



Phytoplankton variability in Admiralty Bay, King George Island, South Shetland Islands: six years of monitoring

Elżbieta E. KOPCZYŃSKA

Zakład Biologii Antarktyki PAN, Ustrzycka 10/12, 02-141 Warszawa, Poland
<elzbieta.kopczyńska@yahoo.com>

Abstract: Surface phytoplankton samples were studied quantitatively and qualitatively in February 1996 – November 1998 and January 2003 – November 2005 at the shore and in the center of Admiralty Bay, King George Island. Phytoplankton assemblages showed spring-summer peaks (maxima $4.0\text{--}5.2 \times 10^6$ cells l^{-1}) associated with small variations in low atmospheric pressure, and low velocity winds. They were dominated by nano-sized ($<20 \mu\text{m}$) flagellates and picoplankton ($\sim 2 \mu\text{m}$). The prevalent nanoflagellates were either Prasinophyceae, Cryptophyceae, or Prymnesiophyceae. Diatoms were next in abundance. Of the seven spring-summer diatom blooms, five had initiated at the shore (maximum 9.8×10^5 cells l^{-1} ; November 1998). They were significantly greater than in the open water, and did not spread into the bay centre. Two observed open water blooms did not reach the shore. Diatoms formed up to 44% of the total cells in the period 1996–98; they only formed $<5\%$ in 2003–05. Shore and open water populations differed by diatom dominance structure. Pennates (*Fragilariopsis* spp., *F. cylindrus*, *Pseudo-nitzschia* spp.), and benthic species were prevalent at the shore; centrics (*Thalassiosira* spp., *Chaetoceros socialis*) were most common offshore. In 2003–05 diatoms were relatively impoverished in *Chaetoceros* spp. and the larger ($>20 \mu\text{m}$) *Fragilariopsis* spp. Nano-sized *Thalassiosira* spp. were the winter dominants. Diatom species dominance structure may change at each of the two sites within a month (e.g. shore site: *F. cylindrus* dominant in October '98; *T. gravis* in November '98). Dinoflagellates showed summer increases associated with diatom blooms. Variations in phytoplankton cell concentrations, the species structures between the shore and open waters, and between seasons appear to be related to physical factors: changes in wind velocity and direction, inflow of waters from the Bransfield Strait, ice melting and changes in atmospheric pressure.

Key words: Antarctica, King George Island, coastal zone, phytoplankton.

Introduction

First phytoplankton studies carried out at a permanent station in Admiralty Bay, in the vicinity of the Polish *Arctowski* Station provided quantitative and qualitative information on the seasonal distribution of major algal groups and species (Kopczyńska 1980, 1981, 1996). In the summer season of 1977/78 nanoflagellates

and “monads” dominated the flora numerically and accounted for 75–90% of the cell counts (Kopczyńska 1981). Flagellate peaks were related to windless days and little variation in atmospheric pressure resulting in an enhanced stability of the water column, a necessary condition for retaining algal cells in the optimum light stratum. Studies of diatoms, the less numerous group, revealed a variety of species, the representatives of such genera as *Thalassiosira*, *Fragilariopsis*, *Pseudo-nitzschia*, and *Chaetoceros*. Based on the whole water samples 86 diatom species were identified, with *T. antarctica* Comber being the year round dominant diatom (Kopczyńska 1996, 1999). Shore water collections included some typical benthic diatoms, and net samples revealed the abundance of large diatoms, such as *Corethron pennatum*, *Thalassiotrix antarctica*, and *Rhizosolenia* spp. (Ligowski 1986). A year round study in the period March 1994 – February 1995 (Kopczyńska 1996) confirmed the prevalence of nanoflagellates of the groups Cryptophyceae, Prasinophyceae and Prymnesiophyceae in the annual cycle, and showed that summer phytoplankton maxima were about five-fold greater than those in the summer of 1977/78. The same study (Kopczyńska 1996) revealed the comparative paucity of diatoms of the genera *Fragilariopsis* and *Chaetoceros* in relation to 1977/78.

Phytoplankton assemblages characterized by the summer dominance of unarmoured nanoflagellates are different from most observed in many other coastal localities of the Southern Ocean, where various diatom species are usually prevalent (Hasle 1969; Steyaert 1973; Kopczyńska *et al.* 1986; Kopczyńska *et al.* 2001, 2007).

Phytoplankton studies in Admiralty Bay showed, that the timing of phytoplankton blooms and the sizes of algal peaks were related to variations in the atmospheric and hydrographic conditions (Kopczyńska 1981). It has long been stated, that in the Southern Ocean phytoplankton maxima and succession are highly influenced by the hydrographic conditions, such as currents, surface water stability and ice duration and recession (Hasle 1969; Steyaert 1973). Extensive hydrographic studies in Admiralty Bay documented a great variability of such local factors, as high velocity currents, deep mixing, upwellings, and inflow of water from the Bransfield Strait (Pruszek 1980; Szafranski and Lipski 1982; Catewicz 1984; Rakusa-Suszczewski 1980, 1993). Inflow of fresh water from land (Rakusa-Suszczewski 1996), strong downfall winds and morphology of the bay basin (Rakusa-Suszczewski and Kidawa 1997; Robakiewicz and Rakusa-Suszczewski 1999) may also considerably affect the plankton populations. Nutrients levels in Admiralty bay are high and typical of the Southern Ocean (Samp 1980; Lipski 1987; results obtained in 2004–05 by Nędzarek, personal communication), and thus not likely to limit phytoplankton growth. In Admiralty Bay nutrient concentrations are being continuously enriched by the biogenic dissolved compounds and particulate matter derived from land (Nędzarek and Suszczewski 2004).

Recently documented climatic changes in Antarctica, *e.g.* an increase of the mean annual air temperature in the region of the South Shetland Islands as compared with the 1940-ties (Martianow and Rakusa-Suszczewski 1990; Ackley *et al.*

1996; Rodriquez *et al.* 1996; Rakusa-Suszczewski and Kidawa 1997) might be expected to affect the physical phenomena and hydrographic conditions of the Antarctic coastal areas. These in turn might considerably influence the phytoplankton development, species composition and succession.

Location of Polish *Arctowski* Station on King George Island, South Shetland Islands, at the shores of Admiralty Bay (62°09' S, 58°28' W) provides an excellent opportunity for extensive ecological studies of the entire coastal zone (Rakusa-Suszczewski 1993), including the monitoring of phytoplankton assemblages. This hydrographically dynamic area suggests considerable seasonal and annual variations in the phytoplankton community structure, and in the sizes and timing of the blooms.

For logistic reasons, unfortunately, very few physical and chemical data were obtained at the time of phytoplankton collections (*e.g.* Table 1; wind and atmospheric pressure data for 1996–98, and nutrient measurements for December 2004 – June 2005; Nędzarek, personal communication). However, physical and chemical parameters have been measured in Admiralty Bay extensively several times in the past (Rakusa-Suszczewski 1993) and they provide a good basis for the environmental characteristics of the Bay.

The purpose of the present studies was to examine and compare variations in phytoplankton assemblages in two periods of three years, the 1996–98 and 2003–05. The questions are, whether the quantitative-qualitative compositions of phytoplankton assemblages at the shore and in the open water of the bay are comparable, or different in the consecutive years; what is the timing and sizes of the summer blooms, do they initiate at the shore, or in the open bay, and what are the seasonal successions of dominant species? An attempt was also made to relate the phytoplankton assemblages to the few available environmental parameters.

