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Primary Productivity, Phytoplankton Standing Crop and Physico-Chemical Characteristics of the Antarctic and Adjacent Central Indian Ocean Waters

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Abstract

Primary productivity, phytoplankton pigments and physico-chemical properties were studied in Antarctic waters and adjoining Indian Ocean between 11° and 67°E longitudes from polynya region (60°S) to equator during the austral summer season viz. 4th January to 23rd March, 1990.

The higher concentration of dissolved oxygen (11.33 mg L^{-1}) due to photosynthesis was observed. The temperature was low (-2.0°C to 2.1 °C) in the coastal ice-edge zone. Often, temperature recorded above zero, lowered the salinity from 34.9 to 33.16 x 10^{-3}. Gradual increase of temperature (-0.8 - 29.0°C) and salinity (33.19 - 36.27 x 10^{-3}) and decreasing trend of DO (av. 9.78 - 4.12 mg L^{-1}) from Polynya towards equator showed an ascending and descending order of these properties from high latitude towards low latitude. Though there was no direct correlation of nutrients to primary productivity, the constant higher concentration of phosphate (av. 4.12 μ mol dm^{-3}), nitrate (18.67 μ mol dm^{-3}) and nitrite (2.74 μ mol dm^{-3}) in the coastal ice zone than those of Antarctic oceanic region (phosphate 3.03, nitrate 16.17 μ mol dm^{-3}) and central Indian ocean (phosphate 2.39, nitrate 15.77 and nitrite 2.47 μ mol dm^{-3}) indicated regeneration of nutrients in the coastal ice-edge zone which supported fairly high growth of phytoplankton (av. 69.89 x 10^4 cells L^{-1}). This resulted in markedly high values of chlorophyll and primary productivity (av. chl. *a* 2.68 mg m^{-3}, PP 1,68 mg Cm^{-3} h^{-1}) in the coastal ice-edge zone as compared to those in the Antarctic oceanic region (chl.a 0.74 mg m^{-3}, PP 0.18 mg C m^{-3} $h^{-1)}$ and central Indian ocean (chl.a 1.86 mg m^{-3}, PP 0.55 mg C m^{-3} h^{-1}).

Fairly higher values of standing crop and column production in the coastal ice-edge zone (av. 179.39 mg m^{-3} & 15.8 mg m^{-2} h^{-1}) than that of Antarctic oceanic region (49.25 mg m^{-3} & 1.92 mg C m^{-2} h-$^{1)}$ and other oceanic region (124.88 mg m^{-3} and 6.71 mg C m^{-2} h-^{1}) suggested the coastal ice-edge zone to be far more productive. Low values (0.003 - 0.009 mg C [mg chl.a]$^{-1}$ h^{-1}) of assimilation number (AN) or photosynthetic rate and high concentration of phaeophytin (av. 12.35 - 23.50 mg m^{-3}) recorded in floating ice samples was the indication of unhealthy phytoplankton cells frozen in the ice.

Introduction

The Southern or the Antarctic ocean, with its unusual combination of the environmental condition is reported (E1-Sayed and Taguchi, 1981, Matondkar *et al.,* 1983, Pant, 1986, Naqvi, 1986, Verlencar and Parulekar, 1987, Goes *et al.,* 1988 and Verlencar et al., 1990) to support a fairly enhanced level of phytoplankton biomass and primary productivity. However, the factors responsible for limiting the primary productivity are not well understood. It necessitates to take up the studies on phytoplankton pigments, primary productivity and physico-chemical parameters in different regions of Antarctica and adjoining areas so as to get a better understanding of the food web dynamics and controlling factors in primary productivity.

Material and Methods

Hydrobiological observations were carried out during 9th Indian Expedition to Antarctica (1989-90) between Polynya (69°51'S) and equator (Fig. 1). Samples were collected from 18 stations during austral summer from 4th Jan to 23 March, 1990 for the estimation of

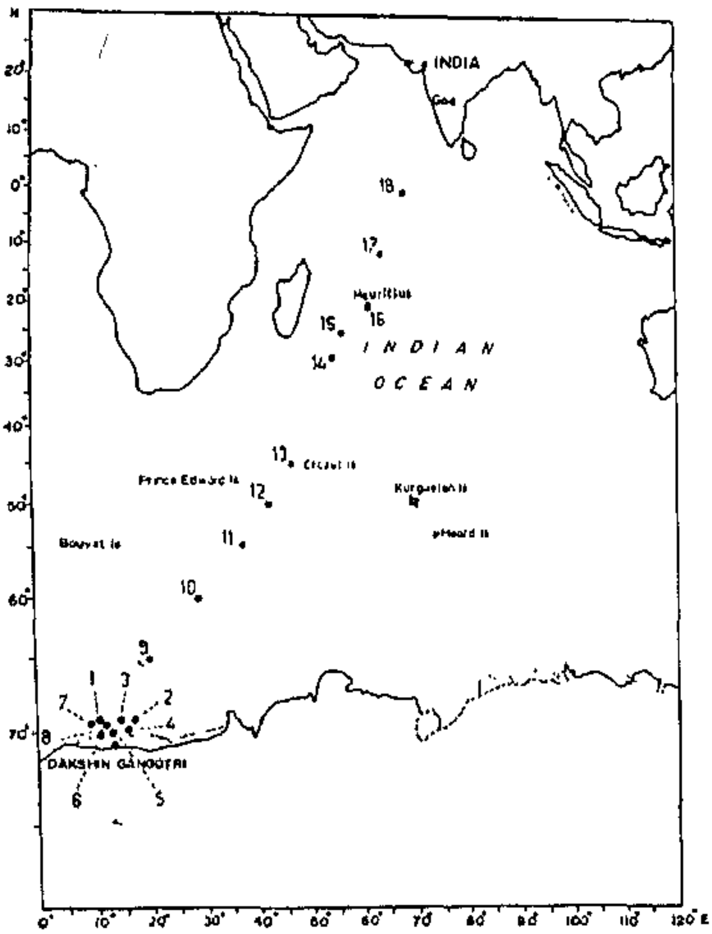

Fig.1. Map showing location of stations.

physico-chemical parameters, phytoplankton pigments and primary productivity. Physico-chemical parameters were estimated by adopting standard methods (APHA, 1985). Chlorophyll samples were collected (Figs 2-6) from different depths (0-200 m). Diurnal variation studies at the interval of 4 hours were also carried out at St. 1 & 2. Primary productivity and phytoplankton pigments were studied in 3 floating ice and 1 ice-edge sample. Ice samples were melted at laboratory temperature of 20°C and sub samples were used for different studies.

