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STUDIES ON QUANTITATIVE ABUNDANCE OF EUPHAUSIACEA (CRUSTACEA) WITH SPECIAL REFERENCE TO DISTRIBUTION IN SPACE AND TIME ALONG THE SOUTHWEST COAST OF INDIA

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ABSTRACT

The quantitative abundance and seasonal and spatial distribution of Euphausiacea within the continental shelf waters between Calicut and Karwar along the southwest coast of India has been studied in detail for the first time. The abundance of total euphausiids in the study area has been numerically estimated to be 1980 per 1000 m^3 of water. A study of the seasonal variations of total euphausiids showed that the maximum abundance was in October followed by August. An examination of the spatial variation of total euphausiids revealed that the northern parts were richer with the maximum concentration in the deep neritic areas. The distribution of total euphausiids in space and time has also been investigated.

When the seasonal and spatial distribution of the various species was considered, it was found that six species were particularly abundant in certain months; those species being *Pseudeuphausia latifrons* (December-February), *Euphausia diomedae* (February), *E. sibogae* (August-October), *Nematoscelis gracilis* (February), *Stylocheiron armatum* (October-April) and *S. affine* (October-February).

INTRODUCTION

THE EUPHAUSIID fauna of the Indian Ocean, especially that of the Indian seas is less investigated for its quantitative abundance and distribution in time and space. What all information we have are based on the results of Expeditions which mostly give faunistic accounts. However, a good deal of investigation on the Indian Ocean euphausiids have been carried out during the last two decades, especially after the INTERNATIONAL INDIAN OCEAN EXPEDITION. Gopalakrishnan and Brinton (1969) and Brinton and Gopalakrishnan (1973) have made comprehensive studies on the distribution of euphausiids of the Indian ocean as a whole. Weighmann (1970) dealt with the euphausiids of the Arabian Sea as a whole during the northeast monsoon. However, there has been no informatin on the quantitative seasonal distribution of Euphausiacea in the neritic waters of the Indian coasts, Sebastian (1966) has listed the euphausiid species available along the southwest coast of India and Lakshadweep and the Maldive seas. The present paper embodies the results of detailed investigations carried out on various aspects of quantitative seasonal and spatial distribution of euphausiids in general and of various species in particular along the southwest coast of India within the continental shelf area between Calicut and Karwar.

I am deeply indebted to Dr. E. G. Silas, Director, Central Marine Fisheries Research Institute, Cochin for suggesting the problem, guidance and for critically examining the manuscript.

MATERIAL AND METHODS

The euphausiid material used for the present study was collected onboard R. V. VARUNA from the continental shelf area between lati-

tudes 11°32'N and 14°54'N. Bimonthly zooplankton sampling from December, 1966 to December, 1967 was carried out from 30 fixed stations distributed in six latitudinal sectors. Open vertical hauls were made from about 5-10 m above bottom to the surface by means of an Indian Ocean Standard Net (IOS Net) of 0.33 mm mesh size (Curie, 1963). Altogether 182 samples were analysed for euphausiids. Complete sorting and enumeration of adult, immature and larvae of all the species available within the study area have been done. The quantitative estimates of euphausiids in general and of the different species have been done for 1,000 m^3 of water. The ring diameter of the IOS Net being 113 cm it covers almost 1 m^3 area and hence the vertical column of water travelled by the net upto 200 m depth could be considered as the volume of water filtered by the net during a haul, assuming that the filteration efficiency of the net is 100 per cent.

The Abundance

The estimates of euphausiid abundance has been made for the Indian Ocean as well as for the other oceans by the previous authors. Gopalakrishnan and Brinton (1969) estimated the euphausiid abundance to be in the range of 2,500-4,000 per 1000 m^3 of water for the 10° zones north of the equator in the Indian Ocean and more than 1000 per 1000 m^3 of water for the major part of the Indian Ocean. These estimates were based on both day and night samples considered together. Ponomareva (1966) estimated the euphausiid density for the entire Pacific and found that majority of the areas comprising the tropics and sub-tropics contain euphausiids at the rate of 100 to 500 per 1000 m^3 of water. The maximum density of over 1000 per 1000 m^3 of water was found to be in the temperate and the subarctic far eastern seas and parts of the California Current. Gopalakrishnan and Brinton (1969) and Mauchline and Fisher (1969) are of the opinion that these estimates by Ponomareva are very conservative. Gopalakrishnan and Brinton are of the opinion that the areas of high population density in the tropical Indian Ocean are proportionately large compared with high density areas in the temperate and subarctic Pacific and that the maximum Indian Ocean densities are at least as high and probably higher than those reported in the Pacific. The density of euphausiid population estimated for the shelf waters of the present study area is given below.

The average density of euphausiids in the area under the present investigation within the continental shelf region based on collections made during the period from December, 1966 to December, 1967 has been estimated to be 1,980.55 per 1000 m^3 of water, pooling the day and night samples together. This estimate is much less than that of Gopalakrishnan and Brinton (1969) but higher than that estimated by Ponomareva (1966) for the Pacific. It is to be mentioned here that the nearshore areas which form no less than a substantial portion of the continental shelf and which are also included for the present estimate, do not normally contain euphausiids and this may be one reason for obtaining a rather low estimate.

Following Gopalakrishnan and Brinton (1969) the day and night samples when considered separately for estimating the population density of the shelf waters it has been found that while the day samples contained at an average rate of 940.07 euphausiids per 1000 m^3 of water, the night samples contained an average of 3,327.49 euphausiids per 1000 m^3 of water. Gopalakrishnan and Brinton while estimating the euphausiid populations of the Arabian Sea, applied a correction factor of 1.5 to the day samples to make them par with the night samples. (They found that the day samples were very poor with respect to euphausiids because, in the first place, the euphausiids exhibit strong vertical diurnal migrations and secondly they may dodge the net in the day

light). A similar treatment was done with the present material also and a value as high as 2,250.00 per 1000 m^3 of water has been obtained for the continental shelf area.

Considering the extreme variability in abundance of euphausiids in the nearshore shallow areas and deeper areas of the continental shelf region an attempt has been made to divide the study area into three depth zones pooling day and night samples together. Areas upto 25 m depth from the shore were included in the first zone. The second zone included the depth zone between 26 and 75 m. The water area between 76 m and the edge of the continental shelf was included under the third division. The estimates thus obtained indicated that while the shallow water areas had a population density of 82.80 per 1000 $m^3$of water, the intermediate depth zone had 1569.15 per 1000 m; of water. The estimate for the third depth zone was 2,541.56 per 1000 m^3 of water.

The seasonal variations in the density of euphausiid populations in the continental shelf area have been studied and the results are given in Table 1. From the Table it is found that the period from August to October accounted for the maximum density of euphausiids.

TABLE 1. *Seasonal variations in the density of euphausiids (day and night samples pooled)*

Month and year	No. of specimens per 1000 m^n of water
December, 1966 ..	707.69
February, 1967 ..	1,528.81
April, 1967 ..	481.33
June, 1967 ..	160.00
August, 1967 ..	4,261.36
October, 1967 ..	5,250.33
December, 1967 ..	835.96

Another approach has been made to study the seasonal variations by considering the population density in the various months in the different depth zones and the results of this study are given in Table 2. It is seen from the Table that the euphausiids came to the shallow waters during August and October ; the months of intense upwelling in the study area. The other depth zones were also richer in euphausiids during these months, with the maximum concentration in the deeper zones. The deep neritic zones was relatively richer during February, April and December also.

TABLE 2. *Density of euphausiid populations in the different bathymetric zones during various months (day and night samples pooled)*

Month and year	No. of euphausiids per 1000 m^3 of water in depth zones		
	upto 25 m	26-75 m	76-180 m
December, 1966		866.21	604.22
February, 1967		972.29	2,319.12
April, 1967		123.17	985.71
June, 1967		89.36	236.00
August, 1967 ..	298.51	3,261.54	5,277.59
October, 1967 ..	200.00	4,667.56	6,029.72
December, 1967		592.16	1,158.94

Gopalakrishnan and Brinton (1969) divided the year into two main seasons based on climatic conditions. The period from April 16 to October 15 agrees with the wind regime of the southwest monsoon (Wooster *et al.*, 1967) and the southern hemisphere's winter. October 16 to April 15 includes the northeast monsoon and the southern summer. The quantitative distribution of euphausiid populations considered separately for the two seasons by them based on the night samples indicated that during the April-October period an average density of 10 per m^3 of water was present off the coasts of Arabia, Somaliland and the Nicobar Islands of the Bay of Bengal. The average estimates obtained for the southwest coast of India extending eastward around the tip of India to Sri Lanka, coast of tropical Africa, Gulf of Oman and the Andaman Islands was between 4 and 10 per m^3 of water. During the October-April period the largest populations

of euphausiids were nevertheless centred at the equator, on the Somali coast. Off Arabia the population density also remained nearly as high as during April-October, but off the west coast of India it decreased appreciably. During this season while the highest densities off Somalia, Arabia and the tip of India were at nearshore stations, those off west coast of India lay somewhat further offshore.

With regard to the population density of the present study area, an attempt has also been made to make separate estimates for the April 16 to October 15 season and the October 16 to April 15 season. (For the first category the samples collected during April, June, August and October were considered and for the second category the samples obtained during December, 1966, February and Decem-

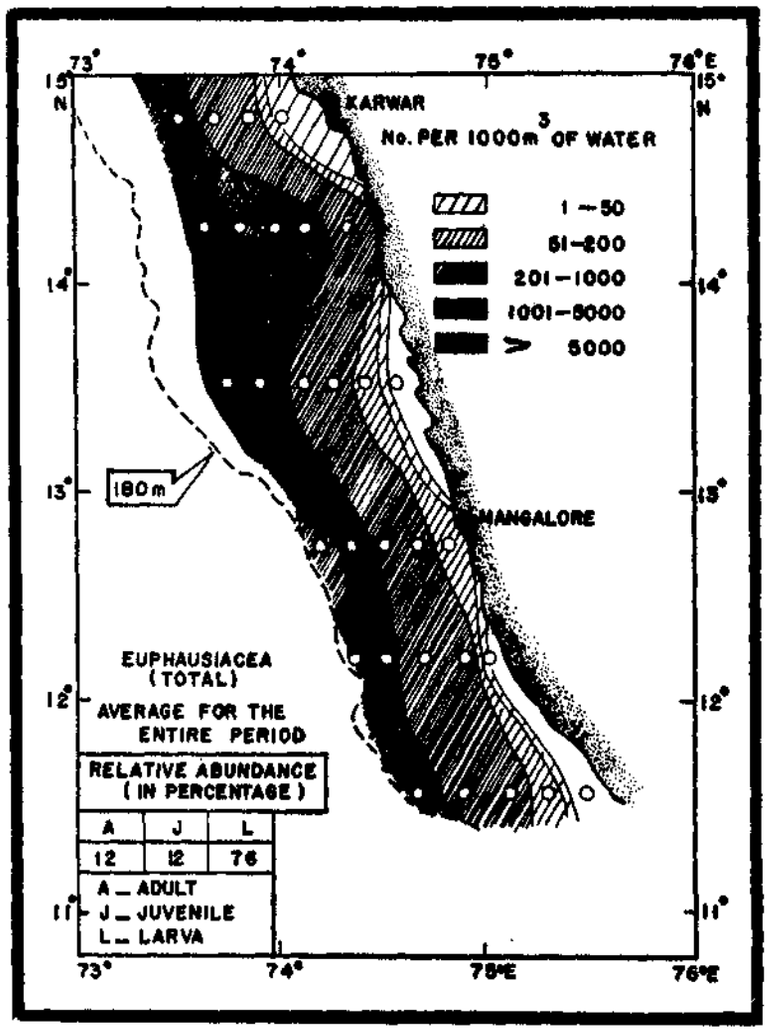


FIG. 1. General picture of spatial distribution of Euphausiacea (total) in the continental shelf area based on estimated average values (No. per 1000 m³ of water) for the period from December 1966 to December 1967. The relative abundance of adults, juveniles and larvae (in percentage) is given in the inset Table.

ber, 1967 were made use of). The estimates showed that during the southwest monsoon period *ie.* April-October the population density was 4.02 per m^3 of water and for the other season the estimate was 1.88 per m^3 of water when estimated taking into consideration the night samples alone. On the other hand when the day and night samples were considered together the values for the former season was 2.95 per m^3 of water and for the latter season it was 1.03 per m^3 of water.

