

## **Ecosystem Characterization in Indian Ocean Sector, Antarctica**

S.G. PRAEHU MATONDKAR, V.K. DHARGALKAR and A.H. PARULEKAR

National Institute of Oceanography,  
Dona Paula, Goa-403004

### **Abstract**

High Chl *a* values characterized the surface water (0.445 - 2.085 mg m<sup>-3</sup>) and column (14.63 - 105.46 mg m<sup>-2</sup>). The rate and magnitude pattern of production varied under pack ice influence and also in offshore region. The divergence zone is most pronounced, which makes Indian Ocean sector an upwelled area marked by high nutrients, appreciable growth rate of phytoplankton and rich organic matter in the water column.

The fractionation studies revealed the importance of picoautotrophs and picoheterotrophs in food chain. The bacterioplankton equals the zooplankton biomass, at second trophic level. The zooplankton biomass recorded was 100 g/1000 m<sup>3</sup>, 50 g/1000 m<sup>3</sup> being krill. The 50% of zooplankton was copepods alone. Its relation to fronts, blooming nature of plankton and other components of ecosystem is assessed and discussed, for delineating ecosystems in Antarctic marine environment.

### **Introduction**

As one sails southward in the Southern Ocean the biological life in the form of birds, seals and whales is clearly discernible. In pack ice, below the shelf and in retreating ice-edges, discolouration due to phytoplankton, ice-algae and krill is visible. Nets towed for zooplankton in polynya gets clogged with blooming algae during austral summer. Pack ice drilled during winter shows remarkable growth of ice-algae within and undersurface of ice and diatoms in surface waters. It is predicted that the Antarctic Ocean can sustain a krill harvest of 100 million metric tons a year, more than present total world fish harvest of about 84.9 million tons per year (Saharage, 1988). This suggests either very high biological productivity or short and efficient food chain. However, presently there is no agreement on either hypothesis.

Recently, it is reported that significant oceanographic events occur with dramatic biological effect. During BIOMASS expedition, a supraswarm of krill struck near Elephanta island was estimated to be 10 million tons of harvestable

size krill (Shulenberger, 1983). In other events, krill were virtually absent in Antarctic Ocean during 1983-84 winter (Heywood *et al.*, 1985). Massive mortality of birds was observed in Antarctica during 1983-84, yet the cause could only be speculated. Since krill is the key organism linking to all the happenings in Antarctic waters, the ecosystem can be characterised studying krill and its environment, in space and time.

Antarctic ecosystem is often characterized by an extreme range of environmental conditions. The physical structure of this system is reviewed by Backer (1979), Bryden (1983), Nowlin and Klinck (1986), Gordon and Owens (1987); plankton and productivity by El-Sayed (1988); benthos by Knox and Lowry (1977), Dayton *et al.* (1986); ice communities by Bunt and Lee (1972), Horner (1976) and vertebrate by Laws (1977). These reviews indicate a wider body of information on this unique habitat and each condition has a direct impact on growth, accumulation and distribution pattern of biological components of ecosystem. The special combination of these conditions give rise to the concept of Antarctic ecosystem. This paper assesses the characteristics of this ecosystem specially of Indian Ocean Sector based upon the data collected during 1982-89 period.

### Material and Methods

The station position sampled during 1982-87 period is shown in Fig. 1 and that of 1989 in Table 4. The winter samples under pack ice were taken by drilling ice. Ice-algae was studied by melting ice in laboratory, and then processing as per normal water samples.

Water samples were collected at standard light depths (100-1%) and prefiltered through 200  $\mu\text{m}$  mesh netting to remove zooplankton. Nutrient and physical oceanographic data were collected routinely as described earlier (Naqvi, 1986).

Autotrophic picoplankton were enumerated by epifluorescence microscopic technique during bacterial counting. Total bacteria were counted with an epifluorescence microscope (Olympus BHF) by acridine orange total count method and viable fraction by plate counts. Frequency of dividing cells (FDC) was assessed according to Hagstrom *et al.* (1979). A minimum of 20 dividing cells per filter were counted.

The method for phytoplankton biomass (Chl *a*), primary production (PP) growth rate ( $\mu$ ), particulate organic carbon (POC), Adenosine tri-phosphate (ATP), zooplankton biomass, taxonomy, benthic biomass and groups are as described earlier (Matondkar and Qasim, 1983; Parulekar *et al.*, 1983; Mathews, 1986). The stations in pack ice were repeated every year. The stations

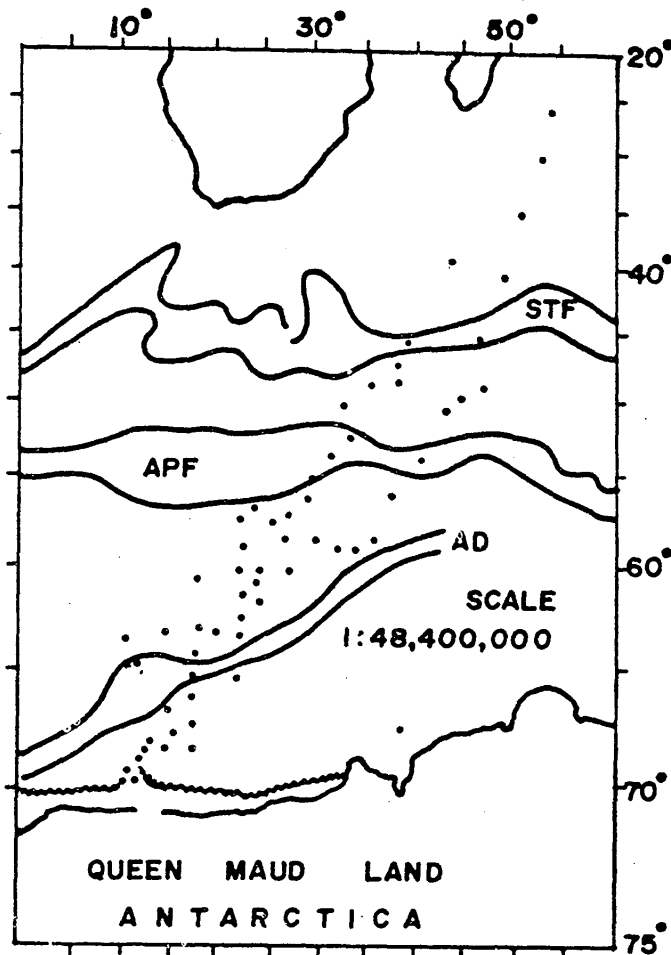


Fig. 1. Station position in the Indian Ocean Sector

with surface Chl *a*  $1 \text{ mg/m}^{-3}$  is classified as bloom stations. The pack ice affected area is described as zone I and offshore as zone II in the present study.

The interrelationship in between biotic components is worked out by regression analysis using standard programmes.

## Results and Discussion

### 1. Physical characteristics

The hydrographic fronts like Sub-Tropical Convergence (STC), Antarctic Convergence (AC), and Antarctic Divergence (AD) being driving forces and are important characteristics of this ecosystem. The probable position of these fronts in Indian Ocean Sector, derived from available information is presented

in Fig. 1. From this it appears that the AD, running tangentially in Indian Ocean Sector influence the major area. The melting of winter ice is seen extended upto edge of the permanent ice-shelf making entire zone I ice free during summer. Calving and melting underneath the permanent ice-shelf was also noticed extensively in this area. The intense storm reaching up to 80 knot, results in drifting of 99% winter pack ice. The polynea formation at 69°S, 12°E is more or less a permanent feature. The high pressure areas were seen near continent and low pressure in offshore areas: The bathymetry of offshore region is irregular with ridges and seamounts influencing the water movement specially in wide divergence zone. The entire study area seems to be an upwelling system whose large scale physical oceanography is dominated by circumpolar and coastal currents, distributing upwelled water homogeneously in entire Indian Ocean Sector of Antarctica.

