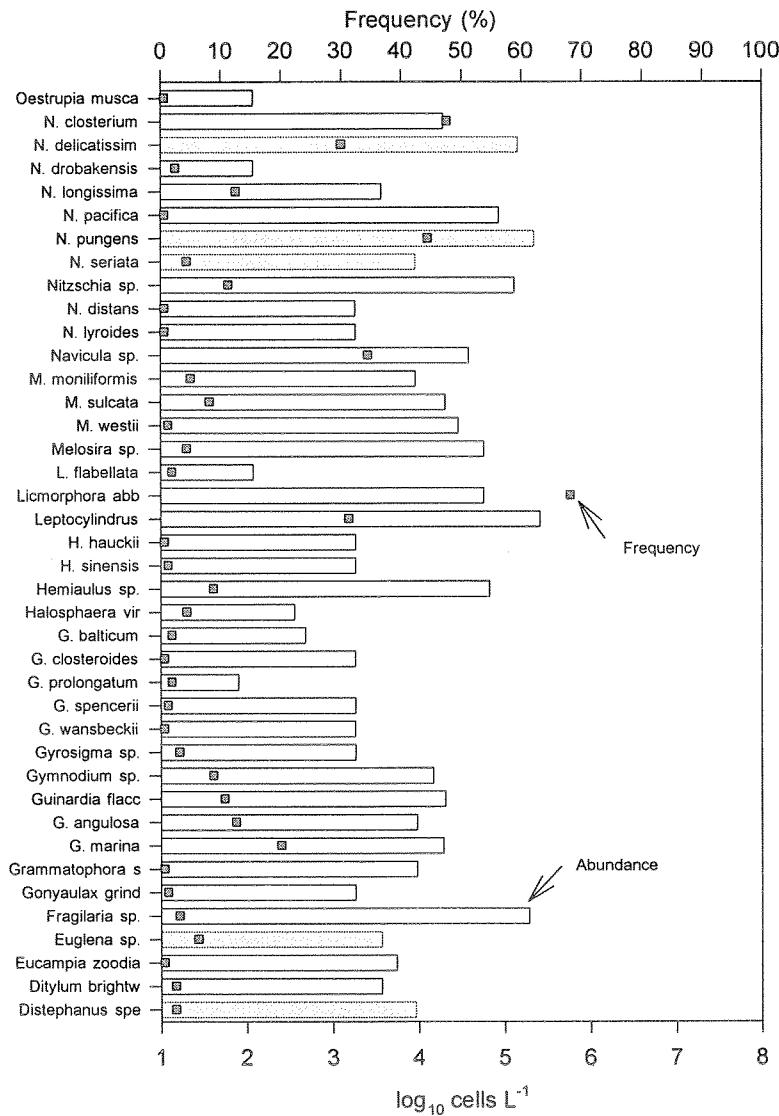


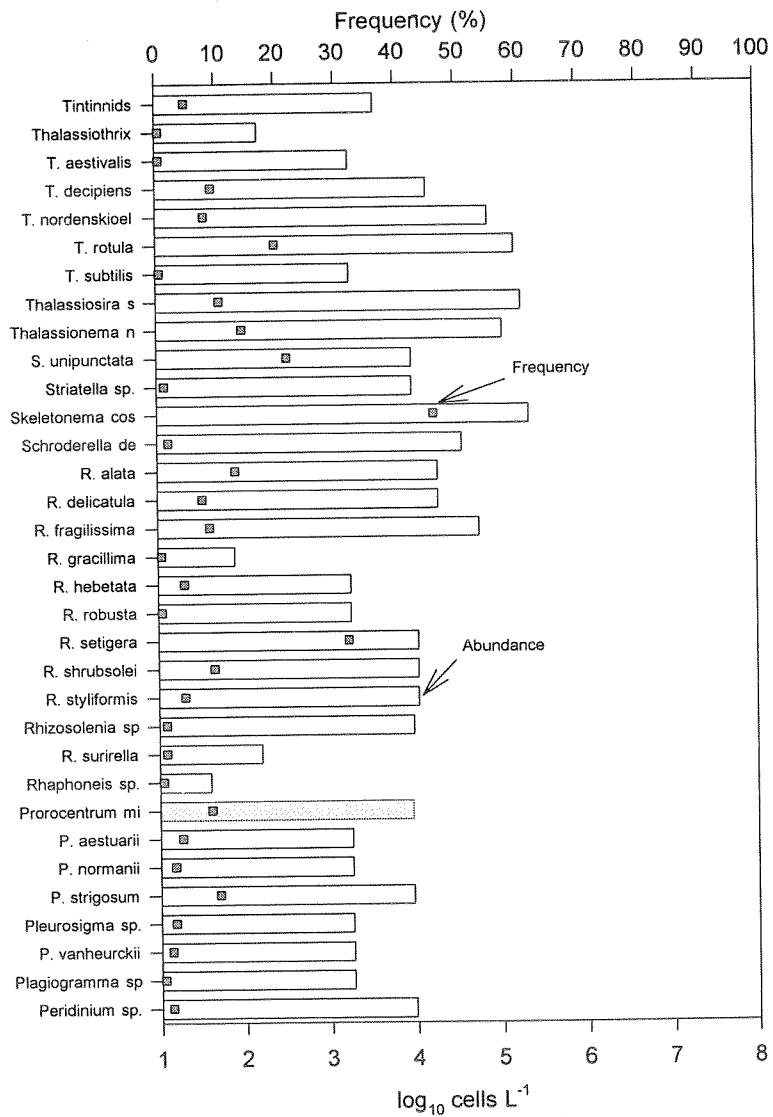


PHYTOPLANKTON - IDENTIFICATION AND ENUMERATION

A total of 115 phytoplankton species were found in samples at the Whitehead Harbour site, with numbers in individual samples ranging from 1 to 36 and averaging 8. Data for all depths for the entire sampling period are condensed to graphs which display for each species the fraction of samples for all years in which it was found (% frequency) and maximum cell density observed. The cell density bars for potentially harmful phytoplankton are shaded. Due to software limitations species names are truncated in these plots; a complete list of species observed is in the Appendix.



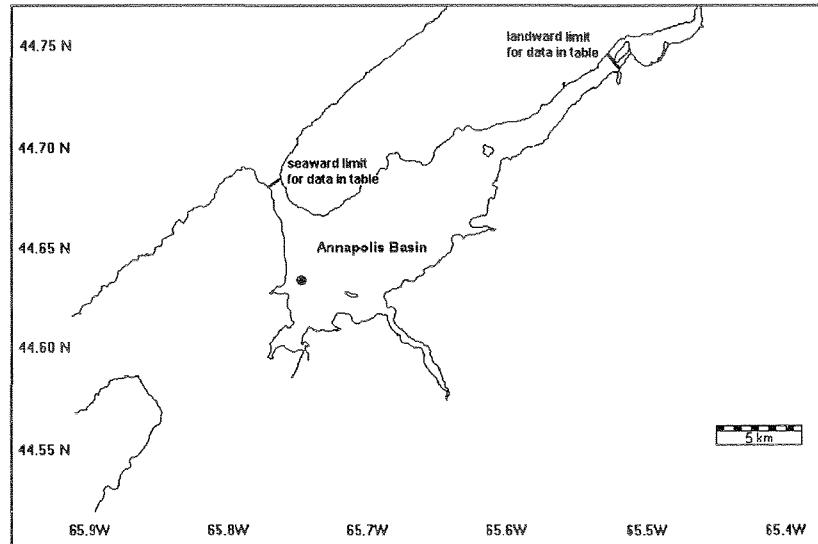




ANNAPOLIS BASIN

Located in western Nova Scotia in Annapolis County, the sampling location was just to the north and east of the town of Digby at the site of an abandoned herring weir, 44.6362°N and 65.7442°W. Depth of water at low tide was approximately 8 m above a sand-silt bottom. Tidal currents in the area are strong. The Basin is surrounded by light residential development, and the extensive watershed is largely developed for agriculture. Industrial development in the area is limited. The following information is from Gregory et al. 1993.

