Antarctic Research, Vol. 7, No. 2, 150～163, December 1996

Vertical distribution and seasonal variation in ice algae biomass in coastal sea ice off Zhongshan Station, East Antarctica*

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Received December 18, 1995

Abstract The biomass of ice algal communities in coastal sea ice off Zhongshan Station, Antarctica were monitored from April to December 1992. The maximum thickness of ice cover was 1.74 m in November/December and covered-snow was less than 35 cm in depth throughout the study period. Brown layers occurred in 2～5 cm of the ice bottom in late April and November, with chlorophyll *a* peak values of 360.7 and 2810 mg/m^3 respectively. The integrated chlorophyll *a* values ranged from 1.17 to 59.7 mg/m^2 with the peak occurring in November when ice algae bloomed, and the values never exceeded 6 mg/m^2 before mid October except at one site, the highest value occurred in April and then decreased fluctuatedly throughout the year. The biomass was concentrated mainly in the bottom of the ice, and might be also partly concentrated in the interior sections where autumn bloom had occurred. The dominant diatoms were composed of *Nitzschia lecointei*, *N. barkleyi*, *N. cylindrus* in austral autumn and *Amphiprora kjellmanii*, *Berkeleya rutilans*, *Nitzschia lecointei* in austral spring, and showed some difference at sites owing to the environmental conditions.

Key words Antarctica, fast ice, ice algae, chlorophyll *a*, biomass, seasonal variation.

1 Introduction

A prominent feature of the Southern Ocean is the sea ice which covers up to 20×10^6 km^2 during wintertime and recedes to less than 4×10^6 km^2 in austral summer (Zwally *et al.*, 1983). The growth, persistence and decay of sea ice has a significant influence on the structure of Antarctic marine ecosystems. Since it acts as a barrier for the exchange of heat, light, momentum and material between water and atmosphere, the sea ice cover is of importance in the global energy balance and the atmosphere-ocean interaction in polar regions (Zwally *et al.*, 1983; Eicken, 1992). Moreover, it creates an important inhabit for organisms, that supports an unique biocommunity with high levels of production. It has been calculated that, the total annual biogenic carbon production in the sea ice zone is *ca.* 2.9×10^{14} gC/a, among which more than 20 percent is from sea ice

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* The research is supported by the State Antarctic Committee of China and Oceanic Science Fundation of State Oceanic Administration.

and the majority is ice algal production(Legendre *et al.* , 1992).

Sea ice ecology has attracted attention since 1960s, so far in Antactica, numerous studies have been conducted in different fast ice regions, such as McMurdo Sound(Bunt, 1963; Palmisano and Sullivan, 1983; Grossi *et al.* , 1987), Soywa Station(Hoshiai, 1977, 1981; Watanabe, 1988), Casey and Davis Stations(McConville and Wetherbee, 1983; Perrin *et al.* , 1987), Sygny Island(Richardson and Whitaker, 1979). However, most of them focused attention mainly on one or serveral special sections, especially bottom section, only a few reports have been made on the vertical and seasonal variations of ice algal biomass in fast ice sites throughout the year(e. g. Hoshiai, 1981). Our program of sea ice ecology, which has been conducted at Zhongshan Station since the Eighth Chinese Antarctic Research Expedition (CHINARE-8) in 1992, aims at revealing the physical-chemical features of the coastal fast sea ice, and the seasonal variations of biomass and community structure. Here we just report the biomass structure and its seasonal change in the fast sea ice off Zhongshan Station, and compare our results with that of other fast ice regions in Antarctica.

2 Materials and methods

Sampling of sea ice during CHINARE-8 was carried out monthly from the fast ice at four sites off Zhongshan Station(69°22′24″S, 76°22′40″E) from April 12 to December 30, 1992(Fig. 1). Ice cores were taken with a PICO ice auger (7. 6 cm internal diameter), the snow and ice thicknesses were measured *in situ* , and samples were transported to the laboratory at Zhongshan quickly. Each ice cores was divided at 10 cm interval for analysing chlorophyll *a*, phaeopigments, algal species composition, abundance and other chemical parameters(will be reported elsewhere).

Each core was cut into segments of 10 cm length from the surface to bottom, the bottom coloured layers in the autumn and spring were regarded as seperate segments. All ice subsamples were naturally melted in the dark at temperature of 5～10℃.

200 ml of each melted water sample was filted through a 0. 45 μm pore-sized HA membrane (Millipore), then determination was made of chlorophyll *a* and phaeopigment concentrations according to Jeffrey and Humphrey(1975) and Lorenzen(1967) , by using a spectrophotometer VIS-723 after 24 hours extraction with 90% aceton at －20 ℃. The remainder of each melted water sample was concentrated by filtration and preserved within 1. 5 % buffered glutaraldehyde in the dark at 4 ℃.

Ice algal enumeration was made by phase-contrast method under a Zeiss Axioskop 50 microscope, and species identification was carried out under a HITACHI S-520 scanning electron microscope(SEM).

