Nutrients and Phytoplankton Production in the Southern Ocean in a Section 10° to 52°E in the Indian Ocean

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ABSTRACT

Chlorophyll *a* (Chl *a*), primary productivity (PP) and nutrients in the coastal and offshore waters of Antarctica have been studied. Distribution of chl *a* and PP suggests that coastal waters (mean chl *a* 1.72 ± 1.0 µg l^{-1} and PP 1.27 ± 1.0 mgC m^{-3} hr^{-1}) are more productive than the offshore oceanic waters (mean chl *a* 0.28 ± 0.1 µg l^{-1},PP 0.31 ± 0.1 mgC m^{-3} hr^{-1}). The particulate oxidisable carbon(POC) concentrations in the coastal and oceanic waters were high and varied from 0.26 to 3.11 mg m^{-1}. In the surface water nitrate and phosphate values south of the Antarctic Convergence remain high (NO_3 > 17 µ mol d m^{-3} PO_4 > 1.2 µ mol d m^{-3}). High Si values of >28 µ mol d m^{-3} were observed south of latitude 50°S. These decreased to > 6µ mol d m^{-3} towards north.

Urea and ammonia concentrations in the Antarctic waters occur in significant proportions (urea ranging from 0 to 2.37 µ mol d m^{-3}) and ammonia from 0.1 to 2.3 µ mol d m^{-3}), which are available for utilization by phytoplankton. Concentrations of total nitrogen (TN), dissolved organic phosphorus (DOP) was also high (TN ranging from 16.9 to 60.9 µ mol d m^{-3} and DOP from 0.8 to 4.5 µ mol d m^{-3}). A sharp decrease in Si from the Antarctic Divergence up to Subtropical Convergence indicates a higher demand of this nutrient by the Antarctic marine diatoms.

INTRODUCTION

Hydrographic data collected during the First Indian Antarctic Expedition identified various processes like convergence, divergence and upwelling occurring in the Southern Ocean (Rama Raju and Somayajulu, 1983; Sengupta and Qasim, 1983). The bathymetric observations showed that in the Antarctic waters, south of 68°S, the isothermal mixed layer extends upto a depth of 200 to 400 m, while in the other regions this mixed layer goes only up to 100m depth (Rama Raju and Somayajulu, 1983). In the region of Antarctic Convergence (AC), the intermediate, deep and the bottom water layers become more or less continuous giving rise to an exchange of heat and nutrient enrichment of the Antarctic surface waters. Thus the Antarctic waters share some similarities with the upwelling systems off the west coast of South America and Africa. But these regions are relatively much warmer and constitute a very small area. Upwelled water is normally associated with a high rate of biological productivity in the photic zone (Friederick and Codispiti, 1981; Nelson et al., 1981).

However, under extreme situations with unusual combination of the environmental conditions as often seen in the Antarctica, the variability of phytoplankton biomass connot be ignored (E1 Sayed, 1970; El-Sayed and Turner, 1977;Holm-Hansen et al., 1977). This makes it necessary to study the primary productivity of different regions of Antarctica and the variability of the nutrients, so as to get a better understanding of the food web dynamics and the general functioning of the ecosystem.

In the First and Third Indian Antarctic Expeditions (INAEXI and III; Sengupta and Qasim, 1983; Naqvi, 1986), several nutrients such as nitrate, phosphate and silicate were analysed. However, during the Fourth Indian Antarctic Expedition (INAEX TV) an analysis of several other nutrients like urea, ammonia, total nitrogen (TN) and dissolved organic phosphorus (DOP) was carried out along with chlorophyll *a* (Chl *a*) and primary productivity (PP). The data obtained during the present expeditions are examined in relation to those obtained during INAEX I and III.