Area (CD)	66.5 km ²	Area (HW)	96.2 km ²
Perimeter	100.2 km ²	Volume (CD)	$612.0 \cdot 10^6$ km ³
Axis Length	25.8 km	Maximum Depth	94.2 m
Tidal Range		Tidal Volume	
Mean	Large	Mean Tide	Tidal Current
6.80 m	9.30 m	$553.2 \cdot 10^6$ km ³	Mean Peak
			0.97 m s^{-1} 1.52 m s^{-1}
Tidal/Freshwater volume	455.46		
Watershed area	2408.4 km ²		



PHYSICAL PROPERTIES

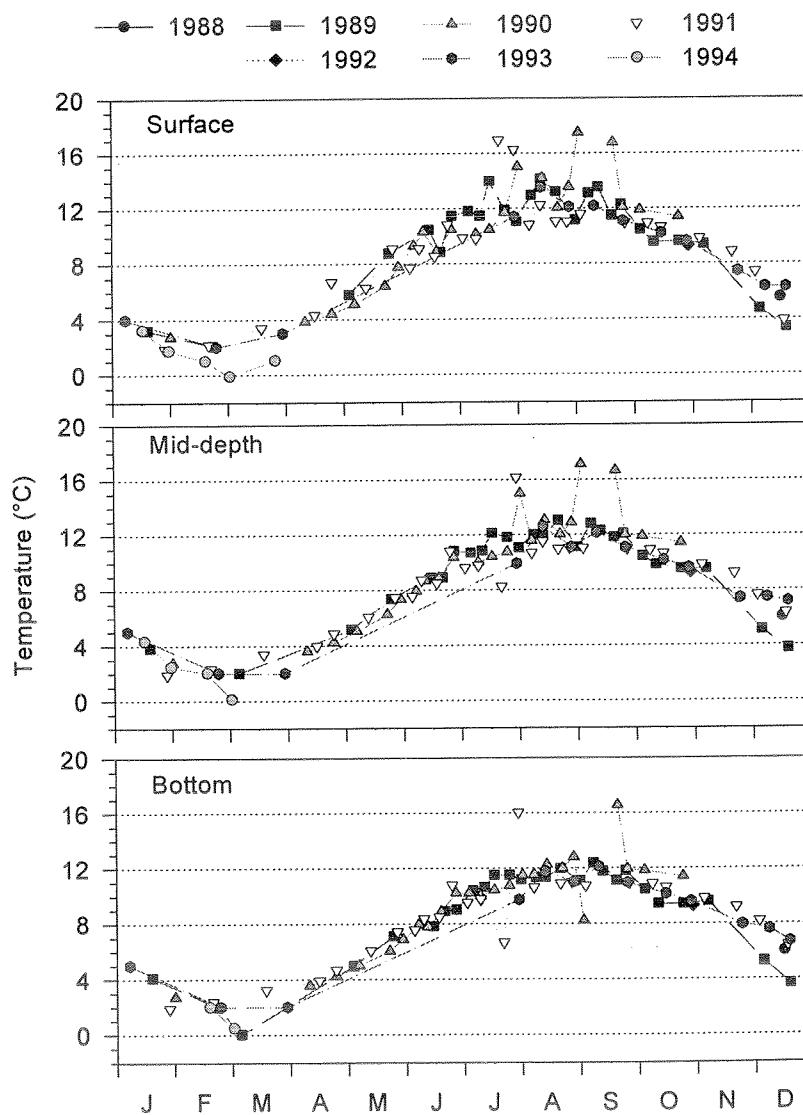
This site was sampled from December 16, 1988, to March 26, 1994, on 105 occasions. Only limited sampling was undertaken in 1988 and 1992 to 1994. Until November 9, 1989, data for the physical variables were collected from the discrete water samples. Starting on that date the information presented were extracted from the continuous depth profiles collected with the SeaBird Model 25.

Temperature

The minimum and maximum water temperatures observed at the site were -0.11 and 17.5°C, respectively. Average water temperatures declined over the study period.

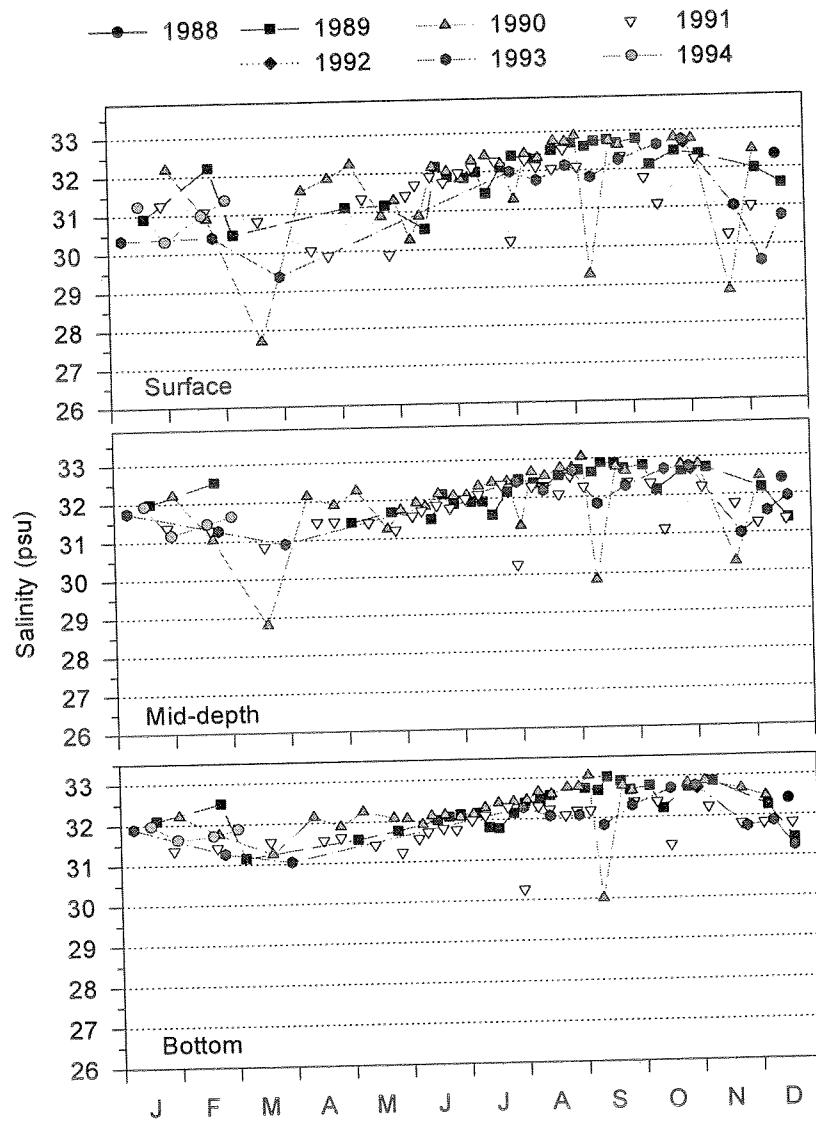
Table 6. Median (mean) water temperatures