3 Results

Sea ice formed in mid March in 1992, and entirely covered the sea surface at the end of March. The ice thickness increased quickly because of the low air temperature and reached 50 cm in late April, a brown layer occurred in 3～4 cm of the ice bottom. The

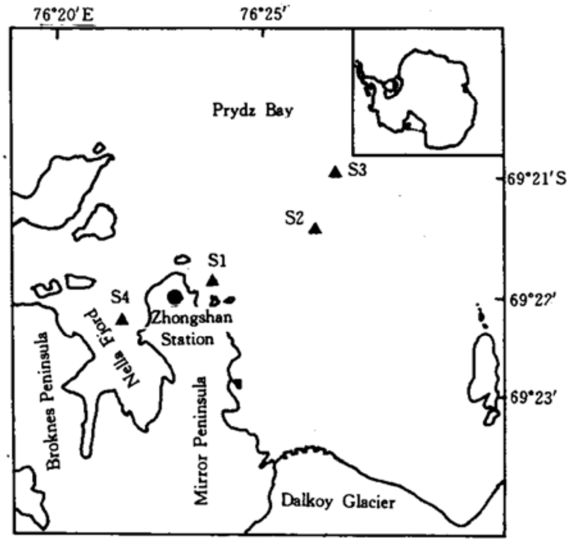

Fig. 1. Location of fast ice sampling sites off Zhongshan Station between April and December, 1992. Distances of sampling sites from the seashore: DS1 = 100 m, DS2 = 2 km, DS3 = 3 km, DS4 = 200 m. Depths of water column at sites: DPS1 = 11.5 m, DPS2 and DPS3 > 200 m, DPS4 = 103.5 m.

colour disappeared rapidly in May. The ice thickness increased continuously and exceeded 1 m in August and 1.5 m in October, reached its maximum of 1.74 m in November/December. The spring brown layer occurred in 2～5 cm of ice bottom in October and the colour became deeper and deeper till late November, the algal strands adhering on the ice bottom surface were found. In mid December, the bottom layer began to melt and the brown layer disappeared again. The fast ice zone remained with a width of 6 km in mid January, and was broken up entirely in early Feberury. The thicknesses of covered-snow varied in a range of 0～30 cm between May and October, when blooms occurred in April and November, only the ice surface of site S2 was snow-covered from May with an average thickness of about 20 cm. The monthly average air temperature and seasonal variation of ice thickness are shown in Fig. 2. The ice thickness increased quickly following the sharp decrease of air temperature in April, and during the period from May to September, the average air temperature varied between −15 ℃ to −20 ℃ and it clearly showed that lower air temperature could lead to quicker growth of sea ice. The growth rate became slower in October and November, and even negative after mid December following the rising of air temperature.

The ice algal biomass measured as chlorophyll *a* is shown in Fig. 3, which indicates two types of seasonal variation with a wide range from 1.17 to 59.7 mg/m^2. One occurred at S1, S3 and S4, where only one main peak occurred in November with the values of more than 30 mg/m^2. In April, the values increased slowly following the increment of ice thickness, and reached an indistinct peak value of 5.72 mg/m^2(S1) in early May, then the values decreased and finally dropped to the lowest value of 1.17 mg/m^2 (S1) in July. From August to mid October, the values rose again with some fluctuation, but within the six months from mid April to mid October, the integrated chlorophyll *a* values never exceeded 6 mg/m^2. At the end of October, the values began to in-

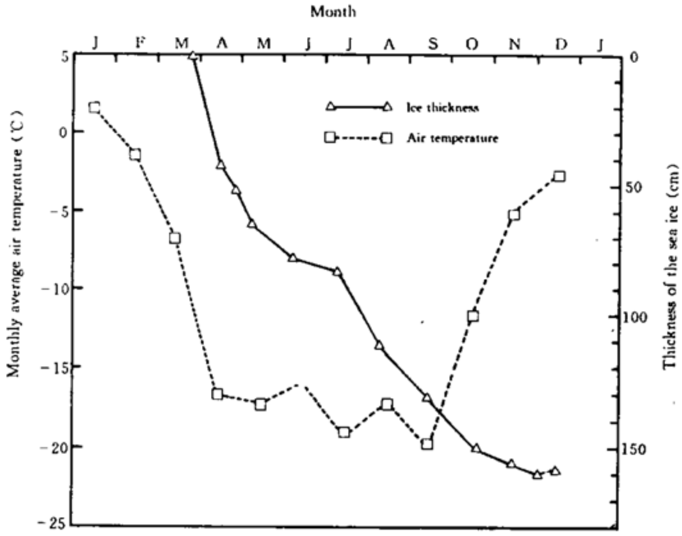

Fig. 2. Monthly average air temperature and seasonal variation of ice thickness(site S4) off Zhongshan Station in 1992.

