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Spatial Distribution of Krill *(Euphausia Superba)* and Other Zooplankton off Queen Maud Land, Antarctica

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ABSTRACT

The *Euphausia superba* Dana, popularly known as the krill is the richest single species resource of the Antarctic waters and they form the chief forage for whales, seals, birds, fishes and squids of this ecosystem. Several estimates regarding the magnitude of krill resource which has a circumpolar distribution within the Antarctic Convergence have been made. However, paucity of substantial data added with the behavioural characteristics of these animals such as forming into patches, shoals, schools and swarms have made it difficult to assess the real stock of these protein rich organisms.

Keeping the above mentioned problems in view, a series of zooplankton samples were collected during the Third Indian Expedition to Antarctica (1983–'84) over an area of more than 60,000 square kilometres between latitudes 67°30'S and 68°00'S and longitudes 14°00'E and 20°00'E off Queen Maud Land just outside the pack-ice, towards the beginning of winter in March, 1984. The standing crop of zooplankton including the krill in the area investigated has been estimated to be 99.8 cc per 1000 m^3 of water. The volume of plankton obtained from different stations varied between 10.02 and 248.82 cc per 1000 m^3 of water.

Large concentrations of krill, as has been reported earlier by others, were not observed because of the heavy blooming of a diatom in the area. The average biomass of euphausiids mainly composed of the krill in the area studied has been found to be 4.45 cc per 1000 m^3 of water. They were represented at an average rate of 212 individuals (9.93 gm) per 1000 m^3 of water. Eleven other groups of zooplankton were also present in the area sampled of which copepods chaetognaths, appendicularians and fish eggs were the most abundant.

INTRODUCTION

The southern ocean, south of the Antarctic Convergence is highly productive at all levels of the food web because of the special environmental features existing there. The krill *(Euphausia superba)* with its immense stock is an important resource in these waters and plays a vital role in the Antarctic marine economy. Attempts are being made by several nations to exploit this protein rich, largest single species resource which is said to surpass the fish stock in the entire world oceans. However, before starting large scale exploitation, it is but necessary to have proper knowledge about the available stock, areas of abundance, seasonal variations etc. which would help in the judicious exploitation and obtaining maximum sustainable yield. The stock estimation would be rather easier for a resource like krill whose present mortality is on account of natural death and of predation by other animals only. But the practical problems involved in reaching these areas render it difficult for a direct estimation of the resource. In spite of such difficulties major attempts have been made since long to study the Antarctic ecology in relation to the living organisms especially the zooplankton including the krill.

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The various aspects of krill – ecological, biological, chemical and economical–are being intensively studied the world over. From the point of view of commercial exploitation, the immediate requirement is a knowledge about their geographical distribution and abundance. The various studies on geographical distribution of *E.superba* have been reviewed by Mauchline and Fisher (1969) and Mauchline (1980). The estimates of the krill stock made by different workers by and large range very widely which suggest that a realistic estimate is yet to be made. In view of their importance in the Antarctic marine economy, according to Mauchline (1980), so much new knowledge on the krill should be obtained. One of the primary objectives of the international programme – the BIOMASS – is the estimation of the biomass of *E.superba.*

Leaving aside the krill, if the general fertility is considered, it could be seen that the polar seas are highly productive at the primary as well as secondary levels. The general characteristics and distribution of Antarctic plankton have been studied by Voronina (1968), Voronina and Naumov (1968), Voronina and Zadorina (1974) and Voronina *et al.* (1981).

The present paper embodies the results of an investigation carried out during the Third Indian Expedition to Antarctica (1983–'84) on the spatial distribution of zooplankton especially the krill, and also the relationship among plankton, euphausiids and the krill over an area of more than 60,000 km^2 off the Queen Maud Land, Antarctica.

MATERIAL AND METHODS

Zooplankton samples were collected from a wide geographic area covering more than 60,000 km^2 within the Antarctic Circle between latitudes 67°30'S and 68°30'S and longitudes 14°00'E and 20°00' E off Queen Maud Land, Antarctica. Altogether 21 stations were occupied along the three latitudinal grids with a Bongo net of 60 cm mouth diameter having a mesh size of 0.4 mm, as open oblique hauls from 1000 m. The seven stations in the southernmost grid were just outside the pack ice. A T.S.K. flow meter was attached to the net for estimating the quantity of water filtered. The heavy bloom of one species of diatom, *Chaetoceros atlanticum,* however, was a limiting factor for the abundance of several groups of zooplankton including the euphausiids and also in the filtration efficiency of the net.

