

Table 2. Rainfall recharge for monsoonal months in 2004

Month	Total rainfall (mm)	Water-level fluctuation (m)	Specific yield (%)	Rainfall recharge (mm)
May	53.6	0.20	3.1	6.2
June	81.6	0.41	3.1	12.7
July	172.2	0.63	3.1	19.8
August	53.1	0.13	3.1	4.0
September	25.4	0.04	3.1	1.2

172.2 mm. The values obtained by the two methods are in agreement and within the error limit of $\pm 10\%$. Recharge for other monsoonal months during 2004 is determined in similar way and presented in Table 2. The analysis shows that the technique of pulse response in water-level fluctuation obtained from automatic water-level recorder can be used for evaluating monthly natural recharge more precisely.

The water-level fluctuation data recorded by an automatic waterlogger, after removal of extraneous noise due to tidal effects, can be more potentially utilized in estimation of natural recharge due to pulse-mode precipitation pattern over the semi-arid tropical region. The recharge values derived from this method are found to be in good agreement with those obtained through tritium injection technique over the entire monsoon period. Long-term study of water-level with rainfall and correlation of results with moisture flux measurement through tritium technique would yield good and reliable results to model different catchments located under varying climatic and geological terrains.

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Zooplankton studies with special reference to krill *Euphausia superba* Dana from fishing area 58 of Indian Ocean sector in Southern Ocean

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Distribution, abundance and species composition of zooplankton collected during the First Indian Antarctic Krill Expedition were studied. Zooplankton biomass values ranged from 9.79 to 303.62 ml 100 m⁻³ (\bar{x} = 142.14 \pm 77.02). High standing stock values were recorded in the study area, where copepods, chaetognaths, euphausiids and salps were dominant taxa. Copepods and chaetognaths formed the major constituents of zooplankton community and comprised more than 70% of zooplankton catch. Swarms of krill and salps were observed during the study period (austral summer), which were the prime cause for high standing stock of zooplankton. The prevailing physico-chemical parameters with rich food supply were important factors influencing the geographical distribution of different zooplankton groups. The study revealed that the present investigation site falls under potential krill fishing ground.

Keywords: Antarctica krill, austral summer, copepods, Southern Ocean, zooplankton.

THE Antarctic pelagic system is one of the most intriguing ecosystems, with its extreme environmental conditions and wide seasonal fluctuations. The typical conditions of the Antarctic waters have large implications for zooplankton stock and special life strategies have been developed to survive under extremely cold, dark winter conditions and to profit

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from the short bloom during summer¹. The Antarctica krill *Euphausia superba* DANA, 1852, is the most abundant zooplankton species in terms of biomass with potential protein resource for human consumption in the Southern Ocean².

The broad geographical distribution, systematic and ecological studies of zooplankton groups in the Southern Ocean have been well investigated and reviewed by several authors^{1,3-6}. However, the literature on the Southern Ocean zooplankton is dominated by studies on euphausiids (Antarctica krill), because of its large biomass, ecological importance and resource potential. Most of these studies on general zooplankton and krill are largely confined to the Atlantic sector of the Southern Ocean. Except for fragmentary information regarding distribution and composition of zooplankton, detailed account of exploitable krill and other living resources of the Indian Ocean sector of the Southern Ocean is meagre⁷⁻¹¹. Little is known about fishing area 58 of the Indian Ocean sector of the Southern Ocean.

The present Indian scientific study is the first of its kind in this direction. In 1995, a programme FIKEX (First Indian Antarctic Krill Expedition) was designed to examine and obtain first-hand information pertaining to zooplankton distribution in Antarctic waters, particularly area 58 of the Indian Ocean sector in the Southern Ocean. Data on composition of Antarctic waters along with other parameters were collected during this expedition. In view of this, the present study on zooplankton distribution in relation to krill will throw some light on the assessment of harvesting potential of krill.