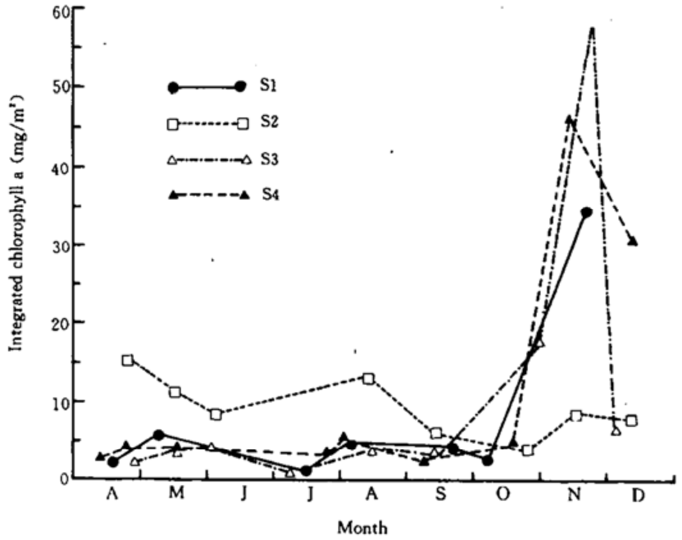

Fig. 3. Seasonal variation of integrated chlorophyll *a* (mg/m²) in the sea ice off Zhongshan Station.

crease quickly and reached its highest value of 59. 7 mg/m²(S3) in late November, and then decreased again. In mid December, the values dropped quickly to less than 10 mg/m². All these indicate that the biomass measured as integrated chlorophyll *a* concentrations was quite dominant only in austral spring when ice algae bloomed. Another type occurred at site S2 where the peak value of 15. 5 mg/m² was found in April during autumn bloom, and decreased fluctuatedly throughout the study period, and the value was less than 10 mg/m² when peak values of more than 30 mg/m² occurred at other three sites in late November.

The chlorophyll *a* values in different ice sections shown in Fig. 4 indicate that the seasonal variation is not apparent in most sections with low concentrations except in two sections: 40～70 cm layer below ice surface and several centimeters on the bottom where the ice algal blooms occurred. The values of more than 10 mg/m^3 in the 40～70 cm layer where the autumn bloom had occurred decreased slowly throughout the study period and mostly dropped to below 1 mg/m^3 in December(S1,S3,S4), or remained throughout the year(S2). The values at the bottom showed a most obvious variation. There were two peak values with maxima in late April and November when brown layers occurred on the bottom. The values rose after ice formed, and reached autumn small peak value of 57.4 ～360.7 mg/m^3 in late April. The concentrations decreased sharply in May and June following the increasing of ice thickness, and dropped to its lowest value of 1.02 mg/m^3 in July(in the 10 cm of bottom at S1) . The concentrations rose again after August, and in late November, the spring peak values in 2～3 cm of ice bottom at site S1, S3 and S4 exceeded 1000 mg/m^3(Table 1). All these indicate that the seasonal variation of biomass in bottom section is very significant, the chlorophyll *a* concentrations vary within three orders of magnitude from 1.02 to 2810 mg/m^3. And it's clearly shown that the start of bottom bloom was closely linked to covered-snow: in bare-ice zone(S3), the value was 10 mg/m^3 in September, and reached more than 100 mg/m^3 in October, which exceeded the autumn peak value; at site S4 with several centimeters of covered-snow, the bloom started in October; at S1 site, where the thickness of covered-snow exceeded 10 cm, the concentrations began to quickly rise in November; and at site S2 with more than 20 cm (even 30 cm) of covered-snow, the values in the bottom layer never exceeded 100 mg/m^3, at least one order of magnitude lower than that of other sites when spring bloom occurred. It suggests that the spring bloom would be more obvious at the sites with less covered-snow.

A conspicuous feature of vertical profile of chlorophyll *a* in the sea ice was that the biomass were mostly concentrated in the 20 cm of the ice bottom, especially in austral autumn and spring. In wintertime, higher concentrations also could occurred in interior sections(40～70 cm below ice surface) because of the autumn bloom remnants and the lowest bottom concentrations. Although the values of more than 5 mg/m^3 could occur in the interior layer where brown colour had occurred in autumn, the integrated chlorophyll *a* concentrations were lower in winter(Fig. 3) , but the ice algal biomass in the bottom section were substantial in autumn and spring, especially during spring bloom, more than 95% of the total chlorophyll *a* concentrations occurred in 20 cm of the ice bottom(except S2) and the integrated biomass were higher at least by a factor of 5 than that in wintertime, so the ice algal biomass in the bottom sections were most dominant than others.

The proportions of chlorophyll *a* (%) to the sum of chlorophyll *a* and phaeopigments are shown in Fig. 5, which indicate the growth status of ice algae in the sea ice. They were usually higher than 80% at the beginning of ice formation, and dropped to 50% or even less than 20% in some layers in August and September, and rose again in the most of sections in spring(>80%)(Fig. 6). It suggests that the activities of ice algae are high in autumn and spring, the variation is mostly dependent upon the changes of en-