Spatial Distribution of Euphausiids

Gopalakrishnan and Brinton (1969) have highlighted the significance of looking into the distribution of Euphausiacea as a whole in space. According to them as majority of the euphausiid material consists of larvae and immature specimens, as all species pass through similar developmental stages, and the younger stages of most specimens are restricted to the near surface strata it is to be expected that the euphausiid community as a whole is representatively sampled. Their further reasoning towards thispoint is concerned with the appendages that function in feeding, based on which the genera are distinguished. According to them whether the food is gathered selectively or by filtering, those species whose feeding habits have been studied are generally recognised as omnivorous and, hence, play similar role in the food chain. This may be particularly true in the epipelagic part of the tropical zones. For the same reasons, during the present investigations also a study in the similar way has been made and the following is a discussion on the same.

The variations in the average number of euphausiids spatially within the continental shelf during the period from December, 1966 to December, 1967 are presented in Fig. 1. While the coastal and contiguous areas accounted for relatively less number of euphausiids, the stations in the deep neritic areas yielded more of them. At three nearshore stations in the 2nd, 5th and 6th latitudinal sectors (from north) the euphausiids never occurred. Heavy concentration was observed in the deep neritic areas of the northern sectors. The highest number of 14,546.48 specimens per 1000 m^3 of water was taken from the shelf edge station in the 3rd latitudinal sector. At the other stations the average number per 1000 m^3 of water ranged between 27.27 at the nearshore station in the northernmost sector to 5,784.62 at a station in the 3rd latitudinal sector. The influx of the euphausiids into the shallow neritic areas was pronounced in the 2nd sector. The relative abundance when worked out among adults, juveniles and larvae, it was found that the adults and juveniles were constituted by 12 per cent each of the total material while the rest 76 per cent was formed by the larvae (Fig. 1 inset Table).

Table 3. *The latitudinal sectors and the sequential order in which the fixed sampling stations are numbered from north to south*

Latitudinal sectors		Sequential order of station numbers					
			Offshore			Nearshore	
	North			North			
Northern sectors	I			4	3	2	1
	II		5	6	7	8	9
Mid-sectors	III	15	14	13	12	11	10
	IV		16	17	18	19	20
Southern sectors	V		25	24	23	22	21
	VI		26	27	28	29	30
	South			South			

Seasonal and Spatial Distribution of Euphausiids

To have a generalised picture of the total euphausiid distribution in the area considered for the present study on a bimonthly basis, distribution charts have been prepared (Fig. 2). (Table 3 is a reference chart which indicates the various latitudinal sectors and the sequential order in which the 30 fixed sampling stations are numbered from north to south. The chart will aid in the proper understanding of the ensuing discussions).

Figure 2 indicates that on the whole the euphausiid fauna was comparatively richer in the area. They showed wide fluctuations in the different months at the various stations ranging from 14 specimens at station 17 in December, 1966 to 62,733 specimens at station-15 in October, 1967 per 1000 m^3 of water. Some stations being closer to the coast never recorded any euphausiids during the one year of study. The shoaling nature of euphausiids was in evidence more than once. Eventhough they are strictly oceanic forms they were brought close to the coast in some months especially when there was the incursion of upwelled oceanic waters into the inshore area. In these months the euphausiids were caught, though in lesser numbers, from stations where the depth to the bottom was as low as 18 m.

While the euphausiids were widely distributed in high and moderate numbers in the months from August to February their distribution was patchy and their density thin during the period from April to June (Fig. 2). In December, 1966 (Fig. 2-a) the euphausiids enjoyed a cosmopolitan distribution in the area under study and their number at the various stations ranged between 14 and 5,300 per 1000 m^3 of water. They showed greater density towards the northern and southern parts of the area in this month. The night samples generally registered high catch rate. In February also the trend was more or less the same as in December, 1966 with regard to the spatial distribution (Fig. 2-b). However, the population density at the various stations was more, which ranged between 29 and 8,857 per 1000 m^3 of water. In April the euphausiid populations were absent in the nearshore stations (Fig. 2-c). The general distribution was highly patchy and the number ranged between 18 and 2,706 per 1000 m^3 of water. In june complete coverage of the area could not be made. However, with the available data it was observed that the euphausiids were poorly represented in this month (Fig. 2-d). A sudden change was noticed in the month of August and October when large quantities of euphausiids were taken from the shelf waters (Fig. 2-e, f). In August their number ranged between 67 and 18,771 per 1000 m^3 of water. In both the months the northern sectors of the area had more number of euphausiids. The maximum number of euphausiids at a single station was collected in October (at station 15) and the number per 1000 m^3 of water in the various samples ranged between 40 and 62,733. The shoaling behaviour of the euphausiids was observed in these two months. Similarly the euphausiid populations came nearer to the coast in these two months. As far as the total number of specimens is concerned the December, 1967 samples were richer than the samples taken during December, 1966 (Fig. 2-g). Eventhough the euphausiids were present in less than half of the total number of stations sampled, their population density ranged from 89 to 8,080 specimens per 1000 m^3 of water.

When an overall consideration was made of the larvae, juveniles and adults among the total euphausiids collected from within the shelf waters for the different months it was found that of the total material the larval forms constituted 23 per cent in June to 91 per cent in August. The juveniles constituted 5 per cent in August to 32 per cent in February and the adults formed 4 per cent in August to 51 per cent in April of the total euphausiids (Fig. 2 h : Inset Table).

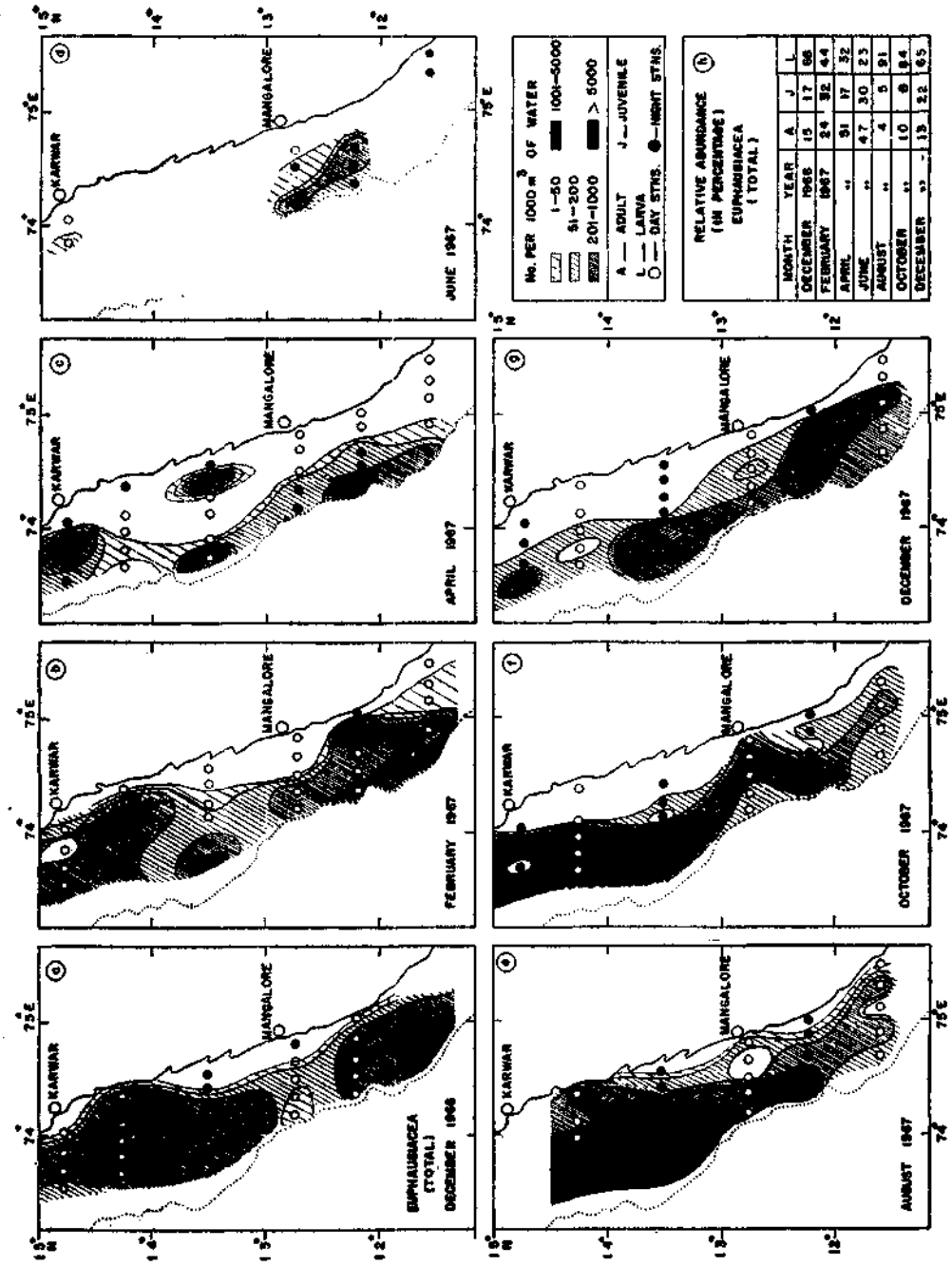


FIG. 2. Seasonal and spatial distribution of Euphausiacea (total) in the continental shelf area (estimated numerically per 1000 m³ of water). Relative abundance of adults, juveniles and larvae (in percentage) in different months is given in the inset Table.