Zooplankton samples were collected from 16 stations during the FIKEX (December 1995 to March 1996) of FORV *Sagar Sampada* to the Indian sector of the Southern Ocean, covering within the geographical limits of latitude 58°00' to 61°17'S and longitude 30°00' to 40°00'E (Figure 1). This area falls between Antarctic convergence and Polar divergence of the Southern Ocean.

Vertical hauls were made from 200 m to the surface using a Bongo net (60 cm mouth diameter; 400 µm mesh size) attached with a flow meter. Zooplankton samples were fixed in 5% formaldehyde. Biomass was determined by displacement volume method and expressed as ml 100 m⁻³ of water filtered. Major zooplankton taxa were sorted out from aliquots (25%) and species were identified wherever possible. The number of organisms was calculated for the whole sample and computed per 100⁻³. Percentage composition of various zooplanktonic groups was calculated. Secondary production was computed using the formula by Cushing^{12,13}. Hydrographic measurements by CTD probes were made at all the sampling sites.

Table 1 summarizes the data on hydrographic characters of surface waters of the study area. The present study was carried out during January and February 1996, which incidentally marks the late Antarctic summer. Accordingly, the water column was characterized by relatively high temperature with wide fluctuations. The surface temperature varies

from 0.84 to 2.47°C ($\bar{x}=1.47 \pm 0.48$). The Antarctic convergence showed short range of variation in surface salinity and dissolved oxygen. Salinity of the surface water ranged from 33.65 to 33.91 $\times 10^{-3}$ ($\bar{x}=33.82 \pm 0.07$). Surface dissolved oxygen reached almost its saturation level during the pre-

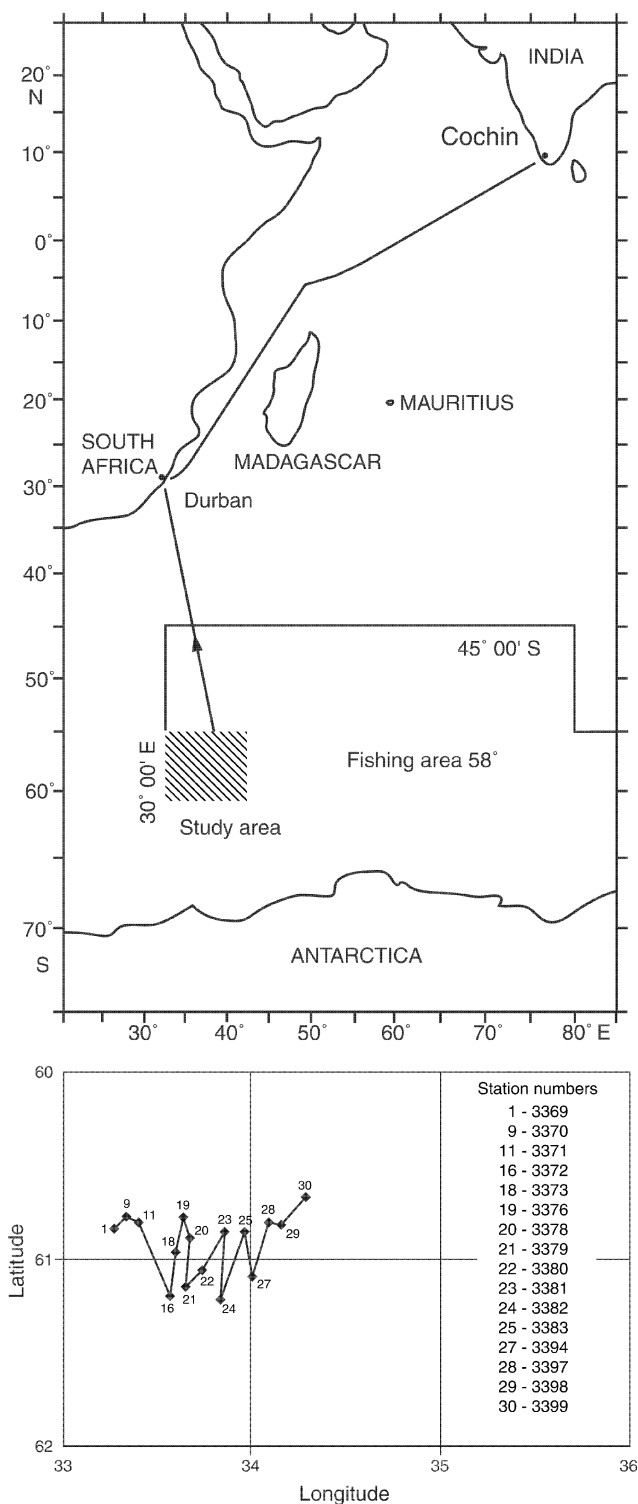
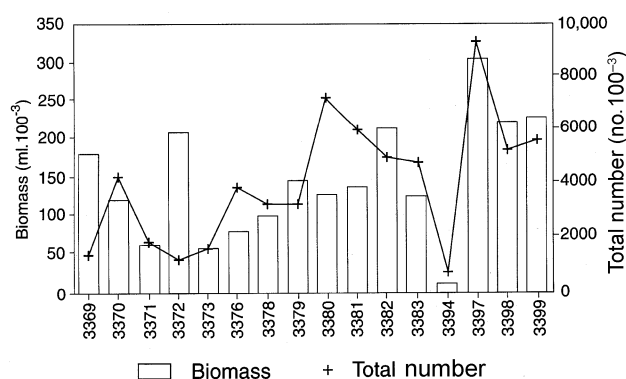


