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Annual study of phytoplankton in Admiralty Bay, King George Island, Antarctica

ABSTRACT: A year-round (3 March 1994 – 28 February 1995) phytoplankton study in Admiralty Bay revealed nanoplankton flagellates (< 20 μm) to be the major algae of the plankton, both in terms of cell numbers and carbon biomass. Their quantities fluctuated widely thoroughly the year showing several peaks, in May, April, December and January. Summer maximum of the group in December was mainly due to Cryptophyceae (4.9×10^6 cells l^{-1}; 98.0 μg C l^{-1}) and Prasinophyceae (7.3×10^5 cells l^{-1}; 33.5 μg C l^{-1}). Diatoms were usually scarce (max. 6.8×10^5 cells l^{-1}; 7.82 μg C l^{-1}) and were dominated by small species of *Thalassiosira* and by *Nitzschia* spp. (*Pseudonitzschia*); the domination structure somewhat differed from that observed in Admiralty Bay in the summer of 1977/78. Algal peaks were related to the surface water (4 m depth) temperature rise from +0.16 to +1.71°C. Summer phytoplankton maxima were about 5-fold greater than those recorded in the summer of 1977/78.

Key words: phytoplankton annual cycle, cell carbon biomass, Antarctica.

Introduction

The first extensive quantitative and qualitative study of phytoplankton in Admiralty Bay was carried out between December 1977 and March 1978 (Kopczyńska 1980, 1981). During that austral summer period the planktonic algae were dominated by naked flagellates (4–15 μm) which accounted for 75–90% of the total phytoplankton numbers. Diatoms were always scarce with maximum numbers (1.5×10^5 cells l^{-1}) found in December after ice breakout. The group was dominated by *Thalassiosira antarctica* Comber and a few species of the genera *Nitzschia* and *Chaetoceros*. Peak flagellate numbers recorded in January and February always followed periods of windless days and stable atmospheric pressure; the increased stability of the water column appeared to be the factor determining the onest of phytoplankton blooms.

A year-round phytoplankton study in Admiralty Bay (Kopczyńska 1992) with samples collected once a month, also showed dominance of flagellates over diatoms with Cryptophyceae and Prasinophyceae being prevalent in summer.

A phytoplankton community structure characterized by the summer dominance of naked flagellates is different from most observed in many other localities of the Southern Ocean, especially in the coastal waters, where various diatom species are usually predominant (Hasle 1969, Steyaert 1973 a, b, Kopczyńska, Weber and El-Sayed 1986, Kopczyńska *et al.* 1995).

In the Southern Ocean seasonal succession of phytoplankton and the timing of phytoplankton maxima are highly influenced by the hydrographic conditions, such as ice duration, surface water stability and currents (Hart 1942, Hasle 1969). Hydrographic studies in Admiralty Bay documented a great variability of such local factors as upwellings, deep mixing, high velocity currents, and an inflow of waters from the Bransfield Strait (Pruszak 1980, Rakusa-Suszczewski 1980, 1993, Szafrański and Lipski 1982, Catewicz 1984, Lipski 1987, Tokarczyk 1987). High nutrient levels in Admiralty Bay are typical of the Southern Ocean (Lipski 1987), but also variable, and in the vicinity of shores are affected by large penguin colonies (Samp 1980, Ballester *et al.* 1987).

The objective of the present study was to gain more information about the annual variation of phytoplankton in Admiralty Bay. Frequent sampling of about three times a month has been carried out for this purpose. This study is first of a planned series of year-round phytoplankton investigations in Admiralty Bay. The questions awaiting answers are whether or not the qualitative — quantitative composition structures of phytoplankton communities are permanent or changeable, are they similar in the shore and open waters, and in the summer blooms of consecutive years. It is our hope that the continuous scientific activity of the Polish *Arctowski* Base will permit such present and future studies.

Materials and methods

Phytoplankton study in Admiralty Bay was carried out in the period 3 March 1994 – 28 February 1995. Samples were collected year-round every 7 to 10 days from 4 m depth at a permanently chosen site in the centre of Admiralty Bay: four samples were taken at 0.5 m depth at the shore. Samples were obtained with an open bucket attached to a scaled line, and/or by a Nansen bottle in the period from December '94 to February '95.