In the laboratory the volume of total zooplankton as well as euphausiids was determined by displacement method. Numerical counts were also taken for all other groups of plankton which were standardised for 1000 m^3 of water. The sampling details along with the volume of plankton obtained, the percentage of euphausiids in the total plankton and the quantity of euphausiids obtained are given in table 1.

RESULTS AND DISCUSSION

The average biomass of plankton in the area investigated has been estimated to be 99.8 cc per 1000 m^3 of water. An analysis of the data for the variations in the zooplankton production in the three latitudinal grids showed that it was relatively less in the southern-most grid which was just outside the pack-ice. The average biomass for this grid was calculated to be 64.88 cc per 1000 m^3 of water. In the middle and northern grids the average production was 108.51 cc and 121.81 cc respectively per 1000 m^3 of water. Thus, a doublefold increase in zooplankton production was noticed between the southern and northern grids. A consideration of the variation in the biomass of plankton on a longitudinal basis showed that it was comparatively more towards the middle and western parts of the area under study.

TABLE 1

Sampling details for the zooplankton collected, its biomass, percentage of euphausiids in total plankton and gravimetric abundance of euphausiids

Gear : Bongo-60, Depth of haul : 100→0 m, Type of haul : Oblique

Sl. No.	Date	Time (hr)	Position Lat.°S.	Long.°E	D. stn. (m)	Zoopln. cc/1000 m^3	% of Euphausiids in pln.	Euphausiids g/1000 m^3
1.	2–3–'84	1100	68°30′	14°00′	3528	20.95	0.92	1.22
2.	2–3–'84	1730	68°30′	15°00′	3739	36.53	0.29	0.84
3.	2–3–'84	2030	68°30′	16°00′	3484	38.49	30.43	21.99
4.	2–3–'84	2340	68°30′	17°00′	3710	185.13	12.11	37.49
5.	3–3–'84	0240	68°30′	18°00′	3982	96.12	4.45	8.25
6.	3–3–'84	0600	68°30′	19°00′	4163	25.42	51.78	24.81
7.	3–3–'84	1335	68°30′	20°00′	3801	41.29	7.92	4.99
8.	3–3–'84	1645	68°00′	20°00′	4072	63.44	6.28	8.89
9.	3–3–'84	1855	68°00′	19°00′	4163	45.51	4.24	2.97
10.	3–3–'84	2140	68°00′	18°00′	4163	107.85	0.25	4.25
11.	4–3–'84	0045	68°00′	17°00′	3891	216.35	2.26	10.50
12.	4–3–'84	0445	68°00′	16°00′	3800	91.66	0.63	5.68
13.	4–3–'84	0800	68°00′	15°00′	3759	134.91	0.19	4.06
14.	4–3–'84	1100	68°00′	14°00′	3077	116.53	0.21	2.74
15.	4–3–'84	1515	67°30′	14°00′	3352	142.15	1.60	15.93
16.	4–3–'84	1730	67°30′	15°00′	2996	248.83	0.27	14.13
17.	4–3–'84	2000	67°30′	16°00′	4072	54.57	0.50	1.10
18.	4–3–'84	2230	67°30′	17°00′	4525	119.95	11.07	22.17
19.	5–3–'84	0100	67°30′	18°00′	4344	188.69	5.49	12.38
20.	5–3–'84	0400	67°30′	19°00′	4549	32.30	0.31	0.63
21.	5–3–'84	0655	67°30′	20°00′	4254	74.62	0.58	3.53

Great variations in zooplankton biomass were noticed among different stations of sampling. The range was between 20.95 and 248.83 cc per 1000 m^3 of water. The standing crop values for plankton obtained by Voronina and Zadorina (1974) from the Antarctic zone was 120–170 cc per 1000 m^3 of water. The volume of zooplankton reported from almost the same area of the present studies by Goswami (1983) had a range of 2 5–48 cc per 1000 m^3 of water with an average of 36.0 cc.

Euphausiid biomass

The average biomass of eupahusiids, constituted mainly by the krill, in the area studied has been estimated to be 4.45 cc per 1000 m^3 of water which was equal to 4.61% of the total plankton. This is not a very high estimate for the Antarctic waters. Several factors were responsible for obtaining such a low value; they being the small mouth area and mesh size of the net, the relatively deep hauls made and the heavy bloom of the diatom *Chaetoceros atlanticum.*

The percentage composition of euphausiids among other zooplankton in the different samples estimated on a volumetric basis ranged between 0.19 and 51.78 (Table 1).