The lowest water temperature recorded was  $-2^{\circ}\text{C}$  during January, height of the summer in zone I (Fig. 2). An interesting characteristics is the stability

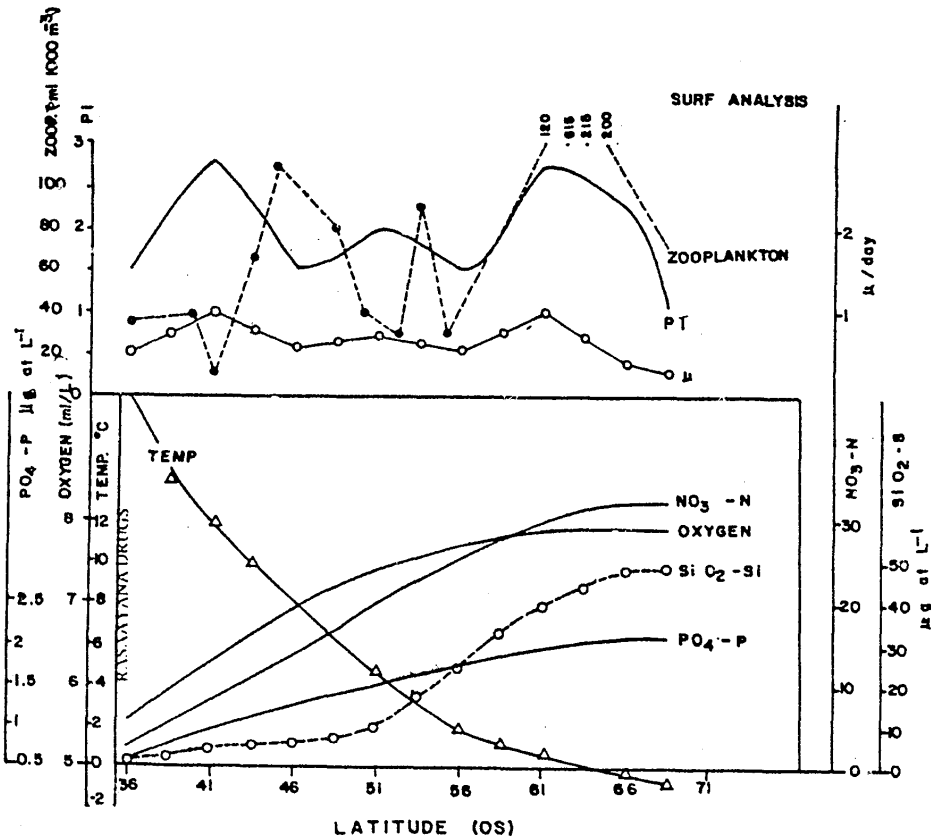


Fig. 2. Physico-chemical conditions and phytoplankton growth

of the temperature regimes, inspite of being low. The salinity data is specially interesting from zone I where salinity ranged from 33.17 to 34.45‰. These variations were particularly reflected in Sigma-*t* ranging from 26.66 - 27.75 and may be due to addition of melt water during summer. In zone II, the higher salinity, temperature and Sigma-*t* were recorded (Naqvi, 1986). The average of surface water south of AC was 27.68‰ reasonably higher compared to 27.75‰ that of pack ice influenced area.

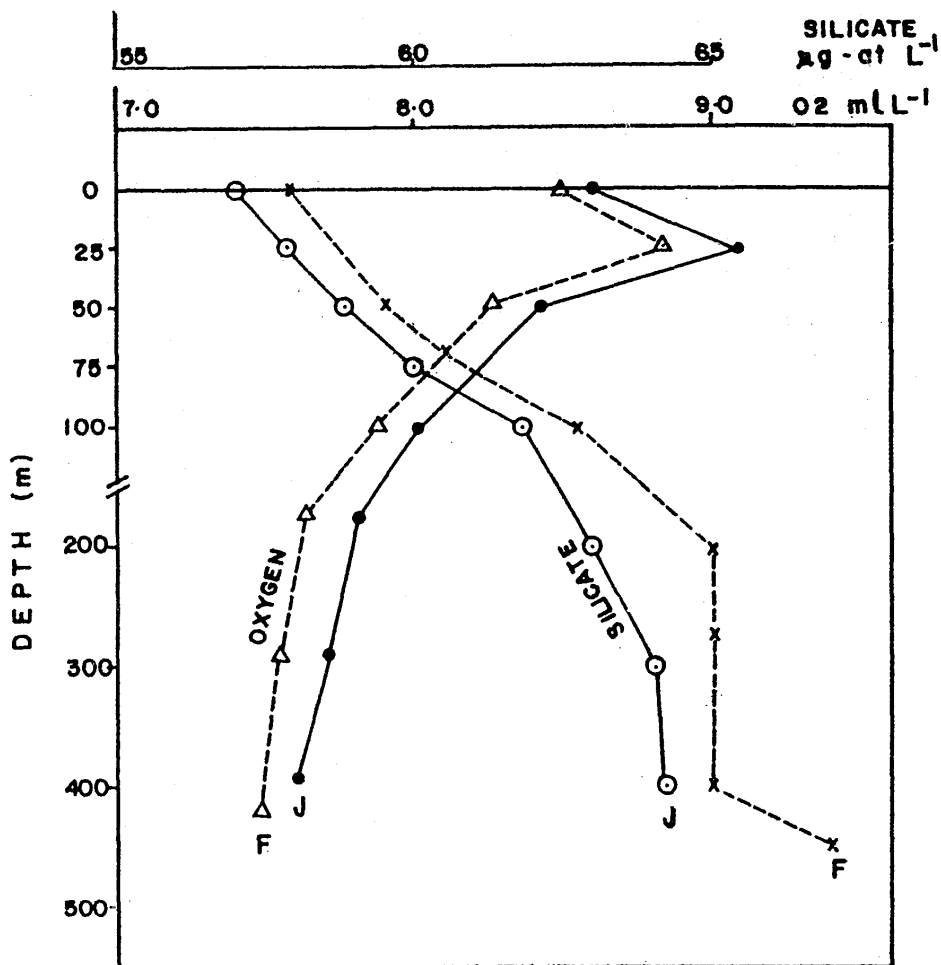
The watermass during austral summer (Jan.- Feb. 1984) in pack ice showed stable temperature regime (<0.5°C), whereas salinity was low, which reflected in density, forming the unique Antarctic surface water which is known to flow in different world oceans.

## 2. Chemical characteristics

As seen in Fig. 1, the divergence zone extends from 58°S - 68°S in Indian Ocean Sector making this as the continued upwelling area, resulting in very high nutrient concentrations in 0 - 100 m column during December-March season (Naqvi, 1986). In zone I and II nitrates and silicates were in excess (NO<sub>3</sub> 15.12 & 25.8, SiO<sub>2</sub> 54.1 and 55 and PO<sub>4</sub>-P 1.53 and 1.95 µg at.l<sup>-1</sup>, respectively). The homogeneous distribution of phosphate and silicate indicates an equal productivity potential of zone I and II respectively, since P and Si are biologically most required element by diatoms and bacterial communities. However, in some areas, decrease in nutrient level is apparent during austral summer as seen in silicate variation in pack ice area during peak summer (Jan-Feb.) months (Fig. 3). It is quite evident that silicate pattern was altered in water column coupled with oxygen pattern. Thus, in Antarctic Ocean, besides the influence of nutrients to autotrophs, the activity of autotrophs appear to be altering the distribution pattern of the inorganic nutrients like phosphate, nitrate and silicate in the water column.

As seen from the data collected during 1982-85 period, the high level of nutrients were found near AD where nitrate, phosphate and silicate concentrations were 26, 2.0 and 60.0 µg at.l<sup>-1</sup> respectively, probably the highest in any surface waters of the world oceans. From the data, it is also understood that, the frontal zones of the Indian Ocean Sector are not only well marked hydrographic structures but major boundaries in nutrient distribution. Because of extensive stretch of AD in study area, the nutrient richness of Indian Ocean Sector of the Antarctic Ocean is more than Atlantic and Pacific Sectors.

As shown in Fig. 1, the Sub Antarctic Convergence which is the northern limit of the Southern Ocean, coincides with the dramatic decrease in nitrate and



PATTERN OF MONTHLY VARIABILITY IN CHEMICAL PARAMETERS

Fig. 3. Season and nutrient pattern.

phosphate in the Indian Ocean Sector (Fig. 2) which is characteristically different than that of other sectors of the Antarctic Ocean.

A very significant biological consequence of the upwelled nutrients from the deep water south of AC is that inorganic nutrients needed for phytoplankton will never be depleted.

Although the utilisation of nutrients by phytoplankton at low temperature is a debatable proposition, the depletion reported from ice-zone was as weak as open ocean water (Priddle *et al.*, 1986). However, the patchy distribution of photosynthetic organisms in Indian Ocean Sector, as observed during 1982-89

period was not only because of excess nutrient but was due to light regime around cells in surface and water column. The light regime is of special interest in this area since the different types of water masses like Antarctic Surface Water (ASW), Antarctic Intermediate Water (AIW), Circumpolar Warm Deep Water (CWDW) and Antarctic Bottom Water (ABW) combine and emerge as turbulent areas.