The larval stages occurred more abundantly in all months, except in April and June, when their percentage composition among other stages was 32 and 23 respectively. These two months registered the highest percentage of adults which formed 51 and 47 per cent respectively. An inverse relationship between the larvae and adults in different seasons was also noticed both presenting a cyclical pattern opposing each other with regard to their seasonal abundance (Fig. 2-h).

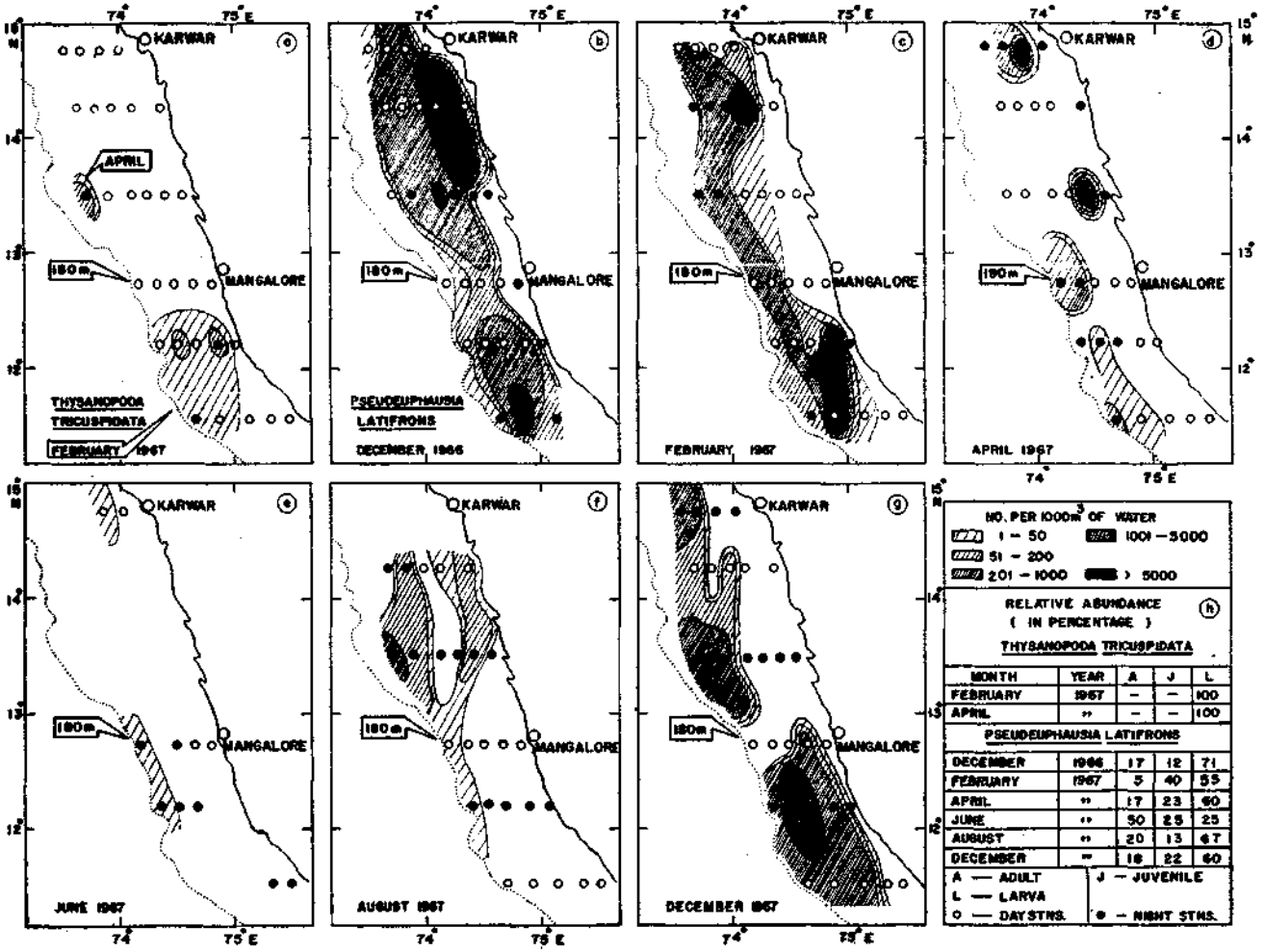
Seasonal and Spatial Distribution of Euphausiid Species

The euphausiid material used for the present study has enabled to understand the distribution of various species in space and time. The earlier investigations on seasonal distribution of euphauiid species of the Indian Ocean are very much limited. Roger (1966) studied the seasonal distribution of some species of the genus *Thysanopoda* of the southeastern Indian Ocean. In 1973 Brinton and Gopalakrishnan published the results of a study of some very common species of the Indian Ocean dividing the year into two broad seasons; May to September and November to April. A detailed investigation on the seasonal distribution of the species of *Nematoscelis* of the Indian Ocean has been carried out by Gopalakrishnan (1974). Legand *et al.* (1975) attempted a study on the seasonal and spatial distribution of the genus *Thysanopoda* of the southeastern Indian Ocean for a period of one year from August, 1962 to August, 1963. Again in 1977, McWilliam made a study of the euphausiids of the same area for the same period.

The following is an account of the seasonal and spatial abundance of 14 species of euphausiids (pooling larvae, juveniles and adults) occurred within the continental shelf waters. The quantitative abundance of species in the various months of observation is given in Table 4. The seasonal variations in the day/night abundance are given in Table 5. A series of charts have been prepared to study the spatial and seasonal abundance and these are presented as Figures 3 to 8.

Table 4. *Monthwise and annual mean abundance of various species of euphausiids in the shelf area (No./1000 m^3 of water; day and night samples pooled)*

Species	Dec. '66	Feb. '67	Apr.' 67	Jun. '67	Aug. '67	Oct. '67	Dec. '67	Total
T. monacantha	.. ..	1.28	9.33	..	..	..	..	1.68
T. tricuspidata	.. ..	16.01	2.00	..	..	..	..	2.94
P. latifrons	.. 416.00	531.37	68.00	8.00	38.96	..	253.94	233.45
E. diomedeae	.. 27.69	198.46	32.67	..	..	39.74	51.10	57.28
E. tenera	.. ..	37.13	0.67	..	..	..	..	6.20
E. sibogae	.. 35.69	72.34	43.33	..	4160.71	5045.03	37.22	1370.51
N. gracilis	.. 27.69	103.07	30.67	6.00	..	..	34.70	32.58
S. armatum	153.85	456.47	263.33	4.00	..	..	242.90	183.41
S. affine	.. 46.15	106.27	26.00	138.00	44.64	160.93	116.00	87.34
S. sulmi	.. ..	5.76	..	2.00	8.12	1.32	..	2.31
S. microphthalma	.. 0.62	0.64	0.67	..	..	..	..	0.32
S. longicorne	.. ..	..	..	..	8.12	3.31	..	1.58
S. abbreviatum	.. ..	..	4.67	..	..	..	..	0.74
S. maximum	.. ..	..	..	2.00	0.81	..	..	0.21



MONTH	YEAR	A	J	L
FEBRUARY	1967	-	-	100
APRIL	"	-	-	100

MONTH	YEAR	A	J	L
DECEMBER	1966	17	12	71
FEBRUARY	1967	5	40	55
APRIL	"	17	23	60
JUNE	"	50	25	25
AUGUST	"	20	13	67
DECEMBER	"	18	22	60

FIG. 3. Seasonal and spatial distribution of *Thysanopoda tricuspidata* and *Pseudeuphausia latifrons* in the continental shelf area (estimated numerically per 1000 m³ of water). Relative abundance of adults, juveniles and larvae (in percentage) of the two species is given in the inset Table.

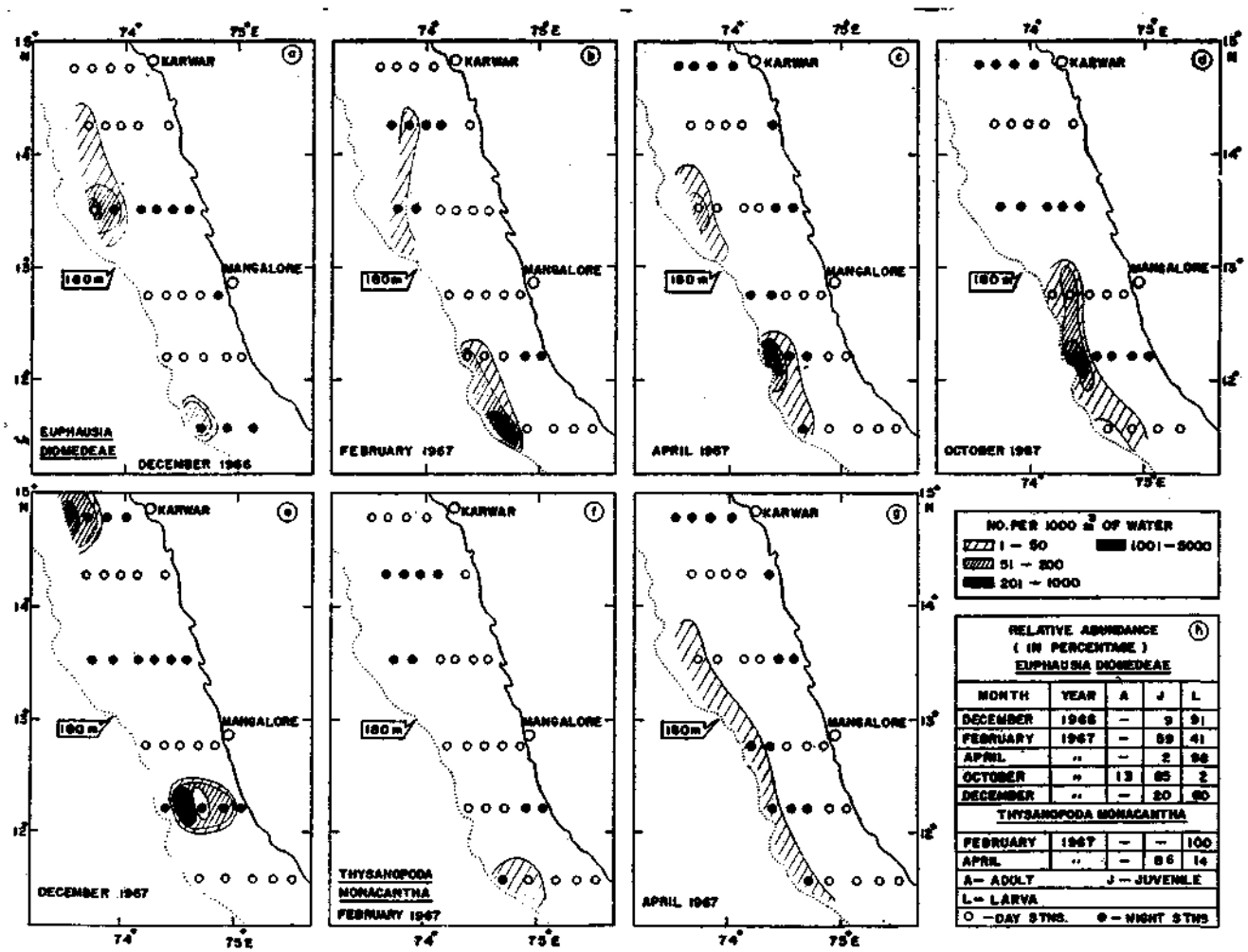


FIG. 4. Seasonal and spatial distribution of *Euphausia diomedeae* and *Thysanopoda monacantha* in the continental shelf area (estimated numerically per 1000 m³ of water). Relative abundance of adults, juveniles and larvae (in percentage) of the two species is given in the inset Table.