Bigelow and Sears (1939) found that at certain of their stations in the North Atlantic, euphausiids constituted as much as 20–30% of the total volume of zooplankton and occasionally more but in general represented only a few per cent by volume of the whole sample. Reviewing the literature on biomass of euphausiids and other zooplankton, Mauchline and Fisher (1969) concluded that the euphausiids represented a major fraction of the total biomass of plankton; this being particularly high in higher latitudes. They found that the percentage composition of euphausiids in total plankton considered for diversified areas has been between 5 and 20 %.

When the rate of production of euphausiids at the latitudinal grids was worked out, the highest value was obtained for the southern-most grid (8.52 cc per 1000 m^3 of water). The least quantity of 1.79 cc per 1000 m^3 of water was obtained for the middle grid. The northern-most grid had the average production of 3.34 cc per 1000 m^3 of water which was less than half that of the southern-most grid.

A numerical estimate was also made for the entire area of investigation and it worked out to be 210 per 1000 m^3 of water. This again is not a very high number for the Antarctic waters. When a numerical estimate of total euphausiids in the different grids was done, it was found that the northern-most grid contributed the maximum with an average of 301 specimens per 1000 m^3 of water. For the southern-most and middle grids the numbers were 168 and 146 respectively. The reason for the almost inverse relationship between biomass and number in the latitudinal grids was the preponderance of larval euphausiids in the stations of the northern grid than in the two southern grids.

In the northern-most grid the maximum concentration of euphausiids was noticed at the station positioned towards west (1024/1000 m^3 of water) whereas, in the middle grid, the maximum number was at one of the middle stations (303/1000 m^3) and the trend of increase was towards the east in the southern grid (339/1000 m^3) (Fig. 1). Thus a tendency for the aggregation of euphausiids in a diagonal manner representing a thinning population from west down diagonally to east in the area investigated was already indicated (Fig. 1).

However, when a gravimetric consideration of euphausiid biomass at the different stations in the latitudinal grids was made the results obtained was different. On the whole the euphausiid biomass was rich in the southern latitude. The maximum quantity of 37.49 gm per 1000 m^3 of water was obtained in this latitude at the middle station (Table 1). Same was the case with the middle and northern sectors being respectively 10.50 and 22.17 gm per 1000 m^3 of water at the middle stations. The increased weight of euphausiids was obviously due to the presence of adults in the area especially those of *Euphausia superba* (Fig. 3). Thus from the point of view of biomass by weight a vertical pattern of abundance was discernible (Fig. 2). The total weight at the different stations ranged between 0.63 and 37.49 gm per 1000 m^3 of water (Fig. 3) and the average biomass at the three latitudinal sectors from south to north was 14.23, 5.58 and 9.98 gm respectively per 1000 m^3 of water. The significant spatial variations in the occurrence of euphausiids was a clear indication of their shoaling behaviour. However, the total quantity of euphausiids obtained even at the richest station was not representative of what ought to have been there under normal conditions.

The abundance of larval forms gave a high number of euphausiids at certain stations while the weight remained low. Similarly when the weight gave high values there was no proportionate increase in number. This was obviously due to the abundance of larval forms which often gave an unrealistic picture of the euphausiid biomass. Therefore a study was made on the relationship between number and weight of euphausiids at the various stations (Fig. 4). Thus the samples collected at the