Materials and methods

The study site. — Quantitative and qualitative phytoplankton studies in Admiralty Bay, King George Island, South Shetland Islands, were carried out in two periods of three years; from February 1996 to November 1998, and from January 2003 to November 2005. Location of the sampling stations (62°09' S, 58°28' W) is shown in Fig. 1. Admiralty Bay is the largest fjord – like bay in the South Shetland Islands, having a free exchange of waters with the Bransfield Strait. The maximum depth varies between 60 m at the shores and 500 m in the centre of the bay. Deep currents generated by tides, frequent upwellings, vertical mixing of the entire water column and current velocities of 30–100 cm s⁻¹ in the 0–100 m surface stratum are characteristic of the bay (Pruszek 1980; Rakusa-Suszczewski 1980, 1993). Distribution of water temperature and salinity values show an absence of distinct thermoclines and pycnoclines (Lipski 1987). Outflow of fresh water from land affects salinity values in the bay. Surface (0–100 m) salinities calculated for the sum-

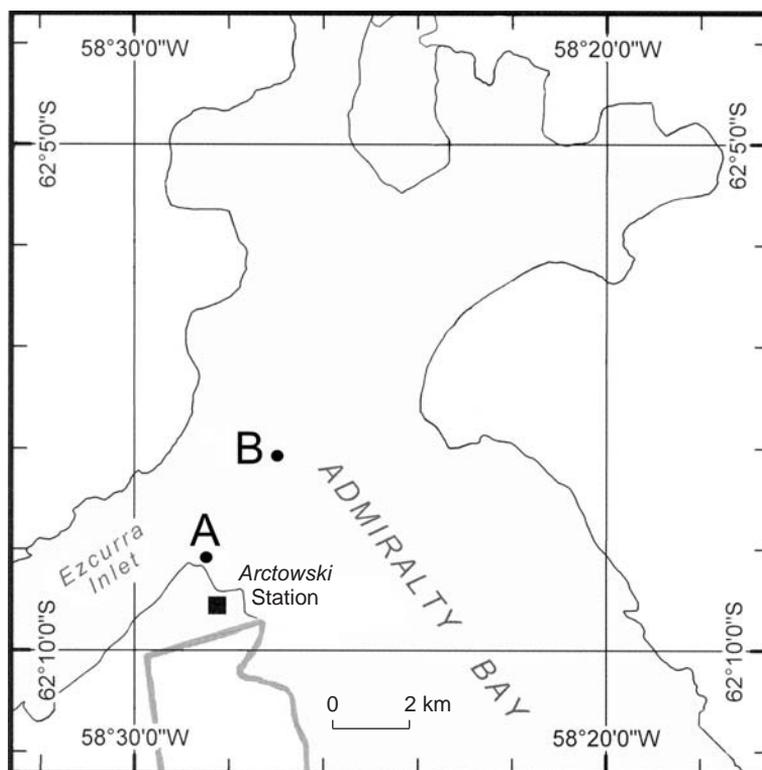


Fig. 1. Location of the sampling stations in Admiralty Bay; A – shore station, B – open water station.

mer periods in the years 1976–89 were lower (mean 33.85 to 34.17) than in the central basin of the Bransfield Strait (mean 34.26 to 34.37), Rakusa-Suszczewski (1996). In the same period summer surface temperatures in Admiralty Bay (mean -0.11 to 0.37°C) were higher than in the centre of the Bransfield Strait (-0.8 to 0.05°C).

There are no continuous records of the water chemistry data for the periods of the present study. Several previous years investigations (Table 1) confirmed the presence of high nutrient concentrations (Lipski 1987). The chemical conditions of Admiralty bay observed once a month in the period December 2004 to June 2005 were typical of the area (Nędzarek, personal communication). Average salinity values in summer (December–March) were 34.2 at the shore, and 34.3 at the centre. Summer silicate concentrations were high and similar at the shore (average: $23.94\ \mu\text{M/litre}$) and in open water ($23.47\ \mu\text{M/litre}$), range 16.43–34.20 $\mu\text{M/litre}$; nitrate+nitrite at both stations ranged 26.27 to 39.76 $\mu\text{M/litre}$; average ammonium: 1.419–1.517 $\mu\text{M/litre}$; phosphate values ranged 1.84–2.52 $\mu\text{M/litre}$; average dissolved iron concentrations were 0.35–0.39 $\mu\text{M/litre}$.

Meteorology data show (Table 1) that low atmospheric pressure ($< 1000\ \text{hPa}$) is characteristic of Admiralty Bay area. In the period 1996–98 the highest winds,

Table 1
Published estimates of physical-chemical data for Admiralty Bay (average values)

Wind velocity (V, m/s) and atmospheric pressure (P, hPa)

	1978-89*		1996 [^]		1997*		1998#	
	V, m/s	P, hPa	V, m/s	P, hPa	V, m/s	P, hPa	V, m/s	P, hPa
January	5.6	991.5	6.3	990.8	5.5	988.4	4.3	985.3
February	6.1	988.7	6.5	989.6	4.0	993.7	5.7	993.9
March	6.7	990.2	6.4	985.7	7.5	990.3	5.7	990.3
April	6.8	991.5	5.3	996.5	5.2	986.2	8.2	994.6
May	6.3	994.0	7.3	986.4	6.1	998.8	5.6	998.5
June	6.9	992.4	6.7	992.9	5.3	1002.7	6.4	996.0
July	6.7	992.7	9.8	990.4	6.1	990.0	6.5	979.4
August	7	992.2	6.9	989.9	6.9	985.6	5.9	986.3
September	7.3	990.9	7.9	995.7	5.9	993.7	5.6	990.2
October	7.8	989.2	8.0	984.9	5.8	991.3	6.3	981.5
November	6.7	986.3	8.3	979.6	5.2	996.6	6.7	984.2
December	5.8	989.4	6.1	988.7	3.6	998.6	5.6	982.5
year	6.4	990.8	7.1	989.3	5.6	993.0	6.0	988.5

Surface water values of temperature and salinity for Admiralty Bay in 1998 #

	open water T (°C)	shore T (°C)	open water S (ppm)	shore S (ppm)
January	1.42	2.14	33.8	34.2
February	1.69	2.27	34.3	34.2
March	1.21	1.82	34.4	34.2
April	0.85	0.45	34.6	33.5
May	0.07	-0.73	34.6	34.4
June	-0.45	-0.44	34.6	33.9
July	-1.21	-1.6	33.9	34.8
August	-1.52	-1.74	34.9	34.0
September	-1.45	-1.95	34.6	35.1
October	-1.45	-1.23	34.7	34.6
November	-0.64	-0.03	34.6	34.7
January–November	-0.03	-0.16	34.4	34.3

Physical-chemical parameters of water (mean values) at standard depths, centre of Admiralty Bay ***

	minimum	maximum	<i>minimum</i>	<i>maximum</i>
T (°C)	-1.9	3.1	-0.2	1.4
Salinity (ppm)	32.0	34.6		
Si µM/litre	73.1	102.0	79.0	86.0
PO4-P µM/litre	0.7	2.8	1.58	2.20
NO3 µM/litre	4.0	34.4	23.0	29.0
NO2 µM/litre	0.01	0.8	0.14	0.18
Chla µg/l	<0.10	2.0		

Source: * Rudka 1997; [^] Kejna and Laska 1997; # Zwolska and Janecki 1999; *** Rakusa-Suszczewski 1993; *italics* (Bojanowski, unpubl. January–February 1978; cited in Kopczyńska 1980).

mostly 6–9.8 m/sec occurred in 1996, and the lowest, <6 m/sec, in the summers of '97 and '98. Data collected during the period November 2003 – November 2004, showed low, but changeable atmospheric pressure (718.4–777.4) (A. Pocięcha, personal communication). Lower winds, from 0.3 to 11.2 m/sec were observed between November 2003 and April 2004, and winds with the maxima of 15–30 m/sec in May–November 2004.

Sampling. — Samples were obtained once to four times a month from 4 m depth at a chosen site in the center of Admiralty Bay, and from 1m depth at the shore. Unfortunately, because of logistic reasons no CTD sampling was done. Collections were made with an open bucket attached to a scaled line. During some winter months, between April and July 1996 and 1997, samples were not taken because of ice cover. No samples were obtained in March 1996 and 1997 at the shore station. In the period 2003–05 samples were not collected in April–June 2003, in April–September 2004, and in May, August, September 2005.

200 ml samples were preserved either with glutaraldehyde – Lugol (final concentration 1%), or with 1% buffered formalin and stored in the dark at 4° C until analysis. Aliquots of 50 ml samples were settled for 24h in an Utermohl-type sedimentation chamber (Utermohl 1958); algal cells were analyzed and counted with a Nikon inverted microscope at 480× magnification. At least 300 cells were examined along 1–4 transects across the counting chamber, and the cell numbers were related to 1 litre volume of water.

Nanoflagellates were examined with a Jenaval Zeiss microscope equipped with an oil immersion objective of 100× magnitude. Care was taken to distinguish the pigmented from the colorless heterotrophic species; they were identified to major groups. Among dinoflagellates in the preserved samples, the obvious heterotrophic species, such as of the genera *Protoperdinium* and *Gyrodinium* (McKenzie and Cox 1991) have been identified. *Prorocentrum* spp. and many of the smaller *Gymnodinium* spp. contain autotrophs. Due to samples preservation and optical resolution, the inverted microscope cell counting technique largely underestimates the picoplankton (<2 µm) sized species.

The following works have been helpful in identification of the algae: Hasle (1965), Priddle and Fryxell (1985), Medlin and Priddle (1990), Sournia *et al.* (1979), Steidinger and Tangen (1997).