200 ml samples were preserved with 1% buffered formalin; 50 ml samples were settled for 24 hours in an Utermohl-type sedimentation chamber. Algal cells were counted with a Zeiss inverted microscope at 500 × magnification. At least

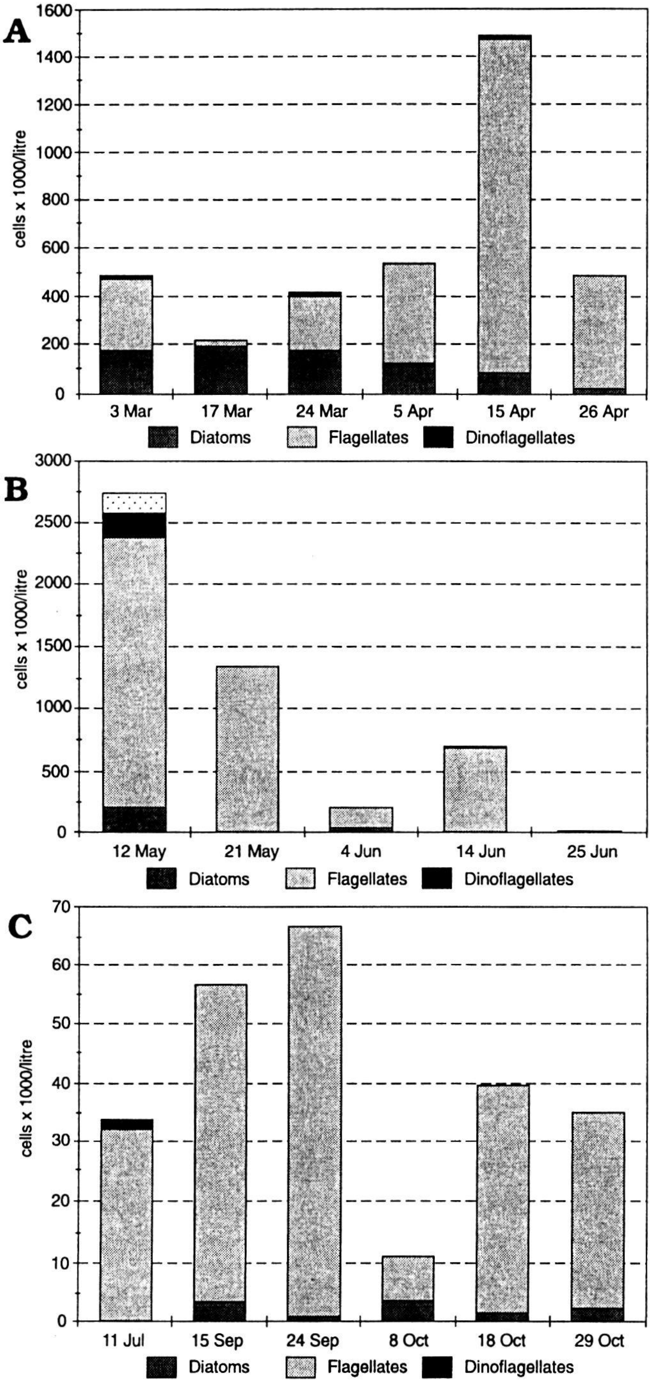


Fig. 1 (A, B, C). Distribution of major phytoplankton groups during austral autumn and winter, March–October 1994, Admiralty Bay. Note the scale changes along y – axis in Figs 1–7.

300 cells were examined and counted along 2–4 transects across the counting chamber, and the numbers were related to the quantities contained in a unit volume of water.

Flagellates 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 colourless heterotrophic species; they were identified to major groups.

Cell carbon biomass was estimated from cell volumes and cell abundancies. Cell volumes were calculated by comparing cell shapes to appropriate geometric figures. The following cell volume to carbon relationships were used for flagellates (Eppley, Reid and Strickland 1970): $\log_{10}C$ (pg) = 0.94 ($\log_{10}V$) – 0.60, and for diatoms: $\log_{10}C = 0.76 (\log_{10}V) - 0.352$.

Results

Seasonal variations in phytoplankton abundance and composition

Unarmoured flagellates. During most months of the year between 3 March 1994 and 6 February 1995 naked flagellates outnambered diatoms and dinoflagellates (Figs 1 A, B, C – 2 A, B, C). In majority of the samples they made up 60 to 99.6% of the total algal numbers. In six summer samples, mainly in February, the group contributed 13–49.4%.

In autumn and winter (Fig. 1 A, B, C) flagellates ranged between 1.5×10^4 (25 June) and 2.2×10^6 cells l^{-1} (12 May). A smaller peak of 1.4×10^6 cells l^{-1} was noted in April. The lowest numbers (6.2×10^3–6.6×10^4 cells l^{-1}) occurred during winter between 25 June and 18 November (Figs 1–2 A).

During summer, beginning with 29 November (Fig. 2 A, B, C) the numbers fluctuated between a minimum of 2.4×10^4 (15 February) and a maximum of 5.8×10^6 cells l^{-1} (12 December). Generally however, the numbers increased from the end of November to a peak in December, declined and multiplied again to another peak of 2.6×10^6 on 28 January (shore station).

Naked flagellates included *Cryptomonas* spp. (6–18 μm), Prasinophyceae (9–12 μm), picoplankton (biflagellates (1.5–3.0 μm), and deflagellated monads (usually 3–10 μm). The latter group contained very likely deflagellated Prasinophyceae.

