STUDIES ON THE PLANKTONIC COPEPODS —CALANOIDA : SCOLECITHRICIDAE— OF THE INDIAN OCEAN

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BY

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DECLARATION

I hereby declare that this thesis entitled "Studies on the planktonic copepods - Calanoida: Scolecithricidae - of the Indian Ocean" has not previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar title or recognition.

T C Gopalakrishnan

Ernakulam,
9th June, 1982.

(T.C. GOPALAKRISHNAN)

CERTIFICATE

This is to certify that this thesis is an authentic record of the work carried out by Shri T.C. Gopalakrishnan, under my supervision at the Indian Ocean Biological Centre and the Regional Centre of National Institute of Oceanography, Cochin and that no part thereof has been presented for any other degree in any University.

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PREFACE

From the very wide variety of animal phyla inhabiting the sea, a great community was drawn, named plankton, meaning 'something which floats passively hither and thither'. Plankton forms the basic food supply of marine life especially to fishes. The areas of abundance of zooplankton were found to support the areas of world's commercial fisheries. Also the acute need for the increasing food supply by growing world populations made it obligatory to look for protein from the vast organic production of the oceans which was worked out to be around 40 million tonnes for the Indian Ocean alone by Prasad and Nair (1973).

Copepods, though small in size, are the most abundant of all crustaceans, forming the bulk of the animal substance of the sea, accounting for about 70 - 90% of the zooplankton. These copepods, which inhabit the upper strata of the sea and have a relatively poor means of locomotion, are the main food of fishes. As such copepod fauna in relation to fisheries is one of the important factors of the environment. Knowing the ways of correlation of commercial shoals of fishes with the distribution of copepods at different seasons of the year, we may be able to predict the occurrence of certain species of fishes. Being the major primary consumer and the efficient link in the marine food web, its study is one of utmost importance. Thus the copepod researchers are confronted with the necessity of knowing its distribution and abundance in the coastal areas and in the open ocean, as an aid to the interpretation of hydrographical data, circulation patterns and environmental variables.

Among the copepods, calanoids rank first in abundance and among calanoids scolecithricid copepods are found in all the oceans with their abundance in the tropics.

Eventhough substantial information on the taxonomy of scolecithricid copepods has been accumulated, a comprehensive study dealing chiefly with their zoogeography and diversity in such a vast area has not been done so far. Hence this study was undertaken to amplify the limited information already available.

Recognising the need for an ocean-wide survey of the Indian Ocean, the Scientific Committee on Oceanic Research (SCOR) of the International Council of Scientific Unions (ICSU) in collaboration with the UNESCO and other international and national organisations developed a large scale scientific programme. This resulted in the Internatioanal Indian Ocean Expedition (IIOE, 1960-1965) a multinational project for the systematic exploration of the Indian Ocean.

The zooplankton samples collected during the IIOE were received at the Indian Ocean Biological Centre (IOBC), the international centre started in 1962 for the systematic analysis of these samples. At the IOBC the samples were sorted out into different taxa and sent to various specialists all over the world.

Copepods were the major components of the sorted groups. So, for detailed studies, they were sub-sorted into either family or genus level, according to the requirements of the specialists. The Scolecithricidae material thus sorted out from the zooplankton samples collected during IIOE, processed and kept at the then IOBC (at present the Regional Centre of the National Institute of Oceanography), was allotted to me by the UNESCO Consultative Committee in 1970. Subsequently, in 1973, I had the opportunity to work at the Smithsonian Institution, Washington D.C., U.S.A., sponsored by UNESCO, during the tenure of which I could pursue a considerable amount of this study.

T.C.G.

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I wish to express my deep sense of gratitude to Prof. C.V. Kurian, D.Sc., Emeritus Scientist, I.C.A.R. and former head, Department of Marine Sciences, University of Cochin for his valuable guidance and supervision throughout the course of the work. I am thankful to late Dr. N.K. Panikkar, former Director of N.I.O., Dr. S.Z. Qasim, former Director of N.I.O. and at present Secretary, Department of Ocean Development, Government of India and Dr. V.V.R. Varadachari, present Director of N.I.O. for providing necessary facilities at the Regional Centre of N.I.O., Cochin to undertake this study and for their keen interest in this work. Thanks are due to UNESCO Consultative Committee for permitting me to work on the Scolecithricidae material from the IIOE zooplankton collections, to UNESCO for the award of a fellowship in 1973 during the tenure of which I could work in the Smithsonian Institution, Washington D.C., U.S.A. The valuable help, advice and encouragements by Dr. M. Krishnankutty, Scientist-in-Charge, NIO Regional Centre, Cochin and Dr. T.S.S. Rao, Head, Biological Oceanography Division of N.I.O., Goa are greatly acknowledged. Thanks are due to Dr. T. Balachandran and Mrs. K. Saraladevi for the overall help rendered to me in the preparation of the thesis. I acknowledge the help rendered by Dr. M. Saraswathy, Mrs. Rosamma Kuriakose and Mrs. P.P. Meenakshi Kunjamma in sub-sorting the copepod taxa, Mr. P. Venugopal in data analysis, Mrs. K.V. Jayalakshmi for the statistical analysis of the data and Mr. K.K. Gopinathan for typing the thesis.

On this happy occasion of the completion of the copepod work entrusted to me, the hard labour involved in the collection and processing of the zooplankton samples by the Scientists of IOBC and the crew of the research vessels taken part in the IIOE and by my colleagues at NIO are gr~~e~~atefully acknowledged.

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1. INTRODUCTION.

1. INTRODUCTION

1.1. Scope and purpose of study of the International Indian Ocean Expedition Zooplankton.

Indian Ocean including the Red Sea and Persian Gulf with an area of about 75 million square kilometres covering 14 percent of the earth's surface is the least explored of the world oceans. Our knowledge on the fauna of the Indian Ocean falls far short of that of other oceans. A number of expeditions have collected oceanographic data in the Indian Ocean and incorporated them in their reports. The more important of these expeditions are Novara (1857-1859), Challenger (1873-1874), Gazelle (1874-1876), Elisabeth (1887), Investigator (1887, 1892, 1893, 1925 to 1938), Penguin (1891), Waterwitch (1895), Stork (1897), Valdivia (1898-1899), Gauss (1902-1903), Sealark (1905-1909), Siboga (1906), Planet (1906-1907), Mowe (1912-1913), Marlin (1920), Amiraglio Magnachi (1924), Ormande (1927), W. Snellius (1929), Dana (1928-1930), Mahabiss (1933-1934), Discovery II (1930-1951), John Murray (1933-1934), Albatross (1947-1948), Charcot (1948-1949), William Scoresby (1955, 1956, 1957), Umitaka Maru (1956), Oven (1957, 1958), Atlantis (1959), Vityaz (1960) and Guilard (1961).

Of these Mahabiss, Sealark, Investigator and John Murray are the only expeditions which spent considerable amount of time in a detailed investigation of some parts of the Indian Ocean. The reports of these expeditions and the papers published by Sewell (1913, 1929, 1939-43, 1947-48) in the Journal of the Royal Asiatic Society of Bengal, Memoirs of Indian Museum and John Murray Expedition Reports, constituted the early important source of oceanographic data for the Indian Ocean.

In spite of the above works involving about 1300 stations covered in 34 expeditions, vast areas in the Indian Ocean remained unexplored. So the International Council for the Exploration of the Sea recommended a large scale comprehensive study that involved methodically collected samples from a wider area. Based on this, Scientific Committee on Oceanic Research of the ICSU in 1958-1959 initiated a programme which materialised in the International Indian Ocean Expedition (IIOE), held during 1960-1965 involving 75 million rupees and traversing 291,000 kilometres of water. UNESCO through the IOC joined the endeavour by co-sponsoring the expedition and establishing the Indian Ocean Biological Centre (IOBC) at Cochin in 1962 for processing the zooplankton collections made during the IIOE.

As seen above our previous knowledge on the distribution of marine plankton in the Indian Ocean is mainly based on single voyage across the ocean. Therefore the earlier biogeographers found it difficult to state precisely the faunal provinces and relative abundance in each.

Before any work on the biology of animals can be attempted the animals that we wish to study must be described and classified. This is a task going on from the earliest days of marine biology and as regards zooplankton, most of our present knowledge has been built up from the results of the collections of the great oceanographic expeditions. The material collected during the IIOE is expected to provide necessary knowledge to the final stage. Coincident with the descriptive work, the knowledge on geographical distribution can grow and as the groups have been better known, the distribution of the species among their faunistic regions can become more detailed.

So one of the main objectives of the IIOE was the study of the qualitative and quantitative distribution (zoogeography) and speciation (diversity) of planktonic organisms. The distributional studies of this sort will also be helpful in (1) evaluating the adaptation of plankton to physical, chemical and ecological properties of the environment and to know more about their community structure, ecology and behaviour and species diversity, (2) proper determination of the species of various plankton groups that occur in this area of investigation and their ecophenotypic variations in the different water masses if any, (3) to deduce taxonomic features characteristic of particular species, so as to trace phases of phylogenitic significance and to draw evidence from larval taxonomy in confirming classification, (4) to estimate their frequency of occurrence and abundance to some extent in relation to the diurnal, seasonal and annual variations, (5) to elucidate the longitudinal and latitudinal zonation of zooplankton, (6) to explain the pattern of distribution as tracing the faunal provinces (zoogeographical regions) in relation to hydrographical parameters as temperature, salinity, oxygen concentration, nitrate and phosphate concentrations of water masses, (7) to correlate their distribution pattern with the physical factors of the environment as upwelling, eddies, thermocline, light, depth, turbidity, hydrodynamics, seasonal reversal of monsoon circulation and large gyral oceanic storms and to use plankton animals as indicators of water masses as done by Russell (1935 b).

Better information on holo and meroplankton could be available if studies are extended to their life histories and seasonal fluctuations, than the mere numerical data.

Our knowledge on the taxonomy and distribution of scolecithricid calanoids from the Indian Ocean is mainly based on some of the earlier expeditions in this area. In the present study 27 species belonging to 7 genera were identified of which 2 were new records from the Indian Ocean and one was described as a new species. No attempt has hitherto been made for such a comprehensive study involving methodically collected samples covering the entire Indian Ocean. Since Scolecithricidae also formed an important link in the food chain, this study has become particularly important. In addition to the general treatment of the taxonomy, zoogeography and species diversity in relation to various environmental parameters are also attempted. The main purpose of the study is to outline the main distributional features of the species of the calanoid copepod family Scolecithricidae in the Indian Ocean Expedition collections and to distinguish and describe their niches.

1.2. Taxonomic history of Calanoida.

Eventhough the earlier works on copepod taxonomy are numerous, those of Zenker (1854), Thorell (1859), Claus (1857-1895) as cited by Saraswathy (1961) and Canu (1892) are worth mentioning. Claus divided Copepoda into two divisions namely Gnathostomata and Siphonostomata, grouping all the free living copepods under Gnathostomata and parasitic copepods under Siphonostomata. Thorell (1859) created a third division known as Poecilostomata for the semiparasitic forms. But the presence of transitional forms made the above system of classification incomplete. Canu (1892) grouped Copepoda under Monoporodelphia with single genital opening in females and Diporodelphia with a pair of genital openings in females. Later, specimens with single and paired genital openings were discovered within the same family. Also this classification could not be applied to males. As a result this system also became unnatural.

In view of the above inconsistencies that existed in the earlier works, the system of classification by Giesbrecht (1892) was followed for subsequent studies. He divided the subclass Copepoda into two orders;

Branchiura comprising a single family Argulidae in which most of the species were parasitic and Eucopepoda to include all the rest. Order Eucopepoda was divided into two suborders namely Gymnoplea in which the last thoracic somite was firmly united with the preceding somite and movably articulated with the first abdominal somite and Podoplea in which the last thoracic somite was movably articulated with the preceding somite and firmly united with the first abdominal somite. Suborder Gymnoplea was divided into two tribes; Amphaskandria with male antennules not geniculate and Heterarthrandria with one of the male antennules geniculate. The former included the family Calanidae and the latter included the families Centropagidae, Pseudocyclopidae, Candaciidae and Pontellidae. Suborder Podoplea was divided into two tribes namely Isokerandria with male antennules not geniculate and Ampharthrandria with both male antennules geniculate. However his system of classification also was not satisfactory on the following grounds: The delimitations of the families under Podoplea, especially the parasitic ones, were left unidentified. So his treatment of Podoplea was incomplete when compared to Gymnoplea.

The first natural and most comprehensive classification of copepoda is that of Sars (1905) who revised the above classification dividing the order Eucopepoda into 7 suborders namely Calanoida, Cyclopoida, Harpacticoida, Notodelphyoida, Monstrilloida, Caligoida and Lernaeoida. Among these, the first three suborders were usually found in plankton, Calanoida being the most dominant. Suborder Calanoida was equivalent to Gymnoplea of Giesbrecht. Sars (1905) divided Calanoida into three divisions; Amphaskandria and Heterarthrandria as proposed by Giesbrecht (1892) for Gymnoplea and a third division Isokerandria for forms with antennules identical in both sexes. The latter name was suggested by Giesbrecht for a division of Podoplea. Instead of a single family Calanidae under Amphaskandria suggested by Giesbrecht, Sars included 8 families under it namely Calanidae, Eucalanidae, Paracalanidae, Pseudocalanidae, Aetideidae, Euchaetidae, Phaennidae and Scolecithricidae. Though the literature on Copepoda has increased considerably, the classification introduced by Sars (1905) remains almost unchanged since it offered a place for every valid genus. 27 species belonging to 7 genera of the family Scolecithricidae were identified in this study.

1.3. Studies on planktonic Copepoda from the Indian Ocean.

From the analysis of 881 publications cited by Prasad (1964) in the bibliography of plankton of the Indian Ocean, it would appear that considerable amount of work has been done on the planktonic copepods of the Indian waters. The most important of those studies are given below. Giesbrecht* (1896) - collections from the Red Sea, Thompson (1900) - collections from (a) east coast of Africa to Ceylon and the head of Bay of Bengal and (b) Durban to Suez Canal through the Red Sea, Cleve* (1901) - along the route from Aden to Java, in the Malay Archipelago and across the Indian Ocean 45°S, 22°E to 30°S, 91°E and thence to 2°N, 94°E, A. Scott* (1902) - from Suez to Colombo, Thompson* and A. Scott (1903) - from Port Said to Colombo and round the Pearl Banks of Ceylon, Cleve* (1904) - from the Red Sea through the Gulf of Aden and across the Arabian Sea, Cleve* (1904a) - from the east coast of Africa and Agulhas Current, Wolfenden* (1906) - from the Maldive Archipelago, A. Scott* (1909) - from Malay Archipelago, Brady (1910) and Wolfenden* (1911) - collections of Gauss from the southern part of Indian Ocean, Farran (1911 & 1913) - collections from the Christmas Island in the Indian Ocean, Sewell* (1912) - from the coastal region of the Bay of

Bengal, T. Scott* (1912) - from the Bay of Bengal and central Indian Ocean, Pesta (1912) - from the neighbourhood of Muscat and Bushire in the Persian Gulf, Pesta (1913) - from the Arabian Sea, Sewell* (1913) - from the coastal region of the Bay of Bengal and the mid water region of the bay, Brady* (1914-1915) - from Durban Bay, Sewell* (1914) - from the Ceylon Pearl Banks, Sewell (1919-1924) - from the Chilka Lake, Sewell* (1929-1932) - coastal region of South Burma including the Mergui Archipelago; the Andaman and Nicobar Islands; the west coast of India and the Malay Archipelago, Menon (1931) - Madras coast, Sewell* (1940, 1947, 1948) - John Murray Expedition collections, Menon (1945) - Trivandrum coast, Bal and Pradhan (1945), Jacob and Menon (1947), Chacko (1950), George (1953) - copepods of Indian waters, Krishnaswamy (1953, 1953a, 1953b, 1954) - copepods of Madras coast, Prasad (1954, 1956) - Bimodal distribution of copepods around Mandapam, Prasad and Kartha (1959) - copepod breeding in relation to the diatom cycle in the Gulf of Mannar, Ganapati and Santhakumari (1962) - planktonic copepods of the Lawson Bay, Kasturirangan* (1963) - key for the more common copepods from Cochin, Calicut, Madras and Mandapam, Saraswathy* (1967) - pelagic copepods from the inshore waters off Trivandrum coast, Ummerkutty (1960, 1961, 1963, 1964, 1966, 1967, 1968) - a series of papers on the copepods of Indian waters, Silas and Pillai (1967, 1973), Pillai (1969, 1971) - Calanoid copepods of the family Pontellidae from the Indian Ocean.

Sewell (1948) gave an account of the distribution along with latitudinal variations and endemic nature of planktonic copepoda of the Indian Ocean collected during the John Murray Expedition. On comparing species distribution in different oceans, he showed the distinct nature of Indo-Pacific copepod fauna from that of the Atlantic.

Among the planktonic Copepoda, eventhough the Calanoida ranks highest in species diversity and numerical abundance, detailed studies of only a few calanoid genera from the Indian Ocean based on the IIOE material have been published.

The results of the IIOE have been published by UNESCO in the form of IIOE collected reprints volumes 1 to 8 during 1965-1972. Besides, Indian Ocean Biological Centre, Cochin has brought out Atlases volumes I to V (1968-1973) showing zones of occurrence and abundance of zooplankton. Also the Centre has issued a series of Handbooks - volumes I to V (1969-1973) based on the

International zooplankton collections. Many papers were also read by individuals at the following four Symposia. (1) NISI/INCOR Symposium on "Indian Ocean" held in 1967 at New Delhi, (2) the International Symposium on "Indian Ocean and Adjacent Seas, their origin, science and resources" conducted at Cochin (1971), (3) "The Biology of the Indian Ocean" held at Kiel, West Germany (1971) and (4) on "Warm Water Zooplankton" held at Goa (1976). Most important of these papers are: Frost and Fleminger (1968), Tanaka (1973), Lawson (1973a, b, 1976, 1977), Gopalakrishnan* (1973, 1974), Saraswathy (1973), Rosamma Stephen and Saraladevi (1973), Saraladevi (1977), Grice and Hulsemann* (1967), Fleminger and Hulsemann (1974), Vinogradov and Voronina (1961) and Jones (1966a, b).