### 3. Light environment

The qualitative and quantitative effects of light on Antarctic ecosystem is presented in Figs. 4, 5 & 6. The subsurface maxima in assimilation number of

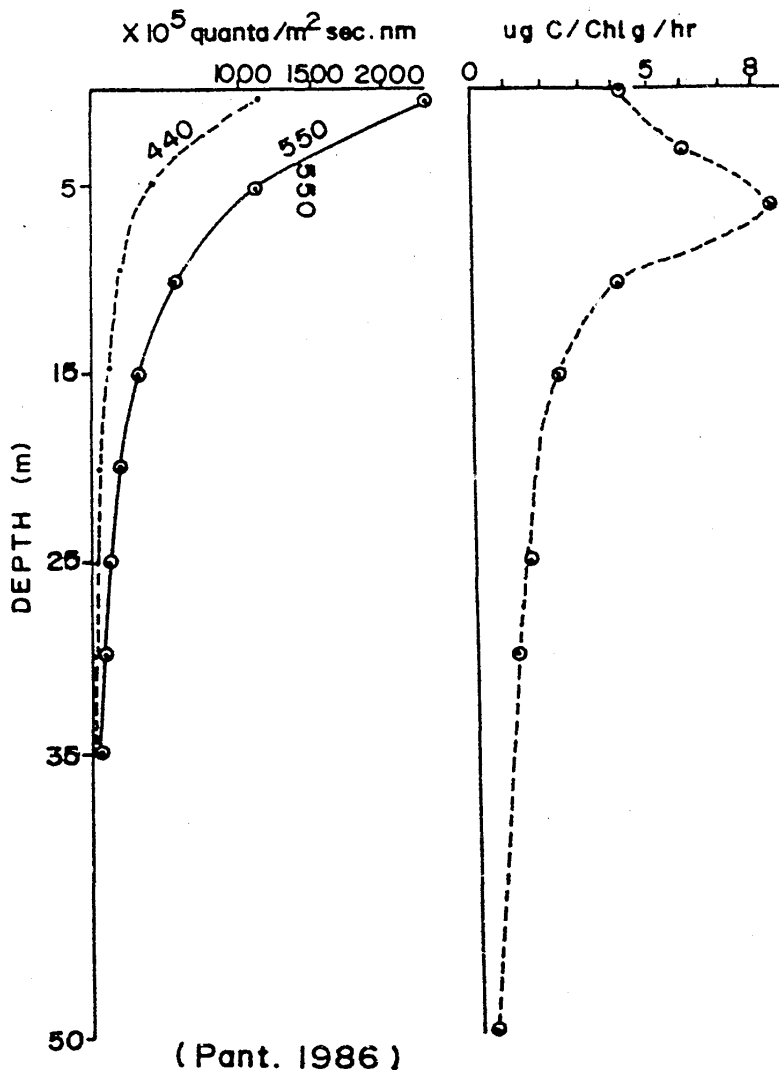


Fig. 4. Light and photosynthesis

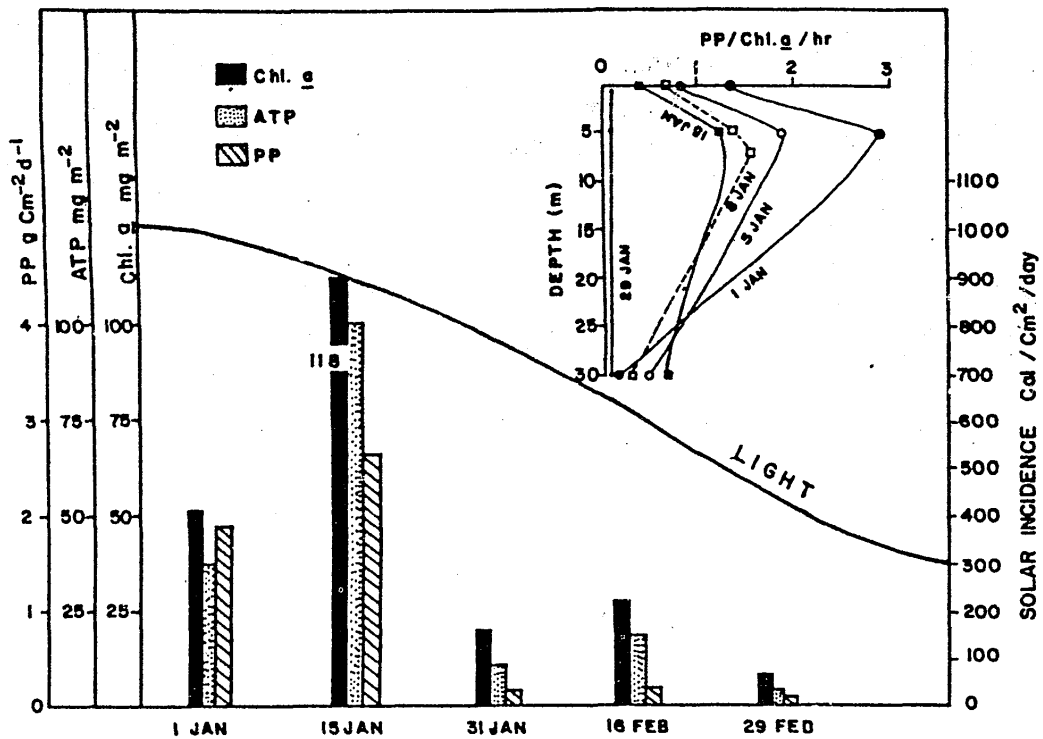


Fig. 5. Effect of light on water column biology

phytoplankton was clearly seen as a function of quantum of light available. However, when less light was available due to cloud or season, the surface maxima were recorded in assimilation numbers (Matondkar and Qasim, 1983). At ice-edge the drastic lowering of the Chl *a*, PP and ATP were recorded with reference to lowering of quantum of light, available. The climatic data collected during 1982-89, when plotted against production of algae, bring out the negative effect of cloud cover on productivity of region to a certain extent (Pant, 1986). During 1984, it was observed that, after winter, when days get longer and nights get shorter until October, phytoplankton blooms of *Chaetoceros* sp, *Fragillaria* sp. and *Navicula* sp. develop under winter pack ice. However, these organisms are well shade adapted and inhibit growth and production during intense light regime during December-January. The sizable portion of organic matter synthesized gets exuded, extracellularly during January (Pant, 1986). Most of the time, low molecular weight compounds released, form the base of the microbial loop which is a most important step in the Southern Ocean ecosystem during adverse climatic conditions. Recently, evidence has accumulated that, surface turbulence interfere with light environment (Fogg, 1977). Turbulence leads to deepening of mixed layer. The Indian Ocean Sector has



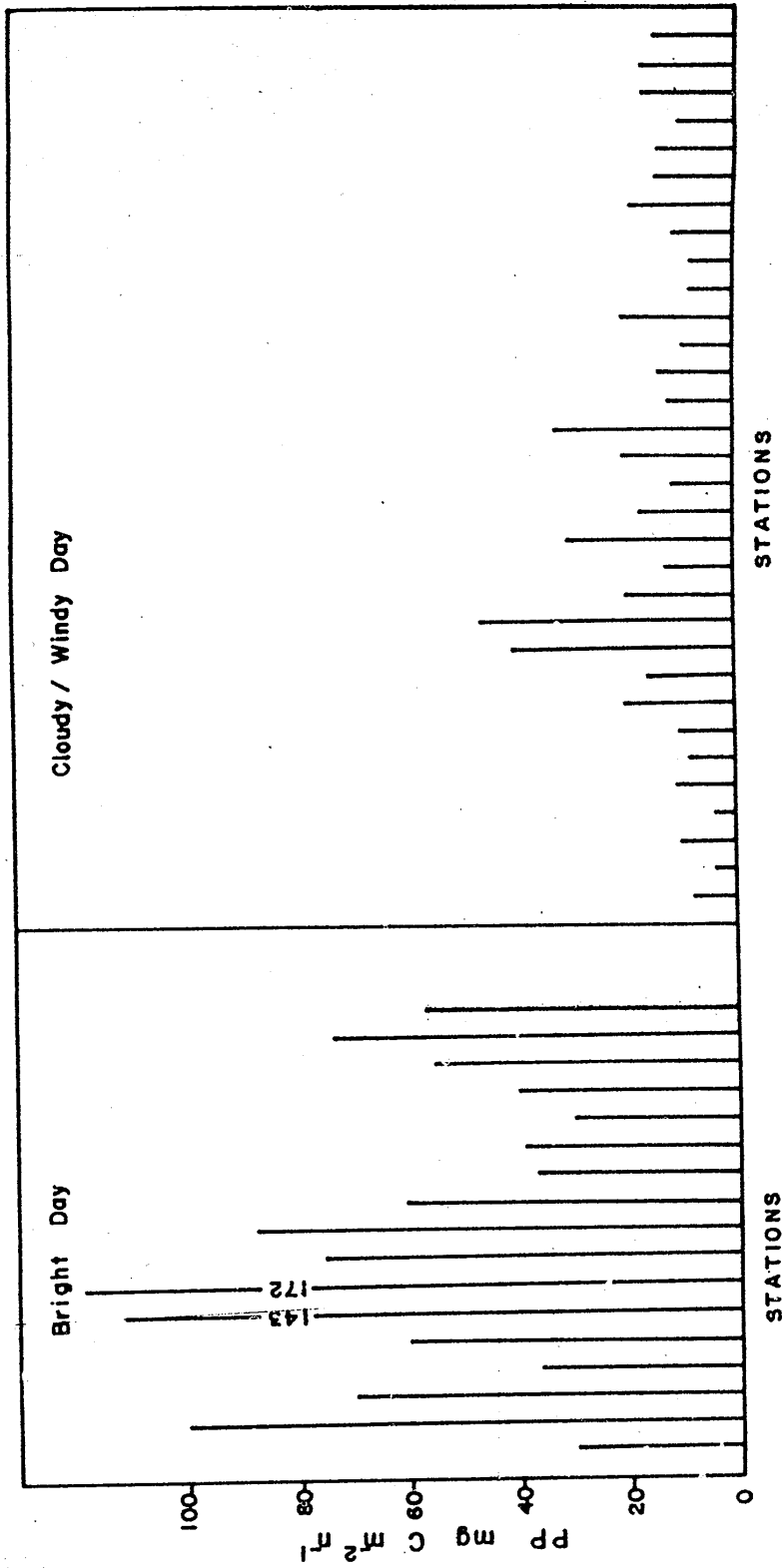


Fig. 6. Cloud and phytoplankton productivity

high and variable winds which deepen depth of mixed layer as deep as 600 m in the study area, making light as the most limiting factor. The bloom areas have indicated the depth of mixed layer to be 20 - 40 m; average being 30 m. Abundance of chlorophyll *a* is seen upto 200 m in the Antarctic Ocean, however may not be producing much, due to the non-availability of light. Sometimes due to water movement, these cells may be exposed to light for one or other time thus contributing to the economy of this area.