Results

Phytoplankton assemblages in 1996–1998

Distribution of phytoplankton cell numbers is shown in Figs 2–5. The combined group of nanoflagellates and picoplankton dominated (71–99%) the assemblages at both stations and in all seasons (Figs 3, 5). Diatoms were next in abundance during summers (average 44% in November 1996) and winters (maximum

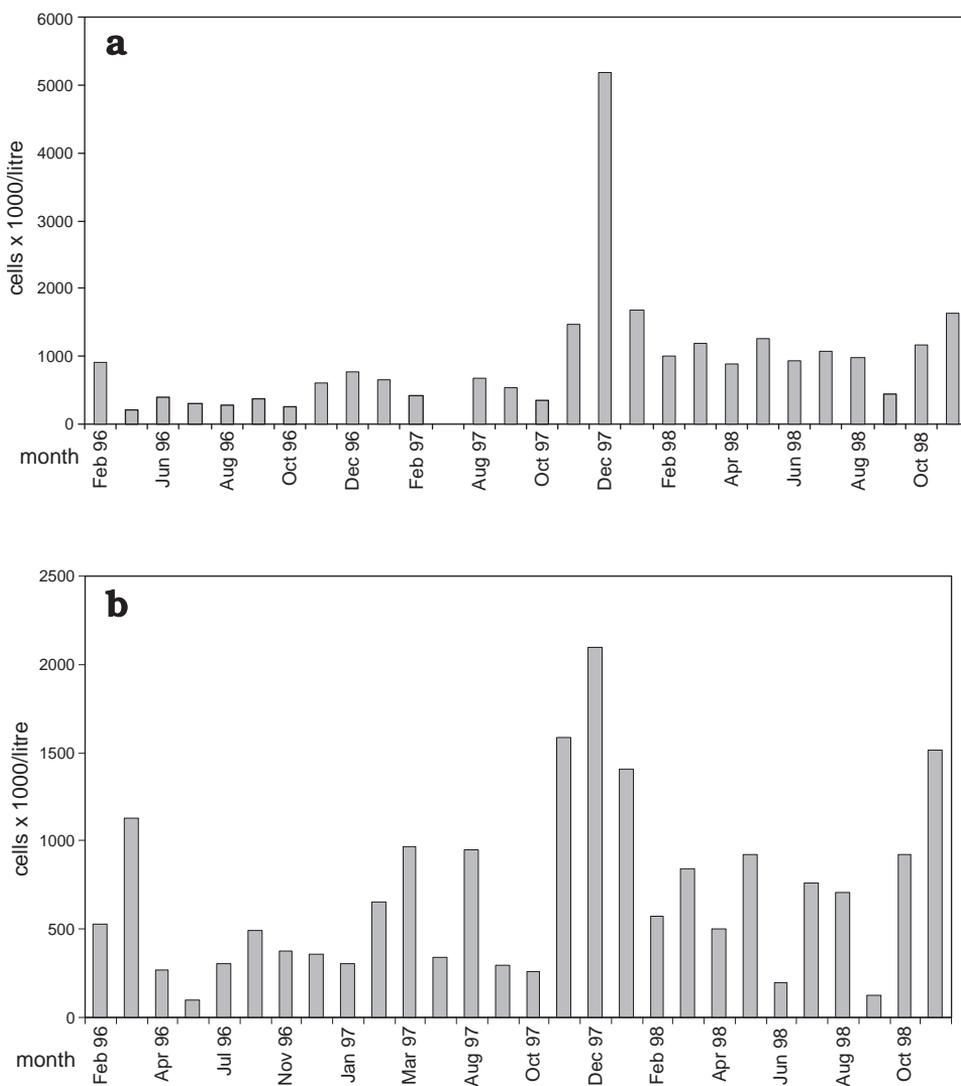


Fig. 2. Admiralty Bay 1996–98. Monthly variations of the surface mean cell concentrations ($\text{cells} \times 10^3 \text{ l}^{-1}$) of total phytoplankton at the shore station (a) and in open water (b). Note differences in scales.

10.8%), Fig. 4; on single summer days (e.g. 7 October and 7 November '98) diatoms reached 54–58% of the cells. Dinoflagellates were either present in very small quantities, or they were not detected at all.

Nanoflagellates. — Nanoflagellates and picoplankton showed distinct peaks during most spring and summer seasons. Their cell concentrations were significantly greater ($p < 0.05$) at the shore site than offshore. Maximum cell numbers were attained in the spring of 1997 (October–December) at both stations; at the shore (at lowest winds) the average count was $2.4 \times 10^6 \text{ cells l}^{-1}$ for the combined

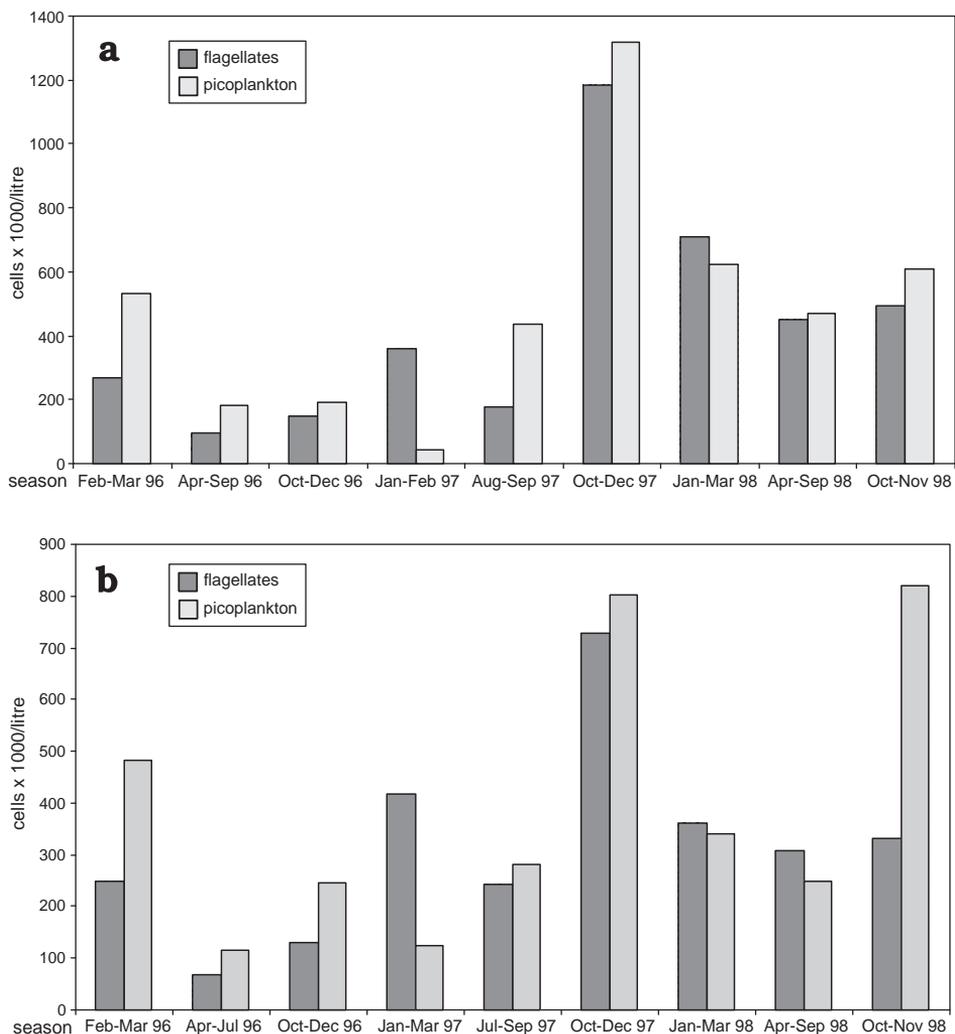


Fig. 3. Admiralty Bay, 1996–98. Seasonal variations of the mean cell concentrations of nanoflagellates and picoplankton at the shore station (a) and open water station (b). Note differences in scales.

group, at the bay 1.5×10^6 cells l^{-1} . The lowest mean quantities of nanoflagellates occurred in winter and spring of 1996; at the shore they were different ($p < 0.05$) than means for the summer seasons of 1997 and the consecutive seasons of 1998.

In 1996 nanoflagellates at both stations (Fig. 3) were composed of Prasinophyceae (maximum 9.7×10^5 cells l^{-1} ; October, open bay), Cryptophyceae, and Prymnesiophyceae and monads (maximum 1.9 – 3.5×10^5 cells l^{-1} ; shore, December).