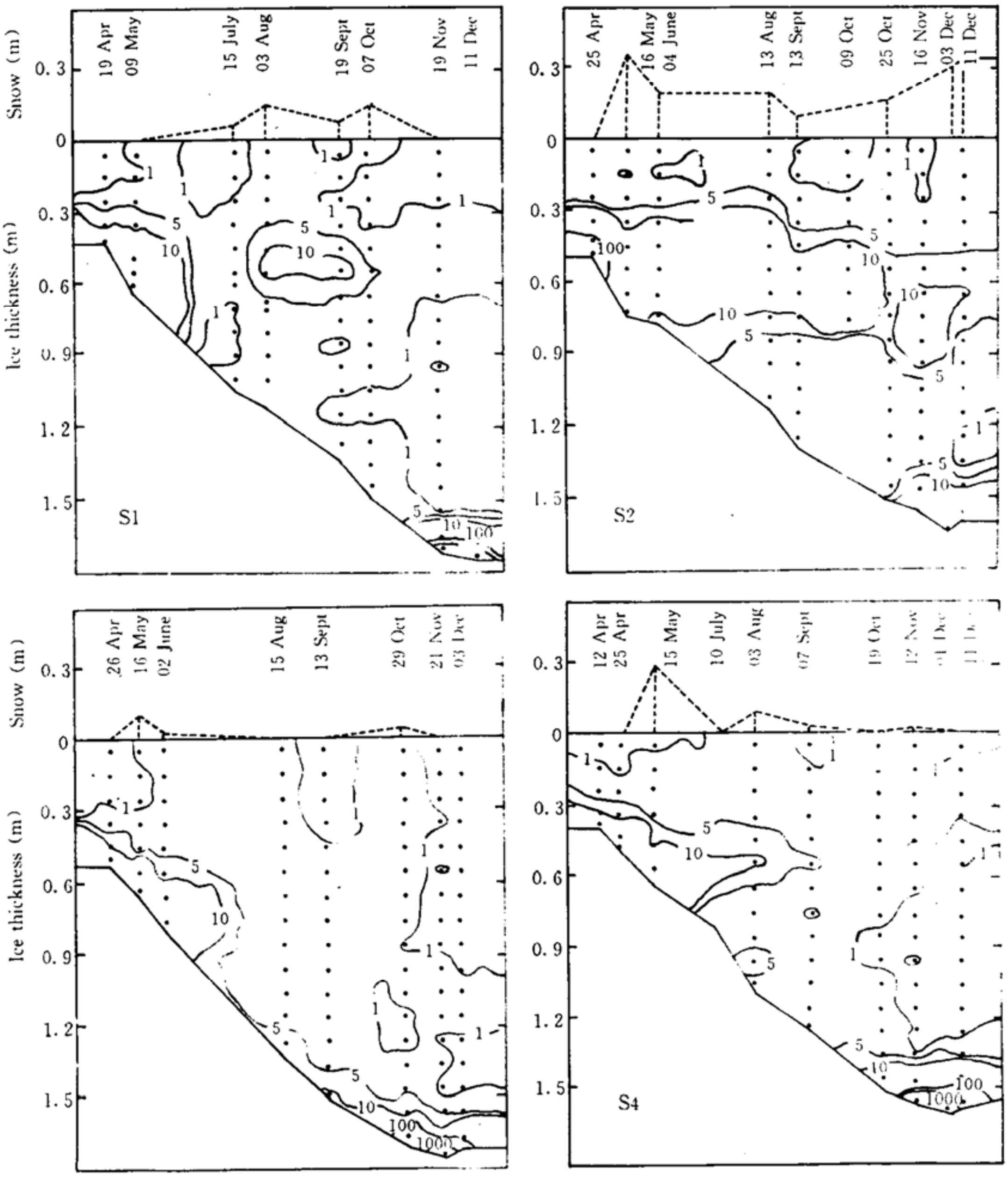

Fig. 4. Vertical distribution and seasonal variation of chlorophyll *a* (mg/m³) in the sea ice off Zhongshan Station. Snow cover is illustrated by dotted lines.

Table 1. The chlorophyll *a* peak values, abundance and dominant species of ice algae in the brown layer of bottom ice off Zhongshan Station

Site	Sampling Data	Thickness of sea ice (cm)	Thickness of color layer (cm)	Chlorophyll *a* mg/m³	Chlorophyll *a* mg/m²	Abundance ×10^7cells/l	Dominant Species (>20%)
S1	19 Apr.	43	3	61.5	2.2	0.06	*Nitzschia barkleyi*
	19 Nov.	171	2	1481	33.9	4.28	*Amphiprora kjellmanii*, *Berkeleya rutilans* *Nitzschia lecointei*
S2	25 Apr.	50	4	360.7	15.5	6.56	*Nitzschia cylindrus*
	03 Dec.	166	5	86.5	—	0.13	*Amphiprora kjellmanii*
S3	28 Apr.	50	3	57.4	2.3	0.09	*Nitzschia barkleyi*
	21 Nov.	174	2	2810	59.7	12.1	*Berkeleya rutilans*, *Amphiprora kjellmanii*
S4	25 Apr.	50	3	88.3	3.9	0.35	*Nitzschia lecointei*, *Nitzschia cylindrus*
	12 Nov.	156	3	>1000	46.6	15.6	*Amphiprora kjellmanii*