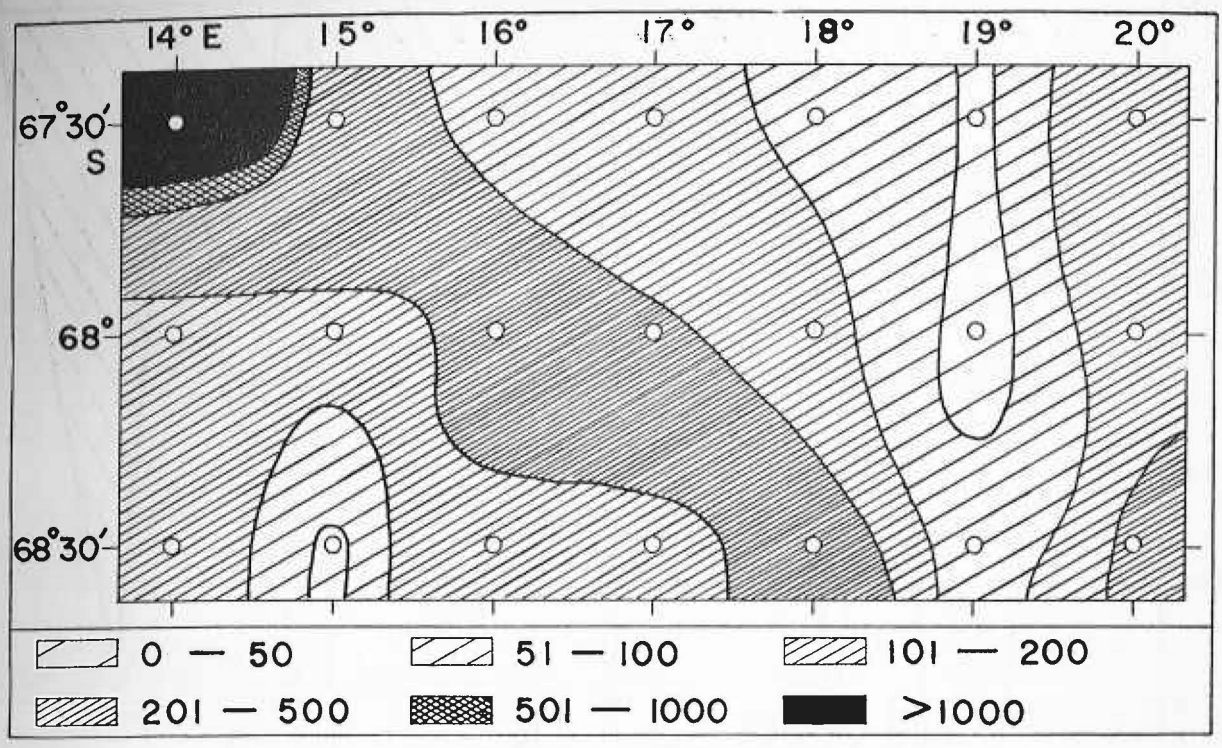

Fig. 1. Spatial distribution of euphausiids (No./1000 m³ of water).

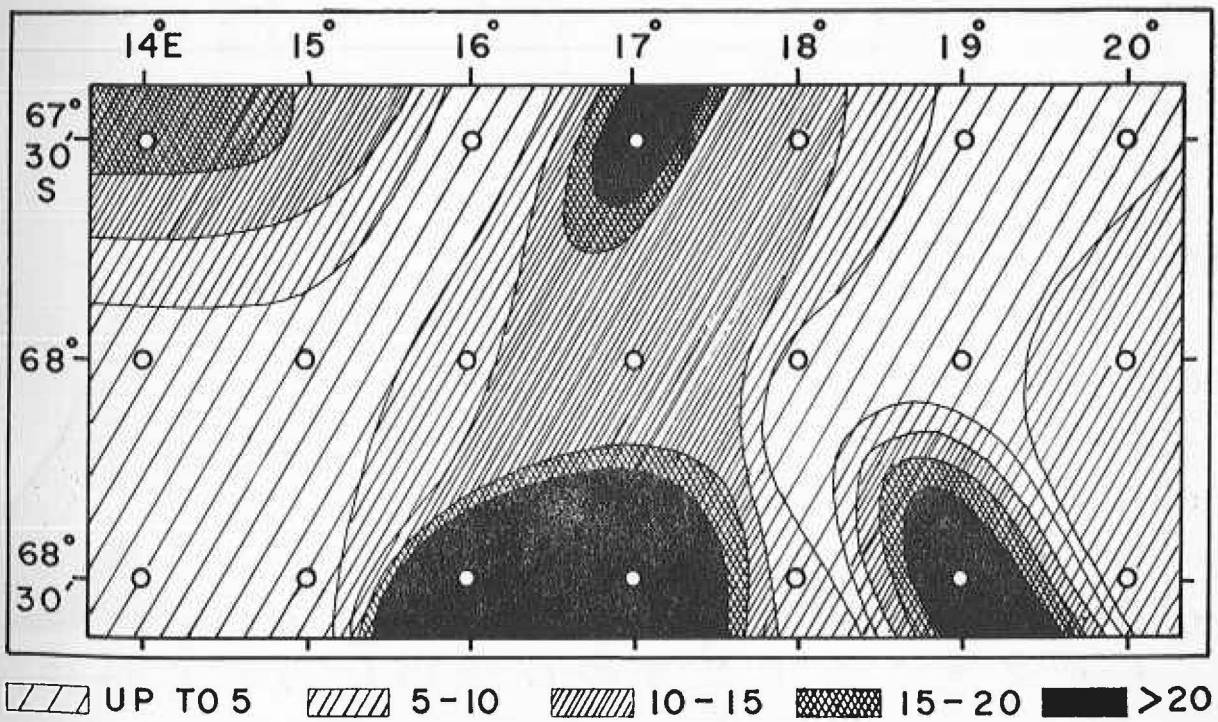

Fig. 2. Spatial distribution of euphausiids (gm/1000 m³ of water)