Figure 1. FIKEX cruise study area and sampling stations.

Table 1. Sampling details with surface temperature, salinity and zooplankton biomass values at different stations

Station no.	Geographical lat.	Position long.	Date of collection	Time of collection (h)	Temperature (°C)	Oxygen (ml/l)	Salinity (ppt)	Biomass (ml/100 m ⁻³)
3369	59°02'S	30°58'E	27.01.96	1010	1.0537	7.707	33.8046	176.30
3370	60°00'S	30°02'E	27.01.96	2135	0.8445	7.620	33.6529	117.53
3371	61°00'S	30°10'E	28.01.96	0800	0.8478	7.756	33.7546	58.77
3372	60°59'S	32°00'E	28.01.96	1730	1.4226	7.411	33.7758	205.68
3373	61°00'S	33°58'E	29.01.96	0410	1.3051	7.654	33.7494	54.85
3376	61°02'S	35°58'E	30.01.96	0445	1.2246	7.560	33.8368	76.40
3378	61°08'S	38°00'E	30.01.96	2245	0.9561	7.832	33.8172	95.99
3379	61°03'S	40°04'E	31.01.96	1145	1.3893	8.029	33.8849	141.04
3380	60°01'S	39°59'E	31.01.96	2235	1.3166	7.864	33.9133	123.41
3381	60°02'S	38°00'E	01.02.96	0815	1.8055	7.715	33.8994	133.20
3382	60°02'S	36°37'E	01.02.96	1830	1.4062	7.820	33.8712	211.56
3383	60°02'S	34°00'E	02.02.96	0800	1.4447	7.794	33.8585	121.45
3394	61°12'S	33°34'E	08.02.96	1450	1.6526	7.222	33.7707	9.79
3397	59°00'S	34°00'E	11.02.96	1645	2.4659	7.431	33.8968	303.62
3398	59°00'S	36°00'E	12.02.96	0135	2.3167	8.010	33.8847	219.39
3399	58°01'S	35°58'E	12.02.96	1320	2.0049	7.251	33.8161	225.27

**Figure 2.** Zooplankton biomass and total number at different stations.

sent investigation and varied from 7.22 to 8.03 ml l⁻¹ (\bar{x} = 7.68 ± 0.24).

Zooplankton biomass values fluctuated widely during the present investigation. They were generally higher and varied between 9.79 and 303.62 ml 100 m⁻³ (\bar{x} = 143.14 ± 77.02). Biomass values along with total counts recorded from station nos 3369 to 3399 are shown in Figure 2.