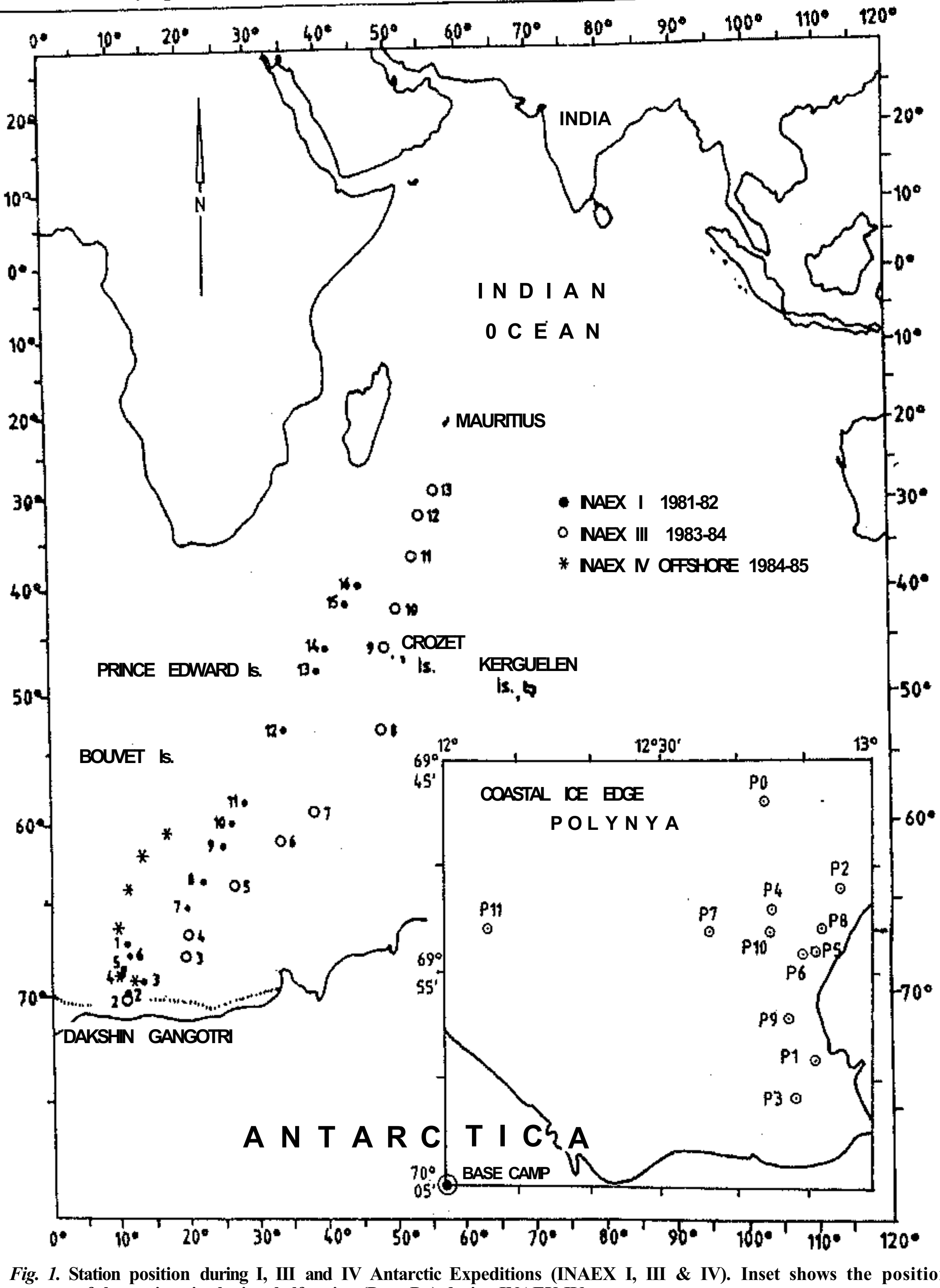

Fig. 1. **Station position during I, III and IV Antarctic Expeditions (INAEX I, III & IV). Inset shows the position of the stations in the ice shelf region (P_0 to P_{11}) during INAEX IV.**

MATERIAL AND METHODS

Oceanographic observations in the euphotic zone during Fourth Indian Antarctic Expedition (INAEX IV) included those in the latitude between 60 to 69°S. These were made during ship's onward journey to the Antarctic continent and thereafter a series of 12 observations were made in a limited area from longitude 12 to 13°E at the coastal ice edge zone during the period extending from December 3, 1984 to February 10, .1985 (see Fig. 1).