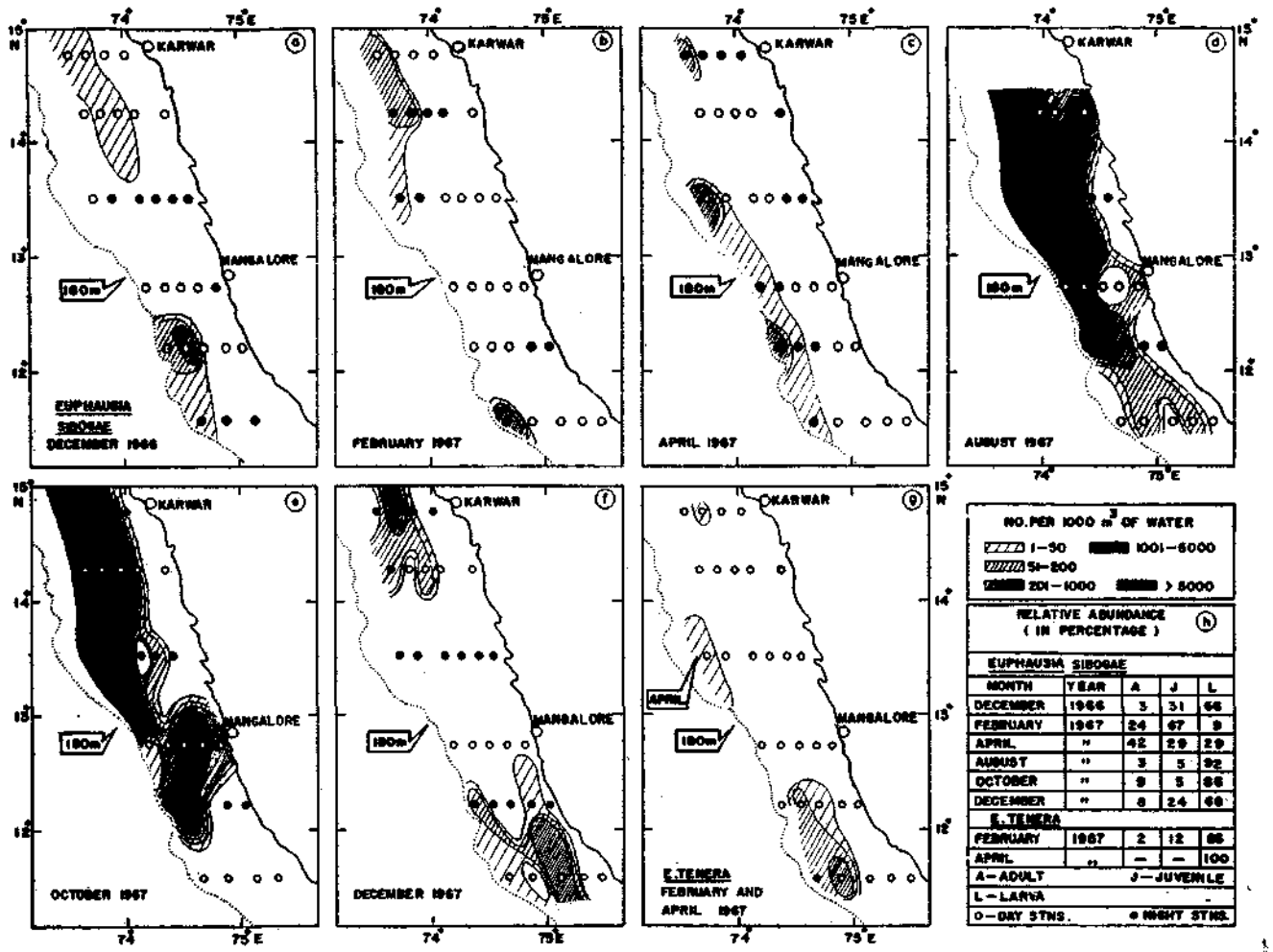
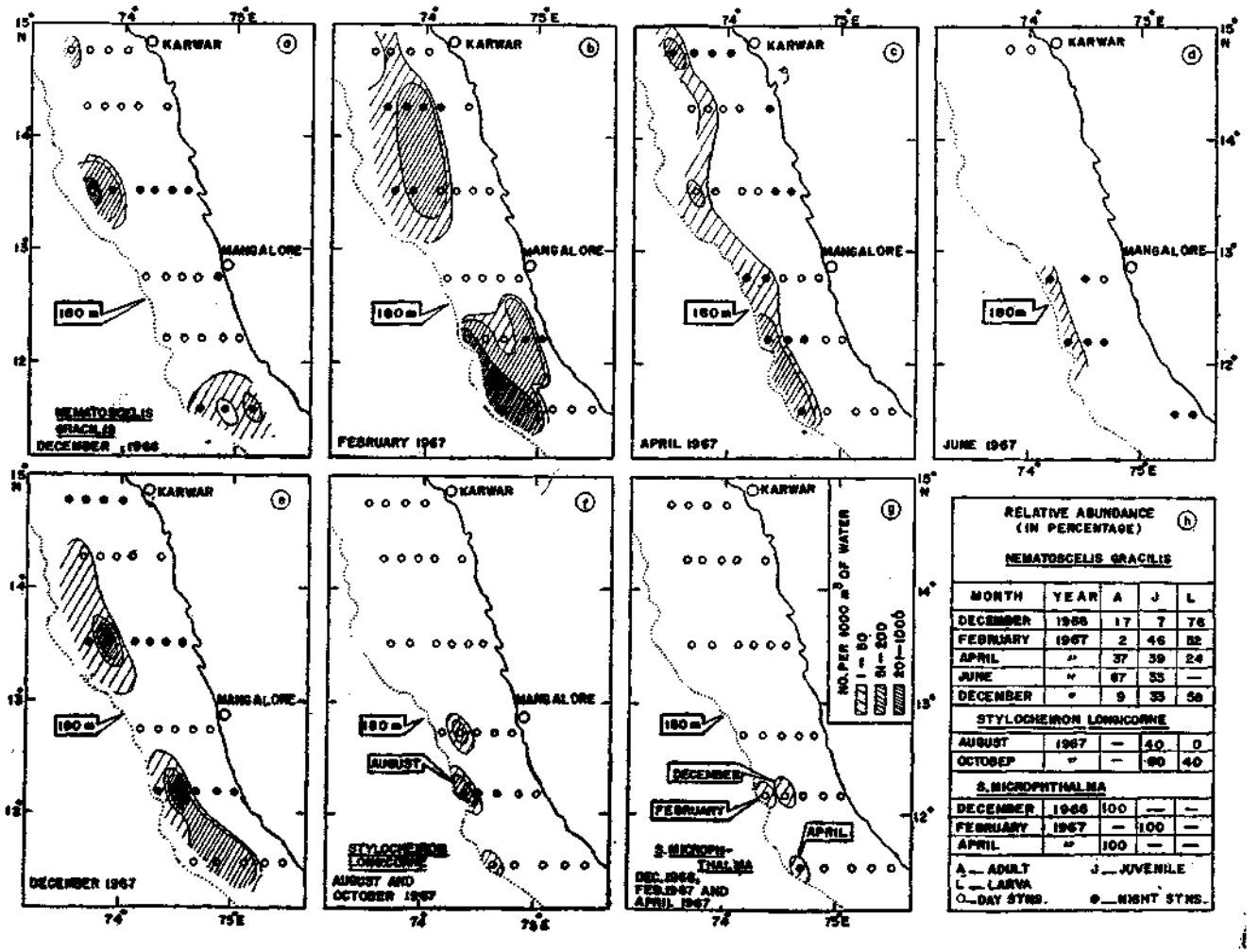


FIG. 5. Seasonal and spatial distribution of *Euphausia sibogae* and *E. tenera* in the continental shelf area (estimated numerically per 1000 m^3 of water). Relative abundance of adults, juveniles and larvae (in percentage) of the two species is given in the inset Table.



MONTH	YEAR	A	J	L
DECEMBER	1966	17	7	76
FEBRUARY	1967	2	46	52
APRIL	"	37	39	24
JUNE	"	67	33	—
DECEMBER	"	9	33	58
STYLOCHEIRON LONGICORNE				
AUGUST	1967	—	40	0
OCTOBER	"	—	60	40
S. MICROPHTHALMA				
DECEMBER	1966	100	—	—
FEBRUARY	1967	—	100	—
APRIL	"	100	—	—

FIG. 6. Seasonal and spatial distribution of *Nematoscelis gracilis*, *Stylocheiron longicorne* and *S. microphthalma* in the continental shelf area (estimated numerically per 1000 m³ of water). Relative abundance of adults, juveniles and larvae (in percentage) of the three species is given in the inset Table.