Population density varied significantly, irrespective of zooplankton biomass. Minimum zooplankton density recorded was 730/100 m⁻³ at station no. 3394, whereas maximum was 9309/100 m⁻³ at station no. 3397. As there is no correlation between biomass and population in accordance with increase in biomass, consequent increase in total number of zooplankton was not generally observed (Figure 2).

Fourteen different groups have been recorded, among which only two, Copepoda and Chaetognatha were invariably present at all stations. The transect covering station nos 3369, 3371, 3372 and 3394 as represented by lesser number of zooplankton groups, i.e. a minimum of six groups. The rich group diversity was recorded from station no. 3380, with a maximum of ten taxonomic groups. Based on total zoo-

plankton counts, groups in order of abundance were Copepoda (74.36%), Chaetognatha (7.59%), Euphausiacea (6.13%), Thaliacea (5.23%), Polychaeta (2.80%), Siphonophora (1.64%), Amphipoda (1.62%), Ostracoda (0.49%), Ctenophora, Decapod larvae and Gastropoda (0.01% each). Occurrence of zooplankton groups at different stations with log density is depicted in Figure 3 and the percentage composition of major zooplankton groups is shown in Figure 4.

Copepods formed the major component of zooplankton community during the present investigation and comprised more than 70% of the zooplankton catch in most of the collections. Distribution of copepod density and total zooplankton count showed almost similar patterns. Their population density ranged from 650 to 7209/100 m⁻³. Percentage composition of this group to total zooplankton count varied from 59.21 as observed at station no. 3371 to 89.04 as observed at station no. 3394. At station no. 3371, their percentage contribution to total count was relatively low due to the abundance of other carnivorous groups. The copepod population at different stations was dominated by calanoids followed by cyclopoids. *Calanoides acutus*, *Calanus propinquus*, *C. simillimus*, *Rhincalanus gigas*, *Canthocalanus pauper*, *Undinula darwine*, *Eucalanus elongatus*, *E. monachus*, *Clausocalanus arcuicornis*, *Oithona similis*, *Oncaea venusta*, *Candacia* sp., *Scolecithrix danae*, *Pontellopsis regalis*, *Oithona* sp. and *Microsetella norvegica* formed the bulk of copepods.

Chaetognaths were common in all the zooplankton collections. This group sustained a relatively higher density and was second in frequency after the ubiquitous copepods. Their numerical abundance ranged from 16/100 m⁻³ (station no. 3394) to 580/100 m⁻³ (station no. 3382), whereas percentage composition varied from 2.19 to 17.52. Chaetognaths were represented by *Eukrohnia hamata*, *Sagitta gazellae*, *S. iyra*, *S. maxima* and *S. tasmanica*.

Euphausiids, particularly Antarctic krill, *E. superba*, were found in great abundance in both adult and larval stages during the present survey. They contributed significantly to zooplankton biomass. This group occurred in almost all transects covered during this investigation. A peak density of 815/100 m⁻³ (8.75%) was recorded from station no. 3397. This group occurred with a low density of 47/100 m⁻³ (3.01%) at station no. 3373.

Among the holoplanktonic class of Tunicata, Thaliacea was present in good numbers. It was represented by two orders, viz. Doliolida and Salpida. Salps were the dominant (more than 95%) group and mainly comprised of *Salpa thompsoni*. The higher zooplankton biomass recorded at some stations was mainly due to occurrence of swarms of this group in large numbers. Their population density varied from 16 to 580/100 m⁻³. Percentage composition of this group was maximum (12.13) at station no. 3370.

Dominance of polychaetes was observed at transect covering station nos 3371 and 3372, where their percentage composition to the total zooplankton count was 10.52 and

12.16, respectively. *Tomopteris planktonsis*, *Vanadis* sp., *Typhloscolex mulleri* and *Sagitella* sp. were common representatives of polychaetes.

