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SEASONAL AND SPATIAL DISTRIBUTION OF LARVAL EUPHAUSIIDS FROM THE SHELF WATERS OFF SOUTHWEST COAST OF INDIA*

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Abstract

The annual mean value of euphausiid larval biomass in the southwest shelf waters of India has been numerically estimated to be 1,507 per 1000 m^3 of water. There was a well defined oscillation in the abundance of larvae mostly in relation to the changes in the environment brought about by upwelling. The June to October period was associated with intense upwelling in the study area. The process of upwelling started in the southern parts and gradually moved to the northern areas, according to which there was a seasonal and spatial shift in the larval abundance too. A monthly estimate revealed that while the larvae were least abundant in June 36/1000 m^3) they were moderate in December, February and April (151-679/1000 m^3) and maximum in August and October (3,856 and 4,393/1000 m^3). The larvae of *Pseudeuphausia latifrons*, *Euphausia diomedeae*, *Nematoscelis gracilis* and *Stylocheiron armatum* were more during the non-upwelling period of December to April. The larvae of *Euphausia sibogae* were abundantly present during the August-October period (of intense upwelling). The larvae of *Stylocheiron affine* were present almost throughout the year. The abundance of larvae of various species in different months was indicative of the breeding seasons.

Introduction

There has been a paucity of information on the distribution of larval euphausiids in space and time, especially from the Indian Ocean. The importance of such studies becomes more evident when we consider the fact that more often the larval stages numerically dominate over the adults in the plankton samples collected from the epipelagic zone.

The geographic distribution in different seasons and vertical distribution and migration of young stages of *Euphausia superba* have been investigated by Fraser (1936) in his classical work on this species. Einarsson (1945) studied the horizontal and vertical distribution of larvae of several species of the northern Atlantic. Lewis (1954) studied the vertical distribution of larvae of five species namely *Thysanopoda tricuspidata*, *Euphausia tenera*, *E. brevis*, *Nematoscelis microps* and *Stylocheiron carinatum* of the Florida Current. The vertical migration of calyptopes and furciliae of *Meganyctiphanes norvegica* and *Thysanoessa raschi* has been studied in detail by Mauchline (1959, 1965) and Lacroix (1961). The horizontal and vertical distribution of larval forms of several species from the Pacific Ocean have been studied by Brinton (1962). Marr (1962) has worked out the vertical distribution and migration of larval *Euphausia superba*. A review of the vertical distribution and migration of larval euphausiids has been made by Mauhline and Fisher (1969). Brinton and Gopalakrishnan (1973) investigated the spatial distribution of larval euphausiids from the Indian Ocean. Gopalakrishnan (1974) studied the quantiative distribution of larvae and juveniles (combined) of species of the genus *Nematoscelis* of the Indian Ocean.

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Brinton and Townsend (1980) studied the seasonal distribution of the developmental phases of some species of the Gulf of California.

In the present study the quantitiative distribution in space and time of the larval euphausiids in general and of some species in particular from the southwest coast of India is attempted for the first time. This study has enabled to understand the active breeding periods of six species of euphausiids in this tropical sea area.

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Material and Methods

The material used for the study was collected during the cruises of R.V. *VARUNA* from December, 1966 to December, 1967 on a bimonthly basis from the continential shelf area between latitudes 11°32'N and 14°54'N. The zooplankton samples were collected using an Indian Ocean Standard Net (0.33 mm mesh size) as open vertical hauls from five metres above bottom to the surface. The larval euphausiids were sorted out and enumerated. The larvae considered here include calyptopses and furciliae only, since the earlier stages of nauplii, pseudometanauplii and metanauplii were not collectd by the sampling gear. Quantitative estimates are expressed as number per 1000 m^3 of water. For this purpose the quantity of water filtered by the net was calculated by the formula $\pi r^2 l$. For the sake of comparative study, the area investigated was divided into six latitudinal sectors starting from north to south based on the cluster of stations in each latitudinal grid.

TABLE 1. *Monthwise and annual mean abundance of larval euphausiids in the continental shelf waters along the southwest coast of India (No. per 1000 m^3 of warer)*

Species	1966	1967						Annual
	Dec.	Feb.	Apr.	June.	Aug.	Oct.	Dec.	
T. monacantha ..	—	1	1	—	—	—	—	1
T. tricuspidata ..	—	16	2	—	—	—	—	3
P. latifrons ..	294	291	41	2	26	—	211	143
E. diomedeae ..	25	82	32	—	—	1	41	30
E. sibogae ..	23	6	13	—	3,808	4,339	25	1,193
E. tenera ..	—	31	1	—	—	—	—	5
N. gracilis ..	21	54	7	—	—	—	20	17
S. armatum ..	89	133	47	—	—	—	186	75
S. affine ..	31	58	7	34	13	52	60	38
S. suhmi ..	—	5	—	—	3	—	—	1
S. longicorne ..	—	—	—	—	5	1	—	1
S. maximum ..	—	—	—	—	1	—	—	1
Total	483	677	151	36	3,856	4,393	543	1,507

Seasonal occurrence of larval euphausiids

Presented below is the general seasonal picture of the occurrence of the larvae of all the species encountered. The euphausiid larval biomass has been numerically estimated to be 1,507 per 1000 m^3 of water (Table 1).