For the determination of chlorophyll *a* (chl.a) and phaeophytin, 1 litre water sample was filtered through millipore filter paper (47 mm diameter and 0.45 μ. pore size) and the pigments were estimated by following the Strickland and Parsons (1971) and Standard Methods, APHA (1985). The phytoplankton standing crop was calculated as per Standard Methods APHA (1985). The samples for the estimation of primary productivity (PP), were collected in light and dark DO bottles (125 ml) from euphotic zone of 100%, 30% and 1% penetration of light, estimated based on Sacchi Disc reading. 5μ Cu of $NaHC^{14}O_3$ was injected to each sample. The samples were incubated for 24 hours and were filtered through millipore filter paper (0.45 μ pore size and 45 mm diameter). Liquid Scintillation Counter was used for the determination of primary productivity as per Vollen Weider (1969). Phytoplankton samples could be estimated only for 8 stations (Sts 1-8). For the taxonomic studies of phytoplankton, 500 ml of surface water was collected with the help of water sampler. Samples were preserved in Lugol's solution. Algal cells were counted by using Sedgwick Rafter counting slide.

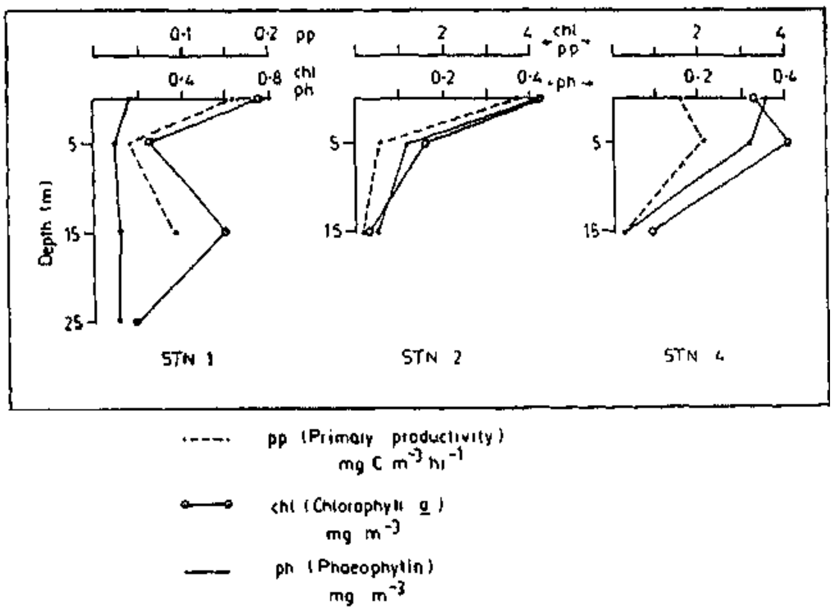

Fig. 2. *Distribution of primary productivity, chlorophyll a and phaeophytin at Stn 1, 2 and 4.*

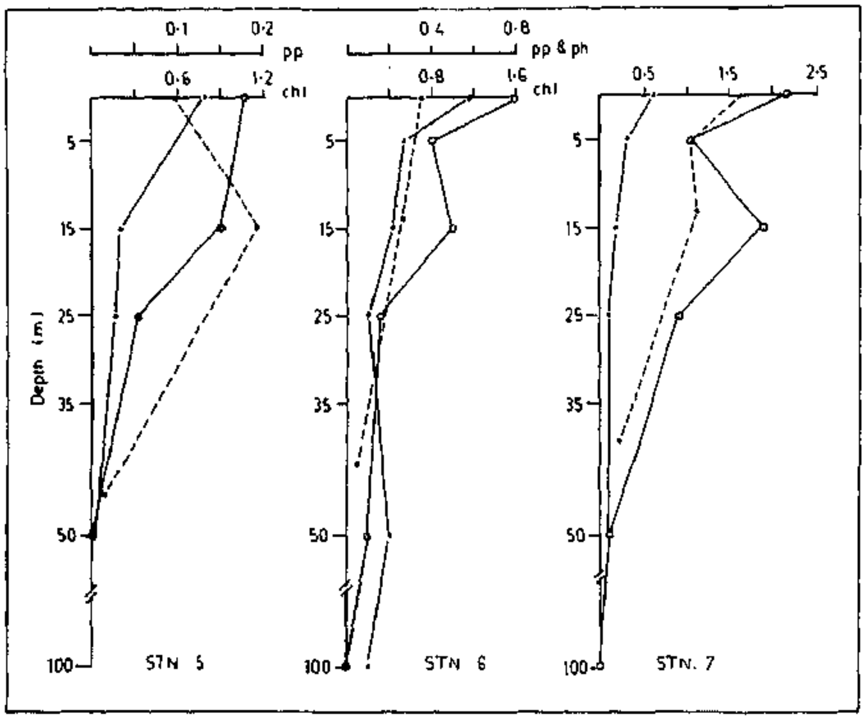

Fig. 3. Distribution of primary productivity, chlorophyll a and phaeophytin at Stn 5, 6 and 7.

Results and Discussion

Coastal Ice-edge Zone (69°S)

The wide variation in temperature could be due to the cloudy nature of the Antarctic region. Often recorded temperature below zero during entire study period could indicate the cold characteristic of Polynya region near ice-edge (Tables 1 & 3). Salinity remained as low as (33.19 x 10^{-3}) at the time of highest temperature due to melting of ice as reported by Fukuchi *et al*, (1985). Maximum recorded salinity (34.86 x 10^{-3}) agreed with the findings of El-Sayed (1967), Verlencar and Parulekar (1987) and Verlencar *et al.,* (1990). The levels of nutrients were good enough for the growth of phytoplankton, (Teixeira *et al.,* 1986). Variations in the concentration of phosphate from 2.90 to 4.26 μ mol dm^{-3}, nitrate from 12.95 to 24.15 μ mol dm^{-3} and nitrite from 2.10 to 3.95 μ mol dm^{-3} recorded in Polynya region (Table 1) were comparable to the report of Verlencar and Parulekar (1987) and Verlencar *et al.,* (1990). Average concentration of nutrients as phosphate (3.75 μ mol dm^{-3}) nitrate 18.67 μ mol dm^{-3}, and nitrite (2.74 μ mol dm^{-3}) exhibited higher level in this zone than that of Antarctic Oceanic and Central Indian waters. This could be attributed to the regeneration of nutrients because of decaying of the dead algal cells which sink at bottom