Siphonophores were recorded in poor numbers and their percentage composition varied from 0.63 (station no. 3382) to 6.03 (station no. 3373). This group was represented by a single species, i.e. *Dimophysys arctica*.

Amphipods constituted an important group of zooplankton community. They were recorded from a majority of zooplankton collections. Their percentage composition ranged from 0.34 (station no. 3380) to 4.79 (station no. 3382). This group was represented by *Hyperiella antarctica*, *Paranthemisto gaudichaudi*, *Primno macropa*, *Vibilia stebbingi*, *Scina* sp., *Hyperia* sp. and *Paranthemisto gracilipes*.

The remaining zooplankton groups were patchy in distribution and present in poor numbers. Ostracods mainly comprised of *Paraconchoecia elegans* and were recorded from majority of the area covered. *Oikopleura* sp. was the representative of Appendicularia, and was patchy in distribution. Pteropods were represented by *Limacina* sp. and *Clione* sp. Groups like Hyromedusae (*Calycospsis borchgrevinki*), Ctenophores (*Beroe* sp.), Decapod larvae (*Sergestes* sp.) and Gastropods were recorded from one or two stations during the investigation.

Euphausiid crustaceans are conspicuous members of the Southern Ocean plankton community. Because of their widespread distribution and abundance, and their central position in the food web, they have attracted much attention. The salient characteristics of the distribution of euphausiids, especially *E. superba*, in the Southern Ocean is their patchiness and aggregation behaviour. Throughout most of its life-cycle, *E. superba* occurs near the surface of the sea in discrete swarms/super swarms or schools¹⁴⁻¹⁶. During the present expedition to the Indian sector of the Southern Ocean, euphausiids were recorded in good numbers even though they were patchy in abundance. In a few transects covered, swarms of krill were noticed. Asymmetrical distribution of euphausiids, is believed by certain authors to be due largely to physical constraints on the population¹⁷. However, numerous behavioural characteristics, including breeding, feeding, predator avoidances and chemo-reception, have also been suggested as factors which govern the distribution of krill and affect their swarming incidence¹⁸.

In the past there have been numerous attempts to estimate the overall biomass of krill in the Southern Ocean but such estimates have little relevance in an ecological sense⁶. Abundance estimates are complicated by the aggregation behaviour of krill. An understanding of the process underlying the formation and persistence of such aggregations is essential for the management of krill fisheries, since they define the site of fishing grounds, major trophic relationships and energy flow within the system. Krill fishing developed rapidly into a major world fishery with a sustained yield in recent years, of approximately 400,000 tones per year^{19,20}. Numerous specimens of krill were obtained in majority of transects covered during the present survey, where high