In the summer of 1997 (January–February, October–December) prymnesiophytes and monads attained peak numbers (1.8 – 2.2×10^6 cells l^{-1}) in December at the shore. They were followed by cryptophytes (bay center; 1.5×10^6 cells l^{-1}), and prasinophytes (2.2 – 3.3×10^5 cells l^{-1}) at both stations in February and December.

In January–March 1998 nanoflagellates were mainly represented by prymnesiophytes and monads (maximum 9.2×10^5 cells l^{-1} ; shore, January). Less abundant were cryptophytes (maximum 2.5×10^5 cells l^{-1} and prasinophytes 3.7×10^4 cells l^{-1} , bay). In November–December 1998 cryptomonads (3.3 – 5.7×10^5 cells l^{-1}) twice exceeded prymnesiophytes.

Diatoms. — Diatom spring–summer blooms in October–December 1996, January–February 1997, and in October–November 1998 (maxima 2.4 to 9.8×10^5 cells l^{-1}) had initiated at the shore and they were twice greater ($p < 0.05$) than the mean quantities observed at the same time in the center of the bay (Fig. 4). In fact, at the latter site diatom cell numbers in 1996 (October–December) and 1998 (October–November) were at the level of those recorded during the preceding winters. No diatom blooms were noted at either station in October–December 1997 when they seemed to be replaced by the peaks of flagellates and picoplankton (Fig. 3). Still another situation was found in January–March 1998 when the mean cell densities in the open water (1.7×10^5 cells l^{-1}) were one order of magnitude larger than at the shore.

In 1996, diatoms (Fig. 4) always included the nano-sized centric species of *Thalassiosira/ Coscinodiscus*. Within this group in summer and winter the most common were *T. antarctica* Comber, *T. gracilis* (Karst.) Hust., and *T. gracilis* var. *expecta* (Van Land.) Fryxell *et* Hasle. Less frequent were *T. frenguelli* Kozlova, *T. tumida* (Jan.) Hasle, *T. ritscherii* (Hust.) Hasle, and *T. lentiginosa* (Jan.) G. Fryxell.

At the shore during November–December 1996 bloom, the species of *Thalassiosira* displayed a peak abundance of 2.9×10^5 cells l^{-1} and contributed 40% to all diatoms. They were somewhat exceeded in quantities by the pennate species of *Fragilariopsis* and *Pseudo-nitzschia* (maximum 3.17×10^5 cells l^{-1} ; 44.3%). *Fragilariopsis* spp. comprised the nano-sized *F. pseudonana* (Hasle) Hasle, *F. cylindrus* (Grun.) Hasle and some of the very small cells of *F. curta* (Van Heurck) Hasle. The less frequently found macro-sized species included *F. kerguelensis* (O' Meara) Hust., *F. angulata* Hasle, and *F. obliquecostata* (Van Heurck) Hasle. *Pseudo-nitzschia* spp. were mainly represented by *P. lineola* Cl. (Hasle), *P. turgiduloides* Hasle and *P. prolongatoides* Hasle. Large cells ($\sim 200 \mu m$) of *Corethron pennatum* Castr. were next in abundance at the shore during spring–summer of 1996 with the highest numbers (5.8×10^4 cells l^{-1}) in November. Summer diatom populations at the shore contained also various other larger species, many of them benthic, such as *Licmophora* spp., *Amphora* spp., *Achnanthes brevipes* (Kützinger) Cleve, *Cocconeis costata* (Gregory) Cleve, *Pleurosigma* sp., *Navicula directa* (W. Smith) Ralfs. At the open water site, some large and rare species included *Thalassiothrix antarctica* Schimper, *Rhizosolenia rhombus* Karsten, *Proboscia alata* (Brightwell) Sundstrom.

Generally, summer 1996 diatom bloom in Admiralty Bay was initiated at the shore in November and was mainly attributed, in the following order of abundance, to *Fragilariopsis* spp. (nano-sized species), *Pseudo-nitzschia* spp., *Thalas-*

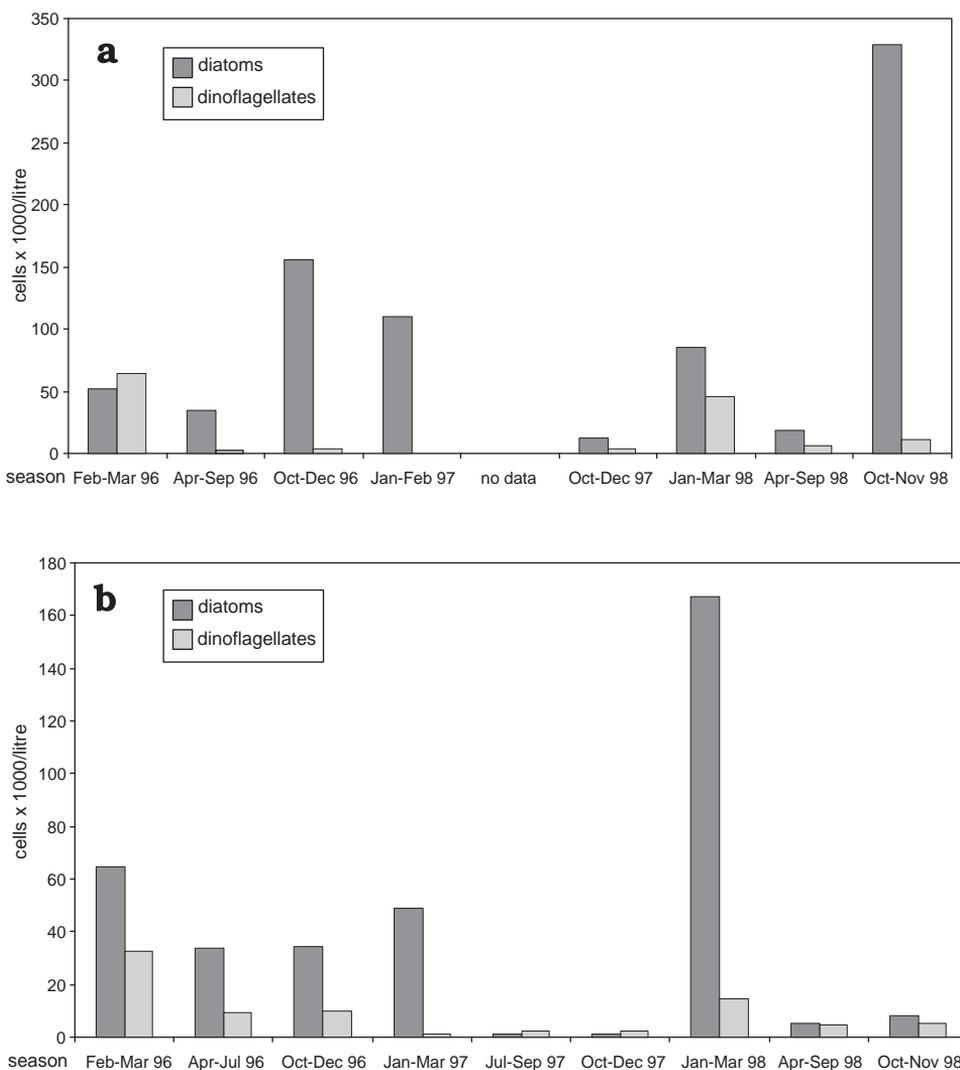


Fig. 4. Admiralty Bay, 1996–98. Seasonal variations of the mean cell concentrations of diatoms and dinoflagellates at the shore station (a) and open water station (b). Note differences in scales.

siosira spp., and *Corethron pennatum* (Grunow) Ostensfeld. The bloom did not spread into the open bay where, at the same time and during the following sampling days, much lower increase of diatoms was observed.

The November–December 1996 diatom bloom continued in January–February 1997; at the shore *Fragilariopsis* spp. and *Pseudo-nitzschia* spp. showed higher cell densities (maximum 1.3×10^5 cells l^{-1} ; 54.5% of all diatoms) than *Thalassiosira* spp. All these diatoms were much less abundant in the open water with *Thalassiosira* contributing about three times as much (average 7.0×10^4 cells l^{-1}) as the pennate species.

The exceptionally poor diatom assemblages at both stations during the next spring–summer period in October–December 1997 contained small and similar for each species quantities of *Corethron pennatum*, *F. curta*, and *Thalassiosira* spp.