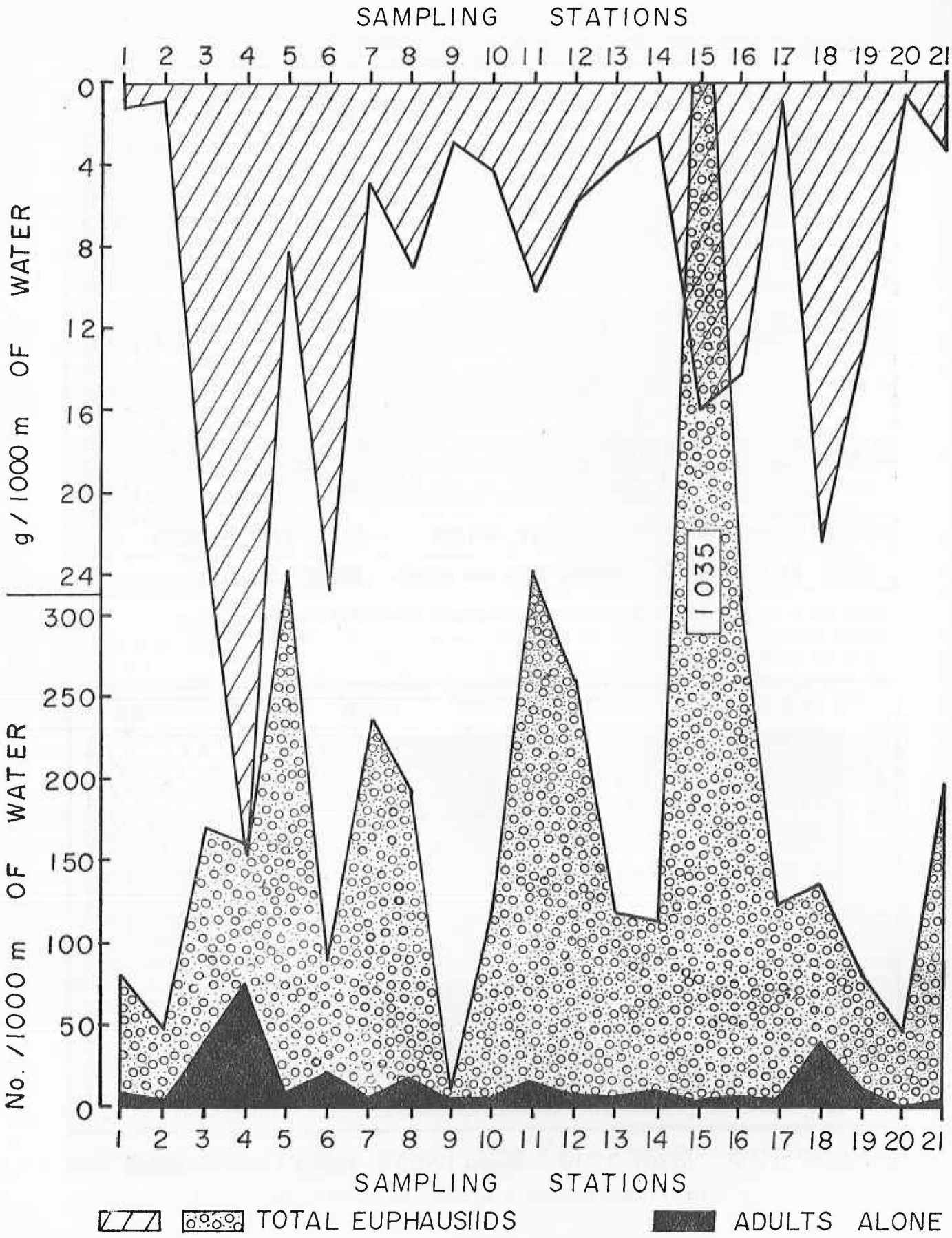

Fig. 3. Relationship between number and weight of euphausiids (adults being shown separately) obtained from different sampling stations.