Near Antarctic Divergence there is a strong upward component of water movement (Naqvi, 1986). It leads to a light environment with net upward flux. Such conditions support a high productivity local areas, further enhancing biological productivity in term of higher and lower trophic level organisms.

#### 4. Organism at lower trophic levels

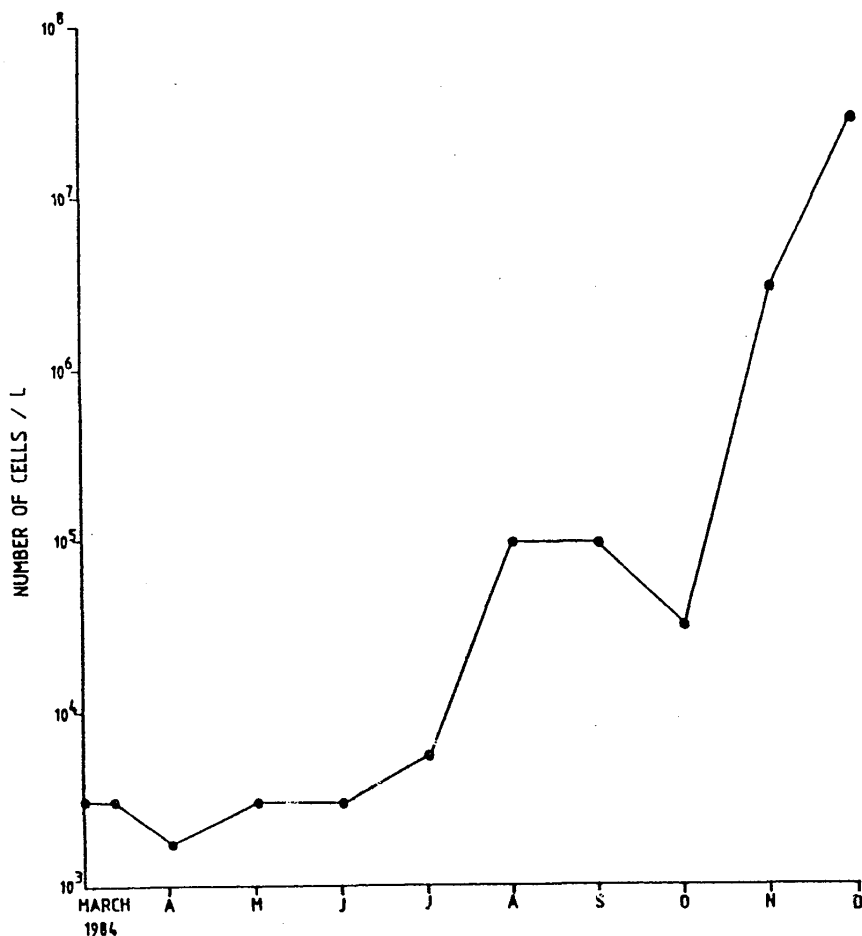
##### Phytoplankton

The phytoplankton is the first step in the Southern Ocean food chain as in other oceans. The only characteristics difference is with respect to number of taxonomic groups. Only 28 species belonging to 23 genera were recorded earlier from this area (Goes and Devassy, 1983), where majority were diatoms. Their relative importance varied in space and time (Pant, 1986). However, fewer groups like *Chaetoceros* sp., *Fragilaria* sp. and *Navicula* sp. were dominating under pack ice during spring '85 (Verlencar et al., 1990). The importance of this community in the Southern Ocean ecosystem is well documented (Priddle et al., 1986; Bodungen et al., 1986; Smith and Schanck-Scheil, 1990) and the population appears to be suboptimally growing entities. However, from our results from Indian Ocean Sector, the growth of phytoplankton is quite appreciable (Figs. 2 and 7).

As presented in Tables 1 and 2, around 36% stations occupied were bloom stations across the track. The blooms of phytoplankton were recorded in zone I and II, respectively. However, the biomass level and pattern of growth of phytoplankton in both the zones is well comparable. The high primary production in zone I is mainly due to water column stability (due to ice melting), well sunlight euphotic zone (<50 m) and psychrophilic type of flora efficient at low temperature. However, rich productivity in zone II is mainly due to continuous supply of fresh upwelled nutrients and growth regulators, mainly because of Antarctic divergence.

As seen in Fig. 2, the low temperature in zone I ( $-0.5^{\circ}\text{C}$ ), do not affect the growth ( $\mu$ ) and photosynthetic index (PI) of phytoplankton. Average growth rate of 0.5 db/day was recorded for the entire study area and at AD growth rate of 1.0 db/day was recorded. The low values were found in pack ice zone (0.25

db/day) during austral summer (Fig. 2). The PI values varied from 1.5 to 3.0 pp Chl  $a^{-1}$  and low PI of  $<1$  at AD may be due to high turbulence identified with a divergence zone. However, as seen in Fig. 2, consistency in growth rate and photosynthetic index was seen irrespective of zone and environmental changes. This suggests that, across transect, the phytoplankton communities are well adapted to hydrographic front, pack ice influence and different types of water masses. The POC and ATP data confirm the productivity of the area (Tables 1 & 2). During winter, light virtually limits the phytoplankton growth and shade adapted communities grow down side of pack ice contributing significantly in primary productivity of the region. The level of organic matter in water column during winter was also optimum, thus indicating that the ice associated phytoplankton processes are dominant during winter (Dhargalkar and Verlekar, 1992).



PHYTOPLANKTON COUNTS UNDER SEA ICE, ANTARCTICA.

Fig. 7. Pack ice phytoplankton

Table 1 : Chl a, PP, ATP and POC in surface and column

	(Zone I) (Ice-edge, polynya, shelf)	
	Bloom	Non Bloom
# Chl a (mg m <sup>-3</sup> )	2.085±0.615	0.51±0.309
## Chl a (mg m <sup>-2</sup> )	105.46±11.65	26.377±13.683
# PP (µg C l <sup>-1</sup> d <sup>-1</sup> )	36.95±29.8	15.46±14.14
## PP (µg C l <sup>-1</sup> d <sup>-1</sup> )	1.426±0.971	0.535±0.435
# ATP (mg m <sup>-3</sup> )	2.667±1.77	0.958±1.29
## ATP (mg m <sup>-2</sup> )	150.4±78.5	33.23±21.35
# POC (mg C m <sup>-3</sup> )	763.5±594.16	580.63±427.54
## POC (g C m <sup>-2</sup> )	59.78±32.74	22.99±13.68
No. of observations	8	20
# Surface		
## Column 0-100 m		

Table 2 : Chl a, PP, ATP and POC in surface and column

	(Zone II) (off shore)	
	Bloom	Non Bloom
# Chl a (mg m <sup>-3</sup> )	3.57±2.35	0.445±0.364
## Chl a (mg m <sup>-2</sup> )	94.639±60.93	14.63±12.2
# PP (µg C l <sup>-1</sup> d <sup>-1</sup> )	4.8±3.06	0.711±0.632
## PP (µg C l <sup>-1</sup> d <sup>-1</sup> )	4.09±2.6	0.5±0.475
# ATP (mg m <sup>-3</sup> )	1.654±1.72	0.311±0.398
## ATP (mg m <sup>-2</sup> )	55.65±56.0	20.53±2.4
# POC (mg C m <sup>-3</sup> )	1253.5±428	495±404
## POC (g C m <sup>-2</sup> )	30.1±15.14	20.35±16.5
No. of observations	10	45
# Surface		
## Column 0-100 m		

Effect of wind field on phytoplankton growth was monitored in pack ice zone where it was negatively affecting to a certain extent (Pant, 1986). However, an extensive bloom of *Phaeocystis pauchetti* was recorded after 3 days intense storm during February-March, 1983. It is quite probable that wind driven nutrients from subeuphotic depths may be important towards the end of the summer. The biomass seasonal cycles monitored in pack ice during windy season also showed similar results where continued increase in phytoplankton and microbial biomass was recorded (Fig. 8). This pattern of productivity in study area is directly linked to ice conditions which is the function of climate specially wind and cloud/sun conditions.