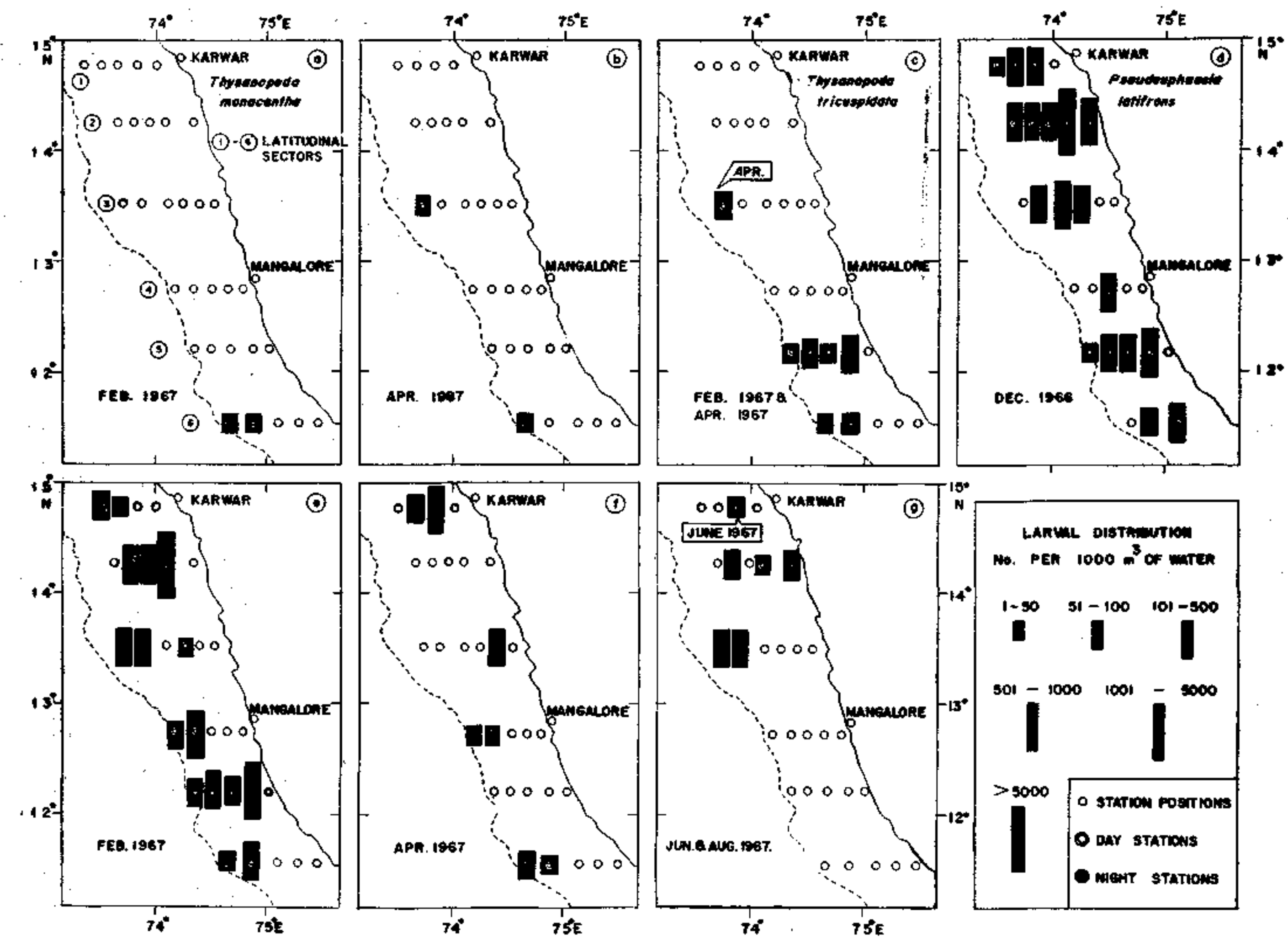

FIG. 1. Seasonal and spatial distribution of larval euphausiids in the continental shelf area: a, b. *Thysanopoda monacantha*: c. *T. tricuspidata* and d-g. *Pseudeuphasia latifrons*.

