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Antarctic Micro- and Nano-sized Phytoplankton Assemblages in the Surface Water of Maxwell Bay during the 1997 Austral Summer

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ABSTRACT. Micro- and nano-sized phytoplankton composition and biomass were investigated in the surface water of Maxwell Bay, Antarctica during the 1997 austral summer. In the micro-sized plankton (>20 μm), benthic diatoms such as *Fragilaria striatula, Licmophora belgicae,* and *Pseudogomphonema kamchaticum* dominated in nearshore, and planktonic diatoms such as *Thalassiosira antarctica* and *Corethron criophilum* dominated in the central zone of the bay (>200 m water depth). Variations in phytoplankton carbon biomass were strongly correlated with Chl *a* concentration. In the nano-sized plankton (<20 μm), *Cryptomonas* spp., *Minidiscus trioculata, Phaeocystis antarctica,* and siliceous cyst dominated in all of the stations. Benthic diatom biomass in surface water was decreased from the nearshore (0.71-5.59 μg C l^{-1}) toward the bay mouth of Maxwell Bay (0.08-1.04 μg C l^{-1}), whereas planktonic diatoms such as *Corethron criophilum* and *Thalassiosira* spp. dominated in the offshore (>1.0 μg C l^{-1}). *Navicula glaciei,* a nano-sized cryophilic diatom, was increased dramatically at stations near glacier cliffs. Nano-sized phytoplankton accounted for 47-86% of total phytoplankton carbons. Although this study was dealt with a day phenomenon, this study emphasizes the importance of benthic diatoms as a major primary producer in nearshore environment.

Key Word: benthic diatom, Maxwell Bay, micro-sized plankton, nano-sized plankton, planktonic diatom,

Introduction

Change of phytoplankton assemblage in Antarctic coastal environments is various during austral summer. The changes are associated with hydrographic characters and physical characters such as local wind and tide effect (Brandini and Rebello 1994). Phytoplankton assemblages in different or changing environments have different representative species. These indicator species help to distinguish hydrographic regimes (Kang and Lee 1995). Also, investigation of ecological structure on species level may help to understand ecological process in nearshore. However, in spite that nano-sized phytoplankton are very important primary producers in the world ocean (Johnson and Sieburth 1982), biomass of nano-sized phytoplankton has been ignored in coastal environment because of their size.

Within the coastal environment, suspended benthic diatoms are important contributor for total primary production (Picken 1985; Klöser *et al.* 1994; Ahn *et al.* 1997), and benthic diatoms are assumed to provide an important food source for benthic animals (Berkman *et al.* 1986; Ligowski 1984). However, distributional patterns of benthic diatoms have been relatively few studies. Maxwell Bay shows open water characters because the bay mouth is open to Bransfield Strait, and shows characters of particular nearshore ecosystems at the same time. Therefore, phytoplankton population is mixed with benthic and pelagic species.

In the present study, phytoplankton biomass, species composition and distributions were investi-

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gated in the surface water of Maxwell Bay. The aim of this study was to observe the dominant species including nano-sized phytoplankton, to understand distributional pattern and importance of them, to understand the relation between physicochemical conditions and distributions of phytoplankton, and to find indicator species as biological parameters to monitor patterns of change of surface water.

Materials and Methods

Environment

Maxwell Bay (62°10'-19' S, 58°35'-58' W) is surrounded by both King George Island and Nelson Island which belong to South Shetland Island (Fig. 1). The bay mouth is opened to southeast so it seems that water mass in the bay is influenced by Bransfield Strait (Chang *et al.* 1990). During the winter, surface water was covering with ice or iceberg were formed on the surface water. In summer, surface ice melts and occasionally drifting ices that come from out of the bay were surged in the bay by wind. Freshwater input also occurs from land and submerged glaciers in summer.

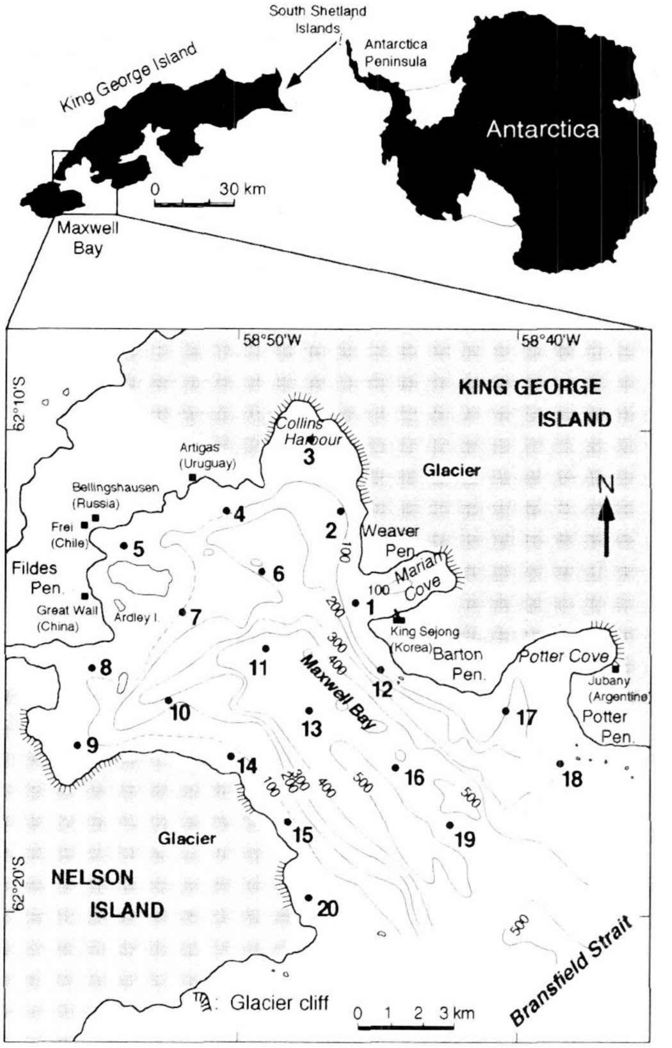

Fig. 1. Location of Maxwell Bay and surface water sampling stations.