	1989	1990	1991
Surface	11.1 (10.0)	10.2 (9.9)	9.8 (8.9)
Mid-depth	10.8 (9.6)	10.2 (9.7)	9.2 (8.5)
Bottom	10.4 (8.9)	10.1 (9.2)	9.2 (8.4)



Salinity

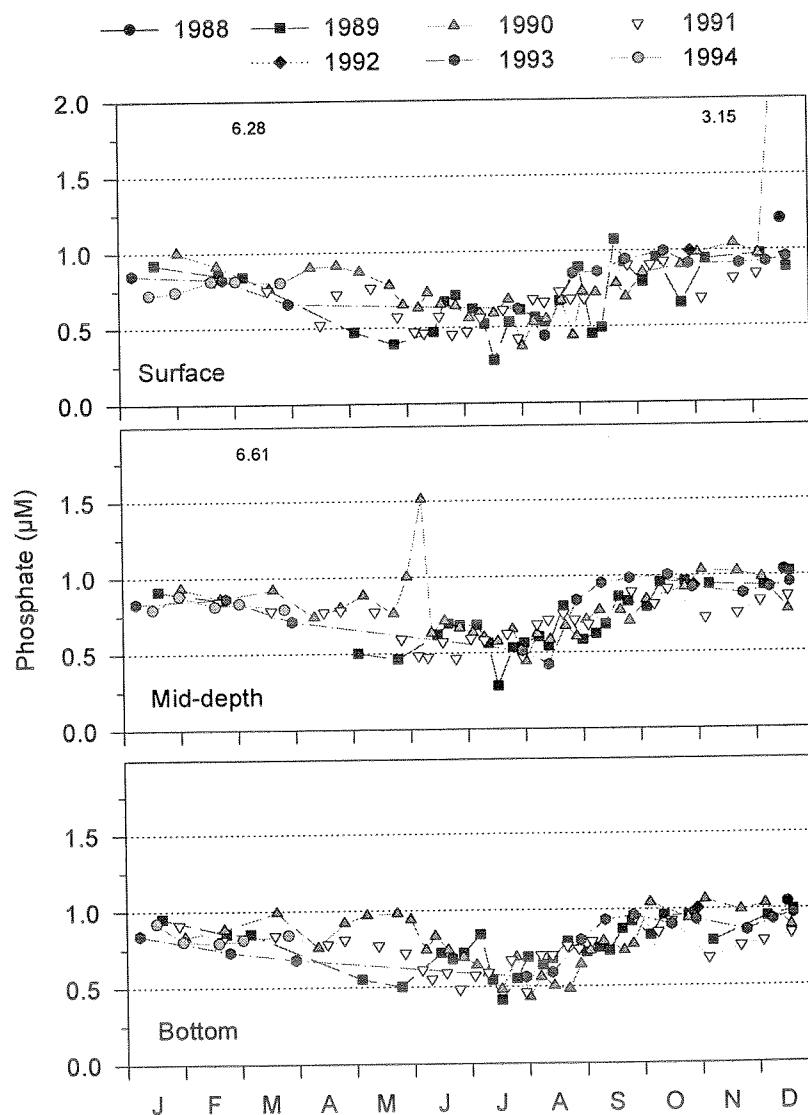
Salinity in the bottom water varied seasonally, with a minimum of 31 psu in March/April and a maximum of 33 psu in September. This same pattern was also apparent in the surface and mid-depth samples with the addition of some low salinity events, less than 30 psu, throughout the year.



PLANT NUTRIENTS

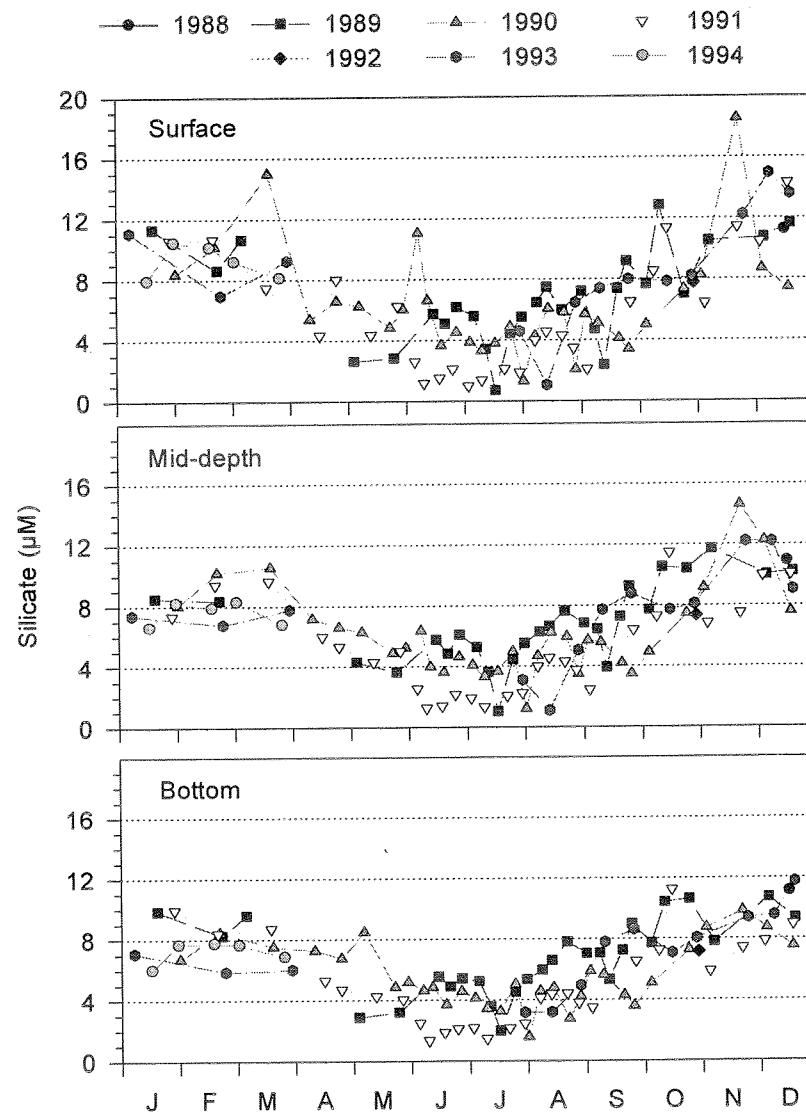
Phosphate

Phosphate concentrations followed a seasonal pattern of higher concentrations, approaching 1 μM , in the winter and lower concentrations, about 0.5 μM , in the summer. Some significant interannual variations are superimposed upon this general trend.