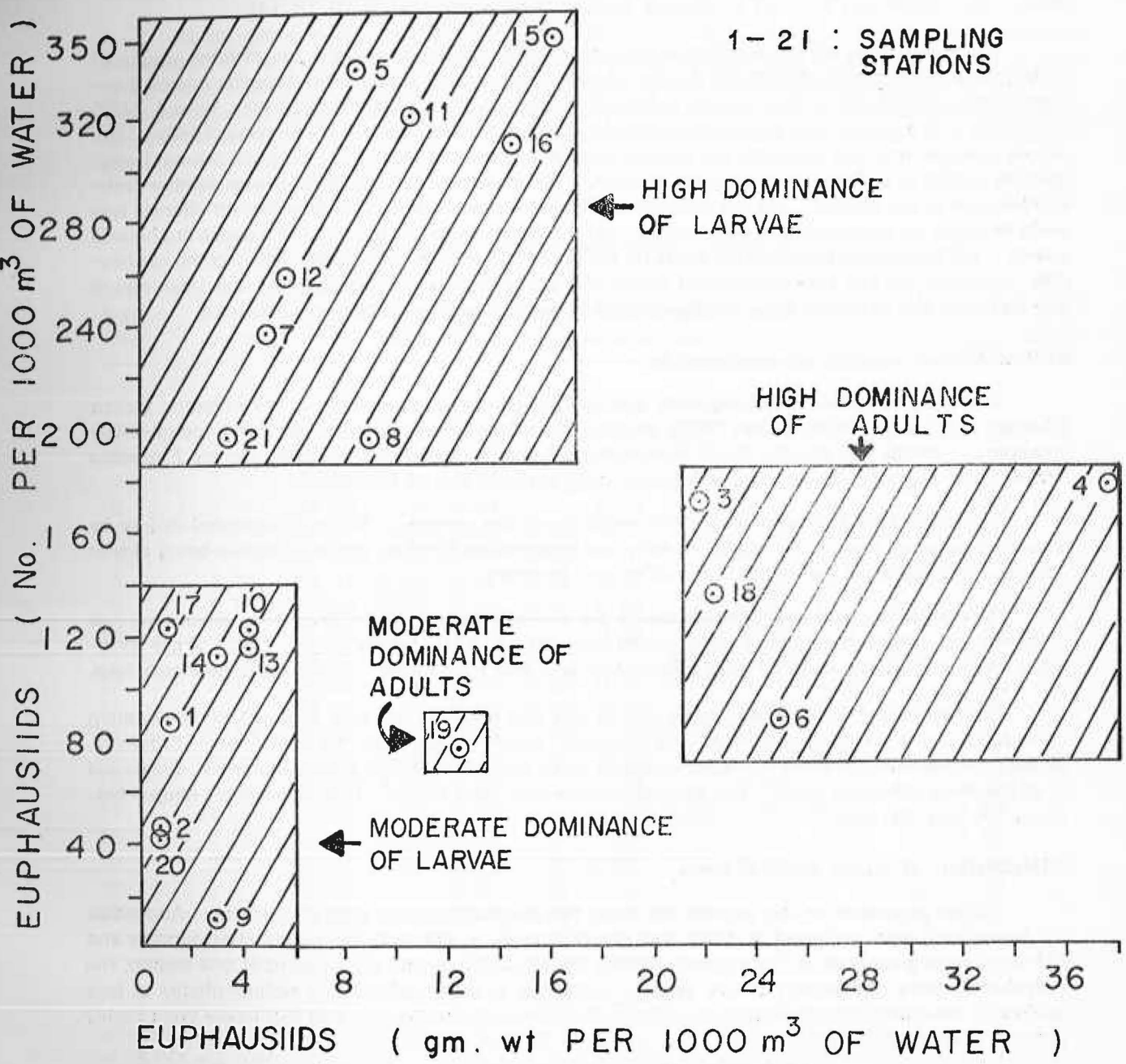

Fig. 4. Adult/larval dominance based on weight/frequency data.

different stations could be categorised into four namely (1) those which had a high dominance of larval forms, (2) those which had a moderate dominance of larval forms, (3) those in which the adults showed a moderate dominance and (4) stations where adults had a high dominance. The study indicated that the biomass was really high, with the presence of adults, in the southern grid (stns. 3,4, 6), while the middle (stns. 8, 11, 12) and northern (stns. 15, 16, 21) grids had a high dominance of larvae. The middle grid also had a moderate dominance of larvae (stns. 9, 10, 13, 14).