Water samples upto 100 m depth were obtained using Niskin bottles. The samples were analysed soon after this collection for NO_3, PO_4, SiO_3, ammonia, urea, total nitrogen, dissolved organic phosphate and dissolved oxygen using standard procedures outlined by Grasshoff (1976). Chlorophyll *a* and phaeopigment were measured fluorometrically (Strickland and Parsons, 1972) using Turner Designs Fluorometer. ^{14}C assimilation was also measured and for this the water samples (125 ml) containing 5 µci were incubated on board for 24 hours and filtered through 0.45 µm millipore filter. The incorporated carbon was measured by liquid scintillation counter. Quench corrections were made using channel ratio method (Herberg, 1965).

RESULTS AND DISCUSSION

From the depthwise study of different oceanographic parameters like temperature, salinity and nutrients (nitrate, phosphate and silicate) during First and Third Indian Antarctic Expeditions (INAEX I and III) the various frontal zones were identified in the region between 10°E to 52°E (Rama Raju and Somayajulu, 1983; Sen Gupta and Qasim, 1983; Naqvi, 1986). The Antarctic Convergence (AC) was identified from south of the latitude 47°S, the Subtropical Convergence (STC) from latitude 38° to 39°S and the Antarctic Divergence (AD) near the latitude 60°S. Temperature and salinity in the surface waters showed a significant variation from the region of STC up to the Antarctic coast 70°S (INAEX I and III).

In this paper we have divided the region between 30°S upto the Antarctic coast 70°S into different zones.

1. Coastal ice edge zone

The temperature recorded in the upper 10 m water column during the 2 months period (January to February, 1985) usually remained below 0.5°C (Fig. 2). The isotherms during most of the period ran vertically (Fig. 2). The surface salinity remained low indicating the effects of melting ice. Variation in density followed the changes in salinity (Fig. 2). Chlorophyll *a*, primary productivity and particulate oxidisable carbon (POC) values in the euphotic zone varied between 21 to 86 mg m^{-2}, 0.3 to 1.0 g C m^{-2} day^{-1} and 14.3 to 67.8 g m^{-2} respectively (Fig. 3 and Table I). These values agree with those reported by El-Sayed (1967) for the most productive regions of the Weddell Sea. PP in general did not show a definite pattern from surface to the depths below. However, the surface water samples when subjected to different light intensities, it was found that ^{14}C assimilation was higher at depths corresponding to 30% of the surface light intensity. This may suggest optimum light conditions for photosynthesis at that depth. ^{14}C assimilation in water samples filtered with 20µ mesh net indicated that the smaller size fraction of phytoplankton are responsible for more than 65% of primary production as compared to net plankton.

2. Antarctic oceanic region south of 58°S

The temperature variations in the oceanic region were almost similar to those of the coastal stations, but the salinity showed slightly higher values (Table I). Similarly the nutrients especially nitrate and silicate showed much higher concentrations in the oceanic region (mean: NO_3-N 20.2 ±