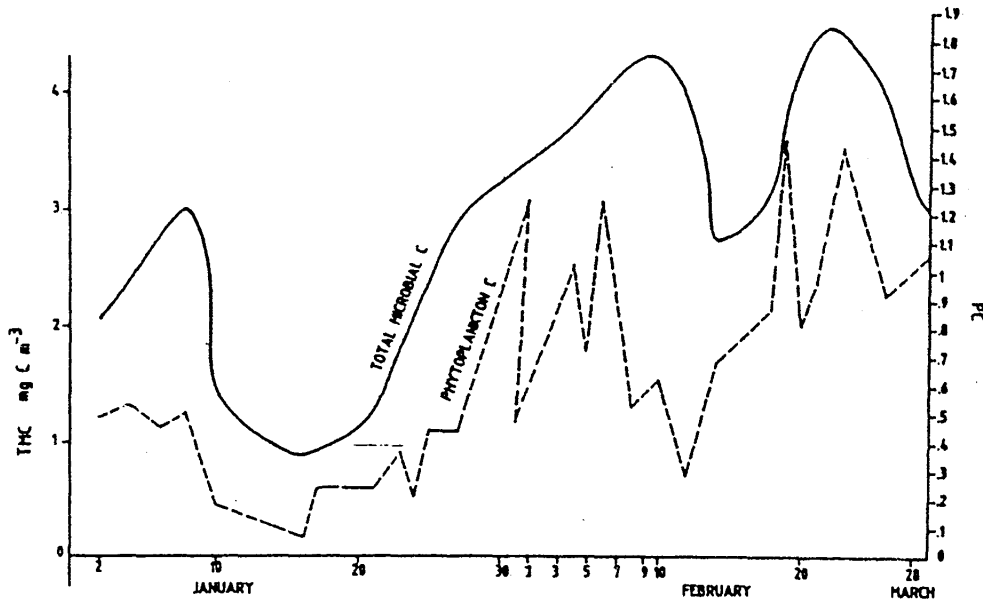


Fig. 8. Season and biomass variation

### Nano-Pico-Bacterioplankton

The contribution of nanoplankton Chl *a* is presented in Table 3. The nanoplankton varied from 5-93% in zone I and 23-100% in zone II. Omitting exceptional values it appears that the average in zone I is around 20% and in zone II 50%. If general understanding about phytoplankton growth is elaborated to nanoplankton contribution, it appears that, the favourable zone I support less nanoplankton as compared to non-favourable zone II. Winter data from 1984 also accounts for such factors indicating variable nanoplankton percentages during summer, winter and spring seasons. The turbulence in the Southern

Table 3: Nannoplankton in zone I and zone II (%)

Year	Zone I			Zone II		
	Range	Mean	n	Range	Mean	n
Jan. 1982	5-15	11.22	9	30-55	37.14	7
Jan. 1983	8-17	13.00	7	23-61	46.14	7
Apr.-Dec. 1984	8-90	38.5	7	-	-	-
Feb. 1985	18-50	31.9	3	-	-	Pant. 1985
Jan. 1987	35-93	70.00	8	27-100	66.00	8 Goes. 1987
Mar. 1989	2-8	5.0	12	-	-	-

Ocean may lead to the domination of  $<20 \mu$  size nanoplankton. During 1989, especially in the month of March, data from zone I gives detailed pictures of autotrophic and heterotrophic populations. Nanoplankton fraction  $<20 \mu$  was 11%, and pico  $<1 \mu$  was 3% of total phytoplankton Chl *a*. However, bacterioplankton counts were high, average being  $6.1 \times 10^5$  no/ml. More than 90% of these total bacteria were free living, biochemically active and utilizing dissolved organic matter. The dissolved organic matter (DOM) pool may be quite high because of higher extracellular production of phytoplankton. The FDC was around 10% indicating active bacterial flora in zone I investigated during 1989 (Table 4).

However, earlier data on bacteria from the Indian Ocean Sector was from total viable counts (TVC). Based upon counts and with appropriate conversion into biomass the role of bacteria in Southern Ocean ecosystem is presented in Fig. 9. In Antarctic Ocean, bacterial carbon (BC) is more than zooplankton carbon (ZC). Again ZC + BC together was supported by phytoplankton carbon at first trophic level. However, the phyto carbon at first trophic level is possibly underestimated by traditional techniques of GF/C filter.

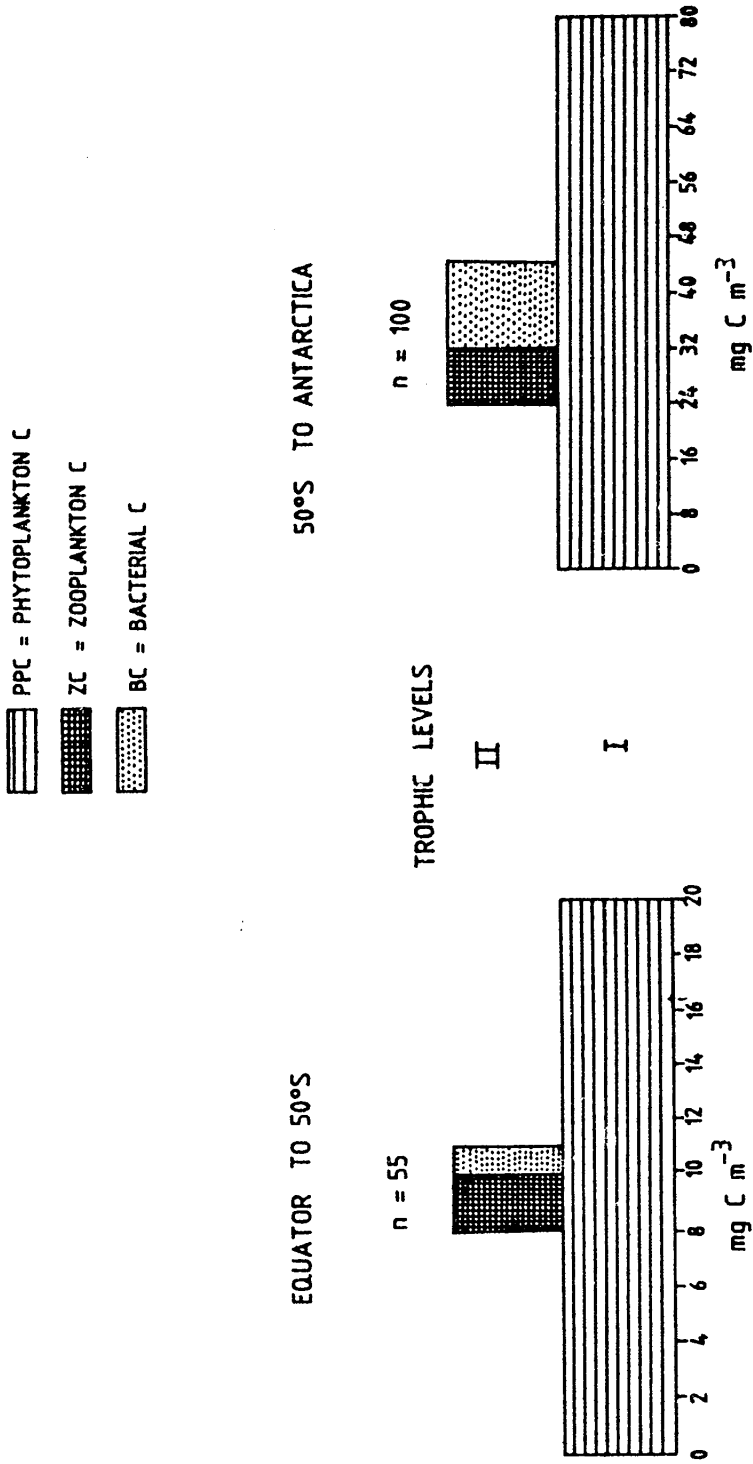
In conclusion, it may be stated that, bacterial secondary production may equally be important as that of zooplankton secondary production. This technique takes care of errors since microzooplankton are not trapped by Heron-Tranter and bongo nets which were used during the study. The high ammonia produced during bacterial activity was also indicator of regenerative type food chain prevailing in the Southern Ocean (Azam and Hodson, 1977; Weber and El-Sayed, 1987; Bouvy and Delille, 1988 and Cota *et al.*, 1990).