The euphausiids are known to make aggregations on the surface of the sea to form groups of varying densities, and according to the density of individuals in each aggregation separate names have been given. Thus a *patch* may contain 1–10 individuals per m^3 of water, a *shoal* may have 1–1000 individuals. In a *swarm* and *school* there may be 1000–10000 individuals (Mauchline, 1980). The sample collected from the station at the extreme west in the northern-most grid during the present investigations qualify to include in the category of patch. Other samples did not yield greater number probably because of the reasons (1) the collections were on a random basis and therefore no attempt was made to locate an aggregation of euphausiids, (2) no station came on the way of a dense euphausiid swarm, (3) the present estimates are made for the upper 100 m of water column, whereas the euphausiids especially the krill are concentrated within the upper 10 m water column, (4) the small mouth area and mesh size of the net and (5) the unusual bloom of a species of diatom in the area.

Krill and other species of euphausiids

There are 12 species of euphausiids that have circumpolar distribution in the Antarctic Ocean (Rustad, 1930; John, 1936; Baker, 1965) of which *E.superba* is the most abundant and commercially important. Of the 12 species three were obtained during the present studies, namely *E.superba* *E.frigida* and *Thysanoessa macrura*. However, great majority was of *E.superba*

E.superba (the krill) was present invariably in all the samples. It was represented mainly by larvae. The larvae were in the stages of early and intermediate furciliae, the late furciliae being almost absent. This indicates uniformity in maturing and spawning.

The larger *E.superba* were mainly adults, the sub-adults being rarer. Size class occurrence was quite distinct. The sub-adult and adult ranged between 35 and 52 mm in length. Most of the specimens were females and majority were fully mature with ripe eggs inside. Spent ones were also seen.

E.frigida occurred at three stations only in very few numbers and was confined to the southern two grids. All were adult specimens and their total length ranged from 16 to 21 mm. *T.macrura,* although represented in fewer numbers, occurred in 10 samples and was almost uniformly distributed in all the three latitudinal grids. The specimens were fully adult forms. Their total length ranged between 14 and 22 mm.

Distribution of other zooplankters

When compared to the warmer sea areas the zooplankton was poor in varieties. Altogether 12 groups only were collected of which four groups namely euphausiids, copepods, chaetognaths and fish eggs were present at all the stations. While the appendicularians were absent at one station, the polychaetes were not present at two stations, ostracods at three stations and siphonophores at four stations. All others namely amphipods, pteropods, planktonic gastropods and fish larvae were highly patchy in their distribution.

The average numerical density of copepods, the major constituent of zooplankton, when estimated for the entire area was 14,280 per 1000 m^3 of water which was equal to 91.39% of the total zooplankton. They were followed by the fish eggs with an average number of 1219 per 1000 m^3

of water (3.93%). The chaetognaths, the third in the order of abundance had an average density of 208 individuals and a percentage contribution of 1.34 of the total plankton. The appendicularians, although had a wide spread occurrence in the area of investigation could take a share of only 0.72% with an average number of 111 per 1000 m^3 of water. Of all the other groups, each had a meagre representation of less than 1% of the total.

At the various stations also the copepods formed numerically the major constituent, contributing between 78.87 and 97.76 %. (Table 2). Contrary to this, the fish eggs constituted 1.01 to 10.22% at the various stations. With regard to the chaetognaths, their contribution was from 0.23 to 9.79%. The next abundant group, the appendicularians also showed great variations in abundance and ranged between zero and 4.97 % (Table 2). The other groups together contributed less than 1 % at the different stations.

TABLE 2

Percentage composition of different zooplankton groups (based on number)