When a bimonthly consideration of the larval abundance was made, it was found that while the larvae were least abundant in June (36) it was moderate in December, 1966 and 1967 and in February and April (range 151-679) and maximum in August (3,856) and October (4,393) (Table 1).

From a species-wise consideration of larval abundance, it was found that *Euphausia sibogae* with 1,193 larvae was the most abundant species, the second being *Pseudeuphausia latifrons* with only 143 larvae. The larvae of *Stylocheiron armatum*, *S. affine*, *Euphausia diomedeae* and *Nematoscelis gracilis* were also fairly abundant. Others had only very low proportion of larvae in the shelf area (Table 1).

It is also seen from Table 1 that out of the 12 species whose larvae frequented the plankton, the larvae of five species namely *E. diomedeae*, *E. sibogae*, *P. latifrons*, *N. gracilis* and *S. affine* occurred in almost all the months under consideration. Similarly February and April appeared to be the period when the larval stages of majority of species (about 10) occurred in the shelf waters.

Larval distribution in space and time

For the purpose of this study, six species whose larvae occurred in sizable quantities in the majority of months under consideration in the shelf area have been taken up. The results are presented in Figs. 1-5. In the figures the day/night differentiations are shown for the positive stations only.

Pseudeuphausia latifrons (Fig. 1 d-g, 2 a)

The larvae of this species were highly abundant in the samples collected in the months of December 1966, February and December 1967. In December 1966, out of the 28 samples collected, 18 contained the larvae (Fig. 1 d). The larval number in the different samples ranged from 5 to 5,300. In this month the larval concentration was noticed towards the northern parts of the area under investigation. It was interesting to note that the larval forms were especially more in those samples taken during the day time. In February out of the 30 samples, 16 contained the larvae (Fig. 1 e) and their number varied from 11 to 6,771. In this month the larval abundance was in areas mostly away from the coast. No marked difference in the north-south distribution was indicated During this month the night samples contained more larvae

From April onwards the larvae of this species became less abundant, its distribution being highly patchy and in April it occurred in seven samples only (Fig. 1 f). The maximum number of 1,000 larvae was obtained at a station in the northernmost sector in a night sample. It was interesting to find that out of the seven samples, six were night hauls. In June out of 10 stations sampled the larvae of *P. latifrons* occurred in one sample at a rate of 29, suggesting that the larval forms were sparse during this month (Fig. 1 g). In August, the larvae were mostly present in the northern area. Although 26 stations were occupied in this months only five yielded larvae of this species, that too in small numbers. The larvae were not present in October.

In December 1967 a good number of larvae were collected from the study area. Out of 30 samples collected, 14 contained them, the highest number being 1,840 present in a night haul from one of the southern stations (Fig. 2 a). At the other stations the occurrence was rather moderate, being between 100 and 580 per 1000 m³ of water. In this month there was no significant difference in the occurrence of larvae between day and night samples.

Euphausia diomedeae (Fig. 2 b-e)

This was one species whose larval forms occurred less frequently in the shelf waters. No larval forms were obtained during June and August and in October they were taken at one out of 28 stations. In December 1966 the larvae of this species occurred at four stations