### Zooplankton

The average zooplankton biomass was  $100 \text{ g}/1000 \text{ m}^3$  of water. The biomass of zooplankton from the Southern Ocean (Indian Ocean Sector) vary with respect to time and season of collection, type of net used and depth of net towed (Mathew and Vincent, 1986). There is a large variation with respect to night and day sampling in spite of the extended photo period during the austral summer. A direct relationship of zooplankton was seen with phytoplankton growth and total microbial biomass (Pant, 1986). The zooplankton biomass and taxa was the characteristic feature of the water mass sampled. The different latitude zones like northern, intermediate and southern coincide with hydrographic fronts and the influence of pack ice. In northern zone, the biomass was relatively poor and dominated by copepodes, salps, euphausiids, chaetognaths and amphipods (Mathew, 1986). Intermediate zone was the seasonal pack ice area where *E. superba* dominate the zooplankton community (Mathew, 1986).

Table 4: Microbacterioplankton in Antarctic Ocean during March 1989

S.No.	Position	Date of collection	Chl-a mg m <sup>-3</sup>	% Nanno in total Chl-a	% Pico in total Chl-a	Total bacteria N × 10 <sup>5</sup> ml <sup>-1</sup>	Free Living bacteria No × 10 <sup>5</sup> ml <sup>-1</sup>	FDC %
1.	69°30'S 12°16'E	2.3.89	NC	NC	NC	5.2	3.2	5.0
2.	69°00'S 02°33'E	3.3.89	NC	NC	NC	6.1	4.3	6.0
3.	08°30'S 13°13'E	3.3.89	NC	NC	NC	6.8	5.2	5.0
4.	65°00'S 14°02'E	3.3.89	1.0	7.5	3.5	7.2	4.2	7.2
5.	67°30'S 14°46'E	3.3.89	0.9	7.0	3.2	4.8	3.8	7.0
6.	67°06'S 15°07'E	3.3.89	NC	NC	NC	1.2	1.0	11.0
7.	66°30'S 15°41'E	4.3.89	0.58	6.5	4.8	3.8	3.5	7.9
8.	60°00'S 16°23'E	4.3.89	0.23	5.2	4.0	4.2	4.1	12.0
9.	65°00'S 17°39'E	4.3.89	0.22	3.5	5.0	5.1	5.0	15.0
10	64°48'S 18°04'E	4.3.89	0.13	3.1	2.0	8.2	7.8	15.0
11	63°00'S 20°07'E	5.3.89	0.46	3.5	1.0	9.0	8.9	14.0
12	62°30'S 21°51'E	6.3.89	0.49	3.1	1.0	8.9	8.7	4.0
13	61°30'S 23°18'E	6.3.89	0.16	7.5	5.0	6.8	6.7	17.2
14	61°00'S 23°53'E	6.3.89	0.24	7.2	3.0	7.8	7.5	15.6
15	60°00'S 23°49'E	6.3.89	0.22	8.0	2.0	8.1	8.0	8.9
16	59°22'S 23°43'E	6.3.89	0.374	8.0	2.0	9.2	8.9	7.0



ENERGY PATHWAYS : INDIAN OCEAN.

Fig. 9. Bacterial secondary production



On an average, 50% of zooplankton population was krill and the rest half was copepod alone. Thus, just by taking accurate biomass of copepods it is possible to predict about the total zooplankton biomass and krill biomass on comparative basis.

As presented in Fig. 2, there was a lag in phytoplankton growth pattern and zooplankton growth. However, at the Antarctic divergence a coincidence was seen, where surge in zooplankton biomass coincided with high nutrient, high oxygen, relatively high temperature ( $2^{\circ}\text{C}$ ) and availability of phytoplankton as continued process. The latitudinal variations in zooplankton and krill have also identical patterns (Mathew, 1986). The latitude wise krill average of 1982-93 period is shown in Fig. 10. The dense krill area between  $58^{\circ}$ - $63^{\circ}\text{S}$  in the Indian Ocean Sector coincides with AD zone. Surprisingly, the average biomass of krill as deduced from Fig. 10 and that from day to day variations in pack ice zone (Mathew, 1986) was in the close range. Thus functioning of krill ecosystem in different latitudinal zone remain identical.

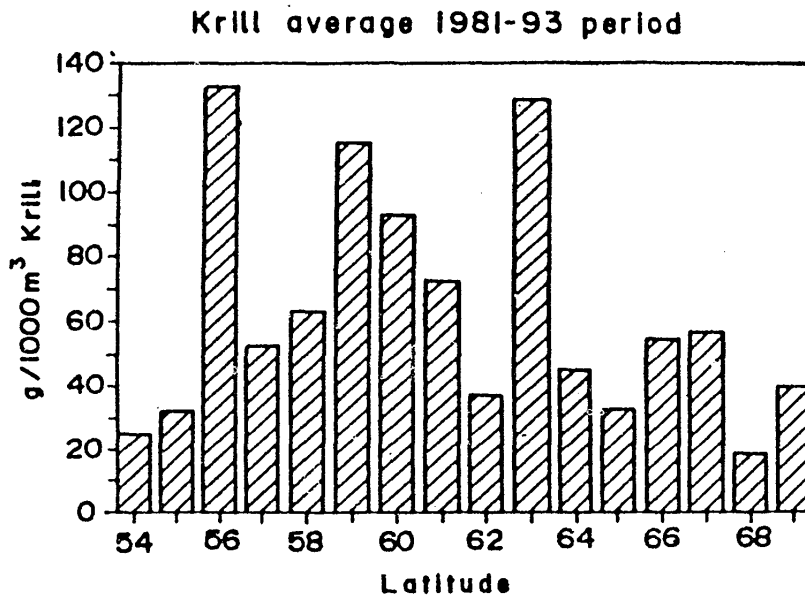


Fig. 10. Patchiness in krill across transect

The study period of 6 years (1982-1987) includes cold years 1982, 1984, 1986 and warm years 1983, 1985, 1987 as described by Saharage (1988). The krill is the most important component in the Indian Ocean Sector of Antarctica (Miller, 1986). The various reports on krill biomass from Indian Ocean Sector are presented in Table 5. As type of nets vary (mouth area and mesh size) krill biomass also vary from  $0.58 - 15 \text{ g}/1000 \text{ m}^3$  (as quoted by Miller, 1986).

Table 5: Krill biomass in Indian Ocean Sector

Indian Sector Net (mouth area)	g/1000 m <sup>3</sup> of wet weight of krill	
Bongo net (0.4 m <sup>2</sup> )	50	(Present study)
Bongo	620-6000	(Hempel, 1986) FIBEX
10 feet I KMT	0.58-16.96	(Terazaki and Wada, 1986)
Neuston net 90 m <sup>2</sup>	3205.2	(Miller, 1986)
Bongo net 0.4 m <sup>2</sup>	8.6-77.5	(Miller, 1986)
KOC-A = 9 m <sup>2</sup>	14490	(Suisancho, 1983)
Trawl = 15 m <sup>2</sup>	150000	(Nemato, 1983)
Bongo	19.0	(Ingole and Parulekar, 1993)

Surprisingly, the krill biomass values from bongo net in our work and that of Miller (1986) from Indian Ocean Sector remain same (Table 5). However, biomass taken in swarm and outside the swarm as well as the grazing activity by predators are the important factors to be accounted for this comparison (Laws, 1977).

In another experiment, the importance of microzooplankton could be established and results are presented in Fig. 11. While working in zone I, 0.4 mm mesh yielded higher zooplankton biomass as compared to 4 mm mesh. Similar results were reported by Mathew (1986). Zooplankton of small size

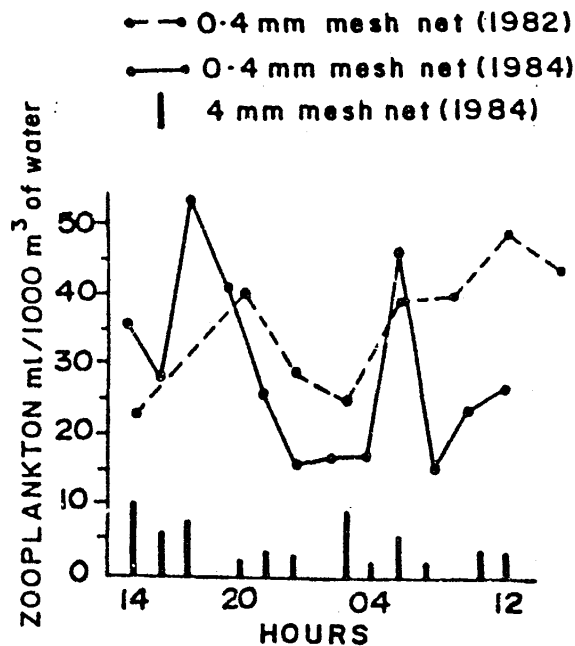


Fig. 11. Microzooplankton

may be easily passing through the traditional nets which are commonly used in Antarctic Waters. However, fine mesh is clogged with algal material. But it is apparent that, zooplankton bacterial secondary production is the most important characteristic of ecosystem studied during present investigation.