Sample collection and measurement of environmental parameters

Surface water assemblages of phytoplankton in the Maxwell Bay were sampled on 3rd January 1997. Surface water samples were obtained from twenty stations (Fig. 1). Salinity and temperature were measured with a Sea-Bird conductivity-temperature-depth (CTD) profiler. Water samples were obtained with 2 l bucket. Aliquots of 125 ml were preserved with glutaraldehyde (final concentration 1%). After samples were returned to the laboratory, sample volumes of 100 ml were filtered through Gelman GN-6 Metrical filters (0.45 μm pore size, 25 mm diameter). The filters were mounted on slide glass with 2-hydroxypropyl methacrylate (HPMA). The HPMA slide counting methods were used for quantitative analysis on cell concentration and biomass (Kang *et al.* 1993).

At least 30 fields or 300 cells were enumerated using a Zeiss Axiophot microscope with a combination of light and epifluorescence microscopy at X400 for microplankton, and at X1000 for autotrophic pico- and nano-plankton (Booth 1993). For species whose identification was not possible under the light microscope, a Philips 515 scanning electron microscope (SEM; Polar Research Center, KORDI) was used. Glass mounted SEM specimens were attached to aluminum stubs and coated with cold-palladium. The photomicrographs were taken by the use of SEM and Carl Zeiss axiophot camera using black-and-white high contrast film (Kodak film, ISO 100 and Kodak verichrome pan film VP-120).

The bacterial cell concentrations were determined by the 4',6-diamidino-2-phenylindole (DAPI) direct count method (Porter and Feig 1980). Ten milliliters

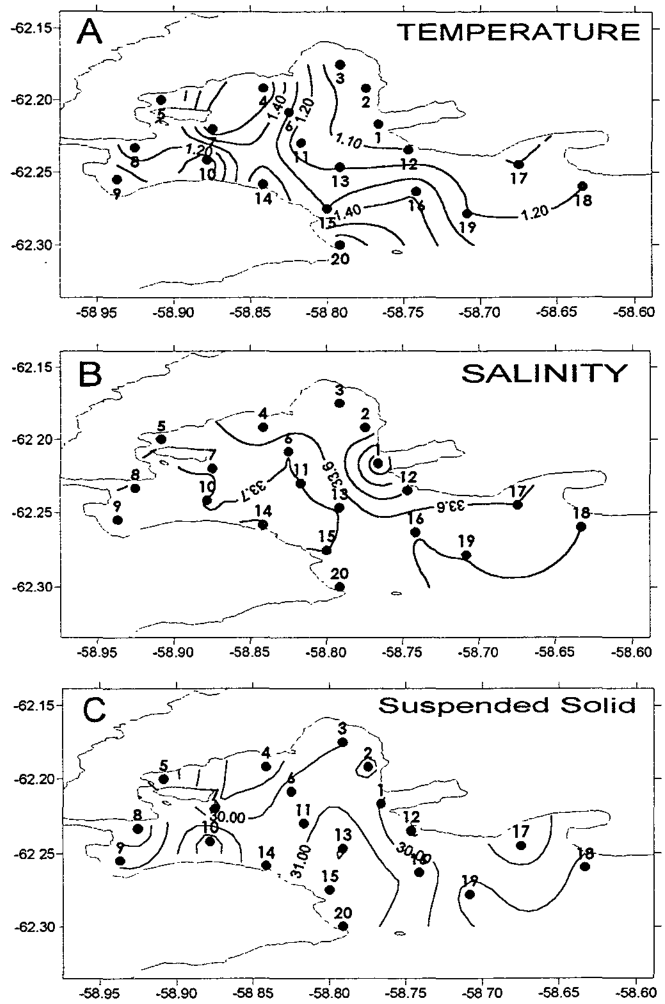

Fig. 2. Hydrography of surface water in Maxwell Bay. A, Temperature; B, Salinity; C, Suspended solid.

of glutaraldehyde-fixed sea water was stained with DAPI, and filtered onto a 0.2 μm black polycarbonate filter, and bacterial numbers were counted under epifluorescence microscopy.

In vivo fluorescence was determined immediately with a Turner Design field fluorometer (Model 10-005R), and converted to Chl *a* by using the correlation between the *in vivo* values and spectrophotometrically measured absolute values. The Chl *a* concentration was estimated spectrophotometrically (Parsons *et al.* 1984). Samples were collected in 25-mm GF/F glass fiber filters and the filters were then left for 12 h in 90 % acetone at 4°C in the dark for pigment extraction.

For suspended solids, one liter of sea water was filtered on pre-dried and weighed GF/F filter, and the filter was dried in 60°C drying oven for 24 h and weighed.

For inorganic nutrients, water samples (500 ml) were filtered through a 47 mm glass fiber filter (GF/F) and the filterates were stored frozen in acid-cleaned polyethylene bottles at -45°C. The samples were kept frozen with dry ice during transport to KORDI. Later in the lab, nutrient concentrations were determined with a Lachat Autoanalyzer.

The SYSTAT 5 statistics package for the Macintosh was used to see the correlations between biological and physicochemical parameters (Pearson correlations) and to extract descriptive summary statistics.

Results

Hydrography

Surface water temperatures varied from 1.0°C at station near a glacier to 1.7°C at the bay mouth (Fig. 2A). Surface water salinity was between 33.2 and 33.7 ppt, with lower values at the mouth of Marian Cove (Fig. 2B). The temperature and salinity values indicated the presence of surface melting water from glacier. Surface water suspended solid was variable between 27.86 and 32.13 mg l^{-1} (Fig. 2C).

Distribution patterns of the dominant phytoplankton species and biomass

Total phytoplankton biomass was variable between stations (Fig. 3A). Phytoplankton cell abundance (PCA) ranged from 15.4x10^5 to 34.9x10^5 cells l^{-1} and phytoplankton carbon biomass (PCB) ranged from 8.14 to 44.8 μg C l^{-1}. Over 38 phytoplankton species were found in Maxwell Bay. Averaged over the entire study area, total PCA was 2.91x10^6 cells l^{-1}, however average of nano-sized PCA was 2.88 x10^6 cells l^{-1} (99% of total PCA). However, nano-sized PCB accounted for 73.3% of toal PCB due to their small cell size (Fig. 3B). Autotrophic nanoflagellates *Cryptomonas criophila* and *Phaeocystis antarctica* (motile) were important carbon contributors among nano-sized phytoplankton (Fig. 4). *Cryptomonas criophila* was relatively high at the bay mouth and absolute concentration of *C. criophila* was decreased towards nearshore stations (Fig. 7D). Although *Pyramimonas* sp., *Minidiscus comicus, M. chilenis,* and