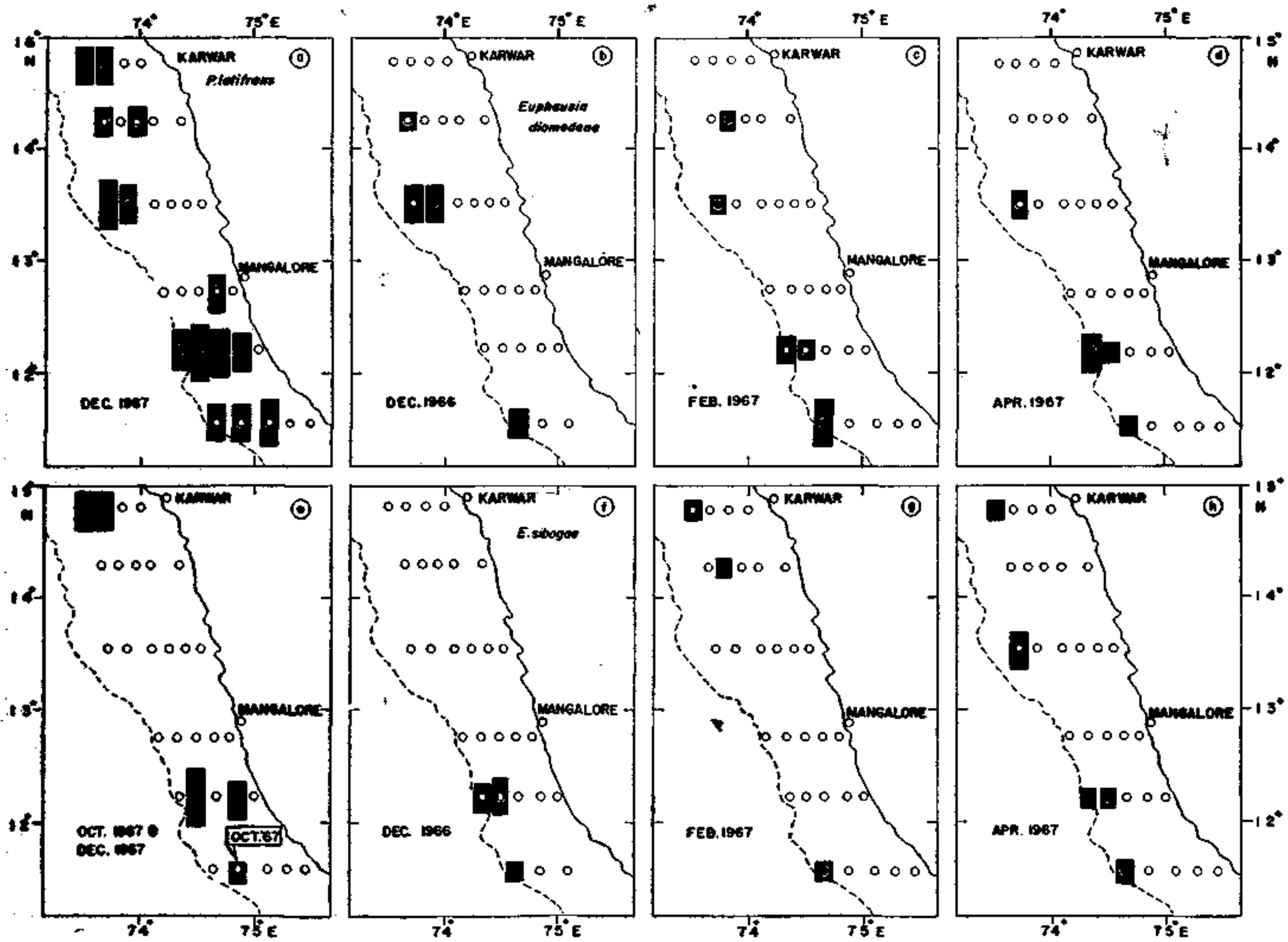

FIG. 2. Seasonal and spatial distribution of larval euphausiids in the continental shelf area: a. *Pseudeuphausia latifrons*; b-e. *Euphausia diomedeae* and f-h. *E. sibogae*.

of which one was in the 2nd sector, one in 6th sector and the rest two in the 3rd sector (Fig. 2 b). Their numbeıs in the respective stations were also less being in the range of 13 to 257. No special day/night difference in their occurrence was noticed in this month.

In February relatively more number of larval forms of *E. diomedeac* were present in samples collected in the southern sectors (Fig. 2 c). While in four samples the number of larvae varied between 11 and 21, in one night sample an estimated number of 633 larvae were present. In April (Fig. 2 d) the occurrence of the larvae of this species was from the same localities where they were present in February except in the 2nd sector. The maximum number of 241 larvae was present at the shelf edge station in the 5th sector. At the other stations, their number varied between 11 and 86.

After April the larvae of *E. diomedeae* reappeared in October when they were collected at a rate of 13 larvae from a single station in the southern sector (Fig. 2 e). Again in December, 1967 the larval forms occurred at four stations at a rate ranging from 120 to 175 at three stations and 1,800 at one station (Fig. 2 e). In this month their spatial distribution was restricted to the northern and southern sectors. The larvae occurred in the night samples only.

Euphausia sibogae (Fig. 2 f-h, 3 a-e)

This species had their larvae sparsely distributed in December 1966, February and April 1967 and again in December 1967. In June they were absent. However, in Auust and October the larvae of *E. sibogae* surpassed all other euphausiids and they occurred in such quantities that they formed the most abundant euphausiid in the area investigated.