1.4. Studies on zoogeography and diversity of zooplankton.

Be' and Tolderlund (1971), Vannucci and Navas (1973a), Della Croce and Venugopal (1972, 1973), Brinton and Gopalakrishnan (1973), Nair (1977), Sakthivel (1972), Pillai (1973), Aravindakshan (1977), Omori (1977), Fenaux (1973) and Rao (1979) conducted studies on Indian Ocean

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* includes studies on Scolecithricidae.

biogeography of zooplankton concerned with species occurrence, pattern of abundance and the relationship of distributional patterns to faunal zones or hydrographic features. Jones (1966a, b), Fleminger and Hulsemann (1973), Saraswathy (1973) and Haq <u>et</u> <u>al</u>. (1973) made biogeographical divisions of Indian Ocean based on Indian Ocean copepods and Gibbs and Herwitz (1967) based on Indian Ocean fishes. Mc Gowan (1971, 1974) discussed interaction of species within communities. Williamson (1961), Grice and Hart (1962), Fager and Mc Gowan (1963), Colebrook (1965), Sheard (1965), Frost and Fleminger (1968), Bowman (1971), Bainbridge (1972) and Angel and Fasham (1975) identified the species which composed oceanic communities, related communities to distinct habitats and categorised components by their trophic relationships. Lawson (1977) studying the process of community formation using species of Candacidae of Indian Ocean, recognised 2 recurrent groups. Schoener (1974) dealt with resources partitioning in ecological communities. Fleminger and Tan (1966), Fleminger (1967, 1975), Frost and Fleminger (1968) and Fleminger and Hulsemann (1974) studied biotic interactions among closely related marine calanoids. Most important of the previous investigations on vertical distribution of copepods were those of Thomson (1898), Wolfenden (1902, 1904), Farran (1926), Stormer (1929), Hardy and Gunther (1935), Moore (1949), Moore and O' Berry (1957), Moore and Foyo (1963), Park (1970), Grice and Hulsemann (1965), Wheeler (1970), Vilela (1968), Seguin (1966a) and Roe (1972 b,c,d). Papers dealing with studies on Scolecithricidae were by Roe (1972 a, b, c & d), Wolfenden (1904), Farran (1926, 1936), Leavitt (1938), Lyshholm and Nordgaard (1945), Østvedt (1955), Grice (1963a), Owre and Foyo (1964, 1967), Park (1970), Vervoort (1951, 1957, 1965), Seguin (1966 a,b), Paiva (1963), Jones (1952), Damas and Koefoed (1907), Stormer (1929), Johnson (1963), Brodsky (1950), Tanaka (1961), Hardy and Gunther (1935), Ostvedt (1955), A. Scott (1909) and Vilela (1968). Other papers of interest were east-west diversity by Shih (1979), north-south diversity by Van Soest (1979), Neritic and oceanic plankton by Tokioka (1979), speciation of macroplankton by Pierrot-Bults and Vander Spoel (1979).

2. MATERIAL AND METHODS.

2. MATERIAL AND METHODS

2.1. Material.

Recognizing the need for an ocean wide survey of the Indian Ocean, the Scientific Committee on Oceanic Research (SCOR) of the ICSU in collaboration with the UNESCO and other international and national organizations developed a large scale scientific programme. This resulted in the International Indian Ocean Expedition (IIOE), a multinational project for the systematic exploration of the Indian Ocean. During this expedition (1960-1965) 18 ships belonging to 9 nations participated in the biological programme (zooplankton collections). Details of the participating nations and the research vessels in the IIOE programme, the area explored and the number of samples collected are given in the Table 1. The number of zooplankton samples collected during the 72 cruises and received at the Indian Ocean Biological Centre (IOBC) amounted to 1927 excluding 218 from the Agulhas Bank. The station list was published by IOBC (1969). These samples were deposited at IOBC and they formed the largest and most important zooplankton collections from the Indian Ocean available today (Hansen, 1966). The collections were made mainly from the upper

200 m water column, occupying only 5% of the total volume of the Indian Ocean, estimated to be 29,195 x $10^4 m^3$ (Pollak, 1958). The major part of the material (90%) delt with, was made during 1962 (386 samples), 1963 (743 samples) and 1964 (586 samples). The geographical coverage was from 25°N to 40°S latitude and 20°E to 120°E longitude excluding the South China Sea. Of the 1927 samples, 21 were outside this limit, thus number of samples from Indian Ocean area being limited to only 1906.

An attempt made to illustrate the density of stations of the IIOE collections in terms of spatial, diurnal and seasonal coverage revealed their heterogenous distribution, as a result of lack of co-ordination for simultaneous observations. Table 2 shows the density of occurrence of species of the family Scolecithricidae in the 4 zones of the Indian Ocean based on day and night collections and seasonal collections, April to September and October to March.

Bay of Bengal had the maximum density of collections in terms of area and number. Bay of Bengal covering 6.26% area only, had 352 collections compared to the Arabian Sea covering 12% area, with only 420 collections.

Numerically, of the 1927 collections, 22% were collected from the Arabian Sea, 18.5% from the Bay of Bengal, 19.6% from the equatorial zone, 10.5% from the south-west, 17% from the south-east and only 12.5% from the south-central Indian Ocean, eventhough the areas occupied was 38%. The northern Indian Ocean extending up to 5°N covering 20% of total area had 38% of the total collections. Most of the observations were clustered along the coastal areas of India and South Arabia. Latitudinally maximum number of samples (495) were collected from an area between 20°N and 10°N i.e. more than 25% of collections were from 10% area. The outcome and reliability of biogeographical studies will be highly influenced by the above discrepancy present in the sampling density.

Of the 1906 collections, 913 were made during night and 993 during day. On an hourly basis, early morning hours (0100 - 0500) and afternoon hours (1600 - 1800) had only few collections (45 to 56 and 55 to 57 respectively) whereas maximum collections of 135, 121, 187 and 124 respectively were made at 1000, 1100, 2000 and 2100 hours. Thus half of the Indian Ocean water had coverage only for one hour. Cassie (1963) showed that no two samples are comparable unless they are taken at the same time with the same lighting conditions. Bogorov (1958) studying diurnal vertical migration to varying depths pointed out the variation in the main day level between species to species. Thus, since the organisms of diurnal vertical migration have been incompletely sampled, this can introduce a disparity in the estimation of abundance. The apparent absence of a species in such an area might also be due to lack of sampling at depth.

An analysis of sample distribution in relation to monsoon changes though showed 665 collections during April to September and 615 collections during October to March in the area north of 10°S, the area sampled during one season (April to September) was not properly repeate in the other seasons (October to March) leading to considerable disparity. Monthly distribution of samples revealed that December, January, April, July and August had 185 - 228 collections while November and June had only 111 - 117 collections.

Discovery 3/64, Umitaka Maru 25/62, Kagoshima Maru 3/63-64, Diamantina 1/63, 2/63, 3/63 and Gascoyne 4/62 and 1/63 were special cruises. These collections were used for zooplankton distribution studies in relation to the thermocline, the annual variation along the 78°E and the seasonal variation along 110°E. Though Discovery made collections from 62 stations (35 night + 27 day) to study the effect of thermocline, the 200 - 0 m haul and the thermocline to 0 m haul were not made simultaneously which might have resulted in sampling different areas.

2.2. Methods.

To begin with, in the absence of a standard gear, different types of nets - organdie net, Juday net, N70V net and 75 M net were used by different ships. Currie (1963) designed the Indian Ocean Standard Net (IOSN) based on proposals made by a team of zooplankton experts who met at Cochin in 1961, that a standard sampling device is necessary for uniformity of collections for quantitative studies. Table 3 gives the number of collections made by the different types of gear fom different depths of haul illustrating zooplankton sampling variability. Sakthivel (1972) and Sakthivel and Rao (1973) have made a critical study of the methods employed during the IIOE zooplankton collections.

The IOSN is a low-speed net (< 3 knots/hr) made of medium gauze (nylon gauze having a mesh width of 330 microns and porosity of 0.46). This ring net having a mouth area of 1 square metre and an open area ratio of

4.3 has a cylinder-cone form with a total length of 5 metres. According to Tranter and Smith (1968) the net is not likely to clog when hauled vertically, in central water masses, but may do so when the wire angle is high or the water is rich in plankton. The net was hauled from stationary or drifting ships, vertically without a flow-meter, from a depth of 200 m to surface at an average speed of 1 metre per second, using 4 mm wire cable in deep waters. In coastal waters where the sounding was less than 200 m, a vertical haul from the bottom to surface was preferred. Motoda et al. (1963) measured the filtering efficiency as 70 - 90 % (0.96). Therefore a vertical haul from 200 m would filter approximately 192 m^3 of water. However, since zero wire angle was not often achieved, while few ships made collections from 200 m to the surface, others paid out more wire to compensate for the wire angle measured. But Motoda et al. (1963, 1964) have shown that hauls at high wire angles filter a greater column of water than the length of wire paid out would indicate.

In view of the considerable sampling variabilities noted, at IOBC samples were classified as standard and nonstandard. Thus 1548 samples were classified as standard and 379 as nonstandard. A standard sample can be defined as the plankton in the water column under one m^2, the stratum sampled being the upper 200 m in deep water and the entire water column where the sounding was less than 200 m. A nonstandard sample is one which was taken in deep water from strata considerably shallower or deeper than 200 m (± 30%), one taken at considerable wire angle (> 45°) and also one taken with a nonstandard net.

The zooplankton samples, generally fixed and preserved in 4% formaldehyde buffered with hexamine were received at IOBC, Cochin and were subjected to the following treatment. The biomass (displacement volume) was measured (Hansen, 1966). The zooplankton material already fixed and preserved in formaldehyde was used for measurement of biomass. The sample was filtered using a silk gauze of 330 micron mesh size to remove the water. After this it was added to a measured volume of dilute formaldehyde in a graduated cylinder and the amount of consequent increase in the formaldehyde level, taken as the measure of its volume. The size of the graduated cylinder used will depend upon the size of the plankton sample. After removing the larger organisms and fish eggs and larvae the samples were subsampled. For this, two types of sub-samplers were used namely the Leas Plankton Divider (Wiborg, 1951) and the Folsom Plankton

Splitter (Mc Ewen et al., 1954, Gopalakrishnan, 1973). An aliquot of 3 - 5 ml was sorted out into different taxa. When the displacement volume was less than 3 ml, 90% of the sample was sorted. The unsorted fraction was kept as archive. The sorted taxa were preserved in 2% buffered formaldehyde and sent to various specialists all over the world. The total number of organisms in each sample were enumerated using hand tally counter leaving behind only the very minute forms in residue. From the number of organisms present in the sorted fraction, their total number was computed for the whole sample.

Copepods were the major components of the sorted groups and were present in all the samples available. So, for detailed studies they were subsorted into either family or genus level, according to the requirements of the specialists. From each sample, after its volume was made up to 100 ml, two 10 ml aliquots were removed using a stempel pipette. The remaining 80% was subsorted. In view of the abundance of copepods in all the samples, and as an early study of this material was imminent, representative samples from each 5° Marsden Square, totalling 385 were picked up, for subsorting. While doing this, particular attention was given in covering important areas in relation to upwelling, primary production and zooplankton biomass. The scolecithricid calanoids thus subsorted formed the material for the present study. They were identified into 7 genera and 27 species.

The identification was mainly done based on the existing descriptions available on Scolecithricidae from world oceans. Total number of each species in each sample was computed for preparing the distribution maps.

As regards the reliability of IIOE samples for quantitative study some drawbacks were pointed out by some of the workers like Cushing (1962), Banse (1964), Clutter and Anraku (1968) and Tranter and Smith (1968). But considering the large number of samples dealt with, obtained from a wide area, in a limited period, this is the best available and from this it is possible to get some general informations regarding the distribution of the group of animals.

While presenting the data for distribution and abundance studies, samples were compared on the basis of catch per unit standard haul (IOBC, 1969). So the total number of each species estimated per unit haul was plotted on the map against the respective station. Numerical abundance was used to indicate the main centre of distribution. According to the numerical abundance of each species 4 ranges per unit standard haul viz. Fig. 13: 0 - 50, 51 - 200, 201 - 800 and > 800. Fig. 14: 0 - 50, 51 - 150, 151 - 450 and > 450. Figs. 15 to 22: 0 - 10, 11 - 20, 21 - 40 and > 40. Figs. 23 to 28: 0 - 5, 6 - 10, 11 - 20 and > 20. Fig. 29: 0 - 5, 6 - 10, 11 - 15 and > 15, were used to indicate the different grades of density. However, for those which were represented in small numbers the actual number at each station were given. While closed circles indicated presence of that particular species in those stations, open circles showed absence. As the number of stations studied could hardly be taken a representative neither in time nor in space, the data could give only incidental information. Russel (1935 b) stated that when we see a sample of plankton caught from a given body of water at a given time we must realise that this does not represent a static condition. We are looking at a cross section at one moment in one place of a continuous phenomenon moving both in time and space. The sample is the result of past history and possessed the potentiality for future history.

The Indian Ocean is a seasonal ocean (Ramage, 1969; Wyrtki, 1973). Hence the entire collections were split on a seasonal basis to study the seasonal variation in occurrence and abundance. Due to the paucity of samples studied the year was split up into 2 seasons only i.e. the Northeast monsoon dominated period from October 16th to April 15th and Southwest monsoon dominated period from April 16th to October 15th. South of 10°S these periods correspond to summer and winter. Also during the study of zooplankton biomass Prasad (1968a) found this division meaningful. Since the copepods were known to undergo diurnal migrations, night and day collections were separately analysed. The samples collected during 0600 and 1800 hours were taken as day and the rest as night samples. Contouring ranges used were similar to numerical abundance in total.

2.3. Statistical methods.

a) A correlation coefficient matrix of size 27 x 27 was constructed to study the coexistence of the species of the family Scolecithricidae from different areas of the Indian Ocean - Arabian Sea, Bay of Bengal, southwest and southeast Indian Ocean. In each case the significance of the correlation coefficient was tested using students 't' test which reduces to critical ratio test when 'n' is very large. The test statistic used was

$$z = \frac{r\sqrt{N-2}}{\sqrt{1-r^2}}$$

r = correlation coefficient

N = number of sample units.

$$r = \frac{\text{covariance } (x, y)}{\sigma x \times \sigma y}$$

$$\text{Covariance } (xy) = \frac{\Sigma (X - \bar{X})(Y - \bar{Y})}{N}$$

$$\bar{X} = \frac{\Sigma X}{N}, \quad \bar{Y} = \frac{\Sigma Y}{N}, \quad \sigma x = \sqrt{\frac{\Sigma (X - \bar{X})^2}{N}},$$

$$\sigma y = \sqrt{\frac{\Sigma (Y - \bar{Y})^2}{N}}$$

given in Tables 9 - (1), 9 - (2) and 9 - (3)

b) The abundance of Scolecithricidae at species level was predicted by means of Multiple Regression Model fitted for the data collected from Aranian Sea, Bay of Bengal, southwest and southeast Indian Ocean separately and all together. In the regression model, the numerical abundance was correlated with temperature, salinity and oxygen. The model was

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3.$$

Y = number of individuals for all species for each station.

X_1 = temperature, X_2 = salinity, X_3 = oxygen at that station.

The constants b_0, b_1, b_2 were called the regression coefficients and were calculated to fit the multiple regression model, by the method of least squares and the normal equation terms obtained were solved by the Matrix Inversion method. The significance of the fitted regression was tested using analysis of variance technique.

c) The relative importance of each of the parameters mentioned in the prediction equation was calculated using the formula of Snedecor and Cochran, 1967

$$\text{Relative importance } of_{bi} = |bi| \sqrt{\frac{x_i^2}{Y^2}}$$

$i = 1, 2, 3.$

The hypothesis was tested using a two way classified analysis of variance table based on 'F' test.

d) The abundance of species in the 4 different regions, AS, BB, SWIO, SEIO was calculated using the Fishers species diversity index α using the formula

$$S = \alpha \log e \left(1 + \frac{N}{\alpha}\right)$$

where S = number of species,

α = species diversity index and

N = total number of individuals for all species.

The consistancy of α calculated was verified using variance of α

$$V(\alpha) = \alpha^3 \left\{ \frac{(N+\alpha)^2 \log e \left[\frac{2N + \alpha}{N + \alpha}\right] - N\alpha}{(SN + S\alpha - N\alpha)^2} \right\}$$

Smaller the value of $V(\alpha)$ more consistant will be α calculated.

3. GENERAL ENVIRONMENTAL FEATURES OF THE INDIAN OCEAN.

3. GENERAL ENVIRONMENTAL FEATURES OF THE INDIAN OCEAN.

This Chapter provides a valuable source of background information and reference relevant for the present study. Eventhough, emphasis was layed on the distribution of properties at the sea surface upto 200 m, the limit of IIOE collections, the study was extended to the entire Indian Ocean in view of the deep sea habitat of many of Scolecithricidae species.

A comparative study of the physical parameters of Indian Ocean with that of Pacific and Atlantic Oceans revealed the following features unique to the Indian Ocean. The land-locked Indian Ocean causes an asymmetrical development of its structure and circulation, which is most obvious in the development of the huge layers of extremely low oxygen content in the Arabian Sea and the Bay of Bengal. Banse (1968) discussed the adverse biological effects of cold upwelled water extremely depleted in oxygen. The land mass of Asia affects the ocean climatologically by causing the seasonally changing monsoons which in turn reverse the oceanic circulation over its northern part. Connected with this circulation are various upwelling areas being operative in only one season in contrast to other major upwelling areas in the world. Another geographical and climatic effect is the high salinity waters in the Arabian Sea, Red Sea and the Persian Gulf, affecting the waters of the intermediate layers, by preventing the waters of the southern hemisphere from penetrating into the northern Indian Ocean.

3.1. Importance of oceanographic parameters.

The role and importance of the above biological and oceanographic parameters in the distribution of plankton biomass and their relation to fisheries have been studied by several workers. It is hoped that increased knowledge of this sort could foster development of fishery and benefit countries surrounding it. The link established between the work of physical oceanographers and biologists was a significant one in the developing field of oceanic zoogeography and sets a pattern which persists today for the design and carrying out of large scale investigations in biological oceanography. Approaches to marine ecology involves complexity of animal relationships and their correlation with their organic and physical environment. The patterns of physical environment which have the dominant influence in determining oceanic distribution, that can be examined are distribution of water temperature, salinity, dissolved oxygen, nutrients, density, specific chemical constituents, daily tidal variations, seasonal variations of weather, sea conditions, water movements, currents, depth and plankton biomass. While properties in the deep ocean remain essentially stationary, in the surface layer seasonal variations are of great importance. The dynamics of upwelling, the enrichment of surface layers, the initiation of primary production followed by zooplankton production, the timing of spawning of animals and development of fisheries all constitute a biological unit and the various factors mentioned are interlinked to form a common ecosystem (Cushing, 1971). The intimate correlation and strong association of water masses with the geographical distribution of species first pointed out by Pickford (1946) was substantiated by Brinton (1962), Mc Gowan (1963), Vander Spoel (1967), Shih (1969) and Pierrot-Bults (1976). Mc Gowan (1971) showed discrete populations being maintained by the semi-enclosed gyres of the water masses. The importance of water masses, convergences and divergences and current boundaries in the partition of marine zooplankton distribution have been commented on (David, 1958; Johnson and Brinton, 1963; Knox, 1970a and others).