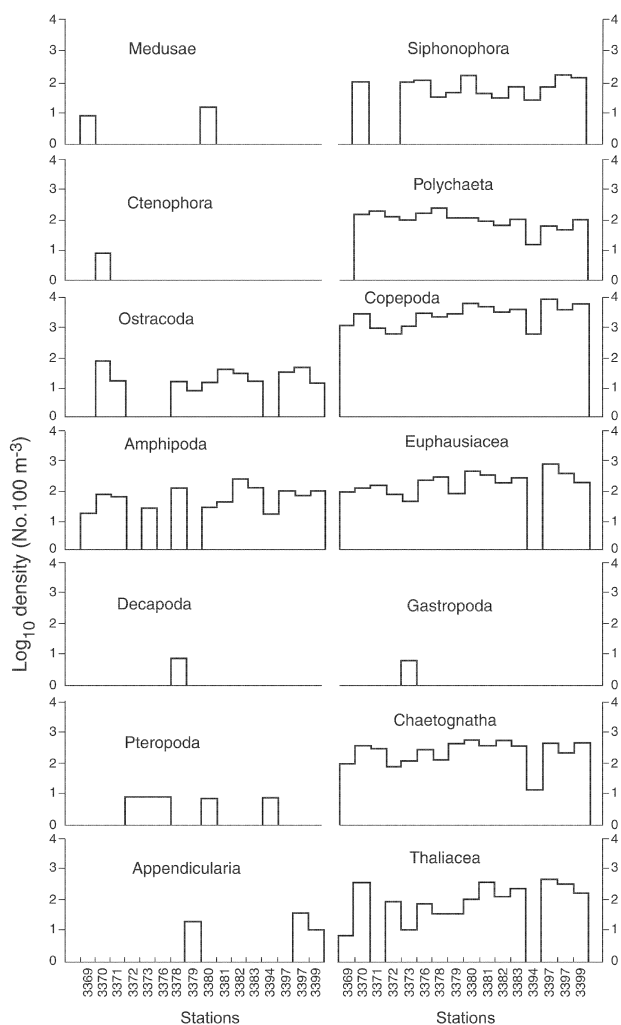


Figure 3. Occurrence of zooplankton groups at different stations.