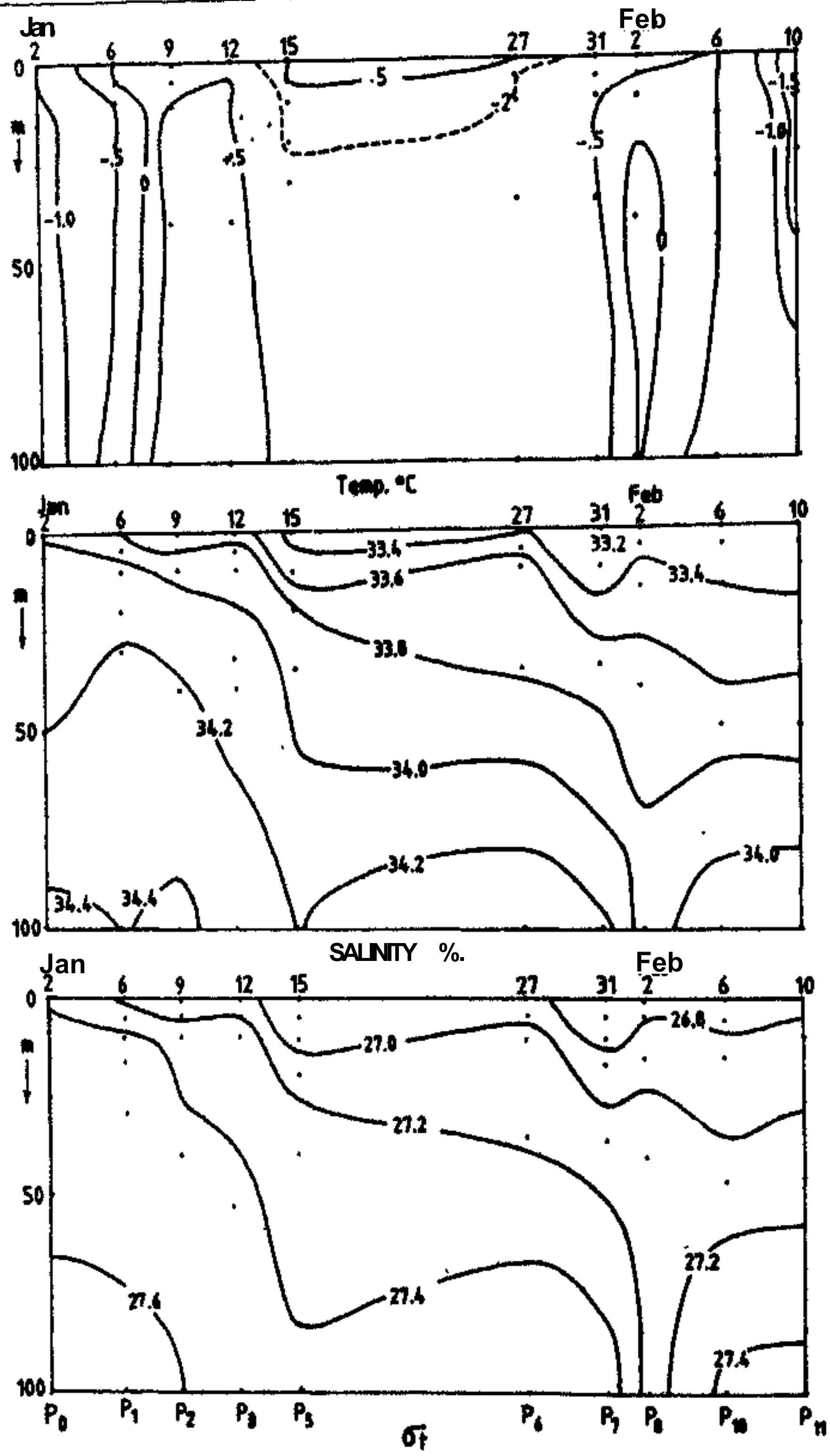

Fig. 2. **Distribution of temperature, salinity and σ_t in the coastal (ice shelf) region during the austral summer (January-February 1985; INAEX IV).**

TABLE I

Maximum, minimum and mean values of diiferent parameters at the coastal ice edge and at the Oceanic Stations in the region south of 60°S Latitude.