In winter (Fig. 3 A, B) picoplankton organisms with a peak in May were more numerous than *Cryptomonas*, prasinophytes and monads. During summer (Fig. 4 A) *Cryptomonas* (2–3 species) showed a maximum (4.9×10^6 cells l^{-1}) on 12 December. A peak (7.3×10^5) of prasinophytes occurred on the same date. They were more prevalent (max. 1.7×10^5 cells l^{-1}) than the former group on 28

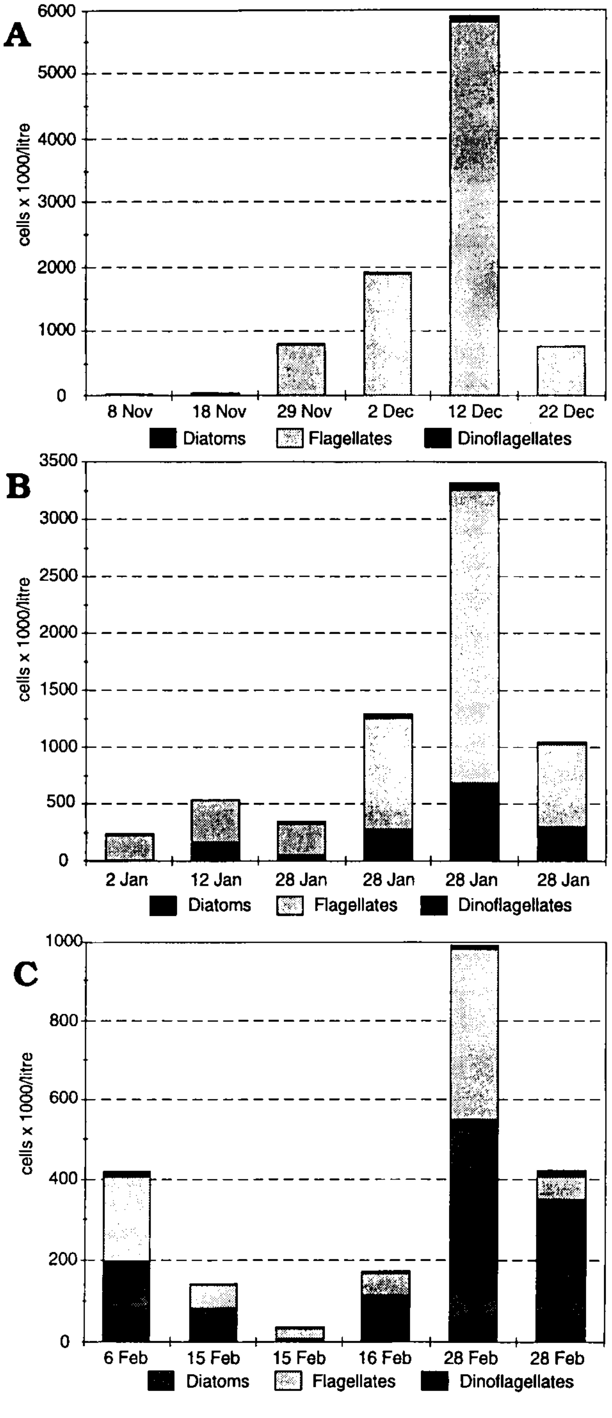
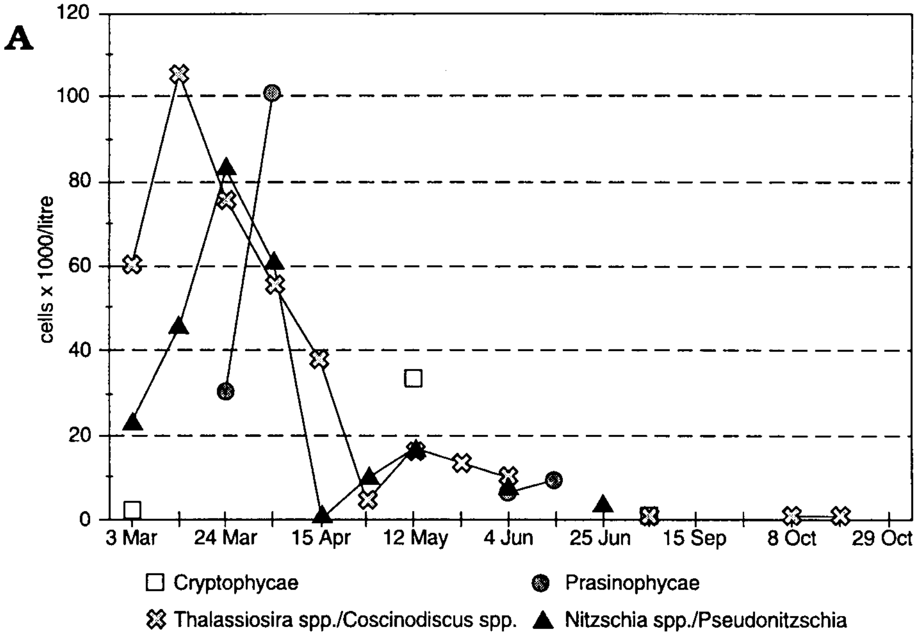


Fig. 2 (A, B, C). Distribution of major phytoplankton groups during austral summer, November 1994 to February 1995, Admiralty Bay.