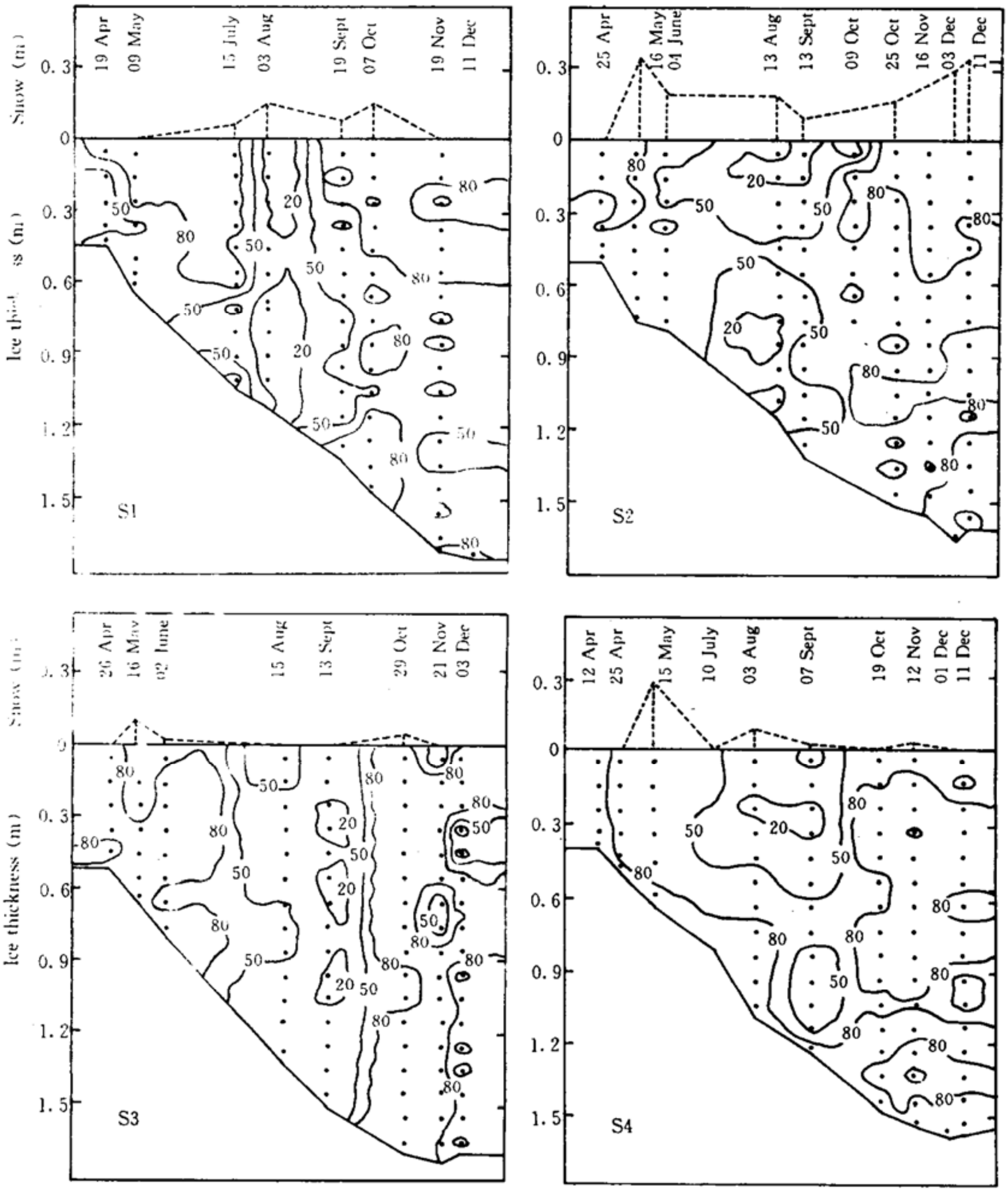

Fig. 5. The proportions of chlorophyll *a* (%) to the sum of chlorophyll *a* and phaeopigments in the sea ice off Zhongshan Station.

vironmental factors.

The abundance and the dominant species during ice algal blooms are showed in Table 1 (The community structure will be reported elsewhere). The cell numbers were 6.56×10^7 and 1.21×10^8 cells/l respectively when algal blooms occurred in autumn and spring. The dominant species were composed of all pennate diatoms in autumn: *Nitzschia barkleyi* (Fig. 6. 1), *N. lecointei* (Fig. 6. 2) and *N. cylindrus* (Fig. 6. 4); in November, the spring dominant species were composed of *Amphiprora kjellmanii* (Fig. 6. 5), *Berkeleya rutilans* (Fig. 6. 3) and *N. lecointei*, which accounted for more than 80% of the total abundance, and *Amphiprora kjellmanii* even could reach about 80% of total numbers in some sites (Fig. 6. 6).