Environmental features	Coastal region					Oceanic region				
	Min	Max	Mean	S.D.	n	Min	Max	Mean	S.D.	n
Temperature °C	-2.0	1.0	-0.43	±0.69	55	-2.0	0.5	-0.38	±1.13	19
Salinity X 10^{-3}	33.17	34.45	33.81	±0.37	55	33.87	34.81	34.40	±0.31	19
Sigma-t	26.66	27.75	27.18	±0.29	55	27.17	28.52	27.66	±0.28	19
Urea μ mol dm^{-3}	0	2.37	0.59	±0.39	55	0.2	2.03	0.84	±0.54	19
Ammonia μ mol dm^{-3}	0.05	2.21	0.54	±0.44	55	0.14	2.31	0.75	±0.56	19
Nitrate μ mol dm^{-3}	7.82	23.1	15.12	±4.05	55	20.19	29.50	24.70	±2.66	19
Nitrite μ mol dm^{-3}	0.02	0.4	0.16	±0.13	24	0.01	0.33	0.14	±0.10	14
Phosphate μ mol dm^{-3}	0.60	3.0	1.53	±0.53	55	1.71	2.35	1.97	±0.17	19
Silicate μ mol dm^{-3}	26.50	54.1	34.91	±6.22	55	50.30	65.28	55.73	±4.07	19
Total N μ mol dm^{-3}	16.9	31.4	21.6	±4.2	39	24.4	60.9	33.1	±9.6	14
D.O.P. μ mol. dm^{3}	0.8	2.9	1.67	+0.6	39	1.3	4.5	2.82	±0.9	14
Chl *a* mg m^{-3}	0.05	4.07	1.72	±0.99	39	0.11	0.55	0.28	±0.14	14
Phaeophytin mg m^{-3}	0	0.12	041	±0.02	39	0	0.1	0.05	±0.04	14
Primary Productivity mg C m^{-3} hr^{-1}	0.08	3.65	1.27	±0.96	39	0.15	3.30	0.31	±0.14	14
POC mg 1^{-1}	0.35	3.11	0.99	±0.62	39	0.26	1.04	0.57	±0.22	14

2.7 μ mol. dm^{-3}, PO_4-P 1.97±0.2 μ mol. dm^{-3} and SiO_3 55.7 ± 4.1 μ mol. dm^{-3}) as compared to those in coastal ice edge waters (Table 1 and Fig. 3). However, the chlorophyll *a* and primary productivity values at the oceanic region (mean values PP 0.24 gC m^{-2} day^{-1} and Chl *a* 7.92 mg m^{-2}) were relatively lower than those in the coastal waters (mean PP 0.75 gC m^{-2} day^{-1} and Chl *a* 54.3 mg m^{-2}; see also Table I). The observations on the primary productivity and phytoplankton biomass suggest that the waters at the continental ice edge are more productive than those in the oceanic region (El-Sayed et al, 1983; El-Sayed and Taguchi, 1981; Fogg, 1977).

POC values were high and varied from 0.26 to 3.11 mg 1^{-1} both in the coastal and oceanic waters. POC values were significantly correlated with Chl *a* and PP values (*r* values being 0.46 and 0.44 respectively at n= 53.) Similarly Chl *a* was significantly correlated with PP (r= 0.49; n= 53.) This suggests that Chl *a* contributes largely towards PP and POC content in the Antarctic waters.

3. Other oceanic regions, north of 58°S

From the data obtained during INAEX I and III, it could be seen that the phytoplankton biomass and productivity in the region north of the latitude 58°S and beyond STC showed fluctuations (Fig. 3). Chl *a* ranged between 7 and 64 mg m^{-2} and PP from 0.05 to 0.55 gC m^{-2} day^{-1}. There appear to have no definite pattern of distribution. Similarly, zooplankton biomass with vertical hauls showed highly fluctuating values (Fig. 3). Nutrient distribution showed that while NO_3 and PO_4 remained constantly high in the surface waters in the entire region south of the AC (NO_3 > 17 μ mol dm^{-3} and PO_4 > 1.2 μ mol dm^{-3}), the Si values showed more pronounced changes (Fig. 3). High silica values of