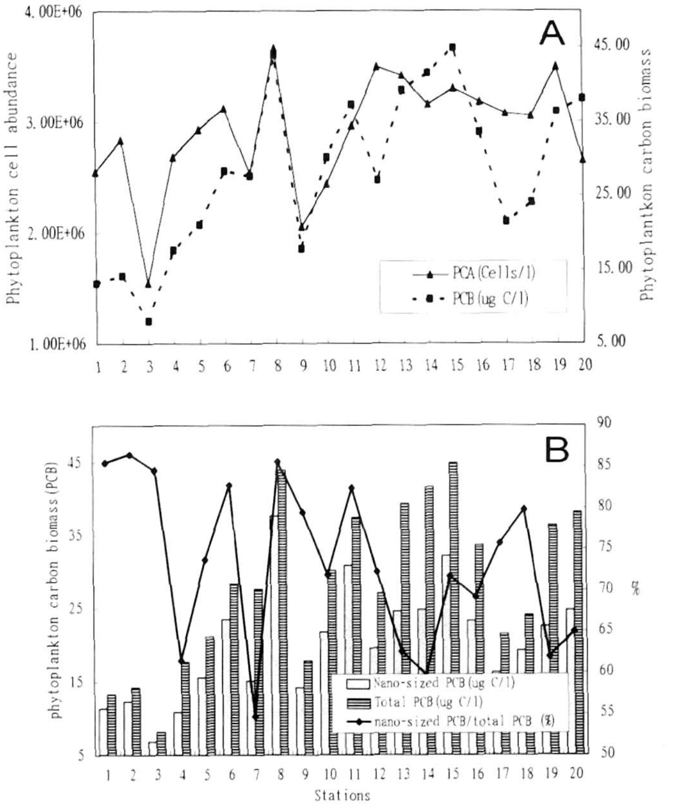

Fig. 3. Abundance and biomass of total phytoplankton (A) and Proportions of nano-sized plankton.

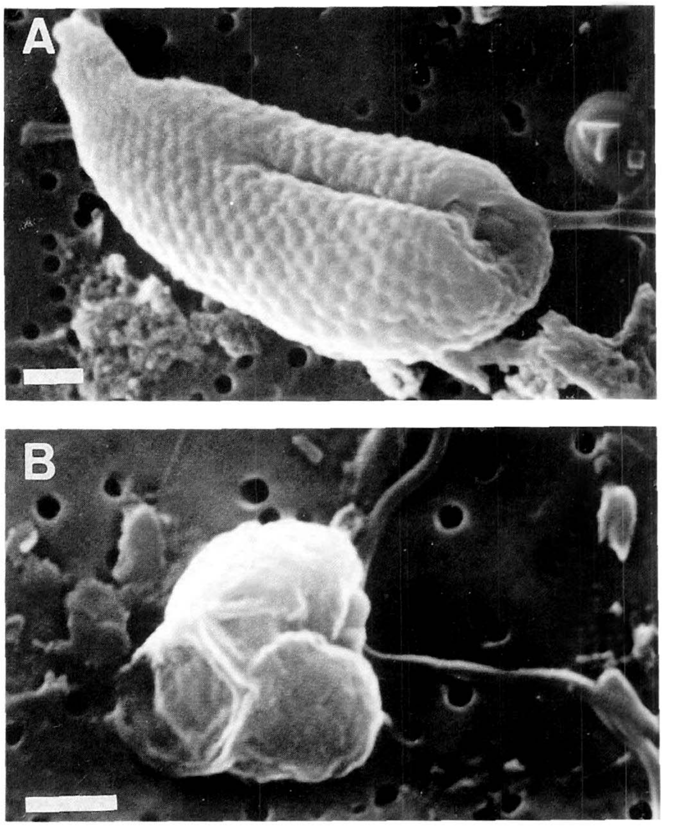

Fig. 4. Scanning electron micrographs (SEM) of nano-sized phytoflagellates. A, *Cryptomonas criophila*; B, *Phaeocystis antarctica* (Scale bars=1 μm).

siliceous cysts were not dominant species, they were observed at all of the stations (Fig. 5).

Species composition varied little among stations, however, dominant diatom species were highly variable between stations. *Navicula glaciei*, nano-sized criophilic diatom, was dramatically increased at the stn. 3, 7, and 15 (Fig. 6B). There were glacier cliffs near these stations. *Corethron criophilum* was abundant at the bay mouth (Fig. 7C). *Thalassiosira* spp. were abundant at the central zone of the bay (Fig. 7B). *Fragilaria striatula*, *Licmophora* spp., and *Pseudogomphonema kamtchaticum* were increased at nearshore stations (Figs 8B, C, and D).

Planktonic diatom carbon biomass (PDCB) was relatively high at the bay mouth and absolute planktonic diatom concentrations were decreased towards nearshore stations (Fig. 7A). Benthic diatom carbon biomass (BDCB) was higher in the nearshore stations (0.27-5.60 μg C l^{-1}) than the bay mouth stations (stn. 13-20) (0.23-1.87 μg C l^{-1}) (Fig. 8A). The proportion of benthic diatoms also decreased towards the bay mouth from 30.9-74.3 to 1.4-13.9% of total diatoms. Figure 9 shows common benthic diatoms in Maxwell Bay.

Relationship to bacterial carbon biomass, Chl a, and nutrients

Bacterial carbon biomass (BCB) ranged from 11.66 to 16.73 μg C l^{-1} in the surface water. A positive correlation was found between BCB and PCB (Fig. 10A and Table 1). Mean BCB (14.3 μg C l^{-1}) was lower as compared to the values of BCB in Bransfield surface water reported by Lee *et al.* (1997) (27.4 μg C l^{-1}). In contrast to the relatively high BCB at the bay mouth, BCB and PCB were low at stn. 1-3 (Fig. 10B).

Chl *a* concentrations ranged from 0.62 to 2.0 μg l^{-1}. Chl *a* concentrations were significantly correlated with the PCB (Table 1). Mean Chl *a* concentrations (1.32 μg l^{-1}) was lower than mean Chl *a* concentrations of Bransfield surface water reported by Lee *et al.* (1997).