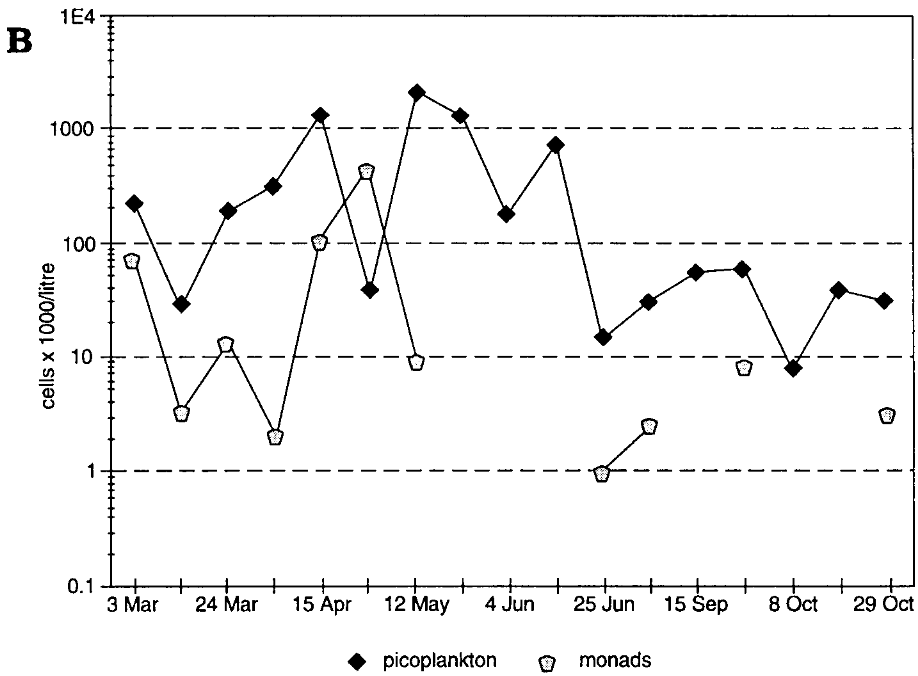


Fig. 3 (A, B). Fluctuations in cell numbers of dominant flagellates (A, B) and diatoms (A) during autumn and winter, March–October 1994, Admiralty Bay.