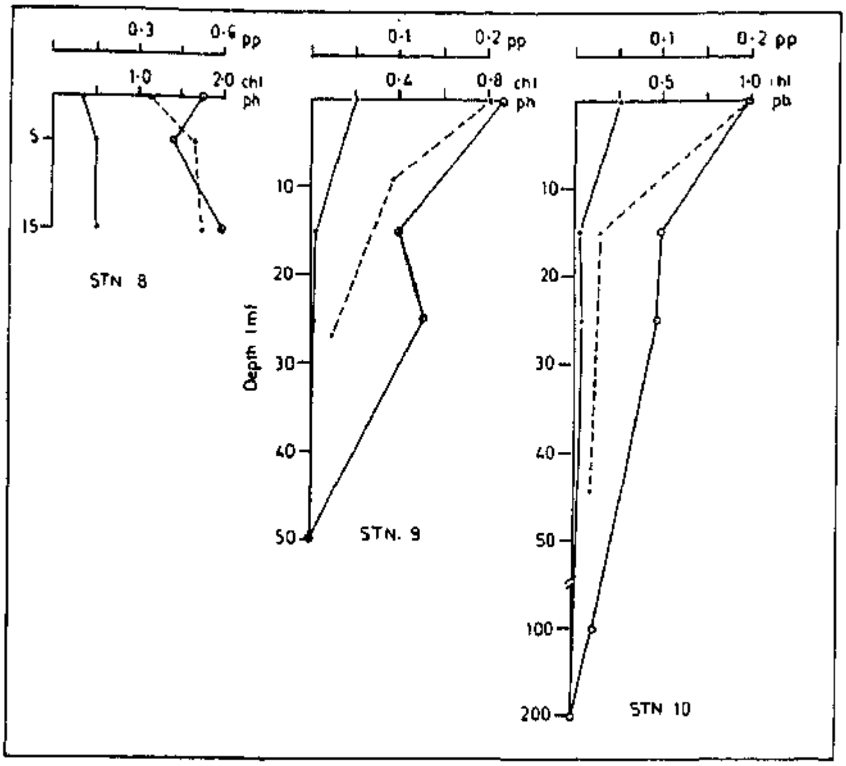

Fig. 4, Distribution of primary productivity, chlorophyll a and phaeophytin at Stn 8, 9 and 10.

due to the stability of water in this zone. Regeneration of nutrients in this region has been reported by Verlencar *et al.,* (1990) and De Master (1981).

High values of DO (8.24-11.33 mg L^{-1}, Table 1) recorded in Antarctic surface water might be due to high population density of phytoplankton and consequent, photosynthetic processes. Highest value of DO was associated with highest concentration of chl.a and primary productivity and lowest DO was obtained at the time of lowest value of primary productivity (Table 1).

Enhanced values of chl.a (0.75 - 6.64, av. 2.68 mg m^{-3}) in Antarctic surface water were due to high phytoplankton population which were higher than the values reported by Pant (1986), Verlencar and Parulekar (1987) and Verlencar *et al.,* (1990). Phaeophytin values ranged between 0.15 - 0.85 mg m^{-3}. Standing crop of the phytoplankton varied from 50.25 to 444.88 mg m^{-3} in. this region. Average chl.a(2.65 mg m^{-3}) was 3.5 times higher than that of Antarctic oceanic region (0.74 mg m^{-3}) and 1.4 times higher than that of Central Indian oceanic region (1.86 mg m^{-3}).

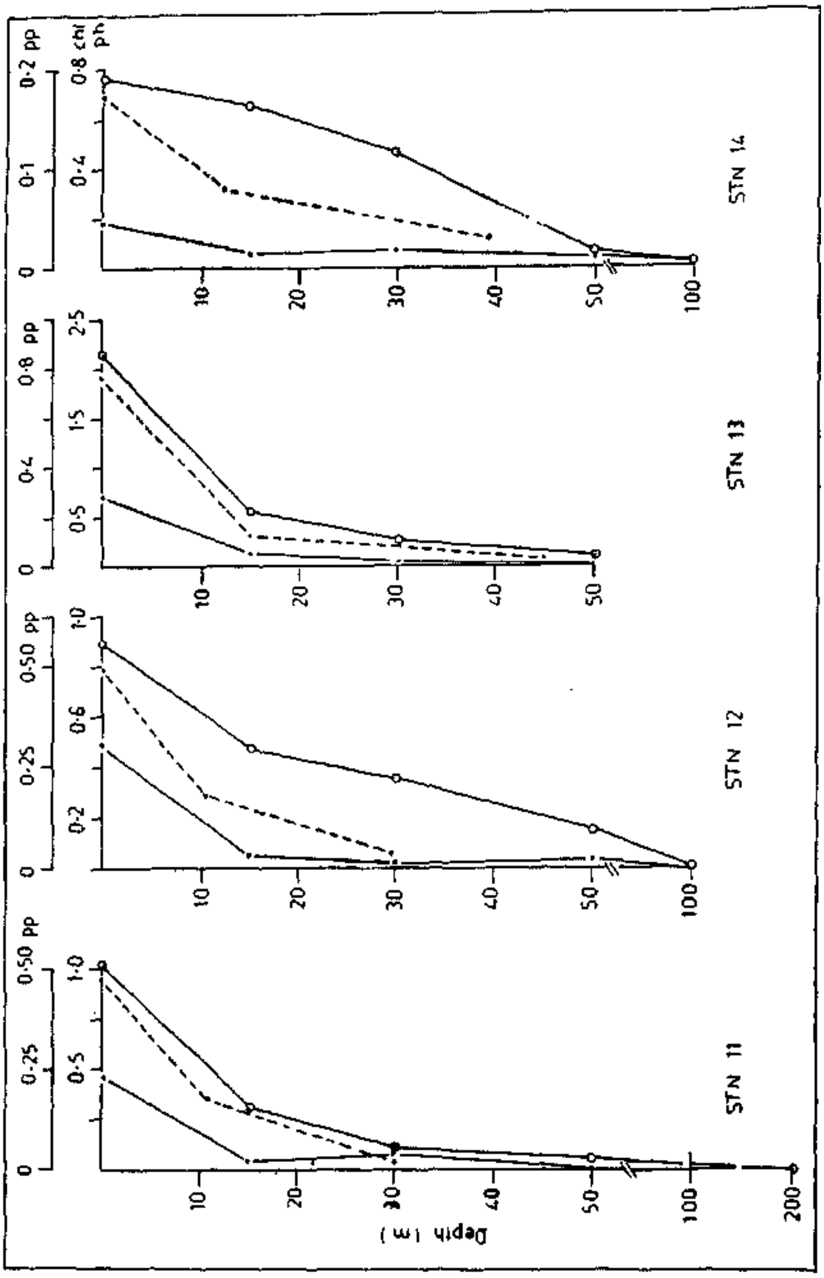

Fig.5. Distribution of primary productivity, chlorophyll a and phaeophytin at Stn 11, 12, 13 and 14.