The patterns established by the global heat balance, the density structure of the waters, and the topography also influence the properties of distinct biological importance, in particular nutrients, light and oxygen. Nutrient salts, ultimately derived from the weathering of the rocks are dissolved in sea water forming the basis of plant production. Since light is rapidly attenuated in water and since certain levels are necessary for photosynthesis, phytoplankton production takes place in relatively shallow surface layers. In the euphotic zone, nutrients are recycled through plants, consumers and decomposers. According to high or low nutrient supply/ regeneration, production too is high or low. The cycle is broken when nutrients sink below the euphotic zone and get removed from the production cycle. However, global circulation ensures return of these nutrients to the surface. Important sites are the divergence zones where upwelling supports tremendous biological production. In the central ocean gyres, wind stirring is the primary agent in returning the nutrients to the surface slowly leading to low production of 0.1 - 0.2 gm C/m^2/day in the central gyre.

Turbidity of the water caused by wind or river borne particles and phytoplankton determines the rate at which light is attenuated and hence the depth of the euphotic zone. When nutrient input occurs at a sufficient rate, growth is so rapid that the water becomes opaque and light can penetrate only a few metres. When this occurs there is a net consumption of oxygen in the deeper layers, with the result that oxygen minimum and even anoxic conditions form. This is a common feature of upwelling regions.

Varadachari and Sharma (1964, 1967) have presented results of the investigations on the divergence and convergence and circulation pattern of surface water in the northern Indian Ocean for different months of the year. Since the divergence and convergence occurring throughout the year in open ocean are seasonal and spatial in the nearshore regions, they affect the production considerably in such areas. Along the west coast of India all the interesting observations in regard to the rich biological and fishery productivity have been attributed to the seasonal upwelling along this coast. Areas of upwelling and divergence are found highly fertile. The importance of upwelling is that they play a prominent role in the fertilization of the surface waters of the region which include high organic production. The mesopelagic plankton biomass are also brought to the surface layers due to upwelling. The divergence occuring along the west coast of India and Somali coast during January to September is replaced by convergence during the rest of the year. The convergence causes dynamically a concentration of zooplankton (Hela and Laevastu, 1962) and during divergence a high production of organic matter leading to zooplankton production takes place. Prasad (1968 a,b, 1969) found the distribution of zooplankton broadly agreeing to the vergence pattern of these areas brought about by the seasonal shift of monsoons. A comparison of the plankton density charts with the circulation maps (Varadachari and Sharma, 1967) indicates a close relationship between zooplankton distribution and the surface currents which are directly connected with the oceanic circulation. These surface currents are important as they induce upwelling along the Somali and Arabian coasts up to the Gulf of Oman. The winds blowing parallel to the coasts too transport surface waters away from the coast giving rise to upwelling which culminate in the high production of zooplankton standing crop. Thus the high plankton concentration can be seen following the route of surface currents. In this way currents help in the transport of plankton. The low plankton biomass values in the southern and central parts of the Indian Ocean during Southwest monsoon can be accounted for the lack of vertical movements in the areas. Monsoon influences zooplankton distribution in different ways apparently by shifting their populations due to the changes in the current patterns. There is a shift of population either to the east or to the west depending on the prevailing monsoon, and by its reversal, the Somali current transport zooplankton mechanically across the equator both in southern and northern directions. Such changes are also found in the latitudinal extensions of species, particularly on the eastern and western sides of the Indian Ocean.

The most important factor which probably controls the distribution of species over large areas, is temperature, while in subsurface areas where temperature variation is small, salinity variation restricts distribution. Zoutendyk (1970) studying zooplankton density in the southwestern Indian Ocean limited its densities with the physical environment using sea temperature as a criterion. The dissolved oxygen content and the density of the water are also equally important factors. Hence the study of the zoogeographical pattern shown by zooplankton and their biomass reflects the biohydrographical regimes in the different parts of the Indian Ocean environments.

From the beginning of the investigations of the International Council for the Exploration of the Sea the possibility of using plankton organisms as indicators of water movements has been consistantly borne in the minds of most plankton workers, for, when the habits of plankton organisms were known these organisms formed ideal drift-bottles. It has been proved in a number of papers that different planktonic forms can present themselves as biological indicators of sea currents. Such a practical application of the data of planktology to hydrological problems is found in papers by Russell (1935 b), Stepanov (1937, 1937 a) and Hmyznikohv (1936, 1937). The composition of the plankton characterises not only the origin of water, but also its physico-chemical state, changes occurring in sea water affect quickly and sharply the composition and quantity of plankton. Thus distinct species of plankton can be considered as indicators of hydrological conditions favourable for the shoaling of fishes in different seasons. It has to be realised that the problem could not be tackled satisfactorily until the full distribution of all species was worked out. Hence considerable attention was paid for the detailed distribution studies of Scolecithricidae and their association with the movement of water masses in the Indian Ocean. Copepods occur in fantastically large swarms in oceans and are considered a vitally important key to the economy and ecological balance of the ocean world. Their distribution is closely related to the water quality as well. Hence distribution studies of this group require a knowledge on the extent of pollution present also.

3.2. Topography.

Indian Ocean, the third largest of the world's oceans, is bracketed by Africa and Australia on the west and the east and Asia and Antarctica on the north and south. The topographical features of the Indian Ocean are unique as it is land-locked in its northern boundary at 25°N. Hence it lacks subtropical, boreal and polar zones in the northern hemisphere. Most of its water lies south of the equator. Compared with the broader southern part of the Indian Ocean which is less influenced by the land masses, the northern part which is considerably narrower is affected climatically by the great land masses of Asia and Africa producing monsoonal conditions which are unparalleled in the world oceans. Its southern end is open and extends right up to the Antarctica like the other major oceans. Including the marginal seas the Indian Ocean covering an areaof 8,16,02,000 km^2 has a mean depth of 4,284 m and occupies a volume of 34,96,00,000 km^3. The maximum depth of

7,450 m is found in the Java Trench south of Java. About 9 marginal seas and identifiable water bodies interfere with the Ocean. They are (1) Mozambique channel, (2) Red Sea and Gulf of Aden, (3) Persian Gulf and Gulf of Oman, (4) Arabian Sea, (5) Laccadive Sea, (6) Bay of Bengal, (7) Andaman Sea, (8) Java Sea and (9) Davis Sea off Antarctica. The Red Sea forms an extension of the Arabian Sea, the Gulf of Aden, a long, narrow and deep basin with an extremely shallow sill about 125 m depth at the narrow southern entrance at the Strait of Bab-el-Mandeb connecting it with the Arabian Sea. The Persian Gulf is a shallow basin having an average depth of 35 m, the maximum depth being 150 m. It is connected with the Arabian Sea through the 50 m deep sill at the Hormuz Strait. The northern part of the Indian Ocean is divided into the Arabian Sea and Bay of Bengal. The Laccadive-Maldive Islands in the Arabian Sea and the Andaman-Nicobar Islands in the Bay of Bengal subdivide these regions again. Major rivers flowing into the ocean are Limpopo and Zambezi of Africa and the Irravaddy, Brahmaputra, Ganges, Indus and Shatel-Arab of Asia. Numerous volcanic islands and several large islands are found in the ocean. Madagascar, Seychelles, Socotra and Srilanka form continental fragments. Other islands include Mauritius Reunion, Rodrigues, Prince Edward, Crozet, Amsterdam, St. Paul and Kerguelen Islands. The Indian Ocean basin was formed by the ongoing process of continental shift. As a result the Indian Ocean is a comparatively young ocean and its basin is one of the most complex in the world. Several ridges and plateaus divide the Indian Ocean basin into a series of separate basins which range from 300 to 9,000 km in width and into smooth abyssal plains - among the smoothest in the world - which occur at depths of 3,000 to 6,000 m. Basins include the north-south series of small basins in the west, the central Indian Ocean Basin in the middle and the great West Australian Basin in the east.

Four north-south trending ridges dominate the topography of the floor of the Indian Ocean. By far the more massive of these ridges is the Mid-Indian Ocean Ridge which joins the Antarctic, African and Indian plates and is part of the 64,000 km long mid oceanic ridge that circles round the globe. To the north the ridge turns westward to enter the Red Sea where its spreading widens. To the south the ridge forks to form the south-west Indian Ocean Ridge and the Southeast Indian Ocean Ridge. Towards the eastern Indian Ocean is the remarkably straight 5,000 km long Ninety East Ridge which towers 2,712 to 3,658 m above the sea floor and lies from 914 to 2,134 m below the water surface. Other ridges include Carlsberg and Broken. Chagos, Laccadive Plateau rises above the water surface to form the Maldive and Laccadive Islands. Important plateaus include Mascarene, Kerguelen, Madagascar, Seychelles-Mauritius, Mozambique and Agulhas. Noteworthy trenches in the Indian Ocean are Sunda Trench, Java Trench and Ob Trench. In the north, the Indus and Ganges rivers on either side of India form conspicuous alluvial fans on the sea floor, being known as the Indus cone and the Ganges Cone respectively.

Compared to the Atlantic Ocean the continental shelves of the Indian Ocean are narrower, ranging from a few hundred metres off some islands to 200 km off Bombay, the brake in the shelf occurring at an average depth of 140 m. In the northern Indian Ocean eventhough the continental shelf area is greater and shallower in the Arabian Sea than in the Bay of Bengal, the eastern sector of Arabian Sea and the eastern sector of the Bay of Bengal have relatively wide continental shelf zones. The prominent shelf off the coasts of Burma, Thailand and Malaysia support rich mangrove swamps. Along the east coast of India the shelf is narrow. The east African coast has narrow shelf area as the 200 m contour line at many places is within 4 km from the shore. This narrow shelf in the coastal region of Mozambique, Tanzania and Kenya are fringed with coral reefs and mangroves. In the Red Sea the shelf is wide at the central part and southern part. These continental shelfs were sliced by numerous submarine canyons as seen off Indus and Ganges rivers.

The floor of the Indian Ocean is covered primarily by pelagic sediments, while red clay covers 25% of the sea floor, calcareous oozes derived from the shells of animals of the Globigerina type form 54%. Siliceous oozes from the diatom shells cover 20% of sea floor below 50°S latitude. Rest of the sediment occurring near land is derived from land.

3.3. Hydrological properties.

3.3.1. Thermal structure.

Over most parts of the Indian Ocean, the yearly cycle of thermal structure is the strongest seasonal signal. In a vertical sense, the ocean is a thermally layered system, with warmer, lighter waters overlying the cold denser ones. The most salient features of the thermal structure are the mixed layer, the upper thermocline which may in part be seasonal, the lower main oceanic thermocline and the deep layer where temperature decreases only very slowly with depth. The mixed layer chiefly controlled by local atmospheric conditions as heating, cooling and wind stirring is practically found everywhere and is between 40 and 100 m thick in the tropical and subtropical regions except in some locations and seasons, when it may be several hundred metres deep. Mixed layer is shallower than 20 m along the coast of Arabia during upwelling seasons. Mixed layer depths of more than 100 m occur more frequently, especially during the Southwest monsoon in the Arabian Sea, off Sumatra and in the southern subtropical anticyclonic gyre during winter. Between 40°S and 50°S mixed layer is several hundred metres deep. The upper thermocline, which usually contains the maximum temperature gradient, is present over most of the ocean and is found between 70 and 300 m depth, and is most strongly developed in tropical regions. In late winter the upper thermocline may be missing in parts of the temperate regions and in the subpolar regions. Because of the monsoonal influence the thermocline depth fluctuates widely in the coastal areas of the Arabian Sea which is subjected to upwelling. Off the southwest coast of India the thermocline is usually found at 100 to 125 m depth during winter and during the stable period between the winter and summer monsoons the thermocline level is usually at 75 to 90 m. With the progress of the Southwest monsoon in summer, thermocline migrates upwards to 20 to 30 m depth and even surfacing in late summer. In the Bay of Bengal the thermocline is usually below 50 to 55 m and occasionally goes down to 100 to 125 m depth, and except for a small area off the east central coast, the shelf waters are for most of the time isothermal or near isothermal, whereas off the west coast of India the thermocline fluctuates a great deal showing a seasonal trend. The main oceanic thermocline, extending from about 300 to 1,200 metres is found everywhere in tropical, subtropical and temperate regions to the polar front. The 20° isotherm related to circulation seen in the middle of upper thermocline in tropical and subtropical regions reaches the surface in the southern parts. This separates the warm surface water from the cooler water of the main oceanic thermocline. The maximum temperature gradient of 1°C per 10 metres is situated just below the mixed layer in tropical region and where a strong summer thermocline is formed. The strongest gradients above 3°C per 10 metres are frequent in the equatorial region. The major features in the temperature and density structure in the upper layer of the equatorial region are the strong, shallow upper thermocline in tropical regions, the doming of isotherms between the equator and 10°S, the almost horizontal isopycnal surfaces in the northern Indian Ocean, and the spreading of the isotherms and isopycnals south of 15°S. Surface density governed by temperature has its seasonal variation parallel to surface temperature. In upwelling areas variations are related to upwelling. Strongest meridional shift of surface density is observed between 30°S and 50°S in the eastern part of the Indian Ocean. In the main thermocline the temperature gradually decrease to about 5°C. Below the main thermocline, beginning at about 1,000 m in mid latitudes, lie the rather uniform deep waters of the ocean at temperatures of 2 - 4°C. The thermocline lies deepest at mid latitudes and is considerably shallower at the equator. In a latitudinal sense there is a similar structure although the changes take place over much greater distances. The temperature of the near surface layers can vary seasonally and the winds keep them well mixed. The warmest waters at the surface lie between the tropics where seasonal averages in excess of 28°C are found. The water cools towards the poles to less than 0°C in the vicinity of ice fronts. A uniform zonal distribution of surface temperature is not found. Instead, the global pattern of currents and counter currents act to modify it considerably. Warm water is transported away from equatorial regions in the well known western boundary currents along the east coasts of continents and cool waters return to lower latitudes in the often less well defined eastern boundary currents along the western shores. One result is that the north to south distance between the same surface isotherm tends to be greater in the west of oceans than in the east (Hutchinson and Scharff, 1947).

The Arabian Sea differs both seasonally and regionally from Bay of Bengal in several biological and oceanographic parameters associated with their water movements. The fluctuations in average surface temperature are wide in the Arabian Sea between 23°C and 30°C (Gallagher, 1966) and the usual range along the Indian coast is from 23°C and 29°C. Along the Indian coast south of 15°N and coasts of Somalia and Arabia relatively cool surface water is present during June to September as a result of upwelling. In the Bay of Bengal the range of average surface temperature is between 27°C and 29°C except in narrow areas near the coast. Robinson (1966) observed a bimodal temperature cycle at the surface in the Arabian Sea and Bay of Bengal.

3.3.2. Salinity gradient.

Salient features of the surface salinity distribution as revealed by bimonthly salinity maps of Wyrtki (1971) are (a) the changing extent of the high salinity water in the north of the Arabian Sea as well as that of the low salinity water off the west coast of India,

(b) advection of the low salinity water from the Bay of Bengal to south of Ceylon during the Northeast monsoon and extension of a tongue of high salinity water to east during Southwest monsoon, (c) spreading of low salinity water from the eastern Indian Ocean around 10°S, (d) the subtropical cell of high salinities near 30°S shifts little with the seasons and highest salinities are always in the eastern part of the cell, (e) in Antarctic waters the summer values from November to May show salinities higher than 34.1 ‰ in March and April, near the Antarctic Divergence.

The salinity of the Indian Ocean water varies from 30 to 37 ‰. Because of the arid climate that prevails in most of the area around northern and central Arabian Sea it is subjected to strong excess of evaporation. Compared to the high evaporation rate, the amount of precipitation is considerably less (Venketeswaran, 1956; Muromtsev, 1959). This high rate of evaporation and influx of high saline (37 - 41 ‰) water from the Red Sea and Persian Gulf cause high salinity in the Arabian Sea and the high precipitation in combination with large river discharge lead to low salinity values in the Bay of Bengal. The Bay of Bengal and the area between Sumatra and Australia tend to be less saline than the average for Indian Ocean because of inflow of lower salinity water from Pacific and the strong rainfall in the intertropical convergence zone during the Northeast monsoon season. The average salinity values of the Arabian Sea ranges from 34 - 37 ‰ while that of the Bay of Bengal from 30 - 33 ‰. The salinity of the Arabian Sea decreases from north to south, while in Bay of Bengal it increases from north to south (Gallagher, 1966).

The high salinity water of the Arabian Sea spreads southwest into the area off Somalia during Northeast monsoon and is further drawn into the equatorial current as a distinct tongue upto 90°E (Wyrtki, 1971). During the Southwest monsoon the high salinity water of the Arabian Sea spreads southwards and is driven along with the monsoon current and is tracable upto south of Sri Lanka. Part of this high salinity water sinks forming a subsurface salinity maximum which spreads throughout the entire monsoon gyre north of 10°S. However, this does not penetrate into the Bay of Bengal. This subsurface salinity maximum Arabian Sea water along with high saline water from the Red Sea and Persian Gulf form the North Indian High-salinity Intermediate Water. This water mass of almost uniform salinity occupies from about 150 to 900 m depth in the Arabian Sea, spreading near 300 m depth southwards in different directions in the monsoon gyre, filling areas west of Sumatra and the entire Bay of Bengal

(Rochford, 1964; Wyrtki, 1971 a,b). The warm tropical surface water of low salinity of the Bay of Bengal has its largest concentration in the Bay of Bengal and to the southwest of Sumatra, from where it extends west all the way from Sumatra to Africa, near 10°S. The tongue of the lowest salinities may be found anywhere between 4°S and 15°S. Below this tropical surface water, extending several hundred metres down, a decisive front in the hydrographic structure of the Indian Ocean is situated. This front is more pronounced in sub-surface layers. Within the upper thermocline, this front is marked by a horizontal salinity minimum separating the salinity maxima of the subtropical waters of the northern and southern hemisphere. This front of the horizontal salinity minimum extending all the way from Timor to north of Madagascar is rather stationary at 10°S and fluctuate between 7°S and 12°S depending upon the variable penetration of the two salinity maxima to the north and south. Deeper down in layers between 300 and 1,000 m depth the front separates the high salinity waters of the northern Indian Ocean, chiefly of Red Sea origin, from the low salinity waters of the southern Indian Ocean which is Antarctic in origin. The upper branch of the Antarctic Intermediate Water occurring at 1,000 m depth at 25°S with a salinity of 34.5 ‰ ascends to 700 m depth at 10°S with a salinity of 34.7 ‰. Subtropical surface water of high salinity forms in the subtropical anticyclonic gyre under the influence of an excess of evaporation over precipitation. The highest surface salinities are found in a belt between 25°S and 35°S, with the absolute maximum occurring close to Australia. Thus the salinity above 35 ‰ extend to more than 500 m depth. From this high salinity core a subsurface salinity maximum extends throughout the entire subtropical anticyclonic gyre spreading chiefly equator-wards.