In December 1966 the larvae of this species occurred at three stations in the southern sector at the rate of 50, 90 and 140 (Fig. 2 f). In February also the larvae occurred in three samples; two from the northern and one from the southern sectors (Fig. 2 g), but their number was less than 70. In April the larvae were present at five day stations; three in the southern, one in the northern and one in the mid-sector (Fig. 2 h)

In August, the larvae of *E. sibogae* were extremely abundant. Out of the total of 26 stations occupied during this month, the larvae occurred at 15 stations (Fig. 3 a). Of these, eight were night stations at which the estimated larval numbers ranged between 111 and 53,200. In the day samples the number ranged from 100 to 4,617. The maximum concentration was observed in the northern and mid-sectors. In October also the larval population of this species was extremely high (Fig. 3 b). They occurred at 11 out of 28 stations sampled during this month. But whenever they occurred they appeared in dense swarms and were concentrated in the northern and mid-sectors. Only four out of the 11 were night stations. While in the day samples the larvee were present at the rate of 100 to 15,000 the night samples contained them within a range of 50 to 58,817. In December 1967 the larval forms of *E. sibogae* occurred at seven stations but in fewer numbers. They were present in the northern and southern sectors only (Fig. 3 c). Altogether three night samples contained the larvae and their number ranged between 46 and 50. The day samples yielded 24 to 425 larvae.

Nematoscelis gracilis (Fig. 3 e-h)

The larvae of this species were present in December 1966, February, April and December 1967 with their maximum occurrence in February. Their absence in June, August and October was highly significant.

In December 1966 the larvae occurred at three stations only of which two were sampled during the night hours (Fig. 3 e). Their number varied from 133 to 257. The larvae

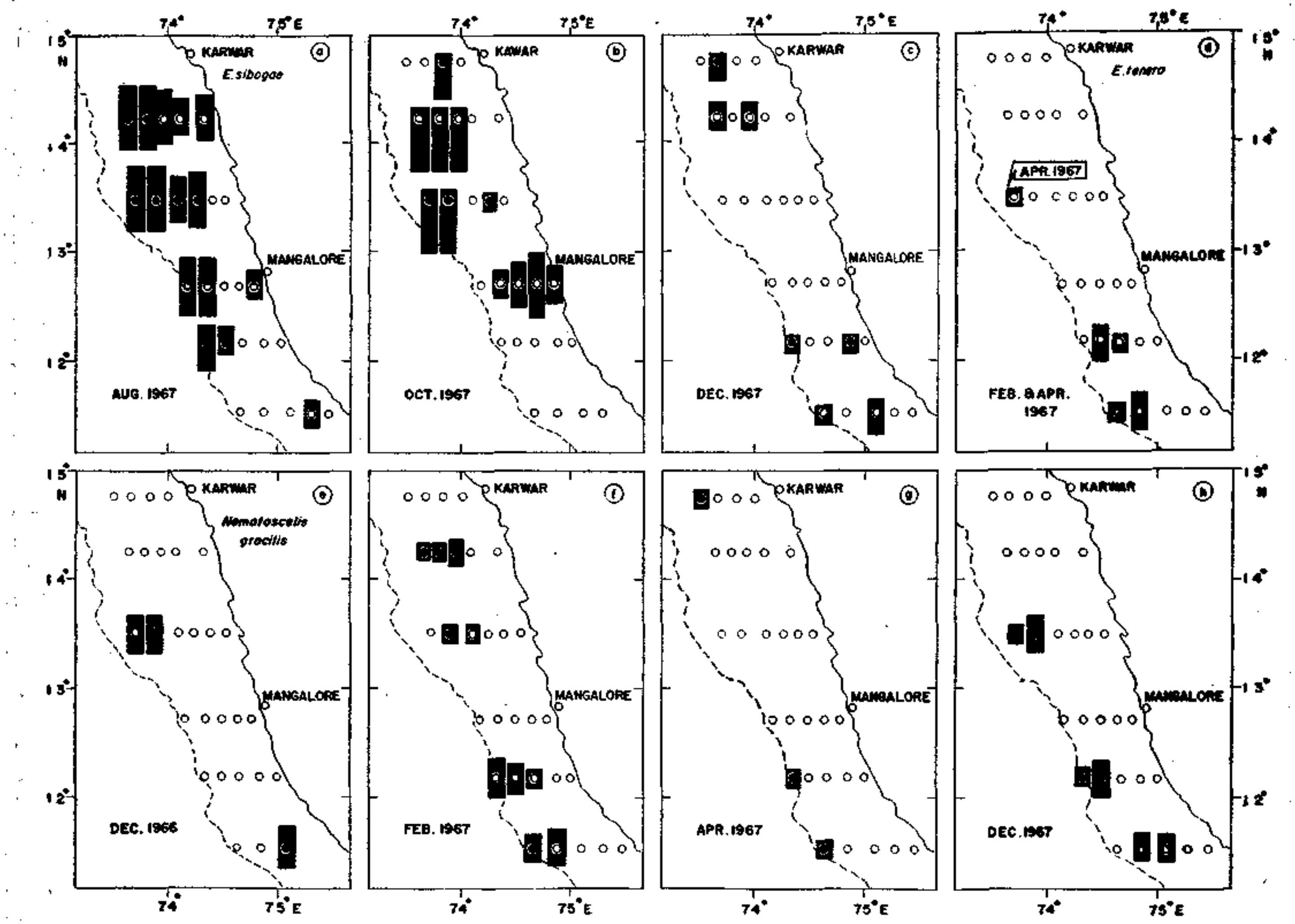

FIG. 3. Seasonal and spatial distribution of larval euphausiids in the continental shelf area : a-c. *Euphausia sibogae* ; d. *E. tenera* and e-h. *Nematoscelis gracilis*.