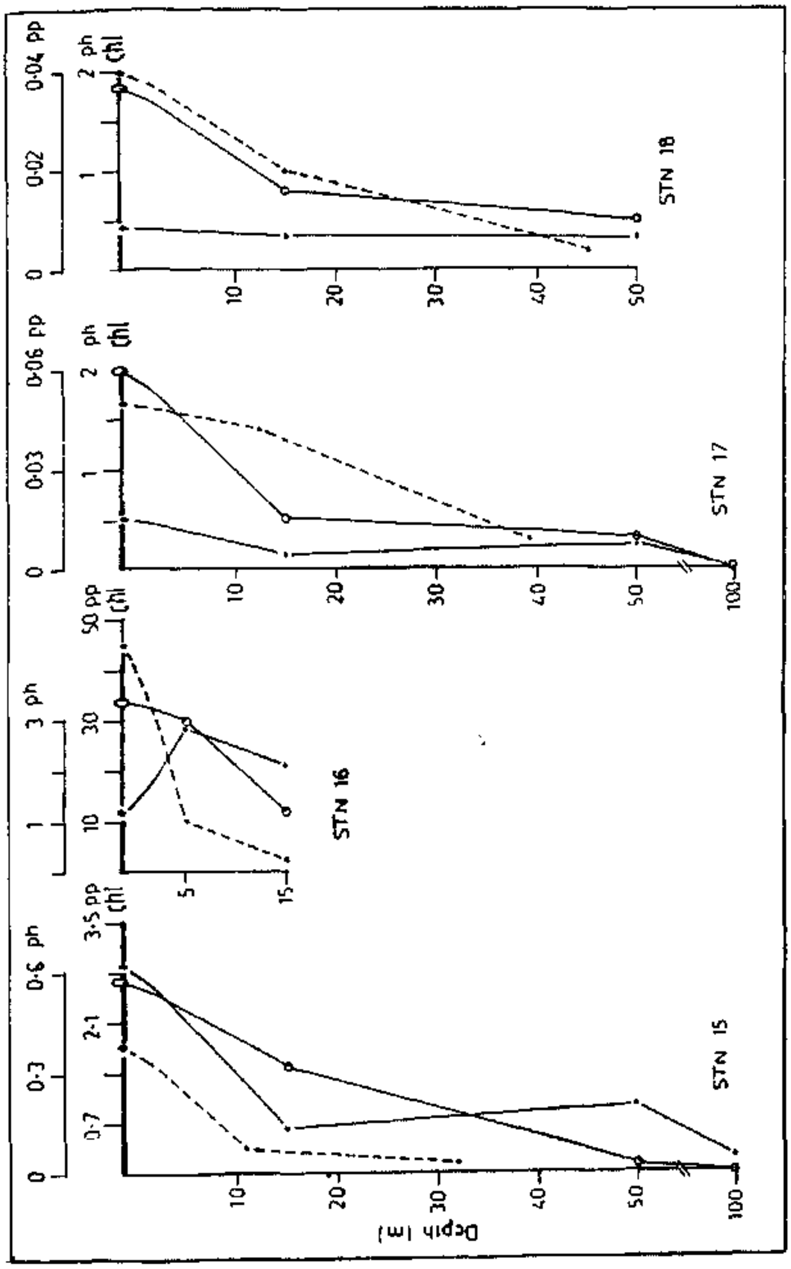

Fig. 6. Distribution of primary productivity, chlorophyll a and phaeophytin at Stn 15,16,17 and 18.

Table 1: Concentration of Physico-chemical Parameters at Different Stations in the Surface Water

Stn	Date	Temp. °C	DO mgr1	S x10~3	PO4-P umol dm"	NO3-N umc-l dm-3	N02-N (imol dm'	Total Depth (m)
1	4.1.90	-0.8	9.78	34.5	6.85	18.10	2.16	255
2	5.1.90	-1.8	9.00	34.86	4.26	21.96	3.50	142
3	6.1.90	-2.0	11.33	34,50	4.10	16.20	2.03	138
4	24.1.90	-0.8	10.56	34.32	4.10	20.12	2.16	199
5	31.1.90	-0.7	8.24	34.19	3.50	24.15	2.10	156
6	3.2.90	1.0	10.04	33.57	2.90	19.10	2.50	150
7	9.2.90	-1.5	9.78	34.76	3.15	12.95	3.95	219
8	12.2.90	0.5	9.53	33.19	4.10	16.80	3.50	184
9	4.3.90	1.5	8.24	34.06	3.80	15.18	3.98	1700
10	6.3.90	1.5	8.24	34.06	3.62	18.20	3.42	5272
11	7.3.90	2.0	8.24	35.19	2.18	18.90	3.12	5000
12	8.3.90	4.5	8.14	34.93	-	-	-	3175
13	1O.3.90	10.5	7.72	35.25	-	-	-	1600
14	14.3.90	24.5	5.66	35.95	-	-	-	2000
15	15.3.90	26.0	4.12	35.76	-	-	-	4900
16	17.3.90	24.5	3.86	36.14	-	-	-	20
17	23.3.90	28.0	4.38	36.14	-	-	-	3000
18	23.3.90	29.5	4.63	36.27	-	-	-	-

The concentration of primary productivity varied from 0.09 to 5.58 mg C m'" h" which wa£ slightly higher than reported by Pant, (1986), Verlencar and Parulekar, (1987), and Verlencar *etaL,* (1990). However, column production was recorded to be fairly high (1.06-53.33 mg C m"2 h"1, av. 15.8 mg C m"2 h"1) in the column of 0-45 m (Table 2). Average PP recorded in surface water (1.68 mg C m'" h") was 9 times higher than that in oceanic region (0.18 mg C m'" h") and 3 times higher than in the Central Indian oceanic region (0.55 mg C m'" h"). This suggested that even the cloudy weather with only a few hours radiation in coastal ice-edge zone could support excellent growth of algae in the euphotic zone.