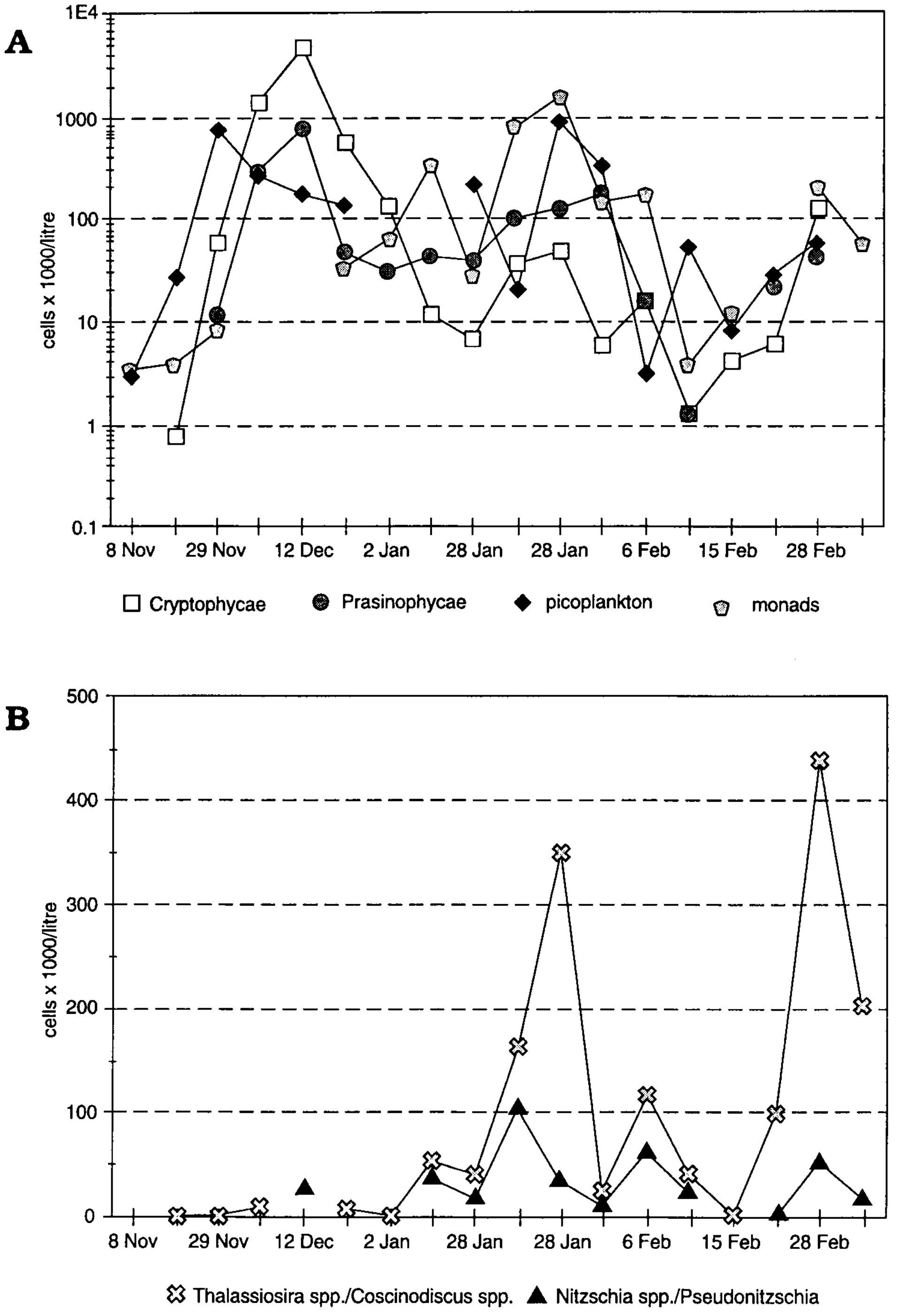


Fig. 4 (A, B). Fluctuations in cell numbers of dominant flagellates (A) and diatom groups (B) during austral summer, November 1994 – February 1995, Admiralty Bay.

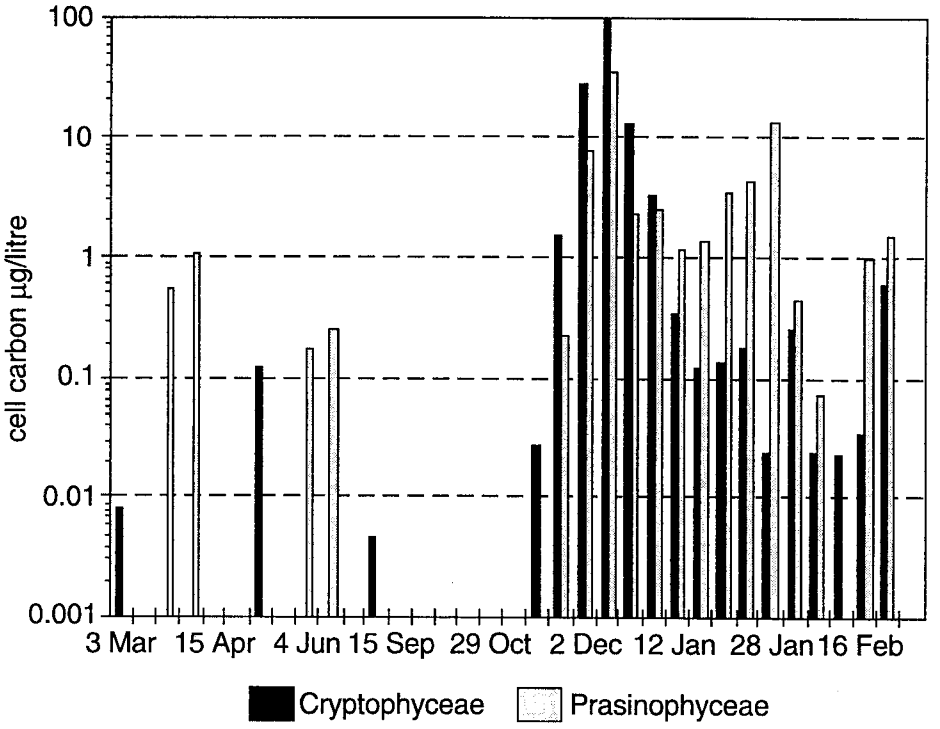


Fig. 5. Contribution to cell carbon by Cryptophyceae and Prasinophyceae, March 1994 – February 1995, Admiralty Bay.

January, however, were exceeded by monads (max. 1.6×10^6) and picoplankton (8.6×10^5 cells l^{-1}).

Diatoms. In most samples diatoms contributed less than 50% (0.99–42%) to the total phytoplankton numbers. In only a few samples taken on various dates (in November, February, March) diatoms made up 55–85.5% of the algae. However, these were not the richest collection in terms of diatom numbers, with the quantities ranging 1.1×10^4 to 1.9×10^5 cells l^{-1}.