### 5. Organisms of higher trophic level

13 species of sea birds and 5 species of marine mammals were observed in Indian Ocean Sector (Parulekar, 1983). Emperor penguin, snow petrel, Skua, Mink whale and Killer whale were observed only in pack ice areas. However, zone II was characterised by other petrels, baleen whales, toothed whales and bottle nose dolphins. Adelie penguins, crabeater seals, leopard seals and cephalopods were common in both the zones. From the above list it appears that, pack ice influenced area is the shelter of more life forms in higher trophic levels. High ammonia (Verlencar *et al.*, 1990) and bacterial counts (present study) support the great deal of activity of these organisms in pack ice area (Table 4). Besides, availability of food, shelter due to pack ice, vicinity of continental land mass and shallow shelf region also contribute to higher biomass. Laws (1977), noted that some species of baleen whales concentrate at the ice zone and retreat southwards. These whales, migrate in order, to maintain themselves in areas where their crustacean prey are concentrated. Similarly, Laws (1977) found that right whale which feeds exclusively on copepods does not migrate southwards. In our study dense krill patches were observed near whale - bird activity zone, supporting above characteristics of the Antarctic ecosystem. The presence of Arctic Tern seen during 1982 in pack ice of the Indian Ocean Sector indicate the richness of area. In general, the fertility of pack ice and dynamic water column processes are the characteristic features responsible for attracting high production biomass, may be of the order of 300 - 500 million tons (Laws, 1977).

### 6. Ecosystem characterisation

As discussed earlier, land mass vicinity, influence of the melting of shelf, pack ice and prolonged winter are some of the important characteristics of pack ice zone ecosystem in the Antarctic Ocean. Compared to zone II, zone I is much shallow with varying bottom topography. The grounded iceberg movement churn the bottom sediment thus introducing growth factor ingredients in water column. Irrespective of this, it is clear that during one or other stages of growth period, ample organic matter is synthesized in water column through auto and heterotrophic activities. The parameters like POC, ATP in surface and water column also indicate high organic matter level in zone I and II (Table 1 & 2). The average POC of euphotic column in zone I was  $54.78 \text{ g C m}^{-2}$  and that of

Table 6: Inter-relationship in Chl-a, PP, ATP, POC of surface and column in Zone I

	Chl-a	Chl-a	PP	PP	ATP	ATP	POC	POC
Chl-a/s	1.0	-	-	-	-	-	-	-
Chl-a/c	0.449	1.0	-	-	-	-	-	-
PP/s	0.249	0.054	1.0	-	-	-	-	-
PP/c	0.977	0.375	0.246	1.0	-	-	-	-
ATP/s	0.497	0.559	0.07	0.462	1.0	-	-	-
ATP/c	0.535	0.752	0.064	0.481	0.883	1.0	-	-
POC/s	0.376	0.283	0.178	0.311	0.492	0.431	1.0	-
POC/c	0.452	0.539	0.207	0.418	0.565	0.588	0.733	1.0
n=54 R=0.27 at r=95%								
s = surface, c = column.								

Table 7: Inter-relationship in Chl-a, PP, ATP, POC of surface and column in Zone II

	Chl-a	Chl-a	PP	PP	ATP	ATP	POC	POC
Chl-a/s	1.0	-	-	-	-	-	-	-
Chl-a/c	0.897	1.0	-	-	-	-	-	-
PP/s	0.414	0.623	1.0	-	-	-	-	-
PP/c	0.38	0.553	0.121	1.0	-	-	-	-
ATP/s	0.23	0.305	0.536	0.576	1.0	-	-	-
ATP/c	0.747	0.278	0.437	0.601	0.025	1.0	-	-
POC/s	0.152	0.023	0.022	0.262	0.424	0.092	1.0	-
POC/c	0.145	0.85	0.423	0.564	0.583	0.710	0.792	1.0
n=28 R=0.35 at r=95%								
s = surface, c = column.								

zone II was  $30.1 \text{ g C m}^{-2}$ . The estimates of phytoplankton, zooplankton and microbial biomass also support the high level of organic matter produced. The interrelationship in between main biotic components is presented in Tables 6 and 7. The phytoplankton biomass (Chl *a*), zooplankton biomass and the total microbial biomass (ATP) were significantly related. Consequently, the organic matter persisting in euphotic zone must have been derived from phytoplankton food chain. This holds true in zone I and zone II, indicating equal richness of entire study area in the Indian Ocean Sector south of AC. The organic matter produced *in situ* get sedimented to bottom (Bodungen *et al.*, 1986) thus passing energy through benthic communities. The patchyness in the level of benthic organic matter found in this region, reflect on the productivity of overlying water column (Tables 1 and 2). Similar, interrelationship between biotic components, has earlier been reported by Hewes *et al.*, 1990.

The benthic biomass reported from this area revealed rich fauna and high standing crop (Parulekar *et al.*, 1983). Nematodes (65%) and polychaetes (53%) were dominant component of meiofauna and macrofauna. The exceptionally high benthic biomass observed along shelf in shallow depth (<1000 m) can be attributed to rain of organic rich sediment during intense blooms in zone I. Recently, Gallardo (1987) reported the clear relationship between primary production and benthic communities in Antarctica. Thus, patterns of productivity, nutrient regeneration (Verlencar *et al.*, 1990) and mass flux to bottom (as seen in benthic studies) are the most important characteristics of the Antarctic ecosystem as observed during present investigations. This supports a new line of thinking that zone I and zone II are equally productive although the pattern of production differs. Generally, biological productivity of Indian Ocean Sector is much more higher than reported earlier.

A model used by Jennings *et al.* (1984) based on the difference in nutrient profiles between the summer and winter, gave  $220 - 420 \text{ mg C m}^{-2} \text{ d}^{-1}$  as the Southern Ocean productivity estimate. Fogg (1977) reported productivity of  $10 \text{ g C m}^{-2} \text{ y}^{-1}$  for the Antarctic waters. Weber *et al.* (1988) reported the organic carbon flux about  $60 \text{ mg C m}^{-2} \text{ d}^{-1}$  in the Southern Ocean which is indicative of high primary productivity in water column, where relationship with melting ice has been established. Dunbar (1984) reported the annual flux of  $107 \text{ g m}^{-2}$  with 50% biogenic component and further observed  $50-600 \text{ mg m}^{-2} \text{ d}^{-1}$  of particle flux especially during the blooms. The varying Antarctic flux rate as reported from the Western Indian Ocean averages to be  $120 \text{ g m}^{-2}$  with organic carbon component of  $1.5-136 \text{ mg C m}^{-2} \text{ d}^{-1}$  (Matsuda *et al.*, 1987). The high level of particulate matter from this area has been reported earlier by Tanoue *et al.* (1986).

The mode of sedimentation in the Southern Ocean is interesting. According to some reported work in Antarctic Peninsula, the area is characterised by particles which are transported through the pellets of *E. superba* (Weber *et al.*, 1988, Dunbar, 1984) and in offshore areas faecal pellets of smaller metazoans dominate. Krill swarms consume the majority of primary production and transport the biogenic particles to seafloor in the form of processed faecal pellets. A super swarm reported in Antarctic waters (Shulenberger, 1983) exhausted plankton within short period by grazing and the faecal pellets produced by krill sank fast to bottom or got mineralised within water column. Treguer *et al.* (1988) reported sinking of diatoms with *E. superba* faecal pellets in the Indian Ocean Sector.

One of the most important characteristic of the Antarctic ecosystem is the prevalence of uninterrupted food chain during winter. During 1984-85, it was observed that the period of total darkness was about one month in pack ice zone and less than one month in offshore areas. Considerably low temperature and generally low light intensity promote shade adapted psychrophilic forms of diatom-algae to appear in succession and thus keep the ecosystem, active and vibrant. The succession of organism may be in such a way that forms appearing may be adapted to varying light environment. Recently, abundance of cyanobacteria are reported from Antarctic waters (El-Sayed, 1988). These forms in picofraction can remain active even at subdued light making a most crucial characteristics of the ecosystem. However, little light can always pass through pack ice or cells which on their part drift from light zone to dark zone within a few days without perishing.

Such findings derived from our observations in Indian Ocean Sector make us to believe the richness of Southern Ocean and Antarctic waters ultimately making krill a most important organism. In short, the krill graze the phytoplankton and other microbial forms (product of microbial loop) and transform organic matter of phyto origin to faecal pellets. These pellets attract bacteria and recycle into nutrients and microbiomass. This makes Antarctic ecosystem most efficient with unique physical, chemical and biological settings. Recently, the net production, at the expense of regenerated nutrients, is reported to be 30% of total production (Collos and Slawyk, 1986) in the Indian Ocean Sector of Antarctica.

The temperature, light variability and climatic range indicate the limit of growth. The forms growing luxuriently may be holding genetic material which require to be analysed and linked to the formation and stability of marine ecosystem.

### Acknowledgements

The authors thank Director, National Institute of Oceanography for the encouragement and support. We are thankful to the expedition members for helping us in sample collection.