The Antarctic surface water of low salinity (below 34 ‰) is caused by excessive precipitation and melting of ice. This water meets waters of high salinity in the Antarctic polar front lying between 48°S and 53°S. Deep water of Indian Ocean is characterized by a weak salinity maximum, originating from the North Atlantic Deep Water. At 200 m depth salinity of Arabian Sea water is as high as 34.8 ‰. In general salinity north of 5°S at 1,500 m depth exceeds 34.8 ‰.

3.3.3. Oxygen content.

Since the surface water is close to saturation, the distribution of surface oxygen content largely parallels that of surface temperature. Large areas of surface water are slightly over saturated with oxygen.

The dissolved oxygen content in the well mixed surface layers of the Arabian Sea down to about 100 m depth varies between 4.5 ml/l and 5 ml/l. In the lower layers oxygen decreases sharply and the subsurface oxygen minimum layer is formed. The values are less than 0.5 ml/l below a depth of about 150 m and the low values persist upto a depth of about 1,500 m (Sankaranarayanan, 1978). At 2,000 m depth the variation in the dissolved oxygen is below 1.25 ml/l and 2.5 ml/l. Upwelling waters are extremely depleted in oxygen.

The subsurface oxygen minimum has been reported by several authors, in the northern monsoon gyre. According to Wyrtki (1973) the North Indian Intermediate Water layer extending from above 200 m to more than 1,200 m depth in the Arabian Sea has an oxygen content of less than 1.0 ml/l everywhere to the north of 3°N. Directly connected with this huge layer of very low oxygen content is the deep oxygen minimum, which is present over the entire Indian Ocean. Near the equator it lies at about 800 m depth, deepens to more than 1,700 m near 40°S and rises again to about 400 m depth below the Antarctic divergence. In the southern Indian Ocean it lies above the deep water and below the Antarctic Intermediate Water. The oxygen content within the oxygen minimum increases slowly southwards and reaches 4 ml/l at 40°S. The oxygen maximum is found in the entire subtropical gyre at depths between 400 and 500 m and the oxygen content decreases only very slightly to the north.

Varying extent of low oxygen water is evident to the north of the hydrographic front, as is the advection of water of high oxygen content south of the front between 300 and 700 m depth, above the Antarctic Intermediate Water. Between the two water masses of different oxygen content (low oxygen content waters of monsoon gyre and high oxygen content waters of subtropical gyre) a very sharp horizontal gradient is developed, but this gradient is most pronounced near 15°S, some 5° south of that indicated in the salinity distribution. As Wyrtki (1971 b) summarises, between 15°S and 10°S, in the hydrochemical front, oxygen decreases suddenly from 5 ml/l to less than 3 ml/l. This oxygen maximum extending to 8°N is situated between the shallow oxygen minimum near 200 m depth (developed in the thermocline) and the deep oxygen minimum between 400 m and 1,700 m. North of 8°N these two layers unite into one huge layer of extremely low oxygen content (0.5 ml/l) where an oxygen maximum layer is absent. A weak oxygen minimum is found near a depth of 180 m in the central and northern parts of the subtropical gyre. Below the subtropical water a high oxygen content is found in depths of 400 to 500 m. Deep water of Indian Ocean has a rather high oxygen content of 5 ml/l decreasing in the direction of spreading.

3.3.4. Nutrients.

The high phosphate content in the Antarctic surface waters contrasts markedly with the low values in the remainder of the ocean. Among the upwelling areas, only those off Somaliland and off Arabia exhibited higher surface phosphate values during the Southwest monsoon, those south of Java and in the Banda Sea indicate little increase in surface phosphate content during the upwelling season. Same distribution in general applies to nitrate and silicate. The nitrate distribution shows the upwelling areas best. The nutrient concentration in the Arabian Sea is of a higher magnitude as compared with that of Bay of Bengal. The inorganic phosphate values in the Arabian Sea vary roughly between 0.2 and 1 µg at/l with a general increase in the phosphate concentration (0.5 µg at/l to 1.5 µg at/l). The phosphate concentration increases gradually till a maximum is reached between 1,000 and 1,500 m, thereafter decreasing uniformly. Studies on distribution of phosphates between 16°N and 19°N latitude in the Bay of Bengal showed a phosphate maximum between 600 and 800 m (Sankaranarayanan and Reddy, 1968). The subtropical water mass is characterised by very low nutrient contents. In the upper layers of equatorial region, the distribution of phosphate, nitrate and silicate show always low values in the surface layer, but the depletion of nutrients reaches to considerable depth in the southern subtropical anticyclonic gyre. In layers between 200 and 1,000 m depth a strong contrast exists between high values in the northern Indian Ocean and low values in the range of the southern subtropical gyre south of this front. With regard to the nutrient properties, the hydrographical front is less well marked and appears less steep than the front in the oxygen content.

3.4. Water masses.

Temperature and salinity act in concert to produce the density structure of the ocean, which everywhere seeks the more stable configuration. As surface waters get cooled they become denser and thus start sinking along surfaces of equal density, so-called sigma-t surfaces, determined by the pattern of heat balance. The middle to high latitudes are such important sites. The convergence zones though not all of them, mark these sites. Water masses thus have such extent and integrity that they must be considered the dominant features in the structure of the upper mid waters of the oceans. Characteristic water masses are formed primarily at the sea surface by the influence of various climatological factors. Water masses thus formed can be identified by the possession of extreme value of a certain property as temperature, salinity, oxygen and phosphate of which salinity and temperature can be changed only at the sea surface by climate. Accordingly the following core layers have been recognised in the study area of the Indian Ocean. (a) The shallow salinity maximum containing the Arabian Sea water in the northern Indian Ocean and the subtropical water in the southern Indian Ocean. (b) The salinity maximum originating from the outflow of water from the Persian Gulf and the Red Sea. (c) The salinity minimum of the Antarctic Intermediate Water originating at the Antarctic Polar Front. (d) The salinity maximum of the North Atlantic Deep Water entering the deep ocean south of Africa as an external water mass. (e) The shallow oxygen minimum usually found in the thermocline. (f) The intermediate oxygen maximum originating north of polar front and spreading above the Antarctic Intermediate Water. (g) The deep oxygen minimum.

Salinity maxima and minima. Excess evaporation causes the formation of areas of high salinity in the Arabian Sea and in the southern subtropical region and from each of these regions subsurface salinity maxima spread. Salinity maxima may also result from the outflow of water from adjacent seas where salinity is high due to excess evaporation, as from Red Sea and Persian Gulf, or from an external source such as the salinity maximum of the North Atlantic Deep Water which enters the Indian Ocean. These two water masses - the subtropical surface water of the southern subtropical anticyclonic gyre and the Arabian Sea surface water - form the shallow salinity maximum. This salinity maximum exceeding 36.5 ‰ in the northern part of the Arabian Sea spreads south and later east upto 10°S. It does not enter Bay of Bengal. While spreading south, temperature and oxygen decrease, while the nutrients increase, and thi/s parts of the upwelling areas off Arabia are marked by very high phosphate and nitrate values. Subsurface salinity maximum of the subtropical gyre is rather shallow in the area of formation where winter temperatures are lower and density higher. One branch of this maximum salinity extends to south, where its depth and density increases. The north branch becomes as deep as 250 m under the South Equatorial Current. Near 10°S it meets the water of core layer originating in the Arabian Sea. Nutrients which are very low in the subtropical region increase both southward and northward. Throughout the shallow salinity maximum there is a strong linear relation between oxygen, phosphate and nitrate. Along 10°S salinity is lowest due to the erosion of core layer by the overlying water of lower salinity. Oxygen content in this area is low and the nutrient content is high. The intermediate salinity maximum is found in the northern Indian Ocean at depths between 150 and 900 m associated with outflow from Gulf of Oman and Persian Gulf. This water seems to spread into the oxygen minimum in the northern Arabian Sea and then along the west coast of India to south. Salinity maximum in the Gulf of Aden is due to the outflow from the Red Sea, and spreads to the Arabian Sea at depths between 500 and 800 m and is identifiable far east to Sumatra and to the south into the Madagascar Channel upto 1,100 m depth at 25°S. The Arabian Sea consists of the three upper salinity maxima-shallow maxima, intermediate maxima and the Red Sea maxima. The deep salinity maximum in the Indian Ocean originates from the North Atlantic Deep Water at a depth of 2,800 m with a salinity of 34.84 ‰, temperature of 2.2°C and oxygen content of 5 ml/l. Low salinity water and salinity minimum in the Antarctic region - the Antarctic Intermediate Water - is the result of precipitation and the melting of ice. The low salinity region in the Bay of Bengal and in Indonesian waters does not form subsurface salinity minima because of the low density of these waters.

Oxygen minima and maxima. In the Indian Ocean two oxygen minima are found. These minima are the outcome of oxygen consumption needed to oxidise the material sinking down from the productive surface layer and their distribution is determined by circulation (Wyrtki, 1962). The deep oxygen minimum which varies widely in oxygen content is found throughout the ocean. In the northern Indian Ocean it is situated in less than 600 m depth which goes on increasing to 1,800 m near 40°S, from where it rises to 400 m below the Antarctic convergence. The oxygen content which is extremely low close to the measurable limit in the north, steadily increases to the south having over 5 ml/l, oxygen minimum near the Antarctica. Almost a linear relation exists between oxygen content and temperature. To the north of 20°S the minimum is situated between 12°C and 5°C. Between 30°S and 50°S and near Antarctica this is at 1°C temperature only. Phosphates and nitrates are high throughout the oxygen minimum layer, northern water having slightly higher values than Antarctic. While phosphate values are same in the Arabian Sea and Bay of Bengal, nitrate values are lower in Arabian Sea. The extremely variable silicate values are higher between equator and 30°S. The shallow oxygen minimum usually found within the thermocline at depths of about 200 m and at temperatures between 12 - 20°C, is present in all tropical and subtropical regions. Lowest values of oxygen content are found in northern Arabian Sea and in the Bay of Bengal. In these areas the shallow and deep oxygen minimum often form a continuous layer of extremely low oxygen content, uninterrupted by an oxygen minimum. The minimum oxygen content probably changes little with the seasons, but the depth of oxygen minimum changes with the seasons. In the northern and equatorial Indian Ocean the oxygen minimum is situated below the shallow salinity maximum. Between 10°S and 20°S it is above the salinity maximum. In the area of the subtropical anticyclonic gyre, the shallow oxygen minimum is only weakly developed and fades away slowly between 35°S and 40°S. Nutrients are relatively high to the north of 15°S and low in the subtropical region. There is a strong linear relation between phosphate, nitrate and oxygen. A marked nitrate deficit exists in the Arabian Sea (Sen Gupta et al., 1976). A layer of higher oxygen content, the intermediate oxygen maximum, originating in the temporate climatic region north of the polar front near 42°S (where oxygen content is more than 5.5 ml/l) which is the transition area between subtropical and subpolar water and spreading above the Antarctic Intermediate

Water to the north, separates the two minima. The oxygen maximum is found in the main oceanic thermocline at temperatures between 10 and 12°C near the boundary between the warm water sphere and the cold water sphere (Wyrtki, 1973). This maximum sinks to depths of more than 500 m below the subtropical gyre and then rises to 300 m near the equator where it is often missing as the oxygen content is reduced to less than 1 ml/l. Thus the line of 1.0 ml/l has been used as its northern boundary. Nutrient content in this layer is lowest between about 30°S and 35°S and increases to rather high values as oxygen decreases northward. Nutrient content at 42°S is more than in subtropical waters. As in shallow oxygen minimum a strong linear relation exists between phosphate, nitrate and oxygen content. The northern Indian Ocean is characterised by the presence of several layers of water masses. The surface water of the Arabian Sea and Bay of Bengal generally occupies a layer from the surface to a depth of about 100 to 150 m. Of the water below the surface layer, the subsurface water masses are the most limited in spatial extent and remain within well defined areas of the ocean. The Laccadive Island Ridge affords a sharp deviation between equatorial water on the west and the Indo-Australian subsurface water to the east. The Indo-Australian water is apparently carried west by the South Equatorial Current until it meets the barrier of the ridge and is then reflected southwards. The equatorial water in the west also flows along the ridge towards the south for some distance. Farther to the north, the Equatorial water finds its way across the ridge and proceeds into the Bay of Bengal and parts away along the coast of Sumatra. While the subsurface water of Bay of Bengal extends upto 1,500 m, that of the Arabian Sea extends only upto 400 m after which Arabian Sea Intermediate Water occurs upto 1,500 m. Below this level deep water is present throughout. The origin of deep sea cold water found in the northern Indian Ocean has been explained by Gallagher (1966) and Wooster _et_ _al_. (1967). The movement of the cold Antarctic bottom water (deep water) from the polar region into the Arabian Sea and Bay of Bengal has a bearing on the organic productivity of the region, because of its low salinity, low temperature and high nutrients. This Antarctic Bottom Water divides into three branches, one going to the east coast of Madagascar, the second touching the Carlsberg Ridge and getting defected to the surface of the Arabian Sea and the third one again dividing into two, one branch striking the coast of Sri Lanka which enters the Laccadive Sea, while the other travels northwards between Carpenters Ridge and Andaman Nicobar Ridge.

3.5. Current systems and patterns of circulation.

The solar energy absorbed by the oceans and atmosphere causes a net heating towards the equator balanced by the pole-ward cooling. The gradation so established drive the major circulation patterns of the winds and currents. The influence of wind is most obvious in areas where it is seasonal as in northern Indian Ocean and in coastal upwelling areas. Major current systems mark the boundaries of the water masses occupying the interior regions of the oceans.

Prevailing wind pattern determines surface water circulation. General circulation pattern and the permanent boundary currents noted in other oceans are either modified considerably or absent in the Indian Ocean. Of the three circulation patterns reported by Wyrtki (1971) in the Indian Ocean, the Antarctic water with circumpolar current and the subtropical anticyclonic gyre are seen in the southern Indian Ocean similar to those in the Atlantic and Pacific. The northern Indian Ocean is characterised by the seasonally changing monsoon gyre. Reversal of equatorial water circulation with monsoon change is unique to Indian Ocean. This circulation reflects the wind system with stronger and steadier currents during the Southwest monsoon compared to those in the Northeast monsoon.

This has no close parallel in the other oceans. This gyre is different from the southern subtropical gyre, because it is very characteristic in its chemical features. All the areas north of 10°S fall under this gyral system. The cyclonic and anticyclonic circulation of the Arabian Sea and Bay of Bengal, the north Equatorial Current (monsoon current), the counter current, part of the south Equatorial Current and Somali Current are the major surface components of the monsoon gyre. The seasonal changes of the oceanic structure do not penetrate more than a few hundred metres and are restricted to the warm upper layer of the ocean, the conditions below 1,000 m being stationary and uniform. The circulation pattern of the surface waters of the northern Indian Ocean for different months of the year has been described by Varadachari and Sharma (1967) and Wyrtki (1971).

A seasonal low pressure area developing over the central Asia during summer, causes the wind system to blow persistently fom the southwest. This also generates the Somali Current (Lighthill, 1969) which flows northwards (from south to north) along the east coast of Africa as a swift narrow current with speed as high as 7 knots as reported by Swallow (1965). The Somali Current results in a general clockwise circulation in the Arabian Sea which in turn develops into a relatively strong southerly current at the surface level along the west coast of India. The southerly currents developed in May continue upto November and then the current reverses until April. It reaches its greatest strength in July. At the height of development, the Somali Current reaches as far north as latitude 12°N, however, most of the water leaves the coast and flows in an easterly direction as monsoon currents south of latitude 12°N. In the Gulf of Aden the flow of surface current is from Gulf to the Arabian Sea from June to August. Along south Arabia the currents are weak and more in the east-northeasterly direction. It flows northerly along the Arabian coast and southerly along the Indian coasts. The southerly current brings comparatively high saline Arabian Sea water southwards and northerly current transports the less saline equatorial water northwards.

In the Bay of Bengal the flow is generally northeast. Upon reaching the continental coast most of this water turns southwards and flows along the continental shelf. South of Sumatra, the current flows southeasterly along the coast of Sumatra and merges with southeast Asian water flowing into the Indian Ocean through the Timor Sea. These waters form the basis of South Equatorial Current in the Indian Ocean. North Equatorial Current is totally replaced by the east flowing monsoon current. The east flowing counter current also joins the Monsoon Current. Off Sumatra the Monsoon Current crosses the Equator and turns into the South Equatorial Current. This is well developed between 8°S and 18°S and most of the water at the western end turns north into the Somali Current. Then the Somali Current, the Monsoon Current and South Equatorial Current form a very strong wind driven gyre in the equatorial Indian Ocean.