Assimilation number (mg C [mgchl.a]"'h"') of phytoplankton (Table 2), showed slightly higher range (0.08-0.74) than Antarctic oceanic region (0.09-0.4) and Central Indian Ocean waters (0.02-0.64). Photosynthetic rate (AN) recorded in ice samples were markedly low (0.003-0.009) whereas AN estimated in the coastal water of Mauritius was very high (1.34 mg Cf mg chl.fl]"h") associated with bloom of phytoplankton. Such a high AN did not show any relation with nutrients similar to the findings recorded by Verlencar *etal.,* (1990). Very low AN as observed in floating ice samples, was due to very low PP values associated with very high chl. *a* (Table 4). This perhaps gives an idea of the weak activity or comparatively

Table 2: Latitudinal Variation of chl.*a* (mg m^{-2}) and PP (mg Cm^{-2} d^{-1}) in the Water Column and Assimilation Number AN (mg C [mg chl *a*]$^{-1}$ h^{-1}) and Standing Crop (mg m^{-3}) in the Surface Water

Stn	Latitude	Chl *a* (column depth) (m)	PP (Euphotic zone) (m)	AN	Standing crop
1	69°46'	9.75 (0-25)	1.06(0-15)	0.21	50.25
2	69°48'	26.98(0-15)	13.75(0-15)	0.87	281.40
3	69°49'	—	—	0.88	444.88
4	69°52'	43.6(0-15)	21.33(0-15)	0.48	221.10
5	69°56'	27.38 (0-50)	6.9 (0-45)	0.08	71.69
6	69°59'	34.68(0-100)	9.53 (0-45)	0.23	107.20
7	69°57'	49.95(0-100)	53.33 (0-45)	0.74	143.38
8	69°57'	24.85(0-15)	4.68(0-15)	0.19	115.24
9	65°00'	22.02(0-50)	1.35(0-27)	0.23	57.62
10	60°00'	44.60(0-200)	1.28(0-45)	0.05	34.17
11	55°00'	24.75(0-200)	4.25(0-30)	0.40	73.70
12	50°01'	28.88(0-100)	0.80(0-30)	0.09	31.49
13	45°01'	29.35(0-50)	9.38(0-45)	0.37	140.70
14	30°04'	27.05(0-100)	3.19(0-39)	0.22	50.92
15	25° 12'	63.70(0-100)	18.72(0-36)	0.64	179.56
16	20°08'	372.5(0-15)	231.10(0-15)	1.34	2278.00
17	10°00'	41.85(0-100)	1.37(0-39)	0.03	132.66
18	0°00'	37.88(0-50)	0.90(0-45)	0.02	120.60

inactive cells of the algae. Assimilation number more than 1 as observed at the time of bloom of phytoplankton indicated towards more active or healthy cells. This needs further confirmation from laboratory tests along with field observations on physical and biological factors. However, such low value of AN as recorded in floating ice samples associated with markedly high values of phaeophytin (Table 4) could again be put towards the thinking of inactive cells frozen in the ice for a long time.

Diurnal Variation: One of the two diurnal studies (Stn. 1, 2) conducted at station 1 was on a cloudy day except for a little break in between chl. *a* and primary productivity ranged from 0.75 to 4.10 (av. 2.68) mg m^{-3} and from 0.16 to 3.12 (av. 1.2) mg C$m^{-3}h^{-1}$ respectively. Significant correlation of chl. *a* with PP was recorded at the highest significance level of 0.001, which was similar to the result of Teixeira *et al*., (1986), Kopczynska and Ligowski (1985) and Verlencar *et al,* (1990) in the coastal ice-edge zone.

PP values were also related significantly (Table 5) with phaeophytin and DO. Positive correlation of chl.*a* with temperature (Table 5) at the significance level of 0.01, proved that

Table 3: Diurnal Variation of Physico-chemical Parameters, Phytoplankton Pigments and Primary Productivity at Different Stations during 1990

Time (GMT)	Temp. (°C)	DO mgl^{-1}	S x 10^{-3}	PO_4-P µmol dm^{-3}	NO_3-N µmol dm^{-3}	NO_2-N µmol dm^{-3}	Chl *a* mg m^{-3}	Phaeo-phytin mg m^{-3}	Primary productivity mg Cm^{-3} h^{-1}
				Stn-1 (4-1-1990)					
1500	-0.8	9.78	34.50	3.85	18.10	2.16	0.75	0.15	0.16
1900	-0.5	8.10	34.80	4.50	25.15	3.50	1.90	0.20	0.18
2300	-0.8	8.50	34.90	2.15	21.50	7.50	2.82	0.26	0.75
0300	1.5	7.85	34.90	3.62	22.95	1.50	2.10	0.28	0.46
0700	1.5	10.80	33.89	2.02	14.80	5.26	3.65	0.18	0.92
1100	2.1	11.00	33.16	2.10	15.65	3.85	4.10	0.32	3.12
1500	-0.5	10.05	34.90	4.10	19.15	3.60	3.42	0.36	2.82
				Stn -2 (2-5-1990)					
1600	-0.8	9.0	34.86	4.26	21.96	3.50	4.20	0.42	3.67
2000	1.1	9.5	34.10	1.95	20.05	4.15	3.20	0.15	2.10
2400	-1.5	9.5	34.62	5.16	20.04	3.85	2.10	0.20	1.18
0400	-0.8	9.0	35.0	2.14	16.60	7.99	1.65	0.16	0.92
0800	2.1	11.2	34.05	2.17	16.15	4.35	7.20	0.36	4.95
1200	1.5	10.0	34.88	3.80	16.85	3.20	5.90	0.46	4.55
1600	1.5	10.5	34.95	2.88	15.50	2.10	5.10	0.38	3.98

Table 4: Concentration of chl *a*, Phaeophytin, PP, AN (mg C[mg chl *a*]$^{-1}$ h^{-1}) and Standing Crop in the Floating Ice at Different Latitudes