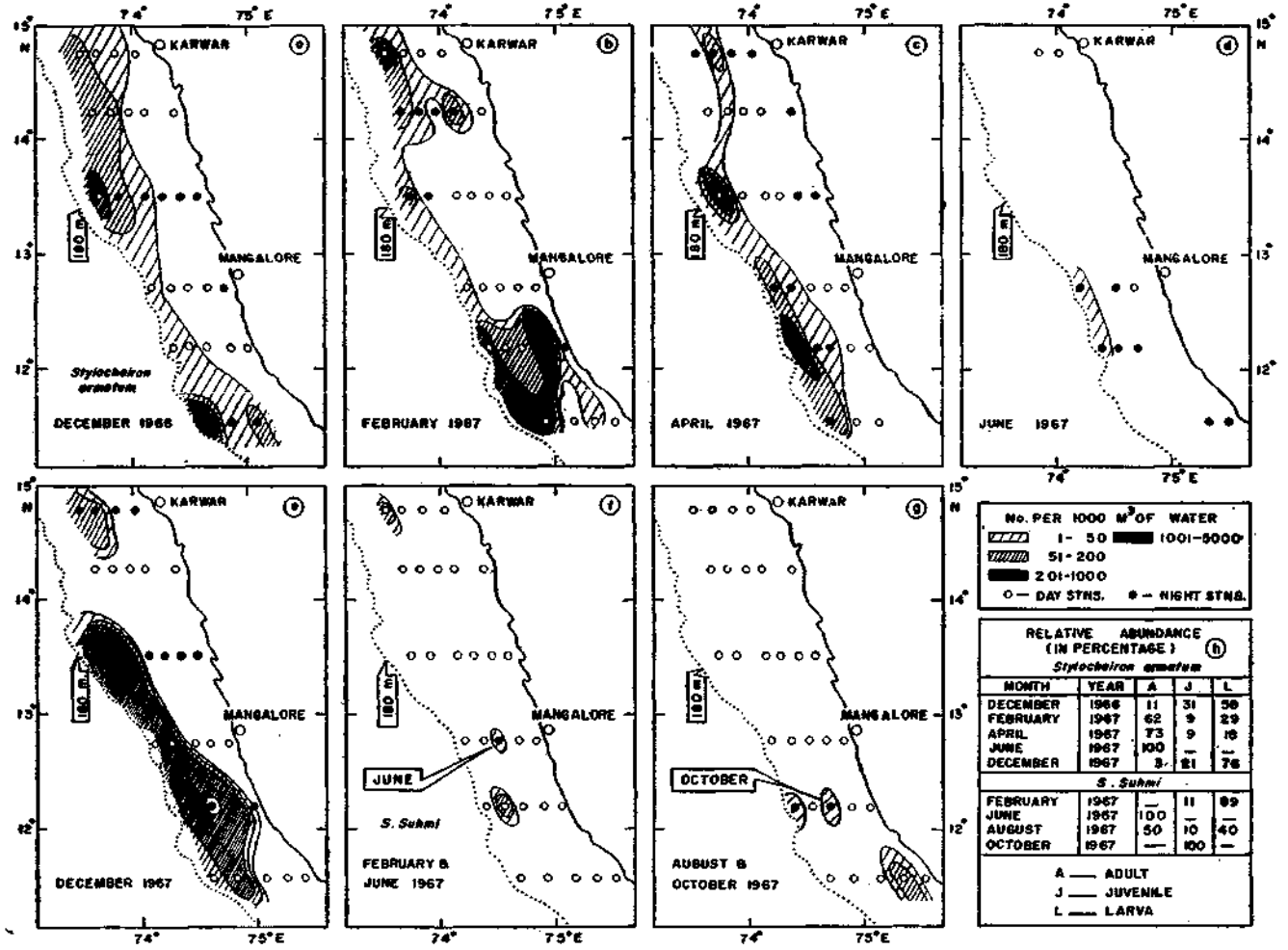


FIG. 7. Seasonal and spatial distribution of *Stylocheiron armatum* and *S. suhmi* in the continental shelf area (estimated numerically per 1000 m³ of water). Relative abundance of adults, juveniles and larvae (in percentage) of the two species is given in the inset Table.

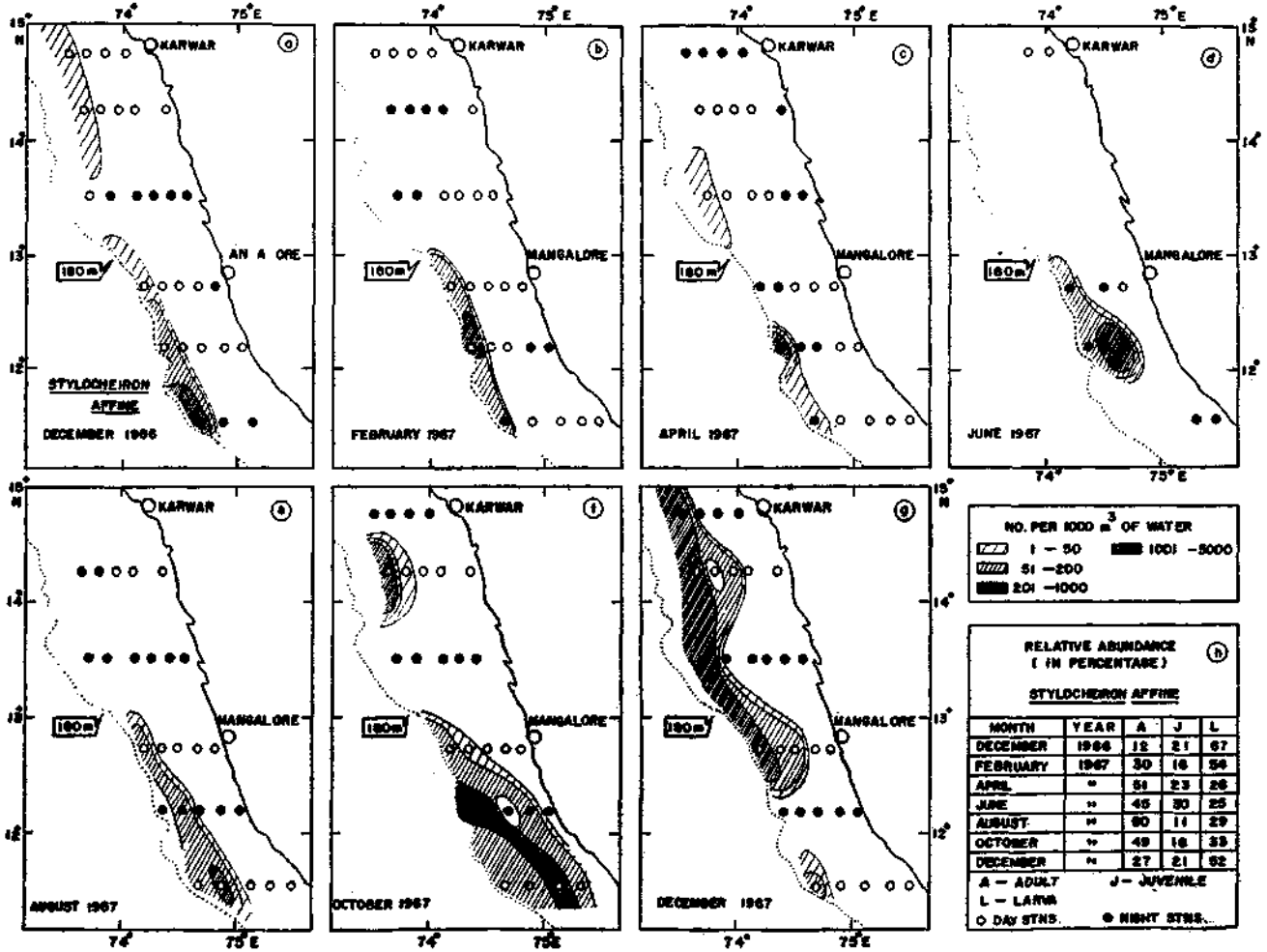


FIG. 8. Seasonal and spatial distribution of *Stylocheiron affine* in the continental shelf area (estimated numerically per 1000 m³ of water). Relative abundance of adults, juveniles and larvae (in percentage) is given in the inset Table.

TABLE 5. *Seasonal variations in the day/night abundance of euphausiid species in the shelf waters (No./1000 m³ of water). No. of day/night samples in which the species occurred is given in parentheses*

Species	Day/ Night	Dec. 1966	Feb. 1967	Apr. 1967	Jun. 1967	Aug. 1967	Oct. 1967	Dec. 1967	Total
T. monacantha	D	..	0.97 (1)	1.59 (1)	..	..	..	..	0.04 (2)
	N	..	1.89 (1)	14.94 (3)	..	..	..	..	3.23 (4)
T. tricuspidata	D	..	14.53 (4)	4.76 (1)	..	..	..	..	3.48 (5)
	N	..	18.87 (2)	..	..	..	..	..	2.30 (2)
P. latifrons	D	394.02 (14)	279.07 (12)	1.59 (1)	11.11 (1)	6.64 (3)	..	173.71 (6)	175.30 (37)
	N	472.53 (6)	1022.64 (7)	116.09 (7)	7.32 (2)	63.84 (5)	..	576.06 (8)	302.76 (33)
E. diomedeae	D	16.24 (2)	10.66 (2)	4.76 (1)	..	..	15.48 (3)	..	8.70 (8)
	N	57.14 (2)	564.15 (3)	52.87 (3)	..	..	65.31 (1)	114.08 (4)	115.21 (13)
E. tenera	D	..	41.67 (4)	1.59 (1)	..	..	..	..	8.50 (5)
	N	..	28.30 (1)	..	..	..	..	..	3.46 (1)
E. sibogae	D	42.74 (6)	7.75 (1)	14.29 (1)	..	1,488.37 (8)	2,708.84 (8)	34.29 (4)	597.60 (28)
	N	17.58 (1)	198.11 (4)	64.37 (5)	..	6,714.29 (9)	7,508.84 (7)	40.85 (3)	2,291.94 (29)
N. gracilis	D	16.24 (2)	73.64 (6)	4.76 (2)	..	..	..	14.86 (3)	21.45 (13)
	N	57.14 (3)	160.38 (7)	49.43 (5)	7.32 (2)	..	..	59.15 (4)	48.85 (21)
S. armatum	D	49.57 (9)	118.22 (8)	60.32 (2)	..	..	..	100.57 (3)	59.14 (22)
	N	421.98 (5)	1115.09 (6)	410.34 (7)	4.88 (2)	..	..	567.61 (7)	355.99 (27)
S. affine	D	16.24 (4)	52.33 (2)	1.59 (1)	..	64.78 (3)	135.48 (8)	172.57 (6)	71.32 (24)
	N	123.08 (1)	211.32 (1)	43.68 (2)	168.29 (4)	25.40 (1)	187.76 (3)	46.48 (2)	106.45 (14)

Table. 5 (*Contd.*)

Species	Day/ Night	Dec. '66	Feb. '67	Apr. '67	Aug. '67	Oct. '67	Dec. '67	Total
S. suhmi	D	..	8.72 (2)	..	..	9.97 (1)	..	..	2.90 (3)
	N	..	..	..	2.44 (1)	6.35 (1)	2.72 (1)	..	1.61 (3)
S. microphthalma	D	0.85 (1)	0.97 (1)	..	..	..	..	..	0.39 (2)
	N	..	..	1.15 (1)	..	..	..	..	0.23 (1)
S. longicorne	D	..	..	..	..	..	6.45 (2)	..	0.97 (2)
	N	..	..	..	..	15.87 (1)	..	..	2.30 (1)
S. abbreviatum	D	..	..	..	..	..	..	..	..
	N	..	..	3.05 (1)	..	..	..	..	1.61 (1)
S. maximum	D	..	..	..	..	1.66 (1)	..	..	0.19 (1)
	N	..	..	..	2.44 (1)	..	..	..	0.23 (1)
Total No. of stations engaged	..	28	30	30	10	26	28	30	182
Total No. of day stations	..	19	21	17	3	13	14	15	102
To tal No. of night stations	..	9	9	13	7	13	14	15	80

Thysanopoda monacantha (Fig. 4 f, g)

Not an abundant species in the shelf area ; occurred in two months ; February and April, at an average rate of 1.28 and 9.33 specimens per 1000 m^3 of water (Table 4) ; more specimens in night samples (Table 5).