Diatom populations increased in abundance in January–March 1998. Contrary to the previous summer seasons, the cell densities were twice as large in the open waters than at the shore (Fig. 4). Peak numbers were displayed in March by *Chaetoceros socialis* Lauder (4.9×10^5 cells l^{-1} ; 87.9% of all diatoms). This species was accompanied by low numbers of *C. tortissimum* Gran. and *Pseudo-nitzschia* spp. (0.58%). At the shore station *C. socialis* was exceeded in quantity by *P. turgiduloides* (1.06×10^5 cells l^{-1} ; forming 37.7% of diatoms) and *P. heimii* Manguin (18%). It is interesting to note, that a month earlier (7–17 February 1998) different *Pseudo-nitzschia* species, (e.g., *P. turgidula* Hust. (Hasle), *P. prolongatoides*), as well as *Thalassiosira tumida* (Janisch) Hasle, and spores of *Thalassiosira* spp. were dominant among diatoms (2.15×10^5 cells l^{-1}) in the open water of Admiralty Bay.

Diatom bloom in October–November 1998 had commenced at the shore. At its November peak (9.8×10^5 cells l^{-1}) it was twice as large as the highest abundance in the open water in March. As in the previous years it did not spread into the center of the bay. At the beginning of October (the 7th), a small diatom ($<10 \mu m$) *Fragilariopsis cylindrus*, typically associated with ice melting was the predominant species; 5.3×10^5 cells l^{-1} ; 97% of diatom cells. A month later (7 November 1998) the dominance structure at the shore had changed; *Thalassiosira gravida* Cleve (maximum 6.7×10^5 cells l^{-1} ; 70.7%), *Navicula* spp. (14.9%) and *Amphora* spp. (13.7%) were the major species. At the same time during the entire October–November sampling period the open waters were nearly devoid of diatoms (Fig. 4b).

In summary, diatom blooms in the spring (October–November) of 1996–98 had developed at the shore, they were twice greater than at the offshore site, and did not spread into the central waters. Peaks at the shore were mainly dominated by the pennate species of *Fragilariopsis* and *Pseudo-nitzschia* spp.; however, the species dominance structure may change within a month (e.g. *F. cylindrus*, *T. gravida* in October–November '98). The only summer bloom in the centre of the bay (January–March '98) was mainly composed of the centric diatom *C. socialis*. It had probably developed in waters inflowing from the Bransfield Strait. It did affect the species composition at the shore, but not the concentration of cells. Also the dominance structure in central waters may change within one month (e.g. *Pseudo-nitzschia* spp. and *Thalassiosira* spp. dominant in February '98; *C. socialis* dominant in March '98).

All the winter seasons of 1996–98 were characterized by small numbers of the centric nano-sized *Thalassiosira* spp.

Dinoflagellates. — This least abundant group (Fig. 4) showed summer increases of cell concentrations associated with diatom blooms. Maxima of 5.1 – 6.4×10^4 cells l^{-1} were recorded on 21 February 1996 at both stations, and the overall peak of 1.4×10^5 cells l^{-1} occurred at the shore on 27 February 1998.

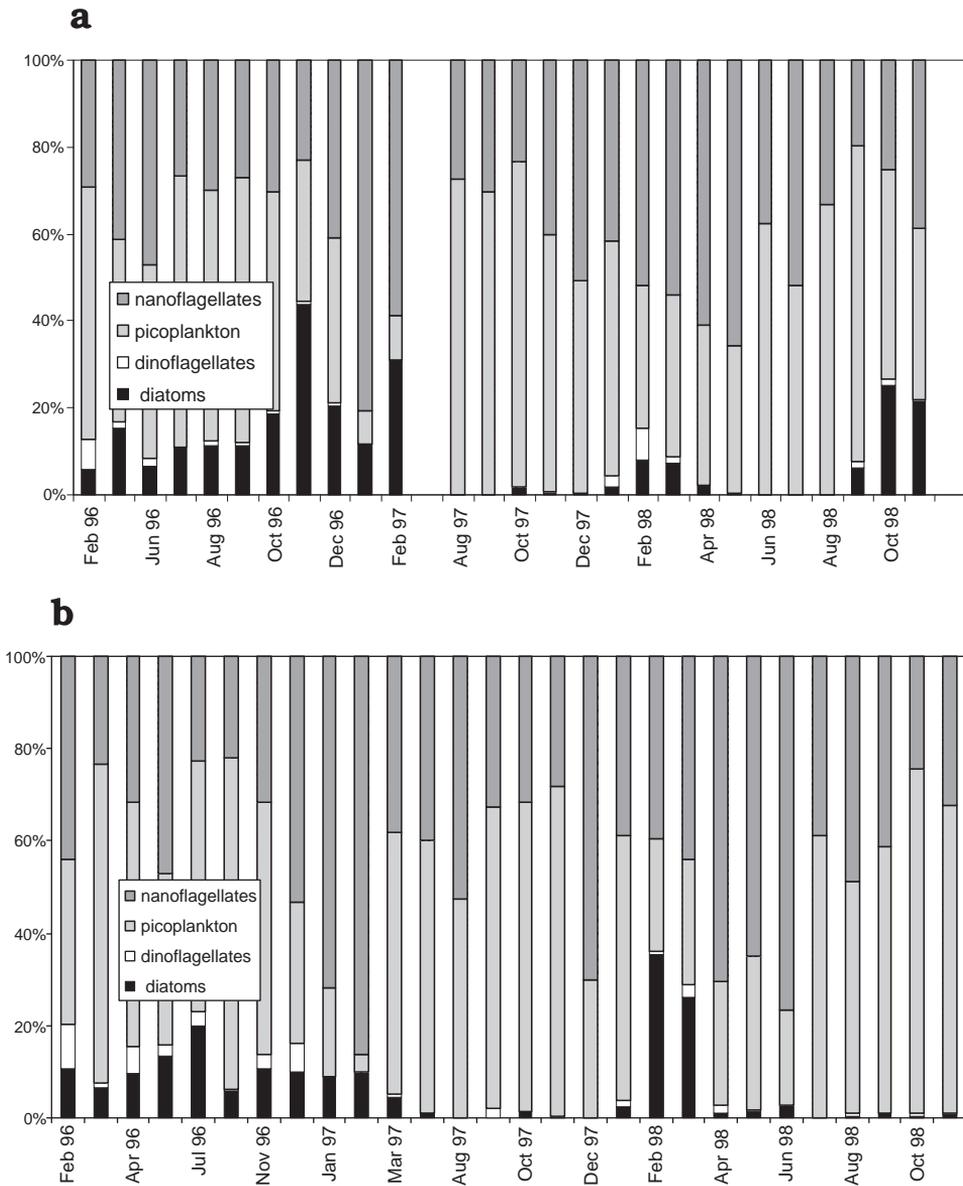


Fig. 5. Admiralty Bay, 1996–98. Monthly average percent contribution of the major phytoplankton groups to total cell concentrations at the shore (a) station and at the open water station (b).

Nano-sized *Prorocentrum* spp. ($\sim 10 \mu\text{m}$) were the most common with the highest numbers ($3.5 \times 10^4 \text{ cells l}^{-1}$) having occurred in February 1996 in the open water. Other most numerous species included the larger ($20\text{--}80 \mu\text{m}$) cells of the heterotrophic *Gymnodinium* spp., *Gyrodinium* spp., *Amphidinium* sp., and *Protoperdinium* spp.