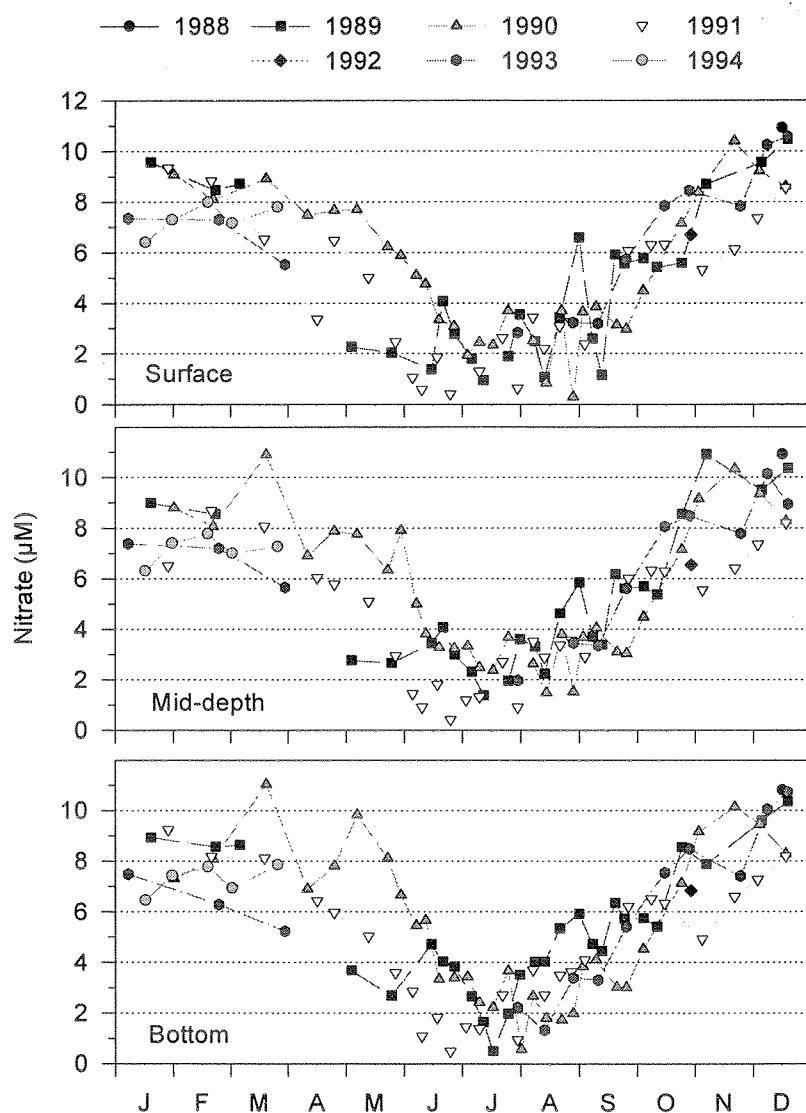
Silicate

Silicate concentrations varied seasonally. In the fall and winter, concentrations ranged from 6 to 19 μM but dropped to less than 4 μM in the summer.



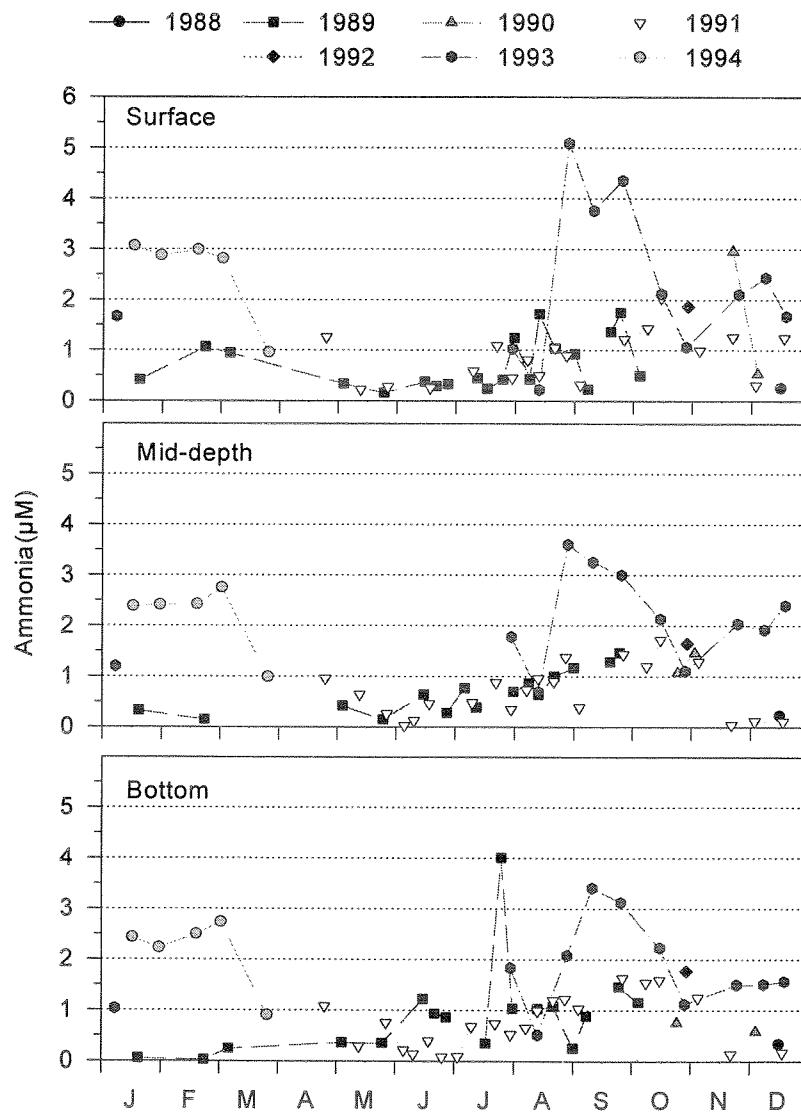
Nitrate

There was also a strong seasonal pattern in the nitrate concentrations, with winter values of approximately 10 μM falling to less than 2 μM in summer.



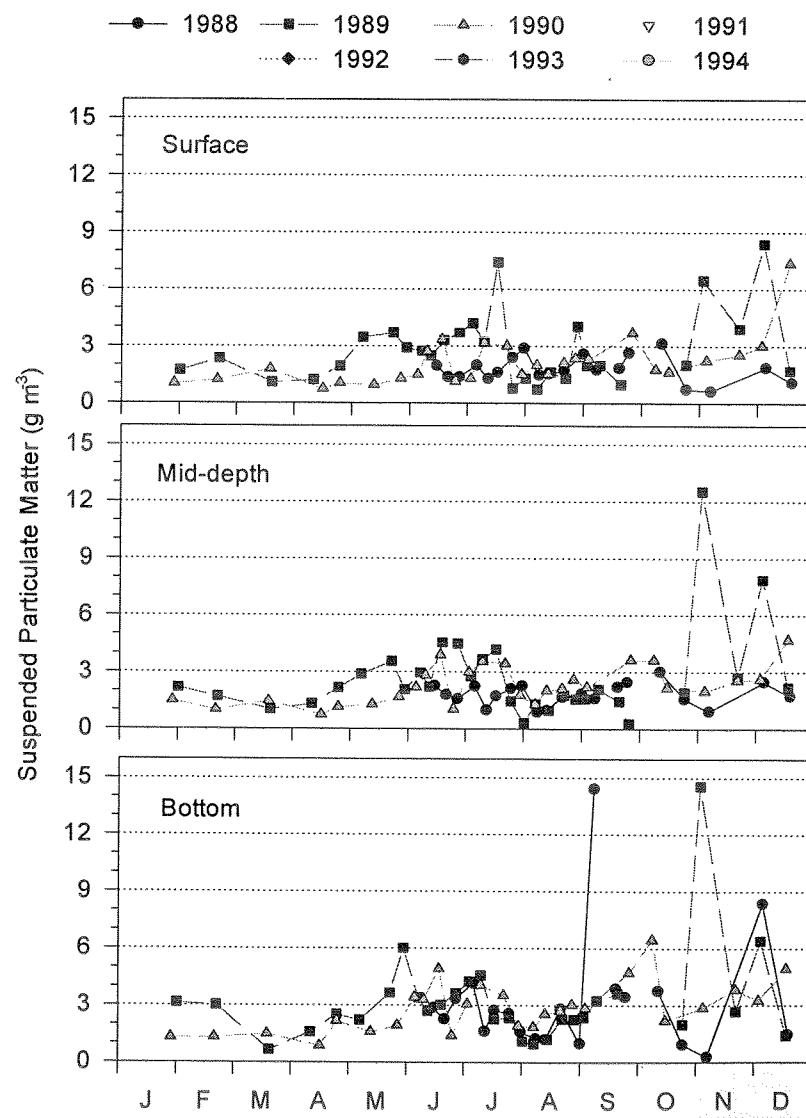
Ammonia

The data for ammonia are limited, but there appears to be a pattern of lower concentrations in the spring and early summer and higher and more variable concentrations in the fall.