Nutrient concentrations were relatively high in overall stations (Fig. 11). Ammonia concentrations ranged from 1.72 to 2.89 μM. Distributions of

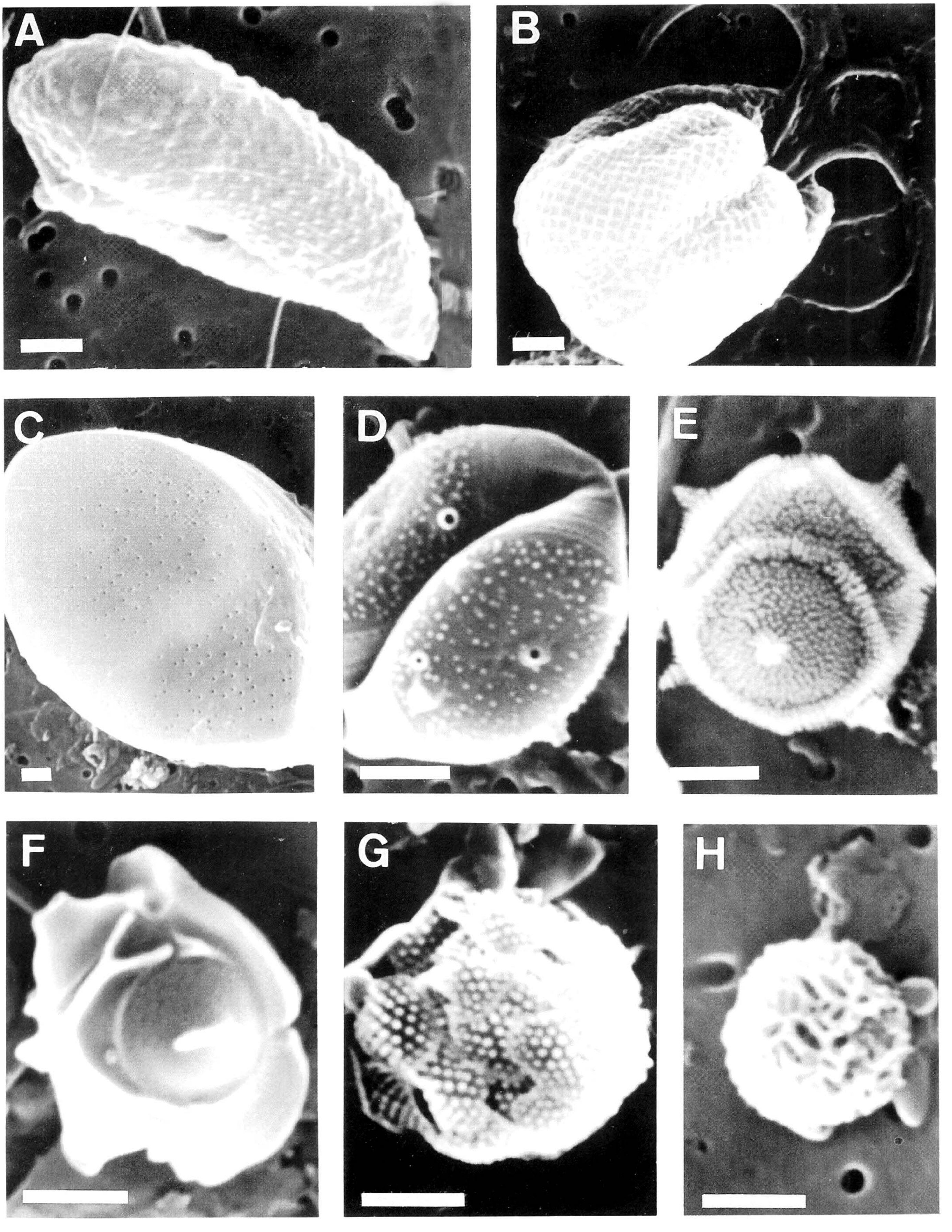

Fig. 5. Scanning electron micrographs (SEM) of nano-sized phytoplankton from the surface water samples. A, *Cryptomonas criophila*; B, *Pyramimonas* sp.; C, *Fragilariopsis angulata*; D, *Minidiscus comicus*; E and F, Siliceous cysts, G and H, Coccolithopholids (Scale bars=1 μm).

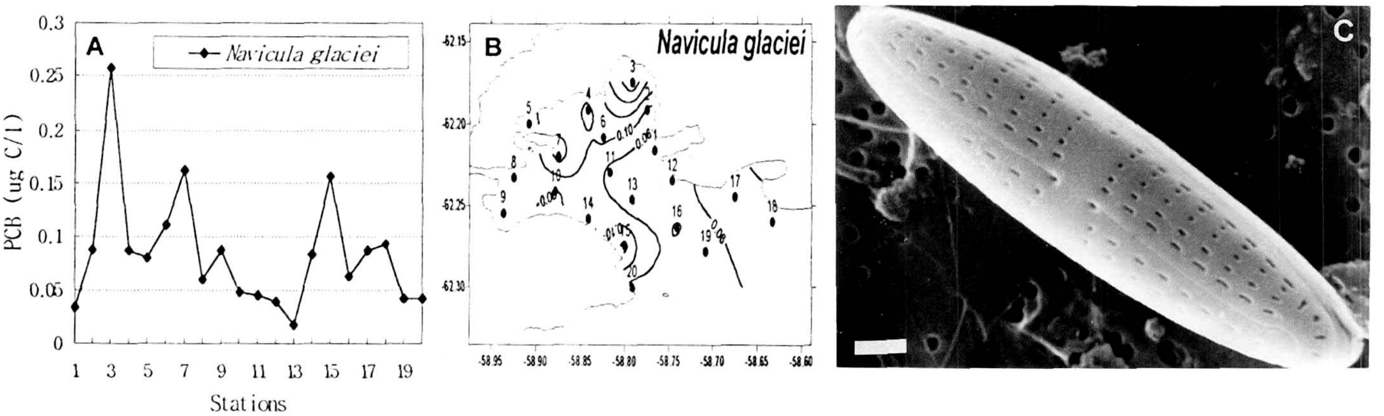

Fig. 6. Carbon biomass of *Navicula glaciei* and (C) photomicrograph by the use of SEM.

