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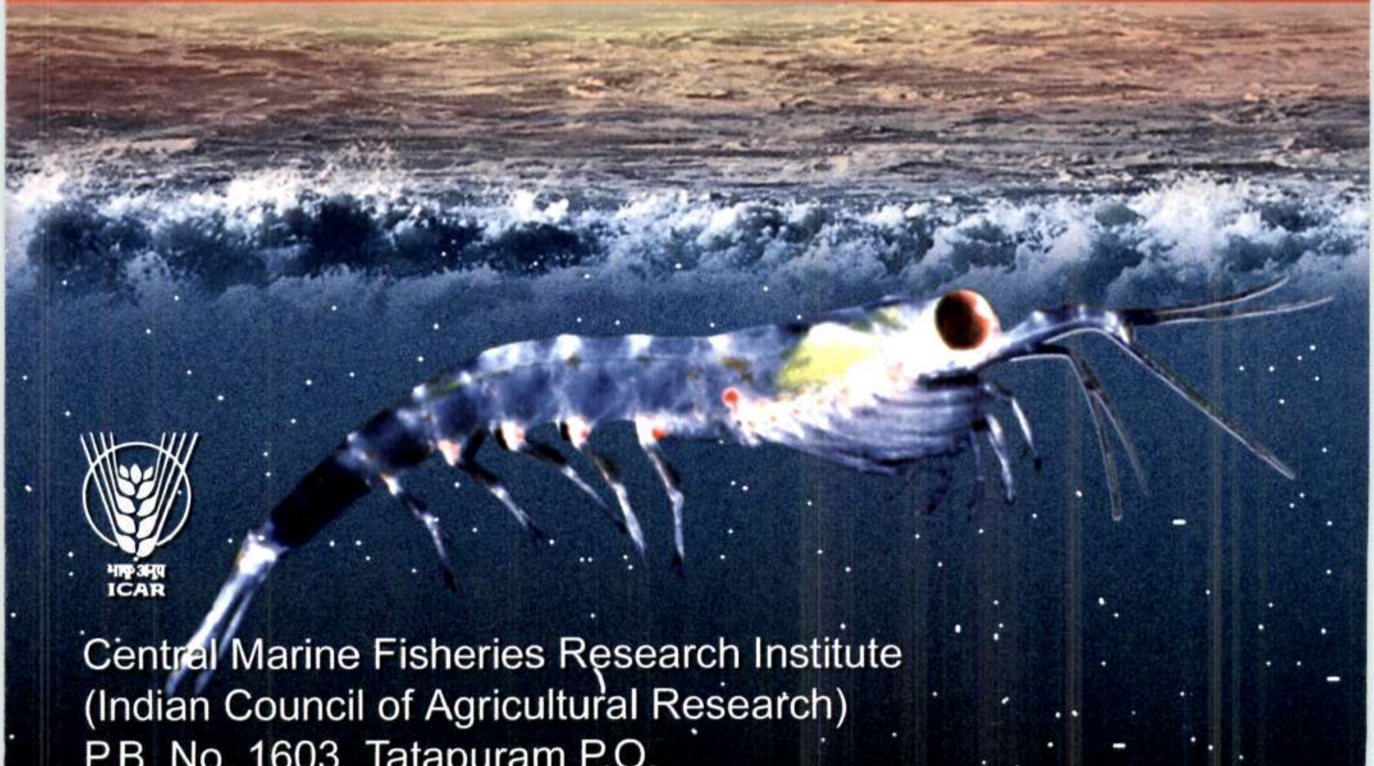

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FOREWORD

In 1985 with the arrival of the multidisciplinary research vessel FORV *Sagar Sampada*, which was capable of cruising in any part of the oceans including the Antarctic seas, a total change occurred in the marine fisheries research scenario in India. The regular research activities which were until then mostly confined to the nearshore waters along the Indian coasts for want of ocean going research vessels (not forgetting the services of R.V. *Gaveshini* and ORV *Sagar Kanya*) found new dimensions in the following years. The marine biology and fisheries oceanography once again came to the forefront and as a result enormous amount of data and material were generated round the year for several years from the entire EEZ of our country. Two workshops were conducted exclusively for the discussion of the research results emanated from the work of *Sagar Sampada* and the proceedings have been published.

One major work of FORV *Sagar Sampada Sampada* was the regular and year round collection of material for the study of secondary production. Large number of zooplankton samples which were collected from the EEZ of India in the Arabian Sea, the Bay of Bengal and the Andaman and Nicobar seas were fully analysed for the study of biomass and the component groups. A lot of man power was put in for the production of basic data on zooplankton. Thousands of samples were sorted into major groups for detailed studies. However, specieswise studies could be completed for a few groups only while many other major groups remained uninvestigated.

The euphausiids, one of the major zooplankton groups form a staple food for many commercially important marine organisms. However, except for some taxonomical and other preliminary studies in the latter part of the 19th Century no oceanwide detailed work has been carried out in this group. A knowledge on the biomass, geographical distribution, monthly and seasonal abundance, breeding, breeding seasons, their relationship with the environment etc. would help in understanding the role they play in the marine economy. A comprehensive work on the euphausiids of the Indian EEZ was a necessity and with the present work the same is partly fulfilled for it gives a picture of the various distributional and other aspects of these organisms in the Arabian Sea part of the Indian EEZ.

By writing this Special Publication for the Institute, Dr. K.J. Mathew, completes a part of his life's mission which he alone could do in India, for he is the only Indian to have specialised on this group. This is one work which he could not do during his official career due to other preoccupations. Now a similar work remains to be done for the Bay of Bengal and the Andaman & Nicobar seas also which I hope he would complete in the coming years. I specially congratulate Dr. Mathew and his co-authors for this original contribution to science and thank them for their goodwill to give this work to the Institute for publication. I am sure this will stand as a model publication in the field of planktonology. Though this work is more useful to advanced researchers it can be a reference to anyone conducting studies on the tropical zooplankton.

Cochin-14,
01-07-2003

Prof. (Dr.) Mohan Joseph Modayil
Director

PREFACE

The distribution in space and time and other ecological and biological aspects of the various species of Euphausiacea (Crustacea) of the Indian EEZ was a long pending study. Eventhough I had the will, the wish and the expertise to carry out this study the changes in priorities of my work during my active service period did not permit me to attempt on such a study. However, the last two undisturbed years were sufficient enough for me to complete a part of the envisaged study which pertains to the EEZ along the west coast of India. Since the time for the present assignment as Emeritus Scientist is over I am rather compelled to keep aside a similar work remaining to be done for the Bay of Bengal and the Andaman and the Nicobar seas which I hope to complete if the situations become favourable. To fulfil the present work I have availed the help and support of several of my old colleagues who deserve my personal thanks.

First of all I wish to express my sincere thanks to the Indian Council of Agricultural Research, New Delhi for appointing me to the position of Emeritus Scientist soon after my retirement which enabled me to complete the present study. I am greatly indebted to Prof. (Dr.) Mohan Joseph Modayil, Director, Central Marine Fisheries Research Institute for sparing all the facilities required for undertaking this work and for agreeing to publish the results in the form of a Special Publication of CMFRI. I am extremely thankful to Dr. Edward Brinton of the Scripps Institution of Oceanography, La Jolla, California for permission to reproduce his figures of 17 species of euphausiids. My special thanks are due to Ms. T.S. Naomi and Dr. (Ms.) Geetha Antony of CMFRI for extending unfailing support in the organisation and execution of the plankton sorting work and for all other further work connected to this study while I was in service in CMFRI. Their help in the critical perusal of the manuscript is also gratefully acknowledged. I also wish to thank Mr. K. Balan and Dr. M. Srinath of CMFRI for the useful discussions I had with them in the course of this work. My sincere thanks are due to Ms. A. Fabeena, Ms. A.K. Omana, Mr. K. Sankaran and all other staff members in the office who directly or indirectly helped me in the successful completion of the present study. The Ocean Science and Technology Cell on Benthos, School of Marine Sciences, Cochin University of Science and Technology is sincerely thanked for allowing to use the PRIMER 5 software package in the biodiversity studies.

Cochin-14
01.07.2003.

Dr. K. J. Mathew
Emeritus Scientist (ICAR)

CONTENTS

EUPHAUSIACEA (CRUSTACEA : ZOOPLANKTON) OF THE EXCLUSIVE ECONOMIC ZONE OF THE WEST COAST OF INDIA

K.J. MATHEW, GISHA SIVAN, P.K. KRISHNAKUMAR AND SOMY KURIAKOSE

ABSTRACT

The euphausiids (Class Crustacea: Order Euphausiacea) one of the major components of the marine zooplankton occurring in the EEZ of the west coast of India (eastern Arabian Sea) and collected during the cruises of FORV *Sagar Sampada* during 1985-1992 period from the epipelagic zone were subjected to specieswise study for their distribution in space and time and for their ecology and biology. Seventeen species were encountered of which *Pseudeuphasia latifrons* (at an average density of 258/1000m^3 of water), *Euphausiia diomedeae* (1,256), *E. sibogae* (1,437), *Nematoscelis gracilis* (309), *Stylocheiron armatum* (230) and *S. affine* (216) were the most abundant and cosmopolitan in occurrence. The other 17 species namely *Thysanopoda monacantha, T. tricuspidata, T. astylata, E. tenera, E. pseudogibba, Nematobrachion flexipes, S. suhmii, S. microphthalma, S. longicorne, S. abbreviatum* and *S. maximum* were rather sparsely distributed and their average number per 1000m^3 of water ranged between 10 and 151 only. The major species exhibited marked variations in population during different months and seasons mainly depending on the changes in the environment. All the major species had a southwest monsoon and post monsoon abundance. The euphausiids had the maximum density of 3,942 per 1000m^3 in the continental shelf waters where the depth to the bottom ranged from 51 to 100 m. The southern latitudes of the study area always supported more euphausiids, the

reason being environmental. The populations gradually tapered to the north. A pronounced variation in the day/night abundance was observed for majority of the species indicating diurnal vertical migration. *E. diomedeae* was found to perform strong vertical migration against *S. affine* which migrated the least. The different life stages such as adults, juveniles and larvae exhibited varying degrees of vertical migration, always the larvae being the least migrating. Notable variations in the different latitudinal sectors during the major seasons and months were shown by the major species, a phenomenon attributed to changes in the environment. The pattern of movement of euphausiids between shelf and oceanic waters during different seasons showed that from an equilibrium level during the premonsoon season the population increased in the shelf region during the monsoon and reached the maximum during the postmonsoon season. However, marked variations were found among individual species. The monthly variations among species in the shelf and oceanic waters were also worked out. A study of latitudinal and seasonal variations in the shelf and oceanic areas for the various species threw some light on their north-south movement during different seasons in the different environments. In this tropical environment all the species showed almost continuous breeding with varying intensities. However, a study of the monthly abundance of the adults, the juveniles and the larvae and also the spermatophore and egg bearing animals in the population gave indications on the breeding periods of the major species; the peak periods being April, May and November for *P. latifrons*, April, May, July and November for *E. diomedeae*, August, September and October for *E. sibogae*, July and November for *N. gracilis*, March, April and May for *S. armatum* and April, August, September and November for *S. affine*. A study of the spermatophore bearing males and females indicated that the copulation success was minimum among the various species.

The numerical abundance of each species and total euphausiids estimated for space and time and in their different combinations were statistically tested for significance. The biodiversity analyses were performed to calculate richness, diversity and evenness of species in each station using univariate techniques. Multivariate techniques were used to evaluate both among the stations and among the sites patterns in overall biodiversity.

1

INTRODUCTION

Members of the Order Euphausiacea coming under the Class Crustacea form a major constituent of zooplankton in the epi, meso and bathypelagic zones of the world oceans, mostly confined to the offshore waters. Considering their greater importance in the marine economy by forming a significant link in the food web, this group of animals has been intensively studied the world over. Being larger in size than many other zooplankters, very often their biomass may surpass any other single group in the zooplankton. The euphausiids feed on a variety of phyto and zooplankters and in turn form forage for several invertebrates, many species of fishes, birds, seals and whales. One single species of this group, *Euphausia superba*, popularly known as the 'Krill' plays a pivotal role in the Antarctic food web.

When compared to the world oceans, the euphausiid fauna of the Indian Ocean is less investigated, especially with regard to the geographic and seasonal distributions, ecology and biology. Some earlier expeditions namely *Challenger* (1873-76) (G.O. Sars 1883, 1885), German Deep Sea Expedition *Valdivia Expedition* (1898-1899) (Illig 1930), *Sea Lark* Expedition (*Percy Sladen Trust Expedition*) (1912) (Tattersall 1912) and *John Murray* Expedition (1933-1934) (Tattersall, 1939) contributed to the faunistic studies. Leaving aside these works, the studies giving more emphasis to the geographical and seasonal distribution in relation to the environment of euphausiids in general and of various species in particular for localised areas in the Indian Ocean are those of Baker (1965), Roger (1966), Weigman (1970), Legand *et al.* (1975), Ponomereva (1975), McWilliam (1977), Mathew (1980b, 1982, 1985, 1988b), Silas and Mathew (1986) and Mathew *et al.* (1990, 2000).

The International Indian Ocean Expedition (IIOE) (1959-1965) attempted studies on the geographic and seasonal distribution of euphausiids for the entire Indian Ocean for the first time using about 2,000 zooplankton samples (Gopalakrishnan and Brinton 1969, Brinton and Gopalakrishnan, 1973). However, when compared to the vast area covered, the material studied upon was small enough to draw authentic conclusions.

The present work carried out for the Euphausiacea of the Exclusive Economic Zone of the west coast of India is an attempt to study the distribution, abundance, ecology, biology and biodiversity of these organisms under various combinations of time and space along with statistical tests. This is the first time that ssuch studies are made for the Indian EEZ.

Biodiversity studies include diversity within species (genetic diversity), between species (organismal diversity) and between communities (ecological diversity) as defined by Harper & Hawksworth (1994). At the organismal level, the most widely used biodiversity measures are those based on the number of species present, perhaps adjusted for the number of individuals sampled, e.g. Margalef's Species richness index (d), or indices that describe the evenness of the distribution of the numbers of individuals among species, e.g. Pielou's evenness (J), or that combines both richness and evenness properties, e.g. Shannon's H' (Magurran 1991). These indices may be of value as comparative biodiversity measures in situation where sampling methods, sample size and habitat types are carefully controlled (Warwick and Clarke 1995).

In the last decade a variety of different biodiversity measures have been devised to measure the degree to which species are taxonomically related to each other such as "variations in taxonomic distinctness" and "average taxonomic distinctness" (Clarke and Warwick (2001). AvTD is the measure of mean path length through the taxonomic tree connecting every pair of species in the list, while VarTD is simply the variance of these pairwise path lengths and reflects the unevenness of the taxonomic tree (Clarke and Warwick 2001). These two indices are not dependent on sampling methods, sample size and habitat types and are widely used for broad scale geographical comparisons of biodiversity, environmental impact assessment and evaluation of surrogates for biodiversity estimation (Clarke and Warwick 2001).

No scientific study has been reported on the biodiversity of euphasiids from the west coast of India with reference to space and time. Therefore, the present study also deals with the biodiversity of euphasiids collected from 491 stations from the EEZ of India with reference to space and time.

HISTORICAL RESUME

Some investigations on the Indian Ocean euphausiids have been carried out in the nineteen sixties and seventies during the IIOE. Brinton (1963) discussed the distributional barriers of euphausiids between the tropical Pacific and the Indian Ocean. Ponomareva (1964) listed the species encountered in the Arabian Sea (28 species) and the Bay of Bengal (25 species) during the cruises of R.V. *Vityaz*. Baker (1965) studied the ecology of 17 species of the genus *Euphausia* collected by the 'Discovery' from the equator to south upto 60°S along 90°E. In 1965 Grindley and Penrith recorded 18 species from the Indian Ocean side of South Africa. The seasonal distribution and ecology of seven common species of the genus *Thysanopoda* of the southeastern Indian Ocean were investigated by Roger (1966). Sebastian (1966) has reported on 23 species of euphausiids from the southwest coast of India. *Stylocheiron* *indicum*, a new species was described by Silas and Mathew (1967) from the continental slope of the southwest coast of India. Gopalakrishnan and Brinton (1969) have given an account of the quantitative distribution of the Indian Ocean euphausiids based on the IIOE material.

Mathew (1971, 1972, 1975) has described the post naupliar stages of three species for the first time. The euphausiid constituent of the DSL as observed in the Lakshadweep Sea has been investigated by Silas (1972). He found that volumetrically the euphausiids formed the second major group of animals in the DSL.

Brinton and Gopalakrishnan (1973) have attempted the quantitative distribution of the euphausiid species of the Indian Ocean based on material collected during IIOE. De Decker (1973) studied the euphausiids of the Agulhas Bank off Cape Town. A detailed study of the zoogeography of some species of *Nematoscelis* of the Indian Ocean was made by Gopalakrishnan (1974). Brinton (1975) studied the distribution of 33 species in the eastern Indian Ocean between latitudes 14°N and 18° S near the Indo-Australian Archipelago. In the same work he also made a review of the pattern of euphausiid distribution in the Pacific, the Atlantic and the Indian Ocean. Ponomareva (1975) carried out investigations on species composition, biology and vertical distribution of euphausiids of the Indian Ocean. The euphausiids of the eastern Indian Ocean have been studied by Taniguchi (1976).

Silas and Mathew (1977) made a critical review of the larval development in euphausiids. McWilliam (1977) studied the ecology of euphausiids in the upper 200 m of the eastern Indian Ocean along 110°E meridian between 9°30'N and 32°00'S for a period of one year. Mathew (1980a) critically examined the taxonomic validity of *Stylocheiron armatum*. The sexual dimorphism in *Stylocheiron indicum* was studied by Mathew (1980b). The growth in two common species of euphausiids was worked out by Mathew (1980c). Another study by Mathew (1980d) was on the egg potential of *Stylocheiron indicum*.

Mauchline (1980) in a supplementary work to the earlier volume by Mauchline and Fisher (1969) has included a detailed review of the works on euphausiids of the Indian Ocean.

Mathew (1983) made a study of the distribution of different stages of larvae of euphausiids of the southwest coast of India. The ecology of the species along the southwest coast was done by Mathew in 1985. The quantitative distribution of Krill of the Antarctic waters and the spatial distribution of Krill off Queen Maud Land, Antarctica were respectively studied by Mathew (1986b, 1986c). Fifteen species of euphausiids of coastal waters of Somalia and Gulf of Aden collected during the southwest monsoon were studied by Fatima (1987). The Somalian waters known for intense upwelling contained more number of species than in the Gulf of Aden waters. The net avoidance behaviour of larval, juvenile and adult euphausiids was studied by Mathew (1988a). Mathew (1988b) made a study of the seasonal distribution of the larval euphausiids. The distribution of euphausiids as a whole in space and time in the EEZ of India was studied by Mathew *et al.* (1990). In another study Mathew and Natarajan (1990) worked on the euphausiid components in the DSL of the Indian EEZ. Tirmizi (1990) studied the economic importance of euphausiids in the marine life of Pakistan. The euphausiids formed the fourth abundant group among planktonic crustaceans and tenth among all the zooplankton groups. Five common species were reported by Fatima (1992) from the central part of the north Arabian Sea at 20°N during the southwest monsoon. Some biological aspects were also considered. In a review work Mathew *et al.* (2000) evaluated the studies on euphausiids made until that time in the EEZ of India.

MATERIALS AND METHODS

The euphausiid material utilized for the present study was collected onboard FORV *Sagar Sampada* during her cruises between 1985 and 1992 in the Exclusive Economic Zone off the west coast of India (eastern Arabian Sea). Oblique hauls were made with the ship cruising at 2 knots per hour from 150 m to the surface using a Bongo-60 net of 0.33 mm mesh size. A pre calibrated Hydrobios digital flow meter was fitted at the mouth of one of the cones of the net. The flow meter reading was noted after every haul and based on the same, the quantity of water filtered by the net was worked out. At those stations where the depth to the bottom was less than 150 m, samplings were done from about 5 m above bottom to the surface. The plankton was preserved in 5 % formaldehyde solution. In the laboratory the total volume of the zooplankton was determined by displacement method. After removing the macroplankton whose volumes were separately found, a minimum aliquot of 5 cc of the zooplankton was sorted out into major groups; one of them being the euphausiids.

The euphausiids were further separated into species based on the morphological descriptions made by Sars (1885), Hansen (1910, 1911), Boden (1954), Boden *et al.* (1955), Brinton (1975) and Baker *et al.* (1990). Majority of the euphausiids were larval stages and their species wise identification was done based on literature by Lebour (1926b, c, d), Mac Donald (1927, 1928), Boden (1950, 1951, 1955), Lewis (1955) and Mathew (1971, 1972, 1975).

The quantitative estimates of total euphausiids and of various species have been done for 1000m^3 of water filtered by the net following the method used by Gopalakrishnan and Brinton (1969) and Brinton and Gopalakrishnan (1973). The samples from each half degree square were pooled and averages were worked out in terms of number per 1000m^3 of water.

For the purpose of spatial comparison, the area under investigation was divided into four latitudinal regions or zones or sectors such as Region-I between 06°00'N and 09°59'N, Region-II between 10°00'N and 13°59'N, Region-III between 14°00'N and 17°59'N and Region –IV between 18°00'N and 23°00'N. The two longitudinal categorisation was (1) continental shelf area within 200 m depth and (2) oceanic area beyond the shelf edge. A further division based on depth to bottom was also made for various comparative studies namely (1) upto 50 m, (2) 51-100 m; (3) 101-200 m, (4) 201-1000 m and (5) more than 1000m.

For the seasonal studies the months were put into three groups such as premonsoon (February to May), southwest monsoon (June to September) and post monsoon (October to January). The samples collected between 0600 hrs and 1759 hrs were considered as day samples and those collected between 1800 hrs and 0559 hrs were considered as night samples. For obtaining finer details of quantitative distribution in space, the biomass values have been worked out for every half degree square area. For this purpose the stations occupied in each half degree square were considered together and the averages worked out.

Fig. 1 shows the locations of sampling stations in the study area. A total of 493 samples have been considered for study from these stations of which 272 were sampled during day and the rest during night. The day stations are shown as open circles and the night stations as closed circles. A few stations between 13°N and 19°30' N which occupied beyond the limit of the EEZ have also been considered for the study.

The variations in abundance of different species for the variables such as months, seasons, depth, shelf/oceanic, latitude and day/night were statistically analysed and tests of significance were carried out using Analysis of Variance (ANOVA) technique. Appropriate transformations were made to meet the normality assumption of ANOVA. The software used for the statistical analysis was SYSTAT (7.0), SPSS INC.

Univariate analysis: The raw numerical abundance data consisted of the number of individuals of species of Euphausiacea collected from the Indian EEZ. Analyses were performed to calculate species richness, diversity and evenness index values for each station (sample), using the PRIMER 5 (Plymouth Routines in Multivariate Ecological Research) software package developed at the Plymouth Marine Laboratory, UK (Clarke and Warwick 1994). Species richness was determined using Margalef's index (*d*), which provides a measure of the number of species (*S*) present for a given number of individuals (*N*) according to the following equation: $d = (S-1)/\log2\ N$.

Diversity was calculated using the Shannon-Weiner (H') index : $H' = -\Sigma i\ pi\ (\log2\ pi)$, where p*i* is the proportion of the total count arising from the *ith* species.

Equitability, the evenness of the species distribution, was determined using Pielou's evenness index (J') : $J' = H'$ (observed)/ H' max, where H' max is the maximum possible diversity which would be achieved if all species were equally abundant = log2(*S*).

Brillouin's index was calculated using $H= (I/N)\ \log_e(N!/i\ Xi!)$.

Simpson diversity was estimated in the form of $\Delta° = 1-\Sigma i\ \{Xi(Xi-1)N(N-1)\}$.

The recently proposed biodiversity indices namely Average Taxonomic Distinctness (AvTD, Δ*) by Warwick &

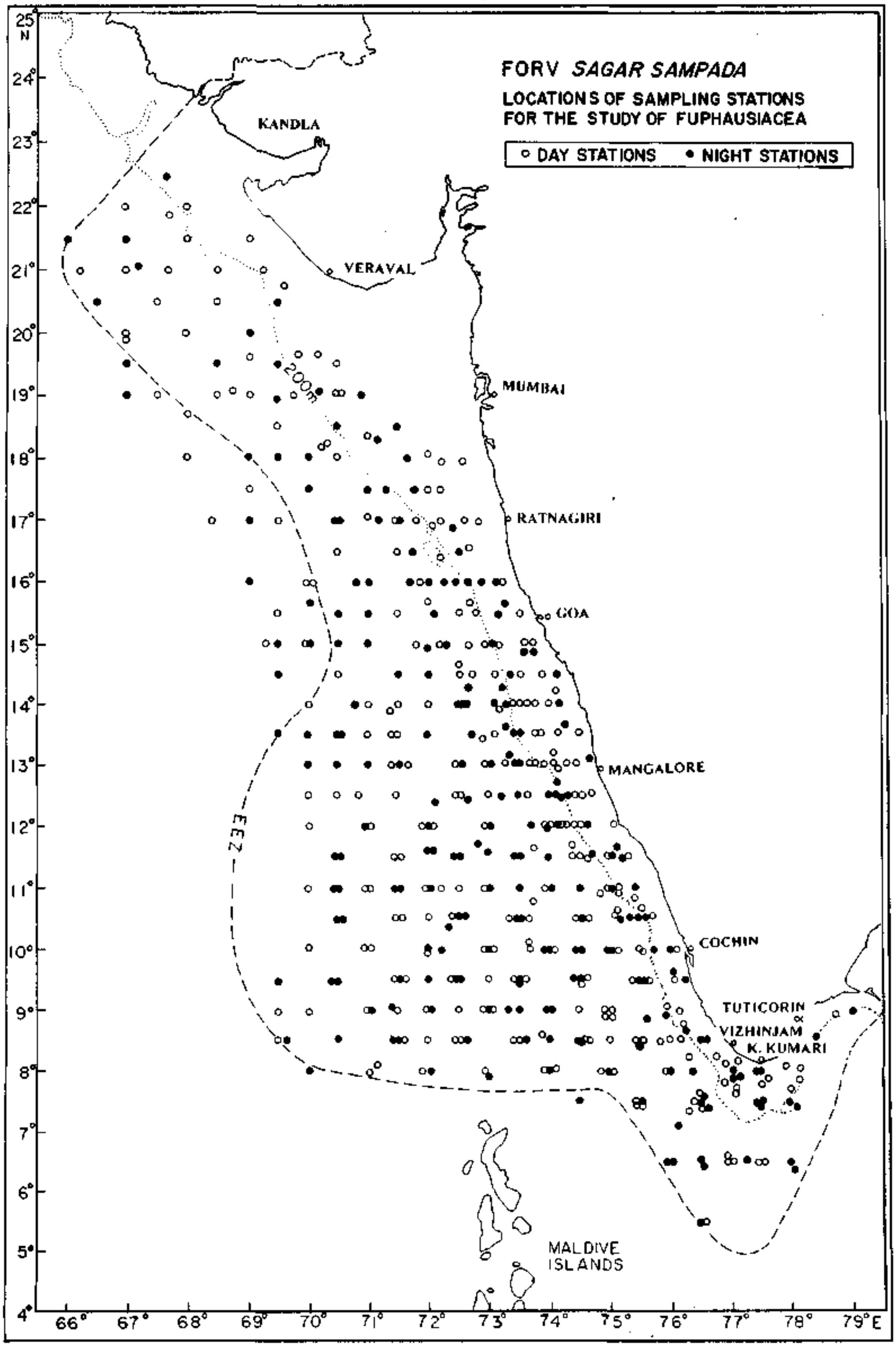

Fig. 1. Location of sampling stations for collecting zooplankton during the cruises of FORV *Sagar Sampada* from the EEZ of the west coast of India. Open circles represent day stations and closed circles night stations.

Clark (1995), and Variations in Taxonomic Distinctness (VarTD, Δ*), by Clark & Warwick (2001) were also computed using PRIMER. All the above indices were determined using the DIVERSE routine within the PRIMER software package.

Multivariate Analysis: Using the PRIMER software package, multivariate techniques were used to evaluate both the among-station and among-site patterns in overall biodiversity. These techniques serve to classify the stations into groups having mutually similar biodiversity pattern. Prior to performing the clustering, the biodiversity values were square-root transformed, and a matrix was then constructed consisting of Bray-Curtis similarity index values (Bray and Curtis 1957) calculated between each possible pair of stations (i.e., pairwise comparisons). Hierarchical agglomerative clustering with group-average linking was then performed on this similarity matrix based on the square-root transformed biodiversity data (Clarke 1993).

Representation of the results was by means of a tree diagram or dendrogram, with the x-axis representing the full set of samples and the y-axis representing the Bray-Curtis similarity level at which two samples or groups are considered to have fused. ANOVA test was carried out (SYSTAT version 8.0.) to find out the changes in biodiversity pattern with reference to different variables.

2

THE ENVIRONMENT

The Indian Ocean has a unique position among the world oceans in that its northern end is closed due to the existence of the Asian continent which is large enough to develop its own far reaching atmospheric circulation that influences the ocean down to 10°S and is known as the monsoon circulation. One manifestation of this situation on the ocean is that the surface circulation in the northern part (Arabian Sea and the Bay of Bengal) reverses every half year. In the winter there is the northeast monsoon and in the summer there is the southwest monsoon circulation.

Another critical situation developed on account of the northern land locked condition is that the ocean is separated from the deep reaching vertical convection areas in the northern hemisphere. Thus it is only in the higher southern latitudes that water of low temperature reaches high density on the sea surface and initiate a deep circulation. The northern part develops its own rudimentary meridional circulation by the water masses of the Red Sea and the Persian Gulf. Both the seas are relatively smaller, yet they both have a very deep reaching convection especially in the winter in the northern part, in the Gulf of Suez and off the mouth of Shatt-el-Arab. Cold water with high salinity is formed by the considerable evaporation in the inner Gulf and it spreads on the bottom. This deep water leaves the Gulf through the sill where the depth is around 50m, sinks further down and forms a layer in parts of the Arabian Sea. This process helps in bringing about some renewal of oxygen minimum water (Dietrich, 1973).

The outflow of Persian Gulf and Red Sea water influenced by the Coriolis Force prefers the western boundary, the eastern boundary being low in renewal. Consequently off the Indian coast the layer with oxygen values below 0.5 ml/l reaches from 100 to 1,500 m and the values in a layer of 500 m thickness are even below 0.5 ml/l. This is the lowest oxygen content in such large region in the entire world oceans (Dietrich 1973). The oxygen minimum layer extends to the shelf off the west coast of India during the southwest monsoon season. Such oxygen deficient conditions are of biological importance.

Circulation pattern

Gallahar (1966) and Varadachari and Sharma (1967) have studied the circulation pattern of the surface waters of the northern

Indian Ocean. The monthly picture of water circulation in the Arabian Sea from January to December is given in Figs. 2 and 3.

During November the water movement to the north of equator starts moving from east to west and reaches its greatest strength in February. The coastal currents during November to January period are set in an anticlockwise direction and the flow is more westerly in the oceanic area. In November the coastal currents move towards north and northwest, while from the equatorial region, the constituents of the east flowing currents join the coastal currents flowing northwest and now flow in the north-northwest direction. From November to January the northward flowing coastal currents bring low salinity water from the Bay of Bengal into the Arabian Sea.

The coastal and oceanic currents are directed northwest during December. A coastal current in the opposite direction is gradually established towards the end of January when the counter clockwise circulation of November to January begins to diminish and the movements of coastal and oceanic water are more oriented towards the west than northwest in January. The clockwise circulation in the Arabian Sea gradually strengthens with a southerly component on the eastern Arabian Sea during March-April. The flow of coastal currents is oriented more towards south and southwest and the predominant flow in the open sea is westerly by the beginning of March when the effect of northeast monsoon diminishes. The strengthening of the south flowing neritic-oceanic surface currents is resulted in April.

With the onset of the southwest monsoon the circulation changes drastically. In April the northeast monsoon currents collapse and in the western Arabian sea the water starts flowing to north along the Somalia coast and by May almost everywhere north of equator the water starts flowing east. During this period along the west coast of India currents are set in a clockwise direction and the resultant flow is predominantly south and parallel to the coast. This circulation is maintained throughout the southwest monsoon period (May to September). In the open sea during this season the current is oriented towards the east.

In October when the transition between southwest and northeast monsoons takes place a definite change in the orientation of the coastal and oceanic currents results and the consequent flow is towards the east and onshore. By November, the phenomenon of turning of the flow is completed and by the strengthening of the northeast monsoon the north and northeast flowing currents are set in.

Two different water masses are formed in the northern Indian Ocean; the high salinity water of the Arabian Sea and low salinity water of the Bay of Bengal (Wyrtiki 1973). The low salinity water of the Bay of Bengal flows during the northeast monsoon along south of Sri Lanka to the west, with one branch continuing westward along the 5°N and the other northwestward along the coast of India, as mentioned earlier.

High salinity surface water is formed by the excess of evaporation in the central and northern Arabian Sea. During the southwest

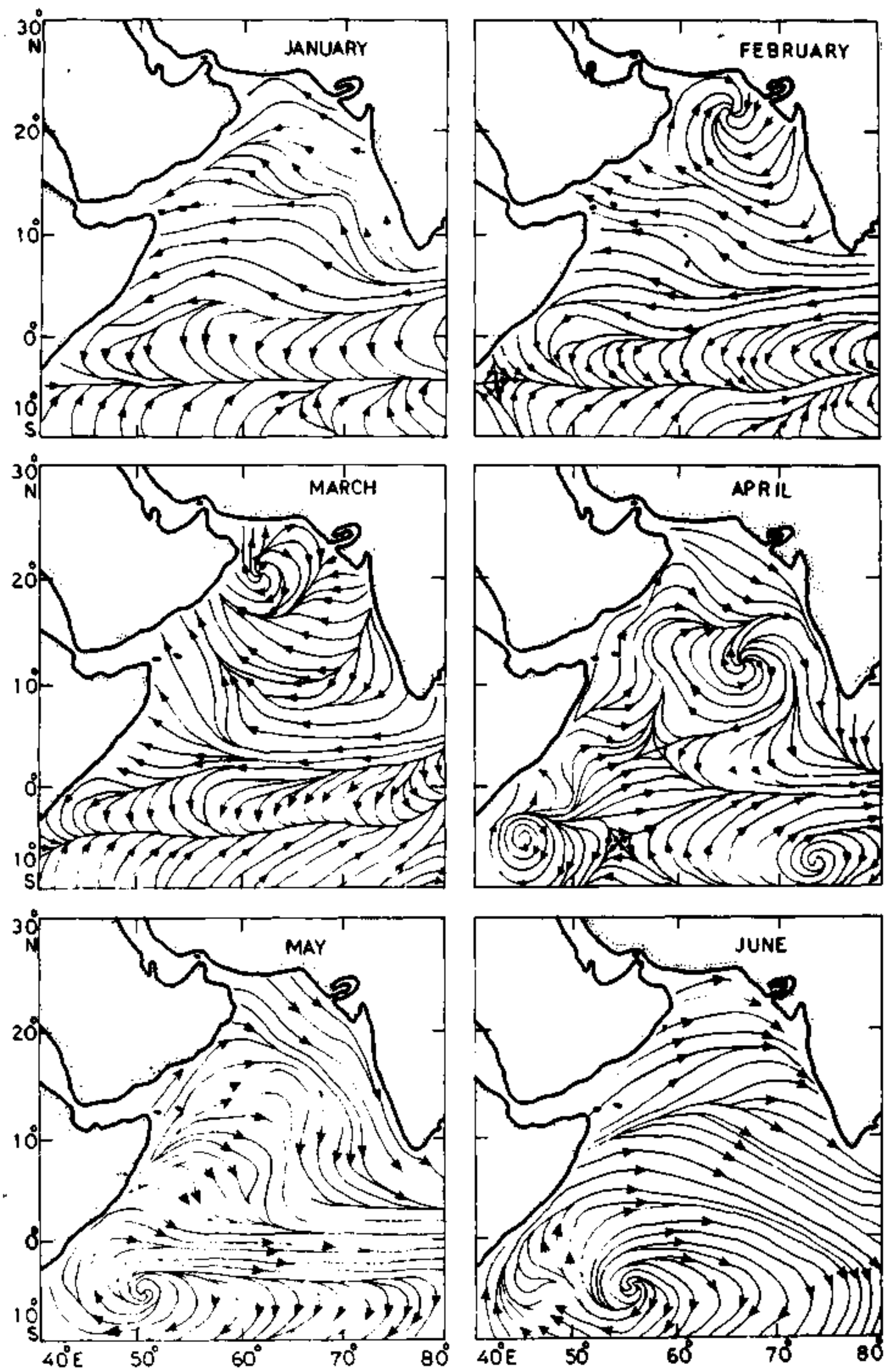

Fig. 2. Monthly pattern of sea surface currents in the Arabian Sea from January to June (after Varadachari and Sharma 1967).

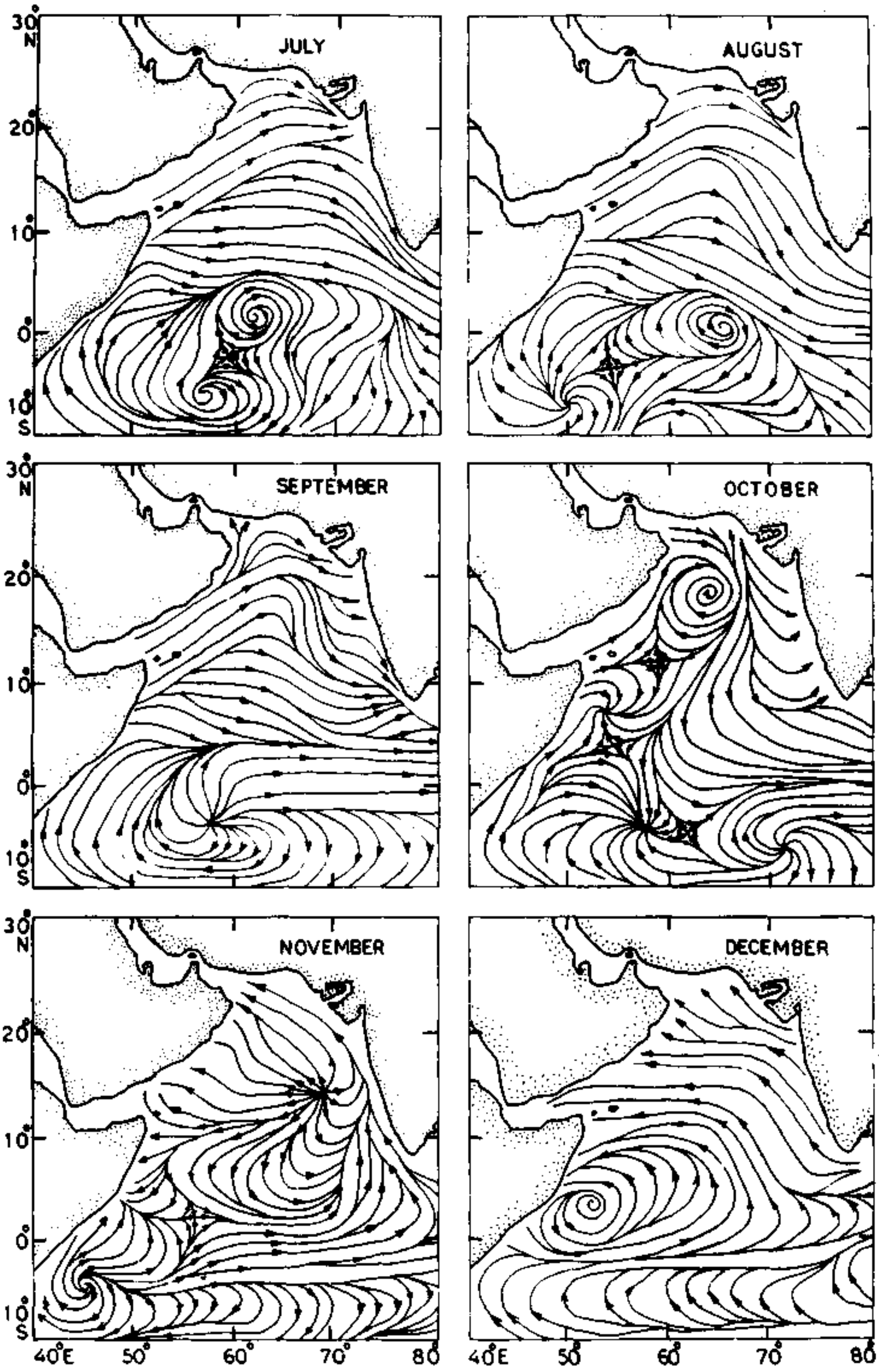

Fig. 3. Monthly pattern of sea surface currents in the Arabian Sea from July to December (after Varadachari and Sharma 1967).

monsoon it spreads southward and then turns east and penetrates with the monsoon current into the region south of Sri Lanka. Some portion of this high salinity water sinks in the Arabian Sea and form a subsurface salinity maximum layer in the upper portions of the thermocline at temperatures between 20° and 22°C. Two other sources of high salinity water, the outflow from the Persian Gulf and from the Red Sea as mentioned earlier further strengthen the intermediate layers of the Arabian Sea. This high salinity water mass formed from three different sources is called the North Indian High Salinity Intermediate Water and occupies a depth range from about 150 to 900 m in the Arabian Sea (Wyrtiki 1973).

The characteristics of the water masses on the shelf have been studied by Drabyshire (1967) according to whom three major water masses are present on the shelf of the west coast of India. The Indian Ocean equatorial water is found at temperatures less than 17°C and is associated with a minimum salinity of 34.9 ‰. This water is present only at deeper levels on the continental slope. The Arabian Sea water is the equatorial surface water which is characterised by a small temperature range between 27 and 30°C and a wide salinity range between 30 and 34 ‰. According to Banse (1968) a third water mass is formed on the shelf at the end of the southwest monsoon period by the mixing of the low salinity surface water and the upwelled water. The subsurface water has a lower salinity than the Arabian seawater and a temperature range covering several degrees down to approximately 20°C.

Sharma (1966) has studied thermocline as an indicator of upwelling in the Arabian Sea. According to him the depth of mixed layer changes from a depth of more than 120 m in January-February to a depth of less than 80 m by March-April. By May-June the mixed layer still moves to upper layers and the least depth of less than 10 m is observed in July-August. From then onwards it starts deepening to a depth of about 40 m by September-October.

The discontinuity layer or thermocline acts as a barrier to the upward and downward movement of water. Banse (1968) has discussed the relation of the discontinuity layer to the vertical distribution of zooplankton. The topography of the thermocline has a seasonal and spatial variation which is closely related to the prevailing monsoon. The changes in the character and level of discontinuity layer are connected directly to the vertical movement of water (upwelling and sinking) which has a bearing on the seasonal distribution of euphausiids.

The more vigorous atmospheric and oceanic circulations during southwest monsoon cause the development of intense upwelling in several places of the Indian Ocean such as off Somalia, off Arabia, southwest coast of India etc. Upwelling in these waters is characterised by the ascent of isolines of one or more parameters such as temperature, density and dissolved oxygen. Panikkar and Jayaraman (1966) reviewed the upwelling along the west coast of India and concluded that it is prevalent along the coast between 7°00' and 18°00'N from August to October.

Sharma (1968) found the upwelling along the west coast of India extending progressively from south to north from February to July-August. This agrees with the observations of Reddy and Sankaranarayanan (1968a, b) for the data on distribution of phosphates and silicates in the upper 200 m.

The process of upwelling is directly controlled by the climatic conditions of a particular region which brings about changes in the hydrographic parameters of the area. Various studies on upwelling showed that there could be considerable variations with regard to the time of beginning and ending, intensity and place of initial incidence of upwelling along the west coast. Banse (1959), Ramasastry and Myrland (1960) and Ramamirtham and Jayaraman (1960) inferred that the upwelling off the west coast of India starts with the onset of the southwest monsoon and lasts until October.

In a study made by Mathew (1982, 1985) along the southwest coast India it was observed that the depth of thermocline was deeper during December-February. It reached the surface layers by August and remained there till the early days of October. Figs. 4 to 10 show the bimonthly behaviour of the vertical profile of temperature along six latitudinal sectors such as (1) 14 45'N, (2) 14°15'N, (3) 13°30'N, (4) 12°45'N, (5) 12°12'N and (6) 11°32'N within the continental shelf area upto 150 m depth. The study showed that the signs of upwelling developed in the deeper layers in February-April first in the southern sectors and this confirmed the findings of Sharma (1968). At the time when intense upwelling was felt in the southern sectors, it was only taking momentum in the northern sectors.

In December of the previous year (Fig. 4) the temperature was almost uniform upto 100 m level in all the sectors and it ranged between 27°C and 29°C only. Below the 100m depth occurred the strata of cold water. In February of the next year (Fig. 5) there was a difference in the temperature distribution particularly in the 5th sector where a strong vertical gradient was found between 50 and 120 m. This change probably indicated the beginning of the reversal of the current in this sector. The occurrence of the reversal of the current during February in the eastern Arabian Sea has been pointed out by Varadachari and Sharma (1967). A thorough change in the vertical profile of temperature was observed in April (Fig. 6). It was obvious that the thermocline depth decreased very much particularly in the southern region. This indicated the moving up of the sub-surface water to the surface after February. A further upward movement of the thermocline was evident in June (Fig. 7). The vertical profile of temperature in this month indicates the incidence of upwelling in the south and its gradual movement to the north as time passed on. In this month intense upwelling was noticed in the 4th and the 5th sectors where the level of cold water was at about 40 m.

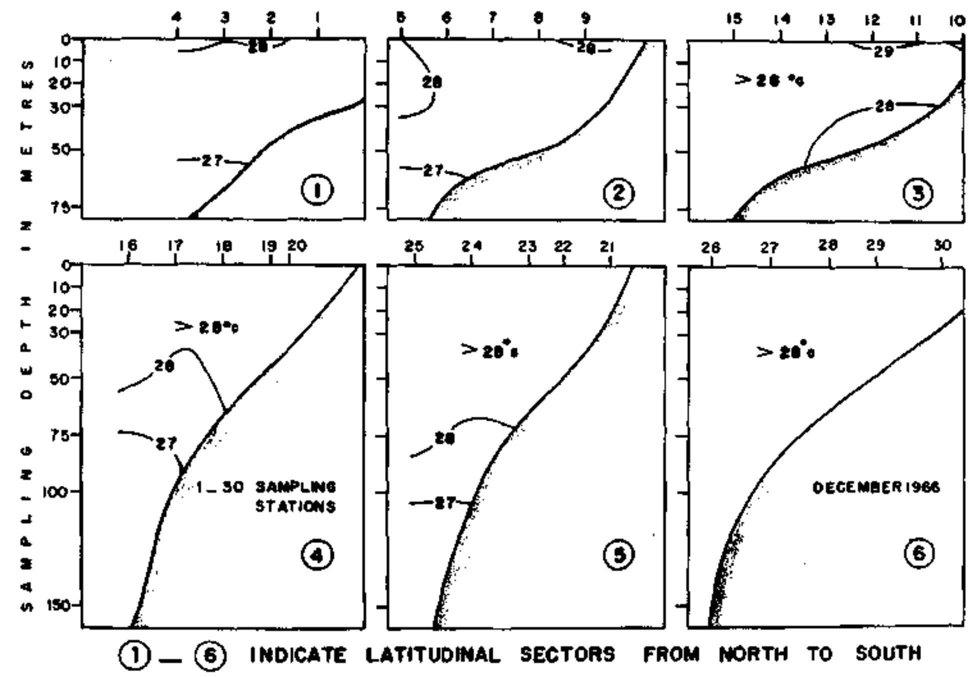

Fig. 4. Pattern of coastal upwelling along the southwest coast of India during December 1966 (after Mathew 1985).

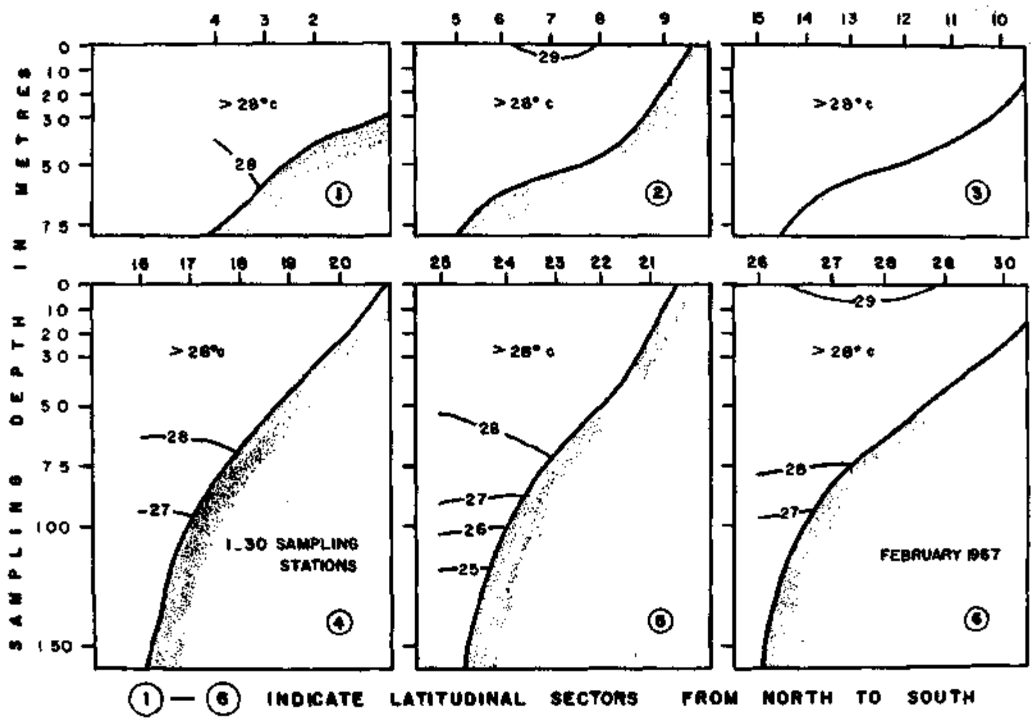

Fig. 5. Pattern of coastal upwelling along the southwest coast of India during February 1967 (after Mathew 1985).

A closer examination of the distribution of temperature between August and October indicates that there was mass re-adjustment in all the sectors which is obvious from the change in the orientation of isotherms between these two months. In August (Fig. 8) the process of upwelling continued. In the southernmost sector, the colder water having temperature around 23°C was found even at 15 m level. In this month the temperature in the surface layers in all except the northernmost sector indicated a decrease. In the month of October (Fig. 9) while sinking was indicated in the southern sectors the cool water remained in the surface layers in the northern sectors. The distribution of temperature in October (Fig. 9) and December (Fig.10) conclusively proved that the surface water moved to a depth of 75 m from October to December.

The water circulation, upwelling and sinking in the Arabian Sea have profound influence on the distribution, abundance and seasonal variations of different species of euphausiids and the same are discussed in detail in the ensuing chapters.

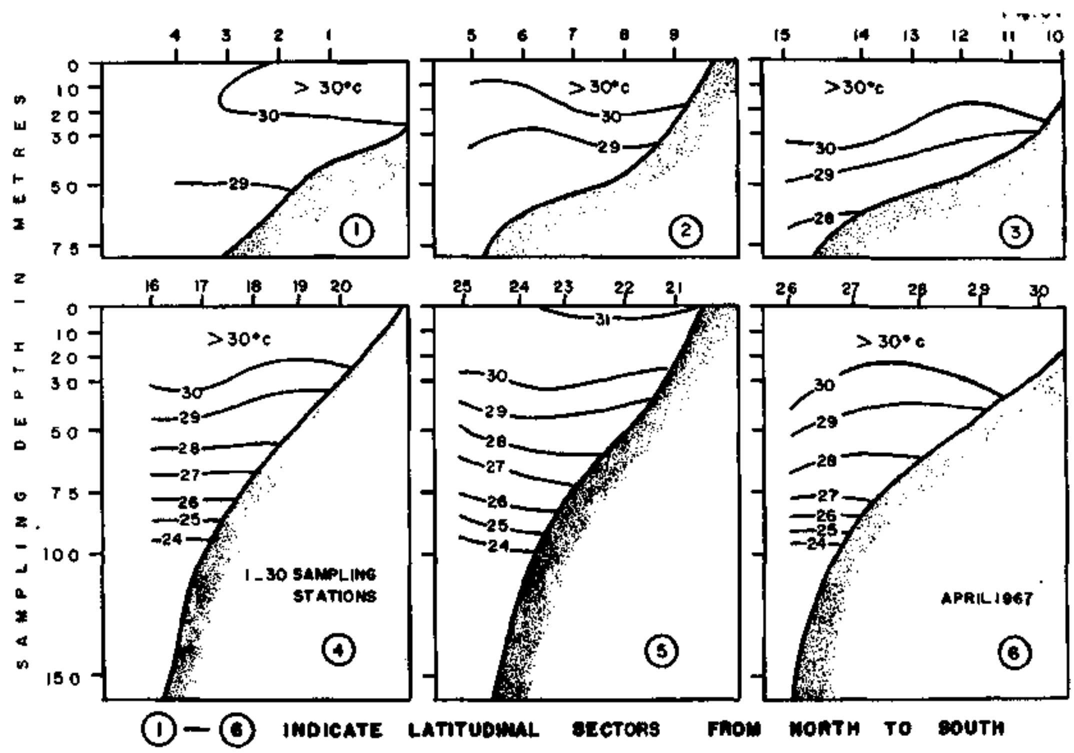

Fig. 6. Pattern of coastal upwelling along the southwest coast of India during April 1967 (after Mathew 1985).

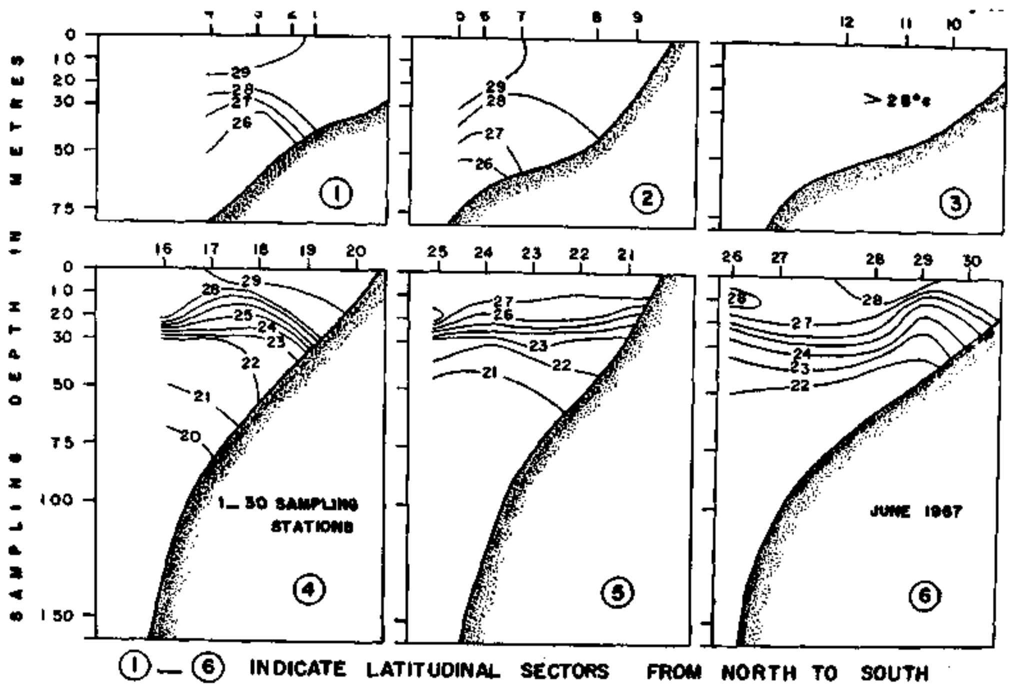

Fig. 7. Pattern of coastal upwelling along the southwest coast of India during June 1967 (after Mathew 1985).