Suspended Particulate Material

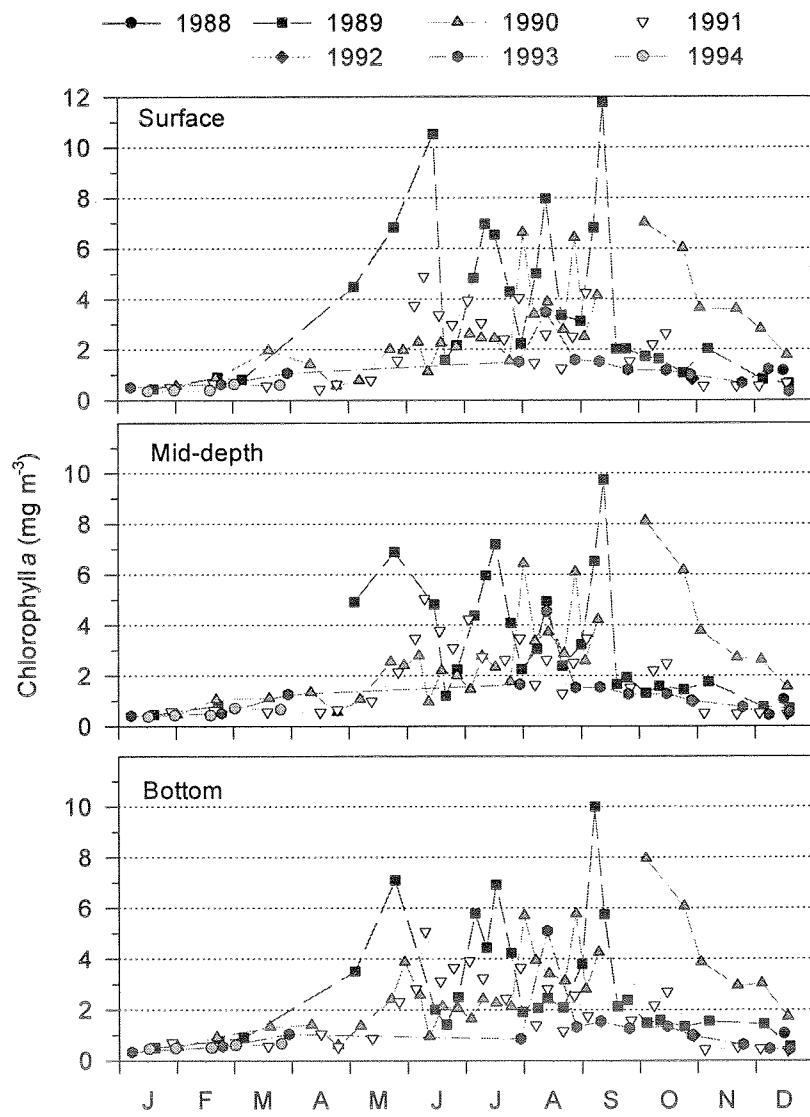
Concentrations of SPM ranged from less than 1 to more than 14 g m^{-3} , with most sample concentrations below 5 g m^{-3} . Concentrations appeared to be lower and less variable in the winter and spring.

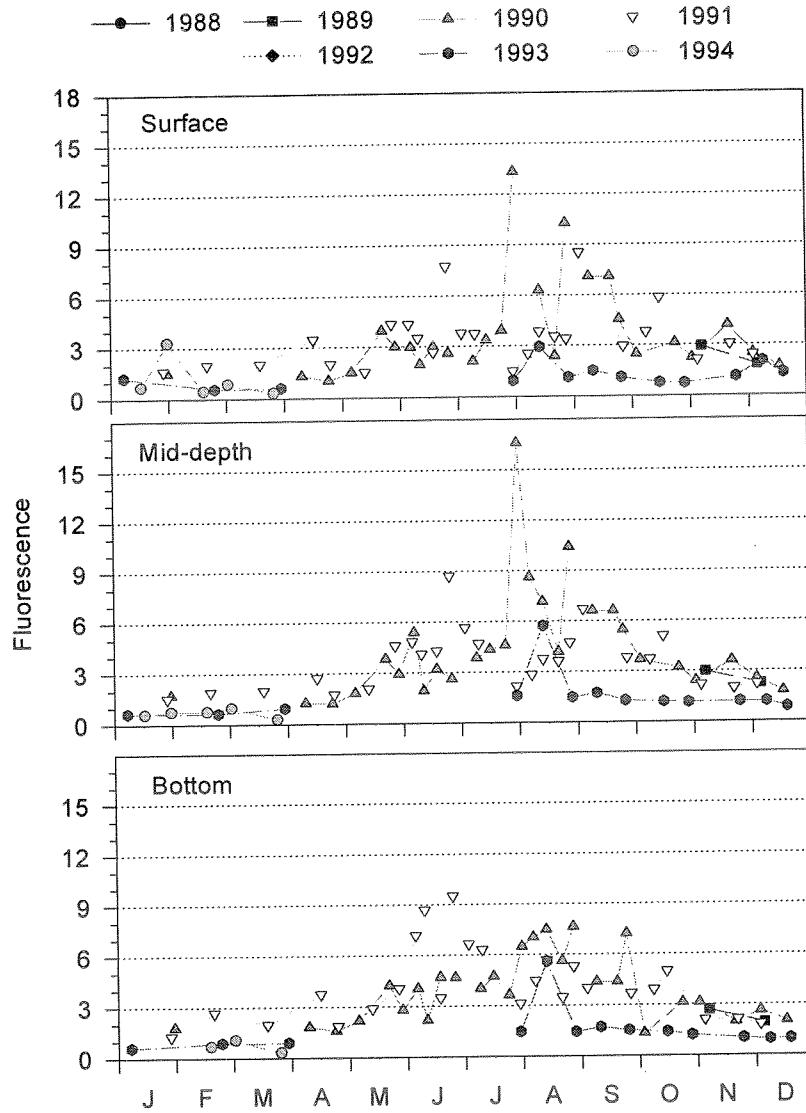


PLANT PIGMENTS

Chlorophyll (Extracted and *in vivo* Fluorescence)