In March, April and May (Fig. 1 A, B) diatom cell numbers were less than 2.0×10^5 cells l^{-1}. In winter, between June and 18 November (Figs 1 B, C, 2 A) the numbers were almost always less than 7×10^3 cells l^{-1}. Diatoms were not found on two dates, 14 June and 11 July.

A summer increase (Fig. 2 A) of diatoms was very slow with more significant quantities having occurred between 12 January and 28 February (Fig. 2 B, C). Peak numbers were recorded on 28 January (6.8×10^5 cells l^{-1}) and on 28 February, on the latter date both, at the shore (0.5 m depth; 5.45×10^5 cells l^{-1}) and in open waters of the bay (4 m depth; 3.5×10^5 cells l^{-1}).

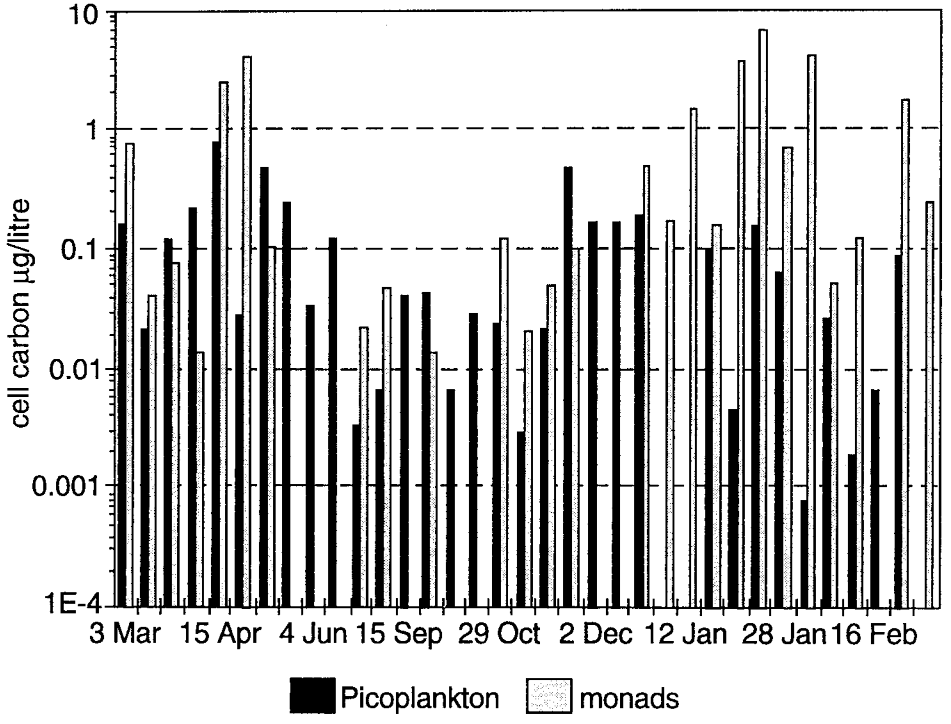


Fig. 6. Contribution to cell carbon by picoplankton (1.5–3 µm) and monads (3–10 µm), March 1994 – February 1995, Admiralty Bay.

Throughout the year diatoms were dominated by *Thalassiosira* spp./*Coscinodiscus* spp. (Figs 3 A, 4 B), followed by *Nitzschia* spp. of the *Pseudonitzschia* group. Peak summer numbers of diatoms were mainly due to these two genera (*Thalassiosira* – 4.4 × 10^5 cells l^{-1} on 28 February; *Nitzschia* – 1.1 × 10^5 cells l^{-1} on 28 January).

Thalassiosira spp. contained chiefly cells of the smaller size 10–12 µm, and were mainly represented by *T. antarctica* Comber, *T. gracilis* (Karst.) Hust. and *T. gracilis* var. *expecta* (Van Land.) Fryxell *et* Hasle.

Nitzschia spp. included in majority *N. prolongatoides* Hasle, *N. turgiduloides*/ /*lineola*, *N. heimii* Manguin, and also small numbers of representatives of the *Nitzschia–Fragilariopsis* group, such as *N. curta* (van Heurck) Hasle and *N. cylindrus* (Grun.) Hasle.

Other diatoms noted in any significant numbers on different dates included: *Chaetoceros socialis* Lauder, *C. neglectum* Karsten and *Corethron criophilum* Castr.

Dinoflagellates. Whenever present the group contributed no more than 0.41–7.2% to the total numbers of the phytoplankton community (Figs 1–2).