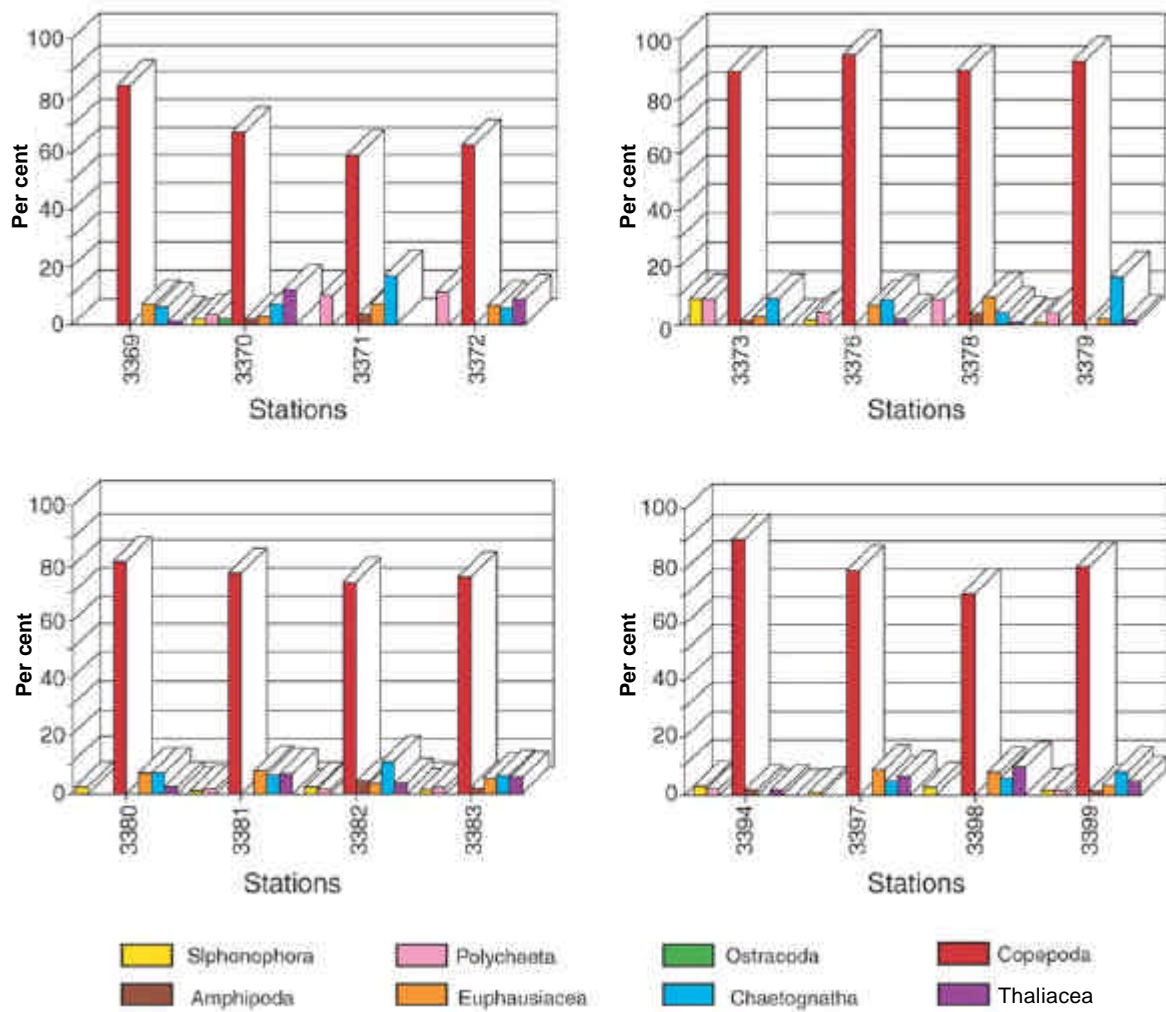


Figure 4. Per cent composition of the major taxonomic groups at different stations.

zooplankton biomass values were recorded. It is generally considered that the Antarctic krill, a dominant herbivorous species which serves as a key link between primary producers and top predators, comprises at least 50% of the zooplankton biomass^{21,22}. However, there is evidence that other groups, especially copepods, are significant in pelagic ecosystems in terms of biomass and production. In the present study, though numerical abundance and percentage composition of euphausiids was not high, they significantly contributed to zooplankton biomass with occurrence of a large number of adults and larvae. Copepods outnumbered euphausiids in total population during this investigation. Since euphausiids are known to avoid the plankton net, their actual population could be much higher than the present estimation. This was clearly evident by the collection of large quantities of krill during this expedition using krill midwater trawl.

Foxton²³, while summarizing on the zooplankton standing crop, revealed that the Antarctic waters have a significantly higher standing crop than the tropical and temperate regions, with a peak during the austral summer. The first and

second cruise of Soviet Antarctic Expedition reported that the stations in the vicinity of the Antarctic convergence have high zooplankton biomass with rich population of copepods²⁴. The present study conducted during austral summer covering Antarctic convergence, exhibited high values of zooplankton biomass. Presence of swarms of physically large animals such as euphausiids and salps was the prime cause for high zooplankton biomass recorded in this area. These groups with rich copepod population density, significantly contributed to zooplankton biomass as well as total population.

Within the zooplankton, the holoplanktonic groups were well represented in the area covered during the present study. In particular, the high concentration (<70%) of copepods indicates that the population of this group in the study area had a high growth rate during the period of investigation. On the other hand, paucity of meroplanktonic larvae of benthic invertebrates and fish, which seasonally form an important component of the zooplankton in temperate and tropical areas was observed. However, it seems that this

is a general phenomenon occurring in the Southern Ocean and is possibly related to strategies of cold adaptations²⁵.

Nakamura *et al.*²⁶, in a study of epipelagic calanoid copepods in the Indian Ocean or of the Southern Ocean, reported dominance of *C. acutus*, *Rhincalanus gigas* and *Candaceia maxima*. During the present study the bulk of copepods were mainly comprised of *C. acutus*, *C. propinquus*, *C. simillimus* and *R. gigas*. Similar results have been reported based on studies of zooplankton distribution in the Southern Ocean^{24,27}.

Chaetognaths, the dominant zooplankton predators were mainly represented by *Eukrohnia hamata* and *Sagitta gazellae* during the present study. David²⁸ reported similar pattern of distribution of species of chaetognaths from the Southern Ocean with great variation in body size. An enormous number of aggregates in swarms of *Salpa thomsoni* obtained during this study may possibly be due to the phytoplankton bloom that occurred during the period of survey²⁹. Some authors have suggested that certain key environmental factors such as temperature⁹ may play role in determining krill and salp aggregation³⁰. The aggregation of salp and euphausiids during the present study may be due to relatively high temperature, near saturation of dissolved oxygen and high phytoplankton concentration.

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