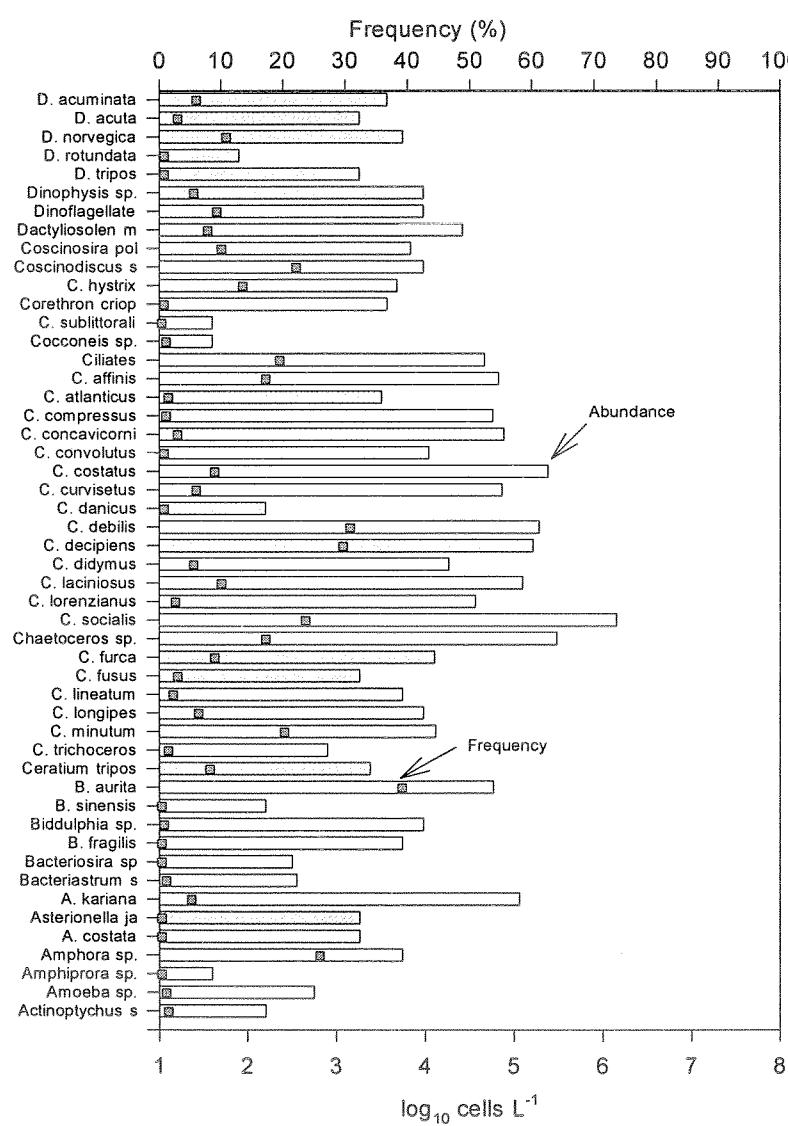
Chlorophyll concentrations exhibited higher values from spring (early May) to the fall. The *in vivo* fluorescence data exhibited a similar pattern.

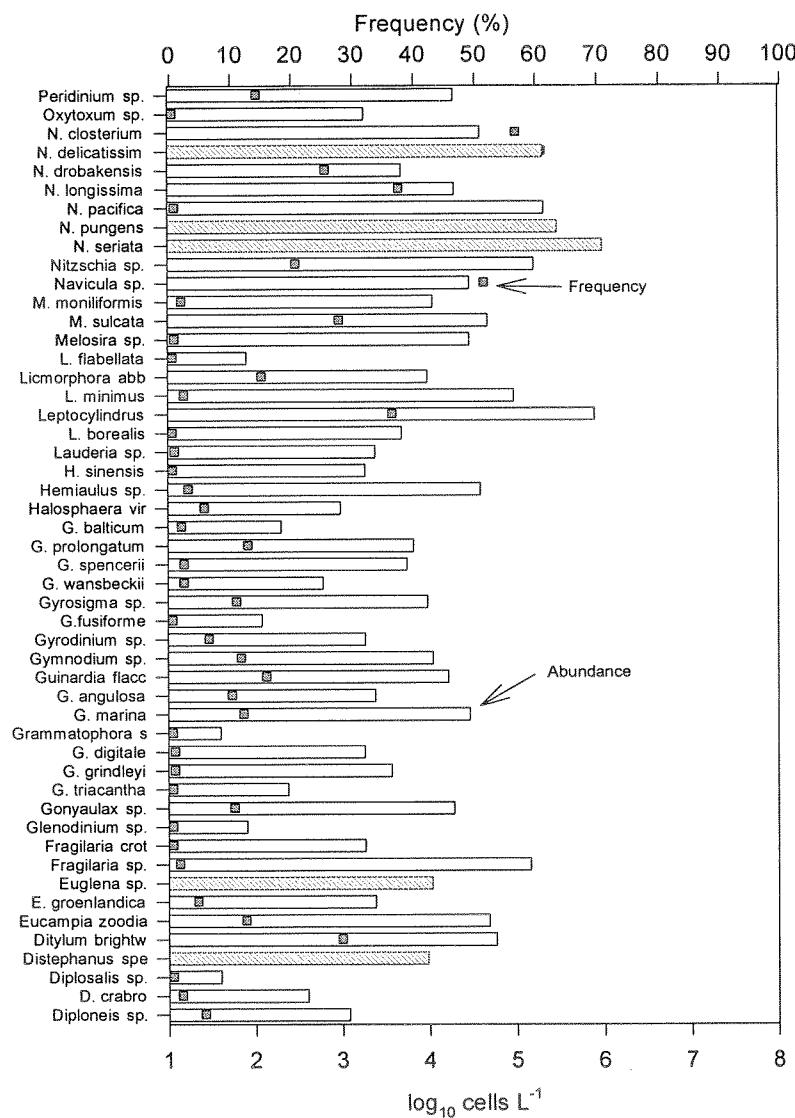


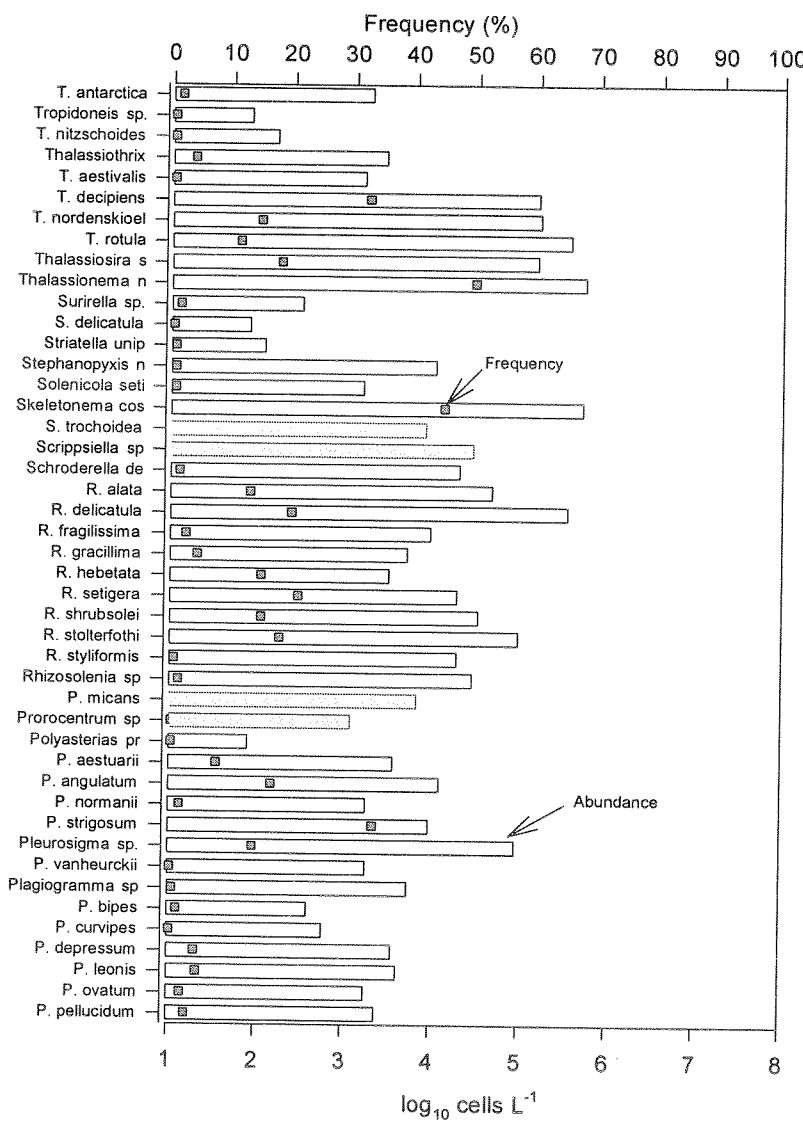


PHYTOPLANKTON - IDENTIFICATION AND ENUMERATION

A total of 148 phytoplankton species were found in samples at the Annapolis Basin site, with numbers in individual samples ranging from 3 to 37. Data for all depths for the entire sampling period are condensed to graphs which display for each species the fraction of samples from all years in which it was found (% frequency) and maximum cell density observed. The cell density bars for potentially harmful phytoplankton are shaded. Due to software limitations, species names are truncated in these plots; a complete list of species observed is in the Appendix.