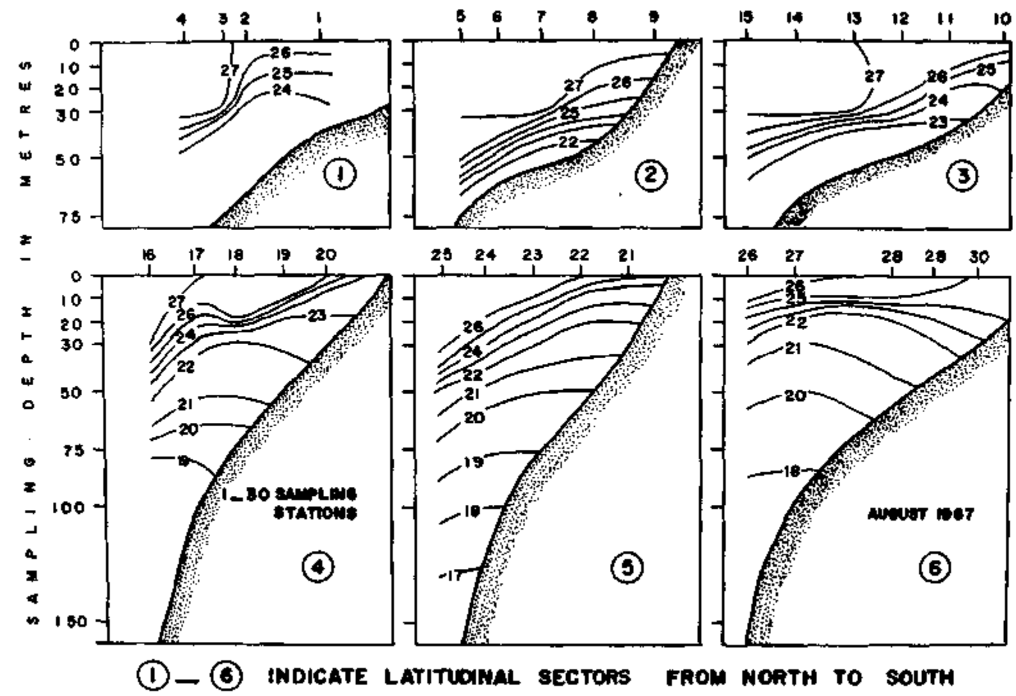

Fig. 8. Pattern of coastal upwelling along the southwest coast of India during August 1967 (after Mathew 1985).

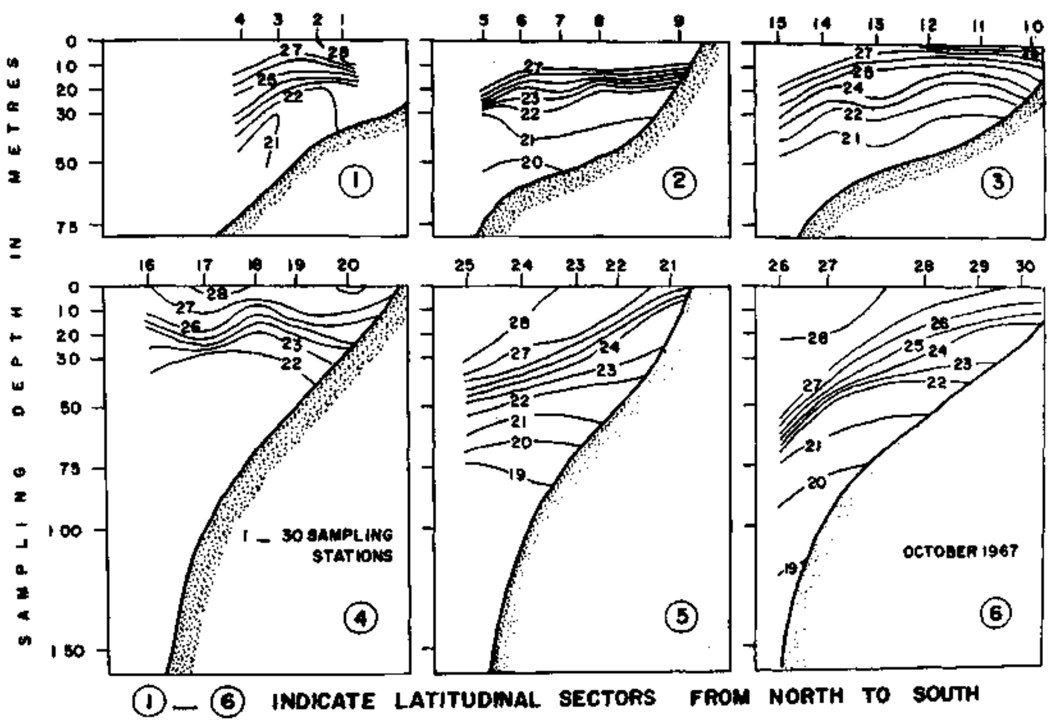

Fig. 9. Pattern of coastal upwelling along the southwest coast of India during October 1967 (after Mathew 1985).

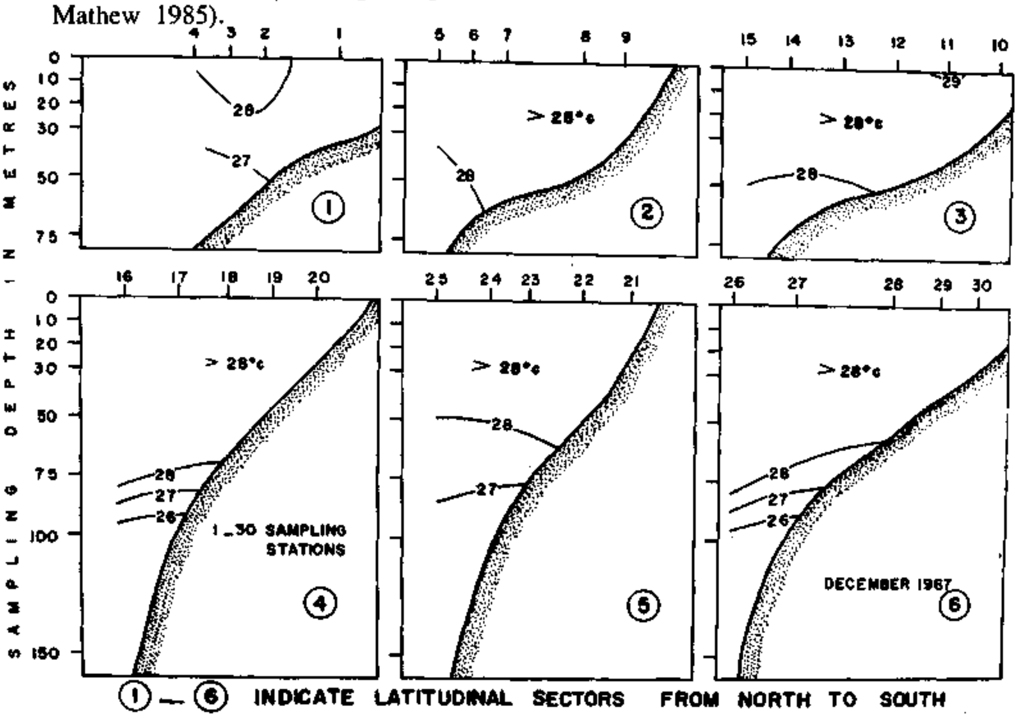

Fig. 10. Pattern of coastal upwelling along the southwest coast of India during December 1967 (after Mathew 1985').

3

SPATIAL DISTRIBUTION OF EUPHAUSIIDS

Gopalakrishnan and Brinton (1969) 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 the species pass through similar developmental stages and as the younger stages of most species 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 this point is concerned with the appendages that function in feeding, based on which the genera are distinguished. 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 zone. Therefore, they concluded that euphausiids constitute an ecological entity in a broad sense. Keeping in view of the above reasons, the euphausiids as a whole are considered in the present studies apart from a specieswise treatment given for all the parameters.

Euphausiids in general

The euphausiids as a group were found widely and abundantly distributed in the present study area comprising the Arabian Sea part of the EEZ (Fig. 11). Their average numerical density in the epipelagic zone (0 to 150 m) was estimated at 3,170 per 1000m^3 of water filtered. (All the numerical values mentioned hereafter will be number per 1000 m3 of water filtered by the sampling net). In a preliminary study made by Mathew *et al.* (1990) the average density of euphausiids in the same area was estimated as 3,680 which is higher than the present value . (This higher value might have crept in by error on the mistaken identity of the earlier larval stages of euphausiids with that of sergestids and decapod larvae while sorting the zooplankton taxa). However, the present value is highly comparable with the average values obtained for any other sea areas. Gopalakrishnan and Brinton (1969) estimated the euphausiid abundance in the range of 2,500 to 4,000 for the area north of the equator in the Indian Ocean and more than 1,000 for the major part of the Indian Ocean. Ponomareva (1966) estimated the euphausiid density for the entire Pacific Ocean and found that majority of the areas comprising the tropics and the subtropics contained euphausiids at the rate of 100-500. However, Gopalakrishnan and Brinton (1969) and Mauchline and Fisher (1969) are of the opinion that the estimates of Ponomareva are very conservative. They are of the opinion that the 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 for the Pacific. Such a situation of high euphausiid production is but normal for the tropical Indian Ocean including the Arabian Sea where certain dynamic environmental forces operate simultaneously which favour high production at the various levels. These include, the bimonthly reversal of the surface currents transporting nutrient rich water from the Gulf areas, formation of water masses from different sources that occupy different depth zones encouraging production and the intense upwelling in some areas which bring up nutrient rich water to the euphotic zone.

In the present investigation the euphausiids were taken from all the stations sampled irrespective of localities or seasons. They were especially abundant south of 15°N latitude, the area encompassing the Lakshadweep waters. The Lakshadweep waters which otherwise would have remained low in productivity due to the poor mixing between surface and deeper water on account of the prevailing strong tropical thermocline are always rich in biological components of all kinds because of the coral lagoons which support very high productivity at the primary level. The outgoing nutrient rich water from the lagoons during low tides enrich the open sea where high rate of production results at all levels. This is true of euphausiids also.

The highest number of euphausiids ever obtained from a single station was 42,603 per $1000m^3$ of water which was from an oceanic station sampled during the night in November off the west of Minicoy Island. Localities of very high density beyond 10,000 were mostly outside the continental shelf edge. Out of the 30 stations which yielded more than 10,000 per 1000 m^3 of water, 10 stations were from the Lakshadweep Sea.

The euphausiids were especially abundant within and outside the Wadge Bank off Kanyakumari an area both biologically and ecologically significant for being the confluence of the Arabian Sea, the Bay of Bengal and the Indian Ocean. Thus the second locality of high euphausiid abundance was the Wadge Bank area south of Kanyakumari in the continental shelf where they occurred at the rate of 37,042 in July. Seven stations in this area contributed to more than 10,000 euphausiids per 1000 m^3 of water.

In the rest of the area studied, the euphausiids often aggregated especially within the continental shelf area. Areas of such high concentrations were noticed off Kandla, Mumbai, Ratnagiri, Goa and between Mangalore and Cochin.

The euphausiids being a highly schooling group of organisms, some of the dominant species especially the epipelagic species namely *Pseudeuphausia latifrons*, *Euphausia diomedeae*, *E. sibogae*, *Nematoscelis gracilis*, *Stylocheiron armatum* and *S. affine*

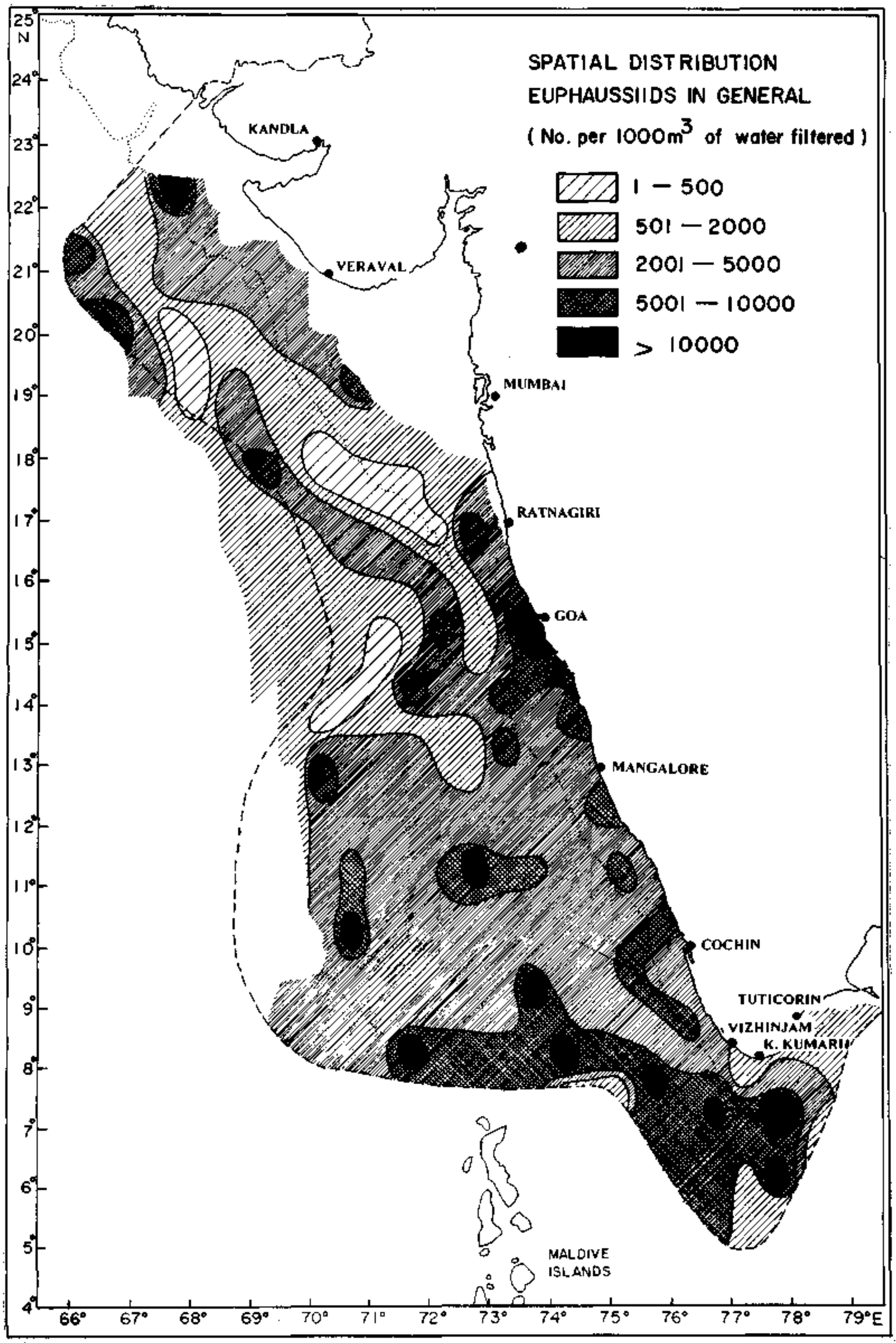

Fig. 11. Spatial distribution of total euphausiids in the EEZ of the west coast of India.

can occur in heavy concentrations and this is the main reason for the presence of very high numbers in certain localities.

***Thysanopoda monacantha* Ortmann 1893** (Fig. 12)

Out of the 493 samples analysed from the study area 150 contained this species of which 39 samples were from north of 10°N. One sample from 15°40'N72°00'E west of Goa contained this species and this was the northern most point of record ever made for *T.monacantha* in the Arabian Sea. The species was represented mostly by larvae and juveniles.

This oceanic mesopelagic species inhabiting between 140 and 1,000 m depths is widely and abundantly distributed in the Arabian sea south of 15°N (Fig. 13). However, being large in size its adult specimens are seldom caught in the standard zooplankton nets and hence a correct evaluation of its population density is not possible unless data are available from different types of gears.

The maximum density at which the species occurred was 615 west of Minicoy Island. The species occurred in fairly good numbers (>200/1000 m^3) at 8 stations around Minicoy and between 100 and 200 at 24 stations again in the Lakshadweep waters. Apart from the Lakshadweep waters high abundance of *T. monacantha* was noticed southwest of Wadge Bank away from the shelf area. The two instances of its larvae entering the shelf area was at 12°00'N 74°34'E at a station with 87 m depth and at 11°01'N 75°27'E where the depth was just 50 m.

According to Brinton and Gopalakrishnan (1973) the southern limit of this species in the Arabian Sea is along the 10°N parallel which forms an effective barrier for many of the oceanic species, the quality of water north of 10°N being "brackish" due to the

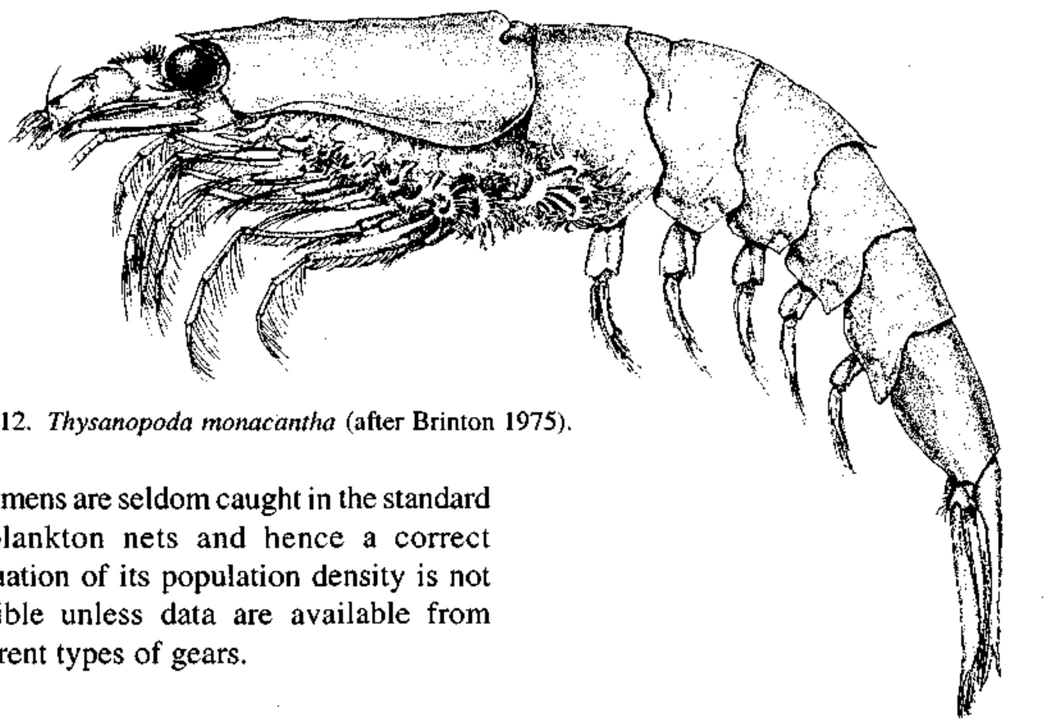

Fig. 12. *Thysanopoda monacantha* (after Brinton 1975).

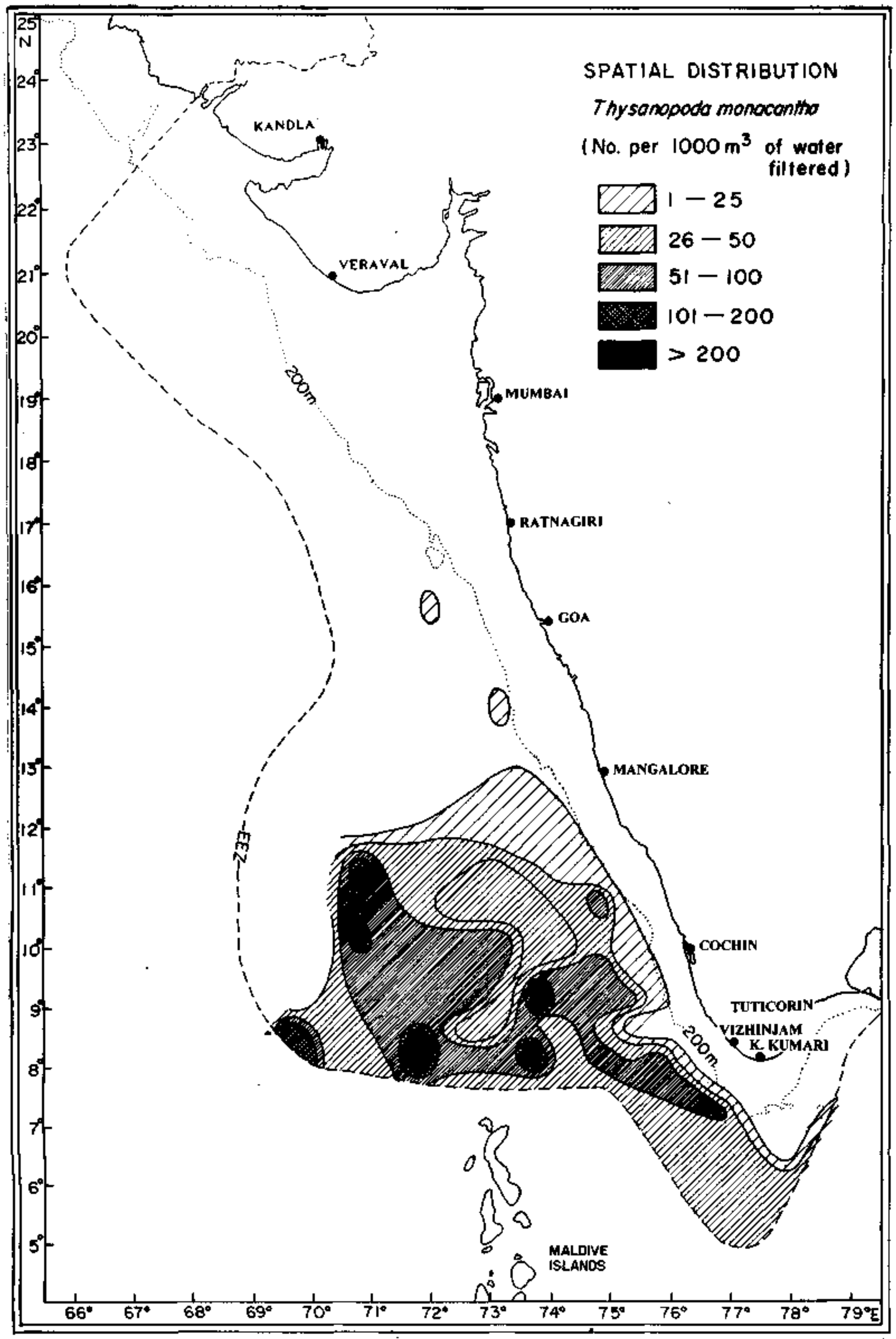

Fig. 13. Spatial distribution of *Thysanopoda monacantha* in the EEZ of the west coast of India.

land run off and the enclosed northern boundary.

T. monacantha has been recorded by several authors from different parts of the Indian Ocean. Some of the records relevant from the Arabian Sea and contiguous areas are worth mentioning. Tattersall (1939) who worked on material collected during the *John Murray Expedition* found this species distributed in a number of localities in the Central Arabian Sea and the Maldive areas. Ponomareva *et al.* (1962) observed it in the Central and Southern Arabian Sea and also south of Sri Lanka. Ponomareva (1964) recorded it again in the Arabian Sea. Gopalakrishnan and Brinton (1969) found *T. monacantha* sparsely distributed at 59 locations in the equatorial waters. Sebastian (1966) reported this species from the southwest coast of India, Lakshadweep and Maldive seas. Weighman (1970) also recorded the species in the Arabian Sea. Mathew (1982) extended the northern limit of *T. monacantha* to 13°23'N.

According to Brinton and Gopalakrishnan (1973) *T. monacantha* is scarce in the Arabian Sea. However, this is not altogether correct. The reason for not obtaining this species in abundance was that (1) the net used by them i.e. The Indian Ocean Standard Net with a mesh size of 0.33 mm was not efficient enough to capture the adults of such large species and (2) their sampling depth of 200 to surface was mostly devoid of this species. Adults of *T .monacantha* were widely and frequently caught by Mathew (1980e, 1982) and Silas and Mathew (1986) with the large meshed Issac Kid Midwater Trawl from the oceanic waters of the southwest coast of India. The adults of this species were taken at a maximum rate of 1,830 specimens per one hour trawling from the Lakshadweep waters.

***Thysanopoda tricuspidata* Milne-Edwards 1837** (Fig. 14)

As in the case of *T. monacantha* the distribution is mainly by larvae and juveniles

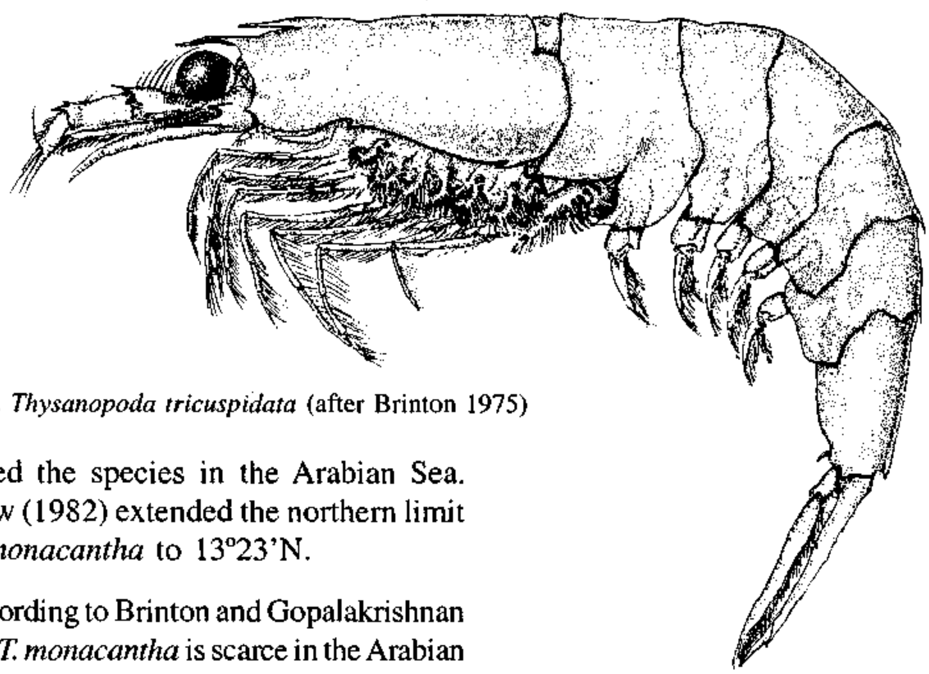

Fig. 14. *Thysanopoda tricuspidata* (after Brinton 1975)

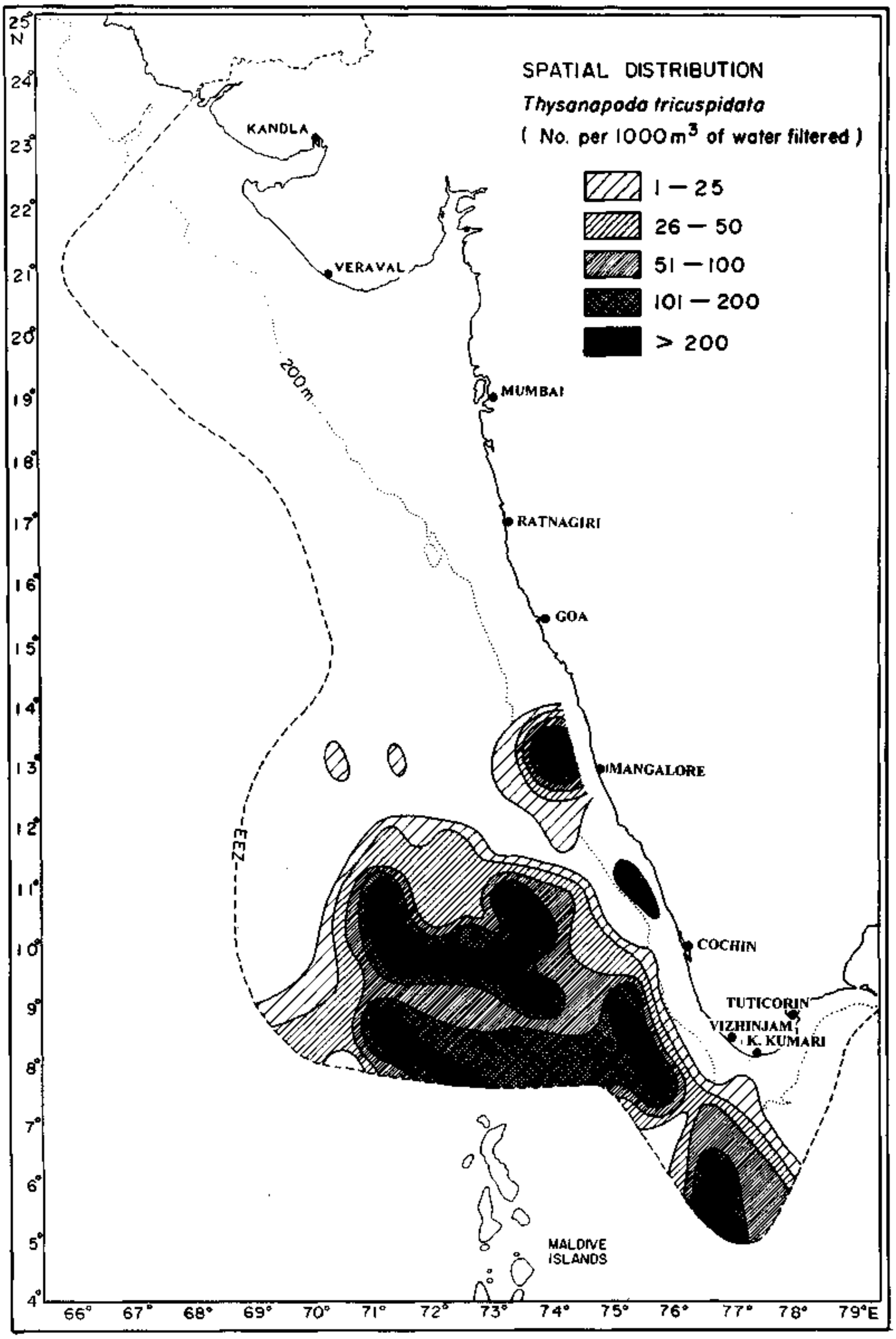

Fig. 15. Spatial distribution of *Thysanopoda tricuspidata* in the EEZ of the west coast of India.

for this large species, although it is also a widely occurring species in the oceanic waters in the tropics and subtropics of the world oceans from surface to 280 m depth. They were strictly confined to the southern parts of the present study area. They have been recorded upto 14°N (Fig. 15). *T. tricuspidata* was especially abundant in the Lakshadweep waters and south of the Wadge Bank. In the shelf area, pockets of high density were observed north of Mangalore (@ 509/1000 m^3) and between Cochin and Calicut (ca. 200/1000 m^3). The highest number ever obtained was 1,066 per 1000 m^3 of water from 08°58'N 75°00'E. Out of the 142 positive samples 34 contained this species at a rate of more than 200 per 1000 m^3 of water.

Tattersall (1912) collected *T. tricuspidata* from the northwestern Indian Ocean during the *Sea Lark* Expedition. Illig (1930) obtained it from the equatorial Indian Ocean during the *Valdivia* Expedition. The *John Murray* Expedition (Tattersall 1939) got one immature specimen from the Central Arabian Sea. Another Arabian Sea record was by Ponomareva (1964). Though in very few numbers *T. tricuspidata* was observed widely distributed in the area investigated by Sebastian (1966) off the southwest coast of India. Gopalakrishnan and Brinton (1969) found it to be one of the most abundant species in the equatorial Indian Ocean.

The north-south range of distribution of *T. tricuspidata* in the Indian Ocean according to Brinton and Gopalakrishnan (1973) is between 10°N and 25°S. However, Mathew (1980e, 1982) and Silas and Mathew (1986) extended the northern boundary of this species in the Arabian Sea upto 16°06'N which was farther than any of the earlier records including the present study.

Thysanopoda astylata Brinton 1975 (Fig.16)

This Indo-Pacific epipelagic species occurs from surface to 700 m depth in the central part of these oceans. It was originally described by Brinton (1975) partly based on *T. aequalis* described by Boden (1954). According to Brinton (1975) *T. astylata* ranges in the Indian Ocean between 10°N and 5°S while *T. aequalis* is distributed south of equator upto 35°S thereby indicating a

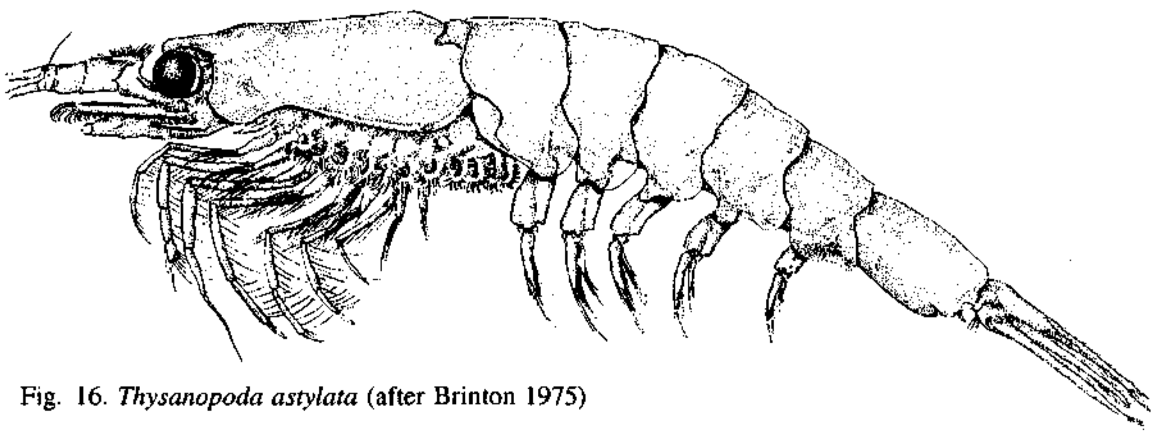

Fig. 16. *Thysanopoda astylata* (after Brinton 1975)

little overlapping in distribution in the tropics. The material from the present study area is more akin to *T. astylata*.

In the present studies the geographic distribution of this sparsely occurring species was confined to areas south of 10°30'N (Fig. 40). This purely oceanic species never intruded into the shelf waters. Its major areas of distribution were in the southern part of the Lakshadweep Sea especially around the Minicoy Island. A population density as high as 95 per 1000 m^3 of water was found west of Minicoy. In most of the localities the number never exceeded 25 per 1000 $m^3$of water.

Assuming that all the earlier records of *T. aequalis* north of equator were that of *T. astylata* the records of this species in the Arabian Sea are as follows:

Tattersall found this species in the tropical Indian Ocean (1912) and in the Arabian Sea (1939). Illig (1930) obtained a few specimens from the northwestern Indian Ocean. Weigmann (1970) recorded it in the Arabian Sea. Other records include Sebastian (1966) from Lakshadweep and Maldive seas, Ponomareva (1964) and Ponomareva *et al.* (1962) from the Central Arabian Sea, Gopalakrishnan and Brinton (1969) from the equatorial Indian Ocean and Brinton and Gopalakrishnan (1973) from the equatorial and northern Indian Ocean. Mathew (1980e, 1982) Silas and Mathew (1986) found it to be a very rare species confined to the oceanic area. Its northernmost limit as found by him reached a little north of 10°N.

***Pseudeuphausia latifrons* (G.O. Sars 1883) (Fig.17)**

During the present investigation *P. latifrons* was represented in the EEZ from 06°N to 22°00'N (Fig. 18). Being a coastal species high density areas were observed mostly within the continental shelf especially towards the southern part. Areas of concentration were occasionally noticed beyond shelf waters also. The species was fairly abundant between 18°N and 22°N and between 07°N and 13°N. In the intermediate region between 13°N and 18°N *P. latifrons* was sparsely distributed with

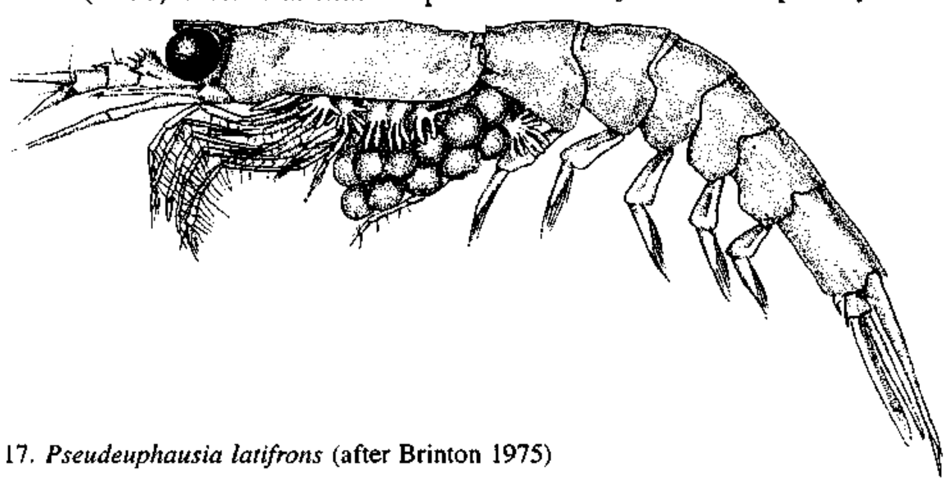

Fig. 17. *Pseudeuphausia latifrons* (after Brinton 1975)

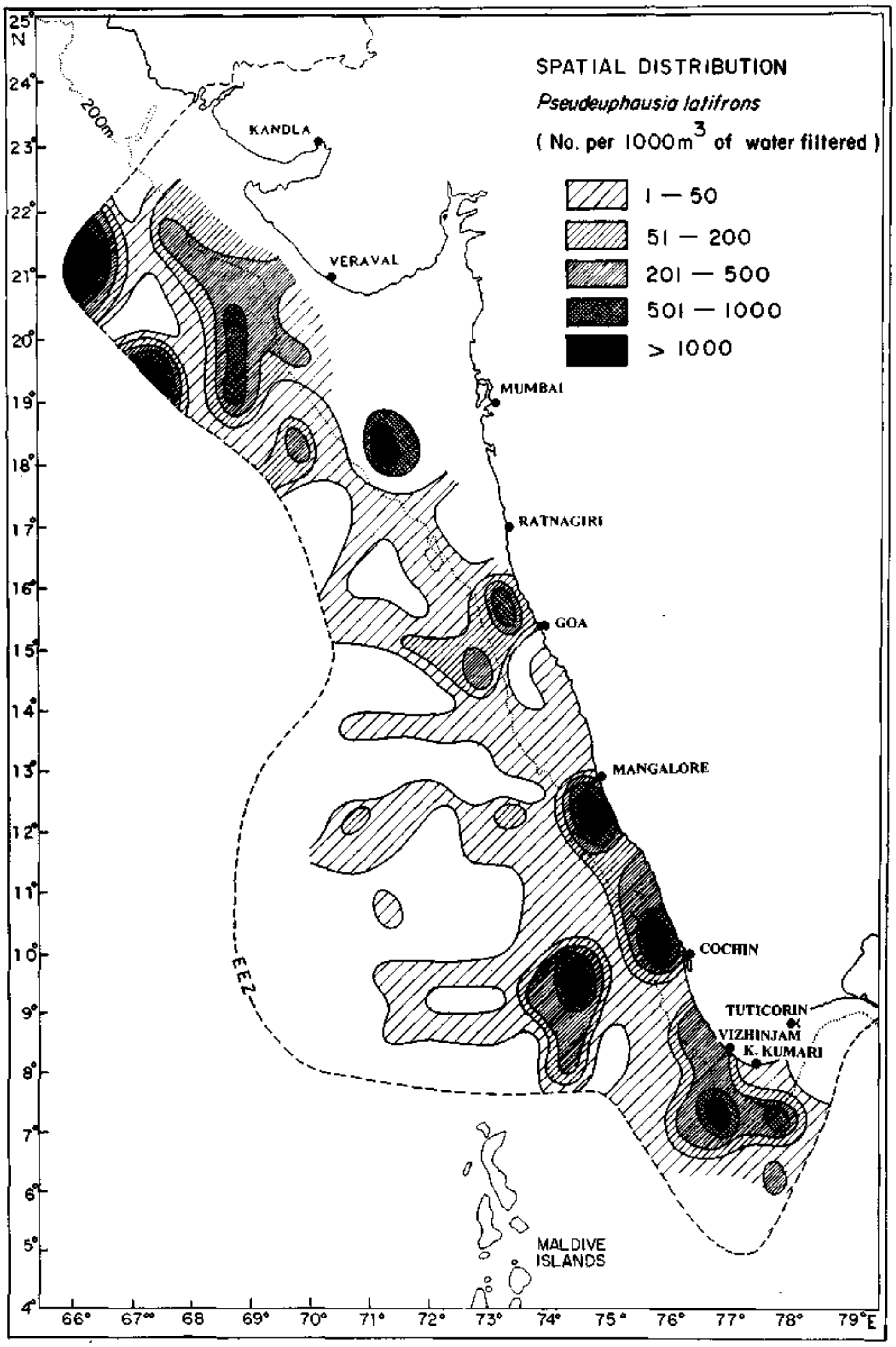

Fig. 18. Spatial distribution of *Pseudeuphausia latifrons* in the EEZ of the west coast of India.

some areas of nil occurrence. Pockets of high density beyond 1,000 per 1000 m^3 of water were found west of Veraval beyond the shelf, within and outside shelf, west and southwest of Mumbai, off Mangalore and Cochin, in the nearshore waters northeast of Minicoy and southwest of Kanyakumari. The species was sparsely distributed or even absent in most part of Lakshadweep oceanic waters though it is known to inhabit around oceanic islands. It was rarely found in the outskirts of the EEZ.

Out of the 493 samples examined this species was present in 200 samples. The numerical abundance of *P. latifrons* varied from 4 to 9,441 per 1000 m^3 of water and the highest was taken from 09°30'N 74°20'E northeast of Minicoy in the early morning in April. Among the total euphausiids *P. latifrons* ranked fourth in abundance with an average density of 258 per 1000 m 3 of water.

Tattersall (1906) was the first to record *P. latifrons* in the Indian Ocean. She obtained it from between Socotra and Lakshadweep Islands, off Galle, off Mutwall and north of Chilaw. During the *Percy Sladen Trust* Expedition (Tattersall 1912) this was encountered off Nazarath Bank. During the *John Murray* Expedition it occurred in the northern Arabian Sea (Tattersall 1939). Pillai (1957) and Sebastian (1966) obtained it from the southwest coast of India. Ponomareva (1964) recorded it in the Arabian Sea. According to Weighmann (1970) it is an abundant species in the Arabian Sea. Brinton and Gopalakrishnan (1973) observed it to be the more abundant euphausiid around the Lakshadweep Islands.

Mathew (1980e, 1982) and Silas and Mathew (1986) found *P. latifrons* to be the third abundant species in the shelf waters of the southwest coast of India where it enjoyed a widespread distribution and also very close to the coast. In the oceanic realm they found the species restricted to the continental slope and nearer to the islands.

Euphausia diomedeae Ortmann 1894 (Fig.19)

This equatorial epipelagic species occurring upto 700 m depth was the second abundant species in the study area . It was present in more than 400 stations (Fig. 20). The average density of the species in the study area amounted to 1,256 per 1000m^3 of water which accounted to 39.65 % of the total euphausiid material obtained. The species was especially abundant south of 14° N. Large concentrations occurred in the Lakshadweep waters and also south of the Wadge Bank. The highest number of 38,622 per 1000 m^3 of water was recorded in the Lakshadweep Sea west of Minicoy at 08°30'N 71°30'E. Specimens above 10,000 occurred at three localities. Pockets of high population density were present between Goa and Mangalore in the shelf area, at several locations in the Lakshadweep Sea and south and west of the Wadge Bank. Patches of high abundance were found in the northern latitudes also.

E. diomedeae is a characteristic and dominant species in the equatorial Pacific also (Brinton 1962). However, most of the distributional records of this species are from the Indian Ocean. Illig (1930) recorded it

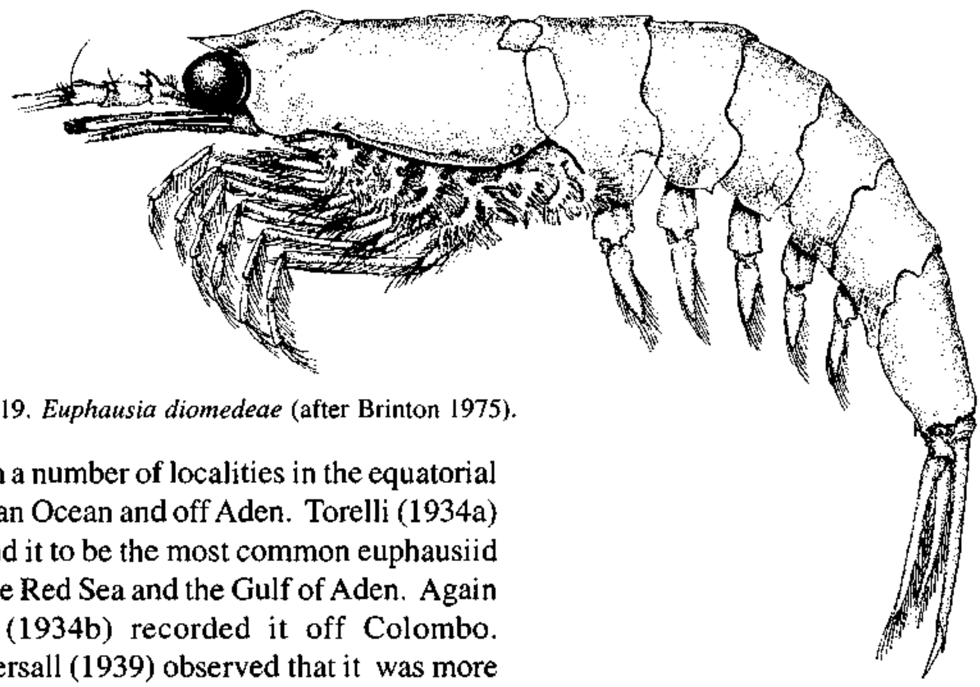

Fig. 19. *Euphausia diomedeae* (after Brinton 1975).

from a number of localities in the equatorial Indian Ocean and off Aden. Torelli (1934a) found it to be the most common euphausiid in the Red Sea and the Gulf of Aden. Again she (1934b) recorded it off Colombo. Tattersall (1939) observed that it was more concentrated in the north and the central Arabian Sea and the Gulfs of Aden and Oman. In 1962 Ponomareva *et al.* reported *E. diomedeae* from the central and western Arabian Sea and the Gulf of Oman. It was present in the Arabian Sea as found by Ponomareva (1964) during the cruises of R.V. *Vityaz*. Sebastian (1966) reported it to be the most abundant species along the southwest coast of India, the Lakshadweep and the Maldive Seas. As found by Gopalakrishnan and Brinton (1969) *E. diomedeae* was one of the most characteristic species in the equatorial Indian Ocean. It was found to be widely distributed in the full tropical belt of the Indian Ocean (Brinton and Gopalakrishnan 1973). Mathew (1980e, 1982) and Silas and Mathew (1986) observed only a relatively smaller population in the shelf waters mostly represented by larvae and juveniles. However, the found the species to be widely and abundantly distributed in the oceanic waters.

Euphausia sibogae Hansen 1908 (Fig.21)

Being categorised as an equatorial epipelagic species found from surface to 280 m depth, *E. sibogae* is the most abundantly occurring euphausiid in the epipelagic zone of the Arabian Sea. Out of the 493 samples analysed during the present study, *E. sibogae* was present in 455 samples. This species very often occur in large schools of high population density (Fig. 22). At the various stations their number frequently exceeded 5,000 per 1000 m^3 of water. The species occurred in the entire area of study from 05°30'N to 22°30'N and was especially abundant in the continental slope and oceanic areas. The density of the population was

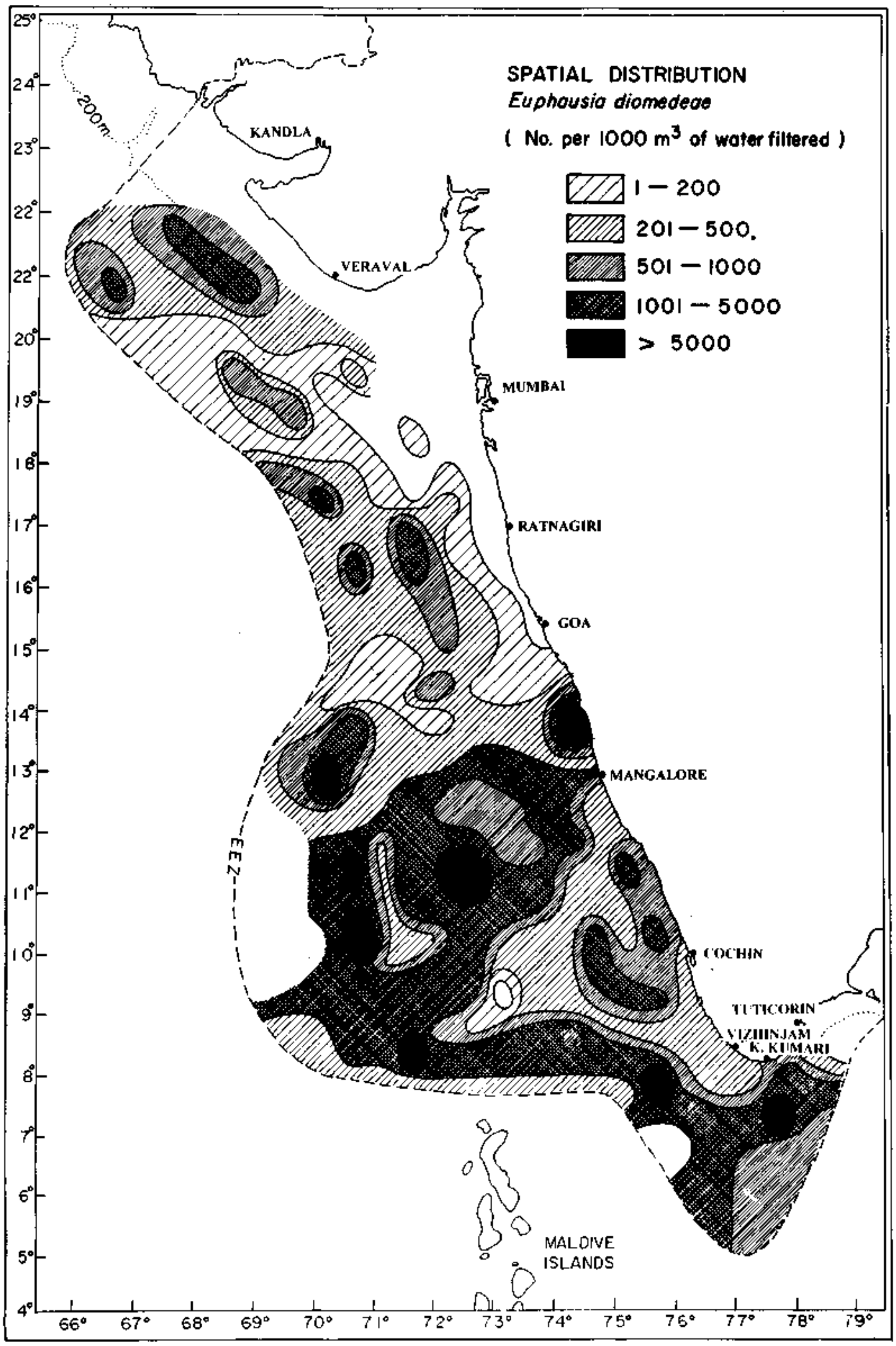

Fig. 20. Spatial distribution of *Euphausia diomedeae* in the EEZ of the west coast of India.

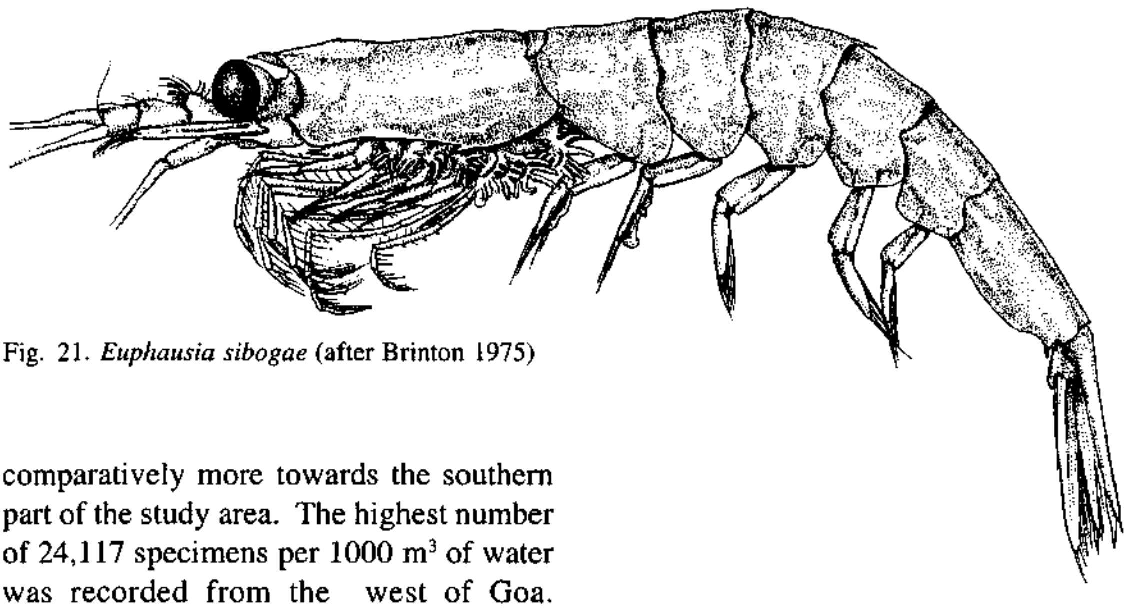

Fig. 21. *Euphausia sibogae* (after Brinton 1975)

comparatively more towards the southern part of the study area. The highest number of 24,117 specimens per 1000 m^3 of water was recorded from the west of Goa. Specimens of more than 10,000 were taken from 16 locations along the west coast. The species was moderately distributed in the Lakshdweep waters. Pockets of high density above 5,000 were found west of Kandla, southwest of Goa, between Mangalore and Cochin and west of Kanyakumari, all within the continental shelf. High population density was noticed also south of Wadge Bank in the oceanic waters. On the whole this is the most successful species in the EEZ of the west coast of India with an average density of 1,437 per 1000 m3 of water and is the most characteristic species of the Arabian Sea.