Sample No.	Date	Position	Chl *a* mg m^{-3}	Phaeophytin mg m^{-3}	PP mg Cm^{-3} h^{-1}	AN.	DO mgl^{-1}
1	20.1.90	69°52'S 12°57'E	44.28	15.34	0.48	0.004	8.15
2		69°50'S 12°52'E	39.52	12.35	0.19	0.005	8.92
3	22.1.90	69°51'S 11°56'E	56.80	20.29	0.92	0.009	9.50
4	23.1.90	69°58'S 09°58'E	96.12	23.50	0.27	0.003	9.27

Table 5: Simple Correlations

	CHLA	DO	NO_2	NO_3	Phaeo	PO_4	PP
CHLA	1.0000						
DO	0.6301	1.0000					
$N0_2$	-0.0959	-0.0597	1.0000				
NO_3	-0.4638	-0.8698	-0.1444	1.0000			
Phaeo	0.7746	0.4629	-0.0553	-0.2629	1.0000		
PO_4	-0.2821	-0.3774	-0.5148	0.5331	-0.1838	1.0000	
PP	0.9233	0.6170	-0.1947	-0.4535	0.6806	-0.1255	I..0000
SAL	-0.2369	-0.6308	-0.0058	0.4494	-0.1793	0.4900	-0.1495
Temp	0.6588	0.5341	-0.2862	-0.4933	0.4378	-0.5454	0.5069
	SAL	Temp					
SAL	1.0000						
Temp	-0.5452	1.0000					

Cases included 14, missing cases 0.

the temperature was one of the main factors responsible for high phytoplankton population resulting in high concentration of chlorophyll. High temperature i.e. more than 1°C, caused melting of a lot of ice in polynya thereby releasing plenty of algal cells which resulted in high concentration of chlorophyll. This was more clear at St. 2 (Table 3) where diurnal variation studies were conducted on a sunny day showing the temperature to be very often above zero (1.1 - 2.1) and this was associated with enhanced values of chl. *a* (1.65- 7.2 av. 4.19 mg m^{-3}). Lutjeha *et al.,* (1985) and Goes *et al.,* (1988) postulated that the melting of sea surface ice resulted in density stratification and enhanced vertical stability in the upper regions of the water column near the ice-edge. As a result of it, phytoplanktons were retained in upper lighted regions.

An enhanced level of primary productivity (Table 2) recorded in coastal ice-edge zone could also be attributed to the melting of ice causing density stratification and enhanced stability in this one. Several other investigators have drawn attention towards the importance of stability of water column in controlling production (Svedrup, 1953, Pingree, 1978, El-Sayed, 1970 and Smith and Nelson, 1985).

Nutrients except nitrate were not found to be significantly correlating with the values of PP and chl. *a.* Nitrate showed significant negative correlation with chl. *a* and PP at the significance level of 0.1 indicating its biogenic uptake by phytoplankton (El-Sayed *et al,,* 1983). A gradual increase in temperature from St. 1 to 2 caused slight decrease in the concentration of salinity (Table 3). The values of DO observed at St. 1 and 2 during diurnal variation, exhibited a high level of significance (0.01) with chl. *a* and PP and also showed positive correlation with temperature at the significance level of 0.02 indicating the impact of temperature on photosynthetic activity. Diurnal studies at St. 1 and 2 proved that though the nutrient concentration play a vital role for the growth of phytoplankton in Antarctic surface waters, the temperature appeared to be one of the responsible factors for the high level of chlorophyll and primary productivity. The values of phaeophytin did not show any clear correlation with temperature (Table 3) directly but at St. 2, on a sunny day due to melting of ice, an enhanced level of chl.a associated with comparatively higher values of phaeophytin could be attributed to the unhealthy frozen algal cells in the ice.

In general, vertical distribution of chlorophyll and primary productivity exhibited the highest concentration in Antarctic surface water except a few stations. Stations 4,5 and 8 showed highest PP values at 30% penetration of light (Figs 2-6). Teixeira *et al.,(*1986) also recorded higher PP values at 30% light penetration only for a few stations in Bransfield Strait Antarctica.

The previous studies in Antarctica waters indicated the surface average chl. *a* and PP values to be 0.23 mg m^{-3} and 0.12 mg C m^{-3} h^{-1} in 1981, which increased to 1.6 mg m^{-3} and 1.6/mg C m^{-3} h^{-1} respectively (Verlencar, *et al.,* 1990). In the present study the average values further increased to av. 2.68 mg m^{-3} and 1.68 mg C m^{-3} h^{-1}. Higher level of chl. *a* and PP values could be attributed to the enhanced level of nutrients (phosphate, nitrate & nitrite - 3.75, 18.67 & 2.74 μ mol dm^{-3}) as compared to those recorded during 1985 (phosphate, nitrate and nitrite - 1.53, 15.12 & 0.16 μ, mol dm^{-3} respectively). Markedly increased temperature (max. 2.5°C) of surface water in present study as compared to that of 1985 (max. 1.0°C, Verlencar, 1990), could also be one of the factors responsible for enhanced level of phytoplankton pigments and primary productivity, (Kopczynska and Ligowski, 1985 and Teixeira *et al.*, 1986). The role of water column stability in promoting the ice-edge abundance of algae appeared to be crucial during the present study.

Integrated values of chl. *a* (0.25-43.60 mg m^{-2}) for the depth column of 0-100 m and column production (1.06-53.33 mg Cm^{-2} h^{-1}) in euphoric zone of 0-45 m depth was also higher than the values obtained by Verlencar *et al.,* (1990) with wide variations in the level of standing crop (50.25-444.88 mg m^{-3}).

Ice sample: First three ice samples were collected from the floating ice of the Antarctic surface waters, which were broken part of either shelf ice or pack ice. These samples were cut from those ice pieces which were looking slightly greenish in colour. The sample no. 4 (Table 4) was collected by cutting the ice piece from ice-edge which was slightly greenish in colour.

Floating ice in Antarctic surface water exhibited high concentration of chl. *a* (39.52-56.80, av. 46.87 mg m^{-3}) and phaeophytin (12.35-20.29, av. 15.99 mg m^{-3}) indicating the existence of high density of algae which was confirmed by the cell counts. Dissolved oxygen in these ice samples varied from 8.5 to 9.5 mg 1^{-1}).