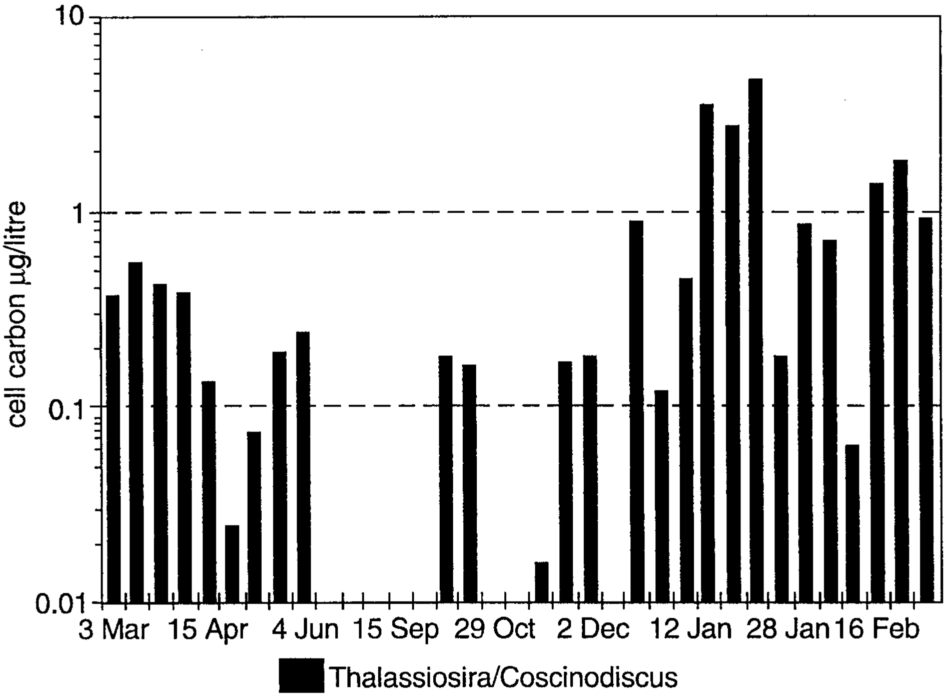


Fig. 7. Contribution to cell carbon by dominant diatoms of the genera *Thalassiosira* and *Coscinodiscus*, March 1994 – February 1995, Admiralty Bay.

Dinoflagellates were absent from single samples in April, May and June, and from all September, October and November collections except one (on 29 November). Peak numbers (2.0×10^5 cells l^{-1}) occurred on 12 May; they were largely due to unidentified species of the genus *Gymnodinium*. Significant numbers were also noted during summer ($1.3–7.7 \times 10^4$ cells l^{-1}) with the maximum recorded on 12 December.

Dinoflagellates contained both autotrophic and heterotrophic species. The former were represented by *Prorocentrum* spp., *Amphidinium* spp., *Gymnodinium* spp. The latter group, conspicuous especially during summer, included larger *Gyrodinium* spp. and *Protoperidinium* spp.

Cell carbon contribution by dominant flagellates and diatoms

Table 1 and Figs 5–7 show that naked flagellates were predominant in terms of cell carbon throughout the entire year. The combined average winter carbon values for Prasinophyceae (0.51 µg C l^{-1}) and monads (0.64 µg C l^{-1}) although small, exceeded ca. 5-fold the carbon value (average 0.23 µg l^{-1}) of the dominant diatoms *Thalassiosira* spp.

Table 1

Average and range of cell carbon values (μg C/l) of major flagellates and diatoms during austral winter and summer in Admiralty Bay.

	Crypthphyceae C (μg/l)	Prasinophyceae C (μg/l)	Picoplankton C (μg/l)	Monads C (μg/l)	*Thalassiosira/ Cosicinodiscus* C (μg/l)
Winter (3 March – 18 November 1994)					
average	0.04	0.51	0.12	0.64	0.23
range	0.004-0.12	0.17-1.08	0.003-0.82	0.01-4.26	0.02-0.56
Summer (29 November 1994 – 28 February 1995)*					
average	9.54	5.06	0.11	1.58	1.22
range	0.02-98.0	0.07-33.47	0.001-0.48	0.05-7.0	0.06-4.63

* Total diatoms at peak abundance on 28 January contributed 7.82 μgC/l.

Cryptophyceae (average 9.54 μg C l^{-1}) and Prasinophyceae (av. 5.06 μg C l^{-1}) provided the major source of phytoplankton cell carbon during summer (Table 1). Their respective maximum values of 98.0 μg C l^{-1} (for cryptomonads) and of 33.5 μg C l^{-1} (for *Pyramimonas*) noted on 12 December, combined together were two orders of magnitude greater than the carbon value estimated for all diatoms (7.82 μg C l^{-1}) at their peak numbers (6.8×10^5 cells l^{-1}) at the end of January 95.