The material considered here as *E. sibogae* was reported by all the previous authors as *E. distinguenda*. However, Mathew (1982) who observed some clear variations in the morphological features of the Arabian Sea material made a thorough comparative study between the two species and concluded that the populations in the Arabian Sea belonged to *E. sibogae*. Hence all the previous records from the Arabian Sea in the name of *E. distinguenda* are considered here as *E. sibogae*.

Eventhough the *Valdivia* Expedition (Illig 1930) could not collect large numbers of this species from the Arabian Sea the *John Murray* Expedition (Tattersall 1939) found it to be the most abundant species there. Sebastian (1966) collected this species in large numbers from the southwest coast of India. Gopalakrishnan and Brinton (1969) found it in samples collected from the equatorial Indian Ocean. Weighman (1970) recorded it in the Arabian Sea. Brinton and Gopalakrishnan (1973) found this species to be widespread in the Arabian Sea. According to Mathew (1980e, 1982) and Silas and Mathew (1986) *E. sibogae* was by far the most commonest and most abundant species in the shelf waters of the southwest coast of India but in low density in the Lakshadweep area.

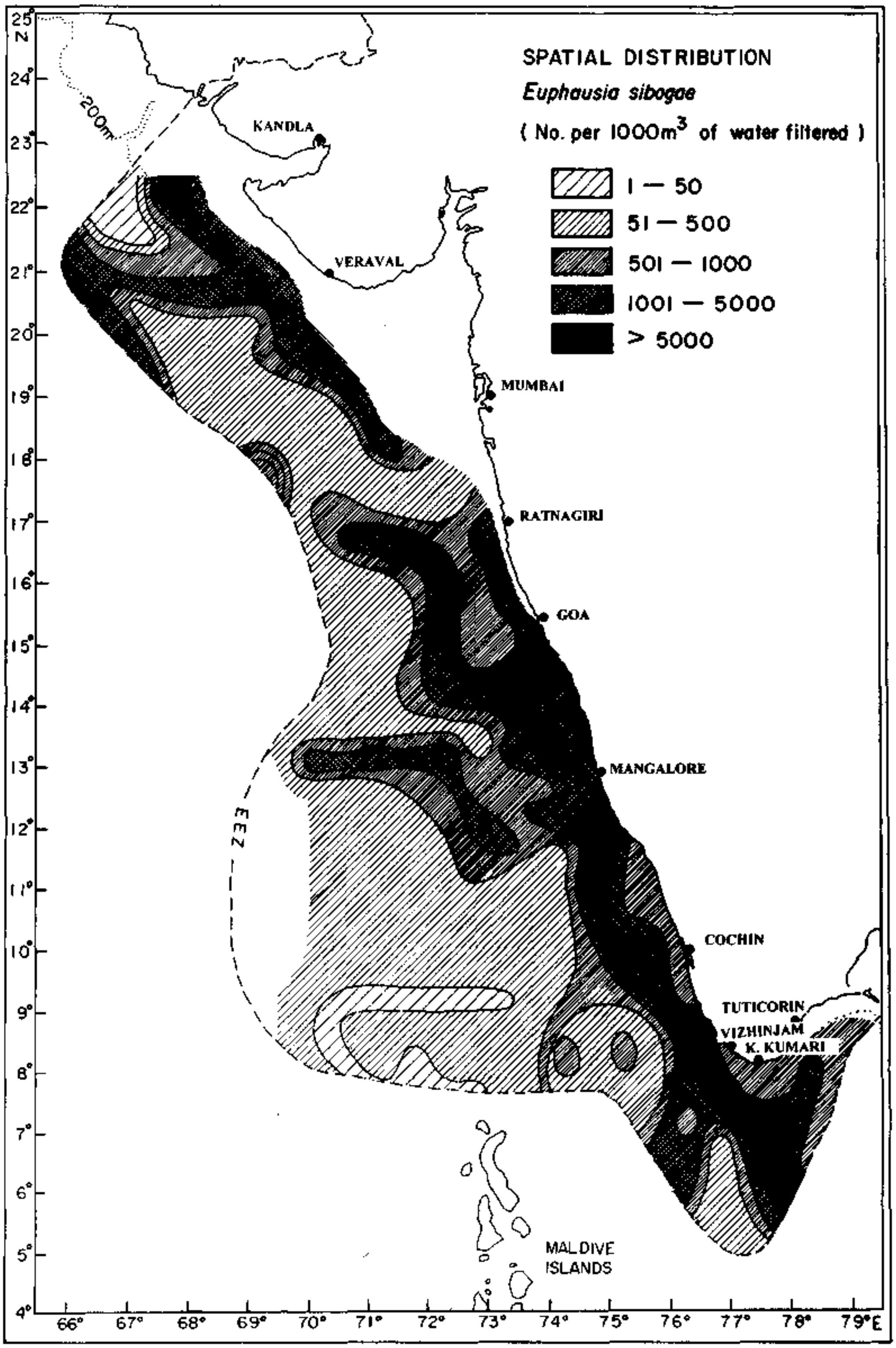

Fig. 22. Spatial distribution of *Euphausia sibogae* in the EEZ of the west coast of India.

Euphausia tenera Hansen 1905 (Fig.23)

This epipelagic species usually occupying a vertical column of 0-280 m (Brinton 1962) was rather widespread in areas south of 13° N only (Fig. 24). They were found strictly confined to oceanic waters beyond the continental shelf. High density areas were observed south of Wadge Bank, west of Minicoy and west of Mangalore. It was moderately abundant in the Lakshadweep waters. The average population density amounted to 119 per 1000 $m^3$of water. The population ranged between 11 and 849 per 1000 m^3 of water at the various locations.

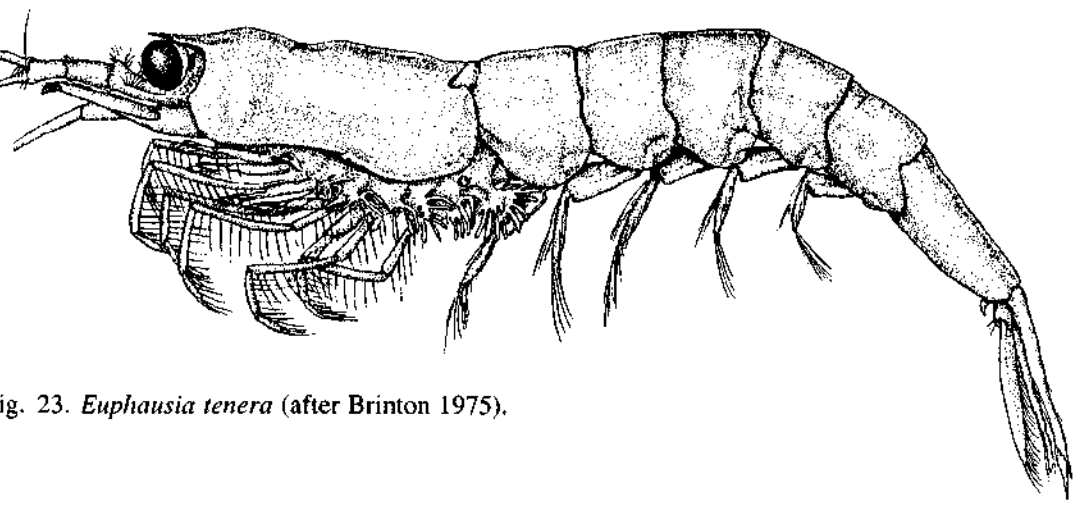

Fig. 23. *Euphausia tenera* (after Brinton 1975).

This warm water epipelagic species is fairly well distributed in the tropical and subtropical parts of the Indian Ocean. Tattersall (1912) was the first to record *E. tenera* from the Indian Ocean at places around Chagos, Mauritius, Tranqubar, Providence and Alphones islands. Illig (1930) recorded the species at 24 stations distributed over a wide geographical range in the eastern and south western Indian Ocean. In 1939 Tattersall found it in the central and southern Arabian Sea and the Maldive areas. Ponomareva (1964) collected the species from the Arabian Sea. Sebastian (1966) recorded *E. tenera* in small numbers from the southwest coast of India and the neighbouring waters. It was present in all the 94 samples collected from the equatorial Indian Ocean between 5°N and 5°S during the *Luciad* Expedition and hence the most abundant species according to Gopalakrishnan and Brinton (1969). The northernmost limit for this species in the Arabian Sea as observed by Brinton and Gopalakrishnan (1973) was 15°N in the mid Ocean. Mathew (1980e, 1982) and Silas and Mathew (1986) recorded the species as north as 11°N in the continental shelf waters and upto 12°N in the oceanic waters.

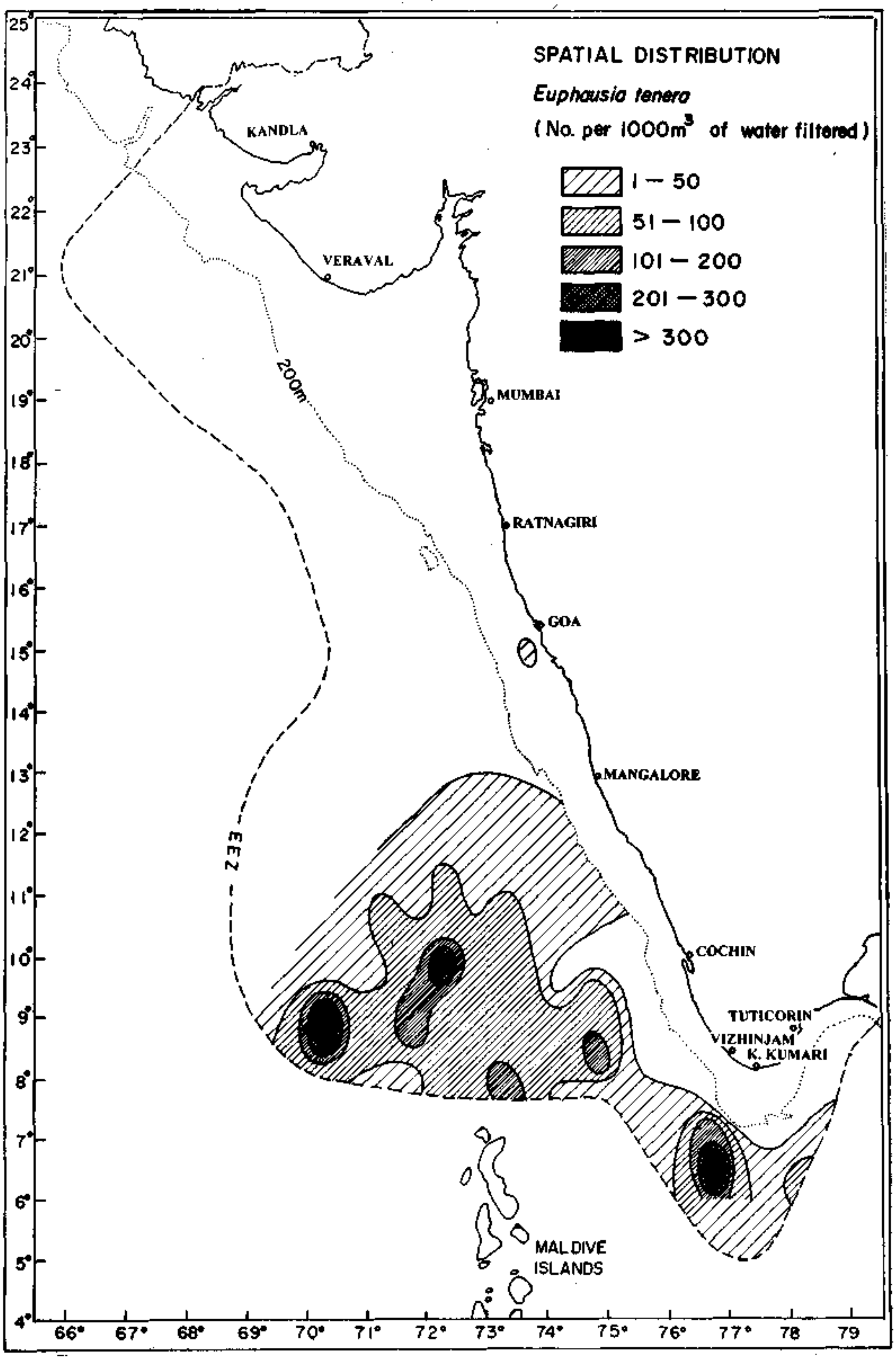

Fig. 24. Spatial distribution of *Euphausia tenera* in the EEZ of the west coast of India.

Euphausia pseudogibba Ortmann 1893 (Fig.25)

This equatorial epipelagic species was found sporadically distributed and was sparsely taken from eight stations south of 09°30'N (Fig. 40). It was confined to oceanic waters south of Wadge Bank and towards the southern part of the Lakshadweep Sea. Geographically this species occupied the same areas as occupied by another species; *Stylocheiron abbreviatum*. Its average number in the areas of occurrence was 87 per 1000 m^3 of water. The highest concentration at a density of 255 per 1000 m^3 of water was found south of Wadge Bank.

Tattersall (1939) could find just seven specimens in four samples collected from the Maldive area. According to Ponomareva (1964) it was an abundant species in the Arabian Sea. Sebastian (1966) collected a few specimens from the southwest coast of India and Lakshadweep and Maldive areas. Gopalakrishnan and Brinton (1969) recorded it at three locations north of the equator. Another record from the Arabian Sea was by Weigman (1970). According to Brinton and Gopalakrishnan (1973) *E. pseudogibba* occurs in the latitudinal zone between 0° and 10°N. A few specimens were present in the samples studied by Mathew (1980e, 1982) and Silas and Mathew (1986) from the oceanic waters off the southwest coast of India upto 10°N.

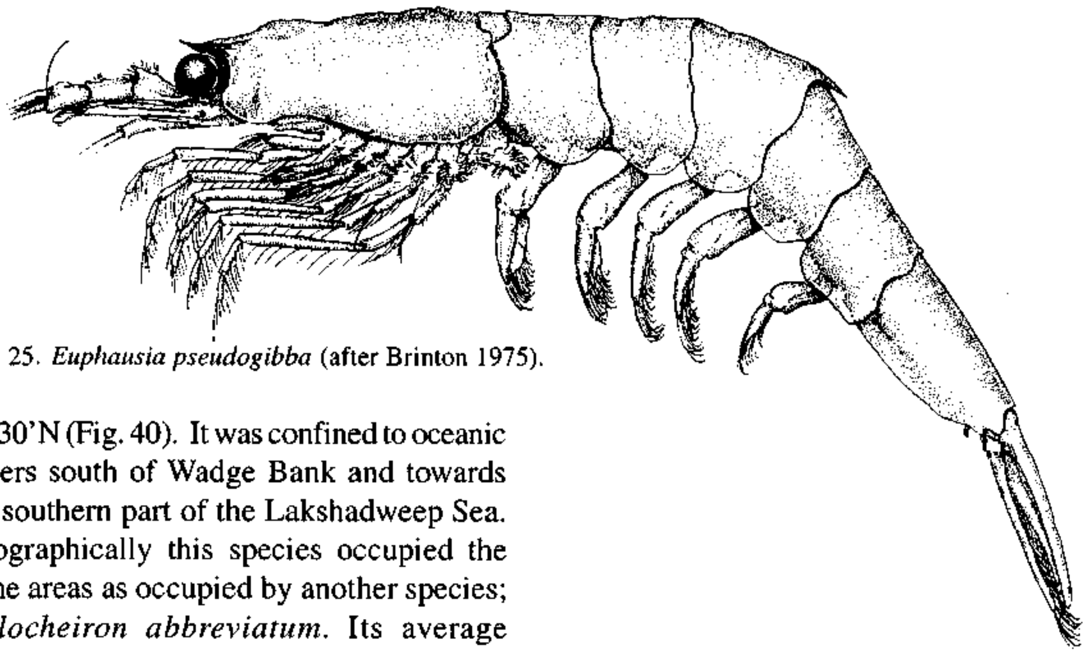

Fig. 25. *Euphausia pseudogibba* (after Brinton 1975).

Nematoscelis gracilis Hansen 1910 (Fig.26)

This epipelagic species is found throughout the equatorial zone of the world oceans. In the present investigation this was found distributed upto 19°N indicating widespread occurrence in the Arabian Sea (Fig. 27). Its average occurrence in the area was 309 per 1000 m^3 of water and it was the third abundant species. It was especially abundant south of 10°N. The species was mostly confined to areas beyond the continental shelf and was frequently caught in the Lakshadweep waters and south of the

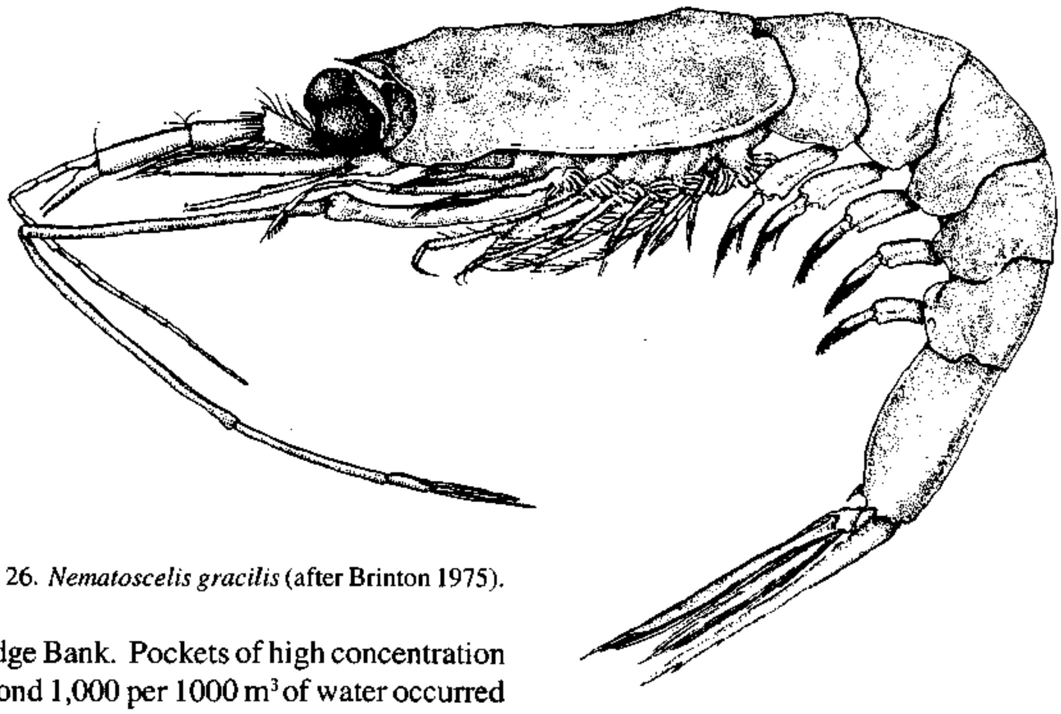

Fig. 26. *Nematoscelis gracilis* (after Brinton 1975).

Wadge Bank. Pockets of high concentration beyond 1,000 per 1000 m^3 of water occurred at several localities in the Lakshadweep waters. The population fluctuated between 4 and 9,675 per 1000 m^3 of water at various stations and the highest number was recorded in the oceanic Lakshadweep waters west of Cochin. The population from a high density in the southern areas thinned out as proceeded towards north.

N. gracilis was poorly represented in the collections obtained during the *Sea Lark* Expedition (Tattersall 1912). Illig (1930) reported good number of its specimens from the equatorial Indian Ocean. This was the characteristic species in the samples made during the *John Murray* expedition (Tattersall 1939) from Central and southern Arabian Sea and the Maldive waters. Ponomareva (1964) also reported it from the Arabian Sea. Sebastian (1966) obtained the species from the southwest coast, Lakshadweep and Maldive areas. Gopalakrishnan and Brinton (1969) observed it as one of the most abundant species in the equatorial Indian Ocean. Mathew (1980e, 1982) found the species moderately distributed in the shelf waters between 3 and 175 per 1000 m^3 of water. The northern limit according to him was 16°N which is now extended upto 19°N. He found the species to be mostly away from the continental shelf.

Nematobrachion flexipes Ortmann 1893 (Fig.28)

This epipelagic not so abundant species was found distributed in the oceanic waters limited to the southern part of the study area (Fig. 29). Its average population density in the area of occurrence was 55 per 1000 m^3 of water. The only two occasions

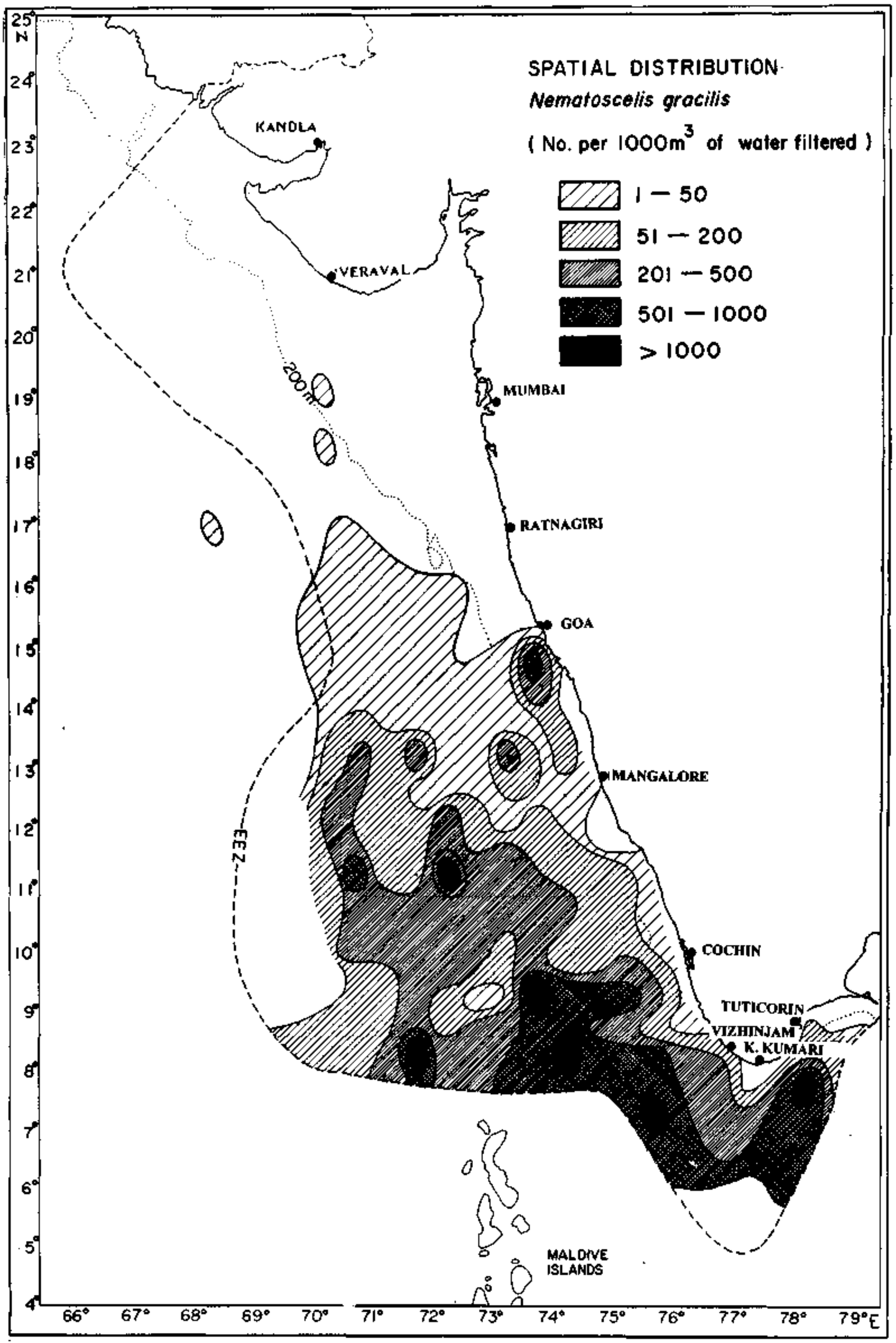

Fig. 27. Spatial distribution of *Nematoscelis gracilis* in the EEZ of the west coast of India.

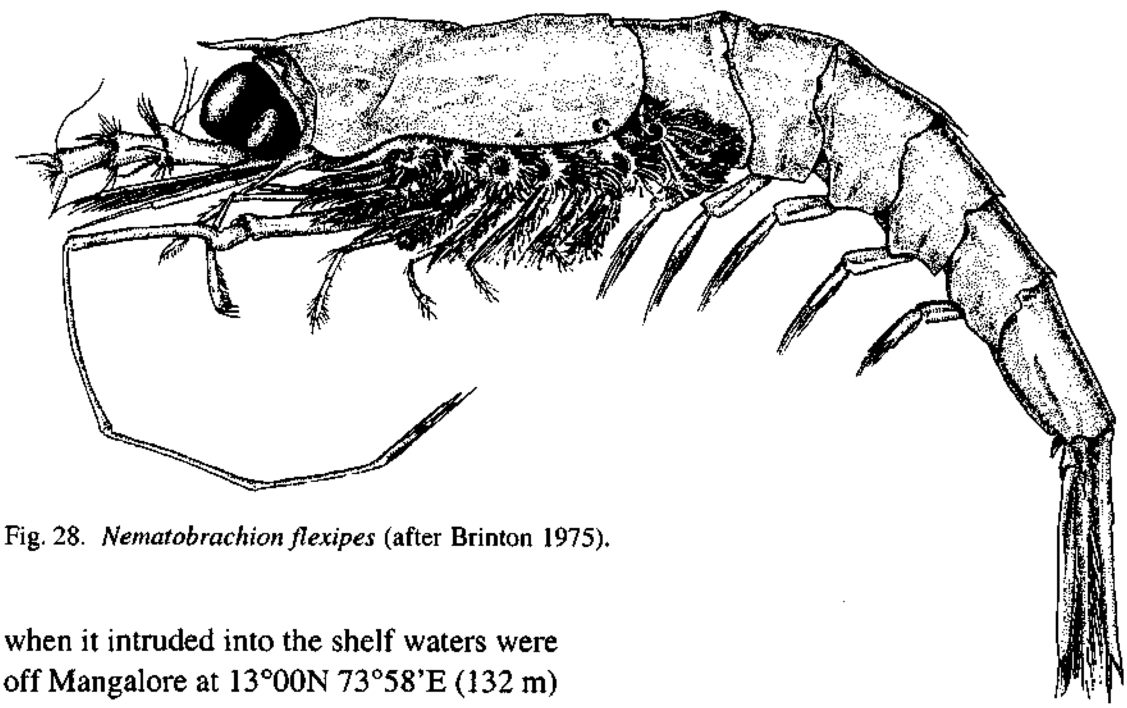

Fig. 28. *Nematobrachion flexipes* (after Brinton 1975).

when it intruded into the shelf waters were off Mangalore at 13°00N 73°58'E (132 m) and 12°29'N 74°20'E (71 m). The species was mostly represented south of 13°N but some stray occurrences were noticed upto 14°N. The pockets of high density were mostly south of 10°N. *N. flexipes* was comparatively more abundant off Cochin and nearer to the Lakshadweep islands. More than 100 specimens per 1000 m^3 of water were obtained on 9 occasions. The highest number of 419 per 1000 m^3 was recorded at 09°30'N 73°30'E in the Lakshadweep waters in April. The distribution of this species was somewhat patchy. Out of 493 samples analysed *N. flexipes* was present in 48 samples only.

N. flexipes though rare in occurrence is a widespread species in the Indian Ocean. Records have been made from several localities by many authors. Tattersall (1912) recorded it off Mauritius and off Nazarath Bank. Illig (1930) found it south of Sri Lanka and near Chagos. Ponomareva (1964) collected it from the Arabian Sea. The species was taken by Sebastian (1966) from the southwest coast of India and the Lakshadweep and Maldive waters. Gopalakrishnan and Brinton (1969) encountered it sparsely in the equatorial Indian Ocean. Brinton and Gopalakrishnan (1973) noticed it to be widely but irregularly distributed in the region between 15°N and 45°S in the Indian Ocean. Mathew (1980e & 1982) could not collect this species from the shelf waters along the southwest coast. However, from the oceanic waters he obtained this species at a rate of 1-7 per 1000 m^3 of water and extended the northern limit of the species in the Arabian Sea upto 16°20'N based on the deep water samples he examined.

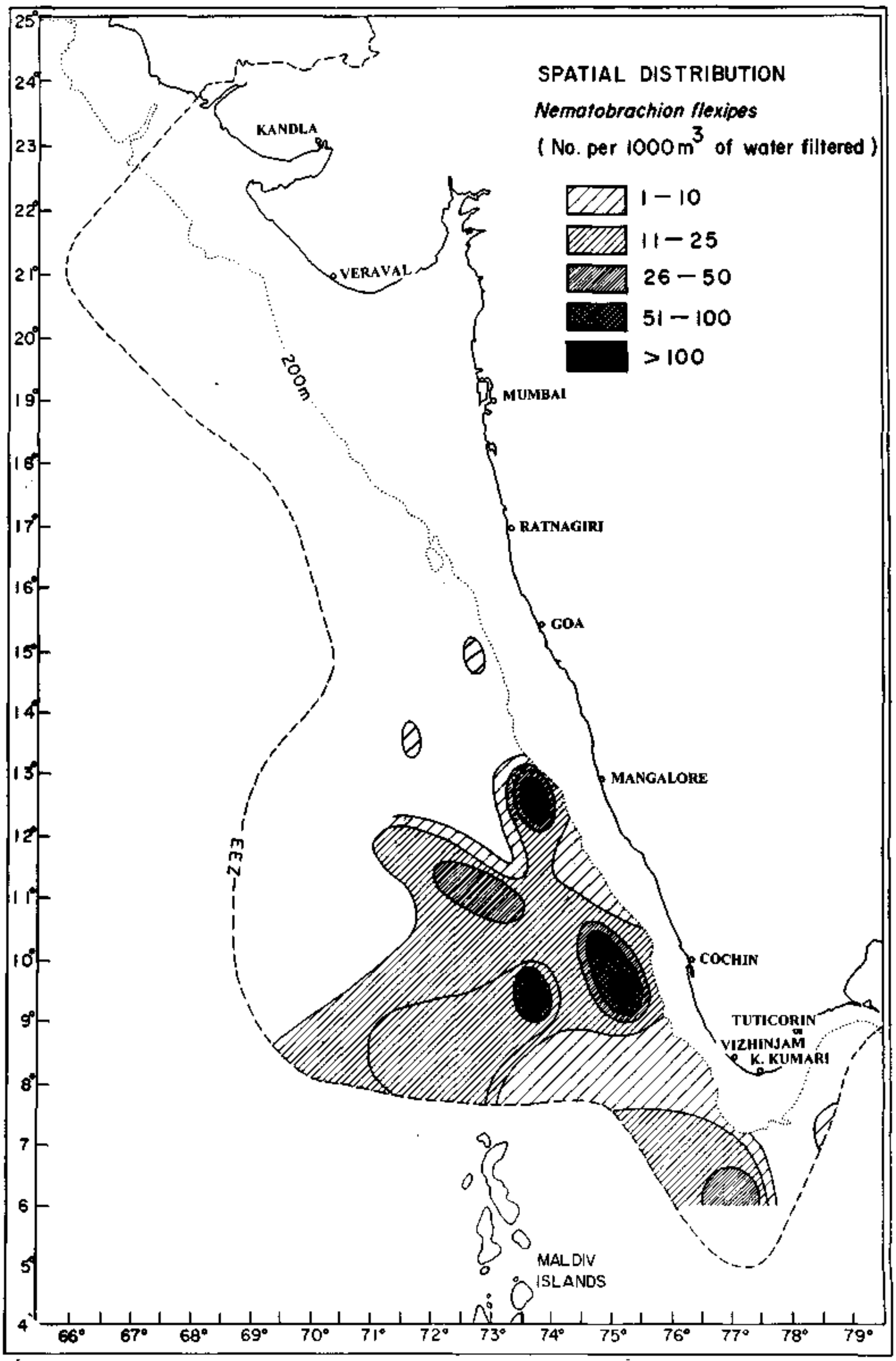

Fig. 29. Spatial distribution of *Nematobrachion flexipes* in the EEZ of the west coast of India.

Stylocheiron armatum **Colosi 1917** (Fig.30)

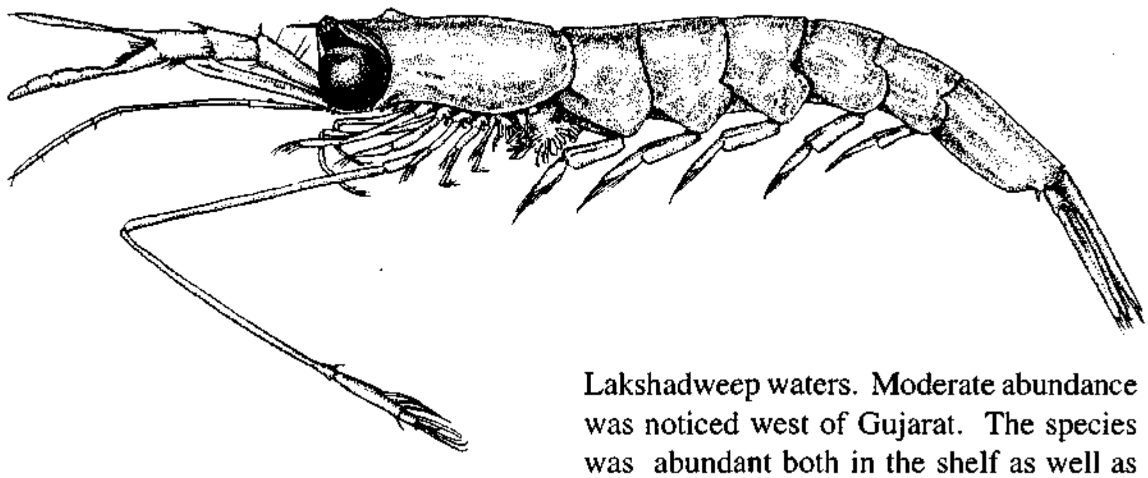

Fig. 30. *Stylocheiron armatum* (after Brinton 1975).

This species from the Arabian Sea was earlier considered as *S. carinatum*. However, studies conducted by Mathew (1980a, 1982) on the material from the southwest coast of India established that it belonged to *S. armatum* a species originally described by Colosi (1917) from the Red Sea and hence the population identified as *S. carinatum* in the Arabian Sea by the previous authors is considered here as *S. armatum*.

S. armatum is another epipelagic species occurring from the very surface to 700 m depth. It was present throughout the study area extending as north as 22°N and was the fifth species in the order of abundance Fig. 31). The average density of the population in the area was 230 per 1000 m^3 of water. As in the case of several other species its area of abundance was south of 12°30'N. *S. armatum* was especially abundant in the Lakshadweep waters. Areas of concentration beyond 1,000 per 1000 m^3 of water were found at several localities in the Lakshadweep waters. Moderate abundance was noticed west of Gujarat. The species was abundant both in the shelf as well as oceanic areas. The highest concentration of 3,592 specimens per 1000 m^3 of water was at a station west of Minicoy. Density of more than 1,000 per 1000 m^3 of water was observed at 32 localities within the EEZ.

Tattersall (1912) recorded *S. armatum* in small numbers from a number of localities in the northern Indian Ocean. Colosi (1917) identified a few specimens from the Arabian Sea along with a number of them from the Red Sea. Illig's (1930) records were from south of Sri Lanka, east of Maldives and further southward. Tattersall (1939) recorded *S. armatum* from the central and southern Arabian Sea and Maldive areas. Ponomareva (1964) recorded the species in the Arabian Sea. Sebastian (1966) found it to be one of the common species which exhibited shoaling behaviour during the breeding season in the southeastern Arabian Sea. This was one of the characteristic species caught from the equatorial Indian Ocean by Gopalakrishnan and Brinton (1969). Another record of the

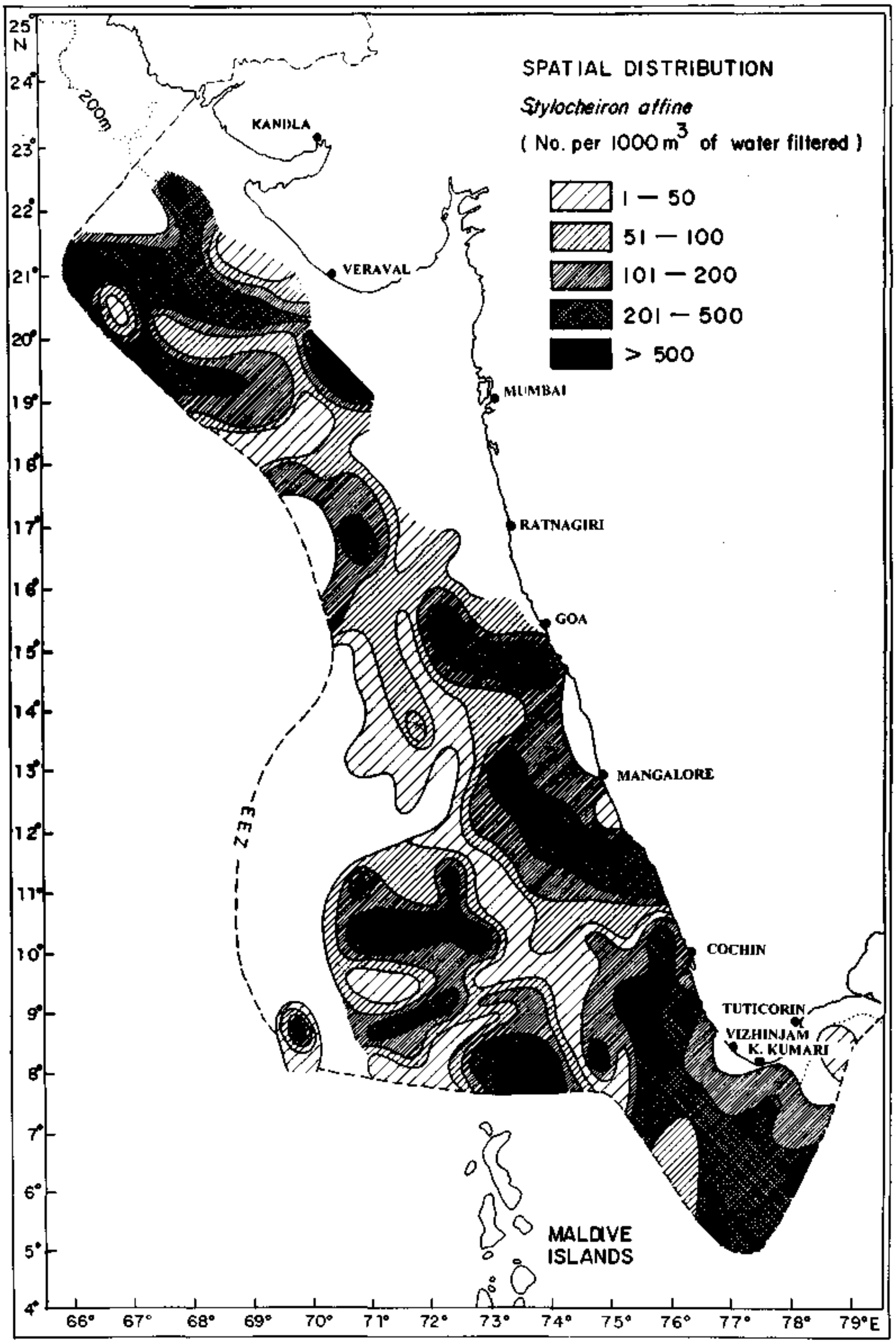

Fig. 33. Spatial distribution of *Stylocheiron affine* in the EEZ of the west coast of India.

recorded the species in the Arabian Sea. As observed by Sebastian (1966) it was a fairly common species of the southwest coast of India and the Lakshadweep and the Maldive seas. In the Red Sea *S. affine* was the second abundant species as found by Ponomareva (1968). In the equatorial Indian Ocean it was taken in small numbers only (Gopalakrishnan and Brinton 1969). Weighman (1970) also reported this species from the Arabian Sea. According to Brinton and Gopalakrishnan (1973) *S. affine* occurs from 35°S to the northern limit of the Indian Ocean. Mathew (1980e, 1982) and Silas and Mathew (1986) found this species widely and abundantly distributed in the shelf as well as oceanic waters.

Stylocheiron suhmii G.O. Sars 1883 (Fig.34)

This central epipelagic species occurring upto 700 m depth was occasionally taken from beyond the continental shelf edge south of 13°30'N. It was mostly confined to the continental shelf edge and the nearby oceanic waters (Fig. 40). The maximum number taken from a station was 32 per 1000 m^3 of water.

Tattersall (1912) found it to be widespread but sparse in the northern Indian Ocean. Illig (1930) reported it from several localities in the Indian Ocean including the Red Sea. Ponomareva (1964) and Weighman (1970) recorded it in the Arabian Sea. Gopalakrishnan and Brinton found it confined to the equatorial waters. Mathew (1980e, 1982) and Silas and Mathew (1986) collected a few specimens of this species from the shelf as well as oceanic areas of the southwest coast of India as far north as 16°N.

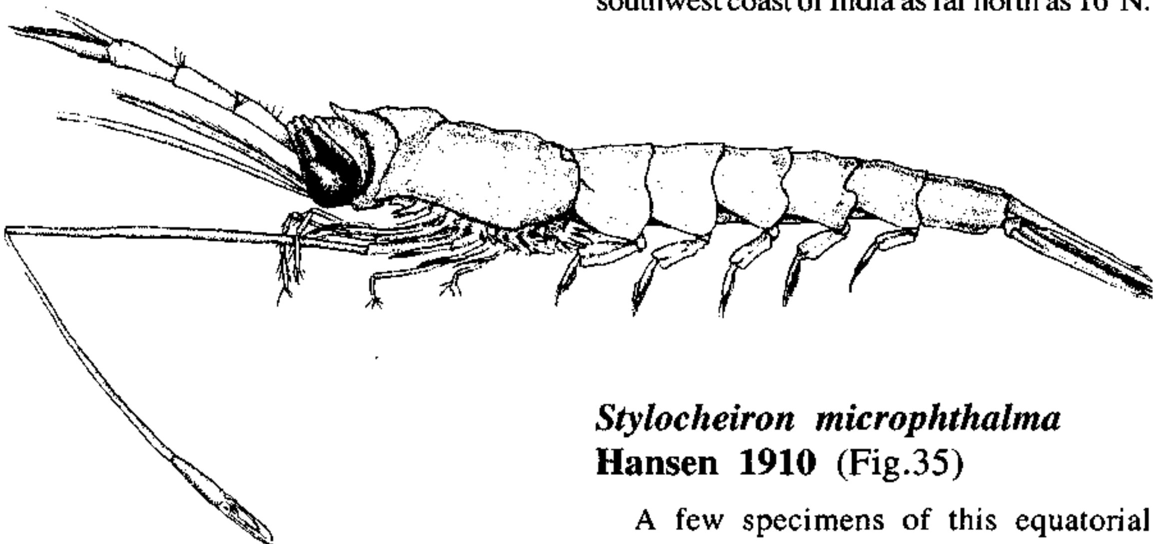

Fig. 34. *Stylocheiron suhmii* (after Brinton 1975).

Stylocheiron microphthalma Hansen 1910 (Fig.35)

A few specimens of this equatorial epipelagic species having a vertical range of 0-280 m were taken from south of 10°N in the purely oceanic waters (Fig. 40). It was present mostly in the southern limit of the

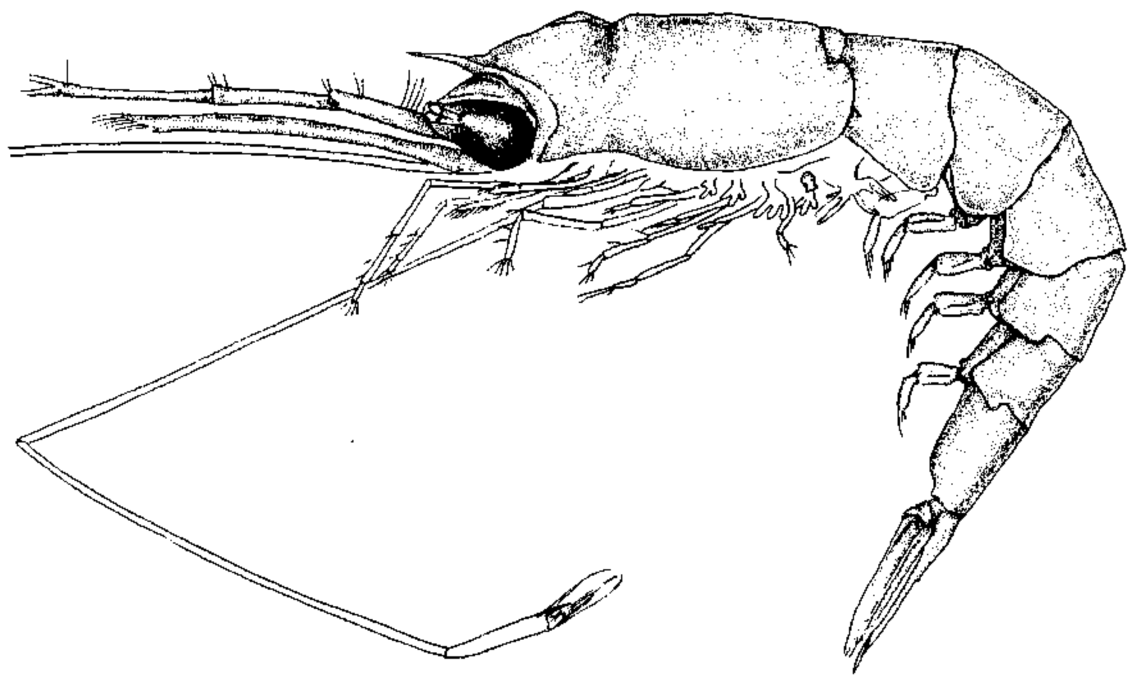

Fig. 35. *Stylocheiron microphthalma* (after Brinton 1975).

Lakshadweep and towards Maldive Islands. The maximum number occurred was 9 per 1000 m^3 of water.

Tattersall found it in the northern Indian Ocean south of equator. Ponomareva (1964) and Weigman (1970) recorded it from the Arabian Sea. Sebastian (1966) reported it from the Lakshadweep and Maldive waters. Gopalakrishnan and Brinton (1969) obtained it from the equatorial waters. According to Brinton and Gopalakrishnan (1973) the species was well represented south of 10N°. Mathew (1980e, 1982) and Silas and Mathew (1986) recorded *S. microphthalma* from a few locations along the southwest coast in the shelf edge and oceanic areas and it reached as far north as 10°40'N.

Stylocheiron longicorne (G.O. Sars 1883) (Fig.36)

This species is considered as central equatorial mesopelagic occupying a vertical range of 140-700 m. In the present studies the species was found strictly confined to the southern latitudes mostly south of 12°N and away from the continental shelf waters (Fig. 37). A few specimens occurred even north of this limit. Though widespread in occurrence it never appeared in large numbers, may be because the sampling was done in the epipelagic zone. The highest number taken was 545 per 1000 m^3 of water at 09°30'N 73°30'E in the Lakshadweep waters. Large concentrations were always found in the oceanic areas of the Lakshadweep.

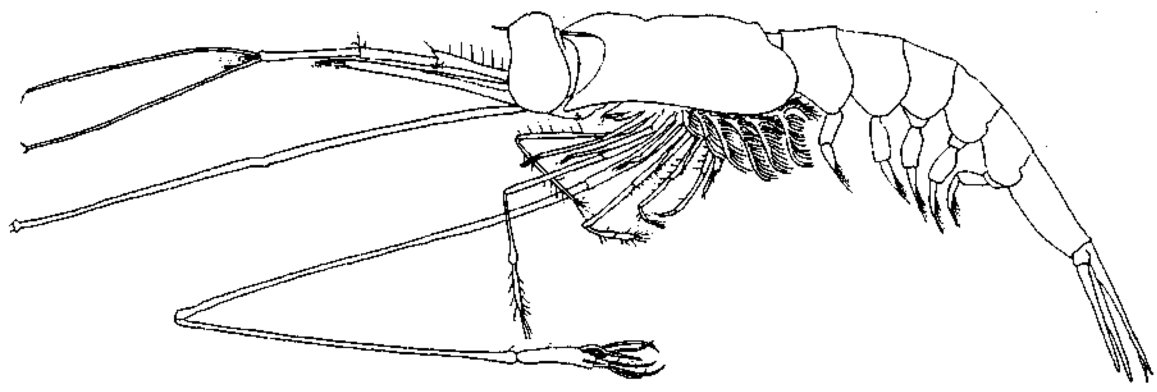

Fig. 36. *Stylocheiron longicorne* (after Brinton 1975).

Tattersall (1912) found *S. longicorne* fairly widespread but in low numbers in the western equatorial Indian Ocean. The species was found widely distributed during the *Valdivia* Expedition (Illig 1930) with the southern limit extending upto 34°14'S. Tattersall (1939) during the *John Murray* Expedition found it distributed in the northern, central and southern Arabian Sea and in the Maldive waters. Ponomareva (1964) made records of the species in the Arabian Sea. It was fairly common throughout the area investigated by Sebastian (1966). Smaller numbers were collected from the equatorial Indian Ocean during the *Luciad* Expedition (Gopalakrishnan and Brinton (1969). In 1970 Weighman reported the species from the Arabian Sea. According to Brinton and Gopalakrishnan (1975) it is a widely occurring species in the tropical Indian Ocean. Mathew (1980e, 1982) and Silas and Mathew (1986) obtained a few specimens from the shelf edge along the southwest coast of India.

Stylocheiron abbreviatum G.O. Sars 1883 (Fig.38)

This typically central epipelagic species moving down upto 700 m during a diurnal cycle was found confined to the oceanic area south of 10°N (Fig. 40). However, there were instances of the species moving upto 12° N. A few specimens were taken from between 10°30'N and 12°N on four occasions just outside the continental shelf limit. The species always occurred in small numbers; the highest number being 134 per 1000 m^3 of water from south of Wadge Bank.

Earlier records of *S. abbreviatum* show that the species extends its northern limit via the western Arabian Sea. It was frequently caught from the Red Sea and the Gulf of Aden by Torelli (1934a). During the *John Murray* Expedition a few specimens were collected from the Red Sea, central and southern Arabian Sea and the Maldive Sea. Ponomareva *et al.* (1962) also recorded it from the western Arabian Sea. Sebastian (1966) found it in the southeastern Arabian Sea. Ponomareva (1968) collected a few specimens from the Red Sea. It was regularly

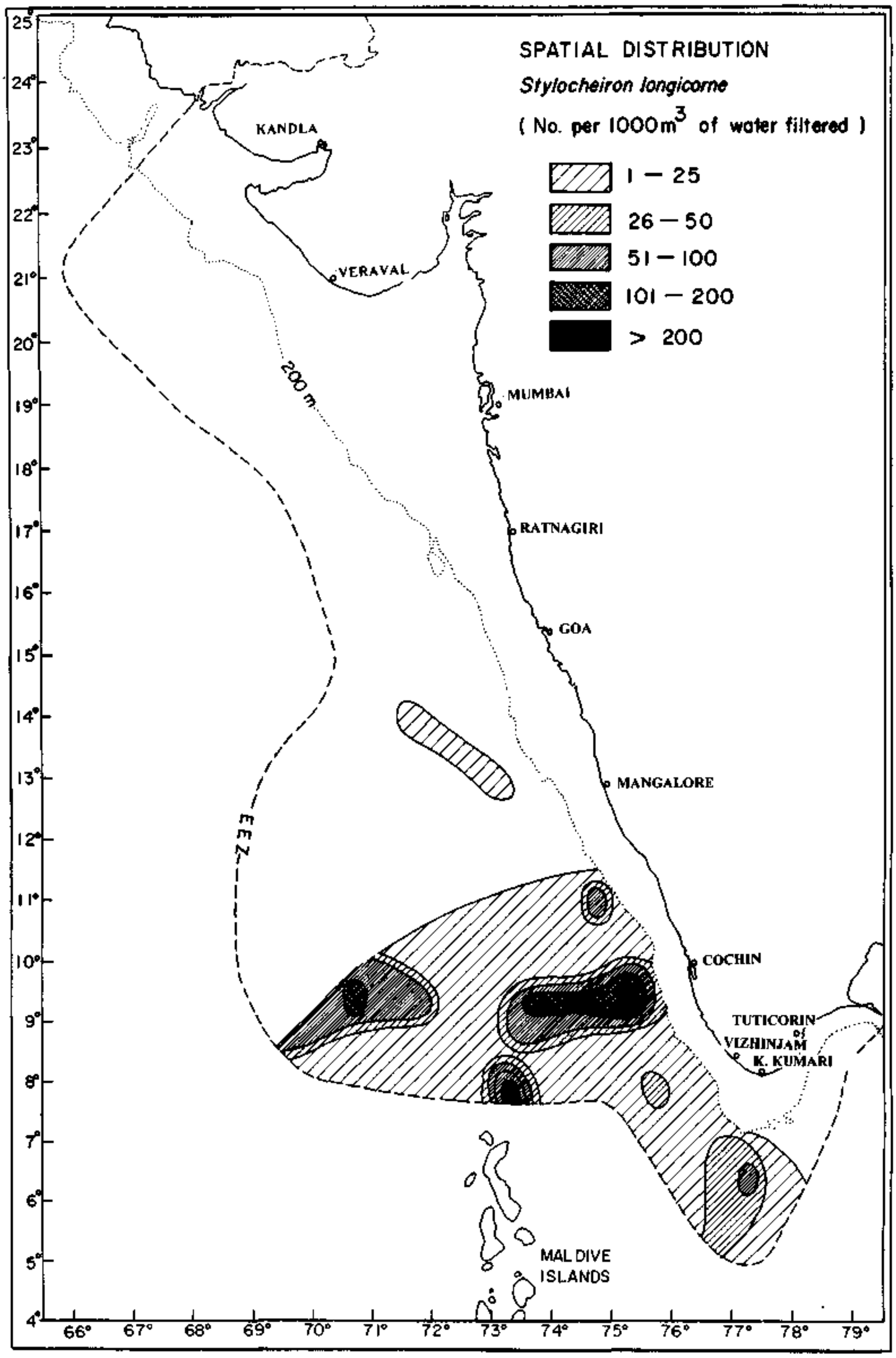

Fig. 37. Spatial distribution of *Stylocheiron longicorne* in the EEZ of the west coast of India.