In February, present at two of the southernmost stations towards shelf edge (stations 25 and 26), at a rate of 5.56 and 16.67 per 1000 m^3 of water ; one day and one night sample. In April available in 3rd to 6th sectors at their outermost stations on shelf edge ; quantity varied between 10.00 and 41.18 per 1000 m^3 of water ; one day and three night samples ; quantity more in night samples. Larvae and juveniles only ; their relative abundance in two months given in Fig. 4-h.

Thysanopoda tricuspidata (Fig. 3-a)

Present in February and April only in small numbers ; mean number per 1000 m^3 of water in February was 16.01 and in April it was 2.00 (Table 4) ; day/night difference was not

much pronounced (Table 5). Larvae alone present (Fig. 3-h).

In February while it occurred at 4 of the 5 stations in the 5th latitudinal sector from north, in the last sector 2 of the outermost stations had it ; quantity at each station varied between 11.43 and 125.00 per 1000 m^3 of water ; found in 4 day and 2 night samples ; yet rate of occurrence more in night samples. In April it occurred at a single station in the 3rd sector (station 15).

Pseudeuphausia latifrons (Fig. 3 b-g)

Second abundant species in shelf waters, especially abundant in December, 1966, February, April and December, 1967 ; mean monthly occurrence ranged from 8.00 in June to 531.37 in February per 1000 m^3 of water (Table 4) ; considerably more in night samples (Table 5) ; relative abundance among larvae, juveniles and adults given in Fig. 3 h.

In December, 1966 out of 30 stations sampled, *P. latifrons* occurred at 20 stations ; more abundant towards northern sectors ; number per 1000 m^3 of water at various stations varied between 11.43 and 5,300.00. Maximum abundance in February when its density at various stations ranged from 28.57 to 8,771.43 per 1000 m^3 of water ; relatively more in northern sectors. A few occurred at 3 stations in June. In August also it occurred in moderate numebrs at 3 stations each in 2nd and 3rd sectors and at one station each in 4th and 5th sectors ; quantity ranged between 10.00 and 480.00 per 100 m^3 of water. Again in December, 1967 it was collected at 14 stations ; had a maximum abundance at station 24 where 3,880.00 per 1000 m^3 of water occurred.

Euphausia diomedeae (Fig. 4 a-e)

It was mostly confined to shelf edge waters in all months under observation and its mean monthly number varied from 27.69 in December, 1966 to 198.46 in February (Table 4). In all months night samples contained more specimens (Table 5). Mainly composed of larvae and juveniles ; their percentage of abundance given in Fig. 4 h.

The species occurred at 4 shelf edge stations in December, 1966, 3 in northern and one in southern sectors ; number ranged from 13.33 to 257.14 per 1000 m^3 of water. In February also the species was more or less confined to shelf edge waters and occurred at 5 stations but found great variations in occurrence being in the range of 11.11 and 1,644.44 per 1000 m^3 of water. In April it occurred at 4 shelf edge stations of which 3 were sampled at night. After April *E. diomedeae* occurred only in October (4 stations) in very small numbers. In December, 1967 though it occurred at 4 stations only (all night samples) it was somewhat abundant, number ranged between 180.00 and 1,960.00 per 1000 m^3 of water.

Euphausia tenera (Fig. 5 g)

A rare species in shelf area, was present in February and April ; monthly mean density per 1000 m^3 of water ranged between 0.67 and 37.13 respectively in the two months (Table 4) ; found more in night samples (Table 5) ; larvae dominated over adults (Fig. 5 h).

In February the species was present in very few numbers at 5 stations of which 4 were from southern sectors. Only a single specimen occurred in April at station 15.

Euphausia sibogae (Fig. 5 a-f)

The species was present in all months except June ; monthly average varied between 36.69 in December, 1966 and 5,045.03 in October per 1000 m^3 of water (Table 4). Except in December, 1966 in all other months abundance of the species in night samples was noticed (Table 5). Adults dominated over juveniles and larvae in April : in all the other months, except February, the larvae dominated (Fig. 5 h).

E. sibogae occurred at 7 stations in December, 1966 ; mostly confined to shelf edge in southern sectors ; all but one, day samples. In February also it was distributed far away from inshore areas and was present at 5 stations only, maximum number of 538.89 per 1000 m^3 of water was taken at station 25 ; out of 5 samples, 4 were collected in night. In April occurred in small numbers in 6 samples of which only one was collected during day. Unusually abundant in August and October. Out of 26 stations sampled in August, *E. sibogae* occurred at 17 stations with maximum of 18,771.42 specimens per 1000 m^3 of water at station 5 in the northern sector. Maximum abundance of this species was noticed in October when it occurred at 15 out of 28 stations sampled ; an all time, all species maximum of 62,733.33 specimens per 1000 m^3 of water was collected in this month from station 15 which was very close to shelf edge. In December, 1967 there was a substantial reduction in abundance of this species ; the number ranged between 35.29 and 425.00 per 1000 m^3 of water.

Nematoscelis gracilis (Fig. 6 a-e)

Except in August and October it was present in all other months under consideration but in moderate numbers ; average monthly occurrence varied between 6.00 specimens in June and 103.07 specimens in February per 1000 m^3 of water (Table 4) ; comparatively more abundant in night samples (Table 5). A mixed trend was observed in the relative abundance of larvae, juveniles and adults in the different months (Fig. 6 h).

In December, 1966 present at 5 stations, all except one towards shelf edge. More wide spread in February ; occurred at 13 stations, in moderate numbers only ; present in shelf edge as well as in intermediate depth zones. From February, populations reduced ; marked north-south difference in occurrence was not noticed though it was absent in one of the mid-sectors. In April, moved towards shelf edge waters. In June it was sparse. Pattern of distribution in December, 1967 almost similar to that in December, 1966.

Stylocheiron armatum (Fig. 7 a-e)

Sometimes occurred in swarms ; present in 5 months ; monthly mean number varied between 4.00 in June and 456.47 in February per 1000 m^3 of water (Table 4) ; invaribly more in night samples (Table 5). The relative occurrence of larvae, juveniles and adults is given in Fig. 7 h).

In December, 1966 it occurred at 14 stations in shallower as well as deeper waters ; no pronounced north/south difference in occurence ; however, maximum at a rate of 1,100.00 per 1000 m^3 of water was caught in southernmost sector towards shelf edge. In February also occurred in shallower, intermediate and deeper depth zones. In April, distribution more patchy ; a tendency for swarming exhibited ; distributed more towards shelf edge and intermediate depth zones ; maximum of 1,794.12 specimens per 1000 m^3 of water occurred at station 25. After a sparse occurrence in June it was present in fairly good numbers in 10 samples collected in December, 1967 ; concentrated towards southern and mid-sectors.

Stylocheiron affine (Fig. 8 a-g)

Present in all months of observation but in moderate numbers ; swarming tendency never indicated ; occurrence maximum in October (160.93/1000 m^3 of water) (Table 4). Except in August and December, 1967, night samples contained more specimens (Table 5). The inset Table in Fig. 9 gives the relative abundance among larvae, juveniles and adults of this species in the various months.

In December, 1966 though present in all latitudinal sectors, strictly confined to shelf edge stations, with more specimens towards south. Out of 5 samples in which it occurred only one was collected during night. In

February and April occurred at 3 shelf edge stations each with more numbers in southern sectors. In June occurred at four night stations mainly concentrating in 5th sector. Distributed more towards south in June also. Maximum occurrence in October; abundance at various stations varied from 20.00 to 800.00 per 1000 m^3 of water. In December, 1967 pattern of distribution different from December, 1966 in that species penetrated a little into shallow areas.

Stylocheiron suhmi (Fig. 7 f, g)

One of the rare species of sporadic occurrence in shelf waters but present in 4 months ; monthly mean varied between 1.32 in October to 9.12 in August per 1000 m^3 of water (Table 4) ; mainly concentrated towards south. No striking day/night difference was noticed (Table 5). The percentage abundance among larvae, juveniles and adults is given in Fig. 7 h.

Occurred in two of the day samples in February ; in June only one night station had it. In August occurred at two stations of which one was sampled at night and in October only one night sample had it.

Stylocheiron microphthalma (Fig. 6 g)

One specimen each in December, 1966, February and April towards shelf edge in southern sectors (Tables 4 and 5). Only adults and juveniles occurred (Fig. 6 h).

Stylocheiron longicorne (Fig. 6 f)

Another very rare species in the shelf area ; occurred only in August and October, towards shelf edge ; in August in a single night sample at the rate of 100.00 per 1000 m^3 of water in southern sector. In October, occurred in 2 day samples, one in mid-sector and the other in the southern sector (Tables 4 and 5). Only larvae and juveniles occurred (Fig. 6 h).

Stylocheiron abbreviatum

Taken at a single station in April in the southern sector at a rate of 41.18 specimens per 1000 m^3 of water (Tables 4 and 5).

Stylocheiron maximum

One specimen each occurred in June (mid-sector) and August (southern sector) towards shelf edge (Tables 4 and 5).

Discussion

A total of 14 species occurred in the shelf waters ; some for a short duration while others for a prolonged duration (Table 4). The variations in the seasonal occurrence and abundance could be mainly due to the changes in the environment brought about by the process of upwelling and by the currents. The different months under observation can be categorised into two following the process of upwelling during the year under consideration, namely the upwelling months (June, August and October) and the non-upwelling months (December, February and April). The species occurrence was apparently minimum during the upwelling months. All the species caught could be brought under three groups such as (1) those occurred during the upwelling months alone, (2) those occurred during the non-upwelling months alone and (3) those occurred during both the period. Thus it is seen from the Table that *S. longicorne* and *S. maximum* belonged to the first group. Both of these species are typically mesopelagic, distributed in the oceanic areas. *S. longicorne* usually has a vertical range of 140-700 m while *S. maximum* has it between 140 and 1000 m (Brinton, 1962). The representation of these species in the shelf area, although by larvae and juveniles only, is highly significant as it testifies the incursion of the cold deep water into the shelf area. *S. longicorne* was caught at 3 stations of which 2 were at the continental shelf edge while one was at a station of 80 m depth. *S. maximum*

was collected at two stations where the depth to the bottom was 80 m and 120 m respectively. The possibility of these species considering as indicators of upwelling along the southwest coast of India needs further investigation by frequent sampling. The present samples do not permit a positive conclusion because of the wide gap in between two sets of sampling and also due to the absence of adults in the samples.