were strictly confined to the southern and mid-sectors. But there was a little change in this condition in February as the larvae extended their distribution to the northern stations also (Fig. 3 f). In this month the number of larvae in each sample varied from 20 to 250. In April the larval occurrence showed a declining trend of 18 to 46 in three night hauls, two of which coming from the southern sector (Fig. 3 g). During December 1967 four southern stations and two mid-sector stations yielded the larvae. Four out of the above six samples were collected in the night (Fig. 3 h). The number of larvae varied between 23 and 320.

Stylocheiron armatum. (Fig. 4 a-d)

The larval stages of this speceis were present in the samples in moderate numbers in December 1966, February and April 1967 and December 1967. In December 1966 out of the 28 samples the larvae of *S. armatum* were present at nine stations. Their number ranged from 27 to 550 ; the maximum being in a night haul (Fig. 4 a). Out of nine positive samples, six were day hauls. In February 11 stations yielded the larvae of this species, their number varying from 20 to 511. Generally a higher incidence of the larvae was seen in the southern sector (Fig. 4 b).

The larval occurrence was scarce in April, being present in seven stations only (five night hauls), the number of specimens varying from 11 to 200. Greater abundance was in the southern sector (Fig. 4 c). In December 1967 seven out of 10 positive stations were night stations and the maximum number of 1,100 larvae were obtained in a night haul in the mid-sector (Fig. 4 d).

Stylocheiron affine (Fig. 4 e-h, 5 a-b)

Though in fewer numbers, the larvae of *S. affine* were present in all the seven months under consideration. However, it is interesting that their occurrence was found more towards the continental shelf edge in all the sectors.

In December 1966 out of the four positive stations, one was a night station which yielded an estimated number of 325 larvae (Fig. 4 e). In February the larvae occurred in three stations ; one in the mid-sector and the others in the southern sector and their number varied between 80 and 294, the maximum occurring in the night haul (Fig. 4 f). The larvae were scarce in April and occurred only in a single night haul in the southern sector (Fig. 4 h). In June, four out of 10 stations were positive for the larvae and all the four were night hauls yielding an estimated number of 30 to 71 (Fig. 4 g). The occurrence was more towards the southern part. In August the pattern of larval occurrence was more or less the same as in June (Fig. 4 h). Their number varied between 11 and 90. October had the maximum number of larvae in three night and five day hauls which yielded an estimated number of 40 to 325 larvae. The greater abundance was noticed in the southern sector (Fig. 5 a). In December 1967 eight of the 30 stations were positive and of these two were occupied during night (Fig. 5 b). The larvae were present in the range of 33 to 150 and most of them were present in the mid and southern sectors.

Besides the above six species, sporadic occurrence of larvae of the following species was also noticed. They were *Thysanopoda monacantha. T. tricuspidata, E. tenera, S. suhmi, S. longicorne* and *S. maximum* (Table 1). They were absent in the collections made in December 1966 and June and December 1967. Larvae of most of these species occurred in February.

The larvae of *T. monacantha* (Fig. 1 a, b) occurred in very few numbers (between 3 and 29) in February and April at two stations each. *T. tricuspidata* (Fig. 1 c) presented at six of the stations occupied in February of which two were sampled during night. Their number ranged between 11 and 125. In April the larvae of this species were taken at a single station at the rate of 86 in the mid-