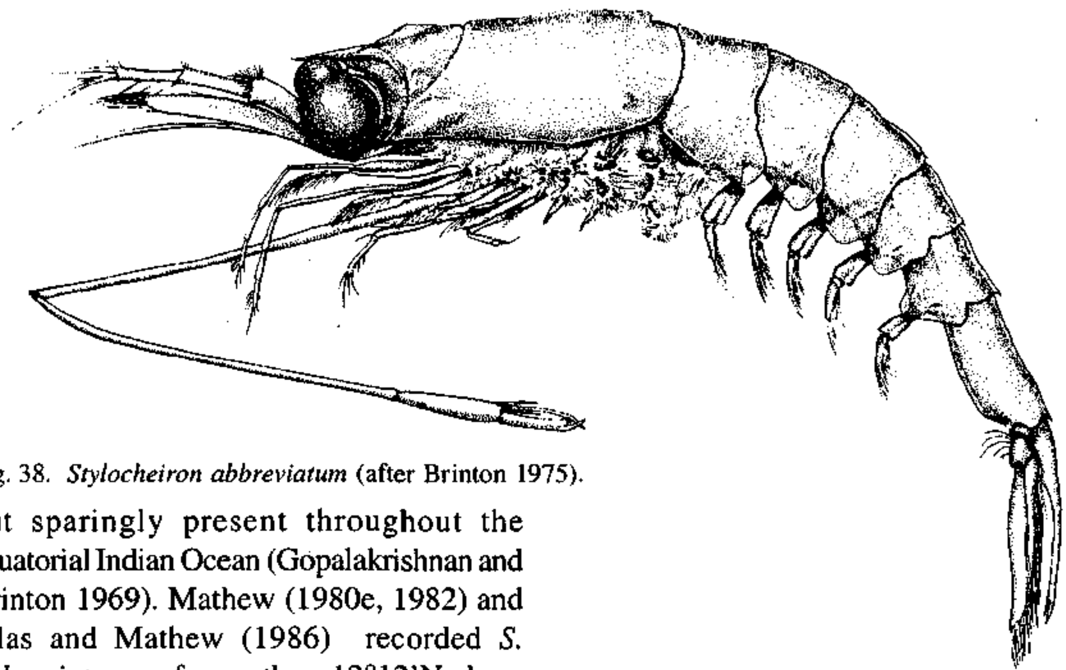

Fig. 38. *Stylocheiron abbreviatum* (after Brinton 1975).

but sparingly present throughout the equatorial Indian Ocean (Gopalakrishnan and Brinton 1969). Mathew (1980e, 1982) and Silas and Mathew (1986) recorded *S. abbreviatum* as far north as 12°12'N along the southwest coast. The trend of occurrence in their study area showed that it was not an abundant species but the presence of 275 adult specimens in a single haul with the IKM Trawl made them to conclude that it was not a rare species at least in the oceanic waters. According to them the capability of this carnivorous species to avoid the net might be one reason for their least capture.

Stylocheiron maximum **Hansen 1908** (Fig.39)

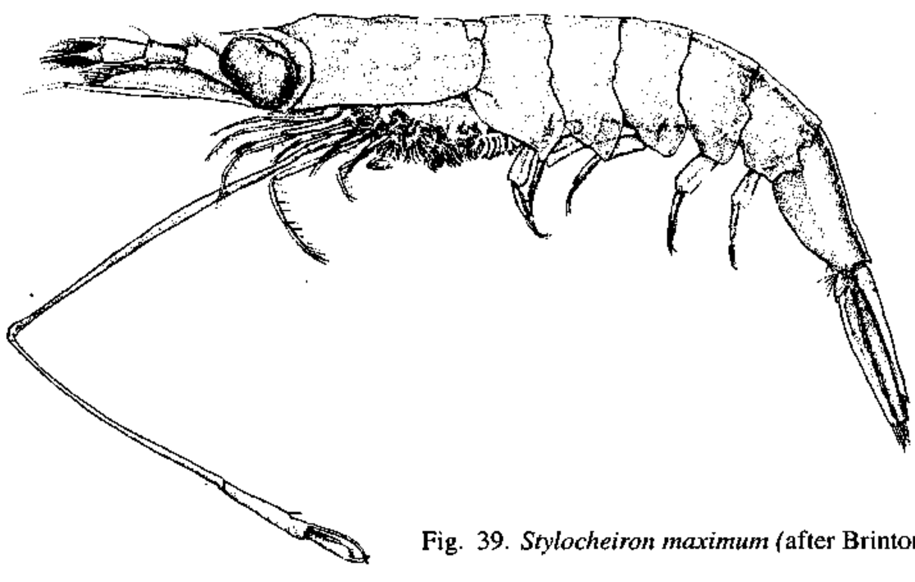

Fig. 39. *Stylocheiron maximum* (after Brinton 1975).

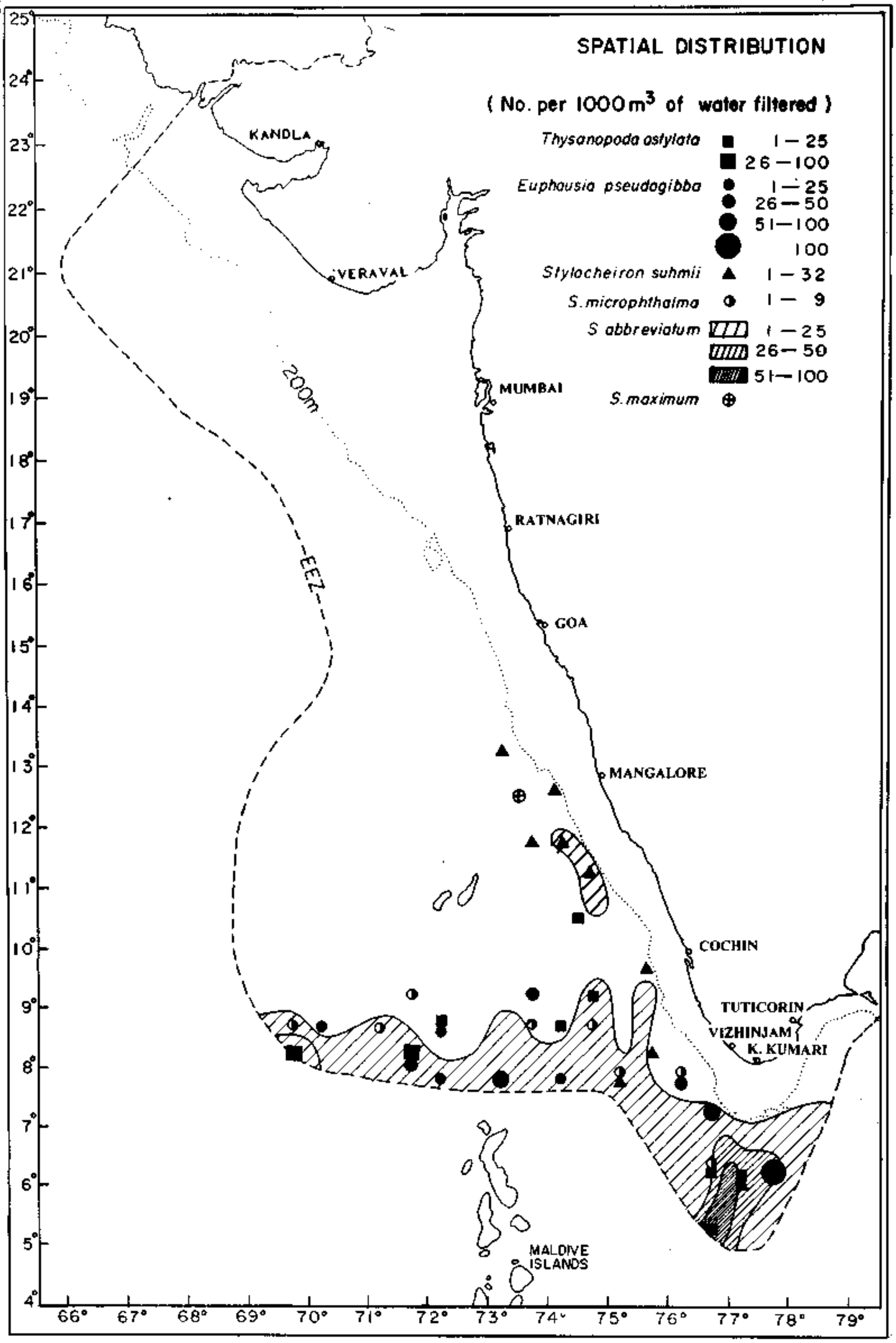

Fig. 40. Spatial distribution of *Thysanopoda astylata*, *Euphausia pseudogibba*, *Stylocheiron suhmii*, *S. microphthalma*, *S. abbreviatum* and *S. maximum* in the EEZ of the west coast of India.

Eventhough qualified as a mesopelagic cosmopolitan species, it was taken only once from a night station at 12°30'N 73°30'E southwest of Mangalore away from the continental slope where the depth to bottom measured 1960 m (Fig. 40). The rather shallow nature of sampling for the studies might have resulted in the poor capture of the species.

Other records from the Arabian Sea include that of Illig (1930) from southwest of Sri Lanka and from near Chagos. During the *John Murray* Expedition Tattersall (1939) collected it from the Central Arabian Sea. Ponomareva (1964) also took it from the Arabian Sea. Sebastian (1966) obtained a few immature specimens from the southeastern Arabian Sea. Ponomareva *et al.* (1962) reported the species from the Mumbai coast. Brinton and Gopalakrishnan (1973) found it to have a broad range of distribution in the Indian Ocean. Gopalakrishnan and Brinton (1969) obtained a few furcilia larvae from the equatorial Indian Ocean. Mathew (1980e, 1982) and Silas and Mathew (1986) recorded *S. maximum* at 10 locations along the southwest coast in the oceanic waters including one juvenile and a larva from the shelf edge station.

4

SPECIES ABUNDANCE

During the present investigations a total of 17 species of Euphausiids were encountered in the Arabian Sea part of the Indian EEZ. Of them six species namely *P. latifrons, E. diomedeae, E. sibogae, N. gracilis, S. armatum, & S. affine* are cosmopolitan in occurrence and numerically abundant too. Others were sparse and restricted to the southern part of the study area of which some are purely oceanic, occurring beyond the limit of the continental shelf.

E. sibogae the commonest and the most abundant species in the eastern Arabian Sea was represented at an average rate of 1,437 per 1000 m^3 of water which means 1.4 specimens per every cubic meter or every 1000 litres of water. This is a good density when compared to other tropical waters. The next in abundance was *E. diomedeae* which exhibited a population density of 1,256 per 1000 m^3 of water. Numerically the above two widely occurring species together constituted 60.12 % of the total euphausiid material obtained from the study area. The third in rank was *N. gracilis* having an average population density of 309 per 1000 m^3 of water. The next abundant species *P. latifrons* occurred at an average rate of 258 specimens per 1000 m^3 of water. *S. armatum* was the next cosmopolitan species in the order of abundance and was present at an average rate of 230 per 1000 m^3 of water. *S. affine* the last among the cosmopolitan species was present at a rate of 216 per 1000 m^3 of water.

The above considered cosmopolitan species can be grouped into two based on their numerical abundance. *E. sibogae* and *E. diomedeae* having a high and an almost equal density in the study area can be grouped together and may be considered as the most successful species; the former within the continental shelf waters and the latter in the oceanic waters. The other four species which can be considered together in the second group maintained their population almost at the same level, of course, much below the level of the two species of the first group and therefore these species can be considered as moderately successful in the epipelagic zone of the eastern Arabian Sea.

The rest of the species numbering 11 are highly oceanic and are restricted to the southern part of the study area, that is, almost south of 12°N. Because some of them namely *T. monacantha, T. tricuspidata, T.*

astylata, *N. flexipes*, *S. abbreviatum* and *S. maximum* are large and deep living the present sampling might not have been representative and hence it is difficult to obtain a correct picture of their population size in the study area. Mathew (1980e, 1982) and Silas and Mathew (1986) who studied on euphausiids collected using different types of nets obtained large number of specimens of *T. monacantha* and *T. tricuspidata* with the IKM Trawl which indicated the presence of large populations of these species in the mesopelagic zone of the Arabian Sea. In the present samples collected from above 150 m depth were almost fully represented by their larvae and juveniles which show the presence of adult populations below 150 m depth.

Among the less abundant species *T. tricuspidata* occurred at an average rate of 151 per 1000 m^3 of water and *E. tenera* at 119. Other species were present at an average number of less than 100 per 1000 m^3 of water and these included *S. longicorne* (92), *E. pseudogibba* (87), *T. monacantha* (68), *N. flexipes* (55), *S. maximum* (51), *T. astylata* (49), *S. suhmii* (46), *S. abbreviatum* (46) and *S. microphthalma* (10).

5

MONTHLY VARIATIONS IN ABUNDANCE

Considerable variations in the monthly occurrence of euphausiids were observed both in the case of total population and individual species which could be attributed to the environment in which they live. April, May and November were the months of peak euphausiid occurrence (Fig. 41). The maximum abundance was in May when an average number of 5,236 specimens were present per 1000 m^3 of water meaning five specimens for every 1000 litres of water. This was followed by April with 4,913 per 1000 m^3 of water.

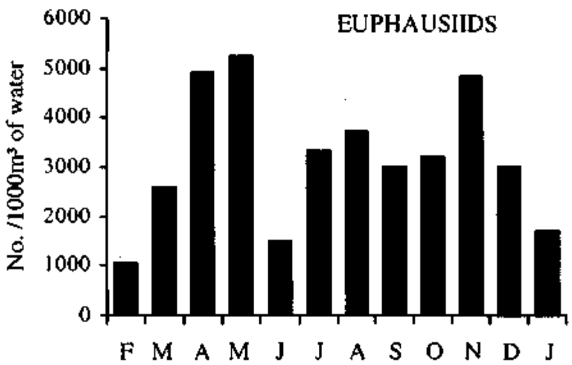

Fig. 41. Monthly variations in the abundance of total euphausiids.

Most of the species followed the general trend described above in their monthly abundance. *P. latifrons* (Fig. 42), the coastal living species showed only one peak of

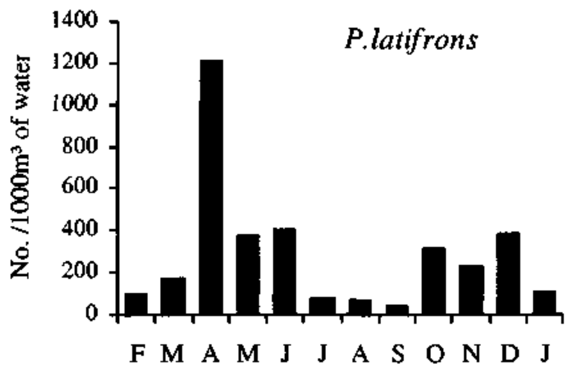

Fig. 42. Monthly variations in the abundance of *P. latifrons*.

1,211 specimens per 1000 m^3 of water being in April. July to September was the period of least occurrence. Again from October to March the population improved but at a low ebb. *E. diomedeae* (Fig. 43) also followed

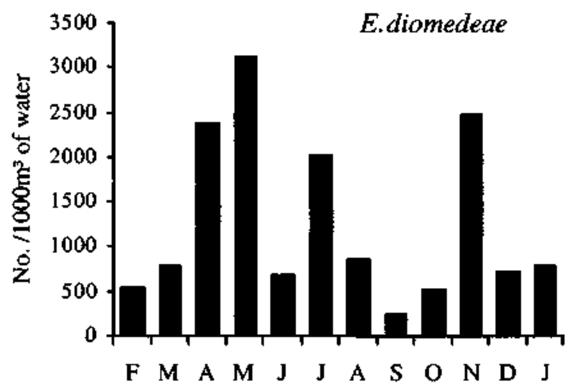

Fig. 43. Monthly variations in the abundance of *E. diomedeae*.

almost the same trend as that of *P. latifrons* by a gradual increase from February to the peak, excepting that the peak was one month later i.e. May. The May abundance was to the tune of 3,116 per 1000 m^3 of water. Again it was low in June but July registered high values. The population decreased further but only for another peak in November with 2,460 per 1000 m^3 of water.

The most abundant species *E. sibogae* (Fig. 44) displayed a different picture of monthly variations. In this species August-December period accounted for the maximum number against the February-May period of maximum in the previous species. In this species the January to June period registered low population rates. The highest value was 2,911 per 1000 m^3 of water in August. The population almost maintained its size until December only for a sudden fall in January. The low ebb then continued until June. The monthly fluctuations as observed by Mathew (1982) for this species is in conformity with the present studies.

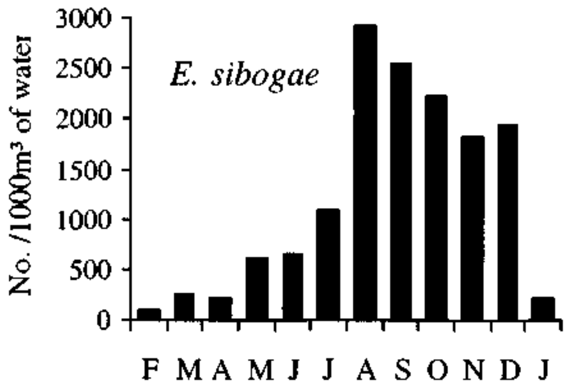

Fig. 44. Monthly variations in the abundance of *E. sibogae*.

S. armatum showed comparatively high population values from January to May maximising in April with the number reaching upto 1,009 per 1000 m^3 of water (Fig. 45). From this point the population dipped to a minimum in June and thereafter the species maintained a minimum number until October in a consistent manner. In November and January significantly improvements were noticed in the population.

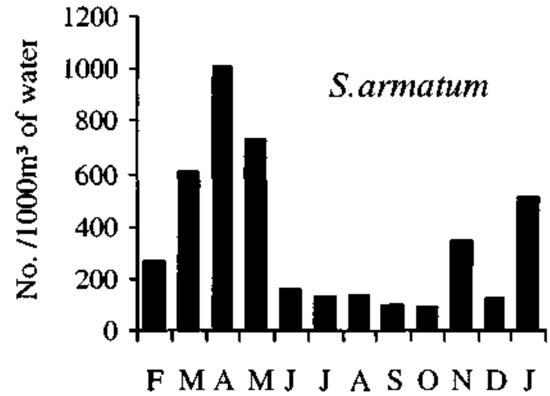

Fig. 45 Monthly variations in the abundance of *S. armatum*.

S. affine though followed almost the same pattern of occurrence as that of *S. armatum* in its monthly variations the population maintained a high density in all the months except in February when the occurrence was just 30 per 1000 m^3 of water (Fig. 46). The

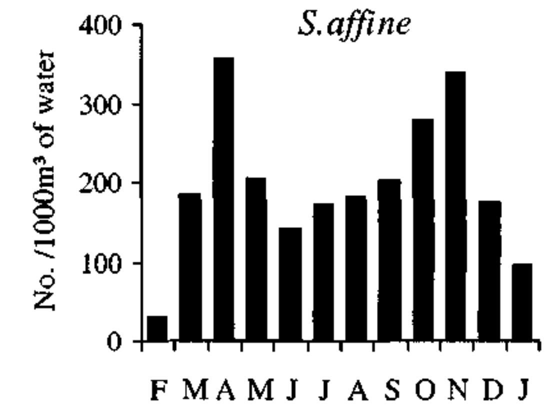

Fig. 46 Monthly variations in the abundance of *S. affine*.

April and November peaks were quite significant, the number during these months being 357 and 339 per 1000 m^3 of water respectively. Eventhough a June dip was indicated in the numerical abundance it was to the tune of 143 which is a significant number for the species.

The species *N. gracilis* (Fig. 47) exhibited three peaks in abundance such as April (797/1000 m^3), July (529/1000 m^3) and November (674/1000 m^3). On the time scale, while the increase was rather sudden in July and November it was a gradual process in April. A decrease in population was effected gradually after every peak.

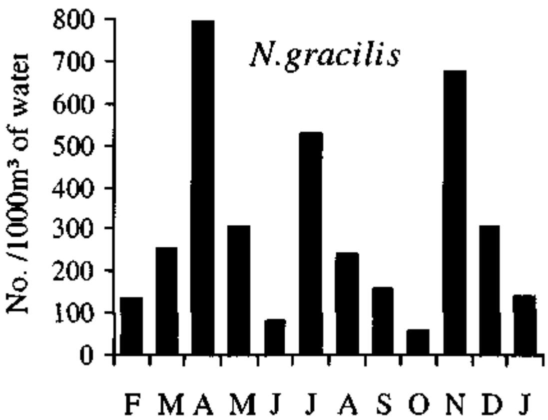

Fig. 47. Monthly variations in the abundance of *N. gracilis*.

In the case of those species which are not cosmopolitan in distribution in the area of investigation, a study on the monthly abundance may not hold good as the whole area was not sampled in each month. A cruise conducted outside the normal distributional limit of such species in a month would not contain specimens of such species and it does not mean that the species was totally absent in the area of study. Therefore a study of the monthly variations of species namely *T. astylata, T. monacantha, T. tricuspidata, E. tenera, E. pseudogibba, N. flexipes, S. suhmii, S. microphthalma, S. longicorne, S. abbreviatum* and *S. maximum* is not attempted here.

A comparative study of the increase and decrease in the population size of the commonest species in different months revealed that a kind of balance in population size was operative among different species. Thus when *E. sibogae*, the most abundant species increased its population size, all the other cosmopolitan species reduced the size of their population and *vice versa*.

The months of April-May is very significant in the Arabian Sea from the point of view of those dynamic forces such as water circulation and the vertical profile of various physico-chemical parameters which influence the fauna and flora to a great extent. Sharma (1966) noticed the ascent of cool subsurface water from a depth of more than 120 m to 20-30 m by April-May. Added to this, the development of clockwise circulation in the Arabian Sea with the onset of the southwest monsoon (Gallahar 1966, Varadachari and Sharma 1967) makes the water to flow towards north along the Somalia coast and by May almost everywhere north of equator the water starts flowing east. Along the west coast the currents are set in a clockwise direction and the resultant flow is predominantly south and parallel to the coast. Such a flow helps to spread the upwelled water along the Somalia and Arabian coasts to the Arabian Sea bringing a part even to the northwest coast of India. Thus the presence of cool waters in the eastern Arabian sea during April-May can be an impetus for euphausiids to shift their habitat from deeper to the epipelagic zone to be easily trapped by the sampling gear.

The May peak in abundance of euphausiids in general was fivefold from the ever minimum number of 1,042 per 1000 m^3 of water in February when the thermocline remained deepest creating an effective barrier against the upward migration of the deep living euphausiids. From the May peak there was a sudden fall in June towards the beginning of the southwest monsoon rains. The euphausiid population gradually increased as monsoon progressed and witnessed the next peak in November. Thus a clear picture of two cycles of maximum and minimum were observed in the course of one year.

Mathew (1980e, 1982) and Silas and Mathew (1986) while studying the euphausiid fauna of the continental shelf waters of the southwest coast of India found October to be the month of peak euphausiid abundance when the occurrence was at a rate of 5,250 per 1000 m^3 of water. Whichever be the month of maximum density, the numerical value obtained at present and by Mathew (1980e, 1982) and Silas and Mathew (1986) appeared to be almost the same suggesting that the carrying capacity for the euphausiids of the EEZ of the west coast is somewhere around 5,000 individuals per 1000 m^3 of water or in other words 5 specimens per 1000 litres of water in the peak period of occurrence. Studies by Mathew *et al.* (1990) also showed almost the same trend excepting that the peak months of occurrence were September and October. However, the June minimum and the two cycles of peak abundance; one from February to June and the other from June to February were indicated in all the three studies.

A test of significance was carried out for total euphausiids and 6 major species for their monthly variations (Table 1) and positive correlations were obtained in all the cases, being significant at 1 & 5 % levels. The result confirms the high influence of the environmental factors on the abundance and distribution of each species.

Table 1. *Test of significance for variations in occurrence during various months for different species and euphausiids in general*

Species	F-ratio	P
P. latifrons	4.294	0.000 **
E. diomedeae	6.422	0.000 **
E. sibogae	8.159	0.000 **
N. gracilis	8.861	0.000 **
S. armatum	24.414	0.000 **
S. affine	7.474	0.000 **
Total euphausiids	4.375	0.000 **

** : Significant at 1 % level.

Biodiversity measures such as S, d, H', Δ^o and H were high during January to May compared to June to December while such a clear trend was not visible for other biodiversity measures such as J', AvTD and VarTD (Fig. 48). All the biodiversity measures except AvTD and VarTD showed statistically significant ($P < 0.001$) variation with months (Table 2). Bray-Curtis similarities of biodiversity measures showed

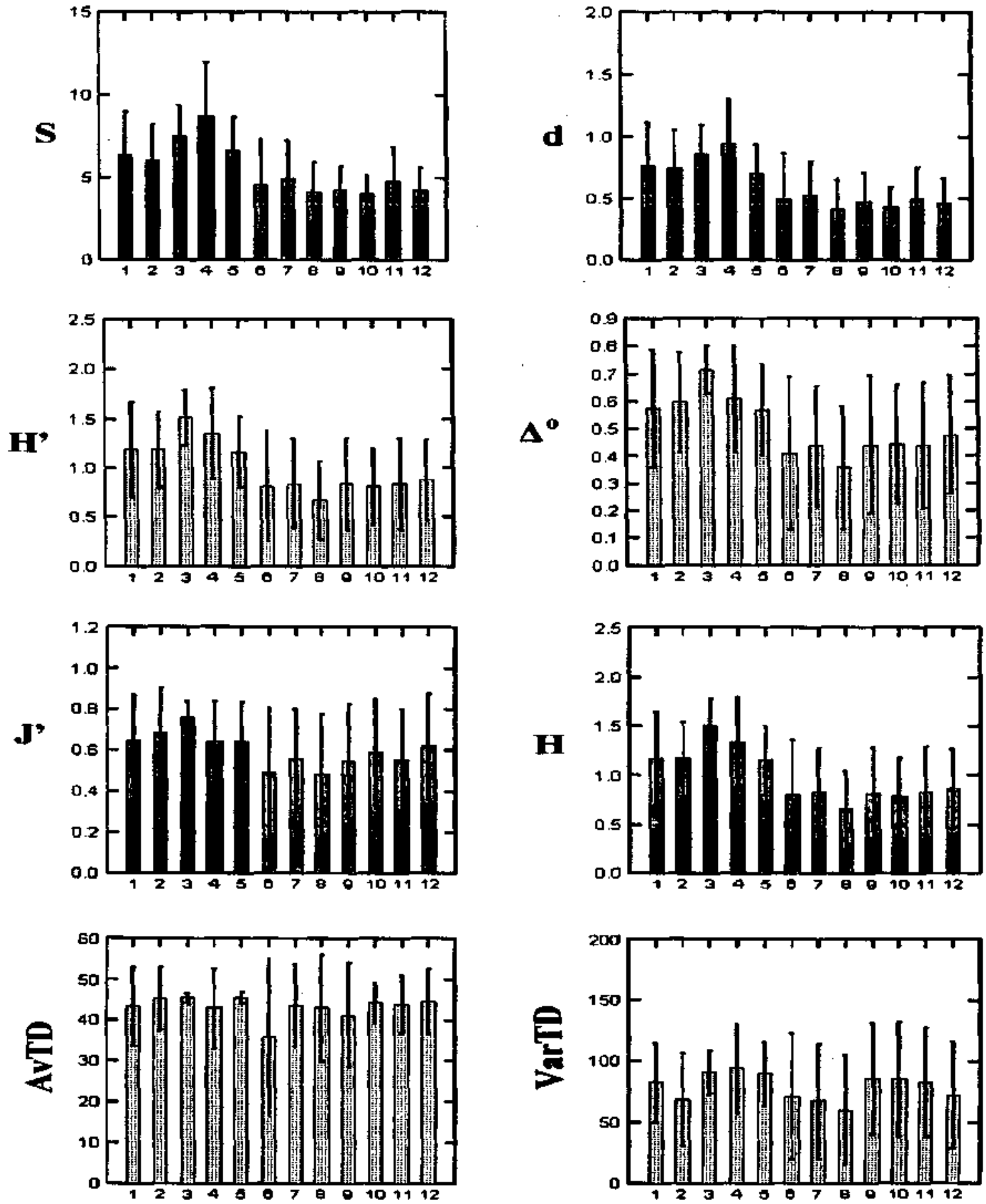

Fig. 48. Monthly variations (1. January – 12 December) in eight biodiversity measures such as Species (S), Margalef's species richness (d), Shannon-Weiner index (H'), Simpson diversity Index (Δ°), Pielou's evenness (J'), Brillouin index (H), Average Taxonomic Distinctness (AvTD, Δ*) and Variations in Taxonomic Distinctness (VarTD, *Λ) calculated using PRIMIER from the species abundance distribution for 491 stations from the EEZ of India.

Table 2. *Results of ANOVA test between biodiversity indices and monthly variations from the EEZ of India*

Biodiversity indices	F-ratio	P
Species (S)	17.714	0.000 **
Brillouin index (H)	12.180	0.000 **
Margalef's species richness (d)	16.096	0.000 **
Pielou's evenness	3.463	0.000 **
Shannon Weimer index (H')	12.055	0.000 **
Simpson index	7.814	0.000 **
AvTD	2.148	0.016 *
VarTD	2.406	0.006 **

** : Significant at 1% level, * : Significant at 5% level.

five different clusters for months (Fig. 49). February formed one cluster while, January and March – May formed the second cluster. August formed the third cluster while September – November formed the fourth cluster. June, July and December formed the fifth cluster. The study shows that the biodiversity indices are influenced by months. High biodiversity indices were recorded during March and April (premonsoon season) and lowest indices were recorded during June – August (Monsoon season). Low species occurrence of euphausiids was reported along the southwest coast of India during the monsoon period when the upwelling was intense (Mathew 1980).

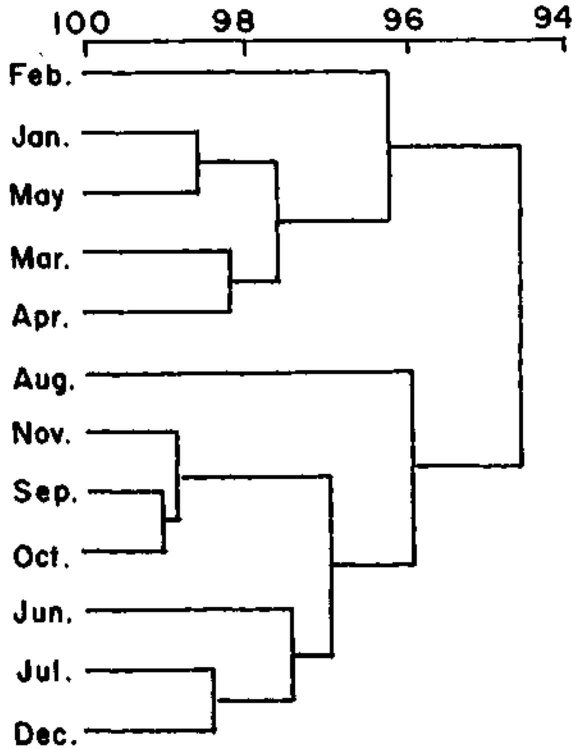

Fig. 49. Dendrograms for clustering of Bray-Curtis similarities based on square root transferred biodiversity data for different months calculated using PRIMER.

6

SEASONAL VARIATIONS IN ABUNDANCE

The Arabian Sea is typically dominated by three seasons of which the southwest monsoon extending from June to September influences the sea part to the greatest extent. Though the visible symptoms of the southwest monsoon are manifested mostly from June onwards, the water in the sea gets its pulse from May onwards by way of water currents, upwelling and the monsoon winds. Such changes in the environment have profound influence on the biotic community and the euphausiids are no exception to this. Hence following a study on the monthly variations in abundance, a study was undertaken on the seasonal fluctuations in the population size of euphausiids as a whole and the various species separately (Figs. 50-59). The seasons are defined as: premonsoon (February-May), S.W. monsoon (June-September) and postmonsoon (October - January). The percentage abundance of total euphausiids and different species during the three seasons is given in Table 3.

During the present study when the euphausiids were considered as a whole (Fig. 50) all the three seasons accounted for them almost equally with the minimum of 32.16 % during the southwest monsoon and maximum of 34.60 % during the postmonsoon season. The premonsoon season rallied closely behind with 33.24 %. Such an almost annual equilibrium level in euphausiid occurrence seemed to be maintained in the ecosystem in spite of varying abundance on the part of individual species in the different seasons. This is a significant factor as far as the social behaviour of a group of organisms is concerned; there being an automatic balancing mechanism in the population by sensing the population size of other species. Such a balancing is known to occur in nature which is essential for the survival of species.

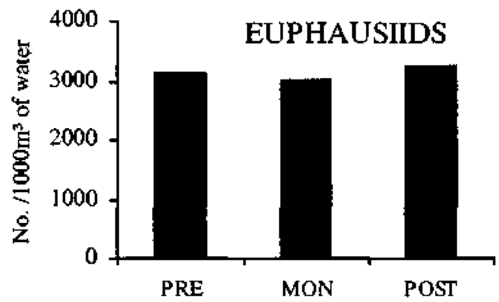

Fig. 50 Seasonal variations in the abundance of total euphausiids.

Majority of the species maintained their minimum population during the south-west monsoon season. They include *T. monocantha* (Fig. 51), *T. tricuspidata* (Fig. 52), *P. latifrons* (Fig. 53), *E. diomedeae*

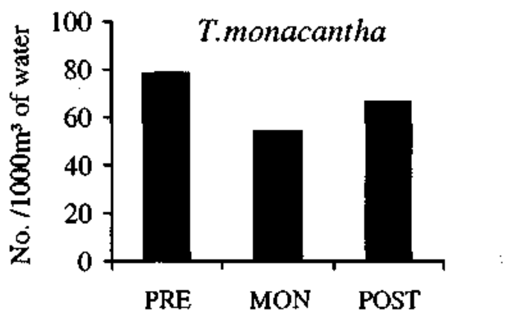

Fig. 51. Seasonal variations in the abundance of *T. monacantha*.

(Fig. 54), *E. tenera* (Fig. 56), *S. armatum* (Fig. 58) and *S. affine* (Fig. 59). Among these species except *E. tenera* and *S. affine* all others had their maximum during the

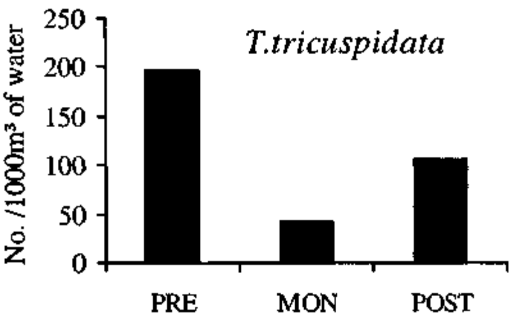

Fig. 52. Seasonal variations in the abundance of *T. tricuspidata*.

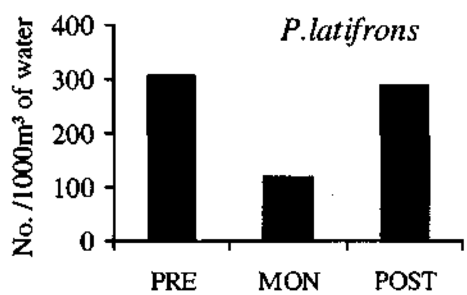

Fig. 53. Seasonal variations in the abundance of *P. latifrons*.

premonsoon season. *E. tenera* and *S. affine* displayed their maximum during the postmonsoon season. Among the minor

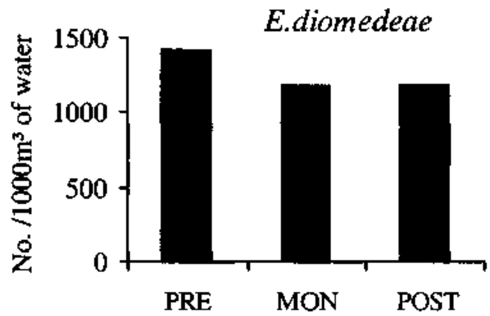

Fig. 54 Seasonal variations in the abundance of *E. diomedeae*.

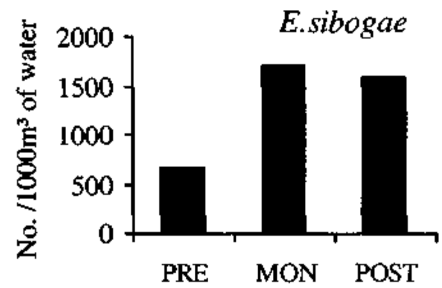

Fig. 55. Seasonal variations in the abundance of *E. sibogae*.

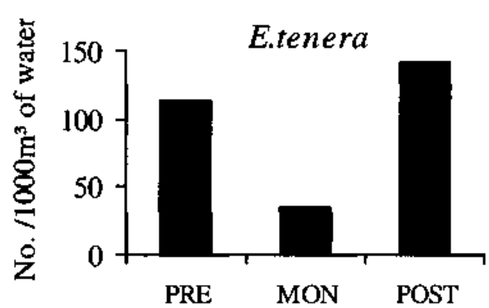

Fig. 56. Seasonal variations in the abundance of *E. tenera*.

species *S. longicorne* and *S. abbreviatum* were the ones which showed a southwest monsoon minimum. A monsoon dominance was shown by *N. gracilis* (Fig. 57), *E. sibogae* (Fig. 55) and *T. astylata*. In *E. diomedeae* (Fig. 54) while a premonsoon increase was evident the next two seasons had an almost equal density in population.

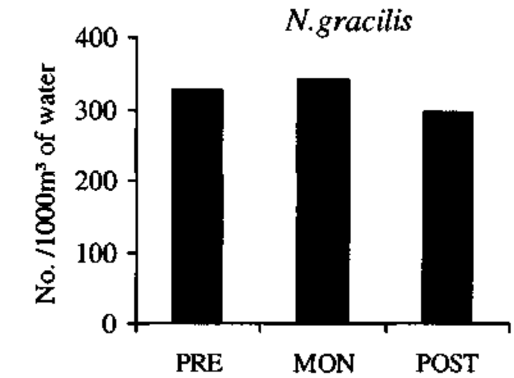

Fig. 57. Seasonal variations in the abundance of *N. gracilis.*

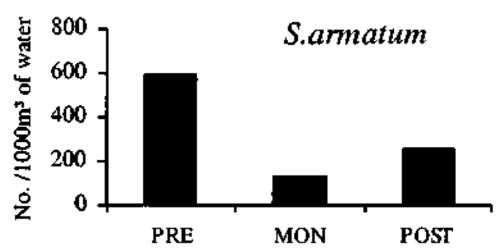

Fig. 58. Seasonal variations in the abundance of *S. armatum.*

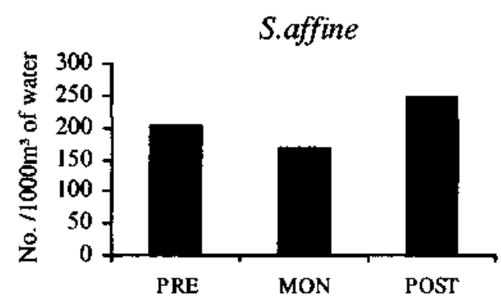

Fig. 59. Seasonal variations in the abundance of *S. affine.*

The very low number among the minor species did not permit a comparison between seasons.

Earlier investigations on seasonal distribution of euphausiid species of the Indian Ocean are very much limited. Roger (1966) studied the seasonal distribution of some species of the genus *Thysanopoda* of

Table 3. *Percentage abundance of euphausiids during major seasons*

Species	Pre monsoon	S.W. monsoon	Post monsoon
Thysanopoda monacantha	39.47	27.17	33.38
T. tricuspidata	56.80	12.64	30.56
T. astylata	5.97	88.45	5.57
Pseudeuphausia latifrons	43.00	16.61	40.38
Euphausia diomedeae	37.67	31.00	31.33
E. sibogae	16.70	43.14	40.15
E. tenera	39.29	11.77	48.82
E. pseudogibba	11.38	21.74	66.88
Nematoscelis gracilis	33.79	35.40	30.81
Nematobrachion flexipes	53.93	31.08	14.99
Stylocheiron armatum	60.62	13.33	26.04
S. affine	32.91	27.16	39.92
S. suhmii	0	48.71	51.29
S. microphthalma	29.51	42.62	27.87
S. longicorne	60.04	17.44	22.52
S. abbreviatum	37.37	22.10	40.53
S. maximum	0	100.00	0
Total euphausiids	33.24	32.16	34.60

the southeastern Indian Ocean. In 1973 Brinton and Gopalakrishnan made a study of some very common species of the Indian Ocean including the Arabian Sea dividing the year into two broad seasons; May to September (southwest monsoon season) and November to April (northeast monsoon season). A detailed investigation on the seasonal distribution of the species of *Nematoscelis* of the Indian Ocean was carried out by Gopalakrishnan (1974). Legand *et al.* (1975) attempted a study of the genus *Thysanopoda* of the southeastern Indian Ocean for a period of one year. Again in 1977 McWilliam made a study of the euphausiids of the same area for the same period. Mathew (1982) and Silas and Mathew (1986) studied the seasonal distribution of 14 species of euphausiids in the continental shelf waters of the southwest coast of India.

A statistical analysis of the seasonal data for different species and for total euphausiids indicated significant correlation at 1 and 5% levels for majority of species (Table 4). Significance at 5% level was indicated for *S. suhmii.* The correlation was not significant in the case of six species namely *E. diomedeae, E. pseudogibba, S. affine, S. microphthalma* and for total euphausiids.

Table 4. *Test of significance for variations in premonsoon, monsoon and postmonsoon for different species and euphausiids in general*

Species	F-ratio	P
T. monacantha	14.245	0.000 **
T. tricuspidata	67.643	0.000 **
T. astylata	1.179	0.308 **
P. latifrons	5.494	0.004 **
E. diomedeae	1.436	0.239 NS
E. sibogae	12.657	0.000 **
E. tenera	32.232	0.000 **
E. pseudogibba	1.932	0.146 NS
N. gracilis	11.442	0.000 **
N. flexipes	29.652	0.000 **
S. armatum	54.627	0.000 **
S. affine	2.216	0.110 NS
S. suhmii	4.140	0.016 *
S. microphthalma	0.212	0.809 NS
S. longicorne	15.309	0.000 **
S. abbreviatum	9.516	0.000 **
Total euphausiids	1.295	0.275 NS

** : Significant at 1% level, * : Significant at 5% level, NS : Not significant.

Highest biodiversity measures were recorded during premonsoon period and the lowest values were recorded during monsoon period (Fig. 61). All the biodiversity measures except AvTD and VarTD showed statistically significant (P < 0.001) variation with season (Table 5). Bray-Curtis similarities of biodiversity measures showed two different clusters for seasons (Fig. 60). Monsoon period formed one cluster while premonsoon and postmonsoon period formed the second cluster.

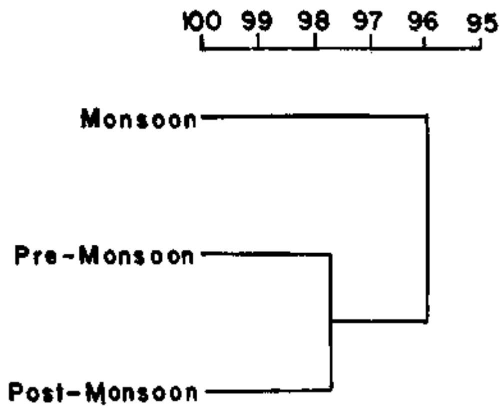

Fig. 60. Dendrograms for clustering of Bray-Curtis similarities based on square root transferred biodiversity data for different seasons calculated using PRIMER.

Table 5. *Results of ANOVA test between biodiversity indices and seasonal variations from the EEZ of India*

Biodiversity indices	F-ratio	P
Species (S)	37.128	0.000 **
Brillouin index (H)	33.267	0.000 **
Margalef's species richness (d)	36.588	0.000 **
Pielou's evenness	11.910	0.000 **
Shannon (H')	33.150	0.000 **
Simpson Index	37.128	0.000 **
AvTD	3.973	0.019 *
VarTD	4.509	0.012 *

** : Significant at 1% level, * : Significant at 5% level.

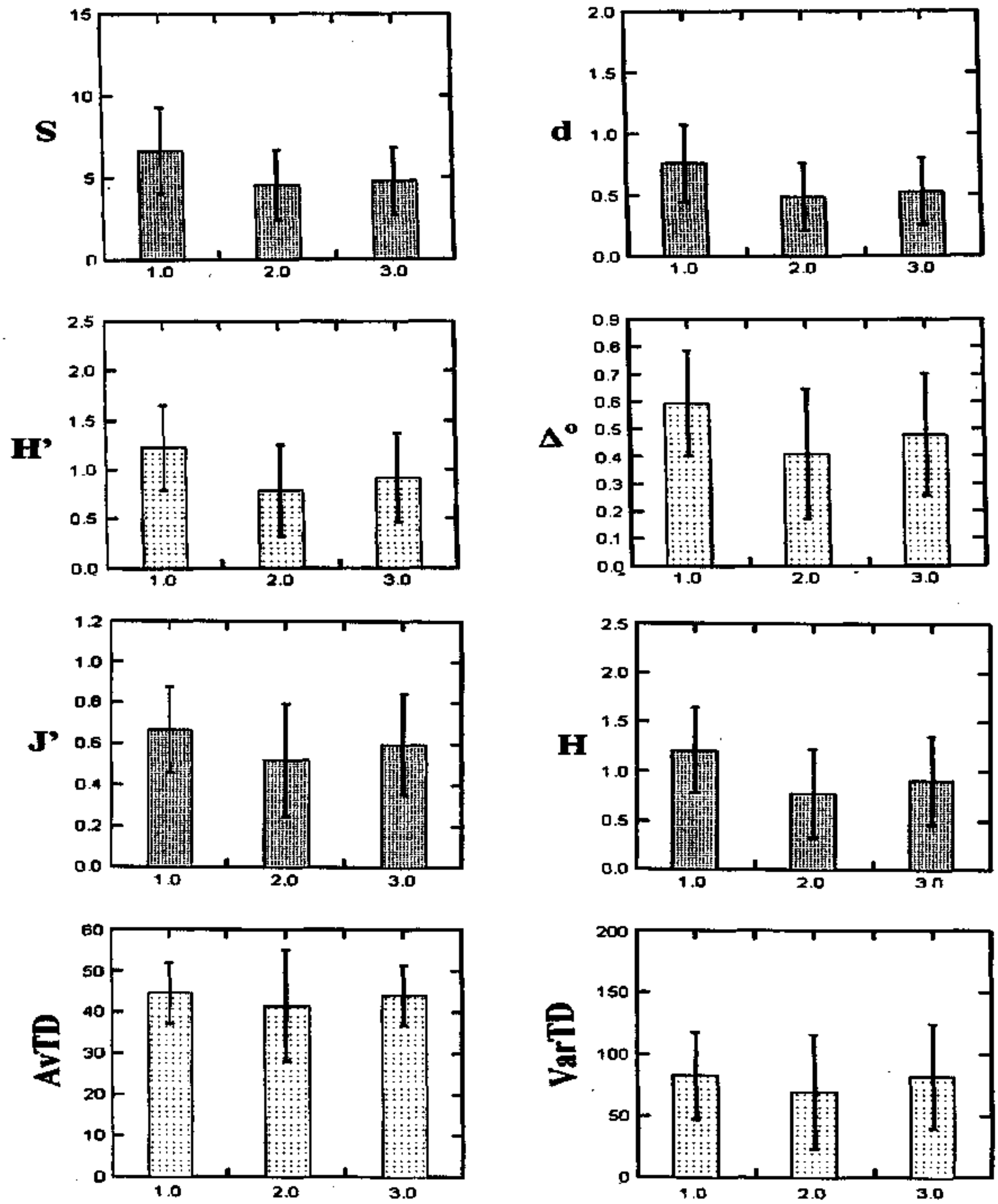

Fig. 60. Seasonwise variations (1. Premonsoon; 2. Monsoon; 3. Postmonsoon) in eight biodiversity measures such as Species (S), Margalef's species richness (d), Shannon-Weiner index (H'), Simpson diversity index (Δ°), Pielou's evenness (J'), Brillouin index (H), Average taxonomic distinctness (AvTD, Δ*) and Variations in Taxonomic Distinctness (VarTD, *Λ) calculated using PRIMER from the species abundance distribution for 491 stations from the EEZ of India.

7

DEPTHWISE VARIATIONS IN ABUNDANCE

The area of investigation has a water depth varying from 24 to 4,619 m and the sampling was done from 150 to surface at those stations where the depth to bottom exceeded 150 m whereas in shallow stations it was done from 5 m above bottom to the surface. The euphausiids being mainly offshore and oceanic, are seldom found in the inshore waters close to the coasts. In the areas of their distribution they used to show variations in populations according to the depth of the water column. While certain species are more abundant within the shelf waters others may have their abundance in areas away from the shelf. Some species may not visit the shelf waters while some others may intrude there occasionally according to the changes in the environment in certain seasons.

In order to understand the preferred areas of their occurrence from nearshore to the offshore waters the total area was divided into five depth zones such as, upto 50 m, 51 to 100 m, 101 to 200 m, 201-1,000 m and above 1,000 m. Of these five, the first three depth zones are within the continental shelf where variations in abundance is rather a rule due to frequent and drastic changes in the environment.

When euphausiids as a whole were considered the maximum abundance in population was noticed in the 51-100 m zone where the population showed an average density of 3,942 per 1000 m^3 of water (Fig. 62). The next zone of abundance

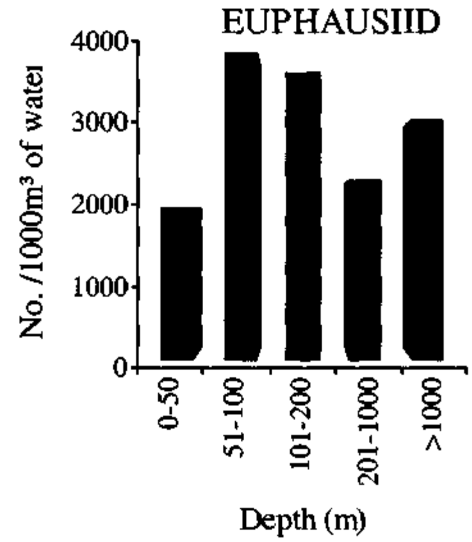

Fig. 62. Depthwise variations in the abundance of total euphausiids.

extended from 101 m to the edge of the continental shelf where the euphausiids occurred at an average rate of 3,309 per 1000 m^3 of water. In the continental slope and pure oceanic waters also significant variations in the rate of occurrence was observed. The least abundance was noticed in the depth zone upto 50 m where they occurred at a rate of 1,946 per 1000 m^3 of water.

The study may not be complete unless the depthwise variations of individual species is also not worked out, for there could be a preferred zone for each species. *T. monacantha* (Fig. 63) which is known to be

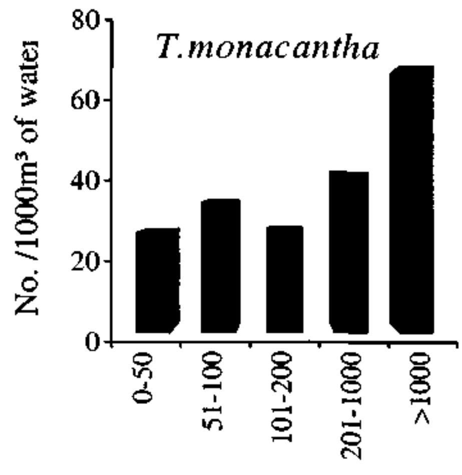

Fig. 63. Depthwise variations in the abundance of *T. monacantha*.

a purely oceanic species had its abundance in depth zones away from the continental shelf while a few of them occurred in the continental slope area also. The highest abundance of 70 per 1000 m^3 of water was in areas having a water depth of more than 1,000 m. The continental slope area contained around 40 per 1000 m^3 of water while in the other three depth zones the population ranged between 26 and 40 per 1000 m^3 of water.

T. tricuspidata which is more of a surface living species occurred in greater concentration (742 per 1000 m^3) upto 50 m depth though it was not wide spread there. From 100 m to the edge of the continental shelf also the species was rather abundant (218/1000 m^3). In the depth zone beyond

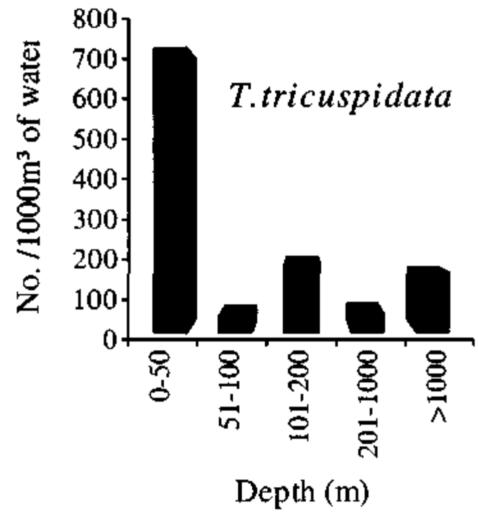

Fig. 64. Depthwise variations in the abundance of *T. tricuspidata*.

1000 m the species occurred at a rate of 151 per 1000 m^3 of water (Fig. 64).

P. latifrons (Fig. 65) which is a neritic species found more closer to the coastal areas

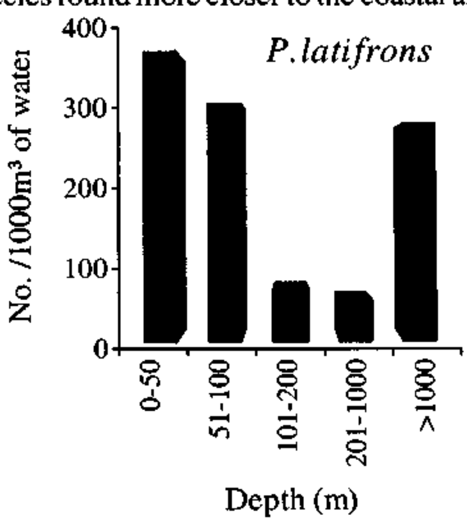

Fig. 65. Depthwise variations in the abundance of *P. latifrons*.

had its maximum abundance of 379 per 1000 m^3 of water in the depth zone upto 50 m followed by the next immediate zone upto 100 m. However, high density of this species at a rate of 284 per 1000 m^3 of water in the extreme oceanic regime beyond 1000 m depth was observed. But the fact that their presence was in the neritic waters around the Lakshadweep islands justify their occurrence in the mid ocean.

E. diomedeae was abundant in the shelf as well as in the oceanic waters. In the shelf waters its preferred area was that which had a water depth between 51 and 100 m where it occurred at a rate of 1,300 per 1000 m^3 of water (Fig. 66). A similar abundance was noticed in the far oceanic zone having more than 1000 m depth. The least abundance

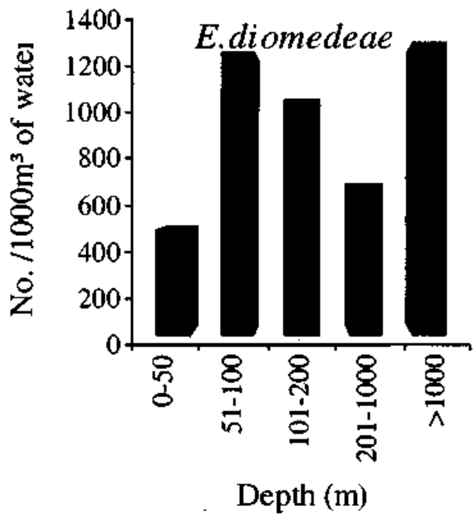

Fig. 66. Depthwise variations in the abundance of *E. diomedeae*.

was in the shelf area closer to the shore upto 50 m.