However, very low values of PP (0.27 mg C m^{-3} h^{-1}) as compared to chl.a (96.12 mg m^{-3}) showed markedly low values of photosynthetic rate (AN) varying from 0.003 to 0.009 mg C[mg chl.a]$^{-1}$ h^{-1}, though the samples were incubated in sufficient sunlight.

Antarctic Oceanic Region (50°- 65°S)

Increased temperature (1.5-4.5°C) recorded in Antarctic Convergence (Table 1) did not indicate any relation in particular with chl.a and PP values. This region sustained comparatively lower concentration of DO (8.14-8.24) than that of coastal ice-edge zone. Slight decrease in the level of nutrients phosphate 2.18-3.8, av. 3.03μ mol dm"^{3}, nitrate 12.4-18.9, av. 16.17 μ . mol dm^{-3} and slightly high values of nitrite (2.10-3.98, av. 4.16 μ mol dm^{-3}) as compared to that of coastal ice-edge zone did not show any correlation to chl. *a* and PP.

This region indicated considerable decrease in the concentration of *chl.a* (0.51-1.10, av. 0.74 mg m^{-3}) and PP (0.03-0.44, av. 0.18 mg C m^{-3} h^{-1}) as compared to the coastal ice-edge zone (Figs 2-5). Integrated values of *chl.a* and standing crop (Table 2) ranged between 22.02-44.60 mg m^{-2} and 31.49-73.7 mg dm^{-3} respectively for the depth of 0-200 m and decreased level of column production (0.8-4.25 mg C m^{-2} h^{-1}), was comparable to Verlencar *et al.,* (1990).

Gradual increase of temperature from 65°S to 50°S at Antarctic convergence could not indicate any influence on primary productivity. Low values of chl.*a* and PP recorded in region was due to the instability (El-Sayed *et al.,* 1983, Mandelli, 1965, Hasale, 1969 and El-Sayed, 1987) of water column due to turbulence to deeper layers, prevents algal cells from remaining in the optical light zone, resulting in lower photosynthetic rate (0.05-0.4 mg C [mg chl.a]$^{-1}$ h^{-1}) as compared to the coastal ice-edge zone.

Higher photosynthetic rate at lower irradiance as recorded in coastal ice-edge zone (0.08-0.88 mg C[mg chl.a]$^{-1}$ h^{-1}) could be due to the fact that light energy used by algal cells was adequate to obtain the saturation level, which was similar to an experiment done by Teixeira (1986). Photosynthetic rate (AN) was more than 2 times lower in this zone than Antarctic coastal ice-edge zone.

Vertical distribution of chl. *a* and PP values indicated similar trend of distribution as recorded in coastal ice-edge zone (Fig.2). However, column production for euphotic zone (av. 15.8 mg C m^{-2} h^{-1}) of coastal ice-edge zone was recorded to be more than 8 times more productive than that of Antarctic oceanic region (1.92 mg C m^{-2} h^{-1}).

Holm-Hansen *et al.,* (1977) found the integrated values for chlorophyll in the upper 200 m of Antarctic waters to be averaged to 10.45 mg m^{-2}.

Other Oceanic Regions North of 50° S to Equator

Gradual increase of temperature from 10°C to 29.5°C was recorded in this region (Table 1). Influence of Antarctic waters was recorded upto 45°S, thereby lowering the temperature. The recorded values of DO in the subtropical and tropical regions varied between 3.86-7.72 mg l^{-1} , which were considerably lower than that of coastal ice-edge zone and was comparable to the report of Verlencar *et al.,* (1990).

Highest DO was observed at St. 13 (45°S) in the waters of STC which was influenced by Antarctic oceanic region (Table 1). The concentration of salinity showed gradual increase from 45°S to 0°. However, decreased concentration of standing crop (av. 124.62 mg m^{-3}) as compared to the coastal ice-edge zone indicated towards low productive region. Column production was also comparatively very low (6.71 mg cm^{-2} h^{-1}) which varied from 0.9 to 18.72 mg C m^{-2} h^{-1}, could be attributed to the instability of water column, due to strong Antarctic circumpolar current (ACC). However, standing crop and column production were noticed to be higher than that of Antarctic Oceanic region. Slight increase in the concentration of chl.a and PP were recorded in equatorial water as compared to the waters of 30°-45°S (Table 2). The values of chlorophyll *a* and PP ranged between 0.76- 2.68 mg m^{-3} and 0.04-1.72 mg Cm^{-3} h^{-1} in surface water. Integrated values of chl. *a* (23.6-44.68 mg m^{-2})

recorded in this region was higher than that reported by Verlencar *et at.,* (1990). The column production was 2.4 times lower than the values of coastal ice-edged zone.

Mauritius Coast: Coastal water of Mauritius sustained comparatively low concentration of phosphate (1.25 μ mol dm^{-3}) with an excellent level of chl.a (34.0 mg m^{-3}) indicating the bloom of algae. Such high standing crop as 2278 mg m^{-3} recorded in this water could be due to the extremely massive algal bloom. DO recorded as low as 3.86 mg l^{-1} might be due to the respiration process going on at the time of sample collection during the dark period (2100 hrs). The concentration of salinity amounted to be 36.14 x 10^{-3} (Table 1) did not show any clear relation with the bloom; whereas temperature was lower (24.5°C) as compared to the neighbouring stations. The level of nitrate observed as high as 22.5μ mol dm^{-3} and nitrite 3.88 μ mol dm^{-3} reflected towards the understanding of fertility of the region. Markedly enhanced values of primary productivity obtained at this station (45.5 mg Cm^{-3} h^{-1}) was higher than chl. *a* giving the assimilation number to be 1,34 which was highest of all the stations studied. El-Sayed (1971) reported the similar assimilation number (1.4) at the time of heavy phytoplankton bloom in Weddell Sea.