ACKNOWLEDGMENTS

This project was initiated following the domoic acid crisis in Prince Edward Island as part of a Regional effort to avoid the occurrence of similar incidents. Dr. Donald Gordon played a major role in planning and implementing the initial monitoring program and had the foresight to include a data management component in the project.. Ann Orr supervised the monitoring program, analyzed the samples for chlorophyll *a* and handled the considerable task of data management until her retirement in 1995. Unfortunately her early retirement resulted in the considerable delay in the publication of this report. Sampling at the sites was done under contract to Sprytech Biological Services. The cooperation and professionalism of Jeff Spry and his colleagues facilitated this aspect of the program. Phytoplankton analyses were conducted by a number of contractors including. Phyllis Butts., Tina Dibaccio and Dr. Youlian Pan. The authors are grateful to Dr. James Stewart and Jennifer Martin who reviewed and provided useful comments regarding the content and layout of the report. A special thanks to Jennifer Martin for correcting the species list for the final draft following Dr. Subba Rao's move to Kuwait.

REFERENCES

- Bates, S.S., C.J. Bird, A.S.W. de Freitas, R. Foxall, M. Gilgan, L.A. Hanic, G.R. Johnson, A.W. McCulloch, P. Odense, R. Pocklington, M.A. Quilliam, P.G. Sim, J.C. Smith, D.V. Subba Rao, E.C.D. Todd, J.A. Walter, and J.L.C. Wright. 1989. Pennate diatom *Nitzschia pungens* as the primary source of domoic acid, a toxin in shellfish from eastern Prince Edward Island, Canada. Can. J. Fish. Aquat. Sci. 46: 1203-1215.
- Bird, C.J., R.K. Boyd, D. Brrewer, C.A. Craft, A.S.W. de Freitas, E.W. Dyer, D.J. Embree, M. Falk, M.G. Flack, R. Foxall, C. Gillis, M. Greenwell, W.R. Hardstaff, W.D. Jamieson, M.V. Laycock, P. Leblanc, N.I. Lewis, A.W. McCulloch, G.K. McCully, M. McInerney-Northcott, A.G. McInnes, J.L. McLachlan, P. Odense, D. O'Neil, V.P. Pathak, M.A. Quilliam, M.A. Ragan, P.F. Seto, P.G. Sim, D. Tappen, P. Thibault, J.A. Walter, J.L.C. Wright, A.M. Backman, A.R. Taylor, D. Dewar, M. Gilgan, and D.J.A. Richard. 1988. Identification of domoic acid as the toxic agent responsible for the P.E.I. contaminated mussel incident. Atlantic Res. Lab. Tech. Rep. 56, 86 pp.
- Keizer, P.D., G. Bugden, D.V. Subba Rao and P. Strain. 1996. Long term monitoring program: Indian Point and Sambro, Nova Scotia for the period July 1992 to December 1994. Can. Data Rep. Fish. Aquat. Sci. 980: v + 20 p.
- Kranck, K. and T. Milligan. 1979. The use of the Coulter Counter in studies of particle-size distributions in aquatic environments. Bedford Inst. Oceanogr. Rep. Ser. BI-R-79-7. 61 p.
- Martin, J.L. , D.J Wildish, M.M. LeGresley, M.M. Ringuette. 1995. Phytoplankton monitoring in the southwestern Bay of Fundy during 1990-92. Can. Man. Rep. Fish. Aquat. Sci. 2277, 154 p.
- Subba Rao, D.V., M.A. Quilliam and R. Pocklington. 1988. Domoic acid - a neurotoxic amino acid produced by the marine diatom *Nitzschia pungens* in culture. Can. J. Fish. Aquat. Sci. 45: 2076-2079.
- Winneberger, J.H., J.H. Austin and C.A. Klett. 1963. Membrane filter weight determination. J. Water Pollution Control Fed. 35: 807-813.
- Strickland, J.D.H., and T.R. Parsons. 1968. A practical handbook of seawater analysis. Fish. Res. Board Can. Bull. 167: 311 p.

APPENDIX

The species and genus names of the phytoplankton species found in the samples may be truncated in the figures which display the summary data. The accepted names for some species have also changed since the database was created; currently accepted names are in brackets. The full names are listed here.

<i>Achnanthes longipes</i>	<i>Chaetoceros laciniosus</i>
<i>Actinptychus senarius</i>	<i>Chaetoceros compressus</i>
<i>Alexandrium sp.</i>	<i>Chaetoceros curvisetus</i>
<i>Amoeba sp.</i>	<i>Chaetoceros concavicornis</i>
<i>Amphiprora surirelloides</i>	<i>Chaetoceros decipiens</i>
<i>Amphiprora alata</i>	<i>Chaetoceros gracilis</i>
<i>Amphiprora sp.</i>	<i>Chaetoceros septentrionalis</i>
<i>Amphora costata</i>	<i>Chaetoceros debilis</i>
<i>Amphora coffeiformis</i>	<i>Chaetoceros danicus</i>
<i>Amphora sp.</i>	<i>Chaetoceros affinis</i>
<i>Asterionellopsis japonica</i>	<i>Chaetoceros vistulae</i>
<i>Asterionellopsis kariana</i>	<i>Chaetoceros didymus</i>
<i>Asteromphalus sp.</i>	<i>Chaetoceros peruvianus</i>
<i>Bacteriastrum elongatum</i>	<i>Chaetoceros tricoceros</i>
<i>Bacteriastrum hyalinum</i>	<i>Chaetoceros socialis</i>
<i>Bacteriastrum sp.</i>	<i>Chaetoceros subsecundus</i>
<i>Bacteriosira bathyonphala</i>	<i>Chaetoceros sp.</i>
<i>Bacteriosira sp.</i>	<i>Chaetoceros convolutus</i>
<i>Biddulphia sp.</i>	Ciliates
<i>Biddulphia sinensis</i>	<i>Coccconeis clandestina</i>
<i>Biddulphia [Odontella] aurita</i>	<i>Coccconeis sp.</i>
<i>Biddulphia mobiliensis</i>	<i>Coccconeis costata</i>
<i>Caloneis linearis</i>	<i>Coccconeis sublittoralis</i>
Centric diatom	<i>Corethron hystrix</i>
<i>Cerataulina pelagica</i>	<i>Corethron criophilum</i>
<i>Ceratium trichoceros</i>	<i>Coscinodiscus sp.</i>
<i>Ceratium sp.</i>	<i>Coscinosira polychorda</i>
<i>Ceratium furca</i>	<i>[Thalassiosira auguste-lineata]</i>
<i>Ceratium lineatum</i>	Cyanobacteria filamentous
<i>Ceratium fusus</i>	<i>Dactyliosolen mediterraneus</i>
<i>Ceratium minutum</i>	<i>Detonula confervacea</i>
<i>Ceratium tripos</i>	Dinoflagellate sp.
<i>Ceratium macroseros</i>	Dinoflagellate cysts
<i>Ceratuim longipes</i>	<i>Dinophysis acuminata</i>
<i>Chaetoceros costatus</i>	<i>Dinophysis norvegica</i>
<i>Chaetoceros lorenzianus</i>	<i>Dinophysis sp.</i>
<i>Chaetoceros constrictus</i>	<i>Dinophysis tripos</i>
<i>Chaetoceros difficilis</i>	<i>Dinophysis rotundata</i>
<i>Chaetoceros atlanticus</i>	<i>Dinophysis acuta</i>
<i>Chaetoceros teres</i>	<i>Dinophysis caudata</i>