E. sibogae, the most abundant species was comparatively more in the shelf waters. The species came closer to the coast than the second abundant species *E. diomedeae* i.e.

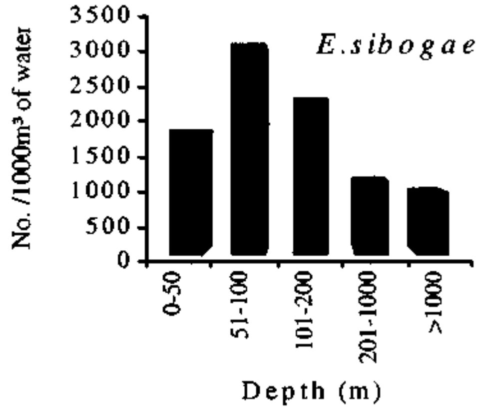

Fig. 67. Depthwise variations in the abundance of *E. sibogae*.

upto 50 m where it occurred at the rate of 1,867 per 1000 m^3 of water (Fig. 67). For this species also the second zone of 51-100 m was found to be the most preferred zone where the population showed an average density of 3,180 per 1000 m^3 of water. It was fairly abundant in the continental slope region also but comparatively less beyond the continental shelf.

Being a purely oceanic species *E. tenera* was least represented in the continental shelf

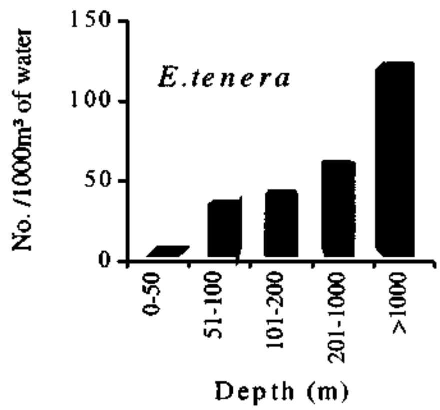

Fig. 68. Depthwise variations in the abundance of *E. tenera*.

waters. The highest number of 126 per 1000 m^3 of water was in the zone beyond 1000 m depth (Fig. 68). *E. pseudogibba* another offshore species had its maximum abundance of 446 per 1000 m^3 of water in the zone between 51 and 100 m.

N. gracilis, another widely occurring species in the Arabian Sea made its presence from the shallow to the far oceanic waters. Its maximum abundance was in the zone

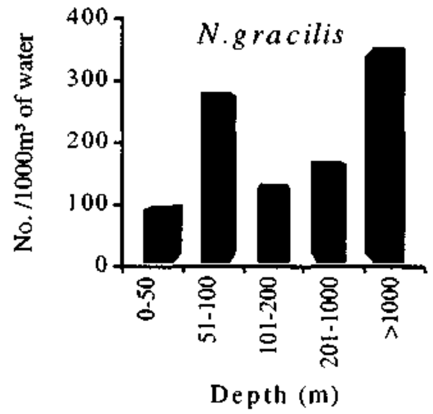

Fig. 69. Depthwise variations in the abundance of *N. gracilis*.

beyond 1000 m where its rate of occurrence was 359 per 1000 m^3 of water (Fig. 69). It

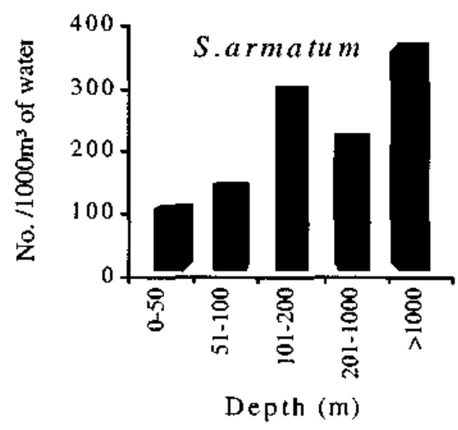

Fig. 70. Depthwise variations in the abundance of *S. armatum*.

occurred at moderate rate in the shelf waters and there itself the least was in the zone upto 50 m.

Another species present almost in all depth zones was *S. armatum* (Fig. 70). Its maximum abundance was in the oceanic waters where it occurred at a rate of 372 per 1000 m^3 of water. In the shelf waters from 101 per 1000 m^3 of water in the 0-50 m zone the species gradually increased to 328 per 1000 m^3 of water in the 101 to 200 m zone.

Yet another species having a cosmopolitan

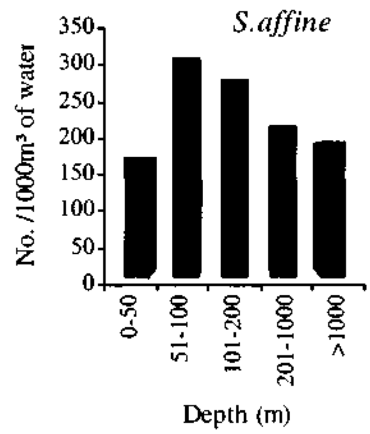

Fig. 71. Depthwise variations in the abundance of *S. affine*.

distribution in the study area was *S. affine*. The members of this species were almost uniformly distributed in the area from the nearshore to the farthest stations (Fig. 71). Its maximum density was in the 51-100 m depth zone.

Among the minor species *T. astylata* and *S. microphthalma* were recorded only from oceanic waters and that too from the depth zone beyond 1000 m and the abundance respectively was of the order of 48 and 10 per 1000 m^3 of water. Two species namely

N. flexipes and *S. suhmii* had their abundance within the shelf in the zone between 51 and 100 m. *S. longicorne* though present in few numbers within the shelf waters had its maximum abundance in the zone between 201 and 1,000 m. In the pattern of depthwise abundance in the shelf waters *S. abbreviatum* resembled *S. longicorne* but its maximum abundance was in the zone beyond 1,000 m. *S. maximum* was taken only once at a station where the water column measured 1,800 m.

The test of significance carried out for the depthwise occurrence of the various species and total euphausiids indicated high significance (P<1) in the case of those species of cosmopolitan occurrence (Table 6). For all those which were present exclusively in the oceanic area, the variations on account of depth difference were not significant. When the euphausiids were considered in

Table 6. *Test of significance for variation in occurrence in various depth ranges for different species and euphausiids in general*

Species	F-ratio	P
T. aequalis	0.708	0.587 NS
T. monacantha	15.960	0.000 **
T. tricuspidata	8.830	0.000 **
P. latifrons	4.438	0.002 **
E. diomedeae	12.463	0.000 **
E. sibogae	7.352	0.000 **
E. tenera	6.302	0.000 **
E. pseudogibba	1.159	0.328 NS
N .gracilis	9.466	0.000 **
N. flexipes	1.588	0.176 NS
S. armatum	16.461	0.000 **
S. affine	3.180	0.013 **
S. suhmi	0.326	0.860 NS
S. microphthalma	1.149	0.333 NS
S. longicorne	2.180	0.070 NS
S. abbreviatum	2.377	0.051 NS
Total euphausiids	1.208	0.307 N.S

** : Significant at 1% level, NS.: Not significant.

Table 7. *Results of ANOVA test between biodiversity indices and depthwise variations from the EEZ of India*

Biodiversity indices	F-ratio	P
Species (S)	46.933	0.000 **
Brillouin index (H)	28.774	0.000 **
Margalef's species richness (d)	50.947	0.000 **
Pielou's evenness	6.309	0.000 **
Shannon (H')	29.009	0.000 **
Simpson Index	21.168	0.000 **
AvTD	13.439	0.000 **
VarTD	25.004	0.000 **

** : Significant at 1% level.

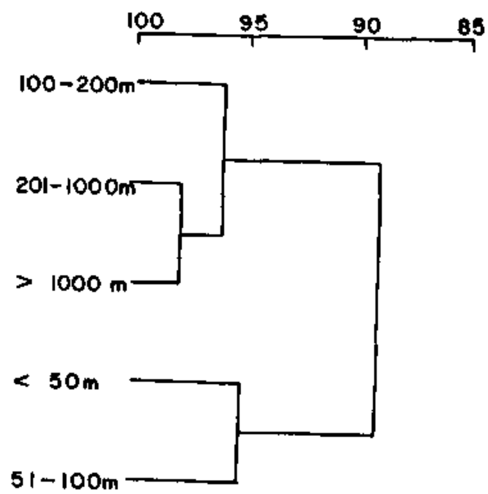

Fig. 72 Dendrograms for clustering of Bray-Curtis similarities based on square root transferred biodiversity data for different depth ranges calculated using PRIMER.

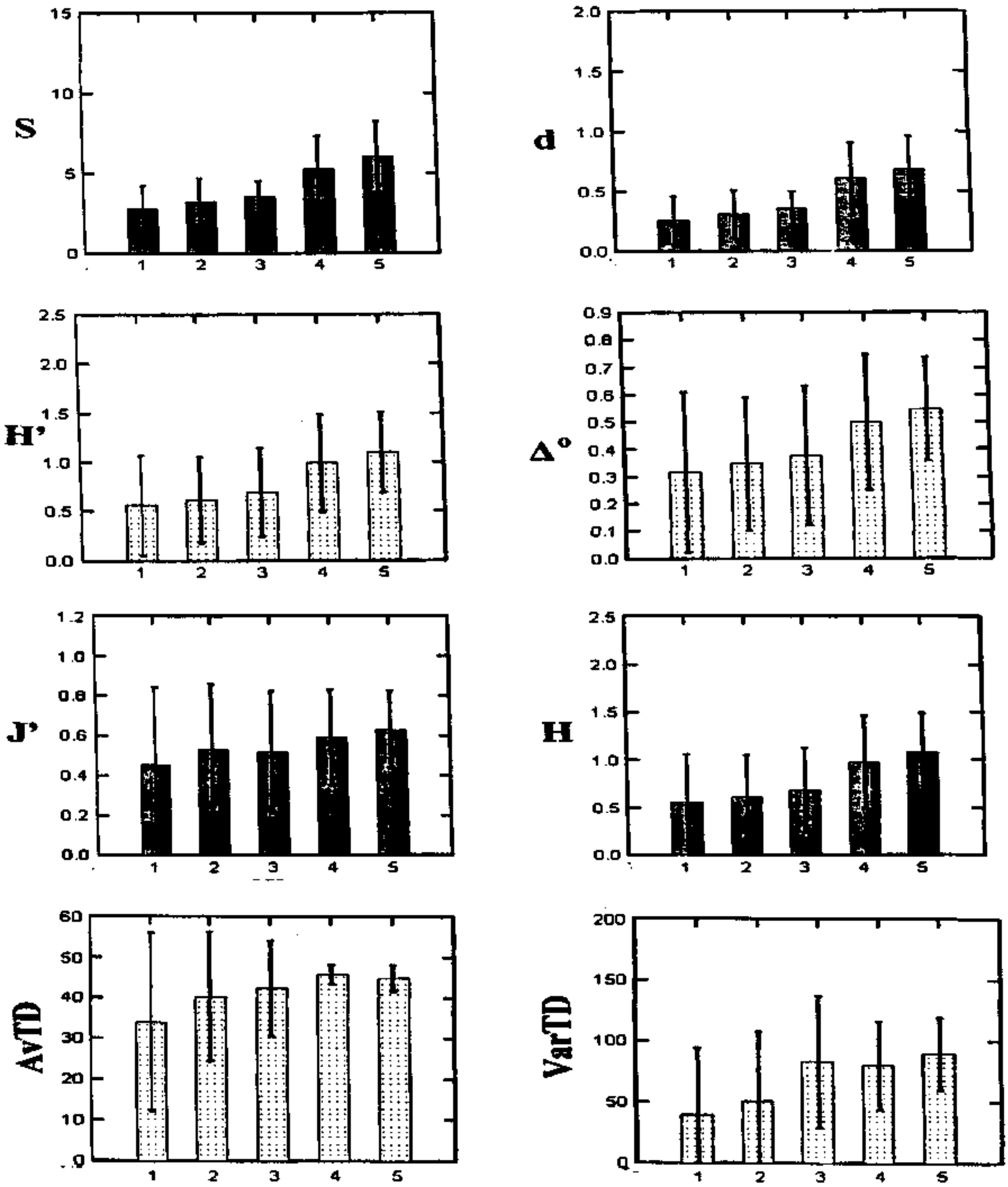

Fig. 73. Depthwise variations (1. <50m; 2. 51-100m; 3. 101-200 m; 4. 201-1000 m; 5.> 1000m) in eight biodiversity measures such as species (S), Margalef's Species richness (d), Shannon-Weiner index (H'), Simpson diversity Index (Δ°), Pielou's evenness (J'), Brillouin index (H), Average taxonomic distinctness (AvTD, Δ*) and Variations in taxonomic distinctness (VarTD, *Λ) calculated using PRIMER from the species abundance distribution for 491 stations from the EEZ of India.

total, significant variations could not be found for their depthwise occurrence.

All biodiversity measures showed increasing trends with station depths and the highest biodiversity measures were registered for the station having >1000m depth (Fig. 73). All the biodiversity measures showed statistically significant ($P < 0.001$) variation with depth (Table 7). Bray-Curtis similarities of biodiversity measures showed two different clusters for sampling depths (Fig. 72). Stations having depth 100 – 200 m, 201-1000m and >1000m formed one cluster, while the shallow stations (<50m and 51-100m) formed the second cluster. The study reveals high species diversity in areas where water depth was more that 1000 m. This may be due to high frequency disturbances in the shallow waters from environmental factors. Low diversity in shallow shelf and contiguous areas may be due to high frequency disturbances in those areas from environmental factors.

8

DISTRIBUTION IN SHELF AND OCEANIC WATERS

The euphausiids are typically oceanic forms. However, certain species live somewhat closer to the coast and such species very often occur in large numbers, being sustained by the high rate of productivity in the neritic waters. The contiental shelf edge and slope areas are significant for euphausiid occurrence. As one moves perpendicular to the coast, drastic changes occur in the environment and such changes are manifested maximum within the continental shelf waters on account of fertility and production at all the levels of the food web; all being caused mainly by the process of upwelling wherever it occurs. The oceanic waters are relatively stable in properties and the thermocline also remains rather deep. All such variable factors could influence the euphausiids also. In order to have a broad idea about the distributional differences of euphausiids in the shelf and oceanic waters a separate study was made.

The study revealed an almost balanced situation in the population of euphausiids in the shelf and oceanic areas, eventhough the shelf outweighed the oceanic to a certain extent. In the shelf while the euphausiids occurred at a rate of 3,440 per 1000 m^3 of water it was 3,065 in the oceanic the difference being 5.76 % (Fig. 74). In a study made by Mathew *et al.* (1990) for the same area he obtained at a rate of 5,326 per 1000 m^3 of water in the shelf and at a rate of 2,907 in the oceanic waters. However, in both the cases the shelf contained more euphausiids.

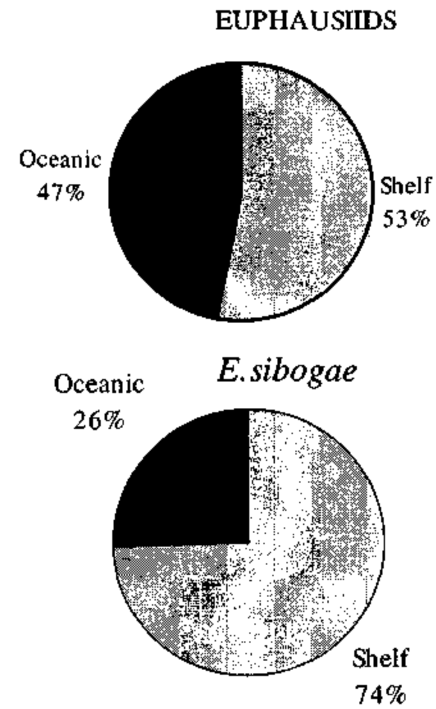

Fig. 74. Distribution of total euphausiids and *E. sibogae* in the shelf and oceanic waters.

Among the species there are neritic and oceanic forms. Some species seldom visit the shelf areas at any stage of their life. However, some such oceanic species may reach some distance in the shelf but they may sustain a very low density there. The high density species are rather cosmopolitan in distribution. The most populous species *E. sibogae* (Fig. 74) had an almost three fold

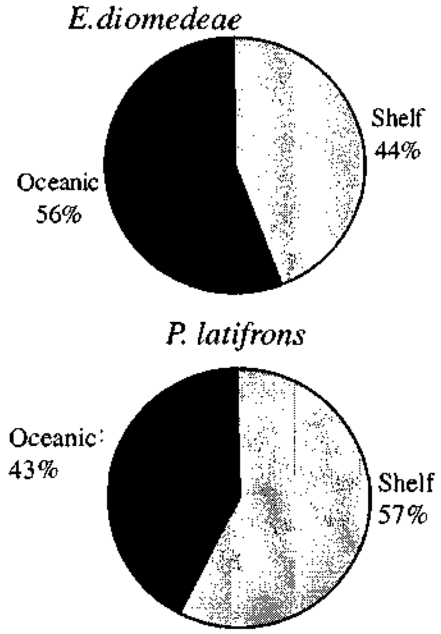

Fig. 75. Distribution of *P. latifrons* and *E.diomedeae* in the shelf and oceanic waters.

increase in the shelf; their average number there being 2,880 per 1000 m^3 of water which amounted to 73.70 % of the species population. Its oceanic representation was at a rate of 996 only. The next in abundance, *E. diomedeae* (Fig. 75) was marginally more in the oceanic waters the respective number in the shelf and oceanic being 1,010 and 1,295 per 1000 m^3 of water. In *P. latifrons* (Fig. 75) the density in the shelf waters was at a rate of 312 which was equal to 57.14 % of its total population. The shelf abundance of this rather neritic species was not to its expected rate but that it was abundantly present in the neritic waters of the oceanic Lakshadweep islands is one reason for its rich population in the oceanic areas. *N. gracilis* was more in the oceanic realm where the rate of occurrence was 340 per 1000 m^3 of water and this equalled 61.26 % of its total population (Fig. 76). *S. armatum* (Fig. 76) with a rate of 363 per

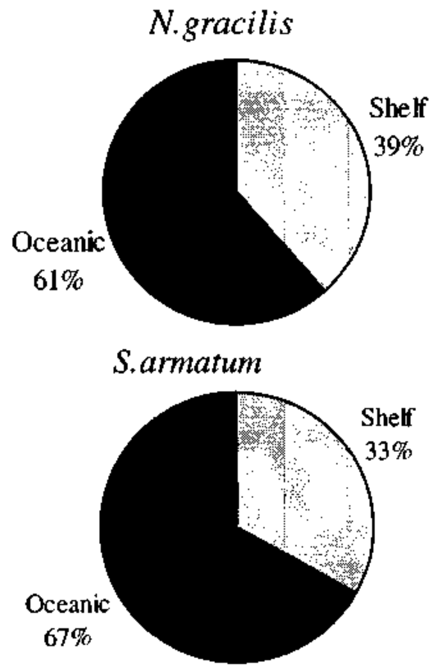

Fig. 76. Distribution of *N. gracilis* and *S. armatum* in the shelf and oceanic waters.

1000 m^3 of water in the oceanic waters formed 66.96 % which was almost similar to that of *N. gracilis*. *S. affine* (Fig. 77) behaved in an opposite manner to the previous two species in that it was more abundant in the shelf waters and percentage wise the species came nearer to *P. latifrons*. In the shelf waters the species occurred at a rate of 276 per 1000 m^3 of water which was equal to 57.62 % of the total. On the

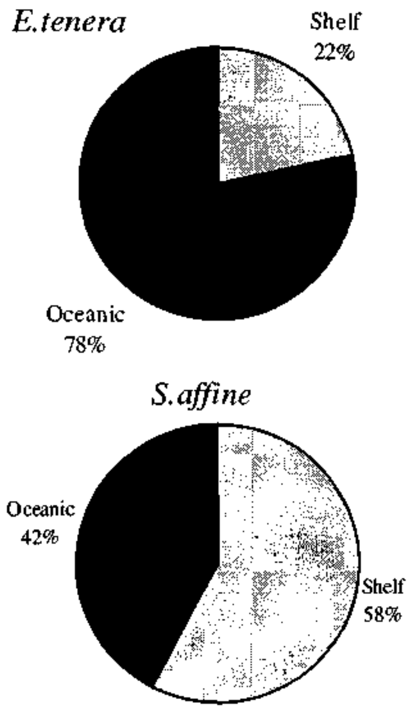

Fig. 77. Distribution of *E. tenera* and *S. affine* in the shelf and oceanic waters.

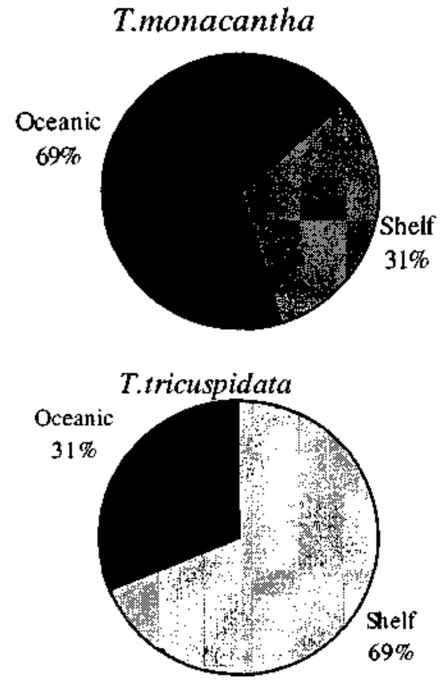

Fig. 78. Distribution of *T. monacantha* and *T. tricuspidata* in the shelf and oceanic waters.

other hand *E. tenera* (Fig. 77) occurred mostly in the oceanic waters (120 per 1000 m^3 of water) against a shelf component of 72. *T. monacantha* (Fig. 78) and *T. tricuspidata* (Fig. 78) which were mostly represented by their larval and juvenile stages behaved opposingly in the two environments regarding the percentage of occurrence eventhough the density of populations differed drastically. In the shelf the latter species increased by a certain percentage while the former decreased its population by similar percentage and *vice versa*.

Other species namely *T. astylata, N. flexipes, S. longicorne, S. suhmii, S. microphthalma, S. abbreviatum* and *S. maximum* were present only in the oceanic waters and hence a comparative study is not warranted.

Table 8. *Test of significance for variation in occurrence between shelf and oceanic areas for different species and euphausiids in general*

Species	F-ratio	P
T. monacantha	45.144	0.000 **
T. tricuspidata	22.627	0.000 **
P. latifrons	14.513	0.000 **
E. diomedeae	46.557	0.000 **
E. sibogae	18.251	0.000 **
E. tenera	19.971	0.000 **
N. gracilis	28.853	0.000 **
S. armatum	9.395	0.002 **
S. affine	10.53	0.001 **
Total euphausiids	0.341	0.560NS

** : Significant at 1% level, NS: Not significant.

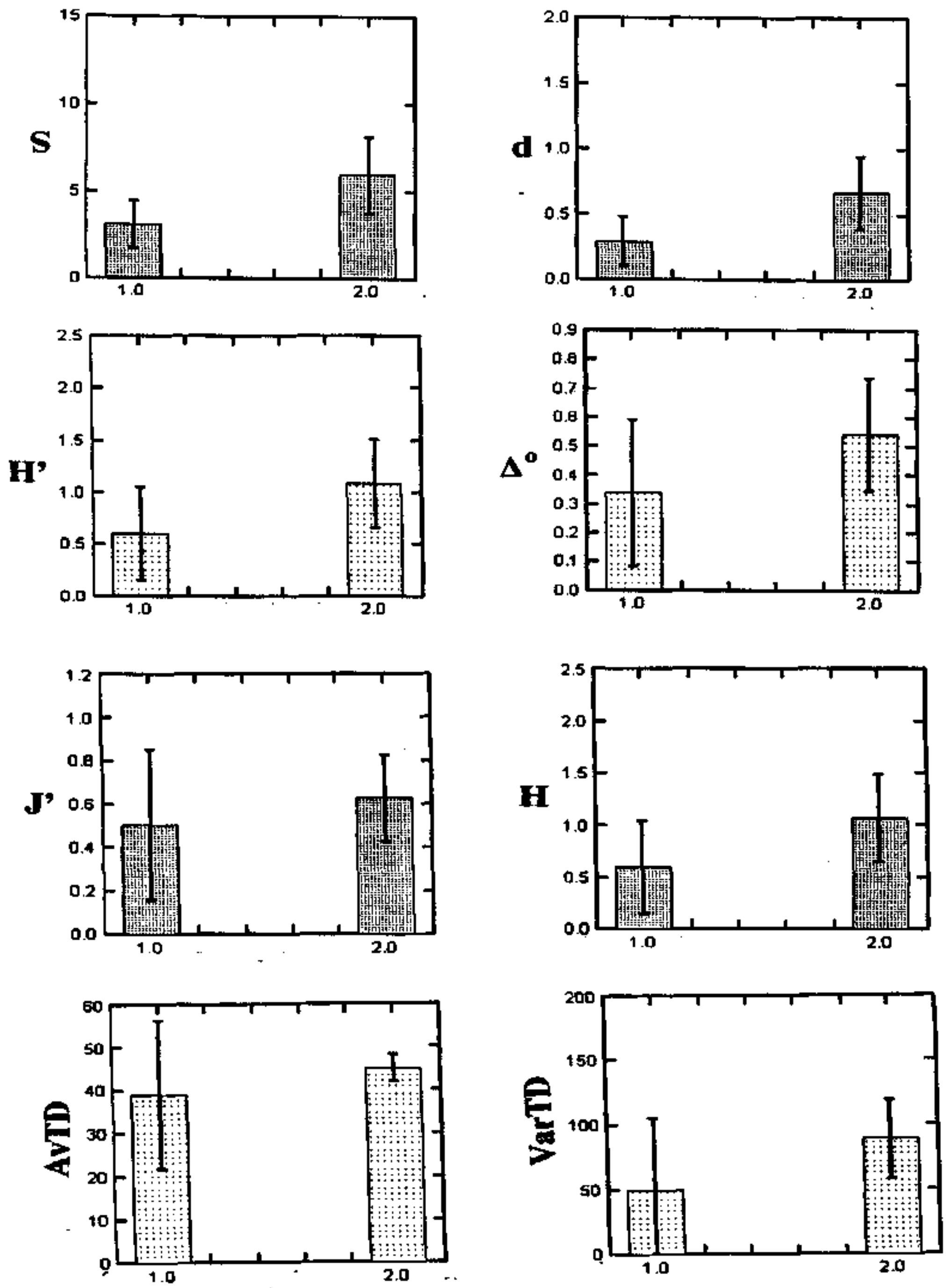

Fig. 79. Areawise variations (1. Shelf; 2. Oceanic) in eight biodiversity measures such as species (S), Margalef's species richness (d), Shannon-Weiner index (H'), Simpson diversity index (Δ°), Pielou's evenness (J'), Brillouin index (H), Average taxonomic distinctness (AvTD, Λ*) and Variations in taxonomic distinctness (VarTD, *Λ) calculated using PRIMER from the species abundance distribution for 491 stations from the EEZ of India.

Table 9. *Results of ANOVA test between biodiversity indices and shelf/oceanic* variations from the EEZ of India

Biodiversity indices	F-ratio	P
Species (S)	183.258	0.000 **
Brillouin index (H)	114.998	0.000 **
Margalef's species richness (d)	199.015	0.000 **
Pielou's evenness	23.503	0.000 **
Shannon (H')	115.828	0.000 **
Simpson index	86.002	0.000 **
AvTD	39.871	0.000 **
VarTD	96.872	0.000 **

** : Significant at 1% level.

The variations of euphausiids in total and different species in particular in the shelf and oceanic were subjected to verification statistically (Table 8) and it was found highly significant in the case of all species whose members occurred in the two environments. However, when the total euphausiids were considered a significant shelf oceanic variation was not evident suggesting, as mentioned earlier, that there was an overall well balanced situation prevailing in the study area with regard to the euphausiid population.

High biodiversity measures were recorded in oceanic waters compared to shelf waters (Fig. 79). All the biodiversity measures were significantly ($P < 0.001$) high in oceanic waters compared to shelf waters (Table 9).

9

LATITUDINAL VARIATIONS IN ABUNDANCE

In the Indian Ocean the region north of 10°N latitude consists of the Arabian Sea and the Bay of Bengal which are closed at the northern ends and according to Brinton and Gopalakrishnan (1973) these sea areas are dominated by coastal species of euphausiids. The abundance of these coastal forms has indicated that these waters are coastal in quality. Therefore the list of euphausiids obtained during the International Indian Ocean Expedition from the Arabian Sea and the Bay of Bengal was very small. The significance of the 10°N latitude in terms of the distribution of euphausiids has been adequately discussed by Brinton and Gopalakrishnan (1973) and Mauchline (1980). Brinton and Gopalakrishnan have found the 10°N as an effective barrier against the penetration of many of the true oceanic species northwards. Thus about 10 tropical and subtropical circum-global species did not occur in their collection north of this latitudinal barrier. However, the study of Mathew (1980e, 1982) and Silas and Mathew (1986) proved that the results of the study by Brinton and Gopalakrishnan (1973) are not altogether correct for they obtained species namely *T. monacantha, T. tricuspidata* and *N. flexipes* further north of 10°N. While Brinton and Gopalakrishnan studied material mostly collected from above 200 m depth, Mathew (1980e, 1982) and Silas and Mathew (1986) examined samples collected from upto 1,300 m depth which indicated large scale presence of deep water euphausiids even north of 10°N. Such occurrences of deep water species may be attributed to the high salinity water in the deeper strata of the Arabian Sea brought from the inner Gulf (Persian Gulf, Suez Gulf etc). This cold water with high salinity formed by the considerable evaporation in the inner Gulf spreads on the bottom forming a layer in parts of the Arabian Sea (Dietrich 1973). This layer of water attracts the oceanic euphausiids towards north in the Arabian Sea. *Bentheuphausia amblyops* one of the deepest living euphausiids has been recorded by Mathew (1982) from 16°06'N 72°10'E at a depth of 1,000 m in the Arabian Sea.

In the present study species to species variations were observed in the occurrence and abundance of euphausiids latitudinally. In order to measure the magnitude of such variations, the study area was divided into four zones such as 06°00'N to 09°59'N, 10°00'N to 13°59'N, 14°00'N to 17°59'N and 18°00 to 23°00'N and the euphausiids in each latitudinal zone were pooled and averaged. The results are given in Figs. 80-88.

As far as euphausiids as a whole were concerned, from a maximum in the southernmost sector a gradual decrease in population was felt to the northernmost sector (Fig. 80). The maximum presence at a rate of 4,241 per 1000 m^3 of water was found in the southernmost sector. In the other sectors, from south to north the abundance was 2,944, 2,366 and 2,424 respectively, the last sector recording slightly more number than the one south of it.

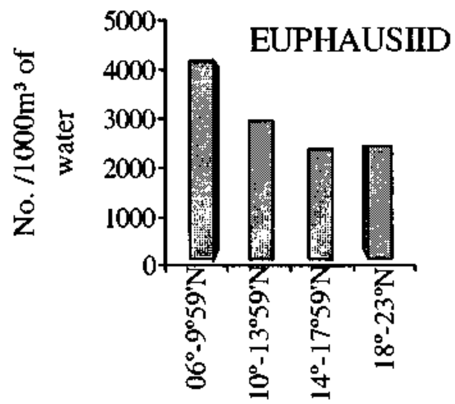

Fig. 80. Latitudinal variations in distribution of total euphausiids.

Six of the cosmopolitan species namely *P. latifrons*, *E. diomedeae*, *E. sibogae*, *N. gracilis*, *S. armatum* and *S. affine* were present in all the latitudinal sectors.

P. latifrons (Fig. 81) was relatively more in the first and last sectors. Its highest density of 501 per 1000 m^3 of water was in the southernmost sector. The second and third sectors had only a moderate population of around 140 per 1000 m^3 of water. From its level in the second and third sectors the

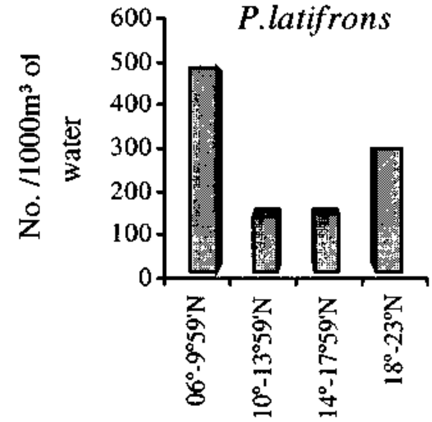

Fig. 81. Latitudinal variations in distribution of *P. latifrons*.

population almost doubled in the northernmost sector.

In the case of *E. diomedeae* (Fig. 82) its number in the southernmost sector got reduced to almost half in the second sector and in the succeeding sector the population got reduced to one fourth of that in the second sector and further north almost the same status quo was maintained. *E. sibogae* was found to be almost uniformly distributed in all the four latitudinal sectors with slight

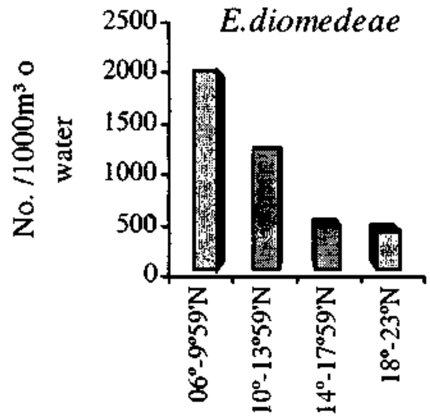

Fig. 82. Latitudinal variations in distribution of *E. diomedeae*.

variations (Fig. 83). The maximum abundance of 1,734 per 1000 m^3 of water was observed in the third sector. In the two

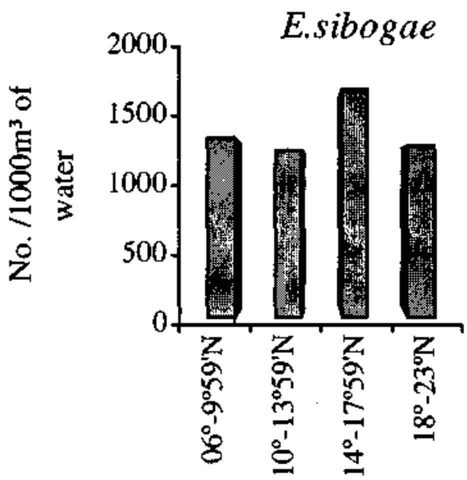

Fig. 83. Latitudinal variations in distribution of *E. sibogae*.

southern sectors the population remained somewhat levelled up. *E. tenera* occurred in the first and second latitudinal sectors only. While the population density of 161 per 1000 m^3 of water was observed in the southernmost sector, the sector north of it had a density of 60 per 1000 m^3 of water

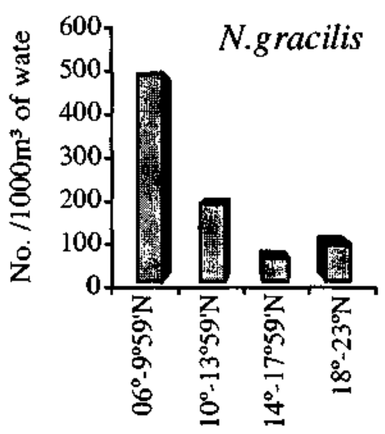

Fig. 84. Latitudinal variations in distribution of *N. gracilis*.

thus indicating a northward tapering of the population.

With regard to *N. gracilis* (Fig. 84) while the southernmost sector enjoyed a population density of 507 per 1000 m^3 of water it reduced to 55 in the third sector, only for a slight increase to 88 in the northernmost sector. Almost the same trend was indicated for *S. armatum* which showed the highest density of 531 in the first sector and the least of 85 in the third sector which increased to 103

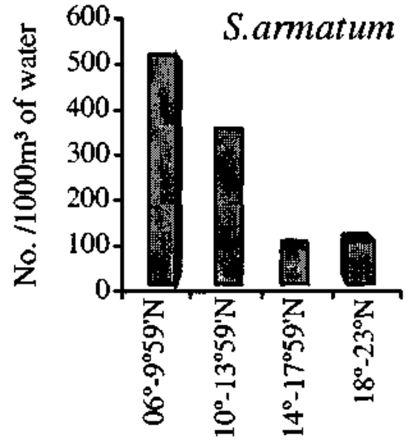

Fig. 85. Latitudinal variations in distribution of *S. armatum*.

per 1000 m^3 of water in the last sector (Fig. 85).

S. affine behaved differently from the other species in having the maximum of 320 per 1000 m^3 of water in the northernmost sector and from there the population showed a reduction towards the south (Fig. 86). However, the southernmost sector registered a two fold increase than the second sector

T. monacantha (Fig. 87) and *T. tricuspidata* (Fig. 88) were significant with their total absence in the last sector. The pattern of latitudinal abundance was almost the same for these two species with a little

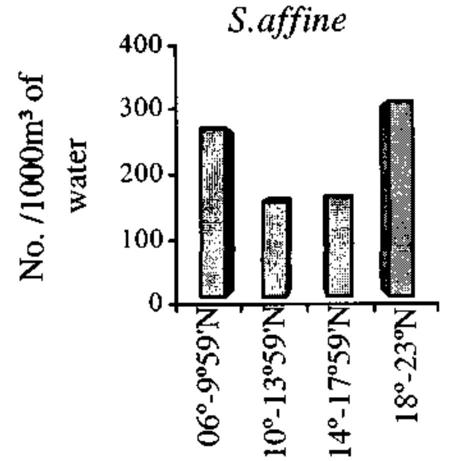

Fig. 86. Latitudinal variations in distribution of *S. affine*.

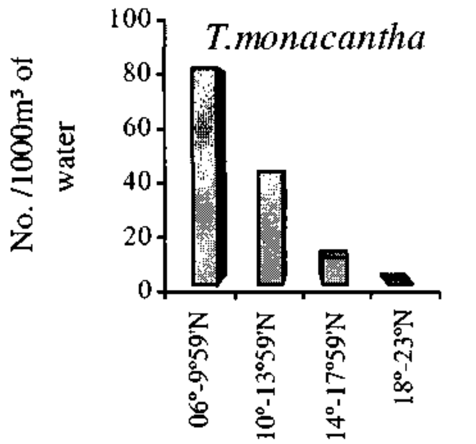

Fig. 87. Latitudinal variations in distribution of *T. monacantha*.

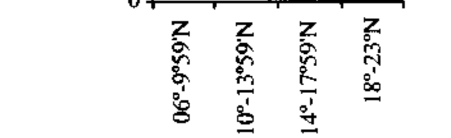

Fig. 88. Latitudinal variations in distribution of *T. tricuspidata*.

variation. Both the species rarely crossed the 13° N latitude.

Four other species which were totally absent in the northernmost sector were *T. astylata*, *N. flexipes*, *S. abbreviatum* and *S. maximum*. Of these, the last mentioned was taken only once from the second sector. *T. astylata* occurred in the southernmost sector at a rate of 51 per 1000 m^3 of water which was reduced to 32 in the second sector and registered nil in the next two sectors. A similar trend was noticed with *N. flexipes* also. The maximum density of *S. suhmii* was in the second sector from where it got tapered on either side. *S. microphthalma* was more in the southernmost sector and were rarely taken in the northern sector. *S. longicorne* was significant in that though it was a rare species its representatives were taken from all the four latitudinal sectors recording the largest concentration in the southernmost sector. *S. abbreviatum* from a density of 51 in the first sector was reduced to 4 per 1000 m^3 of water in the third sector being absent north of that.

In the Arabian Sea high salinity water is formed by the excess evaporation in the central and northern parts. Major part of this high saline water spreads southward during the southwest monsoon season and the other part sinks in the Arabian Sea and forms a subsurface salinity maximum layer in the upper part of the thermocline. Two other sources of high saline water, the outflow from the Persian Gulf and the Red Sea as mentioned earlier further strengthen the intermediate layers and occupies a depth range from about 150 to 900 m (Wyrtki 1973). This may be a favourable factor for the high occurrence of some of the euphausiid species in the northernmost sector when compared to the sector just south of that.

The latitudinal variations when tested statistically revealed very high significance (p<1) for majority of the species except *T. astylata, E. sibogae, S. microphthalma* (p<5) and *S. suhmii* and total euphausiids (p>5) (Table10).

Table 10. *Test of significance for variation in occurrence in various Latitudinal zones for different species and euphausiids in general*

Species	F-ratio	P
T. astylata	2.807	2.807 NS
T. monacantha	45.569	0.000 **
T. tricuspidata	23.931	0.000 **
P. latifrons	9.195	0.000 **
E. diomedeae	10.847	10.847NS
E. sibogae	2.786	0.040 *
E. tenera	16.909	0.000 **
N. gracilis	50.995	0.000 **
N. flexipes	7.754	0.000 **
S. armatum	20.857	0.000 **
S. affine	7.271	0.000 **
S. shumii	0.594	0.619 NS
S. microphthalma	3.781	0.011 *
S. longicorne	7.928	0.000 **
S. abbreviatum	18.037	0.000 **
Total euphausiids	0.572	0.634NS

** : Significant at 1% level. , * : Significant at 5% level, NS: Not significant.

Biodiversity measures such as S, d, H' and H showed decreasing trend while moving from south to north (06°-23 ° N), while such clear trend was not visible for other biodiversity measures such as Δ°, J', AvTD and VarTD (Fig. 90). All the biodiversity measures except Δ°, J', AvTD and VarTD showed statistically significant (P < 0.001) variation with latitude (Table 11). Bray-Curtis similarities of biodiversity measures showed two different clusters for latitude (Fig. 89). The southernmost stations (06-09° 59' N & 10-13° 59' N) formed one cluster, while the northernmost stations (14-17° 59' N & 18-23° 59' N) formed the second cluster. When considering latitudinally the biodiversity of Euphausiids decreased while moving from south to north.

Table 11. *Results of ANOVA test between biodiversity indices and latitudinal variations from the EEZ of India*

Biodiversity indices	F-ratio	P
Species (S)	33.176	0.000 **
Brillouin index (H)	10.566	0.000 **
Margalef's species richness (d)	21.442	0.000 **
Pielou's evenness	2.197	0.088 NS
Shannon (H')	10.144	0.000 **
Simpson Index	4.628	0.003 **
AvTD	2.546	0.055 NS
VarTD	2.358	0.071 NS

** : Significant at 1% level, NS : Not significant

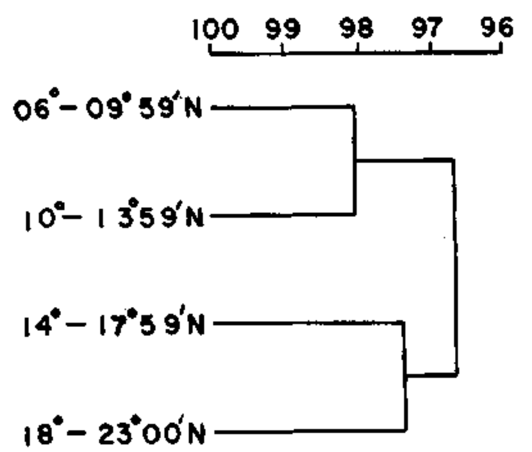

Fig. 89 Dendrograms for clustering of Bray-Curtis similarities based on square root transferred biodiversity data for different latitudes calculated using PRIMER.

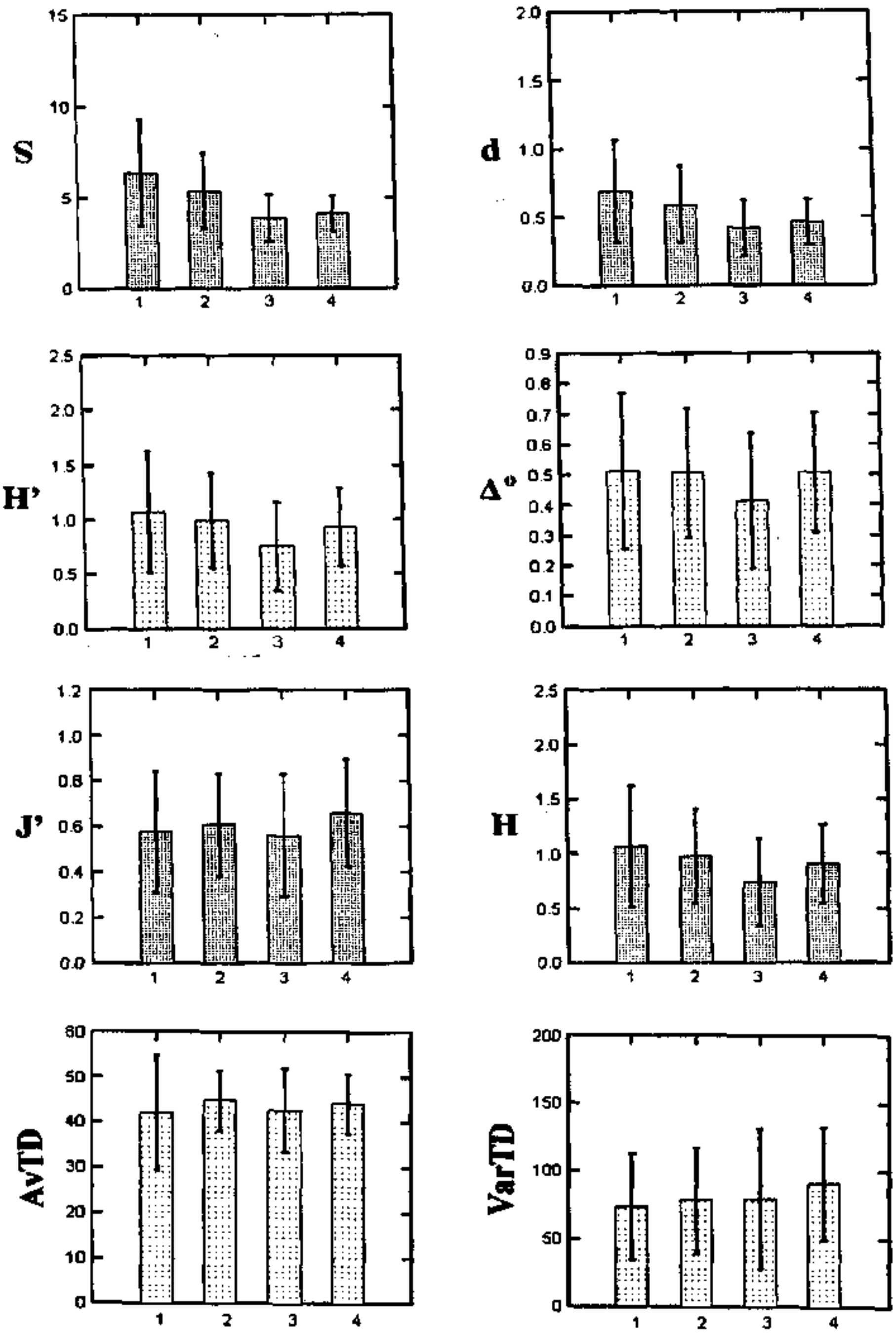

Fig. 90. Latitudewise variations (1. 06-09°59'N; 2. 10-13°59'N; 3. 14-17°59'N; 4. 18-23°59'N) in eight biodiversity measures such as species (S), Margalef's species richness (d), Shannon-Weiner index (H'), Simpson diversity index (Δ°), Pielou's evenness (J'), Brillouin index (H), Average taxonomic distinctness (AvTD, Δ*) and Variations in taxonomic distinctness (VarTD, *Λ) calculated using PRIMER from the species abundance distribution for 491 stations from the EEZ of India.

10

DAY/NIGHT VARIATIONS

The planktonic organisms especially the adults of almost all groups have a tendency to live in the deeper layers of water during the day time due to diverse reasons but mainly to avoid their presence in the day light which might make them visible to their enemies. However, the food of most zooplankters, (being phytoplankton) is produced in the euphotic zone and therefore for the purpose of feeding, these organisms have to visit the surface waters and they do it in the shade of darkness, and to effect this they perform diurnal vertical migration of varying distances. When the sun starts dipping in the afternoon the plankters begin swimming up being guided by the fading light. Similarly their downward journey is also guided by the intensifying light condition.

Various species of euphausiids prefer varying degrees of light so that each one occupy a particular depth during the day. Those which are more sensitive to light inhabit deeper waters and their day/night difference in occurrence in the epipelagic region will be felt stronger than those which are not very sensitive to light. Similarly the highly photosensitive species do not climb up all the way to the surface but may stop their migration somewhere in between where their preferred light intensity is present and such species would be least represented in the day samples.

The vertical distribution and the vertical migration performed by euphausiids have been extensively studied and the literature on the same is voluminous. These have been reviewed by Mauchline and Fisher (1969) and Mauchline (1980).

Studies conducted by some of the earlier authors show that the euphausiids dodge or sink at the sight of an approaching net during the day time (Tattersall 1924, Mackinthosh 1934, Hardy 1936, Barham 1957, Moore 1950, Brinton 1967b, Mathew 1988a). The avoidance capability may be evinced more by adults than larvae or juveniles. Therefore it becomes apparent that the numerical abundance of planktonic organisms in the night samples, especially the adult euphausiids, the larger species of which can perform active swimming, cannot be attributed to vertical migration alone.

It has been observed by some authors that larval euphausiids perform diurnal vertical migrations (Hardy and Gunther 1935, Lewis 1954, Mauchline 1959, Brinton

1967a, 1979). According to Lacroix (1961) nauplius, metanauplius and calyptopes do not apparently undertake true vertical migration. However, he found that older larvae performed more or less extensive migrations. The juvenile euphausiids also perform daily vertical migrations. Brinton (1967a, 1979) found that the juveniles of *E. pacifica* migrated between the surface layer at night and 170-265 m at day time. However, the degree of vertical migration differs greatly for the juveniles of different species.

The observed differences in the occurrence of euphausiids in the day/night samples according to Mathew (1982, 1988a) may also be due to the special pattern of euphausiid distribution in the water column at different times of the day. This points to some problems in the differential distribution of euphausiids in the water column during day or night. Mauchline and Fisher (1969) state that euphausiids are not randomly distributed throughout the water column and there is considerable evidence of patchiness in their microdistribution. During the day the euphausiids may swim down and aggregate in some convenient layer of the water column, determined mostly by the light conditions, and the net while towed vertically may sample, during most of its course, waters devoid of euphausiids. Therefore the chances of trapping more number of euphausiids during the day time is minimised. During the night, the distribution being more diffused, the individuals occupy the entire water column or more in the upper layers. Such a pattern of distribution of the population (added with minimum avoidance of net during the night) enable the net to capture more number of euphausiids. However, in either case active diurnal vertical movements are involved towards the surface or away from the surface.

In the present studies the samples used were categorised into day and night. Out of the 493 samples 218 were collected during night time and the rest during day. An overall consideration of euphausiids as a group revealed a presence of 32 % during the day and 68 % during the night (Fig. 91 a). Mathew *et al.* (1990) also noticed a somewhat similar ratio of 33 to 67 % during day and night respectively. All the major species were represented more in the night samples. The magnitude of such differences are shown in Fig. (91 b-k) for the major species.

The maximum night abundance was exhibited by *E. diomedeae*, for which the percentages of occurrence during day and night hours were 21 and 79 respectively (Fig. 91 b). Brinton (1979) found *E. diomedeae* among the species which exhibited strong vertical migration. The least difference in the diurnal abundance was with *S. affine* (Fig. 91 c) of which the day abundance was 46 % against a night abundance of 54 %. Mathew (1982, 1988a) also observed least tendency for vertical migration with this species. Brinton who did detailed studies on the vertical migration of euphausiids of the California Current water (1967 b) and the eastern tropical Pacific found *S. affine* non-migratory. The juveniles and adults of this species of Canary Island (Baker, 1970) were found not to migrate vertically. Youngbluth (1975) sampling the

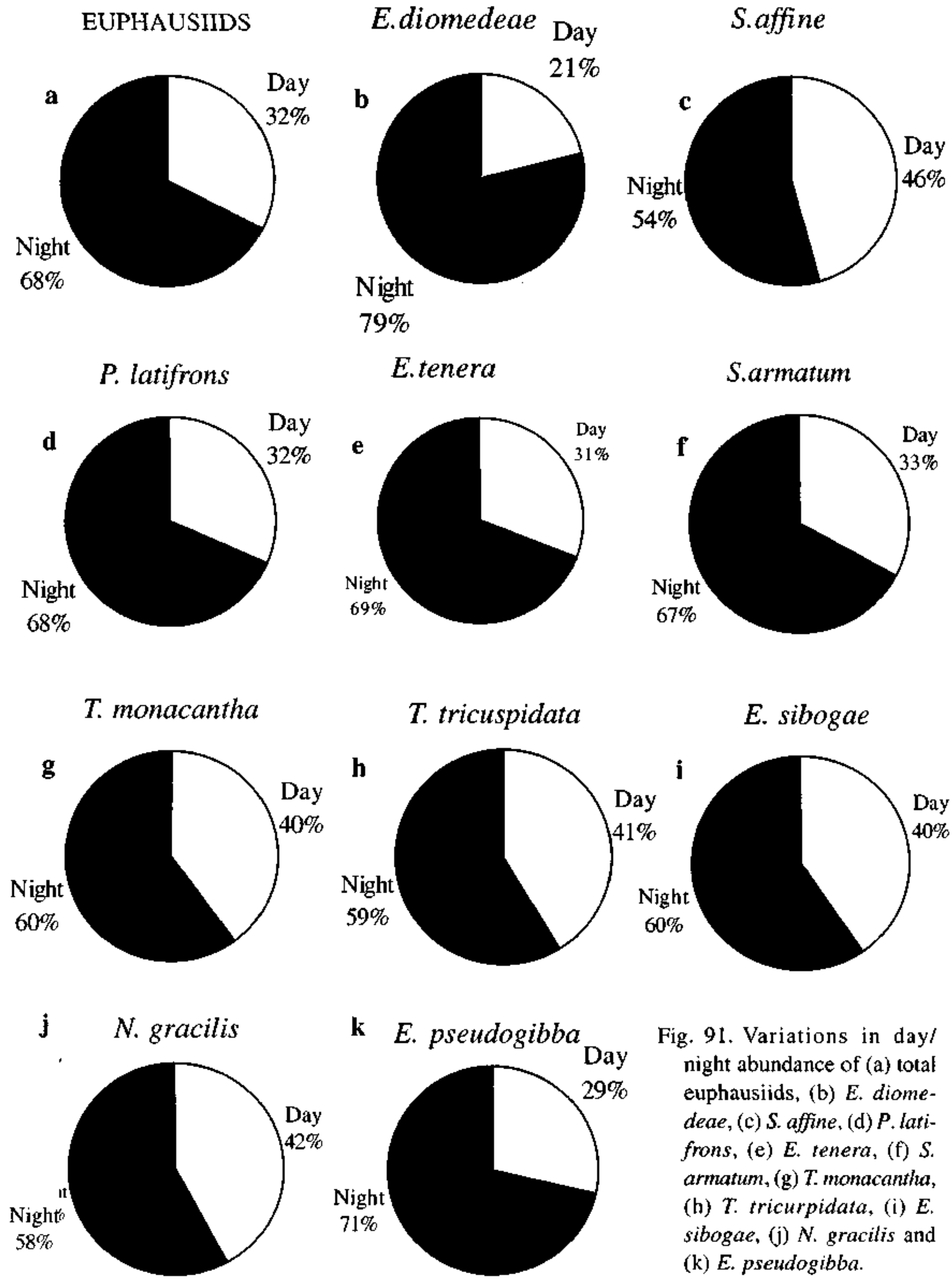

Fig. 91. Variations in day/night abundance of (a) total euphausiids, (b) *E. diomedeae*, (c) *S. affine*, (d) *P. latifrons*, (e) *E. tenera*, (f) *S. armatum*, (g) *T. monacantha*, (h) *T. tricurpidata*, (i) *E. sibogae*, (j) *N. gracilis* and (k) *E. pseudogibba*.

mid-subtropical south Pacific species found adult *S. affine* to occupy the same depth during day and night.