The Northeast monsoon prevails in winter (November-February), the wind generated from a high pressure source forming over the Tibetan Plateau and the neighbourhood move towards the low pressure belt in the Equatorial Indian Ocean from northeast to southwest. This brings about considerable changes in the circulation pattern in the northern seas. Compared to Southwest monsoon, Northeast monsoon is weaker and shorter in duration. The general circulation in the open ocean is westerly with a counter-clockwise circulation along the coasts. The Somali Current reverses direction and flows southerly from December to February lasting until March. Surface current flow in the Gulf of Aden is from the Arabian Sea into the Gulf. In the Bay of Bengal a cyclonic circulation occupies the entire bay in February, however this pattern does not prevail during the entire Northeast monsoon period. The west flowing North Equatorial

Current (Northeast monsoon drift current) is fairly well developed between 8°N and the equatorial latitudes. The flow starting in November reaches its high strength in February. From November to December a weak current flows northwards along the coast of India carrying low salinity water from the Bay of Bengal into the eastern Arabian Sea. This current turns south off the coastal Somalia, crosses the equator and form the Equatorial Counter Current which flows from west to east between 3°N and 5°S in November-December and shifting slightly south (4°S - 8°S) from January through April. The counter current also receives water from a branch of the South Equatorial Current. At the eastern end a large part of the counter current continues to the southeast as the Java Coastal Current or turns directly into the South Equatorial Current. During this season a weak Equatorial Under Current is also developed (Knauss and Taft, 1964; Taft and Knauss, 1967). The South Equatorial Current flows from east to west across the ocean approximately between 8°S and 15°S. South of 10°S the circulation is generally constant throughout the year and forms a counter-clockwise gyre above the southern Indian Ocean basin between 10°S and 40°S. This gyre includes the South Equatorial Current, Agulhas current, West Australian Current and a part of the West Wind Drift. The Mozambique Current joins the Agulhas Current and flows southward along the east coast of Africa where it joins the eastward flowing West Wind Drift Current, off the coast of Antarctica. In the southern summer the West Wind Drift, which is 200 - 240 km wide and flows at a rate of about 45 cm/s turns northward before reaching Australia and is joined by a current flowing in from the Pacific, south of Australia. In the winter the West Wind Drift is joined by a southward flowing current along the west coast of Australia and continues on into the Pacific. The West Australian Current is the eastern leg of the gyre and flows steadily northward during the summer. During the winter it becomes southerly and very much weakened. The subtropical convergence around 40 - 42°S forms the southern boundary.

The west boundary currents in the Indian Ocean is represented by the Agulhas Current while the generally weaker but wider and more diffuse east boundary current is represented by the Western Australian Current. Crossing the ocean at 40°S, the Western Boundary Current becomes more diffuse and slow, to be known as the West Wind Drift in the southern hemisphere.

The hydrochemical front at 10°S form the northern boundary. The South Equatorial Current represents the northern leg of the subtropical anticyclonic gyre, and is the westward continuation of the West Australian Current under the influence of the trade winds in the vicinity of the Tropic of Capricon. After reaching Madagascar, the current splits, the northern arm splits again, with one branch turning westward and then south to form the Mozambique Current, and the other turning eastward. The southern branch joins the Mozambique Current south of Madagascar to form the Agulhas Current. Antarctic water is characterised by a deep-reaching circumpolar current having the polar front, associated with two frontal circulations. The Antarctic convergence is found near 65°S near the southern boundary of the prevailing west winds.

The zones of convergence and divergence of currents in the ocean are the regions where mixing and exchange of water takes place. Currents meet at and along convergence and water sinks. Currents separate at divergence and water from below upwells. At the above areas water properties change abruptly. The subtropical convergence in the southern hemisphere marks the meetings of the large warm water western boundary currents with the colder waters returning from higher latitudes. Divergences, associated with the eastern boundary currents occur over the broad regions where the north and south running currents originate and where the currents turn westward away from the coasts, most well defined divergences occurring at about the tropics. They are associated with the upwelling areas.

3.6. Upwelling.

A general review of the upwelling areas of the world and their biological productivity has been reported by Cushing (1969). Compared to the classical wind induced upwelling observed in the upwelling areas of the world. The Arabian Sea upwelling is known to be due to the prevalent coastal currents in those areas. The effect of the vertical extension of the monsoon extends up to 400 m. According to Banse (1968) the upwelling current system (and not the wind) is the main condition to generate and maintain the upwelling. Darbyshire (1967) concluded that there was no wind generated upwelling during the Southwest monsoon along the west coast of India, and she also indicated that the dense bottom water approached the surface because of the immediate interplay of current with the tilting of the sea surface and the thermocline. In the Arabian Sea one of the most pronounced zones of upwelling is in the waters off South Arabia from Kuria Maria Bay to Rasal Hasd during Southwest monsoon period. This large scale upwelling makes the Saudi Arabia coast the richest area of zooplankton production in the northern Indian Ocean. The second pronounced area of upwelling is off the northern Somalia within 35 km off the coast (Swallow, 1965). The strong winds parallel to the Somali coast intensify the baroclinity in the upper layer and cause strong upwelling. The upwelling along the coast is very intensive between 5°N and 11°N and the surface temperature in the centre of upwelling goes down to 13.2°C (Foxton, 1965). The 20° isotherm reaches the surface (Warren, Stommel and Swallow, 1966). The phosphate concentration reaches more than 1.0 ug at/l and nitrate more than 10 ug at/l in contrast to 0.2 and 0.5 respectively in the offshore areas (Wyrtki, 1971 b). The Somali Current leaves the coast near 11°N and turns east carrying the cold upwelling water which is stopped by a flow of warm surface water from the Gulf of Aden. This temperature front separates the Somali upwelling from the Arabian upwelling. Since the Arabian upwelling is greater in volume than Somali upwelling, the phosphate exceeds 1.5 µg at/l. Ramamirtham and Jayaraman (1960) stated that off Cochin upwelling starts by mid August, establishing by late September and ends by mid October. Banse (1968), Panikkar and Jayaraman (1966) have shown that off the southwest coast of India between 7°N and 16°N strong seasonal upwelling starts with the onset of the Southwest monsoon and attaining maximum intensity during July-August ceases in early October. Sharma (1966) states that the area between 7°N and 14°N latitudes and from longitudes 73°30'E and 77°30'E shows ~~that~~ the upward tilting of thermocline from February to July and sinking after August near the coast, upwelling starts earlier in the south and progressively shifts towards the north. Thermocline in this area reaches the surface layers by July (Sharma, 1968) and is 6°C cooler than elsewhere. Banse (1968) reports that the oxygen deficiency can indeed occur below the thermocline during the upwelling period. Upwelling has also been noticed in the northwest coast of India off Bombay during October (Carruthers, et al., 1959). In the Bay of Bengal, LaFond (1954, 1957, 1958) reported areas of upwelling along the east coast of India from Madras to Hoogly river. Anand et al. (1968) have confirmed upwelling off Madras and Visakhapatnam. A weak upwelling is reported in the area off the Madras coast and Waltair coast (Murthy and Varadachari, 1968). Upwelling is also noticed off the Burma coast and off Andamans (LaFond and LaFond, 1968) during Northeast monsoon. This upwelling has been attributed to the prevailing monsoon winds which cause offshore displacement of surface water from the Burmese coast. The most important upwelling in the eastern Indian Ocean perhaps occurs south of Java, when winds are blowing strongly from the southeast between Australia and Indonesia. Wyrtki (1962) estimated the extent of the area of upwelling as 400 km wide and 1,200 km long. During upwelling the relatively sterile surface water is shifted further out to the sea and the cold deep waters with high concentration of ten to twenty times inorganic phosphates and nitrates are brought to the surface enriching the surface layers to produce spectacular phytoplankton blooms which make ideal feeding ground for fishes. Thus the replenishment of nitrate salts controls the magnitude of the annual organic production leading to fisheries.

In addition to temperature and salinity the other ~~contributing factors to~~ manifestations of the upwelling phenomenon are dissolved oxygen, and nutrient salts particularly phosphates. During the upwelling periods of early August to October the dissolved oxygen occurs in concentrations as low as 0.5 ml/l below 20 m along the west coast between 7°N and 16°N latitudes. The phosphate occurs in high concentrations in the entire water column over the shelf (1.94 to 2.74 mg at/m^3).

In the northwestern Bay of Bengal, coastal upwelling is found as one of the factors governing the distribution of nutrients during January to April. In the northern and eastern Bay of Bengal, the 'Anton Bruun' has observed a winter upwelling area (LaFond, 1965).

3.7. Phytoplankton production.

3.7.1. Chlorophyll 'a'

Chlorophyll 'a' values averaged for upper 50 m (Krey and Babenerd, 1976) were as follows: While Chlorophyll content above 0.2 mg/m^3 was wide spread during May to October period, these values were restricted to only a small area in the northern Arabian Sea and to a narrow strip along east coast of Bay of Bengal during November-April period. Chlorophyll maxima of more than 0.3 mg/m^3 were noted in the northern and western Arabian Sea, Gulf of Aden and southern areas of Peninsular India during May-October whereas during November-April period this maximum occurred only in the northern Arabian Sea and along the continental shelf of east coast of Bay of Bengal. Compared to May-October period, the November-April period was very poor in the chlorophyll content, the entire ocean south of 10°N and the Bay of Bengal having only chlorophyll content lesser than 0.1 mg/m^3. Chlorophyll 'a' measurements for the northern and central western part showed very well the seasonal contrast between the high values, especially in coastal areas, during the development and the persistence of the Somali and Arabian coast upwelling in the Southwest monsoon period and the low values observed during the Northeast monsoon.

Horizontal distribution studies of chlorophyll 'a' at the surface and at depths 25, 50, 75 and 100 m revealed gradual increase in content with depth up to 75 m and then the content started reducing. Vertical distribution of chlorophyll in the upper 100 m showed many isolated patches, but this optical effect seems more realistic for the distribution of phytoplankton than a regular zonal spreading. Larid _et al._ (1964) made chlorophyll measurements and found values greater than 150 mg/m^2 along Somali coast, whereas the chlorophyll concentrations in the Bay of Bengal was less than 10 mg/m^2. This study supports the higher productivity in the Arabian Sea.

3.7.2. _Primary production_.

Marine phytoplankton being the basic source of food (primary producers) in the oceans, their quantitative distribution in terms of chlorophyll '_a_' content and their assimilation efficiency (regenerative capability) interms of productivity rates can indicate the fertility of an ocean area. The actual seasonal variation in the quantity of the primary producers under the influence of the reversing monsoons practically controls the secondary production. Whereas the amount of chlorophyll '_a_' remains almost constant during a 24-hour day, related productivity rates (reproductive efficiency of the phytoplankton standing stock) can undergo great variations within the diurnal period. This variable relationship is dependent not only on seasonal changes and varying hydrographic conditions but also on the geographical location of the area. The effects on primary production of the monsoon induced changes in hydrographic conditions are often evident or occur more frequently in the periods of inter monsoons. Primary production processes in the northern and equatorial Indian Ocean respond to the hydrographical conditions which are strongly influenced by the seasonally changing monsoon winds. Monsoon iteself is not regular but is subject to fluctuations with time and space, in strength and duration. Really high productivity values are restricted to isolated and small coastal areas and inshore waters. Biological productivity in different regions of the Indian Ocean differs considerably depending upon the degree of utilisation of solar energy which varies from 0.33% in high productivity regions to 0.02% in regions with scarse phytoplankton. Thus the differences in the utilization of solar energy in the process of photosynthesis varies from 1 to 16. In the Indian Ocean the areas with scarse phytoplankton are much more extensive than those rich in phytoplankton. Biomass of phytoplankton is practically poor in the Indian Ocean south of south equatorial current due to (a) prevailing anticyclonic water movements and (b) stronger evaporation than precipitation, resulting in an increase of surface salinity and in water sinking.

Potential primary productivity measured and averaged for upper 50 m (Krey and Babenerd, 1976) showed 3/4 of the Indian Ocean area during May-October period capable of producing greater than 0.2 mg C/m^3/hour. However during November-April period the areas having low production rates of less than 0.2 mg C/m^3/hour was on the increase. In both seasons the central and western Bay of Bental water and south central Indian Ocean water were found less productive.

Actual primary production integrated for the euphotic layer showed higher production during May-October period than November-April period. Shelf, coastal and nearshore waters had a productivity in general greater than 250 mg C/m^2/day. In both periods the upwelling areas gave a productivity greater than 500 mg C/m^2/day. Offshore waters of the west coast of India, southern waters of Bay of Bengal and in general oceanic waters south of 10°S showed a production rate of less than 100 mg C/m^2/day. Primary production at the surface varied from less than 1 mg C/m^3/day in the oceanic waters to more than 50 mg C/m^3/day in the upwelling areas. Bay of Bengal waters in general showed values less than 5 mg C/m^3/day but for isolated shelf patches of upto 50 mg C/m^3/day.

Near the shelf, in the south-eastern part of the Arabian Sea the lower boundary of photosynthetic zone is at a depth of 50 m and the rate of photosynthesis is high in the surface waters (Prasad, 1966) towards the coast ($>$ 10 mg C/m^3/hour). The rate of production amounts to over 2,000 mg C/m^2/day near the coasts off Cape Comorin. Outside the continental shelf the rate of production is moderately high between 200 - 500 mg C/m^2/day. Very high production rates exceeding 5,000 mg C/m^2/day have been obtained off the southeastern coast of India in the Gulf of Mannar (Prasad and Nair, 1963) and 2,000 mg C/m^3/day in the surface waters of Palk Bay (unpublished data). Gulf of Oman (Ryther and Menzel, 1965) showed extremely high rates of 5,700 and 6,400 mg C/m^2/day due to bloom conditions. The mean production rate for Arabian Sea was found to be 1,800 mg C/m^2/day. Vitiaz expedition results have low production values, not exceeding 10 - 30 mg C/m^2/day in the open ocean parts and high values in the coastal waters and in the zones of deep water ascent. Thus according to Kabanova (1961) in the region of Madagascar and in the Arabian Sea region, where there is deep water ascent, the values of primary production increase and the day rate is between 50 and 120 mg C/m^3/day.

Galathea expedition showed middle latitudes in the western part of the ocean outside the continental shelf having a production rate between 100 and 200 mg C/m^2/day, which is the normal value for tropical and subtropical oceanic regions where there is no constant replenishment of nutrients from below (Steemann Nielson, and Henson, as cited by Prasad, 1966). Over the shelf the production is high, practically anywhere in the tropics. In the region of Agulhas current, water from the lowest part of euphotic zone showed a value three and a half times higher than the surface water. Galathea also showed moderately high with restricted areas/of very high production as between 57° and 72°E longitudes between Mombasa and Ceylon, in the Equatorial Current systems. Thus the production rate in the equatorial part of the Indian Ocean is significantly higher than that of the tropical waters in general. In the Bay of Bengal the rate of production is reduced by the low transparency of the water near the subcontinent caused by the influx of organic and inorganic material through the big river system. But Andaman Sea recorded higher production possibly by the island effect.

The average production rate for the Bay of Bengal is 0.19 g C/m^2/day compared to 1,800 mg C/m^2/day for the Arabian Sea. The level of organic production in the Arabian Sea which increases to the north and west is estimated to be atleast 3 times that of Bay of Bengal.

* The various expressions used as mg C/m^2, mg C/m^3, mg C per hour, mg C per day and mg C per year are the values taken from different publications and presented as such.

3.8. Zooplankton biomass.

Zooplankton biomass measurements can be used as indices to the amount of living matter present in the form of one or more of the various kinds/of organisms comprising ~~of~~ the ~~a~~ plankton population. This is an important measure of abundance throughout the history of descriptive studies of biological populations in the Sea. The importance of the biomass estimation is that these values can be converted to the third trophic level and used for the prediction of potential fishery resources of an area as done by Subrahmanyam (1959) and Cushing (1971). The organic content is perhaps the most fundamental property which a biomass index seeks to measure to gain insight into their nutritional state or their potential value as food. The classical measures of biomass involving several basic properties are grouped under three general headings, the gravimetric, volumetric and chemical. Of the three, direct volumetric techniques, the displacement method in which the space occupied by the plankton is measured in terms of the equivalent volume of liquid that they displace, is used in the present study and represented as 'biomass'. Prasad (1968 a,b) made a comparative study of the zooplankton biomass in the Arabian Sea and Bay of Bengal and obtained a similar pattern of distribution observed by Bogorov and Rass (1961) and Panikkar and Rao (1973).

High plankton concentration is observed on the northern and western part of the Arabian Sea and south of Cape Guardafui where the average volume is over 30 ml/haul. The highest, exceeding 50 ml, has been found near the Gulf of Oman and the Saurashtra coast. The south-west coast of India and the waters surrounding Ceylon, the Andaman Sea and the Bengal coast are found to have fairly high quantities of plankton, exceeding 20 ml. The equatorial region on the average has only 10 ml of plankton, except near the coastal regions. But Motoda and Osawa (1964) recorded consistently high plankton concentration for the equatorial area between 77° and 79°E. Similar abundance in the centre of vast area of low abundance has been observed by many. South of the equator plankton is comparatively more sparse, dwindling in quantity towards the south. It is normally less than 5 ml in areas south of 15°S. The waters along the west coast of Australia have a low plankton biomass as shown by Tranter (1962), but he observed a higher zooplankton biomass on the continental shelf and in the upwelling area, south of Java. In general, a northward increase of plankton is found in the Indian Ocean from 40°S. During the Southwest monsoon period (April to October) in the Arabian Sea the distribution pattern of the plankton biomass was the same during day and night. Higher plankton biomass ranging from 45 to 60 ml per standard haul occurred towards the western half of the Arabian Sea and about 30 ml per haul along the southwest coast of India. Rest of the areas such as the central zone and Gulf of Kutch to Gulf of Cambay and off Gujarat seemed to have a low plankton biomass especially during day time. In general, the plankton volume decreased from the coastal regions to the open sea. Compared to this the plankton biomass during this period in the Bay of Bengal was considerably less and uniformly distributed having only 10 to 20 ml on the average. During the Northeast monsoon period (October-April) the pattern of distribution of plankton in the Arabian Sea was somewhat diffuse, the day time having 10 to 15 ml of plankton per haul, while that of night having 15 to 30 ml per haul. In the Bay of Bengal the average volume varied from 10 to 20 ml per haul, which was not appreciably different from that of the Southwest monsoon period. However the progressively increasing trend in biomass noted towards the northern region in the day time is reversed in the night time.

To summarise, the distribution of zooplankton biomass in the Arabian Sea showed marked variation during the Southwest and Northeast monsoons, whereas in the Bay of Bengal there was no significant variation. Ryther and Menzel (1965) noticed zooplankton blooms often delineated by extremely clear and unproductive water in the Arabian Sea. This extremely patchy distribution is characteristic of Arabian Sea.

Chidambaram and Menon (1945), Subrahmanyam (1959), Bogorov and Rass (1961), Prasad and Nair (1963), Sudarsan (1964), Longhurst (1966), Uda (1966), Panikkar and Jayaraman (1966) and Cushing (1971) studied the relationship between plankton production and fisheries. They concluded that invariably high concentration of fish particularly the pelagic species occur in areas of high plankton production, which in turn will be areas of upwelling or local enrichments in the tropical oceans. There was also a correlation existing between the upwelling and zooplankton biomass. Always the higher plankton biomass was found to be coinciding with peak periods of upwelling. At the same time in certain areas in spite of high velocity of upwelling the plankton biomass did not show proportional increase in volume. This may be attributed to the rocky bottom of the waters of that area. In contrast to the above certain regions of the Indian Ocean as the northern half of the Arabian Sea is characterised by mass mortalities of fish, covering areas about 1,000 km long and 200 km wide (Jones, 1962) resulting from the explosive plankton production (Brongersma-Sanders, 1957). Because of the intensive phytoplankton production, zooplankton increases and fishes move into these regions. This is an indication of the existence of large populations of fish in the Arabian Sea. Phytoplankton is more directly linked to the physical and chemical environment than zooplankton. Changes in the chemical and physical environments are reflected in the phytoplankton population. Since zooplankton is dependent upon phytoplankton for food, its derivatives are to a large extent governed by distribution of phytoplankton. Similarly the distribution of zooplankton controls the fish larvae population too. Blackburn (1965, 1969) have concluded that there is a general relationship between zooplankton abundance and tuna catch.