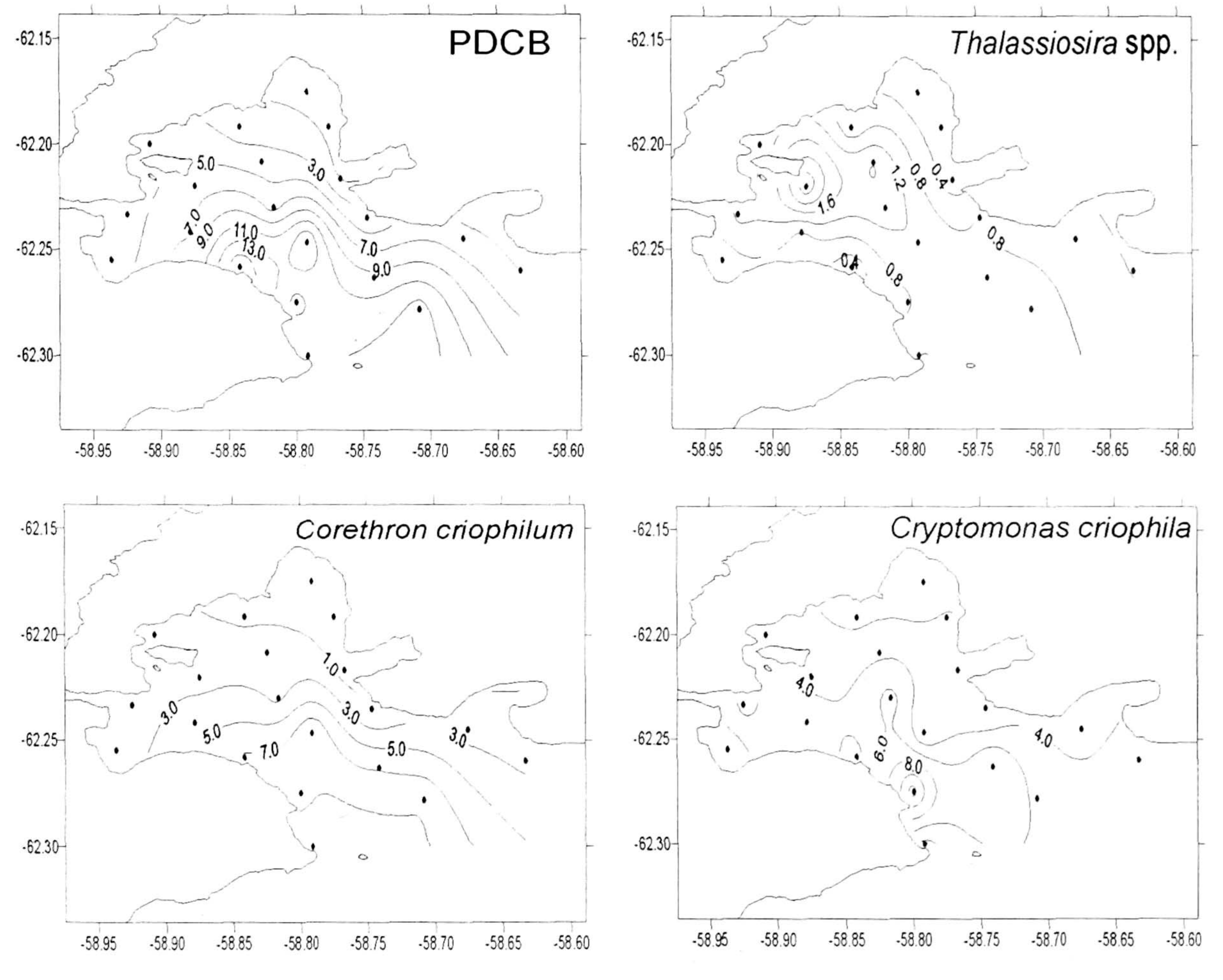

Fig. 7. Carbon biomass of planktonic species in the surface water of Maxwell Bay. A, Total planktonic diatom carbon biomass; B, *Thalassisira* spp.; C, *Corethron criophilum*; D, *Cryptomonas criophila*.

Ammonia concentrations were negatively correlated with the PCB. Nitrite and nitrate concentrations ranged from 0.33 to 0.42 μM and from 2.90 to 33.51 μM, respectively. Silicate and phosphate concentrations ranged from 50.84 to 69.90 μM and from 1.4 to 2.14 μM, respectively. Distributions of nitrite, nitrate, silicate, and phosphate concentrations were not significantly correlated with PCB (Table 1). However, nutrient concentrations of stn. 13-15 where overall PCB was relatively higher were low. The trend of PCB maxima and nutrients concentration minima at stn. 13-15 indicates nutrient uptake by phytoplankton. Most dominant species at these stations was micro-sized diatom, *Corethron criophilum* (Fig. 12E).