In the present studies, *P. latifrons* followed exactly the same trend as that of euphausiids as a whole (Fig. 91 d), *E. tenera* (Fig. 91 e) with *S. armatum* (Fig. 91 f) and *E. pseudogibba* (Fig. 91 k) closely following the general trend. An almost 60 % night and 40 % day abundance were exhibited by species like *T. monacantha* (Fig. 91 g), *T. tricuspidata* (Fig. 91 h) and *E. sibogae* (Fig. 91 i).

Table 12. *Test of significance for day night variations among different species and euphausiids*

Species	F-ratio	P
T. monacantha	3.123	0.078 NS
T. tricuspidata	4.593	0.033 *
T. astylata	6.504	0.001 *
P. latifrons	0.377	0.457NS
E. diomedeae	60.774	0.000 **
E. sibogae	4.113	0.045 *
E. tenera	22.266	0.000 **
E. pseudogibba	3.923	0.048 *
N. gracilis	1.323	0.251NS
N. flexipes	2.269	0.133NS
S. armatum	7.996	0.004 **
S. affine	0.889	0.346NS
S. shumii	0.861	0.369NS
S. microphthalma	2.878	0.090NS
S. longicorne	0.029	0.865NS
S. abbreviatum	3.737	0.054NS
Total euphausiids	1.240	0.000 **

** : Significant at 1% level, * : Significant at 5% level, NS : Not significant.

However, the reason for the least difference between the day and night occurrence in the case of the former two species which are strong vertical migrators may be due to their representation by larvae and juveniles which usually perform comparatively minimum vertical migration diurnally.

Table 13. *Results of ANOVA test between biodiversity indices and diurnal variations from the EEZ of India*

Biodiversity indices	F-ratio	P
Species (S)	3.696	0.055 NS
Brillouin index (H)	2.276	0.132 NS
Margalef's species richness (d)	0.004	0.948 NS
Pielou's evenness	0.674	0.010 *
Shannon (H')	2.589	0.108 N.S
Simpson Index	3.347	0.068 NS
AvTD	0.097	0.756 NS
VarTD	2.901	0.089 NS

* : Significant at 5% level, NS : Not significant.

N. gracilis (Fig. 91 j) as in the case of *S. affine* showed minimum difference between day and night. While 55 % of its population was caught during night, 42 % occurred in the day samples. *E. pseudogibba* (Fig. 91k) made a night time abundance of 71 % against a day time occurrence of 29 % indicating strong vertical migration in this species.

If a high degree of night time abundance can be considered as an index of the intensity in vertical migration, the major species considered for this study may be graded from actively to the least migrating as *E. diomedeae, E. pseudogibba, E. tenera, P. latifrons, S. armatum, E. sibogae, N. gracilis* and *S. affine*.

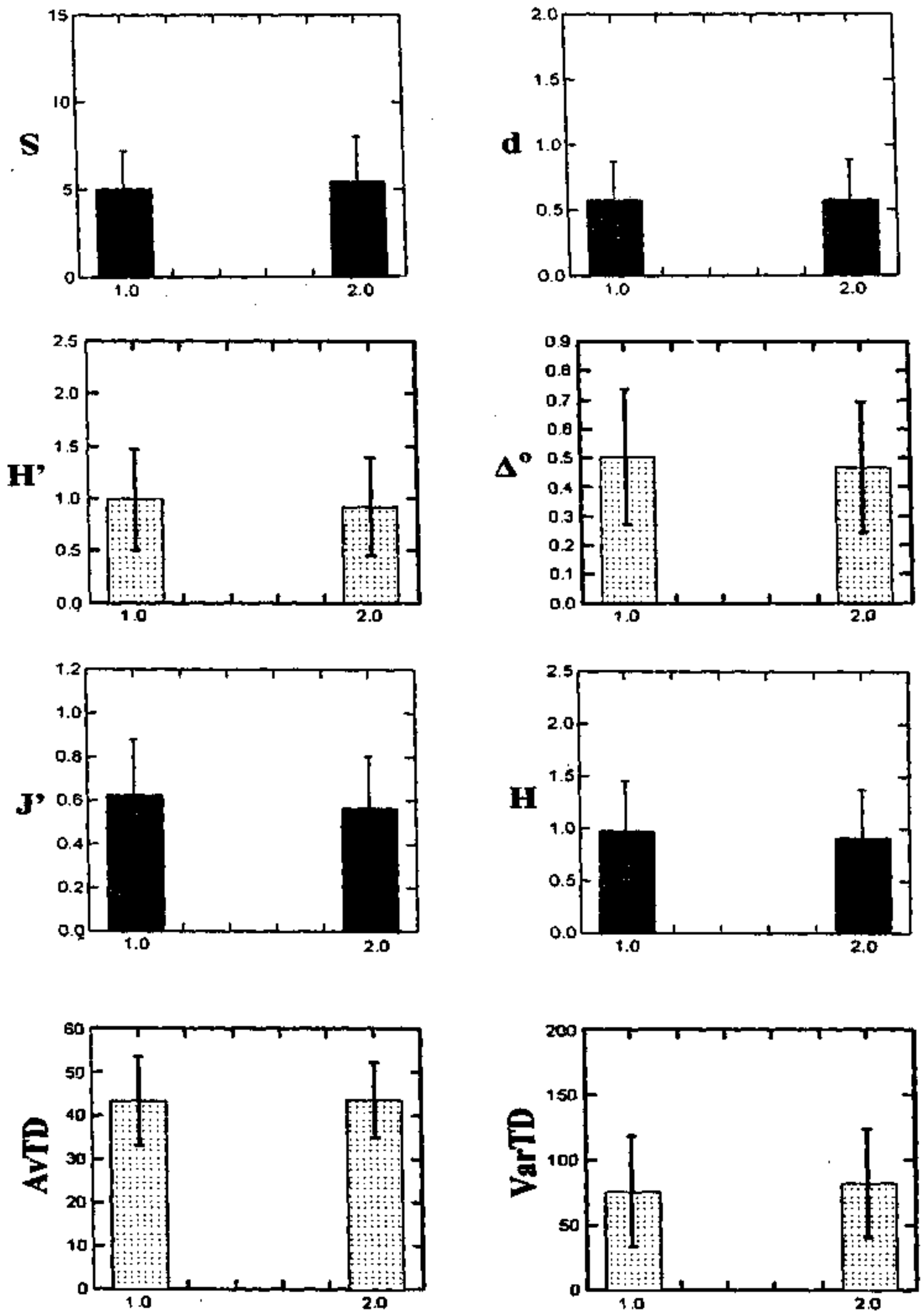

Fig. 92. Diurnal variations (1. Day; 2. Night) in eight biodiversity measures such as species (S), Margalef's species richness (d), Shannon-Weiner index (H'), Simpson diversity index (Δ°), Pielou's evenness (J'), Brillouin index (H), Average taxonomic distinctness (AvTD, Δ*) and Variations in taxonomic distinctness (VarTD, *Λ) calculated using PRIMER from the species abundance distribution for 491 stations from the EEZ of India.

A statistical analysis for testing the significance of the variations in occurrence for all the species between day and night revealed highly significant values at 1% and 5% levels for three species namely *E. diomedeae*, *E. tenera* and *S. armatum* and significant values at 5 % level for four species namely *T. aequalis*, *T. tricuspidata*, *E. sibogae* and *E. pseudogibba*. For all the other species the values were not significant (Table12).

Biodiversity measures such as H', J', Δ^o and H were high during daytime while other biodiversity measures were high during nighttime (Fig.92). None of the biodiversity measures showed statistically significant ($P < 0.001$) variation with diurnal changes (Table 13).

11

MONTHLY DAY/NIGHT VARIATIONS

Eventhough light is the major factor for the vertical migration among zooplankters the changes in the environment also can influence their up and down journey over a diurnal period. In order to understand the influence of environment on the diurnal abundance of euphausiids, the day/night varia-tions in every month for the total euphausii-ds and for the different species were studied.

In the case of total euphausiids, the night time abundance was indicated in all the months with the maximum during July (73.59 %) and November (74.33 %) (Fig. 93). The least night maximum was in August when only 52 % of the animals were present in the night samples.

In the case of *T. monacantha* (Fig. 94) higher night abundance was shown during April-June and September and November only. On the other hand a day time dominance was indicated during February-March, July, August and December- January. Maximum day time abundance was in July. During September only night samples contained this species. The overall day time

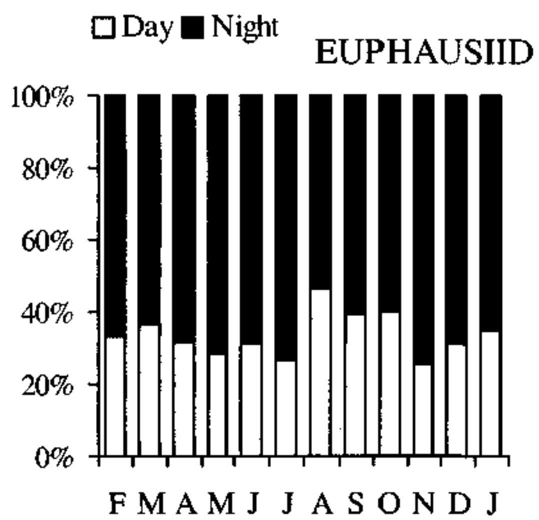

Fig. 93. Monthly variations in percentage in the day/night abundance of total euphausiids.

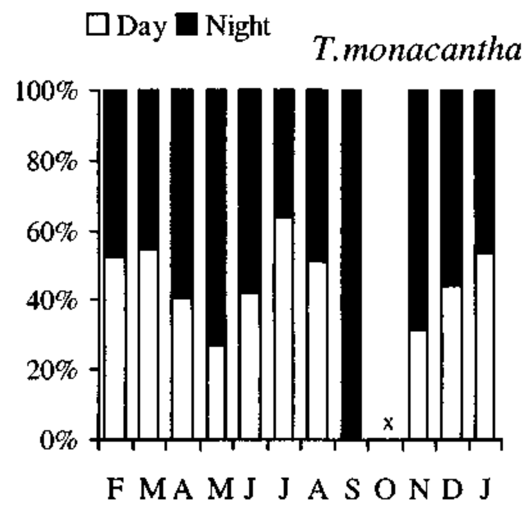

Fig. 94. Monthly variations in percentage in the day/night abundance of *T. monacantha*.

abundance observed in this species may be due to the presence of large numbers of larvae and juveniles which are known to remain in the upper waters even during the day time.

T. tricuspidata was the next species represented exclusively by larvae and juveniles. Here the day time abundance was observed during June, August and January (Fig. 95). In the other months also except February, May and December the percentage of day time occurrence was almost 50 % of the total of the respective months. The high percentage of day time abundance in this

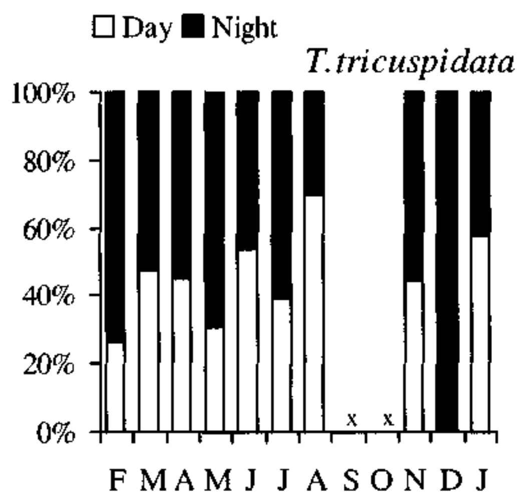

Fig. 95. Monthly variations in percentage in the day/night abundance of *T. tricuspidata*.

species also can be attributed to the dominance of larval forms in the samples.

In *P. latifrons*, the coastal water species, as expected a night time abundance was not very much pronounced but on the other hand a day time high was evident during February-March, June- July, September and January (Fig. 96). The day time abundance was to the extent of 95 % in June. However, in

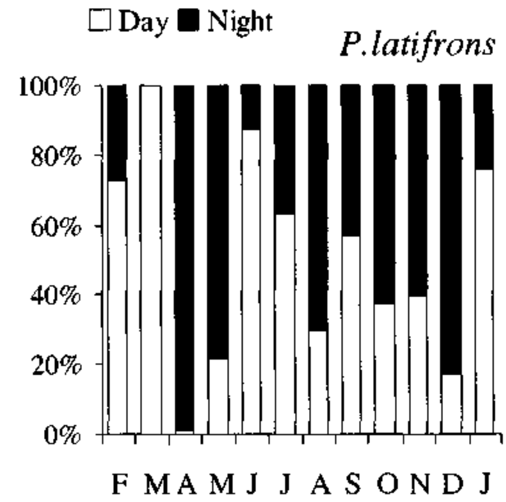

Fig. 96. Monthly variations in percentage in the day/night abundance of *P. latifrons*.

April almost the entire material came from night samples.

E. diomedeae indicated a very strong vertical migration in all the months. The species present in both shelf and oceanic waters was significantly abundant in the night samples and the day/night variation was very consistently felt (Fig 97). The maximum day

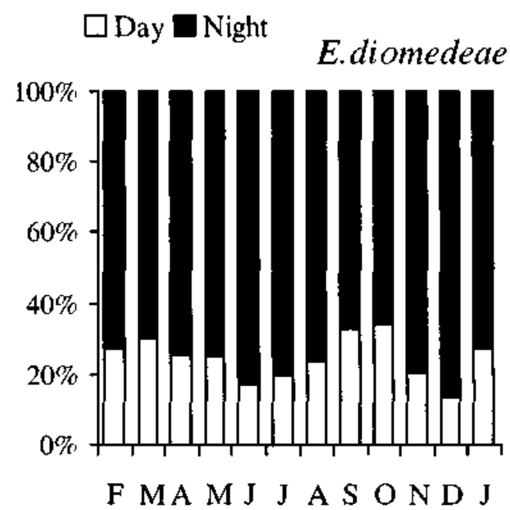

Fig. 97. Monthly variations in percentage in the day/night abundance of *E. diomedeae*.

abundance observed was 33.84 % only which was in October. In December only 13.5 % of the material belonged to the day samples.

Unlike in the case of *E. diomedeae*, in *E. sibogae* a strong monthly night time abundance was not indicated (Fig. 98). In

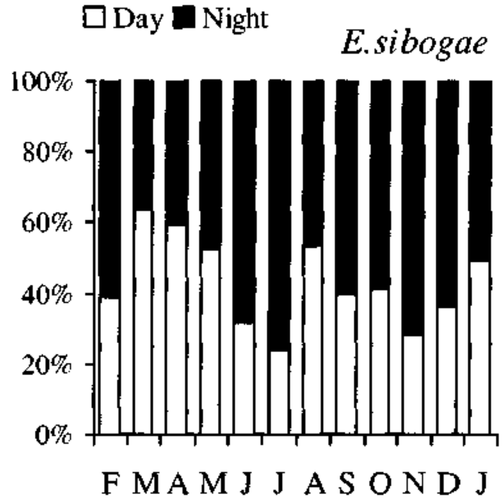

Fig. 98. Monthly variations in percentage in the day/night abundance of *E. sibogae*.

five months, from March-May, August and January more than 50 % of the material was taken in day samples and in another two months more than 40 % of the material was in day samples.

E. tenera which is more of an oceanic species showed strong diurnal vertical migration as indicated by their dominance in the night samples. In all the months of occurrence a clear night time abundance was indicated (Fig. 99). In February and March an almost equal representation was observed during day and night. The species occurred almost exclusively during night hours from July to November period which represent

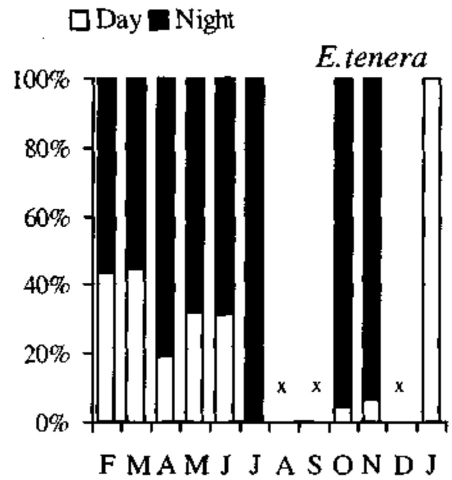

Fig. 99. Monthly variations in percentage in the day/night abundance of *E. tenera*.

the monsoon and the postmonsoon seasons.

E. pseudogibba, though not represented in all the months was significant with their night time abundance. In March, April and July the species was present exclusively in the night samples and in October 12.71% of the material was collected in the day samples. However, from November to January an unprecedented increase of the species in the

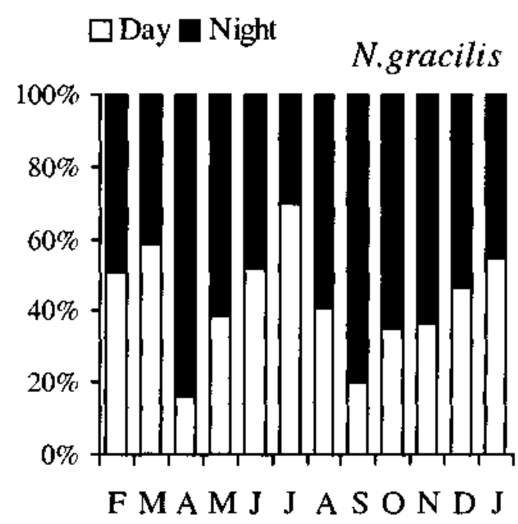

Fig. 100. Monthly variations in percentage in the day/night abundance of *N. gracilis*.

day samples was noted and in December all the specimens belonged to day samples.

In the case of *N. gracilis* a rhythmic increase and decrease was evident in the day and night abundance (Fig. 100). From a level of equal representation during day and night hours in February and March, it reached a night high of upto 83.83 % in April. Afterwards upto July the day time abundance was on the increase and in July the rate of occurrence in day samples was as high as 69.94 %. Again a second spell of gradual night time increase was felt until September when the percentage of night abundance was 79.80 %. Similarly another spell of gradual day time increase was noticed from October to February.

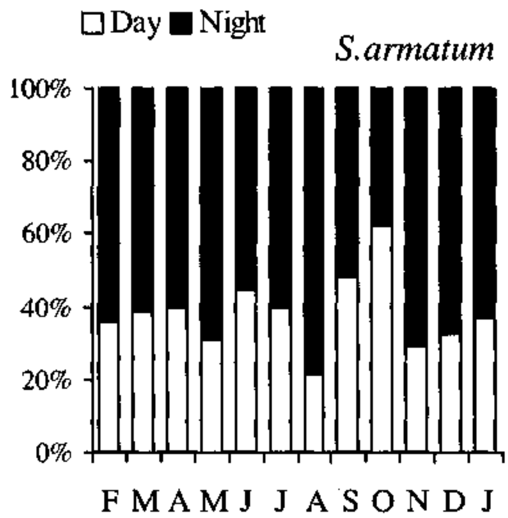

Fig. 101. Monthly variations in percentage in the day/night abundance of *S. armatum*.

Except in October *S. armatum* was taken in more numbers in the night samples. An almost 40 % day time occurrence was the rule in most of the months except August, October and November (Fig. 101). In August the night time abundance reached upto 78.50 %. In October, the only month of day time dominance, the increase was of the order of 62.24 % over the night samples.

When compared to *S. armatum*, *S. affine* (Fig. 102) was present more in day time. In

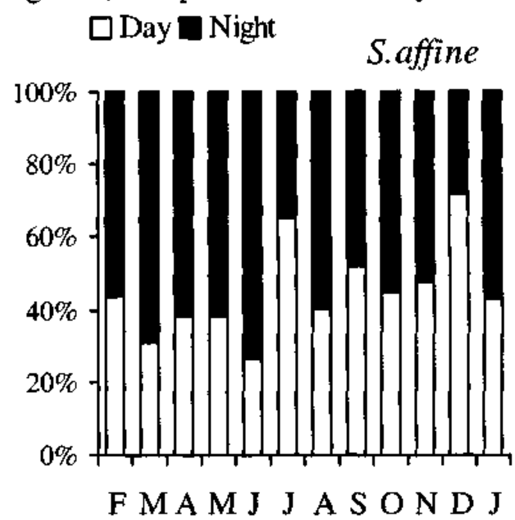

Fig. 102. Monthly variations in percentage in the day/night abundance of S. affine.

Table 14. *Test of significance for day/night variations of major species during different months*

Species	F-ratio	P
P. latifrons	1.380	0.179 N.S
E. diomedeae	1.112	0.350 N.S
E. sibogae	0.532	0.882 N.S
N. gracilis	0.546	0.872 N.S
S. armatum	1.536	0.115 N.S
S. affine	0.753	0.687 N.S

N.S = Not significant.

July, September and December more than 50 % presence in the day samples was indicated. The day samples in December accounted for the maximum number of this species and the percentage was 71.65.

A high abundance in the day samples of certain months was indicated by all the major species of euphausiids. These months mostly fell between July and October. The months of June to September have been categorised as the southwest monsoon season in the Arabian Sea when the incident light on the sea surface is minimum due to cloud cover. Moreover these are the months when the thermocline migrates upwards in areas of upwelling thus pushing the cold water upwards. In such circumstances there could be a tendency for the planktonic animals to take much higher positions in the water column even during the day time and this might be the reason for many of the species to be abundant in the day samples. The reason for the observed abundance of *T. monacantha* and *T. tricuspidata*, during the day as stated earlier, may be because they were mainly represented by larvae and juveniles which may not migrate far down.

The statistical test carried out for understanding the magnitude of monthly variations during day/night proved non-significant for all the species considered (Table 14).

12

DAY/NIGHT VARIATIONS AMONG LARVAE, JUVENILES AND ADULTS

The diurnal variations in abundance can be more meaningfully interpreted if the different life history stages are considered separately for their diurnal behaviour in that while the adults perform strong vertical migration and prefer to remain at greater depths during the day, the larvae and the juveniles stay mostly in the upper layers of water making vertical migration to some extent only which may or may not be reflected in the overall day/night abundance. It has been observed by some authors that the larval euphausiids both calyptopis and furciliae perform diurnal vertical migrations (Hardy and Gunther 1935, Lewis 1954, Mauchline 1959, 1965a, Baker 1959, Wickstead 1961, Marr 1962, Brinton 1967a, 1979).

The abundance of adults, juveniles and larvae of total population (Fig. 103) presented the model migratory pattern of the euphausiids. In the case of the adults when the day time abundance was to the tune of 21.96 % only, the night time abundance was 78.04 % whereas in the case of juveniles the two respective values were 31.67 and 68.33 % and in the case of larvae the corresponding

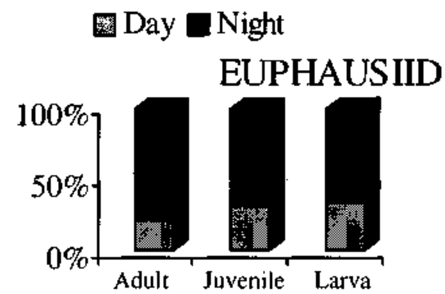

Fig. 103. Variations in the day/night abundance of adults, juveniles and larvae of total euphausiids.

values were 34.17 and 65.83 %.

In the case of adults of all the species considered except *S. affine* a three to six fold increase was noticed in the night samples. The maximum day night variation of adults was seen in *N. gracilis* in which case 85.71 % of the total material belonged to night

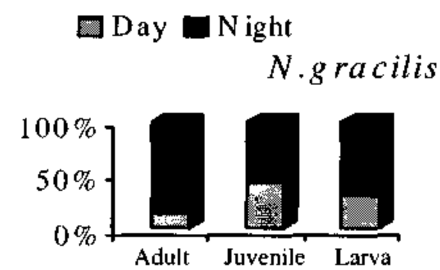

Fig. 104. Variations in the day/night abundance of adults, juveniles and larvae of *N. gracilis*.

samples (Fig. 104). A somewhat similar night time abundance amounting to above 70 % was met with *P. latifrons* (Fig. 105), *E. diomedeae* (Fig. 106), *E. sibogae* (Fig. 107) and *S. armatum* (Fig. 108). The high percentage of adult abundance of these species in the night samples suggests their very strong diurnal vertical migration in the study area. The least differe-nce was in the case of *S. affine* (Fig. 109) but there itself the magnitude of night time abundance of the adults was 61.3 %.

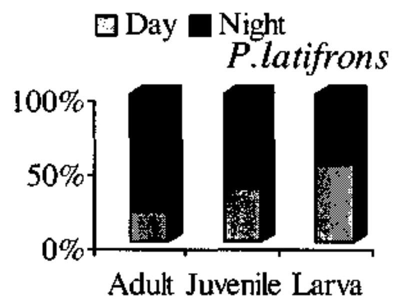

Fig. 105. Variations in the day/night abundance of adults, juveniles and larvae of *P. latifrons*.

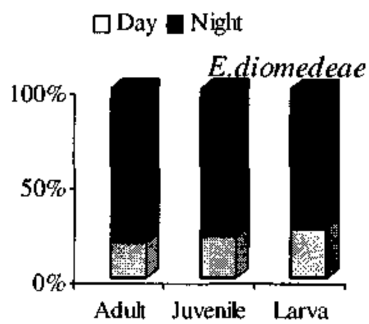

Fig. 106. Variations in the day/night abundance of adults, juveniles and larvae of *E. diomedeae*.

In juveniles the disparity in the occurrence in day and night samples was further reduced than in adults. In the total euphausiids the percentage of abundance was 68.33 to 31.67 in the night and the day samples respectively (Fig. 103). The juveniles of *E. diomedeae* exhibited maximum night abundance to the level of 77.83 % (Fig. 106). In *P. latifrons* (Fig. 105) and *E. sibogae* (Fig. 107) the

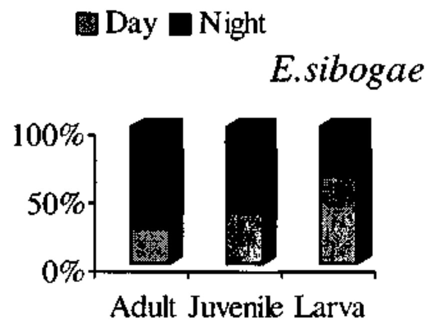

Fig. 107. Variations in the day/night abundance of adults, juveniles and larvae of *E. sibogae*.

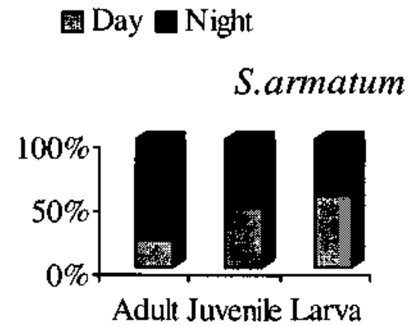

Fig. 108. Variations in the day/night abundance of adults, juveniles and larvae of *S. armatum*.

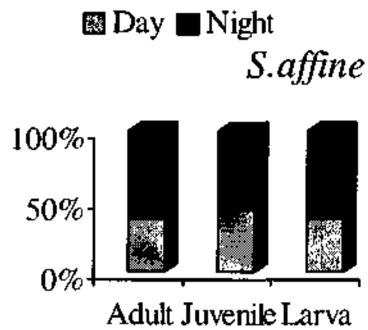

Fig. 109. Variations in the day/night abundance of adults, juveniles and larvae of *S. affine*.

percentage of occurrence of juveniles in the night samples was 62.98 and 61.09 respectively. Such a high abundance of juveniles of these species in the night samples than in day samples indicates their capability to make diurnal vertical migrations.

In the juveniles of three species namely *N. gracilis* (Fig. 104), *S. armatum* (Fig. 108) and *S. affine* (Fig. 109) the difference between day and night occurrences was very low which indicates a reduced tendency for up and down movement of the juveniles over a 24 hour period.

The picture obtained for larvae was different. While in two species namely *N. gracilis* (Fig. 104) and *S. affine* (Fig. 109) a night time abundance of a low magnitude was seen, the larvae of *E. diomedeae* showed a night increase by 73.11 % (Fig. 106). However, three species namely *P. latifrons* (Fig. 105), *E. sibogae* (Fig. 107) and *S. armatum* (Fig. 108) were present more in the day than in the night samples. These findings strongly suggests that the larvae of majority of species perform a little or no up and down movement diurnally.

Though the night time increase of various species of euphausiids can be attributed to vertical migration, other behavioural factors also may be considered. Mauchline and Fisher (1969) state that the euphausiids are not randomly distributed throughout the water column and there is considerable evidence of patchiness in their micro-distribution in the water column. During the day they may swim down and aggregate in some convenient layer of the water column, determined mostly by the light conditions and the net while towed vertically may sample during most of its course waters devoid of euphausiids. Therefore the chances of trapping more number of euphausiids during the day time is minimised. During the night hours the distribution being more diffused, the individuals occupy the entire water column or more in the upper layers. Such a pattern of distribution of the population (added with the minimum avoidance of net during the night) enable the net to capture more number of euphausiids. However, in either case active vertical movements are involved towards the surface or away from the surface.

It would be interesting to recall here the studies made on the vertical distribution and migration of euphausiids based on stratified sampling by different authors. Brinton who did studies on the vertical migration of euphausiids of the California Current waters (1967b) and the eastern tropical Pacific (1979) found *S. affine* among non-migrating species. The juveniles and adults of *S. affine* off Canary Island (Baker, 1970) were found not to migrate vertically. Youngbluth (1975) sampling mid subtropical south Pacific species found adult of *S. affine* to occupy the same depth during day and night but larvae and juveniles were described as moving upward at night. Mathew (1982) found that all three stages of *S. affine* showed least tendency to aggregate or diffuse with time thereby showing minimum variation between day and night abundance.

The present studies on the day/night abundance of euphausiids provide a comparative picture of the intensity in the

Table 15. *Test of significance for the day/night variations among adults, juveniles and larvae separately*

Species	Adults		Juveniles		Larvae	
	F	P	F	P	F	P
P. latifrons	2.236	0.135 N.S	0.161	0.688 N.S	2.582	0.109 NS
E. diomedeae	120.850	0.000 **	63.810	0.000 **	13.544	0.000 **
E. sibogae	44.330	0.000 **	0.743	0.389 N.S	5.651	0.018 *
N. gracilis	10.948	0.000 **	0.895	0.345 N.S	1.501	0.221 NS
S. armatum	41.226	0.000 **	3.214	0.074 N.S	0.132	0.716 NS
S. affine	3.676	0.056 N.S	0.495	0.482 N.S	5.936	0.015 *

** : Significant at 1 % level, * : Significant at 5% level, NS : Non significant.

diurnal aggregation or diffusion of larvae, juveniles and adults of different species. Of all the species the least difference in day-night abundance was noticed with the adults of *S. affine*. The juveniles and the larvae showed only a moderate night time abundance. Even when the three stages were put together the least variation between day and night abundance was with *S. affine*.

In conclusion it may be pointed out that the strongest vertical diurnal migration was exhibited by the adults of *N. gracilis* followed by the adults, juveniles and larvae of *E. diomedeae*. *P. latifrons* took the third place but their larvae performed practically no vertical movement. In *E. sibogae* and *S. armatum* while the adults and juveniles made somewhat strong vertical migration, their larvae did not make any migration at all.

When tested statistically for the day/night variations of the different life stages, significant values were obtained for the adults of 4 of the major species (Table 15) indicating strong diurnal vertical migration in adults. However, no significant value was obtained for adults of *P. latifrons* and *S. affine* which shows no vertical migration in these species. In the case of juveniles *E. diomedeae* alone gave significant value at 1% level which is a sign of their active vertical migration during day/night. All other species proved non-significant. As far as the larvae were concerned again *E. diomedeae* gave significant value at 1% level which indicated strong diurnal vertical migration among the larvae. The larvae of *E. sibogae* and *S. affine* yielded significant values at 5% level. Larvae of other major species namely *P. latifrons*, *N. gracilis* and *S. armatum* indicated no significant variations diurnally.

13

SEASONAL VARIATIONS IN LATITUDINAL SECTORS

The southwest monsoon and the related changes in the environment reflects a lot on the marine living organisms of the Arabian Sea. Most of the species breed during this season, and therefore an increase in population is expected during the monsoon and the postmonsoon seasons. It will be interesting to look into such variations on a microlevel in different latitudinal sectors. For convenience of description the latitudinal sectors are numbered as 1-4 from south to north.

Fig. 110 shows the seasonal variations of total euphausiids in the various latitudinal sectors. While an overall decrease was discernible from south to north, one or the other season accounted for maximum number in each sector. In the first sector

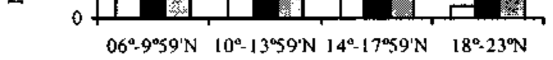

Fig. 110.Seasonal variations of total euphausiids in the different latitudinal sectors.

while the premonsoon and monsoon witnessed equal abundance, an increase was registered in the postmonsoon season. In the second sector a monsoon maximum was indicated with the pre and postmonsoon seasons rallying closely. In the third sector a monsoon minimum was found; the pre and post monsoons showing almost equal abundance. In the last sector only a nominal population was present during the premonsoon and monsoon seasons. A mixed abundance of euphausiid species was noticed in the various sectors and this speaks of the disharmonius behaviour of various species during different seasons in the four latitudinal sectors which is discussed below.

T. monacantha (Fig.111) made an all time premonsoon maximum in the first and second sectors while it was totally absent in the third sector during this season. The monsoon showed a decreased population in the first sector followed by a postmonsoon increase. Thus a clear monsoon minimum was noticed for this oceanic species in the first sector. But a postmonsoon revival was not indicated in the second sector. In the case of *T. tricuspidata* (Fig. 112) also the premonsoon maximum was evident in all the three latitudinal sectors where it was present. The population fell sharply during the monsoon

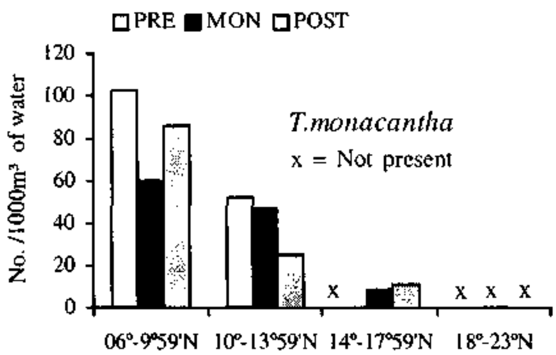

Fig. 111. Seasonal variations of *T. monacantha* in the different latitudinal sectors.

in the first and second sectors with total absence in the third sector. The abundance of *T. monacantha* and *T. tricuspidata* during

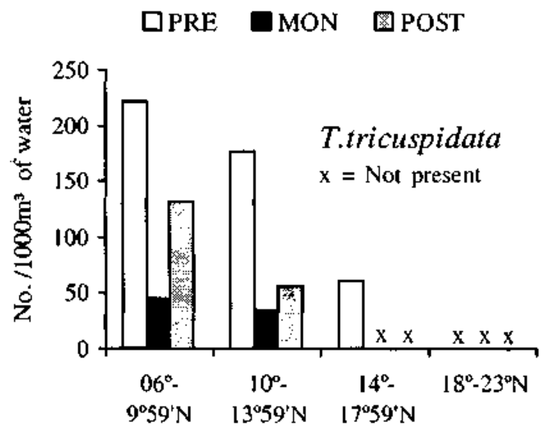

Fig. 112. Seasonal variations of *T. tricuspidata* in the different latitudinal sectors .

the premonsoon season which includes the summer months may be attributed to the high level of salinity prevailing during this season.

The overall postmonsoon abundance of *P. latifrons* over the monsoon season speaks of the postmonsoon increase on account of successful breeding during the monsoon season (Fig. 113). This was evident when a study of the larvae, juveniles and adults was taken up separately (given elsewhere). A preponderance of *P. latifrons* during the premonsoon season in the first latitudinal sector may be because of their proximity to the Lakshadweep islands where a drastic

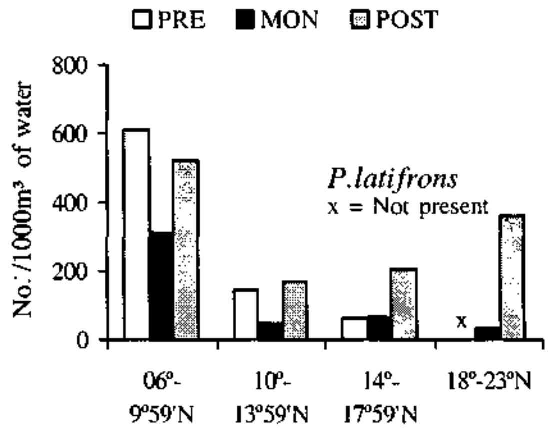

Fig. 113. Seasonal variations of *P. latifrons* in the different latitudinal sectors.

change in the environment may not be the rule as usually happens in the shelf waters. On the whole *P. latifrons* was more abundant in the first sector during all the seasons.

E. diomedeae (Fig. 114) made a postmonsoon abundance in the first sector and this trend was kept up in the third and fourth sectors also though at a low magnitude. The highest number of 2,718 per 1000 m^3 of water was taken from the first sector during the postmonsoon. In the second sector a premonsoon maximum to the extent of 1,701 per 1000 m^3 of water was noticed. During the monsoon there was low abundance of this species in all the sectors.

The latitudewise seasonal abundance of *E. sibogae* presented a regular pattern with respect to the seasons (Fig. 115). Its highest number of 2,182 per 1000 m^3 of water was in the southernmost sector during the monsoon. A monsoon abundance was shown

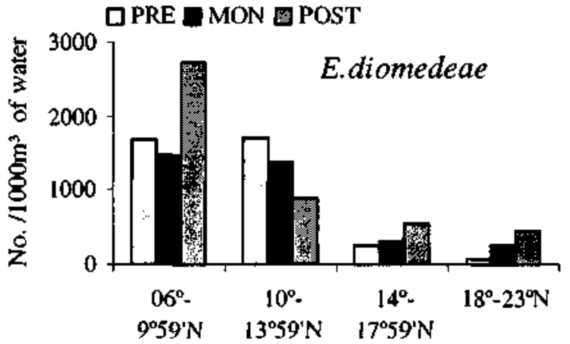

Fig. 114. Seasonal variations of *E. diomedeae* in the different latitudinal sectors.

in the second sector also. Whereas a premonsoon and postmonsoon equilibrium in abundance was evident in the third sector, the fourth sector witnessed an all time premonsoon minimum. While a regular monsoon decrease was indicated from south to north in all the sectors a premonsoon and postmonsoon increase was observed in the first three sectors.

E. tenera (Fig. 116) was mainly present in the first and second sectors and in these sectors the least abundance was during the monsoon. The premonsoon and postmonsoon seasons supported better populations.

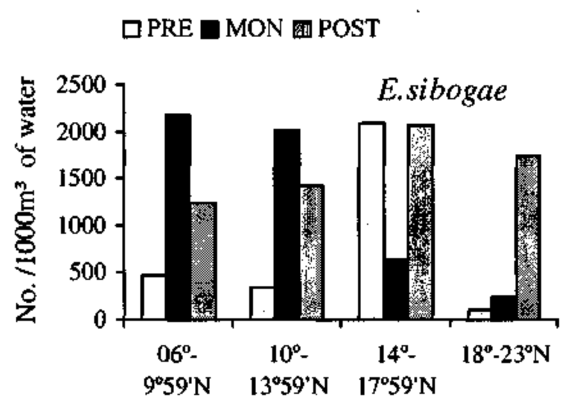

Fig. 115. Seasonal variations of *E. sibogae* in the different latitudinal sectors.

An overall abundance towards the southern latitudes was clearly indicated by *N. gracilis* (Fig. 117). In the southernmost sector where the maximum population was noticed, the species was almost equally abundant in all the seasons. The highest number

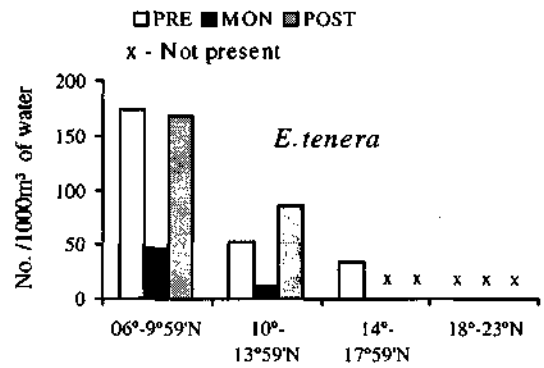

Fig. 116. Seasonal variations of *E. tenera* in the different latitudinal sectors.

of 531 per 1000 m³ of water in this sector was during the postmonsoon season. *S. armatum* (Fig. 118) presented a premonsoon increase in the first three sectors while in the northernmost sector the species was meagrely represented. The monsoon season supported very low population in all the sectors.

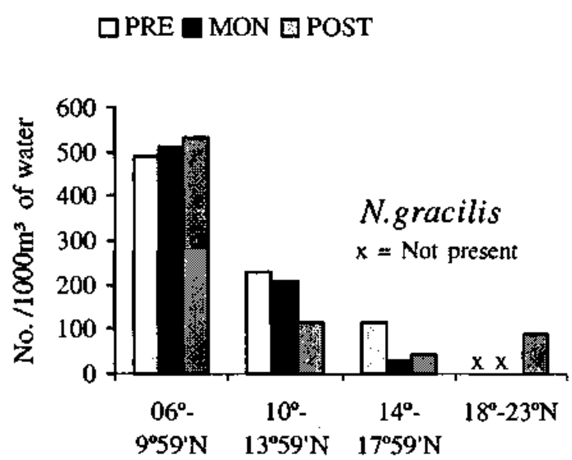

Fig. 117. Seasonal variations of *N. gracilis* in the different latitudinal sectors.

In *S. affine* (Fig. 119) a postmonsoon abundance was the rule in almost all sectors and in the third sector the species showed more abundance during the premonsoon. An overall premonsoon increase in population was indicated in the first and third sectors. In all the sectors this species made notable abundance in all the seasons.

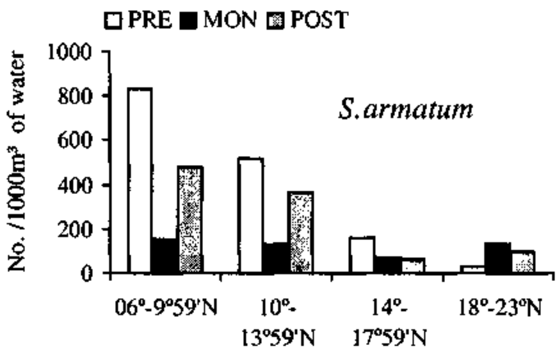

Fig. 118. Seasonal variations of *S. armatum* in the different latitudinal sectors.

To sum, up it may be stated that the different seasons exert profound influence on the euphausiid distribution as one moves from south to north in the eastern Arabian Sea. While the monsoon season presented a low population for most of the species

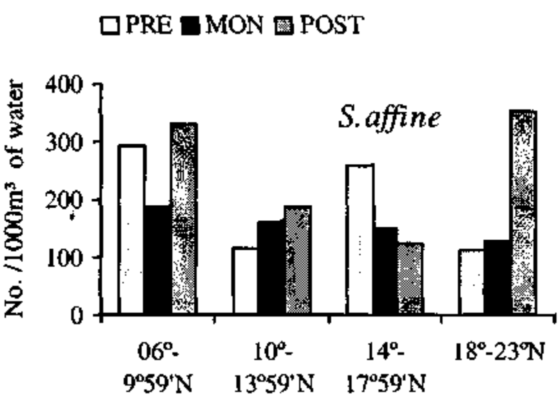

Fig. 119. Seasonal variations of *S. affine* in the different latitudinal sectors.

except *E. sibogae* and *N. gracilis*, in the southern sectors the postmonsoon accounted for the highest population for all the species except *S. armatum* followed by the premonsoon. The changes brought about in the environment on account of the upwelling during the monsoon season resulting in the replinishment of the euphotic zone with nutrients followed by increase in primary production establish favourable conditions for increased production at the secondary level including euphausiids in the postmonsoon season especially in the southern latitudes. A further treatment of the latitudinal data on a monthly basis which follows, would bring out still finer results of the latitudinal variations in abundance over time.

The ANOVA test carried out for understanding the quantum of seasonal variations in the different latitudinal sectors proved significant at 1% level for *S. armatum* only. The probability was significant at 5%

Table 16. *Test of significance for the influence of seasons in the abundance of major species in the different latitudinal sectors*

Species	F-ratio	P
P. latifrons	0.684	0.662 NS
E. diomedeae	1.652	0.131 NS
E. sibogae	2.862	0.010 *
N. gracilis	2.178	0.044 *
S. armatum	4.342	0.000 **
S. affine	1.181	0.315 N.S

** : Significant at 1 % level, * : Significant at 5% level, NS : Non significant.

level in the case of *E. sibogae* and *N. gracilis*. No significant values were obtained for *P. latifrons*, *E. diomedeae* and *S. affine* (Table 16).

14

MONTHLY VARIATIONS IN LATITUDINAL SECTORS

The six-monthly reversal of the north-south direction of water currents, the southwest monsoon and the associated seasonal upwelling exert considerable influence on the latitudinal distribution of euphausiids during different months. The magnitude of such variations for total euphausiids and some of the major species was worked out. However, when the samples were split up into various months in each latitudinal sector, samples to represent a few months were not available and this put some limitation to the study. Therefore only an overall trend trend is presented here.

With regard to total euphausiids in the southernmost sector (Fig. 120) the population density was at its maximum during December with 8,457 per 1000 m^3 of water which coincided with the postmonsoon. However, there was no comparative data for September and October. Population density in this sector was low during February, May and June with 1,211, 1,109 and 1,363 respectively. The population kept a high trend during April, July, August, November and March also (Fig. 120).

The monthly picture obtained for euphausiids in the second latitudinal sector was totally different from the southernmost sector (Fig. 121). Almost all the months in which the population was minimum in the first sector showed an increase in the second

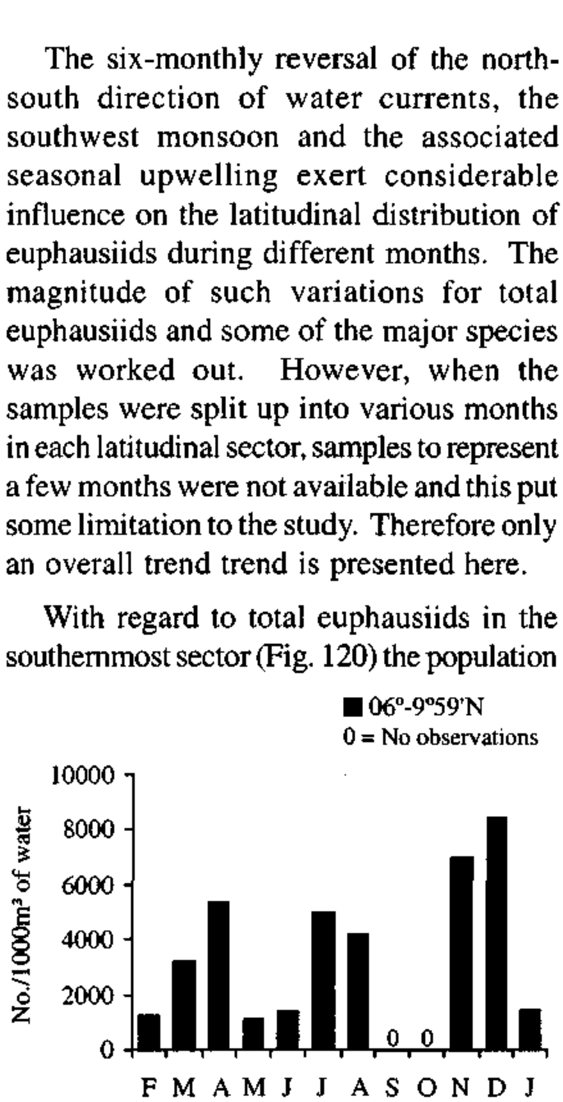

Fig. 120. Monthly variations of total euphausiids in the southernmost latitudinal sector.

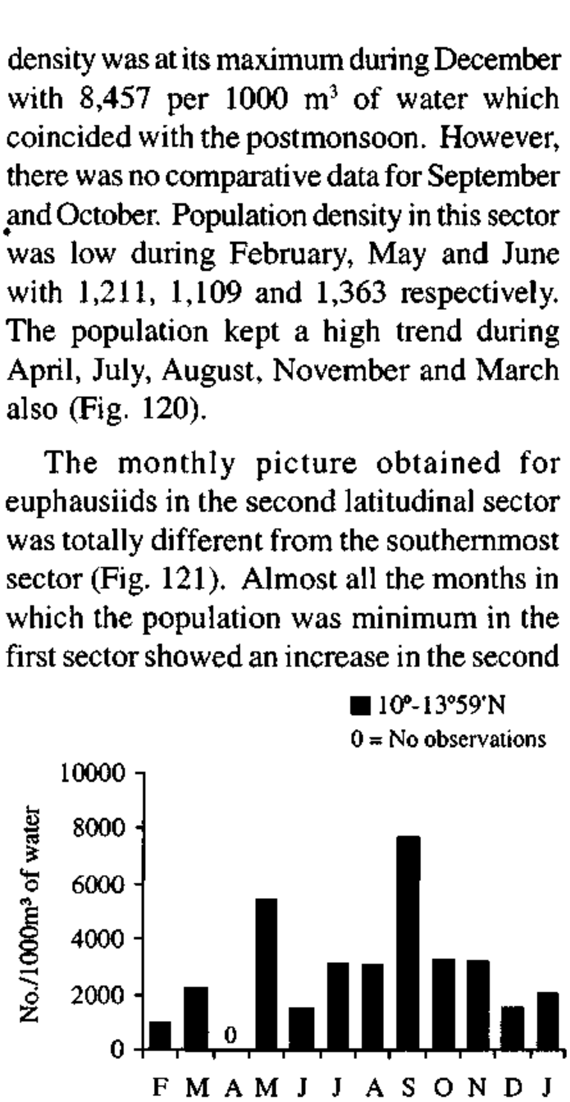

Fig. 121.Monthly variations of total euphausiids in the second latitudinal sector.

sector and *vice versa*. The highest abundance in the second sector was during September. There was no sampling during April in this sector. In the third sector (Fig. 122) an overall abundance was indicated from September to November. There was no sampling in most of the months in the northern sector. The available data indicated an abundance during March, October and December (Fig. 123).

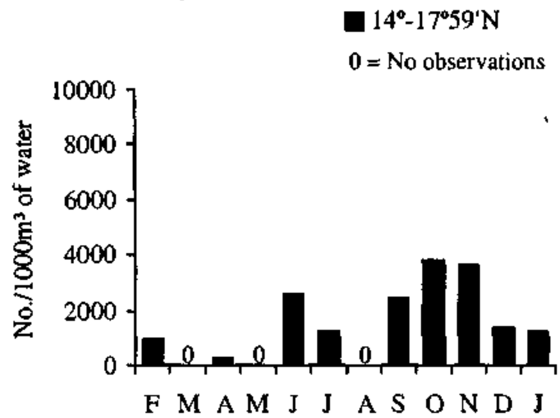

Fig. 122. Monthly variations of total euphausiids in the third latitudinal sector.

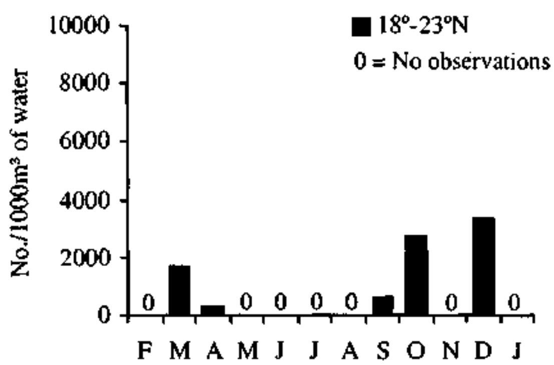

Fig. 123. Monthly variations of total euphausiids in the northernmost latitudinal sector.

T. monacantha was present in the first three sectors only and there also it reduced its population from south to north (Figs. 124-126). The months of its maximum

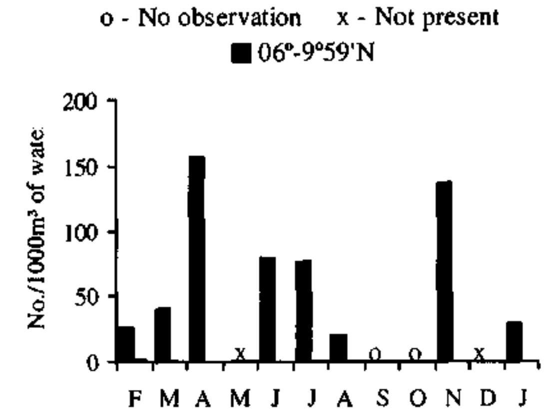

Fig. 124. Monthly variations of *T. monacantha* in the southernmost latitudinal sector.

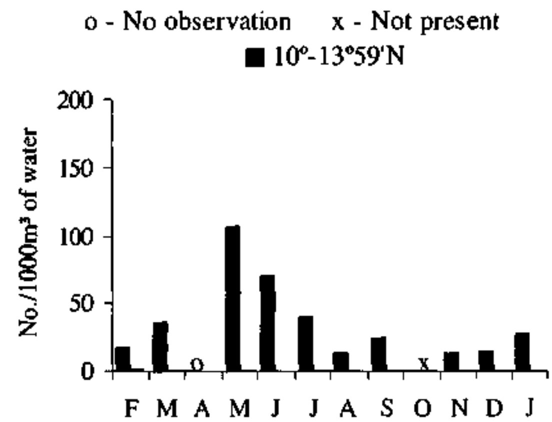

Fig. 125. Monthly variations of *T. monacantha* in the second latitudinal sector.

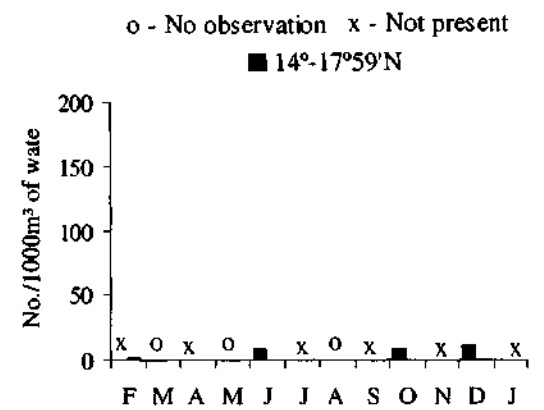

Fig. 126. Monthly variations of *T. monacantha* in the third latitudinal sector.

occurrence in the first sector was April and November (156 and 137 respectively per 1000 m^3 of water). Moderate abundance was noticed during June and July also in this sector. The rest of the months recorded only very few numbers of this species. In the second sector comparatively more numbers were registered in May and June, the maximum of 107 per 1000 m^3 of water being in the former month. The third sector yielded very few numbers around 10 per 1000 m^3 of water during June, October and December.