4. TAXONOMIC FEATURES AND IDENTIFICATION AT SPECIES LEVEL.

4. TAXONOMIC FEATURES AND IDENTIFICATION AT SPECIES LEVEL.

4.1. List of species identified.

The family Scolecithricidae, following Tanaka (1961) is comprised of 9 genera namely *Scottocalanus* Sars, *Scolecocalanus* Farran, *Macandrewella* A. Scott, *Lophothrix* Giesbrecht, *Scaphocalanus* Sars, *Scolecithrix* Brady, *Scolecithricella* Sars, *Amallothrix* Sars and *Racovitzanus* Giesbrecht. Of these, *Scolecocalanus* and *Racovitzanus* were absent in the present collections. Twenty seven species belonging to the remaining 7 genera were identified in this study.

Sub order *Calanoida*

Tribe *Amphaskandria*

Family *Scolecithricidae*

Genus *Scottocalanus*

1. *Scottocalanus securifrons* (T. Scott)
2. *Scottocalanus dauglishi* Sewell
3. *Scottocalanus australis* Farran
4. *Scottocalanus farrani* A. Scott
5. *Scottocalanus persicans* (Giesbrecht)
6. *Scottocalanus thomasi* A. Scott
7. *Scottocalanus helenae* (Lubbock)

Genus *Lophothrix*

8. *Lophothrix frontalis* Giesbrecht
9. *Lophothrix angusta* (Esterly)

Genus *Macandrewella*

10. *Macandrewella cochinensis* Gopalakrishnan

Genus *Scaphocalanus*

11. *Scaphocalanus curtus* (Farran)
12. *Scaphocalanus echinatus* (Farran)
13. *Scaphocalanus longifurca* (Giesbrecht)
14. *Scaphocalanus affinis* (Sars)

Genus *Amallothrix*

15. *Amallothrix indica* Sewell
16. *Amallothrix arcuata* (Sars)

Genus *Scolecithrix*

17. *Scolecithrix danae* (Lubbock)
18. *Scolecithrix nicobarica* Sewell

Genus *Scolecithricella*

19. *Scolecithricella bradyi* (Giesbrecht)
20. *Scolecithricella vitata* (Giesbrecht)
21. *Scolecithricella dentata* (Giesbrecht)
22. *Scolecithricella abyssalis* (Giesbrecht)
23. *Scolecithricella tenuicerrata* (Giesbrecht)
24. *Scolecithricella tropica* Grice

25. *Scolecithricella ctenopus* (Giesbrecht)
26. *Scolecithricella ovata* (Farran)
27. *Scolecithricella marginata* (Giesbrecht)

4.2. Taxonomy and identifying characters.

Sars (1902) set up the families Phaennidae, Scolecithricidae, Diaixidae and Tharybidae for those calanoids previously grouped under the Calanidae, which had the setae of endopod in second maxilla modified into sensory filaments. The Phaennidae and Scolecithricidae were formed from Giesbrecht's (1892) subfamily Scolecithricinae (as Scolecithrichina). Phaennidae was distinct because of the transformation of the setae of the terminal part of the anterior maxillipeds to extremely delicate brush-like appendages (Sars, 1902). In Scolecithricidae these setae were transformed into sensory appendages which were either vermiform or bud-like (Sars, 1902). Head and the first thoracic segment were fused; rostrum, a bifurcate plate with or without two filaments; head sometimes with a crest; thoracic segments 4 and 5 usually fused, in some cases the line of fusion visible and in some cases they are separate; abdomen short; genital segment may project ventrally; antenna 1, 19-23 segmented, fewer segments in male; leg 5 present in female (except in the genus Scolecithrix), uniramous with 2 or 3 segments; male leg 5 asymmetrical, usually biramous on both sides, basipod segments narrow and elongate on left leg, short on right leg with basipod very much swollen.

Genus *Scottocalanus* G.O. Sars, 1905

This genus has been established by Sars (1905 a). Head cristate in both sexes; 5th pair of legs in female 1-jointed with a very long single bristle, apical spines very short when present, 5th pair of legs in male with long basipodite and short rami of very irregular form.

Scottocalanus securifrons (T. Scott)

Scolecithrix securifrons, T. Scott, 1893, p. 47.

Female: (Fig. 1 a) Length, 4.2 mm; head and 1st, 4th and 5th thoracic segments fused; head with a high medium crest, last thoracic segment produced posteriorly into a triangular expansion terminating into a sharp pointed spine on either side; rostrum bifid at the tip (Fig. 1 b). Abdomen 4-segmented. Genital segment swollen ventrally, ventral posterior margin overlaping the following segment. Postero-lateral margins of the genital segment furnished with spines, which are absent on the dorsal and ventral sides. First antenna 23-segmented, reaches up to the posterior tip of the genital segment; 5th pair of legs asymmetrical (Fig. 1 c); apical spines short, subapical spines long and with 2 rows of teeth, that of the left side thicker than that of the right side.

Male: (Fig. 1 e) Length, 4.57 mm. General appearance similar to female. Abdomen 5-segmented. First antenna with 20 segments when the fused 8th to 12th segments are counted as one; 5th leg as illustrated (Fig. 1 f).

Occurrence: 82 males, 199 females and 44 juveniles. Present in 11.2% of the total stations and constituted 0.4% of the total Scolecithricidae.

Scottocalanus dauglishi Sewell

Scottocalanus dauglishi, Sewell, 1929, p.189.

Female: (Fig. 1 d) Length, 4.45 mm. Head and 1st thoracic segment fused, line of fusion visible. Last 2 thoracic segments fused. Rostrum with 2 stout spines. Head with a high medium triangular crest. Postero-lateral margin of the last thoracic segment on either side produced backwards into a rounded lappet. Abdomen 4-segmented; segments 2 and 3 with a row of spines along the posterior margin on the dorsal side. Genital segment swollen ventrally and overlaps the next segment.

Fig. 1.

a. *Scottocalanus securifrons* : Female - Lateral view.
b. " " : Female - Rostrum.
c. " " : Female - Left 5th leg.
d. *Scottocalanus dauglishi* : Female - Lateral view.
e. *Scottocalanus securifrons* : Male - Lateral view.
f. " " : Male - 5th pair of legs.

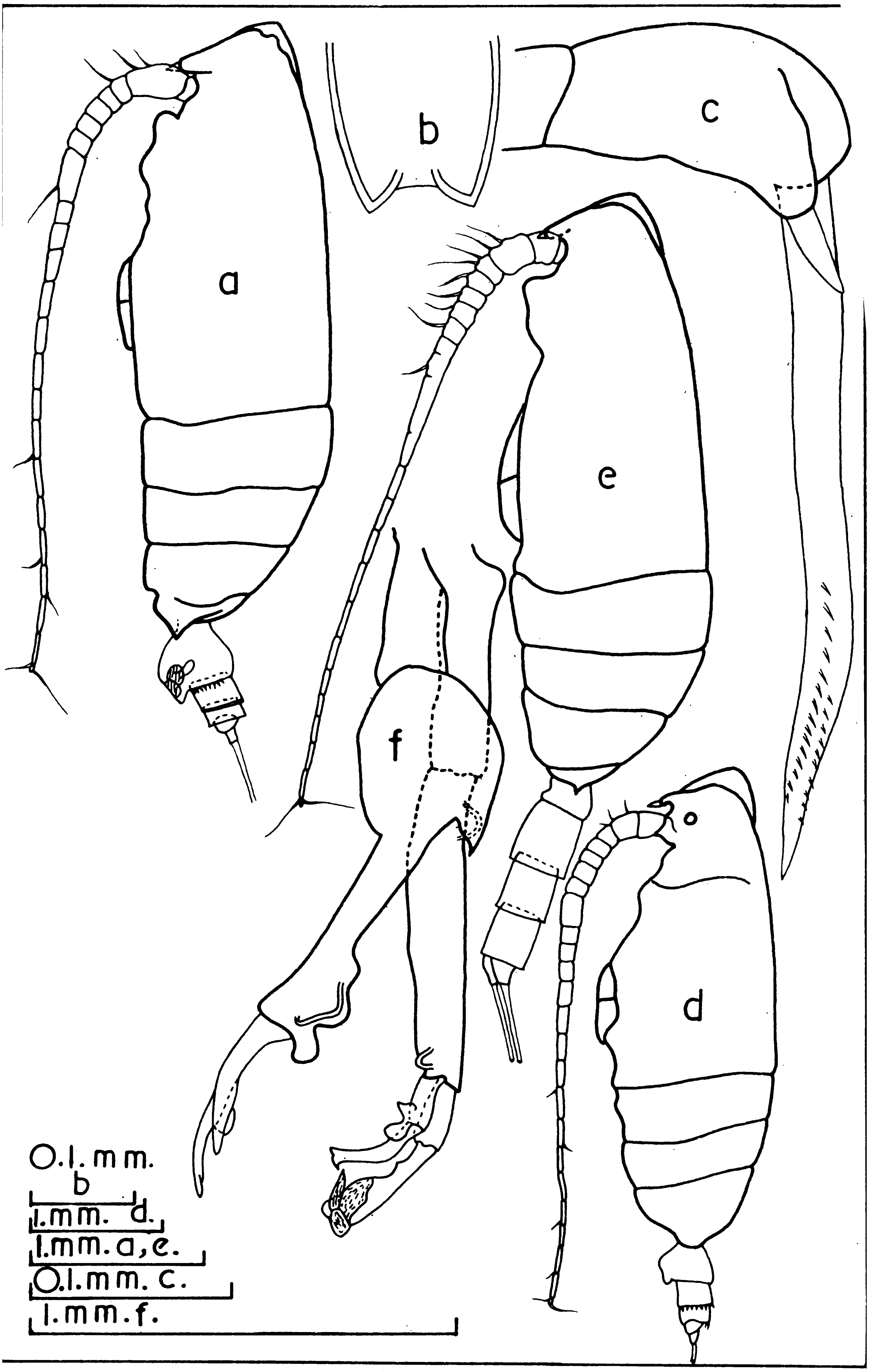


Fig. 1.

First antenna reaches as far back as the end of the furcal ramus, 24-segmented; 5th pair of legs (Fig. 2 a) with a short stout spine and a long subapical spine; subapical spine with 2 rows of spines as shown in Fig. 2 a.

Male: (Fig. 2 b) Length 4.6 mm. In general shape, head and crest resembles female. Abdomen 5-segmented. First antenna reaches beyond the posterior end of the last thoracic segment, 5th pair of legs as illustrated (Fig.2c).

Occurrence: 96 males, 160 females and 108 juveniles. Present in 7.3% of the total stations and constituted 0.5% of the total Scolecithricidae.

Scottocalanus australis Farran

Scottocalanus australis, Farran, 1936, p. 101.

Females: (Fig. 2 d) Length, 3.95 mm. Head and 1st, 4th and 5th thoracic segments fused. Head with a median crest which is low. Postero-lateral cornersof the last thoracic segment produced into rounded lappets as in S. dauglishi, but smaller. Rostral plate deeply notched, rostral spines shorter than the depth of the notch (Fig. 2 e). Abdomen 4-segmented. Genital segment about equal to the 2 following segments, produced ventrally into a small triangle at the genital orifice but not overlapping the following segment. First 3 abdominal segments are fringed with fine spines on the distal margin. First antenna 24-jointed, 8th and 9th segments fused, reaches up to the distal margin of the genital segment. In 5th pair of legs (Fig. 3 a) the terminal joint with an apical spine and a small spine at the base of the apical spine. The subapical spine is 4 times as long as the terminal joint and with 2 rows of fine teeth.

This species is considered as a synonym of S. helenae by Vervoort (1965). The IIOE specimens agree well with the descriptions given by Farran (1936). Hence it is given the status of a distinct species and by doing so this becomes the first record of this species from the Indian Ocean.

Occurrence: 18 females. Present in 1.8% of the total stations and constituted 0.02% of the total Scolecithricidae.

Scottocalanus farrani A. Scott

Scottocalanus farrani, A. Scott, 1909, pp. 106-108.

Female: (Fig. 2 f) Length, 3.6 mm. Head and 1st, 4th and 5th thoracic segments fused. Head with a high median crest. Postero-lateral corners of the last thoracic

Fig. 2.

a. *Scottocalanus dauglishi* : Female - 5th leg.

b. " " : Male - Lateral view.

c. " " : Male - 5th pair of legs.

d. *Scottocalanus australis* : Female - Lateral view.

e. " " : Female - Rostrum.

f. *Scottocalanus farrani* : Female - Lateral view.

g. " " : Female - Rostrum.

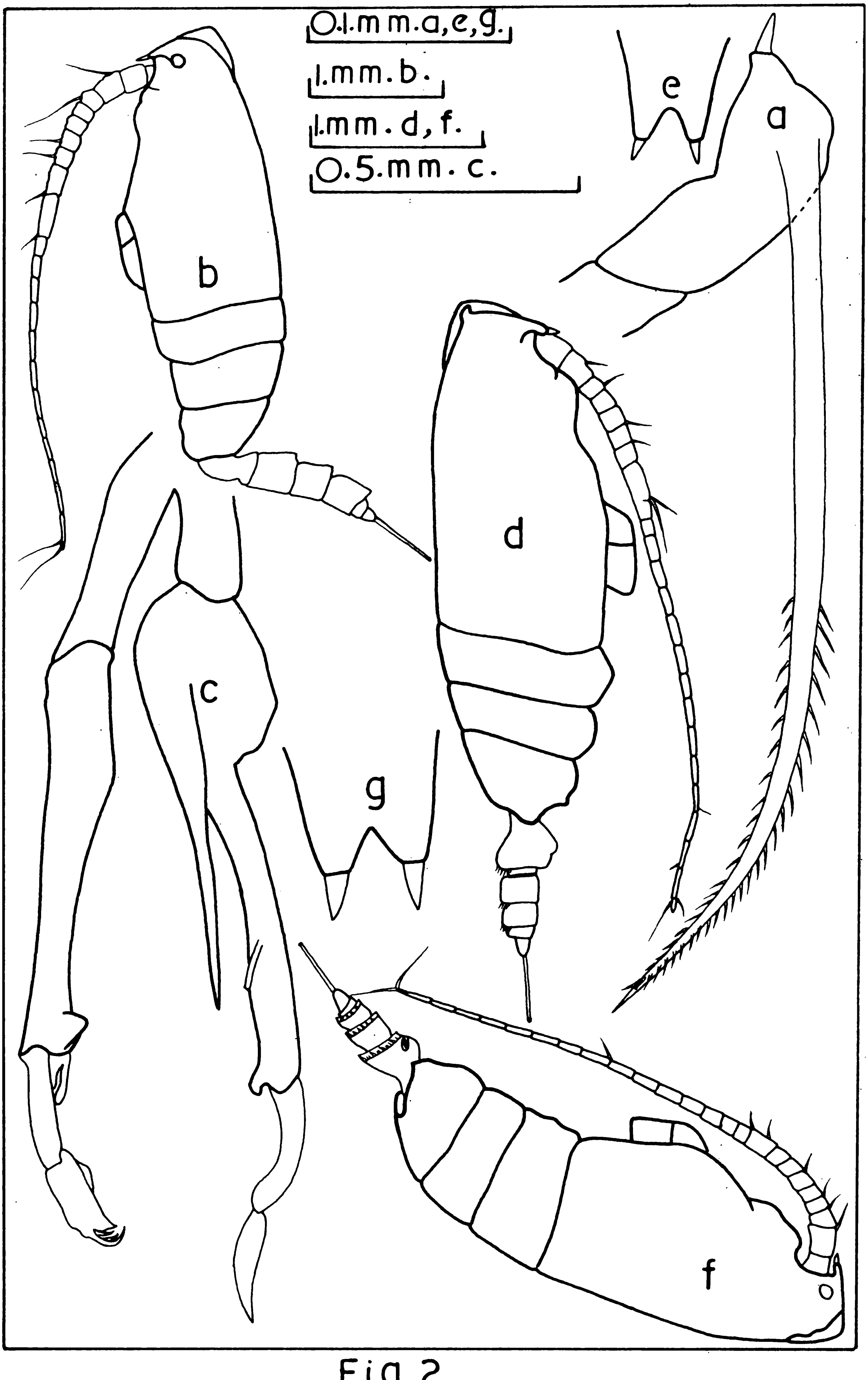


Fig. 2.

segment produced posteriorly into a narrow tip, but with no spines. Rostral spines (Fig. 2 g) equal in length with the depth of the notch. Abdomen 4-segmented. Genital segment almost as long as the combined length of the remaining 3 segments. Ventral side of the genital segment slightly swollen downwards. First antenna 24-segmented, extends up to the tip of the last abdominal segment. In 5th leg (Fig. 3 b), terminal joint slightly concave along the inner margin. Subapical spine 3 times as long as the terminal joint and with the setation as illustrated. Apical spine short and stout.

Male: (Fig. 3 c) Length, 3.65 mm. Line of fusion between the 4th and the 5th thoracic segments clearly visible. Abdomen 5-segmented. First antenna reaches up to the tip of the 3rd abdominal segment, 22-segmented. Fifth leg (Fig. 3 d) distinct in the following characters. Second joint of the basipod of the right foot with a strong tooth along the proximal end of the inner margin, distal inner margin is swollen. Exopod 2-jointed, 1st joint sickle-shaped, 2nd joint lamelliform. Endopod slightly longer than the 2nd joint of the basipod. In the left foot 2nd joint of the exopod with 2 curved spines at the tip.

Occurrence: 45 males, 41 females and 23 juveniles. Present in 2.6% of the total stations and constituted 0.2% of the total Scolecithricidae.

Scottocalanus persecans (Giesbrecht)

Scolecithrix persecans, Giesbrecht, 1895, pp. 253-254.