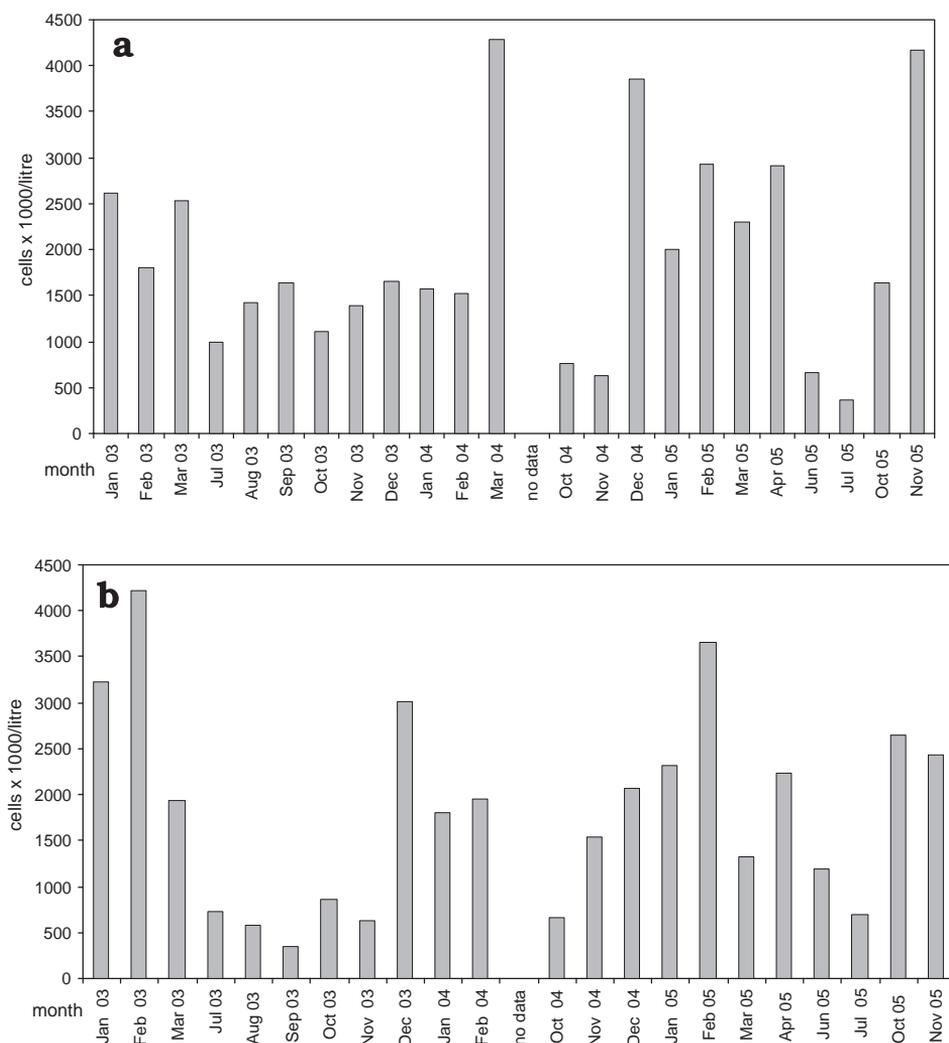


Fig. 6. Admiralty Bay, 2003–05. Monthly variations of the surface mean cell concentrations (cells × 10³ l⁻¹) of total phytoplankton at the shore station (a) and in open water (b).

Phytoplankton assemblages in 2003–2005

As in the period of 1996–98, the total phytoplankton cell numbers were generally greater (>1 × 10⁶ cells l⁻¹) at the shore than in the open water, Fig. 6. Maximum concentrations (~4.0 × 10⁶ cells l⁻¹) were recorded in March 2004, December 2004, and November 2005 at the shore, and in February 2003 in the open water. The dominant group of pico-cells and nanoflagellates (Fig. 7) formed 85–100% of the total cell concentrations (Fig. 9). Among these Prymnesiophyceae and monads were always abundant (maximum 2.9–4.1 × 10⁶ cells l⁻¹, January 2003, both stations). Cryptophyceae showed peaks (maximum 6.4 × 10⁵ and 1.3 × 10⁶ cells l⁻¹) at the

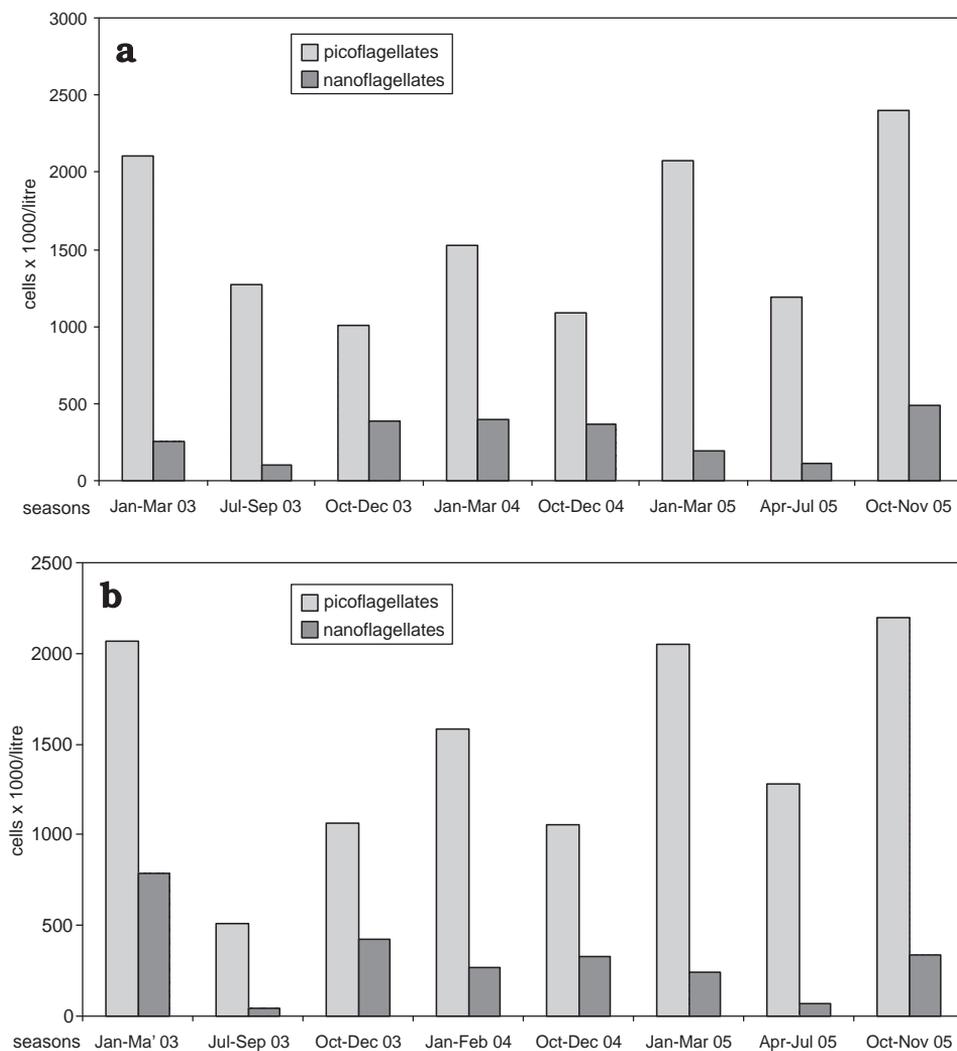


Fig. 7. Admiralty Bay, 2003–05. Seasonal variations of the mean cell concentrations of nanoflagellates and picoplankton at the shore station (a) and open water station (b).

bay and shore in December 2004, and also at the shore in November 2005. *Prasinophyceae* were most numerous ($3.4\text{--}3.7 \times 10^5$ cells l^{-1}) in December 2004, and in January 2003.

Diatoms. — In all the seasons diatoms were generally less abundant than in the period 1996–98 (Fig. 8). They made up $<5\%$ of the total cells, except for February 2004 (shore) when they contributed ca 10% of the phytoplankton (Fig. 9). Diatoms were not detected in samples collected at the shore and bay in September 2003, and unexpectedly they were also absent from both sites in the spring of 2005 (November).