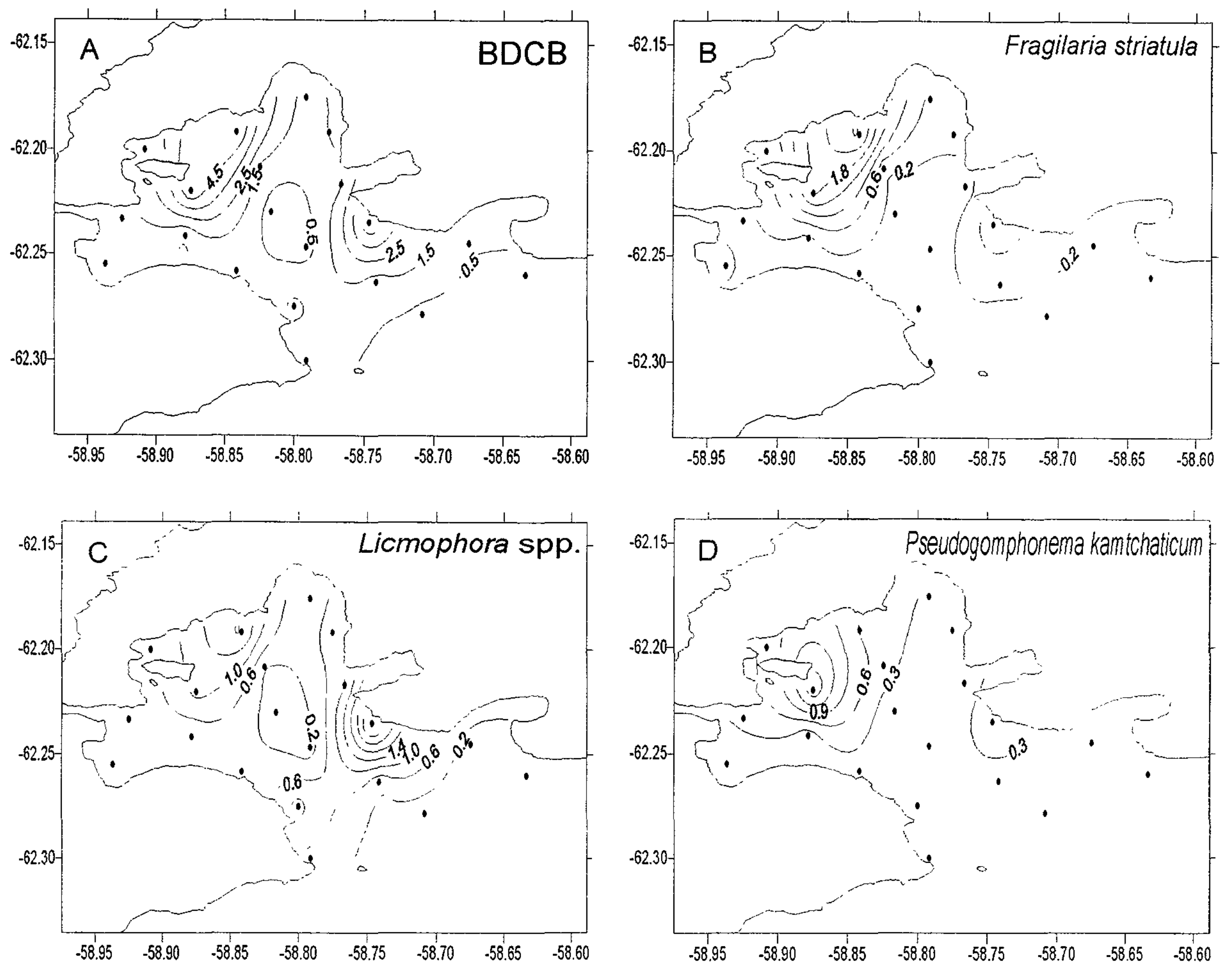

Fig. 8. Typical benthic diatom carbon biomass in the surface water of Maxwell Bay. A, Benthic diatom carbon biomass; B, *Fragilaria striatula*; C, *Licmophora* spp.; D, *Pseudogomphonema kamtchaticum*.

Table 1. Pearson correlation matrix of biological or environmental parameters

	PCB	CHL	BCB	TEMP	SAL	SS	SiO_4	N/P ratio	NH_4	NO_2	NO_3	PO_4
PCB	1											
CHL	0.869	1										
BCB	0.572	-	1									
TEMP	-	-	0.529	1								
SAL	0.575	0.574	0.472	-	1							
SS	-	-	-	-0.842	-	1						
SiO_4	-	-	-	-	-	-	1					
N/P ratio	-	-	-0.559	-	-	-	-	1				
NH_4	-0.551	-0.709	-	-	-	-	-	-	1			
NO_2	-	-	-	-	-	-	0.575	-	-	1		
NO_3	-	-	-0.518	-	-	-	-	0.884	-	-	1	
PO_4	-	-	-	-	-	-	-	-	-	-	-	1

Discussion

Nano-sized phytoplankton was dominated in overall stations and was more important primary producer than micro-sized phytoplankton. Kang *et al.* (1997) observed environmental factors which affect on seasonal variations of microalgal structure such as species composition, biomass, size and succession in Marian Cove, Antarctica from 1 January to 31