The species that were present during the non-upwelling months were *T. monacantha*, *T. tricuspidata*, *E. tenera*, *S. microphthalma* and *S. abbreviatum*. The species that were present during both the periods were *P. latifrons*, *E. diomedeae*, *E. sibogae*, *N. gracilis*, *S. armatum*, *S. affine* and *S. suhmi*. *N. gracilis* and *S. armatum* were represented in June by a few specimens at two of the shelf stations only where the surface water was warmer enough upto 30 m. However, correct picture of occurrence of euphausiids in June could not be obtained due to inadequacy in sampling. Hence the presence or absence of all species of euphausiids in this month may be considered as arbitrary.

While upwelling could be the main agent responsible for the occurrence of the various species in the area under present investigation, the influence of the other parameters such as the currents may also be taken into consideration. It is significant to find that the maximum number of species occurred in February and April when the mass re-adjustment of water took place before the reversal of the current from northerly to the southerly direction. Similarly in October, which was the time of mass re-adjustment of water after the upwelling and also the time of reversal of the southerly current, the minimum number of species occurred in the shelf area.

The euphausiid material obtained from the continental shelf area which was used for the quantitative seasonal distribution was found to be dominated by different species, in varying proportions. Fig. 12-A gives the relative abundance among 6 common species during the entire period of study. *E. sibogae* with 69.19 per cent was the most dominant species. The next abundant species was *P. latifrons* with only 11.80 per cent while others in the order of abundance were *S. armatum* (9.60 %), *S. affine* (4.40 %), *E. diomedeae* (2.89 %), and *N. gracilis* (1.64 %). The remaining 8 species (not shown in Fig.) were relatively rare being represented by less than 1 per cent.

The picture of relative abundance among the various species given above is a generalised one embracing the whole area under consideration for the complete year. A further analysis for the relative abundance of the species in different months, however, showed that there was great seasonal variations with regard to the relative occurrence of them (Table 6).

In December, 1966 the most dominant species was *P. latiforns* with 58.78 per cent. This was followed by *S. armatum* which had 21.73 per cent. Other species ranged between 0.09 and 6.53 per cent. In February also the predominant species was *P. latifrons* (34.77%). *S. armatum* with 29.87 per cent ranked second as in December, 1966. *E. diomedeae* formed the next dominant species and had 12.99 per cent. Other species ranged between 0.04 and 6.70 per cent only. In April *S. armatum* took the first place in the order of abundance and had 54.71 per cent. *P. latifrons* was pushed to the second place which had only 14.13 per cent. *E. sibogae* with 9.00 per cent came next. Others ranged between 0.14 and 6.79 per cent. In June, of the species considered only four were present among which *S. affine* was the dominant species and was constituted by 86.25 per cent. Three other species in the order of abundance were, *P. latifrons* (5.00 %), *N. gracilis* (3.75 %) and *S. armatum* (2.50 %). In August and October, of the species considered for this study only three each were present of which *E. sibogae*

TABLE 6. *The relative abundance (in percentage) among species of euphausiids from the shelf area in the different months of observation*

Species	Dec. '66	Feb. '67	Apr. '67	Jun. '67	Aug. '67	Oct. '67	Dec. '67
T. monacantha ..	..	0.08	1.94	..	..	..	..
T. tricuspidata ..	..	1.05	0.42	..	..	..	..
P. latifrons ..	58.78	34.77	14.13	5.00	0.97	..	42.34
E. diomedeae ..	3.91	12.99	6.79	..	..	0.76	6.11
E. tenera ..	..	2.43	0.14	..	..	..	..
E. sibogae ..	5.05	4.73	9.00	..	97.58	96.09	4.45
N. gracilis ..	3.91	6.70	6.37	3.75	..	..	4.15
S. armatum ..	21.73	29.87	54.71	2.50	..	..	29.06
S. affine ..	6.53	6.95	5.40	86.25	1.05	3.07	13.89
S. suhmi ..	..	0.38	..	1.25	0.19	0.03	..
S. microphthalma ..	0.09	0.04	0.14	..	..	..	..
S. longicorne ..	..	..	..	..	0.19	0.06	..
S. abbreviatum ..	..	..	0.97	..	..	..	..
S. maximum ..	..	..	..	1.25	0.02	..	..

with 97.58 per cent and 96.09 per cent respectively in each month was the most dominant species. *S. affine* constituted only 1.05 per cent and *P. latifrons* 0.97 per cent. In December, 1967 a somewhat same picture as in December, 1966 was obtained with regard to the relative abundance. *P. latifrons* was the predominent species which enjoyed 42.34 per cent of the total euphasiid material. The second position was occupied by *S. armatum* with 29.06 per cent. The third dominant species was *S. affine* which had 13.89 per cent.

The above discussion on the relative abundance of species in different months makes it clear that in each month one of the species dominated over the rest and sometimes the dominance was to the extent of almost cent per cent. In August and October the extreme abundance of *E. sibogae* virtually suppressed all the other species. The most dominant and the second dominant species in the different months are given in Table 7.

TABLE 7. *The most dominant and the 2nd abundant species in the shelf waters during the different months*

Months	Most abundant species	2nd abundant species
December, 1966 ..	*P. latifrons*	*S. armatum*
February, 1967 ..	*P. latifrons*	*S. armatum*
April, 1967 ..	*S. armatum*	*P. latifrons*
June, 1967 ..	*S. affine*	*N. gracilis*
August, 1967 ..	*E. sibogae*	*S. affine*
October, 1967 ..	*E. sibogae*	*S. affine*
December, 1967 ..	*P. latifrons*	*S. armatum*

The succession of species in the shelf waters in the different months as revealed from the above study is interesting. The very noteworthy feature is the complete preponderence of *E. sibogae* during August and October which also coincides with the period of intense upwelling. In 1967 the effect of upwelling

remained in the shelf waters until the early days of October and this makes the occurence of *E. sibogae* in large quantities in the study area more significant. It would be appropriate to find out if this species could be used as an indicator of upwelling. The affinity of this epipelagic species to the upwelled waters needs further studies.

A further study was made to understand the relationship among six common species in the different latitudinal sectors in each of the months (Figs. 9-12). The relative abundance was calculated in terms of all the species present in any latitudinal sector. However, the values for those except the six species are not plotted in the figures.

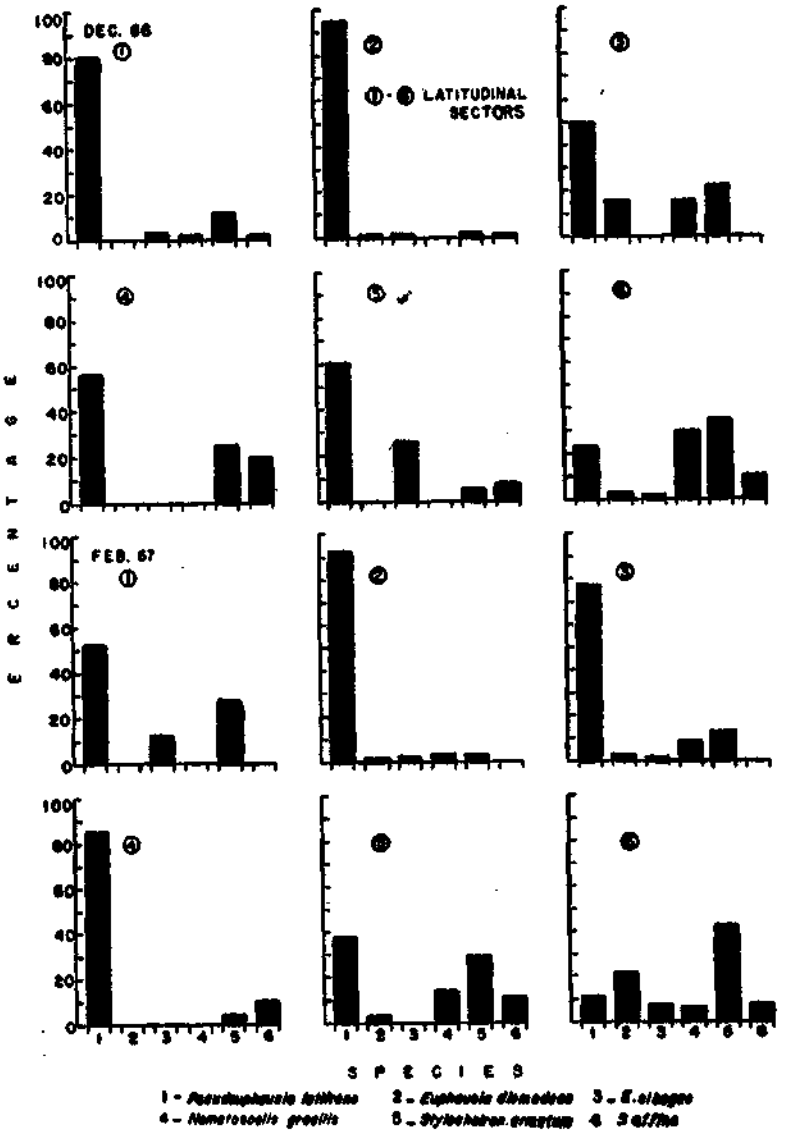


FIG. 9. Seasonal variations in the relative abundance (in percentage) among six common species in the different latitudinal sectors in the continental shelf area during December, 1966 and Febraury, 1967.

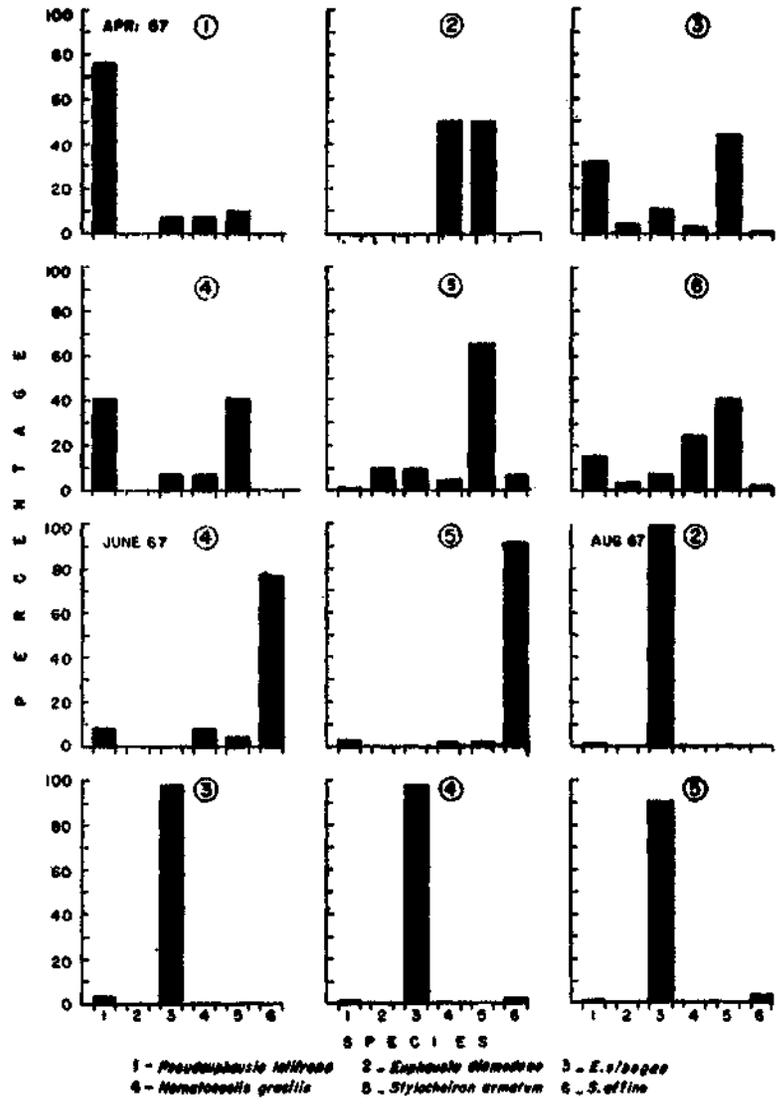


FIG. 10. Seasonal variations in the relative abundance (in percentage) among six common species in the different latitudinal sectors in the continental shelf area during April, June and part of August, 1967.