Phytoplankton

Phytoplankton population varied from 5.63 to 185.44 x 10^4 cells l^{-1} in the coastal ice-edge zone. Marked high population recorded at Sts 2, 3 & 4 was associated with very high level of DO (Table 6), which could be due to the photosynthesis process. Forty-four

Table 6: Distribution of Algal Species at Different Stations (no. x $10^4 1^{-1}$)

Sl. No.	Species	Stations							
		1	2	3	4	5	6	7	8
	Diatoms								
1	*Actinoptychus senarius* (Ehr.)	-	-	-	10.00	0.40	-	-	-
2	*Actinacyclus actinochilus* (Ehr.)	-	-	-	2.00	-	-	0.01	-
3	*Asteromphalus* sp.	0.92	5.00	6.00	-	0.50	0.01	-	-
4	*A. parvulus karsten*	0.02	2.40	-	5.00	-	0.02	-	-
5	*Chaetoceros curvisetus*	-	-	-	-	-	-	0.01	-
6	*C. eibenii*	-	-	3.50	-	-	0.02	-	-
7	*C. negleclus*	1.20	50.50	30.50	10.10	1.50	1.50	2.50	2.00
8	*C. peruvianus*	0.50	15.10	10.50	10.20	0.50	0.20	2.00	0.75
9	*C. dichaeta* (Ehr.)	-	15.10	5.50	-	0.11	-	0.10	0.25
10	*C. socialis* Lauder	-	-	-	-	0.20	0.30	-	-
11	*Corethron criophilum*	-	-	-	-	-	-	0.12	0.01
12	*Coscinodiscus centralis*	-	-	0.50	-	0.01	-	-	0.01
13	*C. concinnus*	-	-	-	-	-	0.20	0.20	-
14	*C. curvatulus*	0.10	3.00	-	-	-	-	-	-

Contd,

Table 6: *Contd.*

Sl. No.	Species	Stations							
		1	2	3	4	5	6	7	8
15	*C. gigus*	-	-	2.00	-	-	0.21	-	-
16	*C. granii*	-	-	1.50	-	-	0.24	-	-
17	*Eucampia* sp.	-	-	-	-	0.91	-	-	-
18	*Fragilaria cylindrus*	1.81	45.43	35.00	10.00	0.01	-	-	-
19	*F. crotonensis*	0.75	13.00	5.00	0.50	0.02	1.55	5.10	3.40
20	*F. nana*	0.10	-	1.50	0.20	0.02	0.20	1.10	2.00
21	*F. oceanica* Cleve	-	-	-	-	-	0.30	0.20	0.20
22	*Licmophora gracilis* (Ehr.) Grunow	-	-	-	-	-	-	0.10	0.10
23	*Navicula directa*	0.02	0.90	-	-	-	-	-	-
24	*N.glaciel*	0.03	2.00	10.20	2.57.	0.20	0.25	1.00	-
25	*Nitzschia closterium* (Ehr.) W. Sm.	0.85	20.00	28.09	2.50	0.75	0.25	1.50	2.85
26	*N. curta*	0.50	2.00	25.00	43.10	1.50	0.20	1.40	-
27	*N.cylindrus*	0.05	5.02	10.00	20.00	0.75	0.50	0.50	2.40
28	*N. panduriformis* Variminor Grunow	0.01	-	5.50	10.50	-	0.50	0.55	-
29	*N. seriata*	0.02	-	-	-	-	-	0.75	3.12
30	*N.sublineata* Haste Grunow	-	0.50	1.50	-	-	-	-	-
31	*Pleurosigma* spp.	0.01	-	-	-	-	-	-	-
32	*Rhizosolenia calcaravis*	-	0.80	2.50	-	-	-	-	-
33	*R. hebetata*	-	-	0.50	-	0.01	-	0.11	-
34	*R. obtusa*	-	-	-	-	0.95	0.50	-	-
35	*R. styliformis*	-	-	-	-	-	-	0.11	0.50
36	*Synedra* sp.	-	-	-	-	0.06	0.20	-	-
37	*Stephanodiscus* sp.	0.01	0.80	-	-	-	-	-	-
38	*Thalassiothrix frauenfeldii*	-	-	-	-	-	-	0.15	0.75
39	*T. longissima* Cleve	-	-	-	-	0.05	0.10	-	-
40	*T. antarctica*	0.03	1.50	1.50	-	-	0.20	-	0.25
41	*T. subtilis* (Ostenf)	0.02	0.50	-	5.00	0.90	0.25	-	-
42	*T. gravida* Cleve	-	·	~	~	~	"	0.50	0.01
	Dinoflagellates								
43	*Peridinium* sp.	-	-	-	-	0.02	0.06	-	-
44	*Phalocroma* sp.	-	-	-	-	0.02	-	0.03	-
45	Unidentified	0.10	0.05	0.15	0.11	0.13	0.12	0.05	0.02

(-) indicates absence of species

species belonging to 19 genera of algae were recorded in the coastal ice-edge zone. Mixed population of common species of *Chaetoceros, Fragilaria* and *Nitzschia* were observed in bloom at Sts 2, 3 & 4 (Table 6) which were associated with high level of chl.a (Table 4), due to the stability (in terms of abiotic and biotic factors) attained by such water masses has evidently provided the necessary conditions for more prolific algal growth (Kopczynska and Ligowski, 1985) as compared to the water masses of different mixing types. Bloom at St. 2 was due to high population of *Chaetoceros neglectus. Chaetoceros neglectus, C. peruvianas, Fragilaria crotonensis* and *Nitzschia cylindrus* were the common species, recorded at these stations. *Nitzschia* was observed to be the dominant genera, at Sts 3 & 4 (36% & 59%) whereas *Fragilaria* was dominant at Sts 6 & 7 (27% & 34%). The species recorded during the present study were comparable to the findings of Ferrario and Ferreyra (1983). Brandini and Kutner, 1986 recorded higher phytoplankton population in the Antarctic waters of Bransfield Strait than that of the present study. The species recorded presently were comparable to the coastal species, studies which clearly indicated the homogeneous distribution of the flora in the waters of Polynya.

Conclusion

Most prominent feature of the present observation is a markedly enhanced production in the coastal ice-edge zone and this zone was to be most productive of all Antarctic, Sub-Antarctic, Subtropical and Central Indian ocean waters. The level of primary production and standing crop in the coastal ice-edge zone indicated an increasing trend as compared to the earlier studies. Such a high production as recorded in this zone could jointly be due to the stability of surface water, availability of nutrients and optimum temperature. Mauritius coastal water exhibited an excellent level of standing crop (2278 mg m^{-3}) indicating massive bloom of phytoplankton. Assimilation number (photosynthetic rate) higher than 1 recorded at Mauritius indicated the phytoplankton cells to be very active, whereas very low assimilation number (lower than 1) recorded in floating ice could give an idea of inactive or unhealthy condition of phytoplankton cells frozen in the ice. The high population of *Chaetoceros* spp., *Fragilaria* spp. and *Nitzschia* spp. in the coastal ice-edge zone could be the means for high population of secondary producers and krills.

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