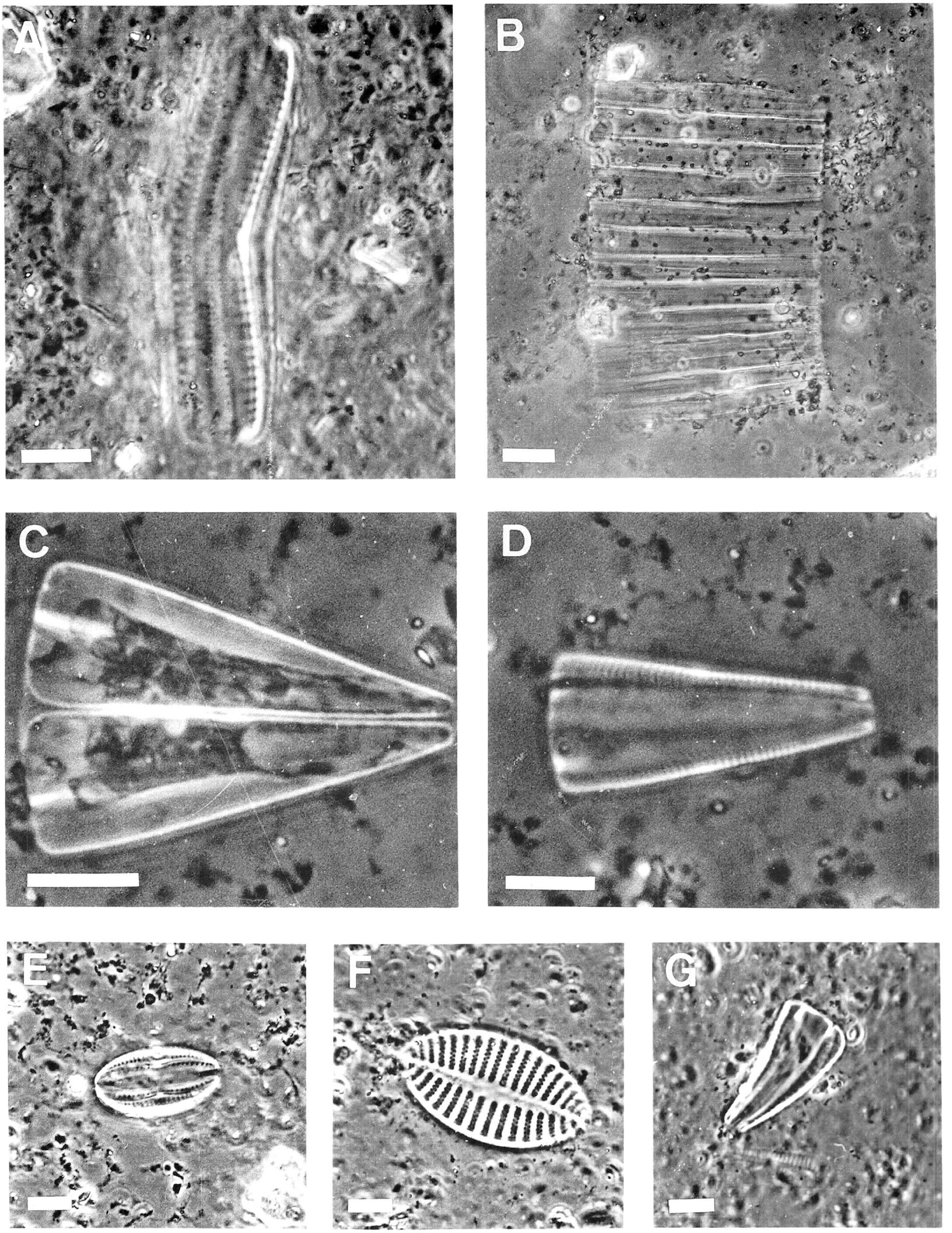

Fig. 9. Light micrographs (LM) of benthic diatoms from the surface water samples. A, *Achnanthes* sp.; B, *Fragilaria striatula*; C, *Licmphora antarctica*; D, *Pseudogomphonema kamtchaticum*; E, *Amphora* sp.; F, *Cocconeis costata*; G, *Rhoikosphenia* sp. (Scale bars=10 μm).

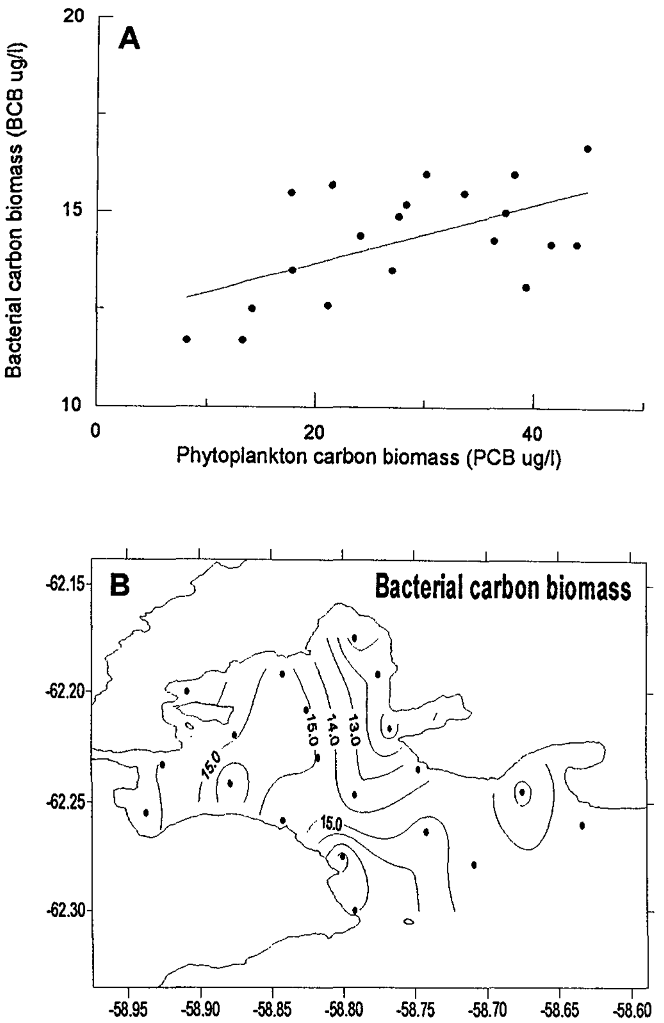

Fig. 10. Bacterial carbon biomass (A) Correlation with bacterial carbon biomass and phytoplankton carbon biomass, (B) Distribution of bacterial carbon biomass in the surface water of Maxwell Bay.

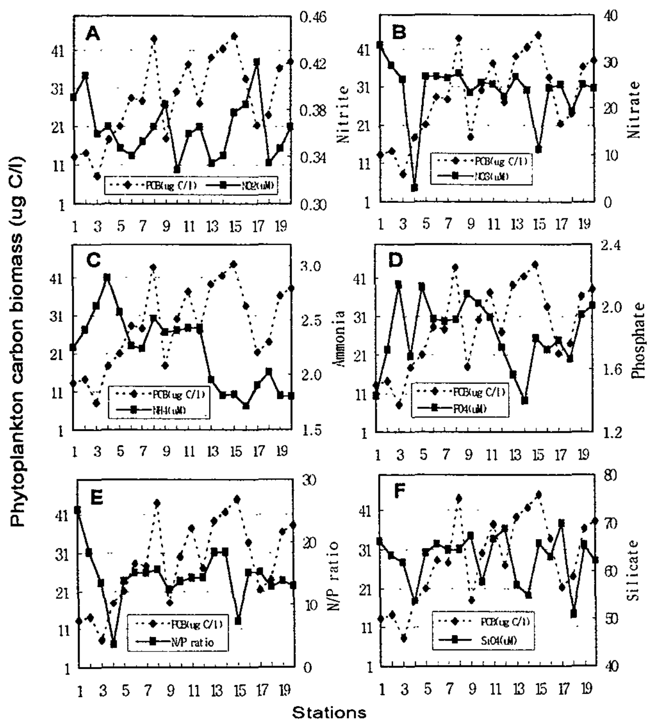

Fig. 11. Phytoplankton carbon biomass and nutrient concentration in the surface water of Maxwell Bay. A, Nitrite; B, Nitrate; C, Ammonia; D, Phospate; E, N/P ratio; F, Silicate.

December 1996. According to the paper, annual mean of nano-sized microalgae was 0.84 $\mu g\ l^{-1}$, accounting for 52% of total Chl *a* and micro-sized microalgae was 0.79 $\mu g\ l^{-1}$, accounting for 48% of total Chl *a*. Our study shows that nano-sized phytoplankton accounted for 47-86% of total phytoplankton carbon biomass in the surface water of Maxwell Bay. This result indicates that nano-sized phytoplankton has been a major primary producer in Maxwell Bay even the cell size is small. The species compositions of nano-sized phytoplankton were similar among stations. However, cell number of nano-sized diatom, *Navicula glaciei* was dramatically increased at stations near glacier cliff. According to McMinn (1996), *N. glaciei* was dominant species that was released from fast-ice Ellis Fjord, eastern Antarctica. *Navicula glaciei* could be an indicator species to show inflow of melting water from glacier.