Female: (Fig. 3 e) Length, 4.25 mm. Head and 1st, 4th and 5th thoracic segments fused. Head with a crest. The rostral filaments are longer than the notch of the rostral plate and they are bifid at the tip (Fig. 3 f). Postero-lateral corners of the last thoracic segments are like small rounded lappets. Abdomen 4-segmented. Small hyaline spines are present along the posterior margin of the genital and 2nd abdominal segment. First antenna 23-segmented and reaches up to the tip of the 2nd abdominal segment. Fifth pair of legs with a strong stout apical spine and a long subapical spine with 2 rows of spinules as in Fig. 4 a.

Male: (Fig. 4 b) Length, 4.6 mm. Line of fusion between the 4th and the 5th thoracic segments visible. Abdomen 5-segmented. Second to 4th abdominal segments with hyalin spines on the posterior margin. Genital asymmetrical on the lateral aspect, with the genital opening on the left

Fig. 3.

a. *Scottocalanus australis* : Female - 5th leg.

b. *Scottocalanus farrani* : Female - 5th leg.

c. " " : Male - Lateral view.

d. " " : Male - 5th pair of legs.

e. *Scottocalanus persecans* : Female - Lateral view.

f. " " : Female - Rostrum.

g. " " : Male - Genital segment - dorsal view.

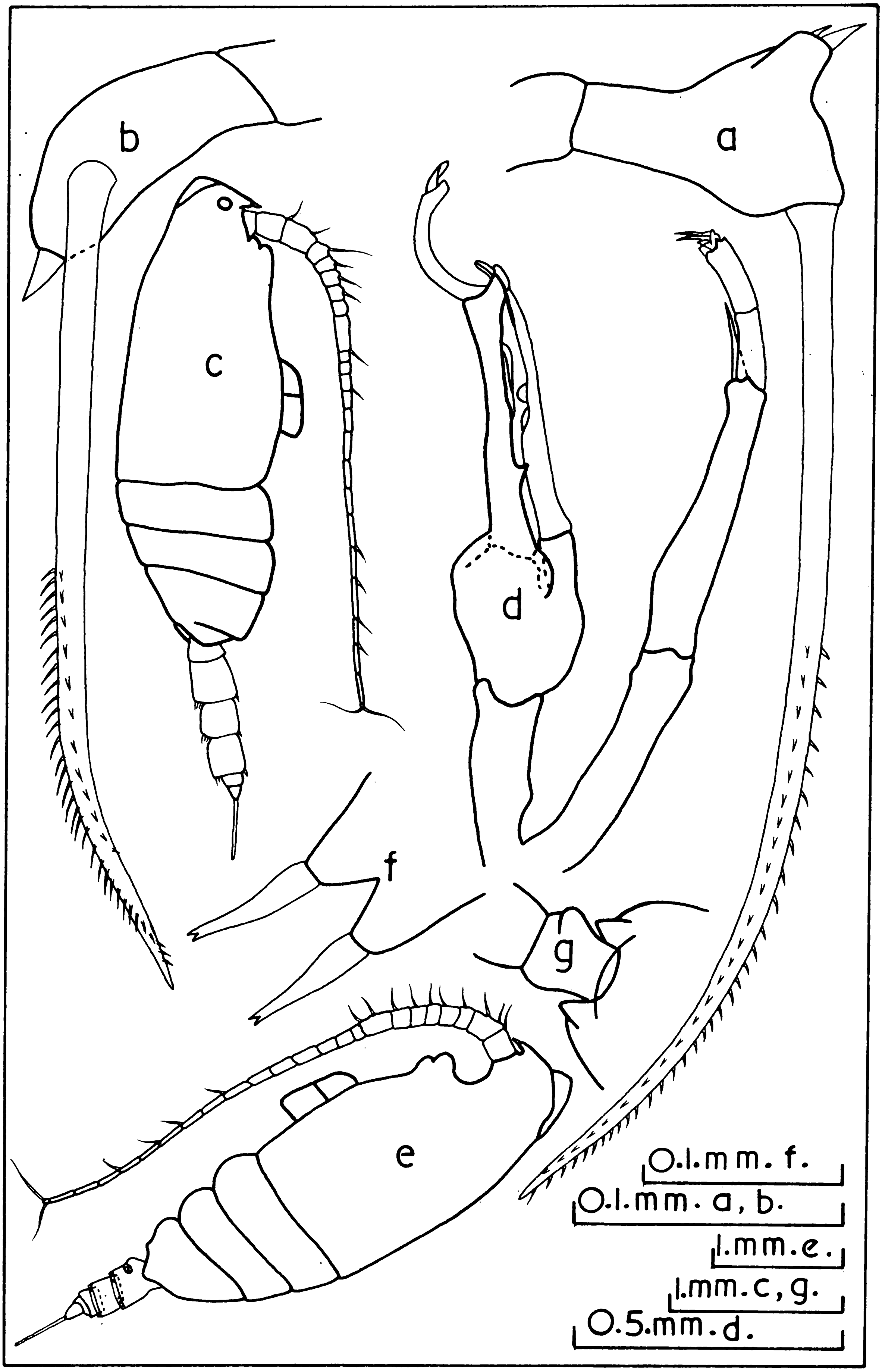


Fig. 3.

side (Fig. 3 g). In 5th leg (Fig. 4 c) right 3rd exppod segment lamelliform. Right endopod 1-segmented, slightly longer than the right 1st segment of exopod. Left endopod 1-segmented and styliform. The structure of the 3rd exopod segment on the left leg as illustrated.

Occurrence: One male and 1 female. Present in 0.3% of the total stations and constituted 0.003% of the total Scolecithricidae.

Scottocalanus thomasi A. Scott

Scottocalanus thomasi, A. Scott, 1909, pp. 109-111.

Female: Head and 1st, 4th and 5th thoracic segments fused. Head with a crest which is characteristic in shape in a lateral view (Fig. 4 d). Postero-lateral corners of the last thoracic segment ends in a small pointed spine. Abdomen 4-segmented. Genital segment swollen on the ventral side (Fig. 4 e). Rostrum with 2 stout short spines which are shorter than the notch of the rostrum (Fig. 4 f). In 5th leg the terminal joint is with a short stout apical spine and a long subapical spine (Fig.4 g). The subapical spine with 2 rows of spinules at the distal two-third length and the arrangement of these spines on the outer margin of the subapical spine as its tip gives the shape of a 'V' as figured by Scott. Since none of the specimens were intact the whole animal could not be drawn.

Occurrence: 17 females and 6 juveniles. Present in 1% of the total stations and constituted 0.03% of the total Scolecithricidae.

Scottocalanus helenae (Lubbock)

Undina halenae, Lubbock, 1856, pp. 25-26.

Female: (Fig. 4 h) Length, 3.5 mm. Head and 1st, 4th and 5th thoracic segments fused, line of fusion between 4th and 5th thoracic segments visible. Head with a median crest. Rostrum with very short stout spines which are shorter than the notch (Fig. 4 i). Postero-lateral corners of the last thoracic segment produced into lappets which are pointed at the tip. Vervoort (1963) has mentioned them as strictly rounded. Abdomen 4-segmented. Genital segment slightly swollen ventrally at proximal part. The abdominal segments are provided with small teeth on the dorsal posterior margin. First antenna 24-segmented. Fifth leg with a common basal portion and a free joint (Fig. 4 j). The free terminal joint with a short apical spine and a long sub-apical spine which is more than 3 times the length of the joint. The sub-apical spine with 2 rows of teeth.

Occurrence: 33 females and 3 juveniles. Present in 2.1% of the total stations and constituted 0.1% of the total Scolecithricidae.

Genus Lophothrix Giesbrecht, 1895

Almost similar to the genus Scottocalanus, with massive bifurcate rostrum. Head with or without crest. Fifth pair of legs with 3 or 4 prominent spines, of which inner most is the longest.

Lophothrix frontalis Giesbrecht

Lophothrix frontalis, Giesbrecht, 1895, pp. 254-255.

Female: (Fig. 4 k) Length, 5.3 mm. Head and 1st, 4th and 5th thoracic segments fused. Head with a median crest. Postero-lateral corners of the last thoracic segment narrowly rounded. Rostrum deeply notched (Fig.4 l), with very small points at the tip. Abdomen 4-segmented. Genital segment with a small ventral swelling. Abdominal segments 1 to 3 with fine teeth on the posterior margin. First antenna with 23 free segments reaches up to the tip of the abdomen. Fifth pair of legs 3-jointed, distal joint with 3 spines in some specimens and with 4 spines on the right leg in some specimens (Fig. 5 a). Three inner spines with spinules on the outer margin and the

Fig. 4.

a. *Scottocalanus persecans* : Female - 5th leg.
b. " " : Male - Lateral view.
c. " " : Male - 5th pair of legs.
d. *Scottocalanus thomasi* : Female - Head lateral view.
e. " " : Female - Posterior end of cephalothorax - Lateral view.
f. " " : Female - Rostrum.
g. " " : Female - 5th leg.
h. *Scottocalanus helenae* : Female - Lateral view.
i. " " : Female - Rostrum.
j. " " : Female - 5th leg.
k. *Lophothrix frontalis* : Female - Lateral view.
l. " " : Female - Rostrum.

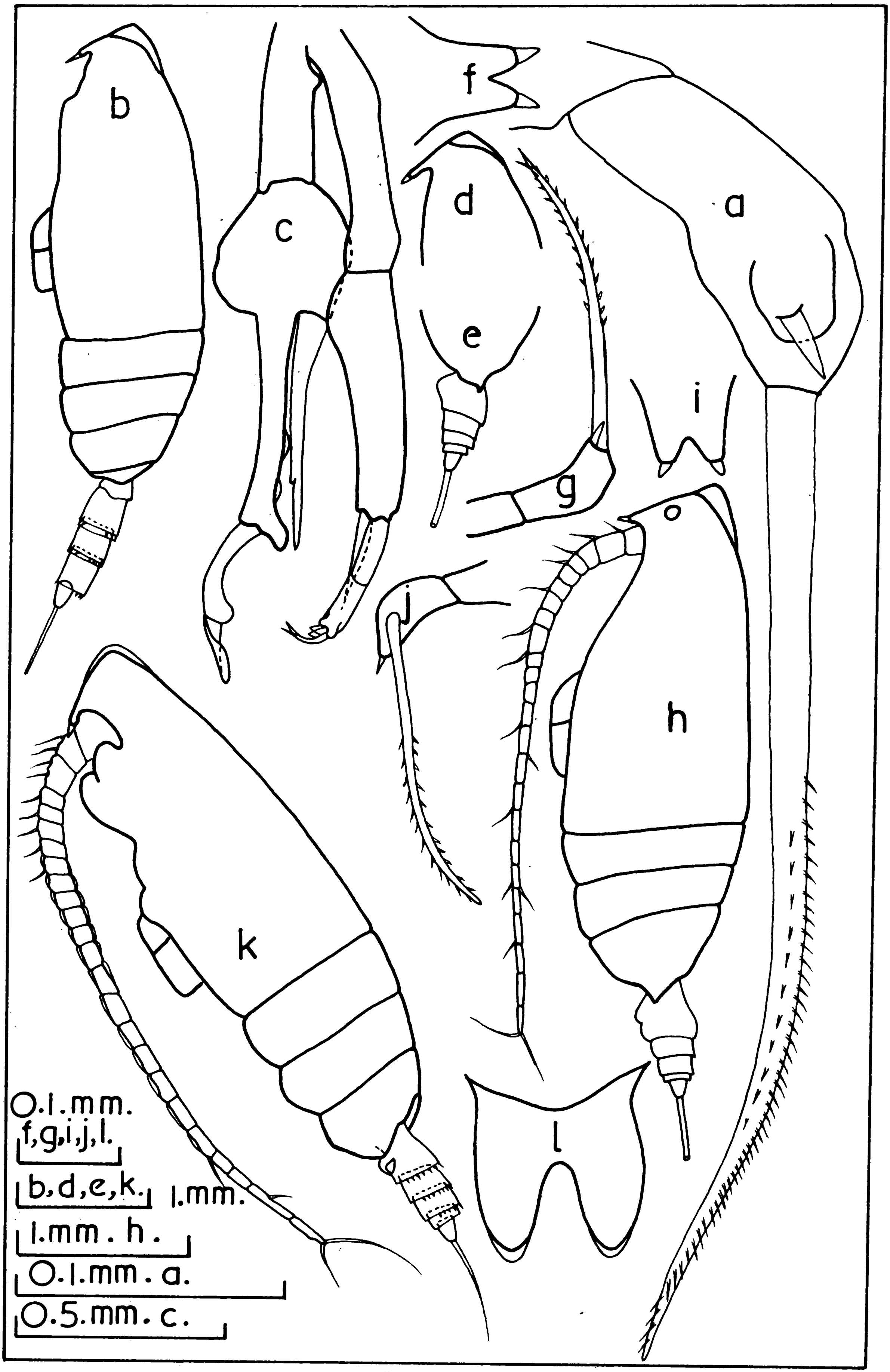


Fig. 4.

outer spine with spinules on outer and inner margins.

Occurrence: 49 females and 23 juveniles. Present in 2.6% of the total stations and constituted 0.1% of the total Scolecithricidae.

Lophothrix angusta (Esterly)

Scolecithrix angusta, Easterly, 1911, pp. 328-329.

Female: (Fig. 5 b) Length, 2.9 mm. Head and 1st thoracic segment fused; 4th and 5th thoracic segments separate. Head with a low median crest. Postero-lateral corners of the last thoracic segment pointed. Below the pointed tip there is a deep notch on either side. Abdomen 4-segmented. Genital segment as long as the total length of the 2nd and 3rd abdominal segments and with a slight ventral swelling. First antenna 23-segmented, reaches up to the posterior end of the genital segment. Fifth leg with 3 spines on the distal joint as illustrated (Fig. 5 c). This species is identical with Lophothrix latipes (T. Scott, 1894).

Occurrence: 501 females and 321 juveniles. Present in 27.5% of the total stations and constituted 1.1% of the total Scolecithricidae.

Genus *Macandrewella* A. Scott, 1909.

A. Scott (1909) established this genus to include the species *Macandrewella jonae* collected by "Siboga" from the Malay Archipelago. The copepod that Giesbrecht (1896) described from Red Sea as *Scolecithrix chelipes* was also included in this genus by Scott. During the course of the present study a number of specimens of both sexes belonging to this genus were obtained. They were different from the 7 known species of the genus and hence described as a new species named *Macandrewella cochinensis*.

Macandrewella cochinensis Gopalakrishnan

Macandrewella cochinensis Gopalakrishnan, 1973, pp.180-18

Female: (Fig. 5 d) Length, 3.15 mm. Head and 1st thoracic segment fused; line of fusion visible laterally. Forehead with a lens-like organ at the base of the rostrum. Fourth and 5th thoracic segments separate. Postero-lateral corners of the last thoracic segment asymmetrical, each side drawn out into a stout curved spine with a distinct tooth at the base. Spine on the left side (Fig. 5 e) longer than the spine on the right side (Fig. 5 f). Abdomen 4-segmented. Genital segment with a ventral backwardly directed protuberance. Posterior margin of 2nd and 3rd abdominal segments with fine spines. First antenna 23-segmented. Leg 5 absent.

Male: (Fig. 5 g) Length, 2.95 mm. Head and 1st thoracic segment fused, with the line of fusion visible laterally. Fourth and 5th thoracic segments separate. Forehead with lens-like organ. Postero-lateral corners of the last thoracic segment symmetrical with stout curved spines. Abdomen 5-segmented. Posterior margin of 2nd, 3rd and 4th abdominal segments with fine spines. Fifth leg as illustrated (Fig. 5 h).

Occurrence: 93 males, 79 females and 5 juveniles. Present in 1% of the total stations and constituted 0.2% of the total Scolecithricidae.

Genus Scaphocalanus Sars, 1900.

Head sometimes with a crest. Rostrum with 2 thin long filaments. First antenna with characteristically flattened proximal part with hyaline fringe. Fifth leg when present in female with long inner spine and 1 or 2 apical spines. Male without crest. Male 5th leg with characteristic sickle-shaped endopod on left leg.

Scaphocalanus curtus (Farran)

Scolecithrix curta, Farran, 1926, pp. 259-260.

Female: (Fig. 6 a) Length, 1.15 mm. Head fused with 1st thoracic segment. Last 2 thoracic segments fused, but the

Fig. 5.

a. *Lophothrix frontalis* : Female - 5th leg.

b. *Lophothrix angusta* : Female - Lateral view.

c. " " : Female - 5th leg.

d. *Macandrewella cochinensis* : Female - Dorsal view.

e. " " : Female - Posterior half - left side.

f. " " : Female - Posterior half - right side.

g. " " : Male - Dorsal view.

h. " " : Male - 5th pair of legs.