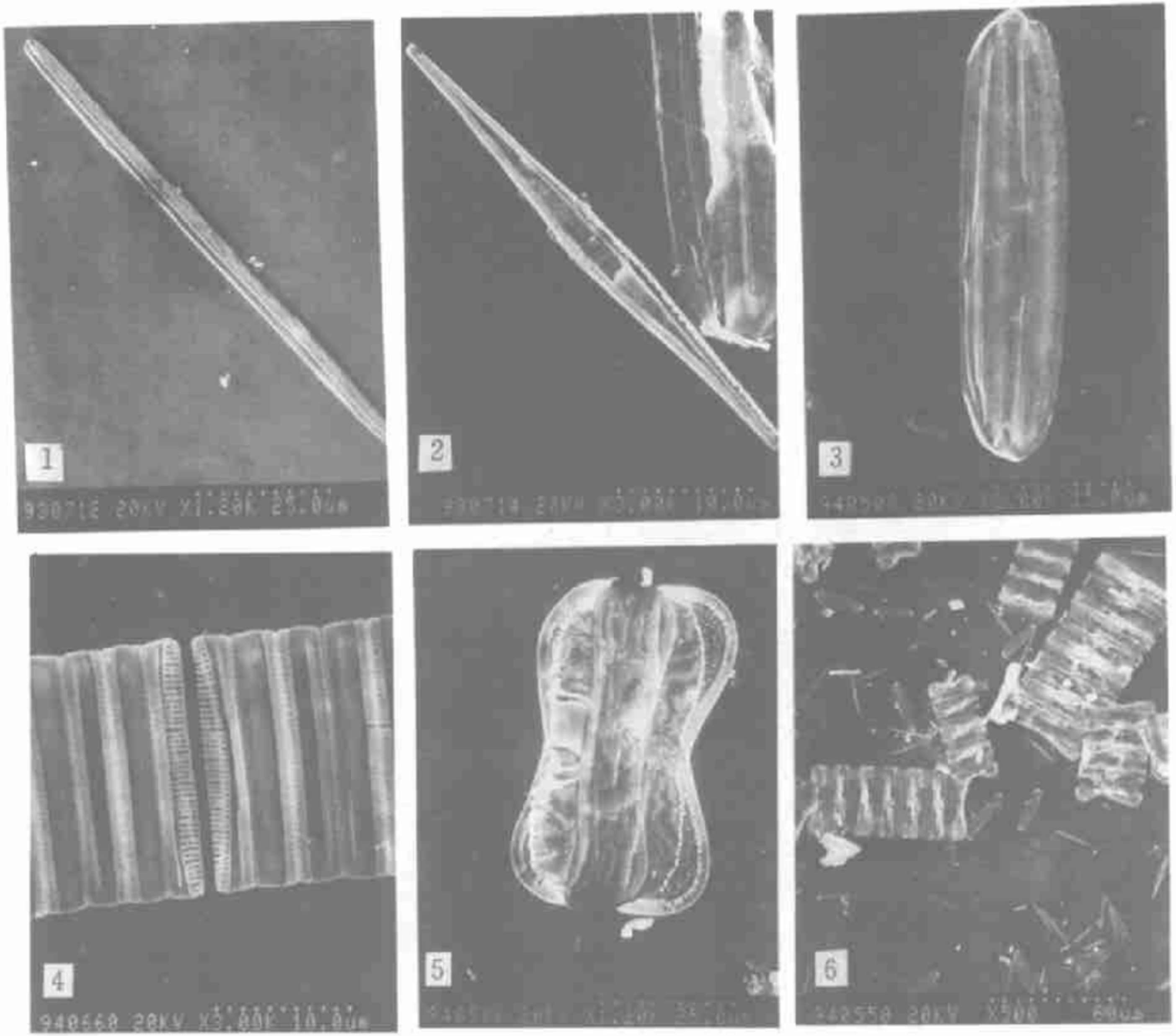

Fig. 6. The dominant ice algal species off Zhongshan Station(SEM). 6(1): *Nitzschia barkleyi* Hust. ;a dominant species in austral autumn; 6(2): *Nitzschia lecointei* Van Heurck; a common species in sea ice; 6(3): ***Brekleya rutilans***(Trent.) Grunow; dominant species in ice bottom in austral spring; 6(4): *Nitzschia cylindrus* (grun.) Hasle; a common species in sea ice; 6(5): ***Amphiprora kjellmanii*** Clave; dominant species during spring ice algal bloom; 6(6): Ice bottom community in austral spring.

4 discussion

Two ice algal blooms occurred in 2～5 cm of the ice bottom both in austral autumn and spring, with the chlorophyll *a* values of more than 100 mg/m^3(even 1000 mg/m^3 in springtime), it's nearly the same as the report from Casey, Davis and Syowa Station (McConville and Wetherbee, 1983; Perrin *et al.*, 1987; Watanabe and Satoh, 1987), but differs from that of McMurdo Sound where the thickness of bottom color layer could reach 20 cm (Palmisano and Sullivan, 1983). Although the autumn bloom could be caused by scavenging algae which lived in the water column through the rising of frazil crystals (Weeks and Ackley, 1982; Spindler, 1994), the analysis of ice structure showed that the bloom occurred in the congelation ice (unpublished data), suggesting that algal growth occurred at this period, and the spring bloom occurred because of the quick growth of ice algae following the increment of irradiance. Although some ice diatoms showed physiological adaptations to overwintering through a reduction in cellular metabolism and an increase in heterotrophic potential (Palmisano and Sullivan, 1982), the activity of the ice algae in winter is relatively lower, the proportions of chlorophyll *a* (%) to the sum of phaeopigments were usually lower than 50 % in wintertime, different sharply from that of more than 80% during autumn and spring (Fig. 5) The quick decline of biomass at the ice bottom is mostly because of the melting of bottom, such environmental factors as the increasing temperature of surface water and the light absorption of bottom communities. The comparison made between the seasonal variations of the biomass of integrated chlorophyll *a* and biomass in several centimeters of bottom indicates that the variation of integrated chlorophyll *a* is mainly dependent upon the variation of chlorophyll *a* values in the bottom layers , especially in springtime. Although the peak values occurred in the upper sections rather than in the bottom at some sites in wintertime, its influence on the biomass distribution in the ice is weak due to the very low biomass, and the main portion of total biomass throughout the study period is concentrated in the bottom sections, especially in several centimeters of bottom. The growth of ice algae in the microhabitat of the bottom sections especially during springtime mostly might be favoured by its relative constant temperature, loose ice structure and available essential nutrients replenished from underlying water column. The fact that chlorophyll *a* contents in the sections except bottom is very low and usually less than 1 mg/m^3 during springtime shows that they aren't fit in with the requirement of ice algal growth with increasing irradiance and air temperature.