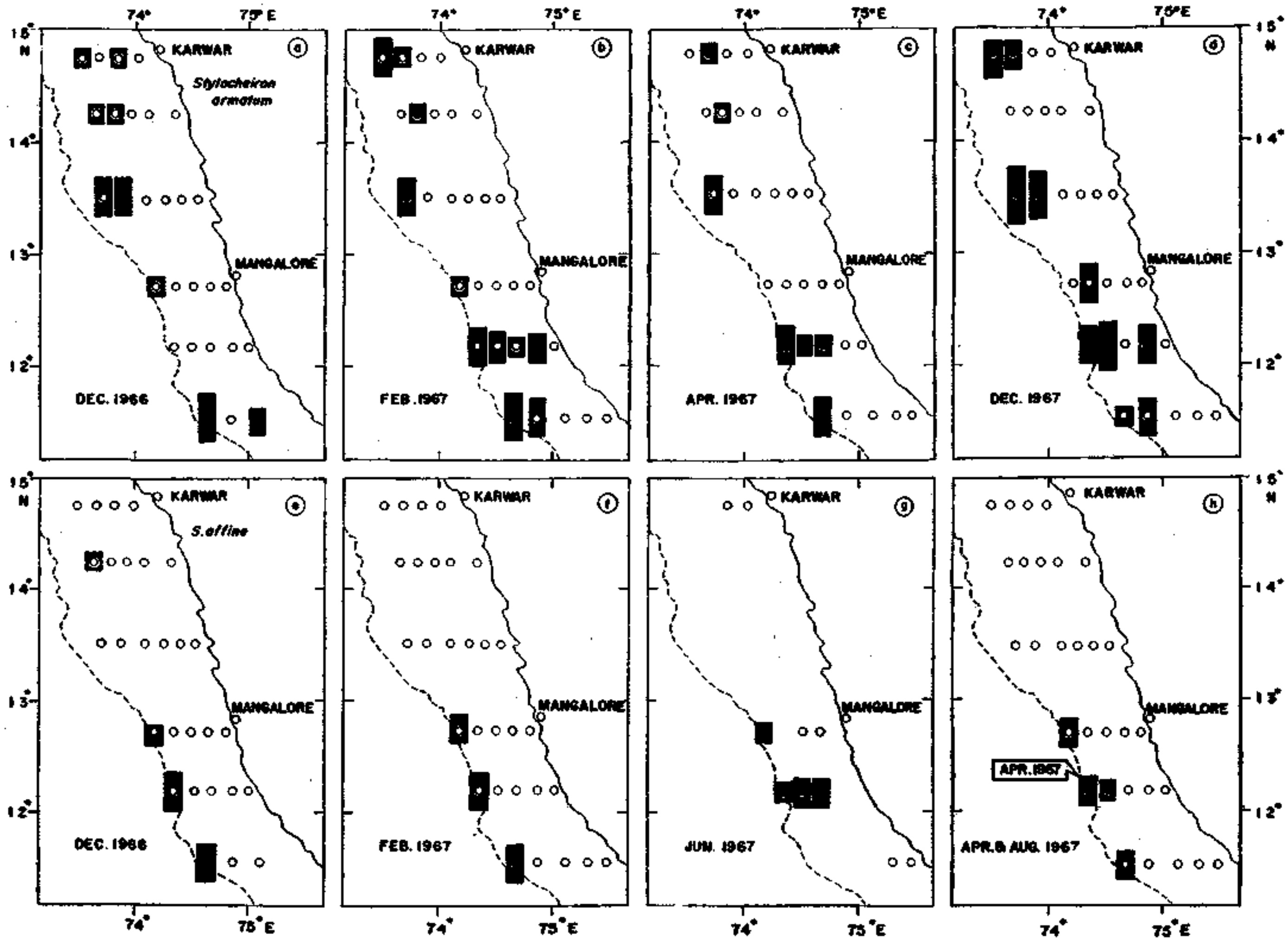

FIG. 4. Seasonal and spatial distribution of larval euphausiids in the continental shelf area: a-d. *Stylocheiron armatum* and e-h. *S. affine*.

sector, *E. tenera* whose larvae occurred in four southern stations in February and one mid-sector station in April behaved almost similar to *T. tricupsidata* (Fig. 3 d). In February their number varied between 33 and 483 and in April it was at the rate of 29 larvae. The larvae of *S. suhmi* (Fig. 5 c) occurred in February and August in two samples each. The rate of occurrence ranged from 10 to 100. A few larvae of *S. longicorne* were present in August and October (Fig. 5 d). One single larva of *S. maximum* was obtained in August from a night station (Fig. 5 d).

A distinct relationship between the seasonal and spatial abundance of larval euphausiids in different months and the upwelling areas was indicated. The significant finding with regard to the larvae of *P. latifrons*, a neritic species, was that they were almost absent in the shelf area during the intense upwelling months. A general tendency observed with the larvae was that they were always absent in the upwelling areas which may be indicative of the pattern of movement of the breeding stock. *E. diomedeae* was another species whose larvae did not occur during the upwelling period.