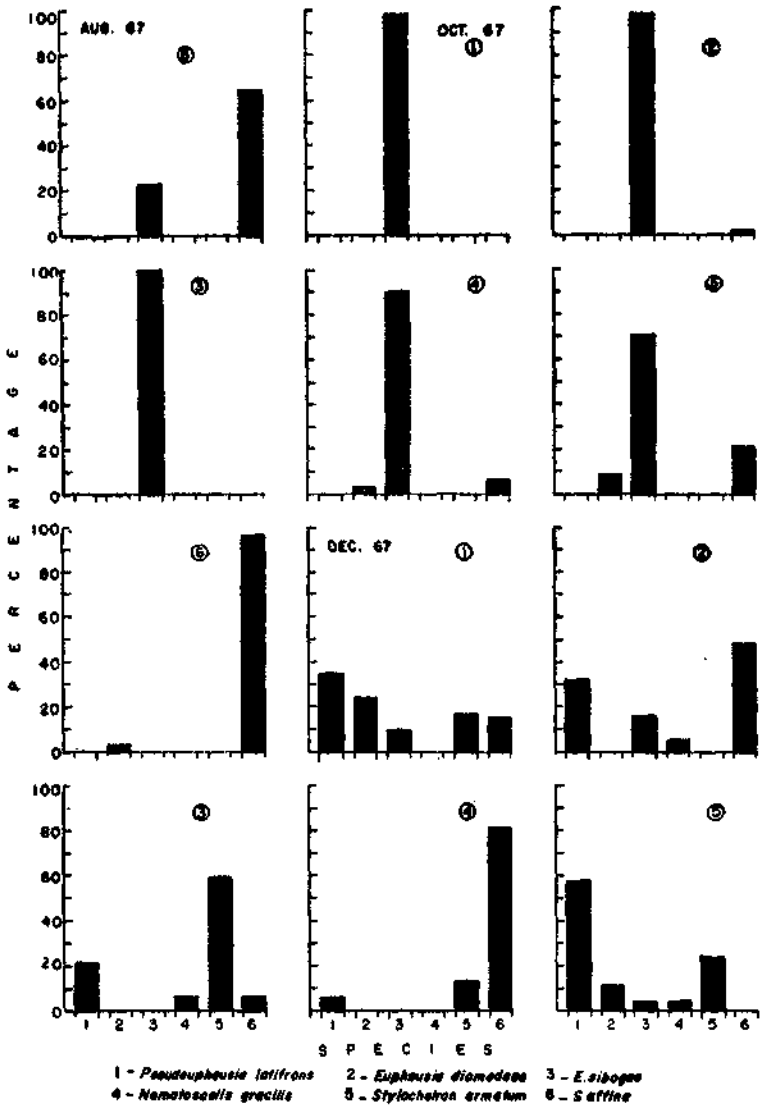


FIG. 11. Seasonal variations in the relative abundance (in percentage) among six common species in the different latitudinal sectors in the continental shelf area during part of August, October and part of December, 1967.

In December, 1966 except in the southernmost sector *P. latifrons* was the most dominant species (Fig. 9). The percentage of abundance in the first 5 sectors varied between 48.68 and 95.31 per cent. In the southernmost sector *S. armatum* with 33.52 per cent was the dominant species. *N. gracilis* and *P. latifrons* took the 2nd and 3rd places. In February also (Fig. 9) almost the same condition prevailed with the exception that the 2nd species in the last sector was *E. diomedeae* than *N. gracilis*. In April (Fig. 10) the *P. latifrons* dominated over the others in the first sector only. In the second sector the euphausiids were almost negligible in this month. In the 3rd sector *S. armatum* with 44.05 per cent dominated which was closely followed by *P. latifrons*. (In this month a single specimen of *P. latifrons* was present in 1st sector which is not shown in figure). However, in August the extreme abundance of *E. sibogae* in the 2nd, 3rd, 4th and 5th sectors (90.93 to 99.71 %) suppressed all the others (There was no collection from the first sector). In this month in the last sector the dominant species was *S. affine* (Figs. 10 and 11). In October the dominance of *E. sibogae* was further intensified in the different sectors and amounted to 100 per cent in the 1st and 3rd sectors (Fig. 11). In the last sector, while *E. sibogae* was absent *S. affine* constituted 96.00 per cent of the total euphausiids. In December, 1967 while *P. latifrons* dominated in the 1st, 5th and 6th sectors *S. armatum* was the dominant species in the

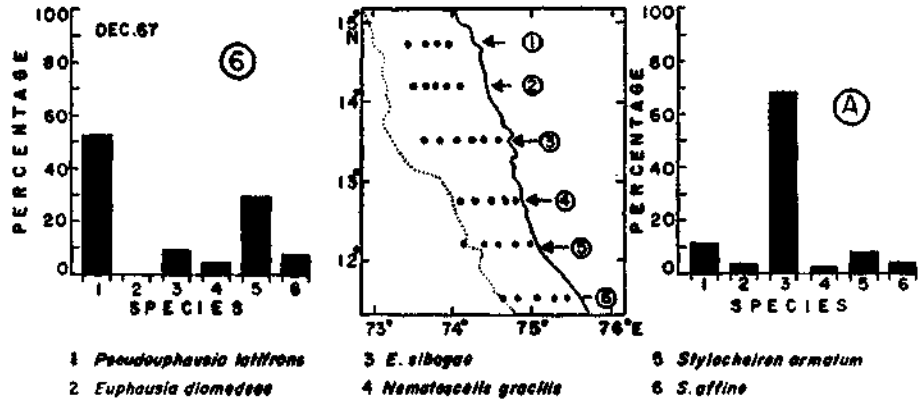


FIG. 12. Seasonal variations in the relative abundance (in percentage) among six common species in the different latitudinal sectors in the continental shelf area during part of December, 1967. A. Relative abundance (in percentage) among six common species in the whole area under study during the entire period of investigation. The inset map shows the various latitudinal sectors.

In the 4th Sector *P. latifrons* and *S. armatum* dominated equally. In the 5th and 6th sectors there was a clear dominance of *S. armatum*. Thus a gradual replacement of *P. latifrons* by *S. armatum* from south to north was evident from December to April. But soon these species were found to be replaced by others. In June eventhough a correct picture could not be obtained on account of inadequate sampling the trend was in favour of *S. affine* (Fig. 10). 3rd and *S. affine* in the 2nd and 4th sectors (Figs. 11 and 12).

An overall consideration of the above facts indicated that *P. latifrons* and *E. sibogae* were relatively more abundant in the northern sectors while others namely *E. diomedeae*, *N. gracilis*, *S. armatum* and *S. affine* were relatively more abundant in the southern sectors. With regard to the species abundance also in the different

latitudinal sectors, the southern sectors (4th to 6th) were richer. This points to the presence of waters of oceanic origin in these sectors.

The species dominance in the various latitudinal sectors in the different months was found to be related to the process of upwelling taking place in this area. By February-April when the indications of upwelling was first felt in the deeper waters of the southern sectors the *P. latifrons* gradually shifted from the south to the north whose place in the south was taken up by *S. armatum*. And this was soon replaced by *S. affine* in June. In August and October, when the upwelling was intensively felt *E. sibogae* dominated in all the sectors except in the 6th sector in October.

References

BRINTON, E. 1967. Vertical migration and avoidance capability of euphausiids in the California Current. *Linol. and Oceanogr.*, **12** : 451-483.

——— AND K. GOPALAKRISHNAN 1973. The distribution of Indian Ocean euphausiids. In : B. Zeitzschel (Ed.) *Biology of the Indian Ocean.* Chapman and Hall, London, pp. 357-382.

GOPALAKRISHNAN, K. 1974. Zoogeography of the genus *Nematoscelis* (Crustacea : Euphausiacea). *Fish. Bull. Nat. Oceanic Atmos. Admn. U.S.*, **72** ; 1039-1074.

——— AND E. BRINTON 1969. Preliminary observations on the distribution of Euphausiacea from the International Indian Ocean Expedition. *Bull. Nat. Inst. Sci. India*, **38** : 594-611.

CURIE, R. I. 1963. The Indian Ocean Standard Net. *Deep Sea Res.*, **10** : 27-32.

LEGAND, M., P. BOURRET, J. A. GUEREDRAT, A. MICHEL, R. REPELIN AND C. ROGER 1975. Aspects ecologiques du plancton et du micronecton dans l'est de l'ocean Indien. *J. mar. biol. India*, **16** (1974) : 1-23.

MC WILLIAM, P. S. 1977. Further studies on plankton ecosystem in the eastern Indian Ocean. V. Ecology of Euphausiacea. *Austl. Jour. Mar. Freshwater Res.*, **28** : 627-644.

MAUCHLINE, J. AND L. R. FISHER 1969. *The biology of euphausiids.* Adv. Mar. Biol., **7** : 1-454.

PONOMAREVA, L. A. 1966. Quantitative distribution of euphausiids in the Pacific Ocean. *Dokl. Akad. Nauk SSSR*, **6** : 690-692.

ROGER, C. 1966. Etude sur quelques especes d' Euphausiaces de l'est l'ocean Indien (110°E). *Cah. O.R.S.T.O.M., Ser. Oceanogr.*, **4** : 73-103.

SEBASTIAN, M. J. 1966. Euphausiacea from the Indian seas : Systematics and general considerations. *Proc. Symp. on Crustacea*, MBAI, **1** : 233-254.

WEIGMANN, R. 1970. Zur Okologie und Ernahrungebiologie der Euphausiaceen (Crustacea) im Arabischen Meer '*Meteor*' *Forschungsergeb.*, D (5) : 11-52.

WOOSTER, W. S., M. K. SCHAFFER AND M. K. ROBINSON 1967. Atlas of the Arabian Sea for fishery oceanography. *Univ. Calif., IMR Ref.* 67-12, 35 pp.