Discussion

The maximum total phytoplankton numbers recorded in Admiralty Bay during summer of 1994/95 were about one order of magnitude greater than those in the austral summers of 1977/78 (Kopczyńska 1980, 1981) and 1981/82 (Kopczyńska 1992). Specifically, the presently noted flagellate peaks in December and January were about 4-fold higher than in 1977/78, and twice as high as in 1981/82. Diatom maxima in January and February 1995 were also 4-fold higher than in 1977, and 2 to 5-fold greater than in 1981/82. The present summer peaks corresponded with a surface (4 m) water temperature rise from +0.16°C on 12 December (flagellate peak) to +1.71°C on 28 January (diatom maximum and second flagellate peak) and +1.15°C on 28 February (second diatom peak). Water temperature data for 1994/95 are given by Rakusa-Suszczewski (1996). Maximum surface water temperatures of +1.1°C to +1.3°C in the summer of 1977/78 (Dera 1979) were lower than in the present study, and thus temperature seems to be one of the important factors affecting the magnitude of all phytoplankton species blooms, including flagellates.

Month to month fluctuations of flagellates appear to be characteristic of Admiralty Bay, as they are of other marine waters whenever the group is present year-round (Smayda 1957, 1980). In the study of 1977/78 flagellate peaks were related to windless days and stable atmospheric pressure resulting enhanced stability of the water column (Kopczyńska 1981). While picoplankton and monads fluctuate throughout the year, Cryptophyceae and Prasinophyceae show distinct summer maxima, both in the present, and in previous studies (Kopczyńska 1992).

The general dominance of flagellates over diatoms, even at low quantities, might be attributed to such factors as selective diatom grazing by krill, and deep mixing of the water column, the latter leading to more favourable light conditions for flagellates' growth as compared to diatoms (Kopczyńska 1992). Deep mixing, upwellings and high velocity currents are characteristic of Admiralty Bay (Pruszak 1980, Rakusa-Suszczewski 1980). Krill and other zooplankton grazing may lead to a shift towards smaller sizes of algal cells within the phytoplankton community (Meyer and El-Sayed 1983, Quetin and Ross 1985).

Presently observed diatom species composition is somewhat dissimilar to that previously reported from Admiralty Bay (Kopczyńska 1980, 1981, Ligowski and Kopczyńska 1993). Nano-size (< 20 μm) *Thalassiosira* species remain dominant, however, the present study revealed comparative paucity of the *Nitzschia–Fragilariopsis* group, as well as of the various *Chaetoceros* spp. Phytoplankton community in Admiralty Bay must be highly affected by phytoplankton compositions of the inflowing waters from Bransfield Strait. The complexities of water masses entering Bransfield Strait from the Weddell and Bellingshausen Seas are discussed by various authors (Patterson and Sievers 1980, Stein and Rakusa-Suszczewski 1983, Tokarczyk 1987, Grelowski and Wojewódzki 1988).

It is interesting to note, that some of the highest cell numbers found in this study were recorded at 2 of the 3 sampled shore stations. This may suggest that blooms may initiate at the shore, and thus more attention should be paid to shore sampling in the future studies.

The highest cell carbon values calculated for summer in Admiralty Bay are contributed by *Cryptomonas* spp. and Prasinophyceae, a situation similar to that observed during ice edge study between Elephant Island and the South Orkneys (Kopczyńska 1991). However, the present maximum values are a few times greater than those recorded at that time in a lens of ice-melt water. On the other hand, the present average values of flagellate carbon are of the order of those estimated for the Drake Passage and Bransfield Strait populations in February – March 1981 and December – January 1983/84 (Kopczyńska 1992).

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Streszczenie

Całoroczne ilościowe i jakościowe badania fitoplanktonu w Zatoce Admiralicji były prowadzone w okresie od 3 marca 1994 do 28 lutego 1995. Dominującą grupą fitoplanktonu w ciagu całego roku, pod względem liczebności komórek i ilości węgla komórkowego, były nanoplanktonowe (< 20 µg) Flagellata (wiciowce) . Znaczne oscylacje tej grupy były widoczne w ciągu całego roku; szczytowe ilości zaobserwowano w maju, kwietniu, grudniu i styczniu. Cryptophyceae (max. 4.9 $\times 10^6$ komórek litr^{-1}; 98.0 µg C l^{-1}) i Prasinophyceae (max. 7.3 $\times 10^5$ komórek litr^{-1}; 33.5 µg C l^{-1}) przyczyniły się najbardziej do letniego zakwitu wiciowców w grudniu. Okrzemek zawsze było niewiele (max. 6.8 $\times 10^5$ komórek litr^{-1}; 7.82 µg C l^{-1}). Dominantami wśród nich były małe gatunki z rodzaju *Thalassiosira* oraz *Nitzschia* spp. (*Pseudonitzschia*). Struktura dominacyjna okrzemek różniła się nieco od tej zaobserwowanej w Zatoce Admiralicji w czasie antarktycznego lata 1977/78. Letni zakwit fitoplanktonu związany był ze wzrostem powierzchniowej temperatury wody od +0.16 do +1.71°C. Ilości komórek w tym czasie były 5-krotnie większe niż latem 1977/78.