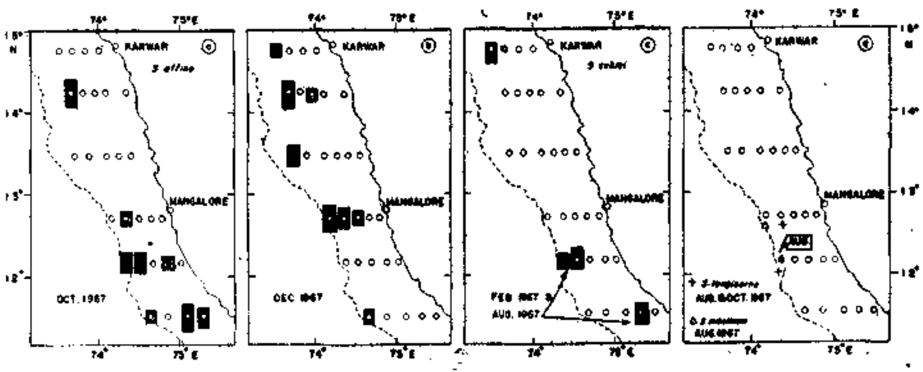

FIG. 5. Seasonal and spatial distribution of larval euphausiids in the continental shelf area: a-b. *Stylocheiron affine* ; c. *S. suhmi* and d. *S. longicorne* and *S. maximum*.

Discussion

A study of the pattern of vertical distribution of temperature in the area of investigation from December 1966 to December 1967 clearly showed the intensity and extent of upwelling taking place in the continental shelf waters along the southwest coast of India. In general the signs of upwelling were indicated in the upper water as early as February-April period, initially in the southern sectors. From there the process gradually moved northward where intense upwelling was observed from June to October. During upwelling there was heavy incursion of cold oceanic water into the shelf area (Mathew, 1985).

The larvae when present were mostly confined to the shelf edge. The larvae of *E. sibogae* were confined to the shelf edge waters during the non-upwelling months, but they made large scale incursion into the coastal areas along with the upwelled waters. *N. gracilis* probably bred far away from the coast since their larvae were encountered only there. There was no special north/south difference in their occurrence. The larvae of *S. armatum* mostly restricted their distribution to the southern sectors and were more abundant towards the shelf edge. They also showed a tendency to avoid the upwelled waters. As far as *S. affine* was concerned their larval forms had no particular reaction to the upwelled waters, but their distribution was restricted to the southern parts of the area of study.

The periods of the year during which larvae of any one species occur depend, of course, on the extent of the breeding season of the adults (Mauchline and Fisher, 1969). The seasonal distribution of larvae of various species studied during the present investigations throws some light of the probable periods of breeding in some of them. Although in the tropical waters breeding could be protracted in many species, still peak seasons may be detected on the basis of the larval abundance. Protracted breeding has been reported in a number of species of the tropical, subtropical or temperate regions. Sheard (1953) found a prolonged period of breeding from eight to 11 months for *Nyctiphanes australis*. In the case of *Euphausia lucens* and *Nyctiphanes couchi*, according to Negpen (1957) and Einarsson (1945) respectively, the eggs may be produced from the beginning of spring to the end of summer with further extension to the winter months. Based on personal communication from Pearcy to Mauchline and Fisher (1969) *Euphausia pacifica* breeds throughout the year off the coast of Oregon, USA. According to Ruud (1936) *Euphausia krohni*, *Nematoscelis megalops* and *N. atlantica* may have long breeding season in the Mediterranean. Similarly prolonged spawning has been observed in species of *Thysanoessa* by Ponomareva (1963).

Ponomareva (1975) found that the eggs develop very rapidly (within 24 hours) and so do the early larval stages. On reaching the naupluis 2 stage, the development slows down and it takes 10-12 days for the larvae to develop into furcilia 1. The larval forms considered for the present studies being of calyptopsis and furcilia stages, it is to be expected that the actual process of breeding which involves egg laying and the development of early larvae must have started well in advance than the period mentioned above. In the absence of such data the actual beginning of the breeding season could not be fixed. However, as mentioned earlier, since the larval occurrence could be considered as an index of the active breeding and rearing period to some extent the following conclusions could be arrived at.

The pattern of abundance of larvae of *P. latifrons* in the various months suggests that the period from December to April could be the active breeding period of this species in the shelf waters with the peak from December to February. Similarly in the case of *E. diomedeae* also the peak breeding season appears to be from December to April. *E. sibogae* seems to be a continuous breeder in the shelf area because their larvae were taken in all months except June, at least in small quantities. Nonetheless, the period from August to December appears to be the peak of the breeding season in this species. *N. gracilis* was a species whose larval forms were strictly seasonal in their occurrence. This points to the possibility that the breeding period of this species extends from December to April. As far as the breeding period of *S. armatum* is concerned, the period from December to April could be considered as the active breeding period. The sparse occurrence of larvae of *S. affine* makes it difficult to say anything definitely on the breeding period in this species. However, their presence in all the months under consideration indicates that breeding takes place almost round the year in the shelf area.

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