The platelet ice layer was absent in the ice bottom near Zhongshan Station (unpublished data), such a phenomenon was different from that of McMurdo Sound and Syowa Station (Bunt, 1963; Palmisano and Sullivan, 1983; Hoshiai, 1977), but similar to that of Casey, Davis and Mawson (McConville and Wetherbee, 1983); the mat-strand community (sub-ice community) occurred in the bottom of ice and the algal strands suspended below the ice, just as those in many other Antarctic fast ice zone (McConville and Wetherbee, 1983; Palmisano and Sullivan, 1983; Watanabe, 1988; Gulliksen *et al.*, 1990), and the dominant species including *Amphiprora Kjellmanii* Clave and *Berkeleya rutilans*(Trent.) Grunow, are similar to those reported from Casey, Davis and Mawson (McConville and Wetherbee, 1983) and other Antarctic fast ice zone(Table 2) . All these confirm the McConville and Wetherbee's hypothsis(1983) that the absence of platelet ice layer under fast ice and the development of a mat-strands community may occur extensively over the inshore areas of east Antarctica.

Table 2. Dominant algal species of mat-strand communities(sub-ice communities) in different fast-ice zones in Antarctica

Location	Zhongshan Station	Mosen, Davis and Cacey(1)	Syowa (2)	North of Dronning Mand Land (3)	West of Mc-Murdo Sound(4)
Amphiprora kjellmanii Clave	+	+*		+	
A. kufferathii Mang.			+		
Berkeleya rutilans (Trent.)Grunow	+	+**	+	+	+
Nitzschia stellata Mang.	+	+***	+		

* : *Amphiprora* spp. * * : *Berkeleya* sp. ; * * * : It seems correct to designate *N. frigid* as *N. stellata* Mang. according to Medlin and Hasle (1990). (1) McConville and Wetherbee, 1983; (2) Watanabe, 1988; (3) Gulliksen *et al.*, 1990; (4) Palmisano and Sullivan, 1983.

The covered-snow seems to deeply influence the ice algal biomass, especially at the beginning of spring when the bottom biomass resumed. Because of the different thicknesses of covered-snow, the concentrations in the bottom sections rose in different months or even no obvious rising was found. The difference of covered-snow thickness actually reflect the difference of irradiance which reached the bottom of the ice. The attenuation rate of light in the snow is much higher than that in the sea ice(Garrison *et al.*, 1986). It supports the issue that light is a major factor in the control of the growth of ice algal communities(Sullivan *et al.*, 1985).

The dominant species were *Amphiprora kjellmanii*, *Berkeleya rutilans* and *Nitzschia lecointei* in the spring which could account for more than 80% of the total cell numbers (Table 1). Table 3 shows that the species are somewhat similar to those reported from Syowa, Cacey and McMurdo Stations (Hoshiai, 1981; McConville and Wetherbee, 1983; Palmisano and Sullivan, 1983) where *Amphiprora kjellmanii/kufferathii* and *Berkeleya rutilans* were the common and dominant species. But *Nitzschia lecointei*, a dominant ice algal species off Zhongshan Station, was not abundant in other Antarctic regions except in fast ice zone near Syowa Station. In other regions, *Nitzschia stellata* was common in place of *Nitzschia lecointei*. The abundance of the dominant species near Zhongshan Station was nearly the same as that of Davis, where *Amphiprora kjellmanii* was prodominant and could account for more than 80% of the total cell numbers in spring bloom (Scott *et al.*, 1994) . But the McMurdo Sound was characterized by the abundance of dominant species *Nitzschia stellata* (Gossi and Sullivan, 1985), which could even occupy more than 99% of total algal cells at some sites(Nichols *et al.*, 1993). The main difference in dominant species composition during spring bloom between Zhongshan Station and other Antarctic fast ice regions was that there was a number of *Nitzschia lecointei* rather than *Nitzschia stellata* in the fast ice zone off Zhongshan Station. There is some difference in Weddell Sea where *Nitzschia curta* and *N. cylindrus* were also the dominant species , and it's very different in sub-Antarctica where *Navicula glaciei* was usually a dominant species(Table 3).