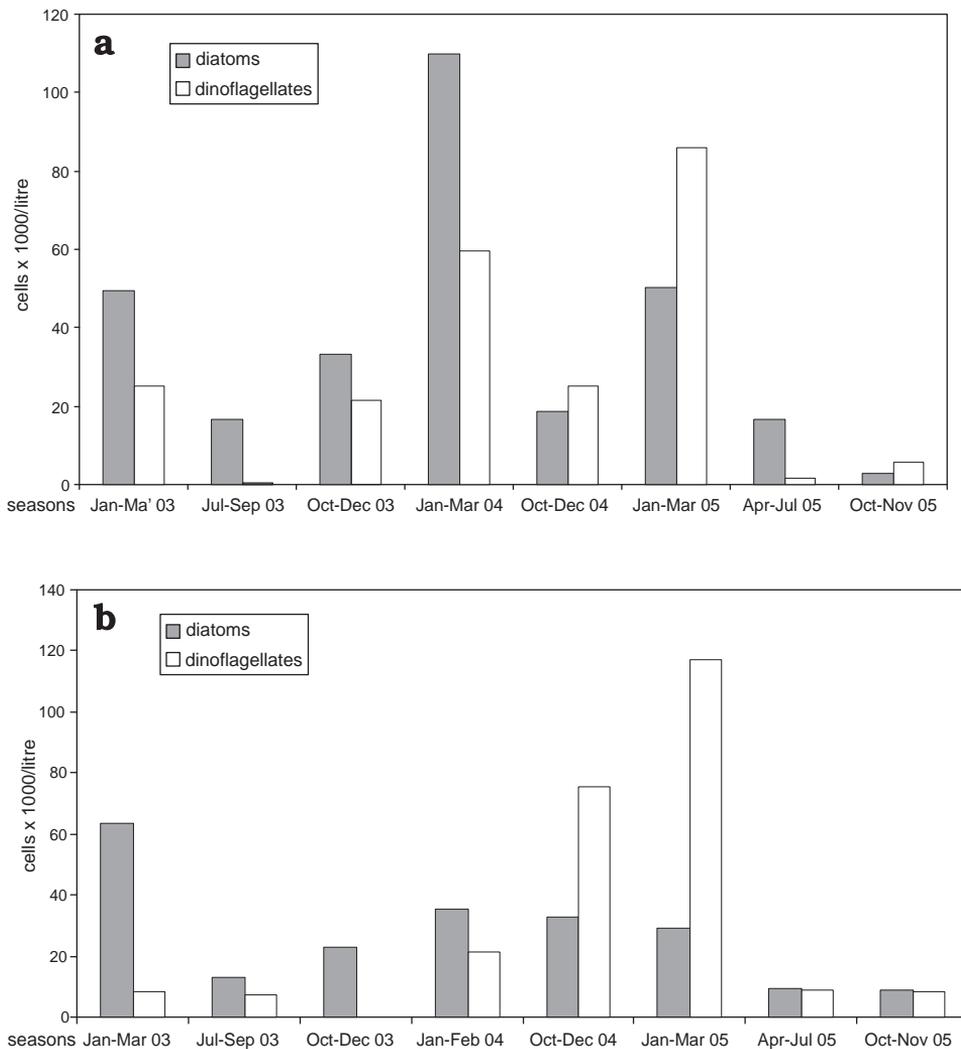


Fig. 8. Admiralty Bay, 2003–05. Seasonal variations of the mean cell concentrations of diatoms and dinoflagellates at the shore station (a) and open water station (b)

Summer peak of diatoms in January 2003 commenced at the bay (1.4×10^5 cells l^{-1} ; January–February average 7.5 – 8.2×10^4 cells l^{-1}); later in March similar concentrations were attained at the shore. The bloom in the open water was attributed to *Corethron criophilum* (= *Corethron pennatum*), *Chaetoceros* spp., *Thalassiosira* spp. and *Nitzschia* spp. The one at the shore was dominated by different species, *Fragilariopsis* spp. Thus open water bloom did not affect diatom development at the shore where independent diatom assemblage had developed.

The highest diatom peak developed in the summer of 2004 (January–March) at the shore (maximum in February; 1.8×10^5 cells l^{-1}). It was attributed to

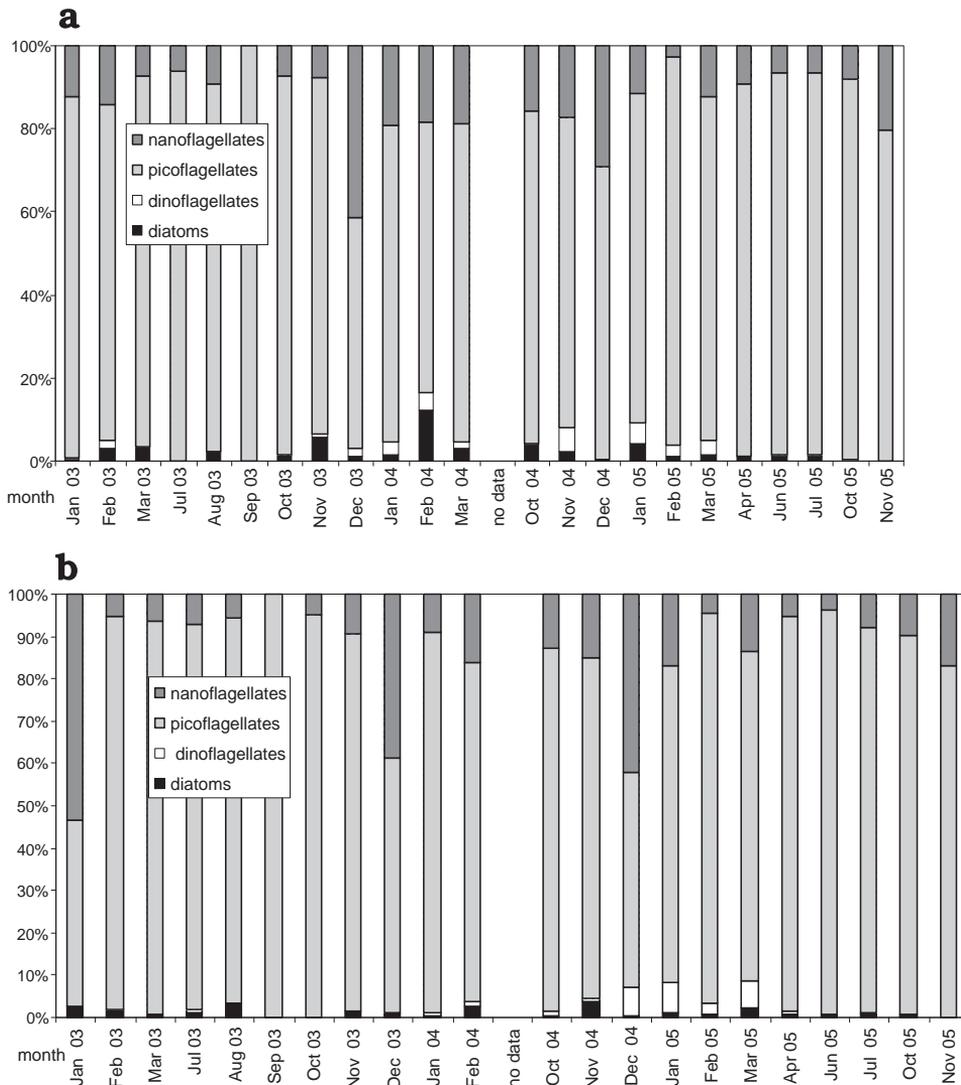


Fig. 9. Admiralty Bay, 2003–05. Monthly average percent contribution of the major phytoplankton groups to total cell concentrations at the shore station (a) and open water station (b).

Thalassiosira spp., *Fragilariopsis pseudonana*, *Nitzschia closterium*, and to various benthic species e.g. *Licmophora* sp., *Navicula* sp., *Cymbella* sp., *Cocconis costata*, *Eucampia* sp. The first three taxa were also found in central waters in much smaller quantities.

The next summer bloom (January–March 2005) initiated at the shore (maximum 1.2×10^5 cells l^{-1} in January) and was of a similar size as in January 2003 in the bay. Diatoms were dominated by *Thalassiosira* spp. and *Corethron pennatum*. The assemblage contained also some benthic species and rare *Fragilariopsis* spp. At the

open bay at the same time (max. 4.0×10^4 cells l^{-1}) dominant were *Thalassiosira* spp. and *Nitzschia* spp., but no *Corethron* was found. *Nitzschia closterium* and *Rhizosolenia* spp., were rarely observed.

In the summers of January–March 2004 and 2005 (at lowest winds), diatom cell concentrations at the shore were up to three fold greater than in the centre.

In winter seasons low diatom populations at both sites mainly contained *Thalassiosira* spp. *Corethron pennatum* was present in higher or fewer numbers in the spring and summers, but not during winters. *Chaetoceros* spp. were only found in January–March 2003 at the open water site.

Dinoflagellates. — They were found in small concentrations (max. 1.3×10^5 cells l^{-1} , February, shore 2005). In the spring-summer of 2004/5 (October–March) they exceeded diatoms at both sampling sites. Small numbers equal to those of diatoms were present in the winter and spring of 2005. The group contained chiefly small gymnodinioid cells, *Prorocentrum* spp., and *Gyrodinium* spp.