### References

- Azam, F., R.E. Hodson (1977): Size distribution and activity of marine microheterotropha. *Limnol. and Oceanogr.*, 22: 492-501.
- Backer, J.D. (1979): *Polar Oceanography 2 Southern Ocean. Rev. Geophysics Space Phys.* 17: 1578-1585.
- Bryden, M. (1983): The Southern Ocean. In: *Eddies in the Ocean*, A.R. Robinson (ed.), Springer Verlag, New York, pp. 265-277.
- Bodungen, B.V., S. Smetacek, M.M. Tilter and B. Zeitzschel (1986): Primary production and sedimentation during spring in the Antarctic Peninsula region. *Deep Sea Res.*, 33(2): 177-194.
- Bouvy, M. and D. Delille (1988): Spatial and temporal variations in Antarctic and Subantarctic bacterioplankton *Nethr. Journal Sea Res.*, 22 (2): 139-147.
- Bunt, J.S. and C.C. Lee (1972): Data on the composition and dark survival of four sea-ice microalgae. *Limnol. Oceanogr.*, 17:458- 461.
- Collos, Y. and G. Slawyk (1986):  $^{13}\text{C}$  and  $^{15}\text{N}$  uptake by marine phytoplankton IV. Uptake ratios and contribution of nitrate to productivity of Antarctic waters (Indian Ocean Sector). *Deep Sea Res.*, 33: 1039-1051.
- Cota, G.A., S.T. TTmeier, D.H. Robinson, W.O. Smith Jr. and C.W. Sullivan (1990): Bacterioplankton in the marginal ice-zone of the Weddell Sea, biomass production and metabolic activities during austral autumn. *Deep Sea Res.*, 37: 1145-1167.
- Dhargalkar, V.K. and X.N. Verlecar (1992): Production of organic matter in Antarctic Sea Shelf. *Indian J. mar. Sci.*, 21: 1-5.
- Dunbar, R.B. (1984): Sediment trap experiments on the Antarctic continental margin. *Ant. J.U.S.*, 15:70-71.
- Dayton, P.K., D. Watson, A. Paarminso, J.P. Barry, J.S. Oliver and S.D. Rivera (1986): Distribution pattern of benthic standing stock at McMurdo sound, Antarctic. *Polar Biol.*, 6: 207-253.
- El-Sayed, S.Z. (1988): Productivity of the Southern Ocean. A closer look. *Comp. Biochem Physiol.*, 90B(3): 489-498.
- Fogg, G.E. (1977): Aquatic primary production in the Antarctica. *Phil. Trans. R. Soc. B* 279:27-38.
- Gallardo, V.A. (1987): The sublittoral macrofaunal benthos of the Antarctic Shelf. *Environ Int.* 13:71-81.
- Goes, J.I. and V.P. Devassy (1983): Phytoplankton organisms collected during First Indian Antarctic Expedition. *Scientific Report of First Indian Expedition to Antartica*, DOD, Technical Publication No. 1, 198-201.

- Gordon, A.L., S.W.B. Owens (1987): Polar oceans. *Rev. Geophysics Space Phys.*, 25:227-233.
- Hagstrom, A., V. Larsson, P. Horsted and S. Normark (1979): Frequency of dividing cells, a new approach to the determination of bacterial growth rates in aquatic environments. *Appl. Environ. Microbiol.*, 33:37: 805-812.
- Heywood, R.B., I. Everson and J. Priddle (1985): The absence of krill from the south Georgia zone, winter 1983. *Deep Sea Res.*, 32: 369-378.
- Hewes, C.D., E. Sakshaug, F.M.H. Reid, O. Holm-Hansen (1990): Microbial autotrophic and heterotrophic eucaryotes in Antarctic waters: relationships between biomass and chlorophyll, adenosine triphosphate and particulate organic carbon. *Marine Ecol. Prog. Ser.* 63: 27-35.
- Horner, R.A. (1976): Sea ice organisms. *Oceanogr. Mar. Biol.*, 14: 167-182.
- Ingle, B.S. and A.H. Parulekar (1993): Zooplankton biomass and abundance of Antarctic Krill *Euphausia superba* DANA in Indian Ocean Sector of Southern Ocean. *J. Biosciences*, 18(1): 141-148.
- Jennings, J.C., L.O. Gordon and D.M. Nelson (1984): Nutrient depletion indicates high primary productivity in the Weddell Sea. *Nature* (London), 308:51-54.
- Knox, G.A. and J.K. Lowry (1977): A comparison between the benthos of the Southern Ocean and the north polar ocean with special reference to the Amphipoda and Polychaetes. In: *Polar Oceans* (M.J. Dunbar eds.), Arctic Inst. North Am, Cargary, pp. 423-462.
- Laws, R.M. (1977): The significance of vertebrates in the Antarctic marine ecosystem. In: *Adaptations within Antarctic Ecosystem* (G.A. Liano ed), Gulf Publ. Co. Houston, Texas, pp. 411-438.
- Mathew, K.J. (1986): Spatial distribution of Krill (*E. Superba*) and other zooplankton off Queen Maud Land Antarctica. In: *Report of 3rd Indian Expedition to Antarctica*, DOD Technical Publicaiton No. 3, 149-159.
- Mathew, K.J. and D. Vincent (1986): Latitudinal distribution of zooplankton in the Southern Ocean with special reference to Euphausiids. In: *Report of 3rd Indian Expedition to Antarctica*, DOD Technical Publication No. 3, 161-174.
- Matondkar, S.G.P. and S.Z. Qasim (1983): Some observations on the biological production of the Antarctic waters. In: *Scientific Report of First Indian Expedition to Antarctica*. DOD Technical Publication No. 1:191-197.
- Miller, D.G.M. (1986): Results from biological investigations of krill (*E. superba*) in the Southern Indian Ocean during SIBEX I. *Mem. Natl. Inst. Polar Res.*, 40: 117-139.
- Matsuda, O., S. Ishikawa and K. Kawaguchi (1987): Seasonal variation of downward flux of particulate organic matter under the Antarctic fast ice. *Proc INPR Symp. Polar Biol.*, 1: 23-24.
- Naqvi, S.W.A. (1986): Some oceanographic observations in the polynea and along a sector in the southwest India/Antarctic Ocean. In: *Scientific Report of 3rd Indian Expedition to Antarctica*, DOD Technical Publication No.3, pp. 75-85.
- Nowlin, W. Jr. and J.M. Klinck (1986): The physics of Antarctic circumpolar current. *Rev. Geophys. Space Phys.*, 24: 469-491.



- Pant, A. (1986): Studies on Antarctic phytoplankton. In: *Report of 3rd Indian Expedition to Antarctica*, DOD Technical Publication No. 3, pp. 87-96.
- Parulekar, A.H., Z.A. Ansari and S.N. Harkantra (1983): Benthic fauna of the Antarctic Oceans and qualitative aspects. *Scientific Report of First Indian Expedition to Antarctica*. DOD Technical Publication No. 1, 213-218.
- Parulekar, A.H. (1983): Sea birds and marine mammals of the first Indian Antarctic Expedition. *Scientific Report of First Indian Expedition to Antarctica*. DOD Technical Publication No. 1, 224-235.
- Priddle, J., I. Hewes, J.L. Ellis Evan and T.J. Smith (1986): Antarctic aquatic ecosystem as habitat for phytoplankton. *Biol. Rev.*, 61: 199-238.
- Saharage, D. (1988): Some indications for environmental and krill resources variability in the Southern Ocean. In: *Antarctic Ocean and Resources Variability*, 33-40.
- Shulenberger, E. (1983): Superswarms of Antarctic krill (*E. superba* DANA), *Ant. J.U.S.* 18:194-197.
- Smith, W.O. Jr. and E. Sakshang (1990): Polar phytoplankton. In: *Polar Oceanography, Part B: Chemistry, Biology and Geology*, W.O. Smith, Jr. (ed.), Academic Press, 477-525.
- Smith, S.L. and S.B. Schanck-Scheil (1990): Polar zooplankton. In: *Polar Oceanography, Chemistry, Biology and Geology*, W.O. Smith, Jr. (ed.), Academic Press, 526-598.
- Tanoue, E., M. Zenimoto, Y. Komaki and N. Handa (1986): Distribution of particulate organic materials in the Pacific and Indian sector of the Antarctic Ocean in the austral summer. *Mem. Natl. Polar Res. Spec. Issue*, 40: 380-394.
- Treguer, P., S. Gueuley and A. Kamatani (1988): Biogenic silica and particulate organic matter from the Indian Sector of the Southern Ocean. *Marine Chemistry*, 23:167-180.
- Verlencar, X.N., K. Somasundar and S.Z. Qasim (1990): Regeneration of nutrients and biological productivity in Antarctic waters. *Mar. Ecol. Prog. Ser.*, 61: 41-59.
- Weber, L.N. and S.Z. El-Sayed (1987): Contribution of the net, nanno and pico plankton to the phytoplankton standing crop and primary productivity in the Southern Ocean. *J. Plankt. Res.*, 9(5): 973-994.
- Weber, G., G. Fischer, D. Fuchera and P. Gersonde (1988): Seasonal particle flux in the Brans field strait Antarctica. *Deep Sea Res.* 35: 891-898.