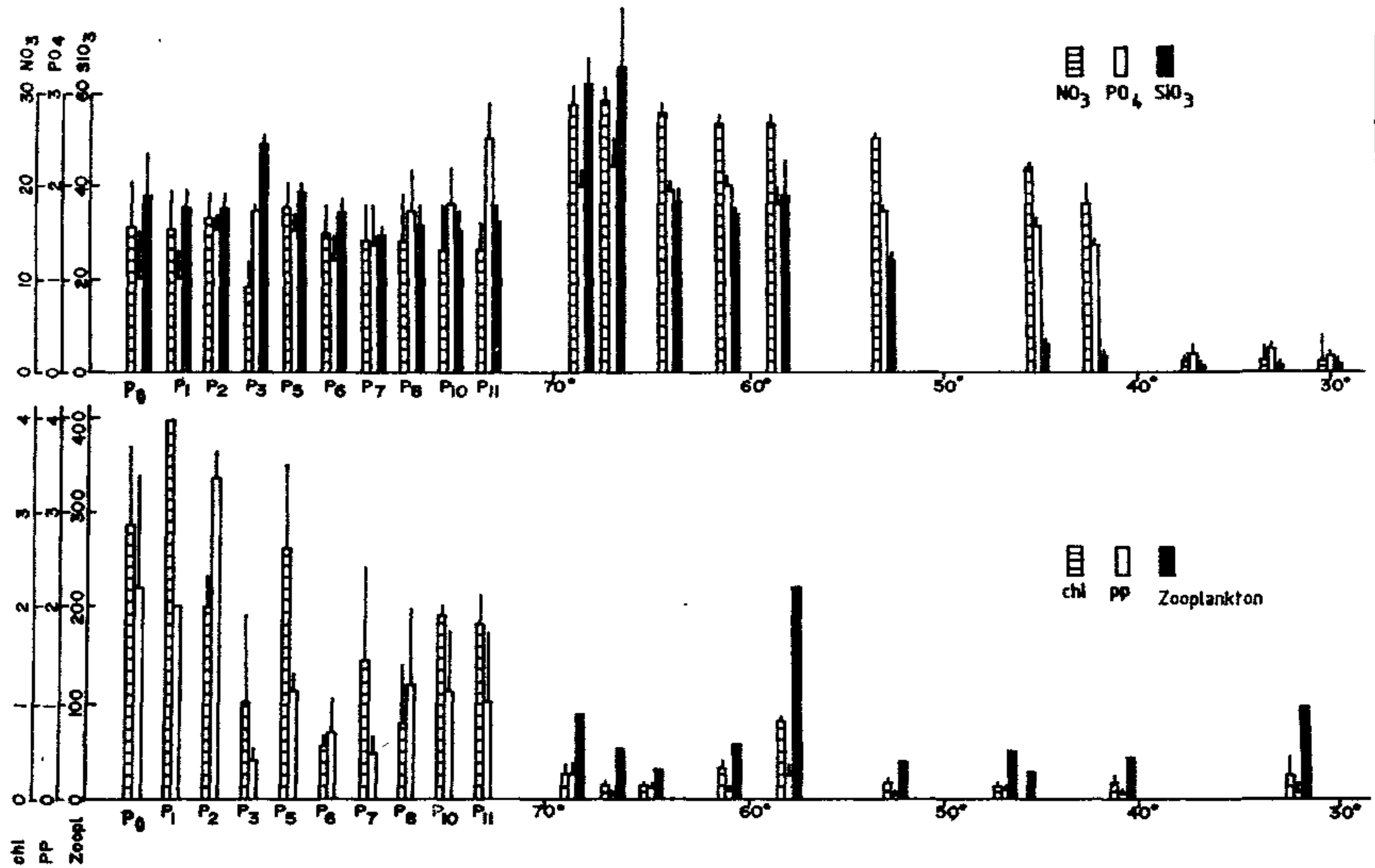

Fig. 3. Variation in nutrient concentrations, chlorophyll, rate of primary production and zooplankton biomass in the upper 100m water column: *(a)* nitrate, phosphate and silicate at the coastal ice edge (P_0 to P_{11}; INAEX IV) and in the transect between 70° to 30°S latitude (INAEX III); *(b)* Chlorophyll *a* (Chl *a*) and primary productivity (PP) at the coastal (ice shelf)region(P_0 to P_{11};INAEX IV) and Chl *a*, PP and zooplankton biomass (vertical haul upto 1000m in depth; INAEX I) in a transect between 68° to 40°S latitude.

more than 28 µ mol dm^{-3} were often found south of 53°S latitude and decreased to less than 6 µ mol dm^{-3} towards north. In the Southern Ocean, Matondkar and Qasim (1983) noted that the chlorophyll biomass ratio between net plankton and nannoplankton was nearly equal to 1. These authors further indicated that the average production by net phytoplankton (2.11 mgC m^{-3} day^{-1}) was less than that of nannoplankton (< 20 µ) production (2.33 mg C m^{-3} day^{-1}). In the western Antarctic Ocean, Brockel (1981) has also reported that nannoplankton organisms were responsible for more than 90% of the production. The results on Chl *a* and PP in different size fractions of phytoplankton in the oceanic region and those in the ice shelf region obtained in the present study suggest that nannoplankton contributes to substantially high portion of phytoplankton production in the Southern Ocean.