T. tricuspidata also occurred in the southern three sectors only being somewhat abundant in the first and second sectors (Figs.127-129). The trend of abundance was almost the same in the first two sectors indicating a maximum density in February-May period which is the premonsoon season. The maximum density of 295 per 1000 m^3 of water was in March in the southernmost sector, followed by 249 in the following month. A relatively low peak was observed during November and January also. In the

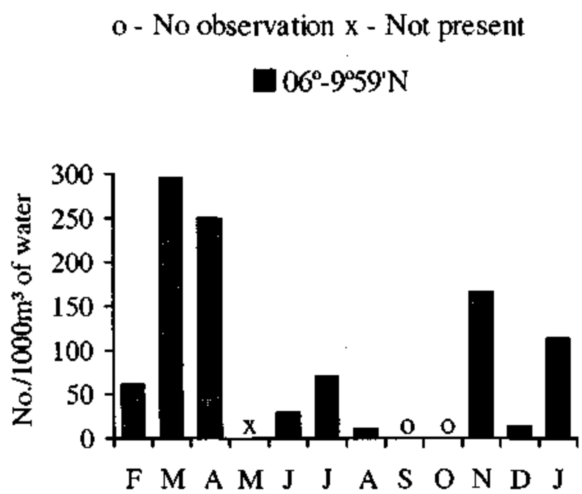

Fig. 127. Monthly variations of *T. tricuspidataa* in the southernmost latitudinal sector.

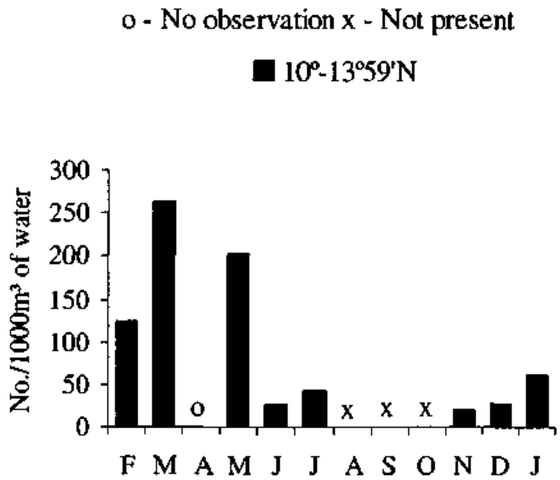

Fig. 128. Monthly variations of *T. tricuspidata* in the second latitudinal sector.

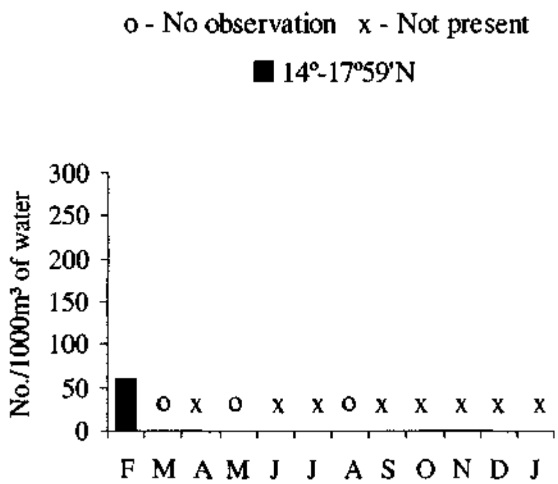

Fig. 129. Monthly variations of *T. tricuspidata* in the third latitudinal sector.

second sector the maximum density was in March with 202 per 1000 m^3 of water. Eventhough there was no sample for April, the period from February to May can be considered as the period of abundance for *T. tricuspidata* in the second sector. A November to January abundance was also indicated for this species in the two southern sectors. In the third sector, February alone accounted for this species that too at a minimum rate of 60 per 1000 m^3 of water.

P. latifrons (Figs. 130-133) presented

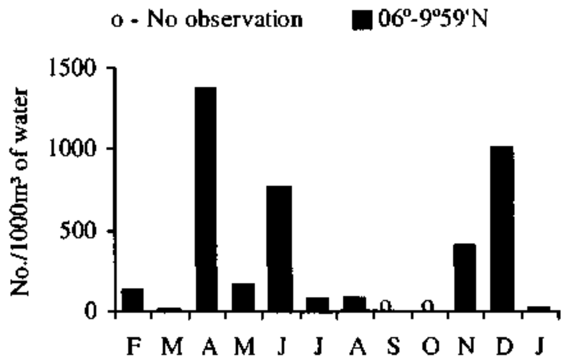

Fig. 130. Monthly variations of *P. latifrons* in the southernmost latitudinal sector.

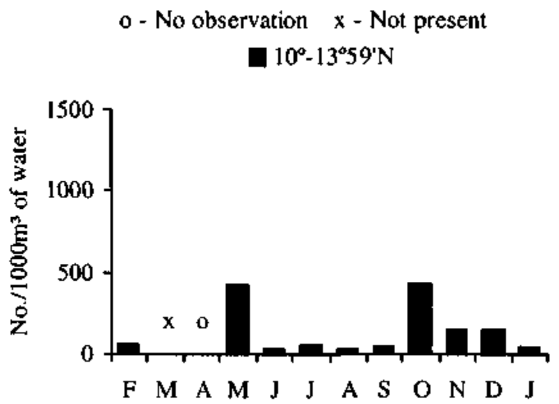

Fig. 131. Monthly variations of *P. latifrons* in the second latitudinal sector.

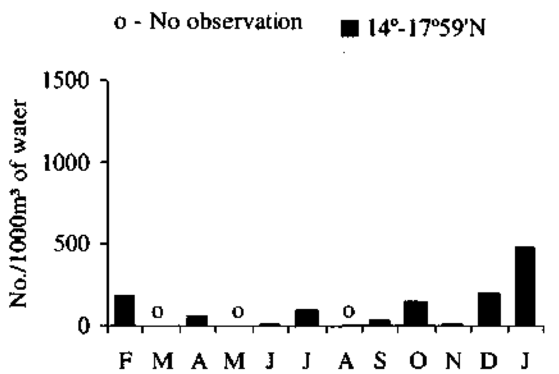

Fig. 132. Monthly variations of *P. latifrons* in the third latitudinal sector.

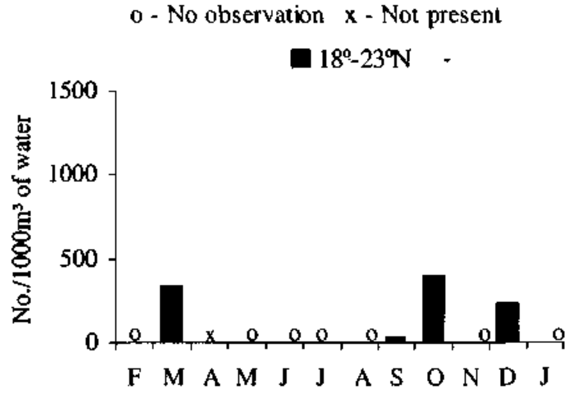

Fig. 133. Monthly variations of *P. latifrons* in the northernmost latitudinal sector.

varying monthly abundance in the various latitudinal sectors. Comparatively more specimens were taken from the southernmost sector, the maximum of 1,383 per 1000 m^3 of water being in April. April to June and November to December seemed to account for most of its population in this sector. In the second sector May and October to December accounted for most of its population. In the third and fourth sectors also the trend in abundance was almost the same as that in the first and second sectors though of a low magnitude.

In *E. diomedeae* (Fig. 134-137) The sectors south of 15°N accounted for most of the material. In the first sector an April, July and November abundance was clearly indicated. On the other hand in the second sector a May, July, December peak was noticed. In the third sector, though of a less magnitude, a June and January abundance was seen. The distributional behaviour of the species in the three southern sectors suggests, a northward migration of the species and this was indicated by shifting of the peak months by one month as one moved

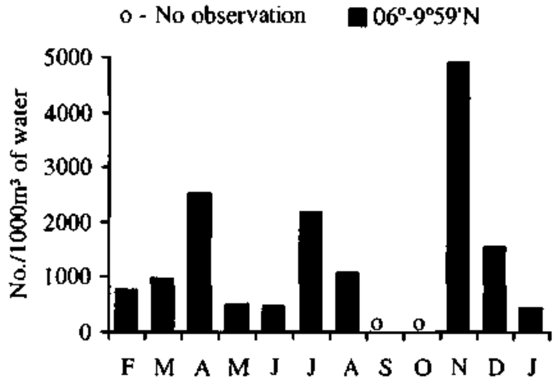

Fig. 134. Monthly variations of *E. diomedeae* in the southernmost latitudinal sector.

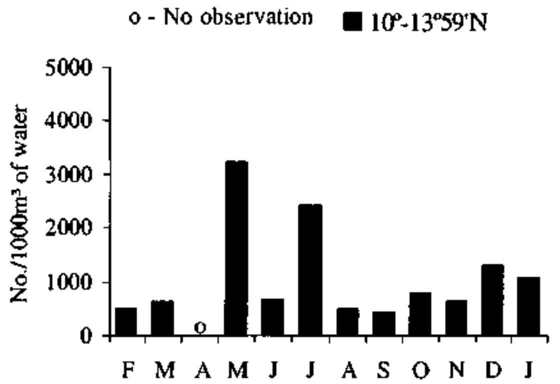

Fig. 135. Monthly variations of *E. diomedeae* in the second latitudinal sector.

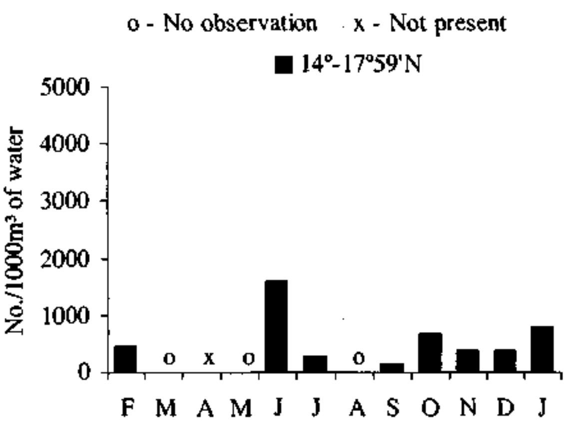

Fig. 136. Monthly variations of *E. diomedeae* in the third latitudinal sector.

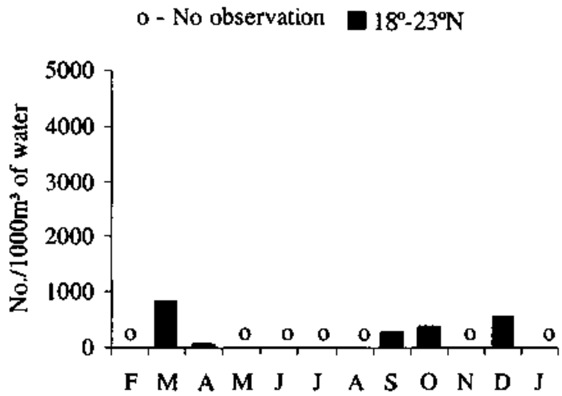

Fig. 137. Monthly variations of *E. diomedeae* in the northernmost latitudinal sector.

from the first to the third sector. In the northernmost sector the available material suggested a March and December peak for this species.

In *E. sibogae* (Figs. 138-141) the trend in the monthly abundance was almost similar in the four latitudinal sectors, though of varying magnitude. In all the sectors the species flourished well from June to December period. In the southernmost sector the population showed a gradual increase from June onwards and culminated in

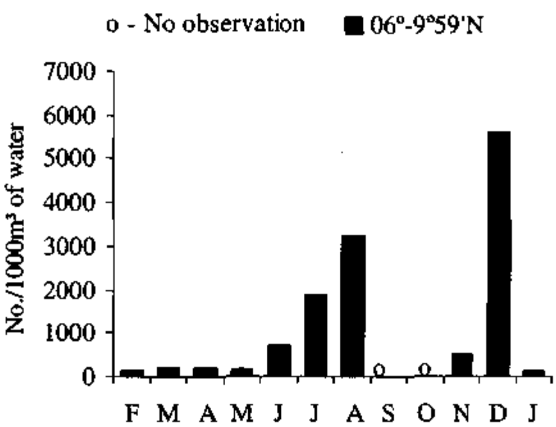

Fig. 138. Monthly variations of *E. sibogae* in the southernmost latitudinal sector.

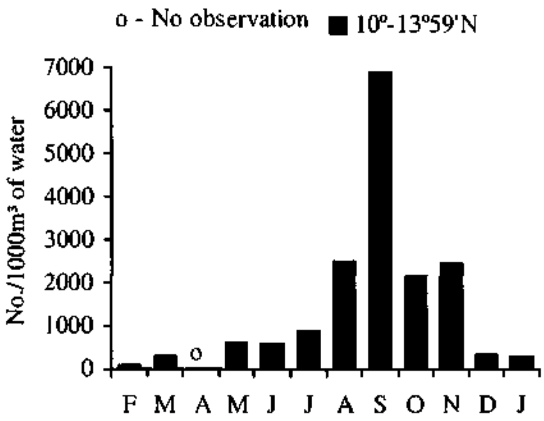

Fig. 139. Monthly variations of *E. sibogae* in the second latitudinal sector.

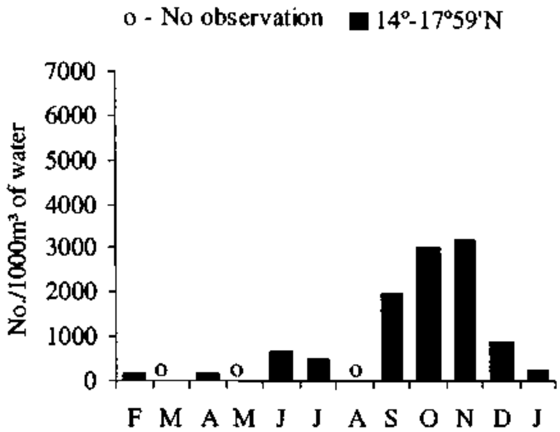

Fig. 140. Monthly variations of *E. sibogae* in the third latitudinal sector.

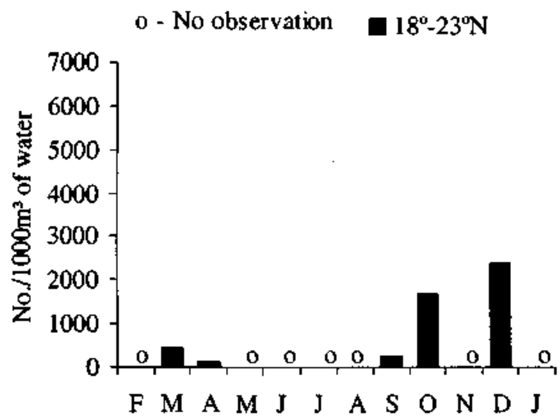

Fig. 141. Monthly variations of *E. sibogae* in the northernmost latitudinal sector.

December having contributed to 5,599 per 1000 m^3 of water. In the second sector while the same trend was observed the peak abundance was in September with 6,869 specimens which thereafter decreased. The maximum material obtained in the third sector was 3,183 per 1000 m^3 of water in November although the preceeding two months also contributed good number of this species. In the last sector, lack of collections does not permit to make any conclusion. However, the abundance in October and December gives an indication of its abundance in this sector.

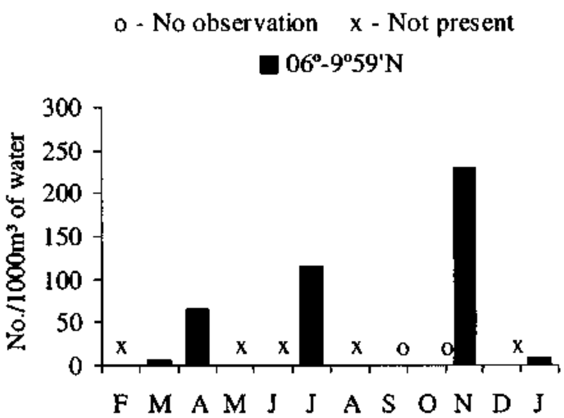

Fig. 142. Monthly variations of *E. pseudogibba* in the southernmost latitudinal sector.

E. pseudogibba (Fig. 142) restricted its distribution in the southern latitudinal sector. An increasing trend from April to November was discernible but the paucity of sampling do not warrant any conclusion on the latitudinal variations of the species in all the months. *E. tenera* (Figs. 143-145) was found mostly confined to the first sector with tongues of distribution extending to the third sector. A March-April and a November abundance was indicated in the first sector. In the second sector while the peak abundance occurred in October the same was shifted to November in the first sector.

A striking difference in the latitudinal abundance during different months was shown by *N. gracilis*. There was a gradual reduction in the overall population of the species from south to north (Figs. 146-148). In the southernmost sector, three peaks were observed in April, July and November respectively. In this sector from a low of 59 per 1000 m³ of water in May, the population increased to 960 in July. Absence of samples in September and October though makes it

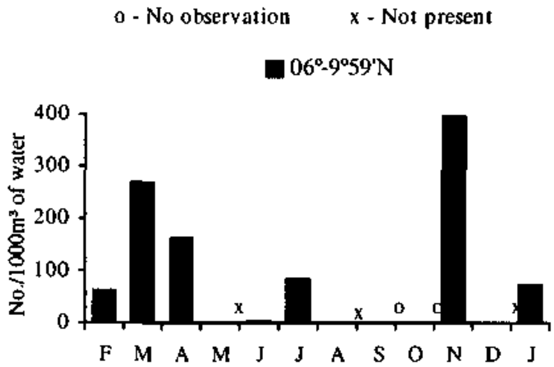

Fig. 143. Monthly variations of *E. tenera* in the southernmost latitudinal sector.

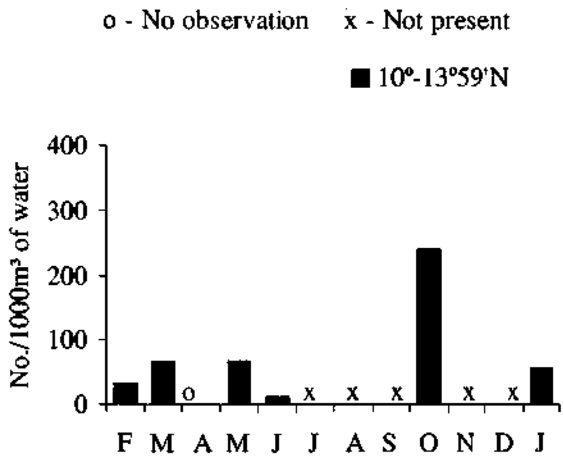

Fig. 144. Monthly variations of *E. tenera* in the second latitudinal sector.

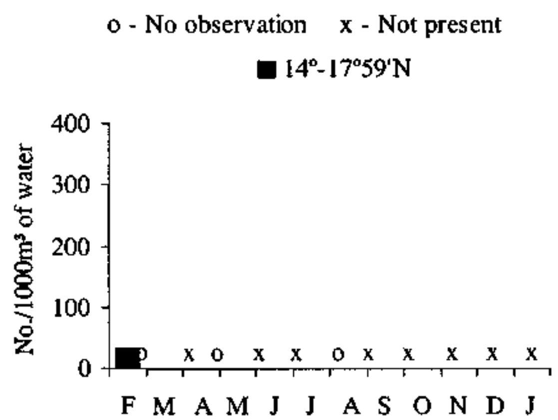

Fig. 145. Monthly variations of *E. tenera* in the third latitudinal sector.

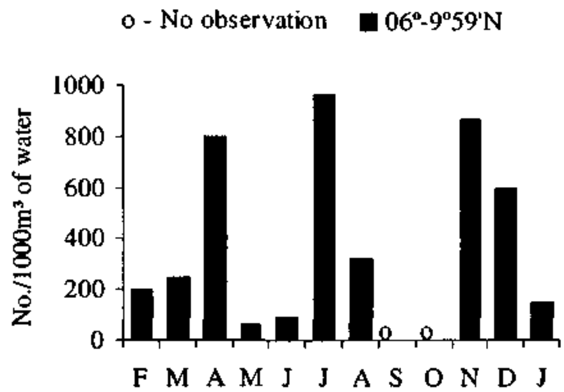

Fig. 146. Monthly variations of *N. gracilis* in the southernmost latitudinal sector.

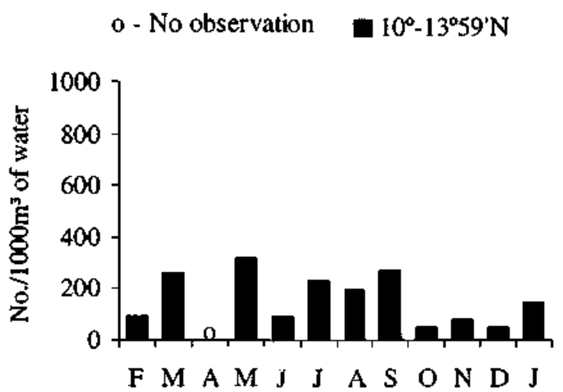

Fig. 147. Monthly variations of *N. gracilis* in the second latitudinal sector.

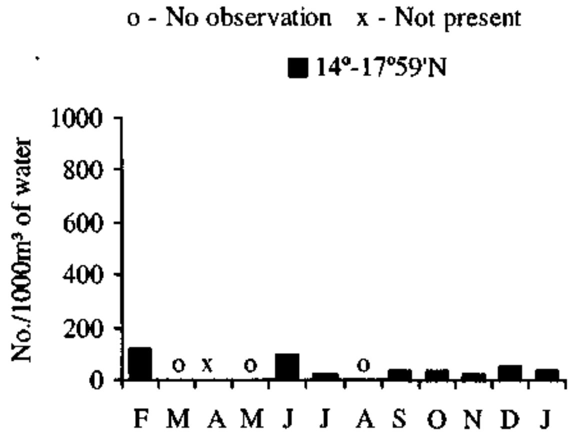

Fig. 148. Monthly variations of *N. gracilis* in the third latitudinal sector.

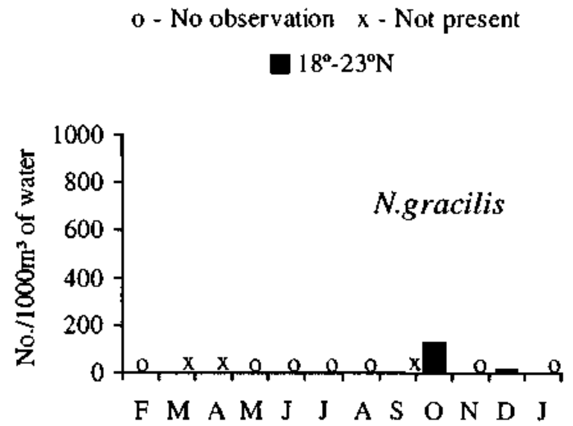

Fig. 149. Monthly variations of *N. gracilis* in the northernmost latitudinal sector.

difficult to follow the trend, a gradual improvement could be assumed as the month that followed immediately registered another peak from which the population was reduced to a minimum in January. In the second sector large scale variations were not observed in the different months. The species ranged between 48 per 1000 m³ of water in October to 321 in May. The magnitude of abundance was still low in the various months in the third sector although the species made its presence in eight months. *N. gracilis* extended its distribution to the last sector during October and December (Fig. 149).

S. armatum (Figs. 150-153) showed two clear periods of abundance in all the sectors. In the first sector from an optimum level of 331 in February the population went upto 1,177 in April. The monsoon months yielded very few numbers of the species. The population increased once again from November to January. Almost the same

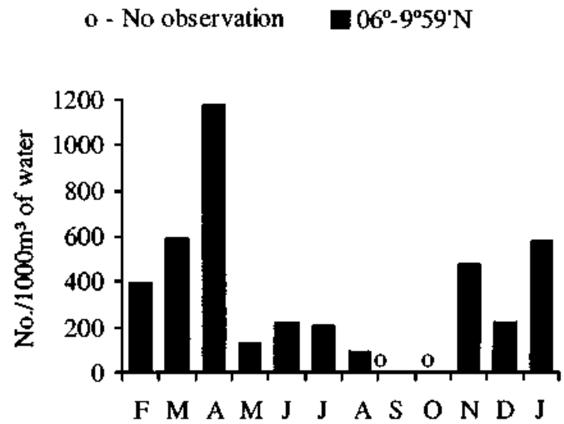

Fig. 150. Monthly variations of *S. armatum* in the southernmost latitudinal sector.

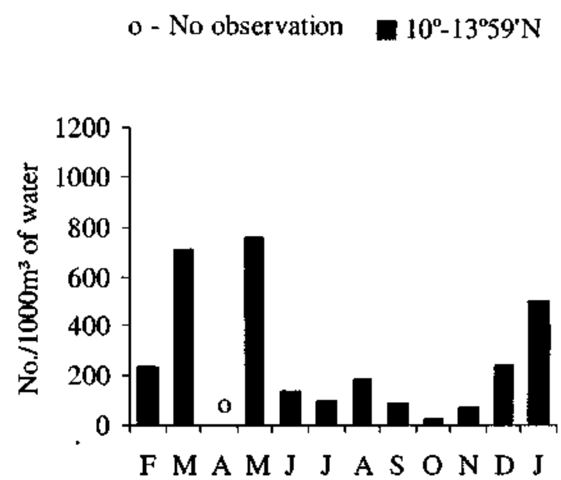

Fig. 151. Monthly variations of *S. armatum* in the second latitudinal sector.

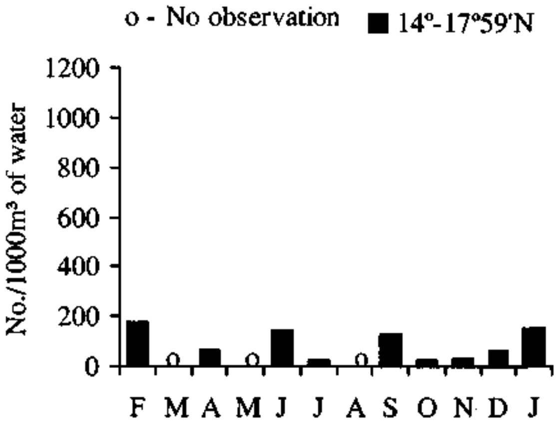

Fig. 152.Monthly variations of *S. armatum* in the third latitudinal sector.

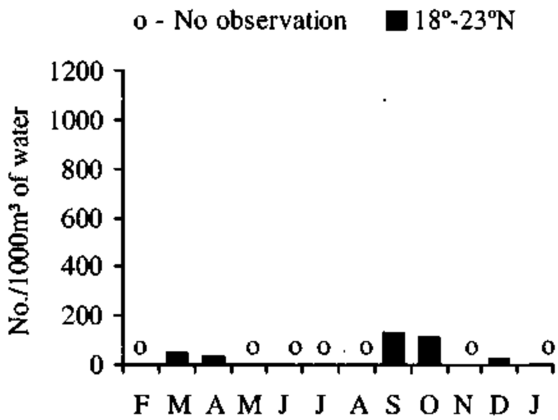

Fig. 153.Monthly variations of *S. armatum* in the northernmost latitudinal sector.

trend was maintained in the second sector also. In the third sector, the population thinned down very much but still showed their presence in February, June, September and January. Lack of observations for three months makes it difficult to understand the trend of this species in the third sector. In the fourth sector there was no observation in most part of the year. *S. armatum* occurred in all the months of observation in all the sectors and it tells on the widespread occurrence of this species throughout the year though in a decreasing manner from south to north.

S. affine (Figs. 154-157) showed no common trend in its monthly occurrence in the various latitudinal sectors. This species also occurred in all the months of observation indicating widespread occurrence throughout the year. In the southernmost sector an increase was registered in March-April, July-August and November. In the second sector, a rather uniform abundance but of a low

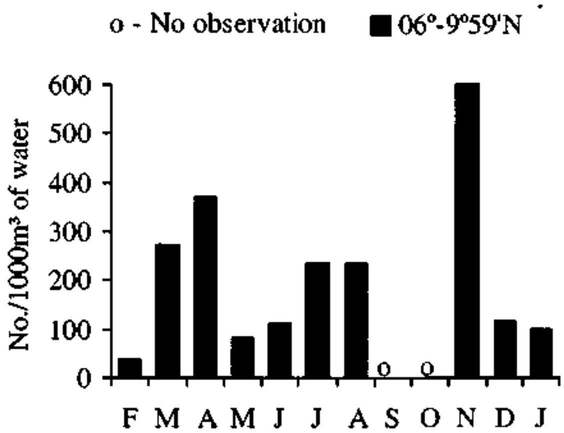

Fig. 154.Monthly variations of *S. affine* in the southernmost latitudinal sector.

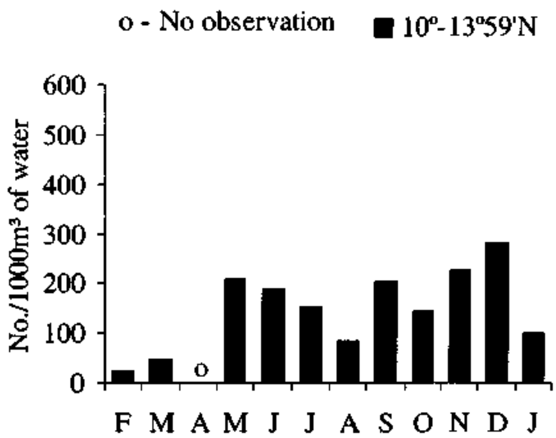

Fig. 155.Monthly variations of *S. affine* in the second latitudinal sector.

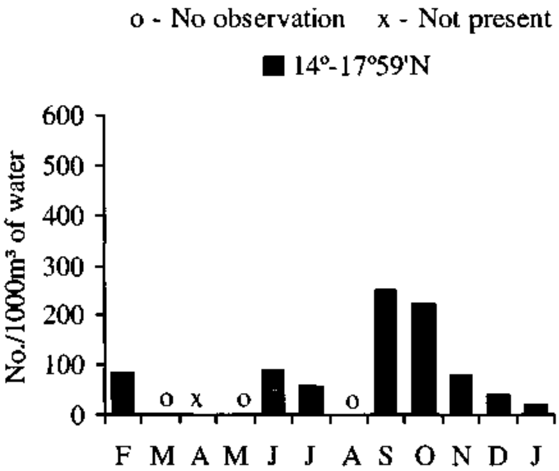

Fig. 156. Monthly variations of *S. affine* in the third latitudinal sector.

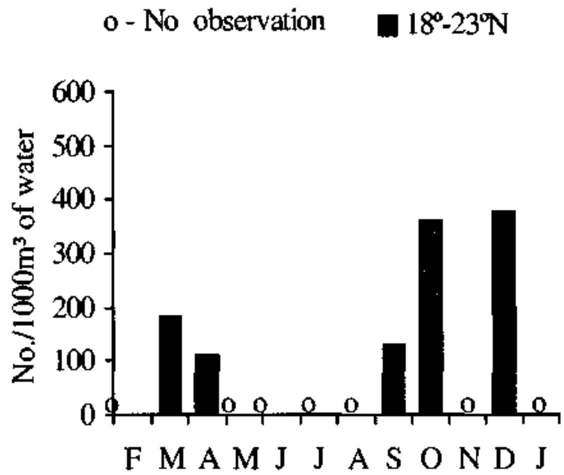

Fig. 157. Monthly variations of *S. affine* in the northernmost latitudinal sector.

magnitude was noticed between May and January. Eventhough a September to October abundance was noticed in the third sector, the absence of samples from March to May and August makes it difficult to speak on its abundance in these months. In the fourth sector also with most of the months having no collection, a definite picture of abundance does not emerge. October and December yielded comparatively more material of *S. affine* in the fourth sector.

15

SEASONAL VARIATIONS IN SHELF AND OCEANIC WATERS

Species of euphausiids have a tendency to move into or away from the shelf region in accordance with the seasonal changes in the environment (Mathew 1985). The process becomes more complex when the species involved are either neritic, oceanic or cosmopolitan in occurrence. The incursion of the upwelled oceanic water into the shelf region reaching almost upto the surface layers may bring with it some species which are characteristic to the oceanic waters. The upwelling along the southwest coast of India associated with the southwest monsoon plays an important role in the onshore and offshore movement of the euphausiid species (Mathew 1985). An attempt was made to understand the variations, if any, in the seasonal distribution of some of the major species in the shelf and oceanic areas.

When all the species were considered together, considerable variations in abundance between seasons in the shelf and oceanic areas were not discernible (Fig. 158 k); something which could be expected on account of the differences in the habitat selection of each species in accordance with the changes in the environment. During the premonsoon season no difference between the shelf and the oceanic areas was noticed in both the environment. During the monsoon season, in spite of the sudden fluctuations in salinity, temperature, density etc. an increase in the euphausiid population was felt in the shelf area. Out of the total, 53.19 % was present in the shelf. However, in the postmonsoon season the shelf became comparatively more populous which amounted to 55.8 % of the total euphausiids.

In *T. monacantha* notable variations were seen in the shelf and oceanic areas in accordance with the seasons (Fig. 158 a). During the premonsoon season 75.5 % of its population was taken from the oceanic realm. However, during the monsoon there was an increase in the shelf population with a corresponding reduction in the oceanic area to 56.4 %. The postmonsoon was significant in that no specimen was encountered in the shelf area. *T. tricuspidata* presented a different picture in such a way that the shelf accou-nted for 66.9 % of the total during the premonsoon season (Fig. 158 b). No specimen occurred on the shelf area during the monsoon. Again during the postmonsoon the species entered the shelf.

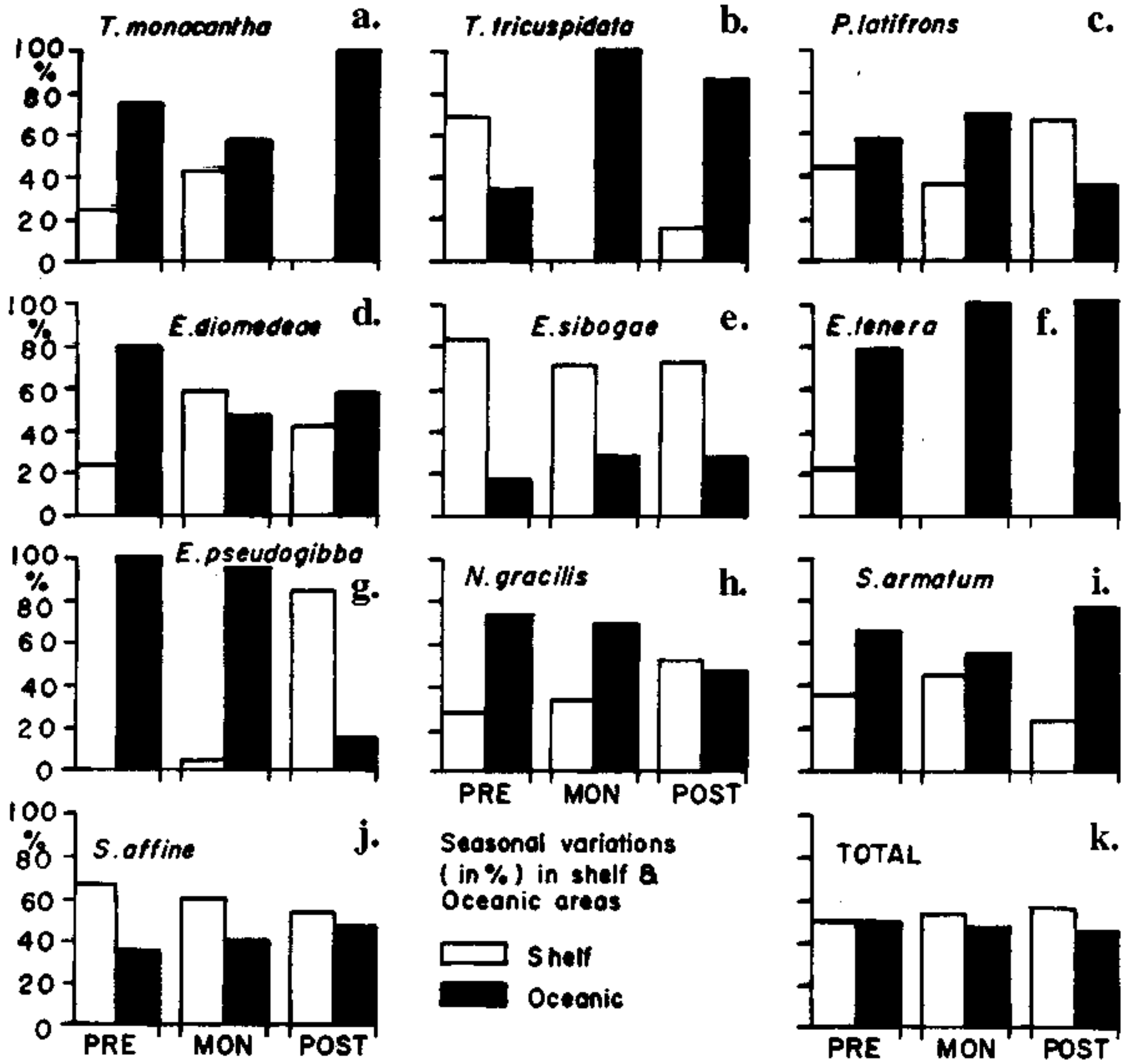

Fig. 158.Seasonal variations (in %) in the shelf and oceanic waters. (a) *T. monacantha*, (b) *T. tricuspidata*, (c) *P. latifrons*, (d) *E. diomedeae*, (e) *E. sibogae*, (f) *E. tenera*, (g) *E. pseudogibba*, (h) *N. gracilis*, (i) *S. armatum*, (j) *S. affine* and (k) euphausiids total.

In *P. latifrons* (Fig. 158 c) the premonsoon season witnessed high population in both shelf and oceanic areas and the proportion was 42.6 and 57.4%, respectively. In the monsoon season there was a little reduction of this species in the shelf. In the postmonsoon season there was an all time high in the shelf and in the oceanic waters the population got reduced to almost half than during the monsoon.

E. diomedeae (Fig. 158 d) exhibited an oceanic preponderance during the pre and postmonsoons. The variation was significant during the premonsoon with 79.6 % of them in the oceanic region. During the monsoon the disparity between the shelf and the oceanic got reduced and a shelf abundance was indicated suggesting that more number of this species moved to the shelf in this season. In the postmonsoon once again there was a reduction of its population in the shelf area to the extent of 42.5 %.

E. sibogae behaved almost in an opposite manner to *E. diomedeae* in that a clear shelf abundance was the rule in all the three seasons but in varying densities (Fig. 158 e) with more than 70 % of the population in the shelf area. Maximum shelf oceanic difference was observed during the premonsoon when 82.3 % of the population was in the shelf.

E. tenera made its presence mostly in the oceanic area during all the seasons. However, a small part of its premonsoon population (22.3 %) entered the shelf (Fig. 158 f). *E. pseudogibba* totally deserted the shelf waters during the premonsoon. But 5.8 % of it came to the shelf during the monsoon (Fig. 158 g). On the other hand the postmonsoon withnessed a profound increase to the extent of 85.7 % in the shelf.

A premonsoon and monsoon abundance to the level of two third of the total population of *N. gracilis* was seen in the oceanic region (Fig. 158 h). However, during the post monsoon the shelf population marginally outnumbered the oceanic population. An increasing incursion of the species to the shelf was noticed from premonsoon to postmonsoon seasons.

S. armatum showed high proportion of its population in the oceanic area during all the seasons with variations. In this region from a percentage occurrence of 64.7 during the premonsoon the population fell to 54.7% during the monsoon but increased to 76.1% during the post monsoon season (Fig. 158 i). On the other hand *S. affine* showed an abundance in the shelf water during all the three seasons (Fig. 158 j). The shelf witnessed a fall from 65.1 % during the premonsoon to 60 % during the monsoon and to 53.3 % during the post monsoon. At any rate while *S. armatum* dominated the oceanic waters during all the three seasons, *S. affine* showed its dominance in the shelf waters.

The ANOVA test conducted for the influence of different seasons on the distribution of the major species in the shelf and oceanic areas proved nonsignificant in the case of all the species considered (Table 17).

Table 17. *Test of significance for seasonal variations of major species In the shelf and oceanic waters—*

Species	F-ratio	P
P. latifrons	2.968	0.052 NS
E. diomedeae	1.289	0.277 NS
E. sibogae	1.413	0.244 NS
N. gracilis	1.928	0.147 NS
S. armatum	2.569	0.076 NS
S. affine	0.058	0.944 NS

NS : Not significant.

16

MONTHLY VARIATIONS IN SHELF AND OCEANIC AREAS

While it was possible to obtain a general idea about the variations in the occurrence of euphausiids in the shelf and oceanic areas on a seasonal basis, a study of the same during each month could give more insight into the variations in distribution in time in the two environments. For this study the whole data was distributed into months separately for shelf and oceanic waters and the variations were noted.

Fig. 159 gives a picture of the monthly variations in the abundance of euphausiids in the shelf and oceanic waters. While an oceanic abundance was the rule during seven months from March to June, August, December and January a shelf abundance

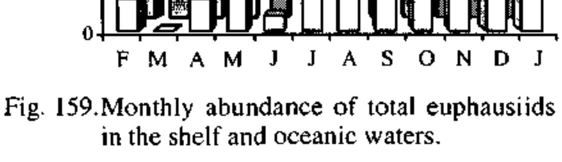

Fig. 159.Monthly abundance of total euphausiids in the shelf and oceanic waters.

was indicated in the rest of the months. When the maximum shelf abundance was observed in September, the oceanic maximum was found in April-May. The July to November increase in the shelf area was the result of upwelling along the west coast of India during which cold upwelled waters enter the shelf from the oceanic region bringing along with it those euphausiids which normally inhabit the oceanic waters (Mathew 1985). Therefore the occurrence of such oceanic euphausiids in the shelf waters during certain months may be indicative of the presence of the water mass characteristic to the oceanic region in the shelf region. Most of the common species also followed the above mentioned trend as observed in the case of total euphausiids.

T. monacantha occurred in the shelf during February and June only and that too in very small numbers of 26 and 42 respectively per 1000 m^3 of water (Fig. 160). In the oceanic area the species was present in all months except October and the number ranged from 13 in December to 156 in April. *T. tricuspidata* made its presence in the shelf during February, May and January only but

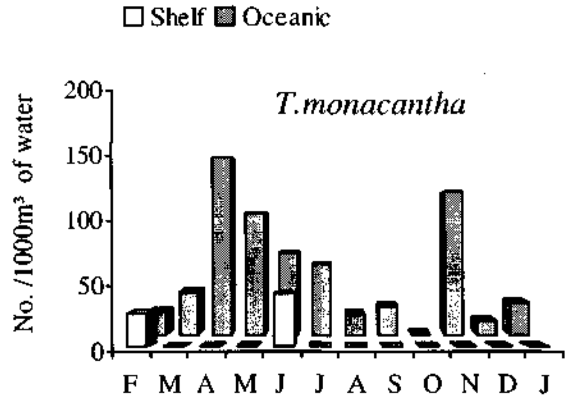

Fig. 160. Monthly abundance of *T. monacantha* in the shelf and oceanic waters.

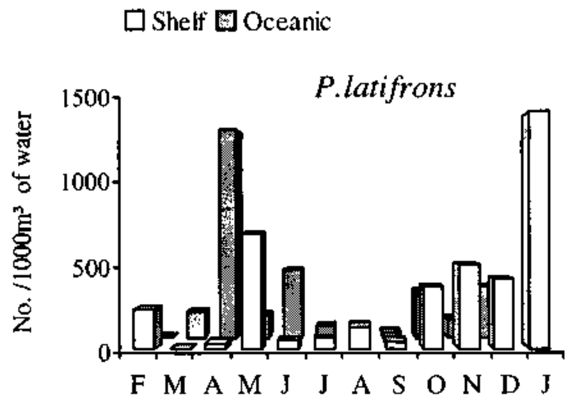

Fig. 162. Monthly abundance of *P. latifrons* in the shelf and oceanic waters.

was more significant than the first mentioned species numerically (Fig. 161). Its abundance during February (341/1000 m^3) and May (509/1000 m^3) was such that the species never occurred in such enormity in any of the months not only in the shelf area but also in the oceanic area.

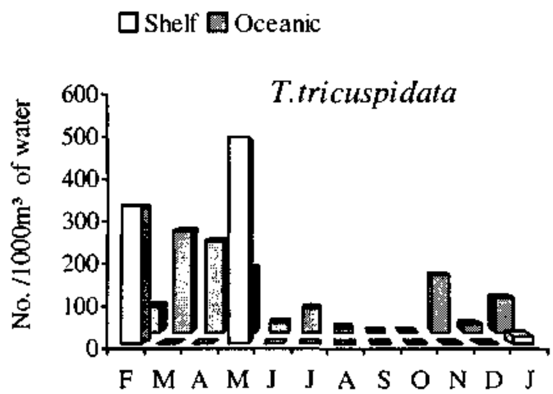

Fig. 161. Monthly abundance of *T. tricuspidata* in the shelf and oceanic waters.

Except in March in the shelf *P. latifrons* was present in all the other months in the shelf and oceanic waters (Fig. 162). The shelf registered high density of population during May and from October to January. The alltime high of 1,428 per 1000 m^3 of water was obtained from the shelf in January. The corresponding number for oceanic waters during this month was 31 only. The highest number taken from the oceanic waters was 1,387 per 1000 m^3 of water and it was in April. An interesting feature noted with this species was that whenever a rise in population was noticed in either shelf or oceanic a corresponding decrease was noticed in the other environment during the same month and *vice versa*.

E. diomedeae was significant with its absence in the shelf area during March and April. An unprecedented increase of this species to the tune of 3,972 per 1000 m^3 of water was noticed in July (Fig. 163). Another increase observed in this region was in November. On the whole a shelf abundance of this rather oceanic species was indicated from July to November which could again be attributed to the upwelling prevalent along the coast during the southwest monsoon months. Also the oceanic abundance was substantial in all the months suggesting once again the affinity of the species to the water beyond the shelf edge.

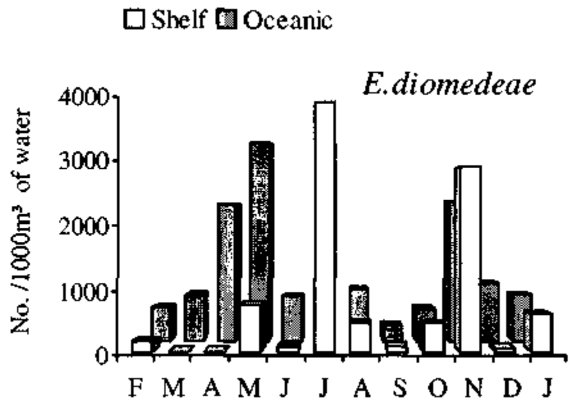

Fig. 163. Monthly abundance of *E. diomedeae* in the shelf and oceanic waters.

The half year period from July to December coincide with the southwest monsoon and the postmonsoon seasons and this appeared to be the prime period for *E. sibogae* especially in the shelf waters (Fig. 164). The only two months in which an oceanic abundance was noted were March and June when the overall density of population in the two environments was very low. The all time high of 11,651 per 1000 m^3 of water was taken from the shelf area in December.

The only month when *E. tenera* occurred

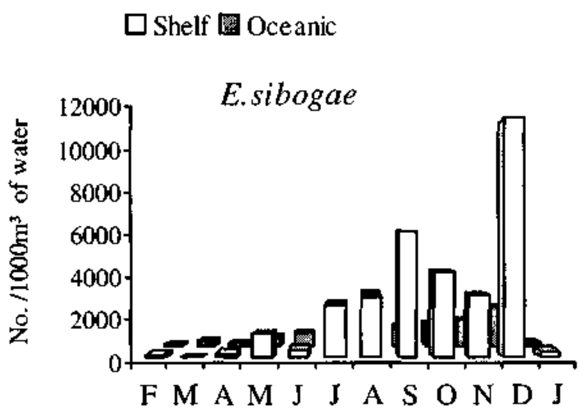

Fig. 164. Monthly abundance of *E. sibogae* in the shelf and oceanic waters.

in the shelf waters was February when it was taken at a rate of 33 per 1000 m^3 of water (Fig. 165). In the oceanic realm the species was not taken during August, September and December. March to May and October to November appeared to be the months of abundance of this species in

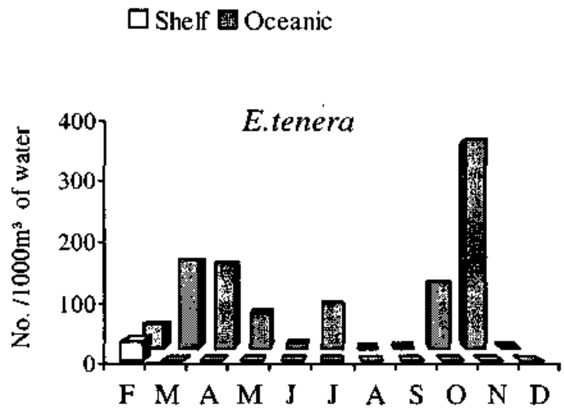

Fig. 165. Monthly abundance of *E. tenera* in the shelf and oceanic waters.

the oceanic waters. *E. pseudogibba*, a rather oceanic species was mostly found in the oceanic environment during in April, July and October to January. The species intruded into the shelf in October (a month of intense upwelling towards the middle part of the west coast) when an unusually high number at a rate of 452 per 1000 m^3 of water was present in the shelf (Fig. 166).

N. gracilis presented an alternate pattern of abundance in the shelf and oceanic areas during different months. There was a predominance of the species in the shelf waters during the November-February period and an abundance in the oceanic area during the March-May period (Fig. 167). A very high abundance was noticed in both shelf and oceanic waters during July with more than 500 per 1000 m^3 of water. High oceanic

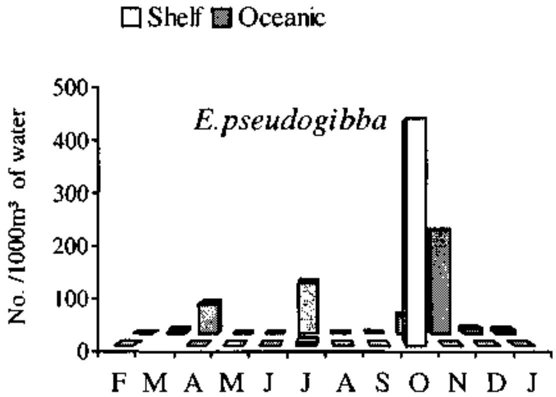

Fig. 166. Monthly abundance of *E. pseudogibba* in the shelf and oceanic waters.

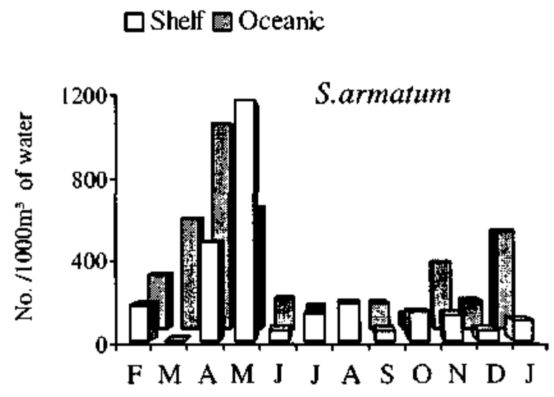

Fig. 168. Monthly abundance of *S. armatum* in the shelf and oceanic waters.

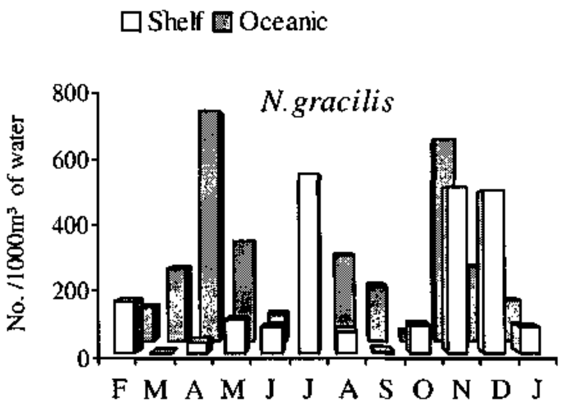

Fig. 167. Monthly abundance of *N. gracilis* in the shelf and oceanic waters.

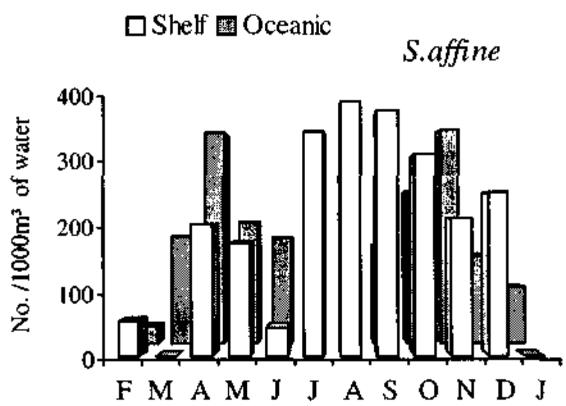

Fig. 169. Monthly abundance of *S. affine* in the shelf and oceanic waters.

abundance occurred in April and November with 840 and 700 specimens respectively per 1000 m^3 of water.

S. armatum (Fig. 168) was abundant in the shelf waters during April and May although the species was available in the shelf in smaller numbers from June-February. Corresponding equal abundance was recorded in the oceanic waters also in all the months with high abundance during March to May and January. *S. affine* presented a mixed pattern of distribution in the shelf and oceanic waters in different months. An oceanic abundance occurred during March to June while the period from January to October and December to February showed a shelf abundance (Fig. 169). The maximum shelf abundance was in the monsoon month of August when 398 specimens per 1000 m^3 of water were taken. July, September and October rallied closely. The highest oceanic occurrence was in November at a rate of 369 per 1000 m^3 of water.

17

LATITUDINAL AND SEASONAL DISTRIBUTION IN SHELF AND OCEANIC WATERS

A northward and southward movement of euphasiids during different seasons was examined for the shelf and oceanic waters separately. When all the species were considered together (Fig. 170), the shelf abundance was rather uniformly felt in certain seasons in the different latitudinal sectors. Thus the seasons of the monsoon of first and second sectors, the premonsoon and the postmonsoon of the third sector and the postmonsoon of the northernmost sector of the shelf presented an almost uniform abundance of above 4,000 specimens per 1000 m^3 of water. When split into various seasons in each of the latitudinal sectors for the shelf and oceanic waters separately, the overall indication was of a shelf abundance. In the third and fourth sectors a shelf abundance was indicated during the post monsoon season being dominated by the coastal species namely *P. latifrons* and the cosmopolitan species namely *E. sibogae* which, as stated earlier was the most abundant species in the study area. The southern two sectors were rich in euphausiid population in all the seasons for both shelf and oceanic waters except for the shelf waters during the premonsoon in the first sector. The influence of oceanic water over the shelf in areas south of 10°N is clearly indicated by the pattern of distribution of the total euphausiids as well as individual species in the different seasons.