Discussion

During the study periods of 1996–98 and 2003–05 nanoflagellates and picoplankton were the numerically dominant phytoplankters in Admiralty Bay, both at low and high cell densities, including nearly all sampling days during summer diatom blooms. Earlier studies in Admiralty Bay and adjacent waters of the Bransfield Strait and Drake Passage gave evidence, that numerical dominance of nanoflagellates at low cell densities was related to deep mixing (~100 m) (Kopczyńska 1992). It follows, that the prevalence of nanoflagellates over other algae can be most likely attributed to very dynamic hydrographic conditions characteristic of Admiralty Bay, *i.e.* strong currents, deep mixing and frequent upwellings (Pruszk 1980; Rakusa-Suszczewski 1993). On the other hand, a greater stabilization of the water column gives rise to algal development, and may give rise to nanoflagellate proliferation in waters with initially poor diatom populations (Kopczyńska 1991, 1992). The highest concentrations of nanoflagellates and picoplankton were recorded at both stations in December 1997, a month characterized by the lowest, for the year, monthly average wind velocity (3.6 m/sec) and small variations in atmospheric pressure (J. Rudka, Meteorological observations for 1997, personal communication). Also total phytoplankton and diatom peak at the shore in January–March 2004 followed the period (November 2003 – April 2004) of lower winds (0.3–11.2 m/sec) records at the bay (Pociecha, personal communication). Similar observations were made during a summer study in 1977/78 in Ezcurra Inlet, Admiralty Bay, which showed (Kopczyńska 1981) that maxima of flagellates were associated with windless days and little variation in atmospheric pressure that resulted in an increased stability of the water column, a necessary condition for retaining algal cells in the optimal light stratum.

Most of the spring-summer diatom blooms (three of the four in 1996–98; October–December 1996, January–February 1997, October–November 1998, and two of the three in 2003–05; February 2004, January 2005) had initiated at the shore, and they did not spread towards the centre. This phenomenon of a diatom bloom being restricted to the shore area might be largely associated with such physical factors, as current and wind velocities and directions. Currents entering the bay from the Bransfield Strait are highly influenced by wind and are known to reach high velocities at the shores (Robakiewicz and Suszczewski 1999). Also northern winds blowing onto shore are frequent and strong in Admiralty Bay area (Kowalski 1985; Zwolska and Janecki 1999), and might hinder the merging of shore diatom blooms with the assemblages in the open water.

The dominance structure of diatoms at the two localities usually differed. Shore blooms in 1996–98 and in March 2003 contained pennates, while central water assemblages included mainly centrics. Shore blooms were dominated by the species of *Fragilariopsis* and *Pseudo-nitzschia*, and were enriched by benthic diatoms, or species originated from ice (e.g. *Fragilariopsis cylindrus*). They also contained low concentrations of the centrics, e.g., *Thalassiosira* spp., *Corethron*. On the other hand, the open water bloom in March '98 was dominated by the centric *Chaetoceros socialis* (87.9% of all diatoms) the likely intruder from the Bransfield Strait, while at the same time at the shore small numbers of the same species were much exceeded by the pennate *Pseudo-nitzschia turgiduloides*, and *P. heimii*. Thus open water bloom had only slightly affected species composition at the shore.

During two seasons (January–February 2004 and January–February 2005) diatom blooms had quite similar species compositions at both sites, the shore and the central waters, and they were dominated by centric diatoms, although some species, e.g. *Corethron pennatum* were only present away from shore. Such composition structure suggests the prevailing influence of the open waters rich in such species as *Thalassiosira* spp. (Kopczyńska, 1996).

All these 6 years observations lead to the conclusion, that shore and open waters diatom populations have usually different sources, and they do not merge entirely. It is clear that different factors affect the development of particular species in the bay. For example the initiation of *Fragilariopsis cylindrus* development at the shore in October 1998 was associated with ice melting. During the preceding period in September, Admiralty Bay was covered with fast ice (Zwolska and Janecki 1999), thus the likely source of *F. cylindrus* (Ligowski 1987, 1998; Fryxell and Kendrick 1988; Kopczyńska *et al.* 2007). The successive November 1998 shore peak of a diatom assemblage dominated by *T. gravida* coincided with an increase of water temperature to + 3.09°C indicative of an inflow of a different warmer water current. A considerable part of the shore populations is made of benthic species; they find easily their way to the plankton as the result of turbulence, strong currents and stormy conditions. Great contribution of the benthic

diatoms to shore populations was also recorded by Lange *et al.* (2007) during their two weeks study of microphytoplankton in Admiralty Bay. Similar observations in the neighbouring Maxwell Bay were made by Kang *et al.* (1997) and Ahn *et al.* (1997).

The peak cell densities at the open bay site (March 1998) coincided with the lowering of water T from + 1.38°C to + 0.98° C, and an increase of water salinity from 33.9 on a previous sampling date to 34.6. These two measurements suggested an inflow of waters from the Bransfield Strait and an introduction of associated diatom species, such as the dominant, at that time, *Chaetoceros socialis*. (This bloom, probably carried by water current and wind, had slightly affected the species composition at the shore.)

Pennate diatoms such as *Fragilariopsis* spp. found here mainly at the shore are typical for the entire Southern Ocean, although are observed to occur in the highest numbers in coastal areas (Kopczyńska *et al.* 1987). *Thalassiosira* spp. are characteristic of open waters in Admiralty Bay (Kopczyńska 1996).

All diatom species found during the two (1996–98, 2003–05) periods of phytoplankton study in Admiralty Bay are typically found in this bay (Kopczyńska 1981, 1996; Ligowski 1998), as well as in the entire Southern Ocean (Hasle 1969, 1976; Stayeart 1973; Kopczyńska *et al.* 1986, 1995; Kopczyńska and Fiala 1998; Kopczyńska *et al.* 2001; Fiala *et al.* 2003). On the other hand, comparisons of the present results with our earliest studies in Admiralty Bay in 1977/78 (Kopczyńska 1980, 1981) reveal the lowering contribution of the larger diatoms (>20 µm) *Fragilariopsis* spp., such as *F. kerguelensis*, *F. obliquecostata*, *F. angulata*, and the almost entire absence of *Chaetoceros* spp. Exceptional are the occasions when such species, e.g. *C. socialis*, may enter the bay with waters inflowing from the Bransfield Strait.

The last years (2003–05) of the monitoring have shown a diminished percentage contribution (<5%) of diatoms in the phytoplankton assemblages. In the previous period 1996–98 diatoms made up to 43–69% of the cell numbers on four single days during different summer seasons. Also the highest diatom numbers noted during the last years (shore peak in February 2004; 1.8×10^5 cells⁻¹) were five fold lower than the maximum diatom concentrations (shore peak 9.8×10^5 cells⁻¹) in November 1998.

In some spring months, such as November 2005, diatoms were not detectable in samples collected at both study sites. One may speculate, that these phenomena might be related to such global changes as the warming of the climate, or an increase of UV in Antarctica (Pociecha, work report for 2003–06), but any explanations of these results would require many years of phytoplankton monitoring and comparisons with complete data sets of hydrology, hydrochemistry and meteorology.

Phytoplankton nutrients in Admiralty Bay are typically high for Antarctic waters, and are not likely to hinder, or limit diatom growth.

Conclusions

Several features are distinguished of the phytoplankton assemblages in Admiralty Bay. One is the overall year round dominance of nanoflagellates and picoplankton observed even on most summer days during diatom blooms. The cell densities fluctuate independently of the season, but summer peaks may occur on windless days and periods of little variations in atmospheric pressure. Anyone of the nanoflagellate groups *i.e.* Cryptophyceae, Prymnesiophyceae, or Prasinophyceae might be numerically prevalent at different summer periods.

Diatom blooms usually initiate at the shore and they are about twice- or three fold larger than in the open bay. Shore blooms do not spread into the bay center and seem to be kept at the shore by strong currents and winds. Less often diatom populations in the open water are greater than at the shore and appear to be seeded by the species (e.g. *C. socialis*) inflowing with waters from the Bransfield Strait. Diatom cell numbers fluctuate considerably during summer seasons and may show at least two peaks in one locality (e.g. shore or open bay in 1998) each separated by a period of about one month. These consecutive maxima in one locality are characterized by a different dominance structure.

Summer diatom populations at the shore and in the open bay differ by the dominance structure. Pennate diatoms (*Fragilariopsis* spp., *Pseudonitzschia* spp.) and benthic species prevail in the shore populations, while centric species (*Thalassiosira* spp., *Chaetoceros* spp., *Corethron pennatum*) dominate in the open waters. However, during some summer periods diatom assemblages might be similar at both sites.

The typical winter diatoms in Admiralty Bay are small (<15 µm) centric *Thalassiosira* spp. which might be accompanied by fewer *Pseudo-nitzschia* spp, or *Corethron pennatum*, and at the shore by some benthic species (e.g. *Achnanthes* spp, *Licmophora* spp).

Thalassiosira spp. form a constant component of the plankton throughout the year.

Dinoflagellates are scarce, but they increase in quantities during summer phytoplankton blooms.

Phytoplankton populations in Admiralty Bay seem to be mainly controlled by physical factors, such as current and wind velocities and directions, turbulence, ice melting, water temperature, atmospheric pressure, degree of water column stability.

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