The most prominent feature of these observations is the markedly high production in the coastal (ice shelf) zone of Antarctica as compared to the rest of the Antarctic, Sub antarctic and Subtropical regions. Nutrient contents did not indicate any link with the productivity. However, sharp reduction in silica from the region of divergence upto AC (Fig. 3; Sengupta and Qasim, 1983;Naqvi, 1986) may represent some link with the utilization of this nutrient by the Antarctic diatoms and its subsequent remineralisation. Ks values for Si for certain diatom species (*Nitzschia* species Ksi= 12 to 22µ mol. dm^{-3}; Jacques 1983; *Corethron criophilium* Ksi = 59.6 µ mol. dm^{-3}, *Nitzschia Kerguelensis* Ksi= 89.4 µ mol. dm^{-3}; Sommer, 1986) are high and some times exceed the ambient Si concentration in the surface Antarctic waters. This shows a high relationship between Si and the Antarctic diatoms. High concentration of particulate Si at the polar front and in the southern region (Copin Montegut and Copin-Montegut, 1978), further confirms the high incorporation of biogenic Si in marine diatoms. However, the affinity constant for NO_3 was reported to be low (Ks = 4.4 µ mol dm^{-3} for *Nitzs-Chia cylindrus* (Sommer, 1986), and the Antarctic phytoplankton are known to prefer reduced N sources like NH_4 and urea (Probyn and Painting, 1985; Koike et al., 1986). The urea and ammonia concentrations in the region south of 60°S and in the coastal (ice shelf) zone were found to be high and varied from 0.14 to 2.31 µ mol dm^{-3} and 0.2 to 2.03 µ mol dm^{-3} respectively (Table I). Ammonia values were negatively correlated with the phytoplankton biomass suggesting its biogenic uptake by phytoplankton (El-Sayed et al. 1983). Ronner et al., (1983) have indicated that mineralization of the organic matter leads to faster recyling of nitrogen upto 8 times in the surface waters. Excretion from zooplankton may also contribute to a substantial amount of N in the form of ammonia (Biggs, 1982; Koike et al., 1986). Total nitrogen content in these waters varied from 17 to 61 µ mol dm^{-3} and during its decomposition could substantially contribute to the ammonia content (Hattori, 1982). Dissolved organic phosphorus was also found to be high and varied between 0.8 to 4.4 µ mol dm^{-3}. Si on the other hand is progressively utilised by the diatoms whose frustules disappear rapidly from the surface waters without being quickly remineralised (Jacques, 1983).

It can be stated, therefore, that Si pool in the Southern Ocean is replenished by the influx of Si rich water by the vertical eddy diffusion and advection. A sharp decrease in its concentration around the Antarctic convergence zone suggests its high utilization with comparatively low remineralization in the surface waters or its low replenishment from the bottom water. Persistently, the highNO_3 and PO_4 concentrations in the surface waters to the south of AC, on the other hand, suggest that besides their influx by the above processes, the remineralization of these nutrients was high in the surface waters as well (Ronner et al., 1983; Hargrave and Green, 1968). The N:P ratios of the subsurface and deep waters obtained from the results of INAEX I and III observations were 19 and 13.5 respectively (Sengupta and Qasim, 1983; Naqvi, 1986) which are close to the Redfields value of 16 and the Si:N ratio is more than one for the Southern Oceans.

ACKNOWLEDGEMENTS

Authors wish to thank Shri B.S. Ingole, M. Manoharan (participants) and D.K. Pandey, Deputy Leader of the expedition for their help. One of us (X.N.V.) is deeply indebted to Director, NIO and Dr. S.Z. Qasim, Secretary, DOD for their help. Thanks are also due to Dr. B.B. Bhattacharya for his interest in this work and to the Captain, officers and crew of M.V. *Finnpolaris* for their help and co-operation.

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