<i>Diploneis</i> sp.	<i>Licmophora flabellata</i>
<i>Diploneis bombus</i>	<i>Licmophora</i> sp.
<i>Diploneis didyma</i>	<i>Melosira nummuloides</i>
<i>Diploneis crabro</i>	<i>Melosira sulcata</i>
<i>Diplosalis rotunda</i>	<i>Melosira moniliformis</i>
<i>Diplosalis</i> sp.	<i>Melosira westii</i>
<i>Distephanus [Dictyocha] speculum</i>	<i>Melosira</i> sp.
<i>Ditylum brightwelli</i>	<i>Mesodinium rubrum</i>
<i>Donkinia recta</i>	Microflagellate
<i>Donkinia</i> sp.	<i>Navicula lyroides</i>
<i>Eucampia</i> sp.	<i>Navicula</i> sp.
<i>Eucampia groenlandica</i>	<i>Navicula lyra</i>
<i>Eucampia zoodiacus</i>	<i>Navicula elegans</i>
<i>Euglena</i> sp.	<i>Navicula distans</i>
<i>Fragilaria crottonensis</i>	<i>Nitzschia drobakensis</i>
<i>Fragilaria</i> sp.	<i>Nitzschia [Pseudo-nitzschia] seriata</i>
<i>Glenodinium</i> sp.	<i>Nitzschia frigida</i>
<i>Gonyaulax digitale</i>	<i>Nitzschia [Cylindrotheca] closterium</i>
<i>Gonyaulax triacantha</i>	<i>Nitzschia [Pseudo-nitzschia] delicatissima</i>
<i>Gonyaulax polyedra</i>	<i>Nitzschia [Pseudo-nitzschia] longissima</i>
<i>Gonyaulax grindleyi</i>	<i>Nitzschia [Pseudo-nitzschia] pungens</i>
<i>Gonyaulax</i> sp.	<i>Nitzschia paradoxa</i>
<i>Gonyaulax [Alexandrium] tamarensse</i>	<i>Nitzschia</i> sp.
<i>Grammatophora angulosa</i>	<i>Nitzschia pacifica</i>
<i>Grammatophora</i> sp.	<i>Nitzschia debilis</i>
<i>Grammatophora marina</i>	<i>Nitzschia bilobata</i>
<i>Guinardia flaccida</i>	<i>Noctiluca scintillans</i>
<i>Gymnodinium</i> sp.	<i>Oestrupia musca</i>
<i>Gymnodium</i> sp.	<i>Oxytoxum</i> sp.
<i>Gyrodinium</i> sp.	<i>Peridinium [Protoperidinium] ovatum</i>
<i>Gyrodinium fusiforme</i>	<i>Peridinium [Protoperidinium] steinii</i>
<i>Gyrodinium lachryma</i>	<i>Peridinium [Protoperidinium] divergens</i>
<i>Gyrodinium spirale</i>	<i>Peridinium [Protoperidinium] leonis</i>
<i>Gyrosigma prolongatum</i>	<i>Peridinium [Protoperidinium] pellucidum</i>
<i>Gyrosigma balticum</i>	<i>Peridinium [Protoperidinium]</i> sp.
<i>Gyrosigma closteroides</i>	<i>Peridinium [Protoperidinium] depressum</i>
<i>Gyrosigma spencerii</i>	<i>Peridinium [Protoperidinium] bipes</i>
<i>Gyrosigma wansbeckii</i>	<i>Peridinium [Protoperidinium] granii</i>
<i>Gyrosigma</i> sp.	<i>Peridinium [Protoperidinium] crassipes</i>
<i>Halosphaera viridis</i>	<i>Peridinium [Protoperidinium] curvipes</i>
<i>Hemiaulus</i> sp.	<i>Peridinium [Protoperidinium] pentagonum</i>
<i>Hemiaulus membranaceus</i>	<i>Phaeocystis ponchetti</i>
<i>Hemiaulus hauckii</i>	Picoplankton
<i>Hemiaulus sinensis</i>	<i>Plagiogramma</i> sp.
<i>Lauderia</i> sp.	<i>Plagiogramma vanheurckii</i>
<i>Lauderia borealis</i>	<i>Planktonella sol</i>
<i>Leptocylindrus minimus</i>	<i>Pleurosigma aestuarii</i>
<i>Leptocylindrus danicus</i>	<i>Pleurosigma angulatum</i> var. <i>strigosa</i>
<i>Licmophora abbreviata</i>	<i>Pleurosigma angulatum</i>

<i>Pleurosigma carinatum</i>	<i>Thalassiosira gravida</i>
<i>Pleurosigma</i> sp.	<i>Thalassiosira gravida</i>
<i>Pleurosigma normani</i>	<i>Thalassiothrix longissima</i>
<i>Polyasterias</i> sp.	<i>Thalassiothrix nitzschoides</i>
<i>Polyasterias problematica</i>	<i>Thalassiothrix frauenfeldii</i>
<i>Polykrikos</i> sp.	Tintinnids
<i>Prorocentrum lima</i>	<i>Tropidoneis</i> sp.
<i>Porosira glacialis</i>	<i>Tropidoneis antarctica</i>
<i>Prorocentrum scutellum</i>	
<i>Prorocentrum</i> sp.	
<i>Prorocentrum micans</i>	
<i>Prorocentrum minimum</i>	
<i>Rhabdonema arcuatum</i>	
<i>Rhabdonema</i> sp.	
<i>Rhaphoneis</i> sp.	
<i>Rhaphoneis surirella</i>	
<i>Rhizosolenia hebetata</i>	
<i>Rhizosolenia shrubsolei</i> [imbricata]	
<i>Rhizosolenia alata</i>	
<i>Rhizosolenia delicatula</i>	
<i>Rhizosolenia robusta</i>	
<i>Rhizosolenia stolterfothii</i>	
<i>Rhizosolenia gracillima</i>	
<i>Rhizosolenia</i> sp.	
<i>Rhizosolenia setigera</i>	
<i>Rhizosolenia fragilissima</i>	
<i>Rhizosolenia styliformis</i>	
<i>Schroderella delicatula</i>	
<i>Scrippsiella faeroense</i>	
<i>Scrippsiella</i> sp.	
<i>Scrippsiella trochoidea</i>	
<i>Selenastrum westii</i>	
Silicoflagellate	
<i>Skeletonema costatum</i>	
<i>Solenicola setigera</i>	
<i>Stephanopyxis nipponica</i>	
<i>Stephanopyxis turris</i>	
<i>Striatella delicatula</i>	
<i>Striatella unipunctata</i>	
<i>Striatella</i> sp.	
<i>Surirella</i> sp.	
<i>Synedra</i> sp.	
<i>Thalassionema nitzschoides</i>	
<i>Thalassiosira angulata</i>	
<i>Thalassiosira aestivalis</i>	
<i>Thalassiosira rotula</i>	
<i>Thalassiosira nordenskioeldii</i>	
<i>Thalassiosira</i> sp.	
<i>Thalassiosira imbricata</i>	