Since the chlorophyll *a* value, occurring in the bottom layer of ice at site S2 during autumn bloom, was as high as 360.7 mg/m^3, the remnants of this layer was obvious throughout the study period, such a phenomenon just as that of other Antarctic regions

Table 3. Dominant ice algal species in different Antarctic fast ice zones in austral spring

Dominant Species	Zhongshan Station	Davis (1)	Casey (2)	Syowa (3)	McMurdo Sound(4)	Weddell Sea(5)	Palmer (6)	Signy Island(7)	Great Wall Station(8)
Amphiprora kjellmanii Clave	+	+	+(*)						
A. kufferathii Mang.				+	+	+			
Berkeleya rutilans (Trent.) Grunow	+		+(**)	+	+(**)	+			
Nitzschia curta (V. H.) Hasle						+		+	
N. cylindrus (Grun.) Hasle						+			+
N. glaciei van Heurck				+	+		+	+	+
N. lecointei Van Heurck	+			+					+
N. stellata Mang.		+	+(***)	+	+	+			

* : *Amphiprora* spp.; * * : *Berkeleya* sp.; * * * : It seems correct to designate *N. frigid* as *N. stellata* Mang. according to Medlin and Hasle (1990). (1) Perrin *et al.*, 1987; (2) McConville and Wetherbee, 1983; (3) Watanabe *et al.*, 1990; (4) Palmisano and Sullivan, 1983; Grossi and Sullivan, 1985; (5) Spindler *et al.*, 1990; (6) Krebs *et al*, 1987; (7) Richardson and Whitaker, 1979; (8) Lü *et al.*, 1991.

(e. g. Syowa Station, Hoshiai, 1981), it's a very common phenomenon in Antarctica (Hoshiai, 1977; Ackley *et al.*, 1979; McConvill and Wetherbee, 1983). But at other three sites with bloom values of less than 100 mg/m^3, the remnants were not so obvious as that of S2, the colour was disappared in May and the chlorophyll *a* concentrations were only slightly higher than vicinity sections (Fig. 4). It is shown that the remnants in the interior sections are mostly dependent on the autumn higher bloom which occurred depending on ice structure and different species in water column when sea ice formed. The highest value of spring chlorophyll *a* concentration of 2810 mg/m^3 occurred at S3 on 21 November, similar maximum values were also reported in other Antarctic fast ice regions, such as at Syowa Station(5319.6 mg/m^3, Hoshiai, 1981; 2980 mg/m^3, Watanabe and Satoh, 1987) and southeastern Weddell Sea (2220 mg/m^3, Spindler *et al.*, 1990). But as far as the integrated concentrations were concerned, that in the McMurdo Sound was one order of magnitude higher than that at Zhongshan, Syowa and Davis Stations (Table 4).

Table 4. Maximum algal biomass measured as chlorophyll *a* in different fast ice zones of Antarctica

Location		mg/m^2	mg/m^3	Reference
Syowa	in fall		829	Hoshiai, 1977
	in spring		>1000	Hoshiai, 1977
	in fall	30	944	Hoshiai, 1981
	in spring	35	5320	Hoshiai, 1981
	in spring		2980	Watanabe and Satoh, 1987
Davis Station		15	—	McConville *et al.*, 1985
McMurdo Sound		309	>656	Palmisano and Sullivan, 1983
Weddell Sea			2220	Spindler *et al.*, 1990
Zhongshan	in fall	16	361	Present study
	in spring	60	2810	Present study

The disappearance of bottom ice algal bloom in spring is probably because of the absorption of ice algae to light energy and the rising of water temperature. Because the dominant species of *Amphiprora kjellmanii* and *Berkeleya rutilans* mostly existed as aggregates, they tended to sedimentate quickly (Sasaki and Hoshiai, 1986; Riebesell *et al.*,

1991) which could provide food to plagic and benthic biota. The mean integrated chlorophyll *a* value in spring bloom was 46. 5 mg/m^2, assuming a ratio of cabon to chlorophyll *a* as 50 : 1, the ice algal biomass in the fast ice zone off Zhongshan Station during the bloom was 2. 33 gC/m^2, which was lower than that of Syowa Station(3. 3～3. 5 gC/m^2, Watanaber and Satoh, 1987; Satoh *et al.*, 1991) and McMurdo Sound(>4. 1 gC/m^2, Palmisano and Sullivan, 1983), although it might be overestimated for higher carbon to chlorophyll *a* ratio(Bunt and Lee, 1970; Palmisano and Sullivan, 1983).

5 Conclusions

(1) The seasonal variation of ice algal biomass was significant, especially in the bottom layer where the biomass increased quickly in late April and November when ice algal blooms occurred, the chlorophyll *a* concentrations could reach 360. 7 and 2810 mg/m^3 respectively, and dropped to less than 5 mg/m^3 from July to September.

(2) The biomass was mainly concentrated in several centimeters of the bottom, especially in autumn and in spring; but there was an exception, the relative higher values also could occur in the upper layer where the remnants of autumn bloom occurred.

(3) The covered-snow could deeply influence the vertical distribution of chlorophyll *a* concentrations and the total biomass in the ice column, the great thickness of covered-snow would cause the remnant of autumn bloom and hinder the occurrence of spring bloom, and then reduce the total ice algal biomass.

(4) The vertical distribution and seasonal variation of the ice algal biomass were similar to those of other fast ice regions in East Antarctica, and the total biomass were relatively lower in this fast ice area.

(5) The dominant ice algal species of *Amphiprora* spp. and *Berkerkelya rutilans* are common in austral spring in Antarctic fast ice zones, but *Nitzschia lecointei* was also a dominant species off Zhongshan Station instead of the most common species of *Nitzschia stellata.*

Acknowlegements The authors would like to thank Wu Wen, Zeng Weimin, Tong Laixi, Li Shuanke, Xue Bingsheng and other members of winter expedition of CHINARE-8 for their kind field assistance.

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