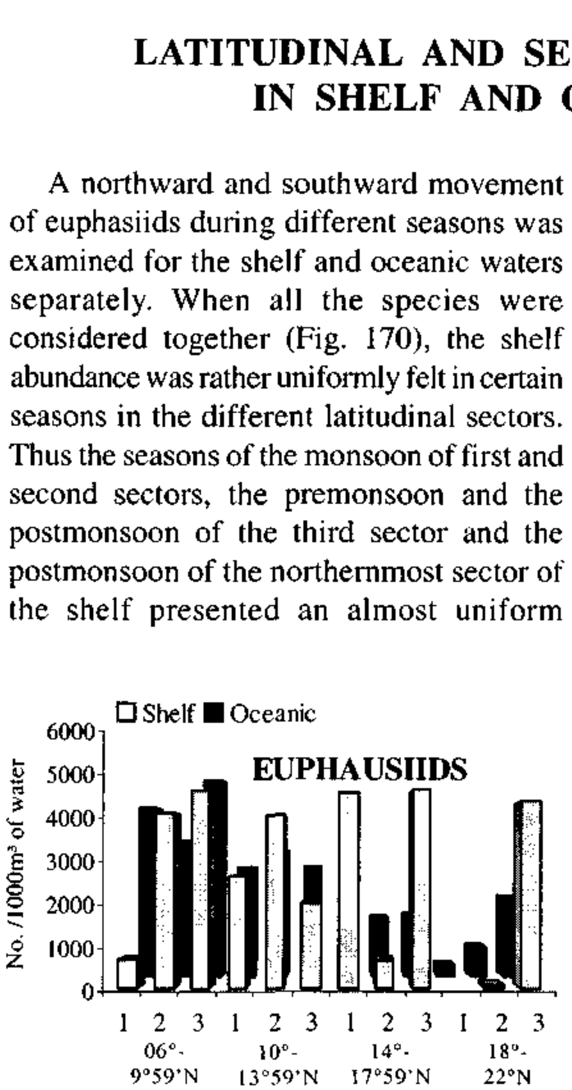

Fig. 170. Seasonal distribution of total euphausiids in the various latitudinal sectors in the shelf and oceanic waters. 1, 2 and 3 indicate premonsoon, monsoon and postmonsoon seasons respectively.

In the southernmost latitudinal sector (first sector) *T. monacantha* migrated to the shelf in the premonsoon season during which period the salinity was high and favourable for this oceanic species. In the second sector a shelf occurrence was noticed during the premonsoon and the upwelling season of monsoon. Other than these sporadic occurrences, the species remained off the shelf in all the sectors in all the seasons (Fig. 171). Almost similar was the case with *T. tricuspidata* another oceanic species (Fig.172). A premonsoon occurrence predominated in the first, second and third sectors during the premonsoon season. In the first and second sectors the species

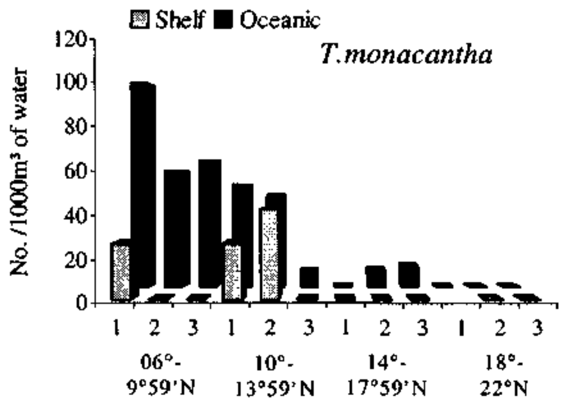

Fig. 171. Seasonal distribution of *T. monacantha* in the various latitudinal sectors in the shelf and oceanic waters.

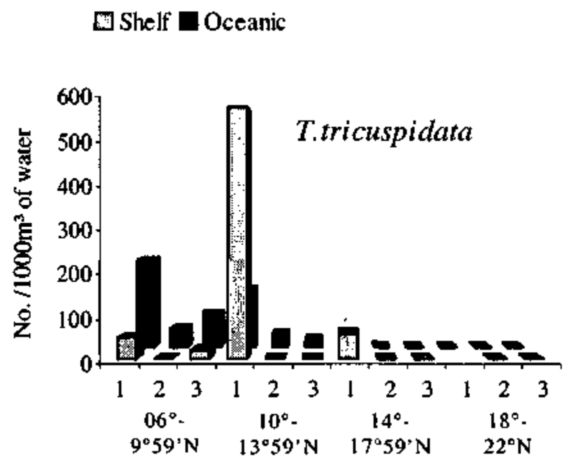

Fig. 172. Seasonal distribution of *T. tricuspidata* in the various latitudinal sectors in the shelf and oceanic waters.

occurred during all the seasons in the oceanic waters.

Except in the northernmost latitudinal sector (fourth sector) *P. latifrons* occurred in all the other sectors in the shelf as well as oceanic areas in all the seasons (Fig. 173).

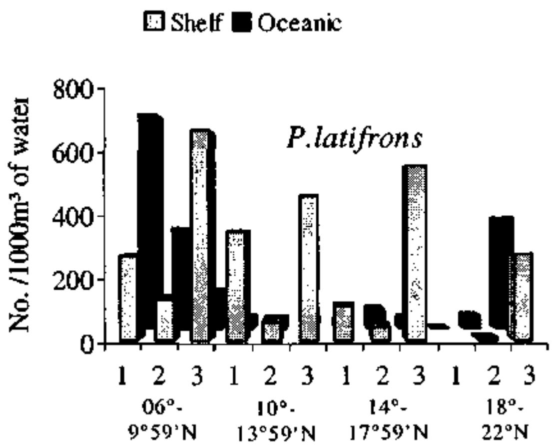

Fig. 173. Seasonal distribution of *P. latifrons* in the various latitudinal sectors in the shelf and oceanic waters.

That this nearshore species was maximum abundant in the oceanic waters during the premonsoon at a rate of 760 per 1000 m^3 of water and somewhat abundant during the monsoon though looked rather strange is explained as a result of its abundance in the nearshore waters of the oceanic islands of the Lakshadweep. During the post monsoon season in the first three sectors the swing was towards shelf. In the northernmost sector both the shelf and oceanic waters contained moderate densities of this species during the postmonsoon season.

E. diomedeae (Fig. 174) made a post-monsoon maximum (6,375/ 1000 m^3) in the shelf waters in the southernmost latitudinal sector. The second high but of a low

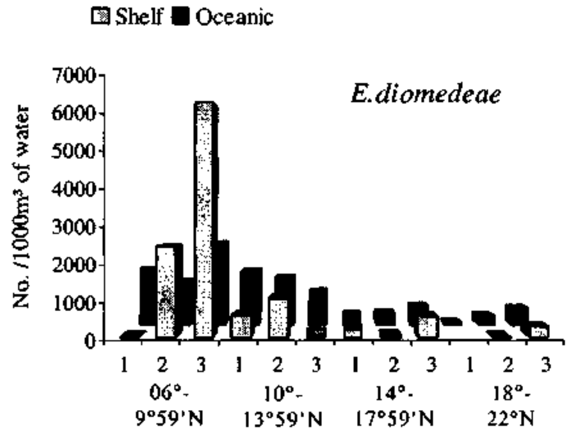

Fig. 174. Seasonal distribution of *E. diomedeae* in the various latitudinal sectors in the shelf and oceanic waters.

magnitude was also registered in the same sector during the monsoon. Though in smaller numbers the species made its abundance in the oceanic waters in all the sectors year round. The shelf abundance whenever it occurred was at the highest level in the first sector. *E. tenera* never occurred in the shelf area at any latitudinal sector in any season (Fig. 175). The material was

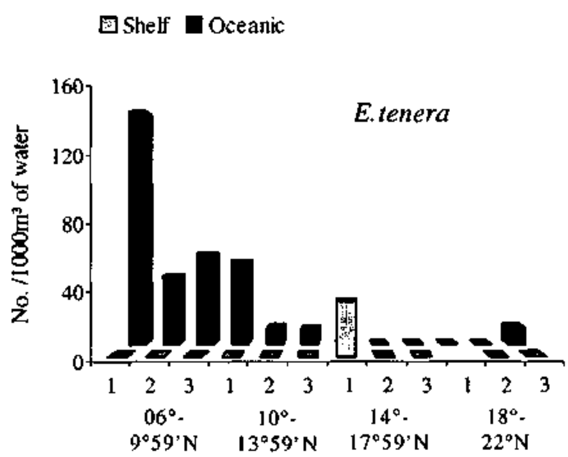

Fig. 175. Seasonal distribution of *E. tenera* in the various latitudinal sectors in the shelf and oceanic waters.

mostly obtained from the first and second sectors. The premonsoon season in the southernmost sector accounted for the maximum quantity in the oceanic waters.

Exceptional abundance of *E. sibogae* was found in the shelf area during the monsoon season in the first two latitudinal sectors (Fig. 176). A post monsoon abundance was the rule in the shelf waters of the third and fourth sectors in the shelf. The species remained at low levels of concentration in

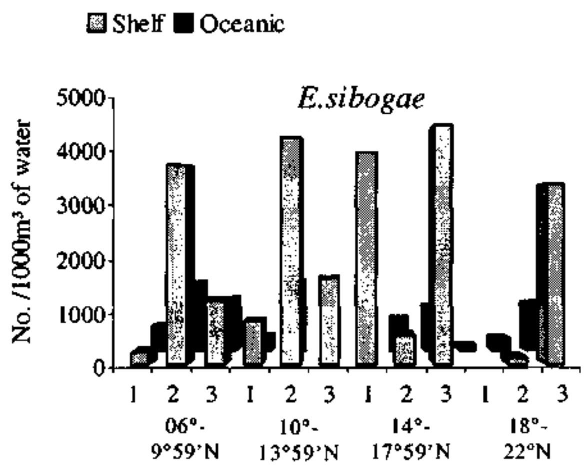

Fig. 176. Seasonal distribution of *E. sibogae* in the various latitudinal sectors in the shelf and oceanic waters.

all the sectors in the oceanic waters in all the seasons

A seasonal variation in the different latitudinal sectors of the shelf and oceanic waters was very much pronounced in *N. gracilis* (Fig. 177). Heavy concentration of the species occurred in all the seasons in the shelf as well as oceanic areas in the southernmost sector. The intensity of abundance was reduced from south to north in the shelf as well as oceanic areas during all the seasons. Most of the time the species

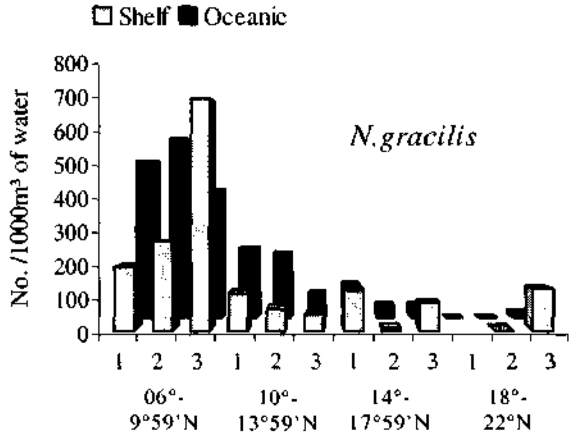

Fig. 177. Seasonal distribution of *N. gracilis* in the various latitudinal sectors in the shelf and oceanic waters.

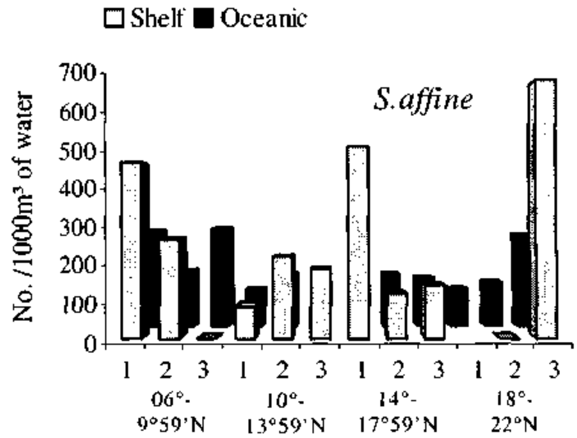

Fig. 179. Seasonal distribution of *S. affine* in the various latitudinal sectors in the shelf and oceanic waters.

occurred in comparatively greater concentration beyond the shelf edge. However, the all time high was in the shelf area of the southernmost sector during the postmonsoon season.

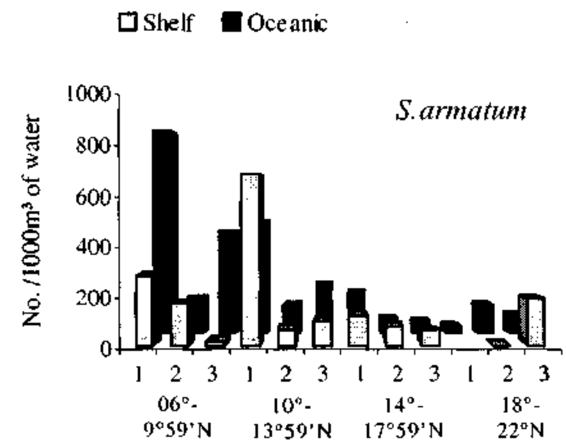

Fig. 178. Seasonal distribution of *S. armatum* in the various latitudinal sectors in the shelf and oceanic waters.

A mixed pattern of shelf and oceanic seasonal abundance was observed in *S. armatum* in the various latitudinal sectors. The premonsoon oceanic abundance which occurred in the first sector was the maximum noted anywhere at any time (Fig. 178). In the second sector also the greater abundance was during the premonsoon but the same was in the shelf. The population being of a lower density in the third and fourth sectors, a notable latitudinal variation was not found in any of the sectors during any seasons either in the shelf or the oceanic. Excepting a premonsoon abundance in the first and third sectors and a postmonsoon maximum in the northernmost sector off the shelf waters *S. affine* presented an almost uniform type of distribution in all the latitudinal sectors in all the seasons in both shelf and oceanic waters (Fig. 179). This speaks of the cosmopolitan distribution of the species in the study area.

18

SEASONAL VARIATIONS OF ADULTS, JUVENILES AND LARVAE

There was considerable seasonal variations in the occurrence of different life stages of euphausiids as a whole and each species and an attempt was made to measure the variations in terms of the three major seasons. The study would give some information on the breeding habits of the various species. Altogether six species whose adults, juveniles and larvae were represented in sizeable quantities in the samples were selected for the study.

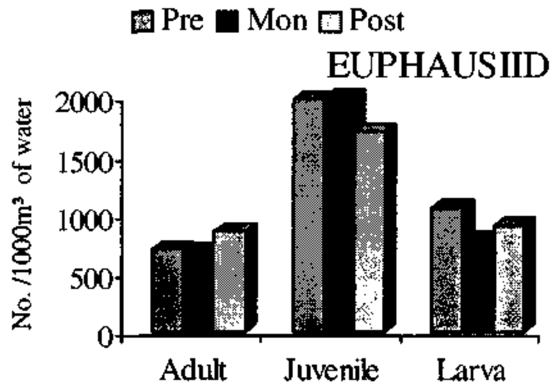

Fig. 180.Seasonal abundance of adults, juveniles and larvae of total euphausiids.

When all the species were considered together marked changes were observed in the seasonal composition of the life stages. In all the seasons the adults had a population of less than 1,000 per 1000 m^3 of water (Fig. 180). On the other hand the juveniles dominated over the adults and the larvae by about three times and the highest was during the monsoon. The quantitative larval abundance during the three seasons fell in between the adult and juvenile populations.

Adults

When the adults of *P. latifrons* were taken, from a monsoon low of 30 per 1000 m^3 of water the species showed a seven fold increase during the postmonsoon from which another fourfold increase was noticed during the premonsoon period (Fig. 181). In the case of *E. diomedeae* the monsoon season accounted for the maximum number of 305 per 1000 m^3 of water and a one third reduction in the adult population was experienced during the post and pre monsoon seasons (Fig. 182). From a density of 460 per 1000 m^3 of water in monsoon, *E. sibogae* showed a 50 % increase during the postmonsoon but only for a 75 % reduction during the premonsoon season (Fig. 183. From a very low adult population of around 40 per 1000 m^3 of water during the monsoon and postmonsoon seasons *N. gracilis* made an

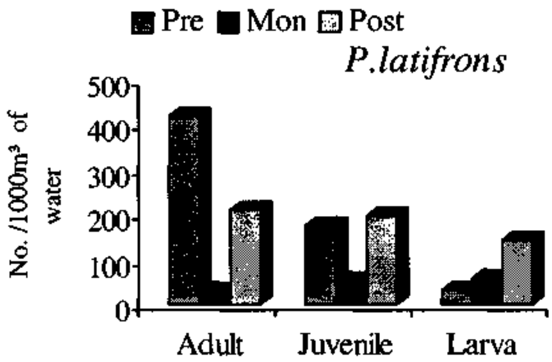

Fig. 181. Seasonal abundance of adults, juveniles and larvae of *P. latifrons*.

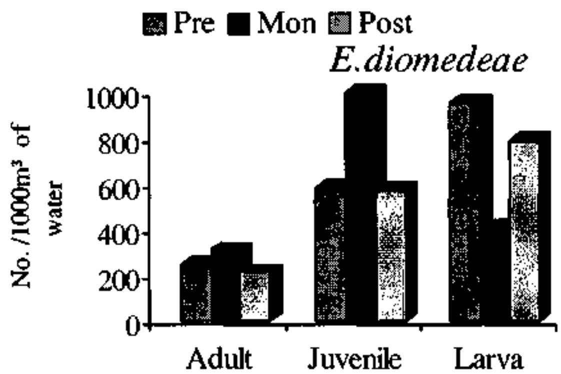

Fig. 182. Seasonal abundance of adults, juveniles and larvae of *E. diomedeae*.

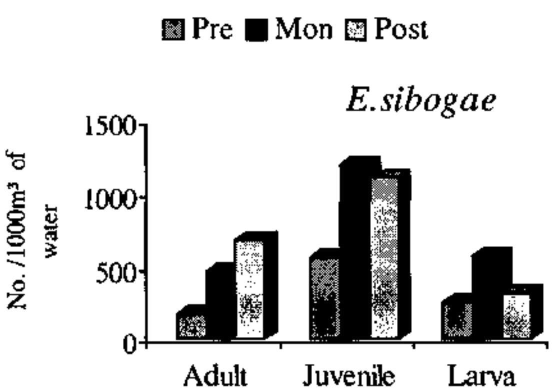

Fig. 183. Seasonal abundance of adults, juveniles and larvae of *E. sibogae*.

88 % increase during the premonsoon (Fig. 184). *S. armatum* also had a low adult population during the monsoon and it increased progressively during the postmonsoon and premonsoon seasons (Fig. 185). *S. affini* also presented a monsoon minimum of 100 per 1000 m^3 of water but increased by about 50 % during the postmonsoon but only for a reduction by 29 % during the premonsoon (Fig. 186).

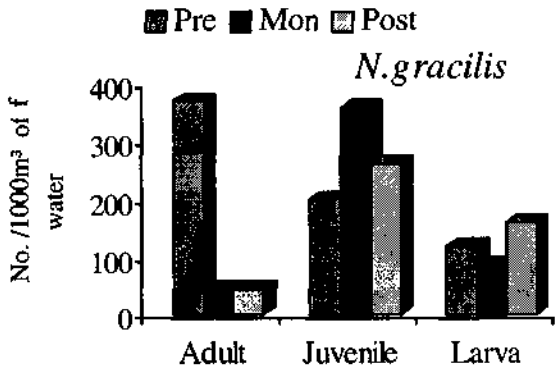

Fig. 184. Seasonal abundance of adults, juveniles and larvae of *N. gracilis*.

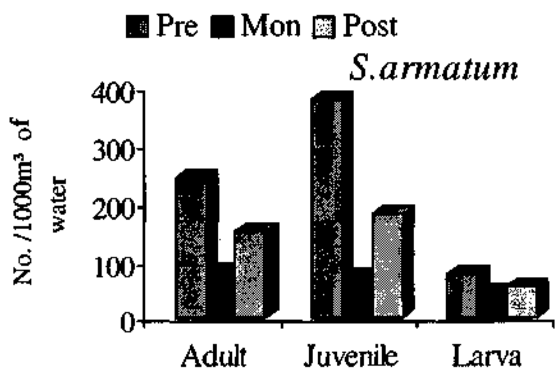

Fig. 185. Seasonal abundance of adults, juveniles and larvae of *S. armatum*.

Thus while the adults of *E. diomedeae* alone showed a monsoon maximum, two species namely *E. sibogae* and *S. affine* made a postmonsoon dominance and three species namely *P. latifrons*, *N. gracilis* and *S.*

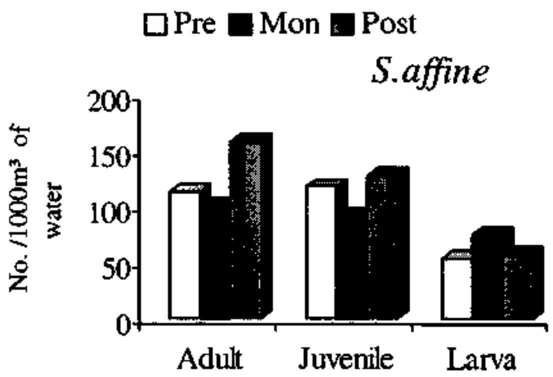

Fig. 186.Seasonal abundance of adults, juveniles and larvae of *S. affine*.

armatum presented a premonsoon maximum.

Juveniles

With regard to juveniles, striking seasonal variations were found in all the major species. From a monsoon minimum of 30 per 1000 m^3 of water *P. latifrons* registered a four fold increase in postmonsoon and almost the same trend was continued to the premonsoon season (Fig. 181). *E. diomedeae* had a monsoon maximum of its juveniles. From a maximum of 572 per 1000 m^3 of water the population made a 42 % reduction during the postmonsoon and the same rate was maintained throughout the premonsoon (Fig. 182). *E. sibogae* sustained a high juvenile population of 1,182 per 1000 m^3 of water during the monsoon and the post monsoon seasons (Fig. 183). From its maximum of 356 per 1000 m^3 of water during the monsoon *N. gracilis* made a progressive reduction by about 23 % in its juvenile population through the rest of the seasons (Fig. 184). From monsoon through postmonsoon to premonsoon, *S. armatum* made a substantial increase (Fig. 185). Thus a 60 % increase from the monsoon minimum of 71 per 1000 m^3 of water was noticed in the postmonsoon and from this number another 52 % increase was registered during the premonsoon period. In *S. affine* the juvenile population was low during the monsoon with only 91 per 1000 m^3 of water but were increased by 28 % during the postmonsoon and the same trend was continued during the premonsoon also (Fig. 186).

Larvae

Wide variations in the occurrence of larvae also were noticed during the various seasons. From a low population density of 60 per 1000 m^3 of water during the monsoon season, *P. latifrons* more than doubled its larval population during the post monsoon season. However, the population plunged to the minimum of just 30 per 1000 m^3 of water during the premonsoon season (Fig. 181). With regard to the larvae of *E. diomedeae* from a minimum population size of 40 per 1000 m^3 of water during the monsoon there was 97 % increase during the postmonsoon and another 34 % increase during the premonsoon (Fig. 182). Larvae of *E. sibogae* were represented maximum during monsoon at a rate of 559 per 1000 m^3 of water from which a 43 % reduction was observed during postmonsoon. The larval population got further reduced by 21 % during the pre-monsoon (Fig. 183). From a maximum of 158 per 1000 m^3 of water during the postmonsoon the larvae of *N. gracilis* was reduced to 117 during the premonsoon and was further reduced to 86 during the monsoon period (Fig. 184). *S. armatum* did not show much of a seasonal variation of its larvae having fluctuated between 45 per 1000 m^3 of water during monsoon and 75 during the premonsoon (Fig. 185). *S. affine* also maintained a low level of larval abundance during all the seasons with the maximum of 75 per 1000 m^3 of water during monsoon and a minimum of 53 during premonsoon (Fig. 186).

In *T. monacantha* significant variations were not observed either in the composition of adults, juveniles and larvae or in their occurrence during the three major seasons (Fig. 187). Adults and larvae were comparatively less during the monsoon while the juveniles were more abundant during the premonsoon season. The population was dominated by juveniles.

Adults of *T. tricuspidata* (Fig. 188)

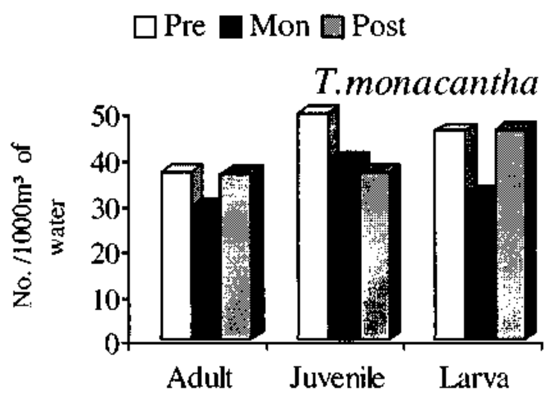

Fig. 187. Seasonal abundance of adults, juveniles and larvae of *T. monacantha*.

showed dominance over other stages during premonsoon and occurred at a rate of about 50 per 1000 m^3 of water. All the life stages were least represented during the monsoon season. The juveniles showed high abundance during the premonsoon season; its number exceeding 150 per 1000 m^3 of

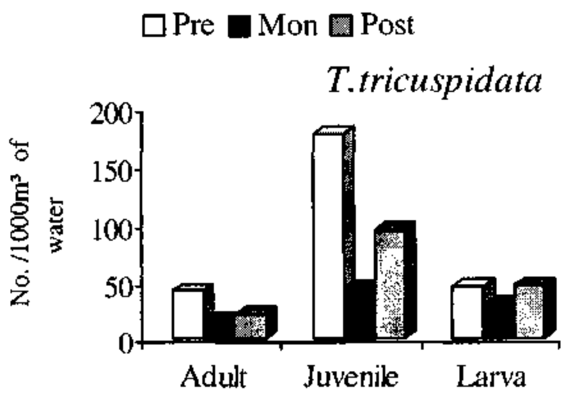

Fig. 188. Seasonal abundance of adults, juvenile and larvae of *T. tricuspidata*.

water. The larval forms though occurred in small numbers outnumbered the adults during all the seasons.

Adults and juveniles of *E. tenera* occurred at a rate of about 80 per 1000 m^3 of water during the premonsoon season, but its larval representation was less than 10 during this season (Fig. 189). All the three stages made least representation during the monsoon. The larvae and the juveniles showed a post-monsoon maximum of over 100 per 1000 m^3 of water.

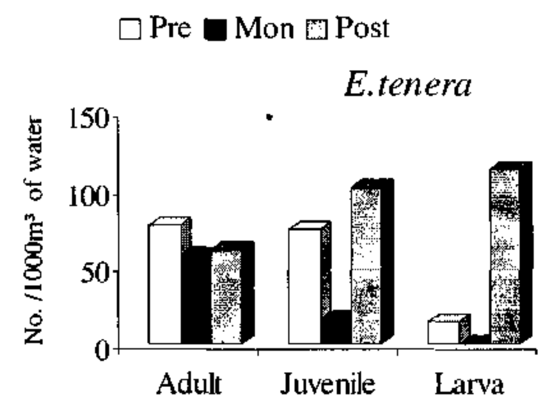

Fig. 189. Seasonal abundance of adults, juveniles and larvae of *E. tenera*.

Table 18. *Test of significance among adults, juveniles and larvae of major species during different seasons*

Species	Adults		Juveniles		Larvae	
	F	P	F	P	F	P
P. latifrons	4.216	0.006 **	3.921	0.009 **	2.430	0.033 **
E. diomedeae	0.012	0.988 NS	1.458	0.234NS	4.783	0.009 **
E. sibogae	9.376	0.000 **	5.522	0.001 **	4.175	0.006 **
N. gracilis	2.799	0.040 *	6.601	0.000 **	2.679	0.046 *
S. armatum	16.524	0.000 **	46.184	0.000 **	7.151	0.000 **
S. affine	0.860	0.462 NS	4.755	0.009NS	6.348	0.091NS

** : Significant at 1 & 5% levels, * : Significant at 5% level, N.S : Not significant.

The above study throws some light on the breeding seasons among the major species of euphausiids in the area of investigation. Thus *P. latifrons* had its intensive breeding during postmonsoon season, *E. diomedeae*, *S. armatum* and *S. affine* during all the three seasons, *E. sibogae* during the monsoon and postmonsoon seasons , *N. gracilis* during monsoon and postmonsoon seasons and *E. tenera* during the postmonsoon season. A further analysis attempted in the ensuing chapter on the monthly variations in the abundance of larvae, juveniles and adults and also the spermatophore and egg bearing animals would present a more clear picture on the breeding periods of the major species.

The seasonal variation when tested statistically separately for the adults juveniles and larvae (Table 18) revealed the following. For the adults the significant variations at 1 and 5% levels were found with *P. latifrons*, *E. sibogae* and *S. armatum*. Significance at 5% level was observed for *N. gracilis* while no significant correlation was met with among the adults of *E. diomedeae* and *S. affine*. An almost similar result was obtained for the juveniles of the above species except *N. gracilis* in which case the juveniles presented highly significant value at 1 and 5 % levels. The larvae also behaved almost in the similar manner as that of the adults except that the larvae of *E. diomedeae* showed high variations during the sesons whereby indicating significant seasonal variations

19

VARIATIONS AMONG ADULTS, JUVENILES AND LARVAE IN THE SHELF AND OCEANIC WATERS

As a general rule, eventhough the euphausiids do not come very close to the coast except around oceanic islands, certain species are known to be distributed more in the shelf waters. The majority of the species are oceanic and deep living and seldom migrate to the shelf region. In the present study most of the widely distributed species were found to occur in the shelf as well as oceanic areas. But striking variations occurred in the distribution of the different life history stages larvae, juveniles and adults in the two environments. Following is a discussion of such variations met with among the life stages of the major species.

When the euphausiids as a whole were considered an equilibrium was found in the relative occurrence of adults, juveniles and larvae in the shelf and oceanic areas (Fig. 190). While the adults shared 23 and 21 % of the total in the shelf and oceanic realms respectively the juveniles occurred at a rate of 52 and 53 % and the larvae at 25 and 26 %. This unusual similarity in the relative occurrence in the two environments suggests the social sense of this group of animals

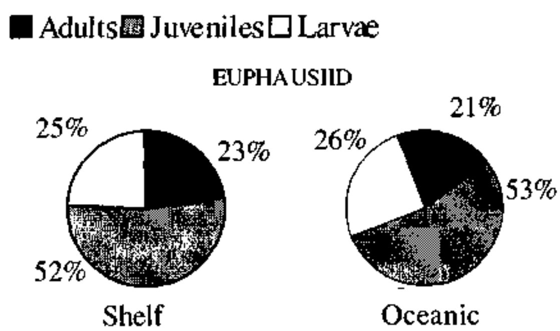

Fig. 190. Distribution of adults, juveniles and larvae of total euphausiids in the shelf and oceanic waters.

within their populations in that they always try to keep an equilibrium between the different life stages and thus within the entire population. However, when the species were considered separately great differences were noticed among the various stages in both the environments.

The adults of the neritic species *P. latifrons* were represented by 51 %, the juveniles took a share of 37 % and the larvae just 2% in the shelf waters whereas in the oceanic area the adults took a share of 21 % only against a juvenile part of 32 % and the major share of 47 % going to the larvae (Fig. 191).

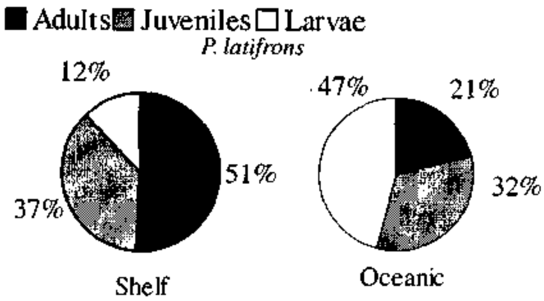

Fig. 191. Distribution of adults, juveniles and larvae of *P. latifrons* in the shelf and oceanic waters.

Thus an almost diametrically opposing trend was presented by *P. latifrons* in the environments.

The life stages of *E. diomedeae* behaved almost in the same manner in the shelf and oceanic waters. An almost 10:40:50 ratio was maintained for the adults, juveniles and larvae respectively in both the environments (Fig. 192). This striking similarity among the life stages in the shelf and oceanic areas can be attributed to the successful breeding of the species.

E. sibogae also presented an almost identical picture in the relative abundance of the three stages in the shelf and oceanic

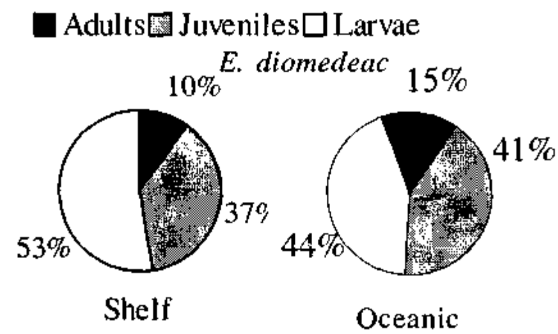

Fig. 192. Distribution of adults, juveniles and larvae of *E. diomedeae* in the shelf and oceanic waters.

waters (Fig. 193). However, the species differed from *E. diomedeae* in that while the larvae dominated in the former environment it was the juveniles that dominated in the latter. The adults also took a major share in the case of *E. sibogae*.

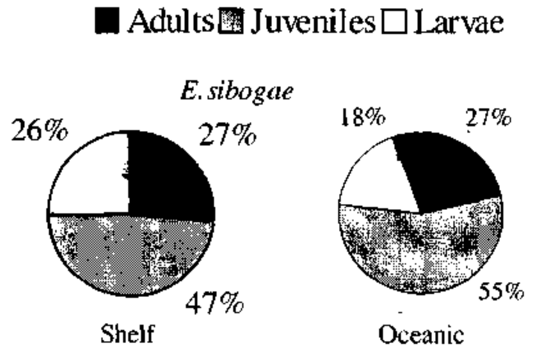

Fig. 193. Distribution of adults, juveniles and larvae of *E. sibogae* in the shelf and oceanic waters.

N. gracilis (Fig. 194) presented opposing results in the case of its adults and larvae in both the environments. While the oceanic area had a 31 % adult representation the same in the shelf was 9 % only indicating the oceanic nature of the species. The larvae were proportionately more in the shelf region. The juveniles had a 50 % representation in both shelf and oceanic.

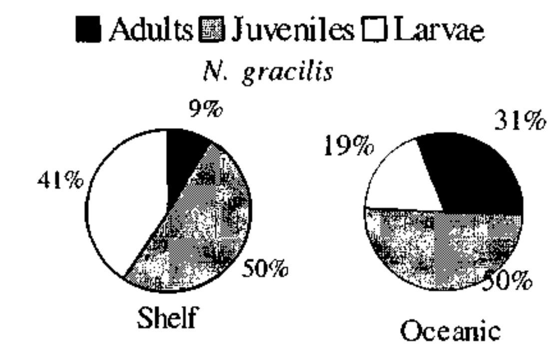

Fig. 194. Distribution of adults, juveniles and larvae of *N. gracilis* in the shelf and oceanic waters.

The proportionate occurrence of the adults, the juveniles and the larvae of *S. armatum* was more or less the same in the shelf and the oceanic. The least occurrence of the larvae in both the environments was rather interesting. Almost 50 % of the population consisted of juveniles (Fig. 195).

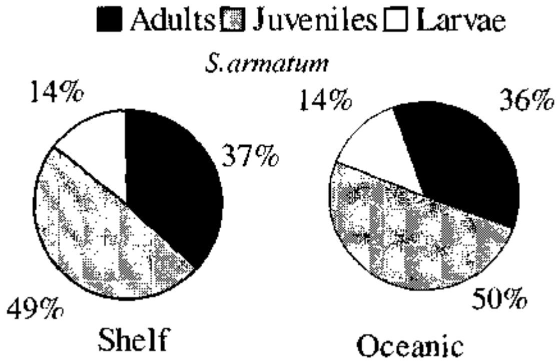

Fig. 195. Distribution of adults, juveniles and larvae of *S. armatum* in the shelf and oceanic waters.

The ratio among the three life stages of *S. affine* also was almost the same in the shelf and the oceanic with slight variations in the case of adults and juveniles (Fig. 196). The adults which formed more than 40 % in the two sea areas dominated over the other two stages. In this species also the larvae made an equal representation in both the environments.

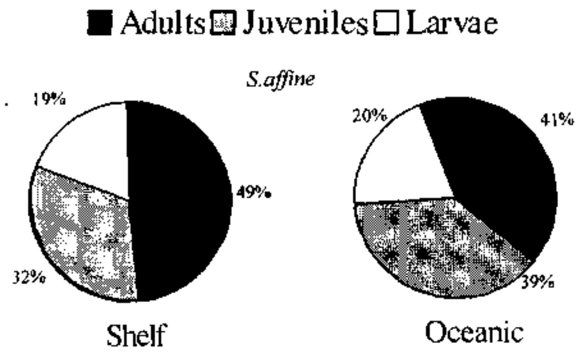

Fig. 196. Distribution of adults, juveniles and larvae of *S. affine* in the shelf and oceanic waters.

Significant differences were observed in the distribution of adults, juveniles and larvae of majority of the major species in the shelf and the oceanic waters (Table 19). The occurrence of adults was significant at 1 and 5% levels in the case of *E. diomedeae, E. sibogae, S. armatum* and *S. affine*. While it was significant at 5% level only with *P. latifrons* no significant difference was found for *N. gracilis*. Regarding juveniles, all the species except *S. affine* gave significant values at 1 and 5% levels. The shelf/oceanic difference was not pronounced for *E. sibogae, N. gracilis* and *S. affine*. For the larvae of the rest of the species the test proved highly significanct at 1 and 5% levels.

Table 19. *Test of significance for variations among adults, juveniles and larvae in the shelf and oceanic waters*

Species	Adults		Juveniles		Larvae	
	P	F	P	F	P	F
P. latifrons	3.050	0.048 *	18.360	0.000 **	7.418	0.007 **
E. diomedeae	40.962	0.000 **	35.744	0.000 **	26.246	0.000 **
E. sibogae	40.227	0.015 **	6.883	0.001 **	2.841	0.059 NS
N. gracilis	2.896	0.056 NS	20.323	0.000 **	1.159	0.315 NS
S. armatum	26.261	0.000 **	20.712	0.000 **	7.828	0.000 **
S. affine	5.543	0.004 **	1.803	0.146 NS	1.808	0.165 NS

** : Significant at 1 and 5% levels, * : Significant at 5% level, NS : Not significant.

20

BREEDING PERIODS AND BREEDING INTENSITY

Earlier studies on the breeding, the breeding seasons and the intensity of breeding of euphausiids have brought to light a complexity of problems. Smiles and Pearcy (1971) and Brinton (1976) found that euphausiids of not only equatorial region but also of mid latitudes may have a proportion of breeding females at all times of the year, however, with periods of more intense breeding. Therefore it is but natural to find spermatophore bearing males and females, and egg bearing females of a few species and the larval and the juvenile stages of all the species throughout the year.

During the breeding seasons the male extrudes the sperm sacs or spermatophores through the vas deferens situated on either side of the thorax and carry them externally. These spermatophores are deposited into the thelycum of the female and the female carry them externally until impregnation is over.

When the euphausiids as a whole were considered the larvae and the juveniles were present in all the months indicating breeding throughout the year being performed by any one species or a group of species at any one time. However, high dominance of young stages over adults was noticed especially during the alternate months of February, May, July, September and November and these can be roughly considered as active breeding periods for any one species. Analysis of individual species would throw more light into their specific periods of breeding.

The larval abundance in *P. latifrons* (Fig. 197, 1) in terms of 1000 m^3 of water was highly pronounced in April (1,359/1000 m^3 of water), May (2,234) and November (2,219). In the other months they varied between 43 in September and 411 in December. The Juveniles made their abundance in May, October, November and December. A few numbers of spermatophore/egg bearing adults were also found in May, June, September, October and December. The result indicated continuous breeding in this species also with intense breeding during April-May and November, moderate during July-August, October, December and January and least during February-March, June and September. The breeding period for this species as found by Mathew (1982, 1983, 1988 b) was from December to April. However, since he had no samples for May and November he could not make any conclusion for these months which also are now found to be active breeding months.

In *E. diomedae* (Fig. 197, 2) high larval

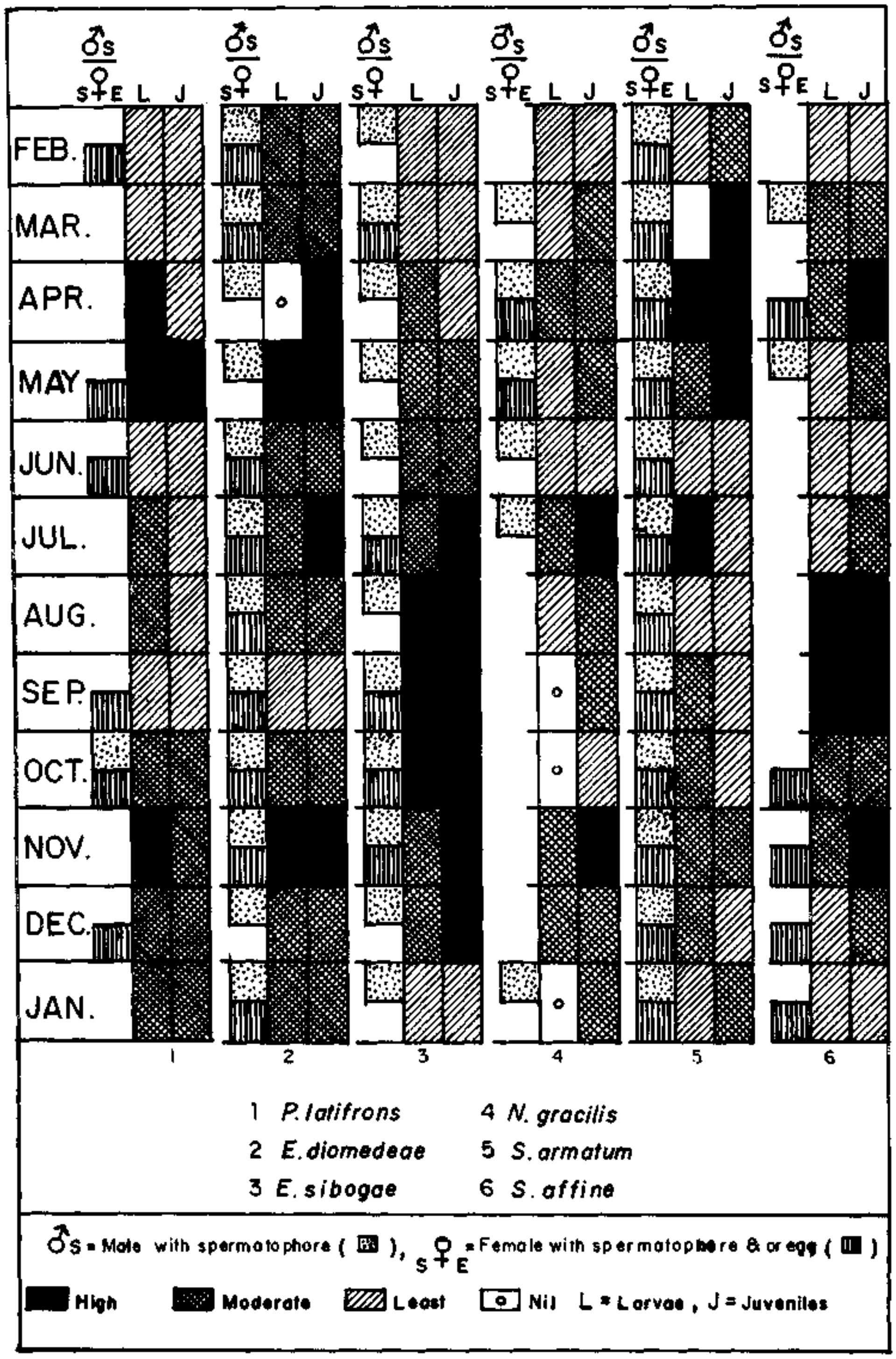

Fig. 197. Breeding and breeding seasons in some species of euphausiids based on the monthly availability of juveniles and larvae, and spermatophore and egg bearing organisms.

abundance was indicated in May and November, moderate in December to March, June to August and October and least during April and September. The highest number occurred was 1,943 per 1000 m^3 of water in May. Being mostly an oceanic species the relationship between breeding and upwelling need not be reflected in this species. The juveniles also had a proportionately high abundance in all months except May and November. In this species the males carrying spermatophores exceeded 100 per 1000 m^3 of water during April-May, July- August and November. Similarly good number of females with spermatophore were also taken during June, August and October. The pattern of abundance of gravid specimens, larvae and juveniles of *E. diomedeae* suggests its active breeding period to be in April, May, July and November, moderate during January – March, June, August, October and December and least during September.

Mathew (1982, 1983, 1986 b) based on material obtained from the shelf waters of the southwest coast suggested an active breeding period for this species from December to April. The present study has further extended the breeding period of *E. diomedeae*.

In *E. sibogae* (Fig. 197, 3), the most abundant species eventhough continuous breeding was indicated, high larval abundance was noticed from August to October period and the number ranged from 604 to 1,047 with the maximum in September. In the other months the number ranged between 68 and 273 only. As far as the juveniles of this species were concerned high abundance was indicated from July to December with the number per 1000 m^3 of water exceeding 900.

The spermatophore bearing males were present in all the months but were especially abundant during September to December, the highest being in October at a rate of 546 per 1000 m^3 of water. The occurrence of spermatophore bearing females (89 per 1000 m^3 of water) was highest in October. The pattern of abundance of the gravid specimens, the larvae and the juveniles indicates that in *E. sibogae* the breeding started as early as July, which coincides with the southwest monsoon season and upwelling along the west coast of India, got intensified from August onwards and reduced by October, the time when upwelling ceases along this coast. The juvenile abundance continued for two more months after the larval abundance and this is reasonable as it would take some time for the larvae to become juveniles and adults.

Mathew (1982) observed very low numbers of larvae of *E. sibogae* from December to April and unusually high numbers from August to October which he considered to be the active breeding period for this species which thereafter continued at a moderate rate until December. The occurrence of early furciliae in August made him to conclude that the active breeding had started as early as July. The present finding based on large quantity of material confirm the findings of Mathew (1982) regarding the breeding period of *E. sibogae*.

In the case of *N. gracilis* eventhough larvae were not encountered in certain months, the juveniles were present in all the months in highly varying densities (Fig. 197, 4). Males with spermatophores were found in six months and females with spermatophore or eggs were present in two months only. This species also indicated almost continuous breeding. November presented the highest number of larvae at a rate of 183 per 1000 m^3 of water. April, June and December also accounted for good number of larvae. July was the month of highest juvenile abundance when the rate of occurrence was 538 per 1000 m^3 of water. The other months of juvenile abundance were January to April, August, September and November. The study indicated that *N. gracilis* breeds intensively in July and November, moderately in March to May, August, September, December and January and least in February, June and October.

S. armatum was quite unique with the presence of spermatophore bearing males and spermatophore and egg bearing females in all the months (Fig. 197, 5). It gives strong evidence for continuous breeding in this high abundant species of the area. However, variations in intensity of breeding was often indicated by the density of larval and juvenile populations. The highest larval abundance of 180 per 1000 m^3 of water was in April followed by 93 in July. In the other months the number varied between 20 in August and 75 in December. The juveniles were especially abundant from March to May with the highest of 621 per 1000 m^3 of water in April. January and February also presented good number of juveniles. March-May and July can be considered as intensive breeding periods for *S. armatum*, moderate in February, September to January and least in June and August. Mathew (1982, 1983, 1988 b) who examined samples from the shelf waters found discontinuous breeding in this species. The present material being from a wider area gives a better picture of breeding in *S. armatum*.

Another cosmopolitan and abundant species *S. affine* also indicated somewhat continuous breeding with young ones represented in all the months (Fig. 197, 6). Females with spermatophore or eggs were present in five months while males with spermatophores were found in two months only. August and September were the months of high larval abundance and the highest number of 133 per 1000 m^3 of water was in September. In the other months the number ranged from 15 to 87. Juveniles were present in high numbers in April, August, September and November. The highest number of 155 per 1000 m^3 of water was in August. From the pattern of occurrence of the breeding adults, the larvae and the juveniles, the months of April, August, September and November can be considered as high breeding months, while March, May, July, October and December as moderately breeding months and January, February and June as low breeding months for *S. affine*. Mathew (1982, 1983, 1988 b) also collected larvae of this species throughout the year and therefore he considered the species to be a continuous breeder with the peak breeding in the shelf area during October and December and least during January and February.

An interesting observation made was that the spermatophore bearing males and females and the egg bearing females of all species except *S. affine* were found to occur mostly in the night samples. Out of 231 samples in which such animals were found, 179 (77 %) samples were collected during the dark hours (Fig. 198). A few samples collected during day time contained a few spermatophore/egg bearing specimens, but most of such samples were from shallow stations where almost the entire water column was sampled.

The maximum night abundance of gravid specimens was seen in *N. gracilis* (92 %)

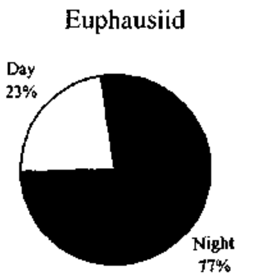

Fig. 198. Day/night variations of spermatophore bearing males and spermatophore and egg bearing females of total euphausiids.

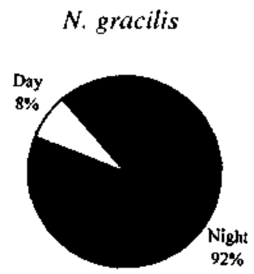

Fig. 199. Day/night variations of spermatophore bearing males and spermatophore and egg bearing females of *N. gracilis*.

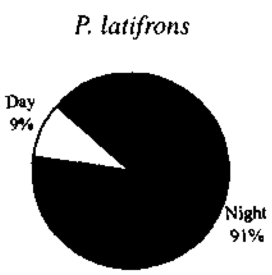

Fig. 200. Day/night variations of spermatophore bearing males and spermatophore and egg bearing females of *P. latifrons*.

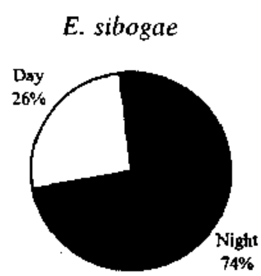

Fig. 201. Day/night variations of spermatophore bearing males and females of *E. sibogae*.

(Fig. 199) and in *P. latifrons* (91 %) (Fig. 200). *E. sibogae* (Fig. 201) and *S. armatum* (Fig. 202) had it to the tune of 74 and 73 % respectively. *E. diomedeae* also had night time abundance of gamete bearing animals

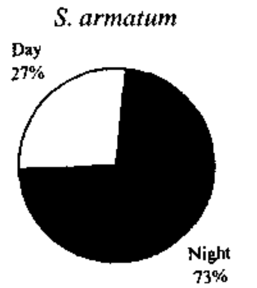

Fig. 202. Day/night variations of spermatophore bearing males and spermatophore and egg bearing females of *S. armatum*.

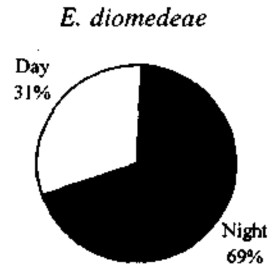

Fig. 203. Day/night variations of spermatophore bearing males and females of *E. diomedeae*.

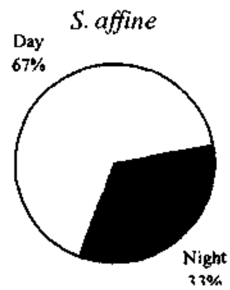

Fig. 204. Day/night variations of spermatophore bearing males and spermatophore and egg bearing females of *S. affine*.

and it was of the magnitude of 67 % (Fig. 203). The only exception to the above general rule of unusually high night abundance of gravid specimens was *S. affine* (Fig. 204) in which only 33 % of such animals only were found in the night samples. This may not be surprising when one considers the fact that the species by nature prefers to be in the upper water column diurnally.

The above observation indicates that the spermatophore/egg bearing animals prefer to stay in dark areas much deep in the water column during day time and they usually come to the surface waters only in the night. Most of the samples have been collected from above150 m depth which is the euphotic zone and therefore it is unlikely that the deep staying gravid specimens are taken in the net.

21

COPULATION SUCCESS AMONG SPECIES

The males of euphausiids when mature produce sperms and these sperms are stored in a sac called spermatophore. The spermatophores are sent out through the vas deferens and the males carry such sperm sacs externally on either side of the thorax on the ventro-lateral side at the point of opening of the vas deferens. During copulation the males transfer these sacs into the thelycum of the females with the help of the copulatory organ which is the modified endopods of the first pair of pleopods. Thereafter the females carry these sacs attached to the thelycum on the ventral side of the thorax until fertilization is over.

Each gravid male is capable of impregnating an adult female and hence if there is a cent percent success in the impregnation process, there should be an equal proportion of males and females with spermatophores in the population. On the other hand if the percentage of spermatophore bearing females is less than spermatophore bearing males in a population then it could be assumed that all the males are not successful in impregnating all the eligible females and any variation in the percentage would reflect on the degree of success or failure by the males to impregnate the females.

In the present study three very common species were subjected to the above study. The males and females carrying spermatophores were enumerated separately and the percentage of occurrence of the respective category was found out. In *E. sibogae*, the most abundant species in the study area, out of the total gravid specimens 96.02 % were males carrying spermatophores and only 3.98 % were females with spermatophores. This indicates that the success of copulation was 3.98 % only. A somewhat similar percentage of occurrence was observed in *E. diomedeae* the second abundant species. In this species, out of the total gamete bearing organisms 95.38 % were constituted by males.

In *S. armatum* though no females were found to carry spermatophores, a number of them carried eggs. Since egg laying is a subsequent act of mating a comparison between spermatophore bearing males and egg bearing females would tell on the copulation success. Thus it was seen that of the total such specimens 87.67 % were males and 12.33 % females.

The above study conducted with all its limitation throws some light on the success by the males in impregnating the females.

The results show very low percentage of copulation success among these species. The fact that very often the male-female ratio is to the tune of 1:3 respectively brings the percentage of copulation success further down. However, more studies are required in this direction as there is no information regarding the duration of time the two sexes carry the spermatophore. If the males carry them for a longer duration naturally more number of such specimens could be seen in the population.

Another factor to be considered is the frequency at which the spermatophores are extruded by the males or in other words, the interval between the production of two sets of spermatophores. If the male can produce more sets of spermatophores within the time when the female produces one brood, it is but natural to find more number of males with spermatophores in the population than females with spermatophores, as the impregnated females may not receive another set of spermatophores until the fertilized eggs are laid. But in such a case also the fact that the females outnumber the males in the population increases the chances of finding out more number of females for impregnation by the males thereby increasing the chances of getting more number of females with spermatophores than males. Therefore it is reasonable to conclude that every adult male does not succeed in copulating with every eligible female.

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