Carbon biomass of planktonic diatoms such as *Thalassiosira dichotomica, T. ritcheri, T. gracilis* and *Corethron criophilum* were relatively high at the bay mouth and absolute planktonic diatom concentration was decreased towards nearshore stations. Figure 12 shows common planktonic diatoms in Maxwell Bay. Nano-sized phytoflagellate, *Cryptomonas criophila*, was relatively high at the bay mouth. Because *C. criophila* is a dominant species in Bransfield Strait (Lee *et al.* 1996; Kang and Lee 1995), it seems that the water mass of the bay mouth was introduced from Bransfield Strait. These results suggest that *Thalassiosira* spp., *Corethron criophilum*, and *C. criophila* could be indicator species in open water.

Benthic diatoms such as *Licmophora belgicae, L. antarctica, Pseudogomphonema kamtchaticum, Fragilaria striatula,* and *Cocconeis costata* were relatively higher in the nearshore stations (stn. 4,5,7,8 and 12). The proportions of benthic diatom decreased towards the bay mouth (Figs. 8A-D). These diatoms in the

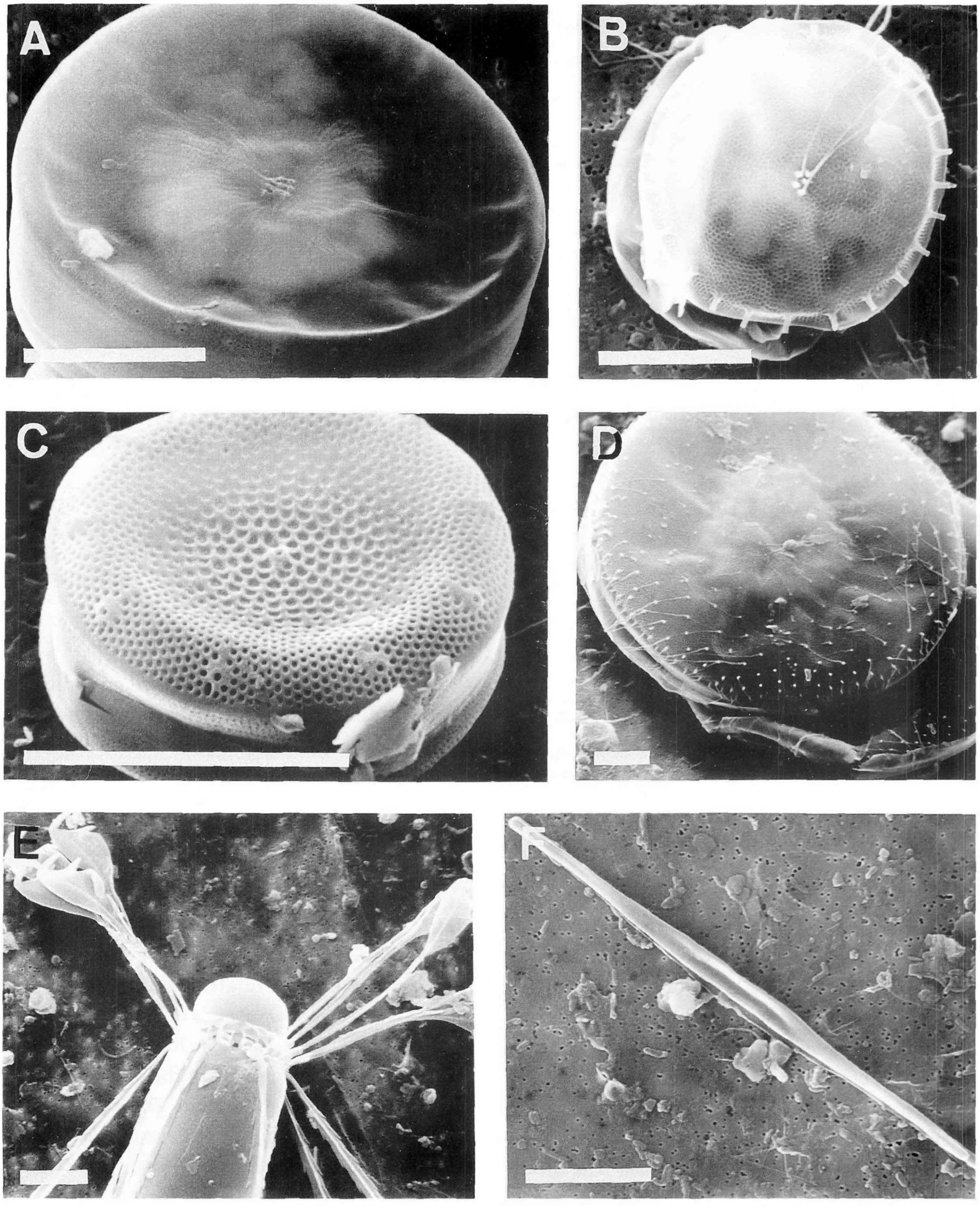

Fig. 12. Scanning electron micrographs (SEM) of planktonic diatoms. A, *Thalassiosira ritscheri*; B, *T. dichotomica*; C, *T. gracilis*; D, *T. lentiginosa*; E, *Corethron criophilum*; F, *Pseudonitzschia* sp. (Scale bars=10 μm).

surface water appear to have been detached from macroalgae such as *Ulothrix* sp. and *Desmarestia* spp. (personal observation) and detached out of the intertidal zone and moved to the central part of bay by tidal effect, local current or wind generated wave. According to Ahn *et al.* (1997), diatom biomass and wind speed were highly correlated and these diatoms were detached from benthic substrates. Brandini & Rebello (1994) in Admiralty Bay, where is located near Maxwell Bay, reported that temporal variations of Chl *a* and nutrients in the euphotic zone were associated with changes in the wind/hydrological regime. Thus it is speculated that major factors for controlling temporarily suspended benthic diatom concentrations in the surface water of Maxwell Bay are tidal effect or local wind.

Our results suggest that micro-sized phytoplankton assemblages in the surface water of Maxwell Bay may be more associated with physical characters. Distributions of hydrographical parameters did not affect directly on phytoplankton biomass. Phytoplankton biomass were influenced by other physical parameters such as, tide and currents in Maxwell Bay, during the season. Because phytoplankton assemblages in different or changing environments have different representative species, these indicator species may help to distinguish origins of surface water.]

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