Station No.	*Eupha-usiids*	*Cope-pods*	*Chaeto-gnaths*	*Appen-dicularia*	*Ostra-cods*	*Poly-chaetes*	*Amphi-pods*	*Siphono-phores*	*Gastro-pods*	*Ptero-pods*	*Fish eggs*	*Fish larvae*
1.	0.90	83.56	5.35	4.97	0.40	0.68	0.68	0.17	0.56	..	1.96	..
2.	0.48	91.31	3.40	0.91	0.18	0.24	0.42	..	0.48	0.36	2.23	..
3.	1.70	95.55	0.64	0.25	0.17	0.05	0.25	..	0.05	0.10	1.18	..
4.	1.96	87.51	2.48	0.62	..	0.21	0.21	..	..	1.03	5.78	..
5.	2.17	88.59	1.15	0.47	..	0.31	..	0.16	..	..	7.83	0.05
6.	3.02	85.87	0.66	0.42	0.14	0.07	0.10	0.07	0.10	..	10.22	..
7.	1.69	97.76	0.23	0.17	0.06	..	..	..	0.02	0.02	2.54	..
8.	1.84	93.37	0.55	0.41	0.07	0.07	..	0.34	0.03	0.03	4.10	..
9.	0.07	91.39	0.29	0.46	0.06	0.63	..	0.57	..	0.06	6.31	..
10.	0.75	91.87	1.50	0.86	..	0.43	..	1.18	..	..	2.99	0.11
11.	1.64	95.39	0.59	..	0.10	..	0.10	0.30	..	0.10	3.31	..
12.	2.13	88.63	1.64	0.74	0.25	0.25	..	0.49	0.08	..	5.64	..
13.	1.98	88.94	1.68	0.98	0.56	0.28	..	0.28	0.42	0.88	0.60	..
14.	3.14	87.62	1.43	0.95	1.19	0.24	..	0.95	..	..	5.48	..
15.	8.20	84.76	2.35	1.93	1.34	0.42	..	0.67	0.08	0.08	1.01	..
16.	4.61	78.87	9.79	1.55	0.52	0.26	..	1.03	..	..	4.38	..
17.	1.79	92.42	0.79	0.42	0.26	0.53	0.05	0.32	0.05	..	3.92	..
18.	0.86	90.81	0.42	0.92	0.18	0.27	..	0.37	0.09	..	5.95	..
19.	0.24	93.82	0.51	0.41	0.15	0.61	..	0.05	..	..	3.97	..
20.	1.32	93.47	0.42	0.60	0.32	0.60	..	0.23	..	0.05	3.98	..
21.	1.86	94.29	0.58	0.66	0.45	0.41	..	0.04	..	0.04	2.42	..

The copepods were aggregated more towards the eastern part of the area of study. When considered latitudinally, they were found to be more abundant in the southern grid with an average number of 16,144 per 1000 m^3 of water. However, in the first four western stations in this grid the copepods were poorly represented. But this was made good of with their enormous number in the easternmost station (33,659 per 1000 m^3 of water), which was the highest number obtained during the present study. In the middle grid the copepod population was of moderate magnitude with an average number

of 12, 738 per 1000 m^3 of water. In the northern-most latitudinal grid the average number was slightly increased to15,172.

With regard to fish eggs, when the average density in each of the latitudinal grids was worked out it was found to be surprisingly similar being from south to north 622, 603 and 605 per 1000 m^3 of water suggesting an uniform mode of distribution. In spite of having a good number of fish eggs in the plankton, the contribution of fish larvae was extremely poor. Only two out of 21 stations collected them at the rate of 15 and 17 per 1000 m^3 of water.

An area-wise consideration of chaetognaths showed that they were highly irregular in distribution with random aggregations. While an east–west difference in occurrence was not found, the north-south variations in abundance was significant being less in the southern and middle grids where an average number of 196 and 137 individuals respectively per 1000 m^3 of water were present. In the northern grid which was more closer to the Antarctic Circle, the number was 280 per 1000 m^3 of water.

The appendicularians were more towards the western part. While in the northern grid 145 specimens per 1000 m^3 of water were obtained, from the middle and southern grids the numbers taken were 78 and 107 respectively. The polychaetes were relatively more towards the east. A distinct difference in the north–south distribution was indicated being 78 and 28 for the northern and southern grids respectively per 1000 m^3 of water.

The ostracods showed an almost cosmopolitan distribution. However, a slight aggregation was indicaged towards the northwestern part of the area. The latitudinal difference in distribution was remarkable being more towards the north. Their average abundance at the three latitudinal grids was 13,30 and 74 per 1000 m^3 of water.

Almost in the same magnitude as that of the polychaetes and ostracods were the siphonophores. In the total plankton, their share was 0.30%. Among the other zooplankters of the various stations they ranged between 0.05 and 0.68 % (Table 2). Their average density in the area of study was estimated as 46 individuals per 1000 m^3 of water. However, not much variations were observed in their occurrence at the various stations. When considered latitudinally the siphonophores were more towards the north. The numbers obtained from the southern, middle and northern grids 10, 72 and 55 respectively per 1000 m^3 of water.

The amphipods were present in a few stations only, mainly in the southern grid and hence their distribution was highly patchy. Their latitudinal occurrence was interesting in that they were almost concentrated towards north. The middle and northern grids had them only at one station each that too in very small numbers. The occurrence of amphipods in each of the grids from south to north was 17, 2 and 1 respectively per 1000 m^3 of water.

Small quantities of planktonic molluscs (pteropods and gastropods) were also obtained during the investigation. Eventhough sparsely distributed, they were found in all the three latitudinal grids at one station or the other. But any difinite pattern of distribution either north-south or east-west was not discernible. While the pteropods had a percentage composition of 0.07, the gastropods had 0.06 in the total plankton.

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