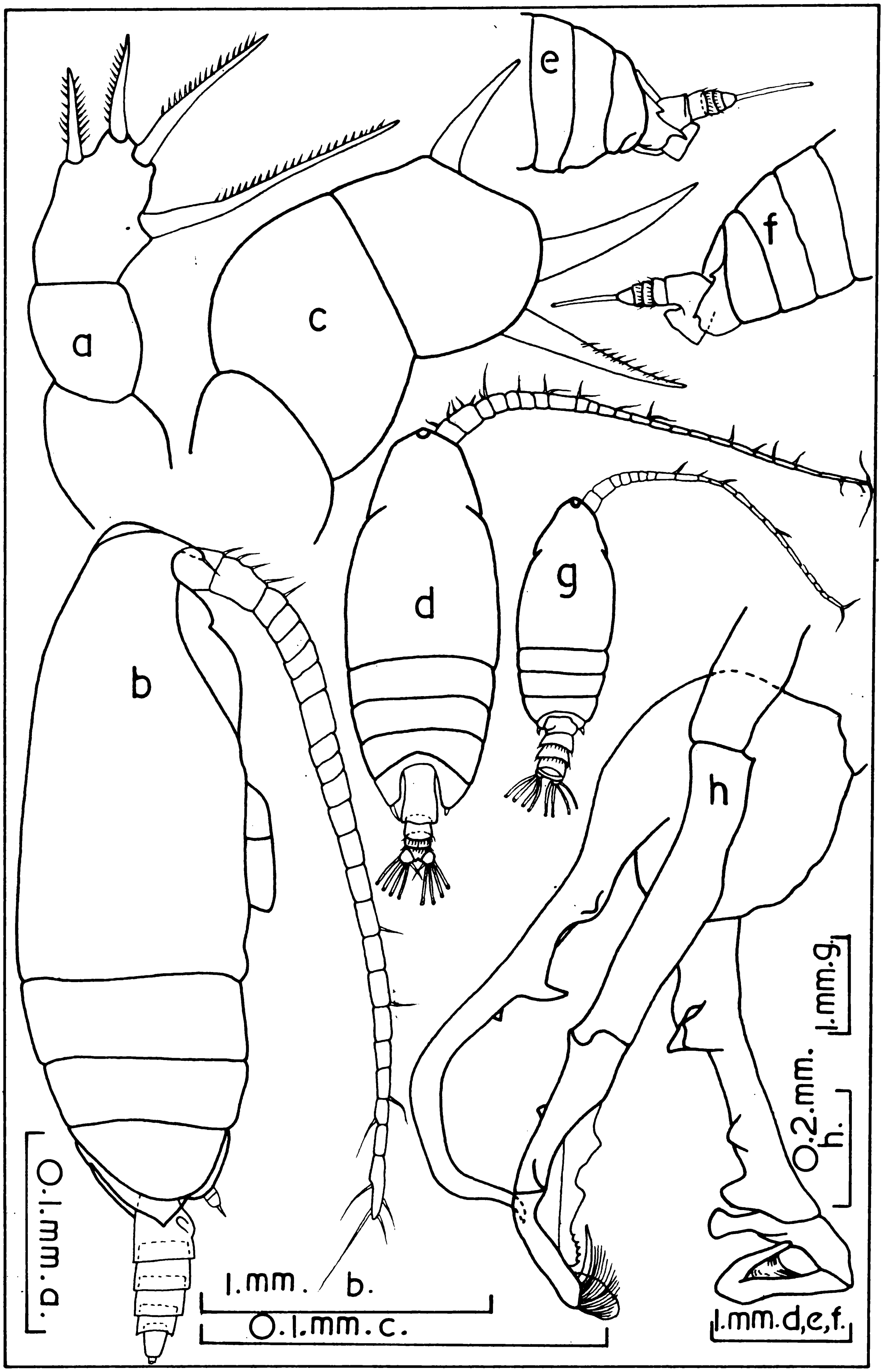


Fig. 5.

line of fusion partially visible. Head with 1st antennae, in a dorsal view, give this species a characteristic shape. Postero-lateral corners of the last thoracic segment angular and blunt. Abdomen 4-segmented. In 1st antenna, proximal part characteristically flattened and with a hyaline fringe (Fig. 6 b). Fifth pair of legs absent.

Male: (Fig. 6 c) Length, 1.4 mm. Abdomen 5-segmented. Fifth pair of legs as illustrated (Fig. 6 d).

Occurrence: 229 males, 1991 females and 239 juveniles. Present in 35.1% of the total stations and constitued 3.4% of the total Scolecithricidae.

Scaphocalanus echinatus (Farran)

Scolecithrix echinata, Farran, 1905, pp. 37-38.

Females: (Fig. 6 e) Length, 1.85 mm. Head and 1st, 4th and 5th thoracic segments fused. Postero-lateral corners of the last thoracic segment rounded. Head ovate, rostral filaments long and slender. Abdomen 4-segmented. First antenna with flattened proximal part having hyaline fringe. Fifth leg (Fig. 6 f) with distinct shape as illustrated. The terminal joint has 3 spines. The inner marginal spine provided with strong minute teeth on its outer margin with which this species can be easily identified.

Occurrence: 2,416 females, 2,142 juveniles. Present in 34.3% of the total stations and constituted 6.2% of the total Scolecithricidae.

Scaphocalanus longifurca (Giesbrecht)

Scolecithrix longifurca, Giesbrecht, 1892, p.266.

Female: (Fig. 6 g) Length, 1.5 mm. Head and 1st, 4th and 5th thoracic segments fused. Postero-lateral corners of the last thoracic segment angular and rounded. Abdomen 4-segmented. Genital segment slightly swollen below at the orifice at about the middle. First antenna 22-segmented and reaches up to the posterior end of the 4th abdominal segment. Fifth leg 2 jointed with 2 spines on the terminal joint (Fig. 6 h) which are provided with spinules.

Male: (Fig. 6 i) Length, 1.45 mm. Head and 1st, 4th and 5th thoracic segments fused. Posterolateral corners of the last thoracic segment rounded. In 5th leg (Fig. 7 a) endopod of the left leg characteristically sickle-shaped, but not as curved as figured by Tanaka (1961).

Occurrence: 13 males, 203 females and 20 juveniles. Present in 2.9E of the total stations and constituted 0.3% of the total Scolecithricidae.

Fig. 6.

a. *Scaphocalanus curtus* : Female - Lateral view.

b. " " : Female - Head with 1st antenna - Dorsal view.

c. " " : Male - Lateral view.

d. " " : Male - 5th leg.

e. *Scaphocalanus echinatus* : Female - Lateral view.

f. " " : Female - 5th leg.

g. *Scaphocalanus longifurca* : Female - Lateral view.

h. " " : Female - 5th leg.

i. " " : Male - Lateral view.

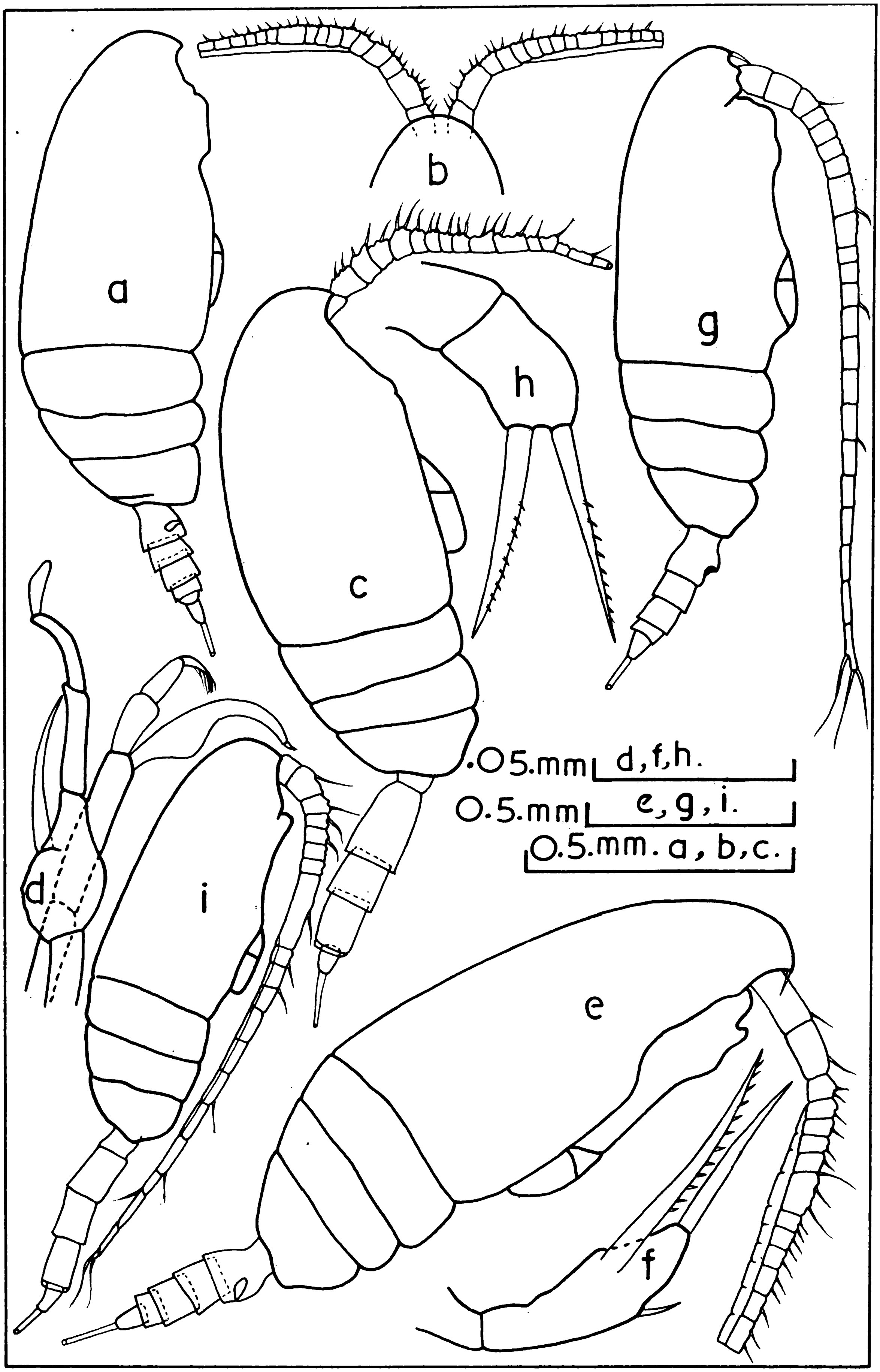


Fig. 6.

Scaphocalanus affinis (Sars)

Amallophora affinis, Sars, 1905, p. 21.

Female: (Fig. 7 b) Length, 3.35 mm. Head and 1st, 4th and 5th thoracic segments fused. Head with a low median crest. Rostrum with 2 long slender filaments. Postero-lateral corners of the last thoracic segment produced into triangular expansions which end in blunt points. Abdomen 4-segmented. Genital segment swollen downwards at the proximal one-third. Fifth leg (Fig. 7 c) 3-jointed. Terminal joint with 4 spines. Inner marginal spine, which is the longest has two spinules on the outer margin. The two outer marginal spines are small.

Occurrence: 44 females and 49 juveniles. Present in 3.9% of the total stations and constituted 0.1% of the total Scolecithricidae.

Genus Amallothrix Sars, 1925

This genus was created by Sars (1925) to include a number of species formerly included in Scolecithrix and Scolecithricella. First swimming leg with an outer edge spine on the proximal joint of the exopodite. In 5th pair of legs in female, spines on the distal joint are shorter, a short apical spine and a longer inner spine are usually present, sometimes a short outer spine also present. Rostrum shorter than in Scaphocalanus.

Amallothrix indica Sewell

Amallothrix indica, Sewell, 1929, pp. 219-221.

Female: (Fig. 7 d) Length, 3.1 mm. Closely resembles *Amallothrix emarginata* (Farran, 1905). Head and 1st, 4th and 5th thoracic segments fused. Line of fusion between 4th and 5th thoracic segments partially visible on the dorsal side. Postero-lateral corners of the last thoracic segment slightly notched. Abdomen 4-segmented. Genital segment swollen downward at the genital orifice. First antenna with 23 separate segments, reaches up to the tip of the 2nd abdominal segment. Terminal joint of the 5th leg (Fig. 7 e) with a short apical spine and an inner marginal spine which is 3 times longer than the apical spine. Both spines are provided with spinules on the outer margin. Eventhough the present specimens are identified as *Amallothrix indica* Sewell (1929), Sewell himself doubts that it may be only a growth stage of *Amallothrix emarginata* (Farran, 1905).

Occurrence: 383 females and 156 juveniles. Present in 8.6% of the total stations and constituted 0.7% of the total Scolecithricidae.

Amallothrix arcuata (Sars)

Scolecithricella arcuata, Sars, 1920, p.10.

Female: (Fig. 7 f) Length, 2.5 mm. Head and 1st, 4th and 5th thoracic segments fused. Postero-lateral corners of the last thoracic segment round, slightly indented, but not as much as in Amallothrix indica. Rostrum deeply notched with 2 short slender filaments (Fig. 8 a). Abdomen 4-segmented. Genital segment slightly swollen downwards. First antenna 23-segmented, reaches up to the posterior margin of the 2nd abdominal segment. In 5th leg (Fig. 8 b) terminal joint with one stout short outer marginal spine, an apical spine which is twice as long as the outer marginal spine and a long inner marginal spine which is more than 4 times the length of the apical spine. Inner marginal spine with spinules on its outer margin.

Occurrence: 13 females. Present in 0.3% of the total stations and constituted 0.02% of the total Scolecithricidae.

Genus Scolecithrix Brady, 1883

This genus once included a large number of species. Sars (1902) divided the group into 2 genera namely Scolecithrix and Scolecithricella. In the former 5th pair of legs is completely absent in the female and in the latter it is present in the female. Sars (1925)

Fig. 7.

a. *Scaphocalanus longifurca* : Male - 5th pair of legs.
b. *Scaphocalanus affinis* : Female - Lateral view.
c. " " : Female - 5th leg.
d. *Amallothrix indica* : Female - Lateral view.
e. " " : Female - 5th leg.
f. *Amallothrix arcuata* : Female - Lateral view.

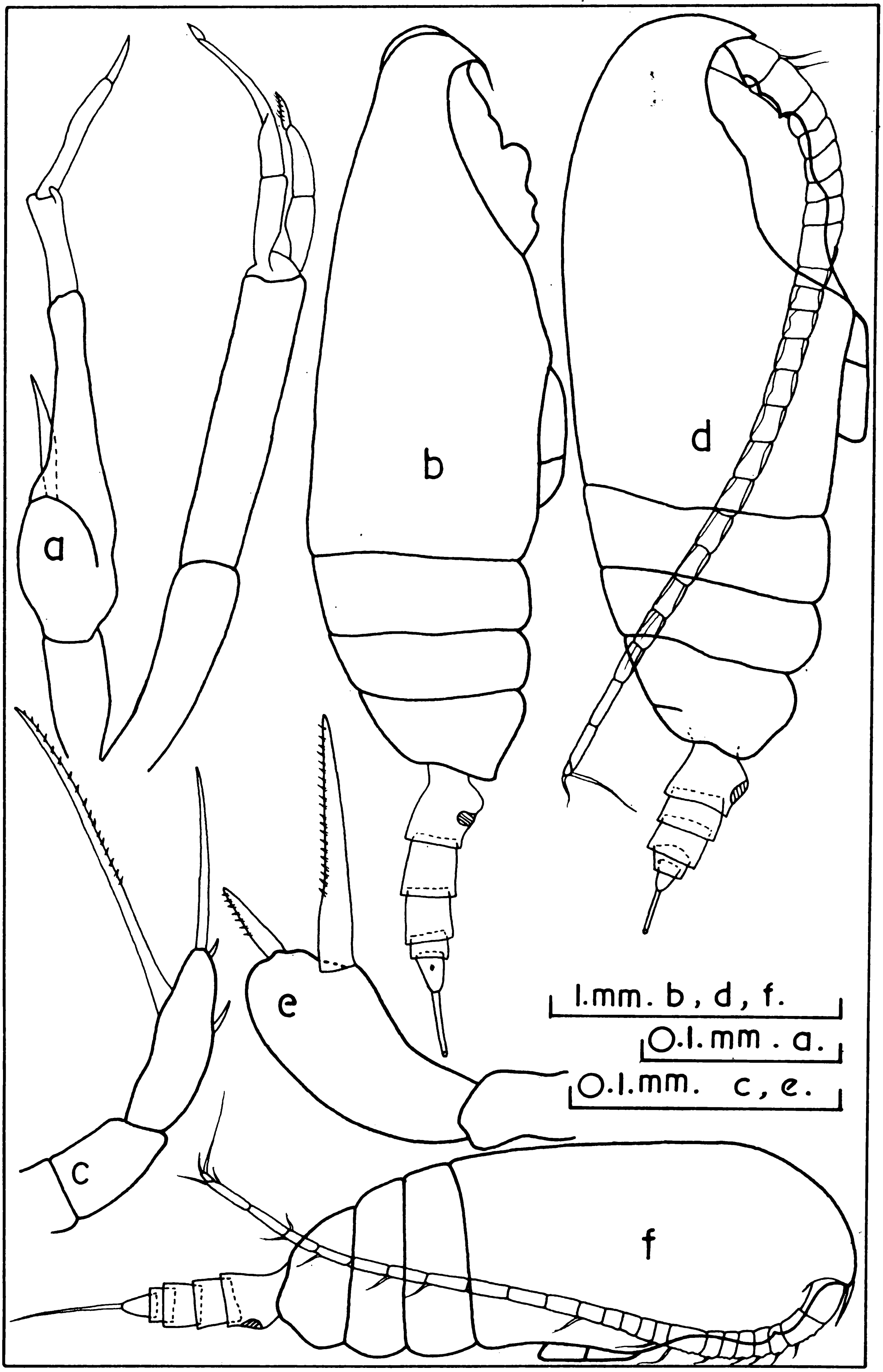


Fig. 7.

further divided Scolecithricella into Amallothrix in which female 5th leg segments are cylindrical and Scolecithricella in which the terminal segment of the 5th leg in female is lamelliform. In the genus Scolecithrix 5th pair of legs is totally absent in female and in male it is massive.

Scolecithrix danae (Lubbock)

Undina danae, Lubbock, 1856, pp. 21-23.

Female: (Fig. 8 c) Length, 2.0 mm. This species can be very easily identified by its characteristic robust nature. Head fused with the 1st thoracic segment. Fourth and 5th thoracic segments separate. Postero-lateral corners of the last thoracic segment produced into rounded lappets. Abdomen 4-segmented. Genital segment with a shovel-like process on the ventral side. First antenna 19-segmented, reaches up to the posterior end of the last thoracid segment. Fifth pair of legs absent.

Male: (Fig. 8 d) Length, 2.2 mm. In general appearance like the female. In 5th leg (Fig. 8 e) joints are very stout and massive. It has its characteristic shape.

Occurrence: This was the most dominent species in the present collections, present in almost all samples. 10,485 males, 15,727 females and 17,475 juveniles. Present in 82.3% of the total stations and constituted 59.7% of the total Scolecithricidae.

Scolecithrix nicobarica Sewell

Scolecithrix nicobarica, Sewell, 1929, pp. 209-211.

Female: (Fig. 8 f) Length, 1.35 mm. Head and 1st, 4th and 5th thoracic segments fused. Postero-lateral corners of the last thoracic segment rounded and slightly indented. Abdomen 4-segmented. Genital segment not swollen below. First antenna 20-segmented, reaches beyond the last thoracic segment. Fifth pair of legs totally absent.

Male: (Fig. 9 a) Length, 1.35 mm. Heed and 1st, 4th and 5th thoracic segments fused. First antenna 18-jointed. In 5th leg (Fig. 8 g) endopod of left leg very small, exopod 3-jointed, the distal joint of which carries a thin lamellous plate. The distal segment of the exopod of the right leg very slender.

Occurrence: 56 males, 808 females and 317 juveniles. Present in 19.5% of the total stations and constituted 1.6% of the total Scolecithricidae.

Fig. 8.

a. *Amallothrix arcuata* : Female - Rostrum
b. " " : Female - 5th leg.
c. *Scolecithrix danae* : Female - Lateral view.
d. " " : Male - - Lateral view.
e. " " : Male - 5th pair of legs.
f. *Scolecithrix nicobarica* : Female - Lateral view.
g. " " : Male - 5th pair of legs.

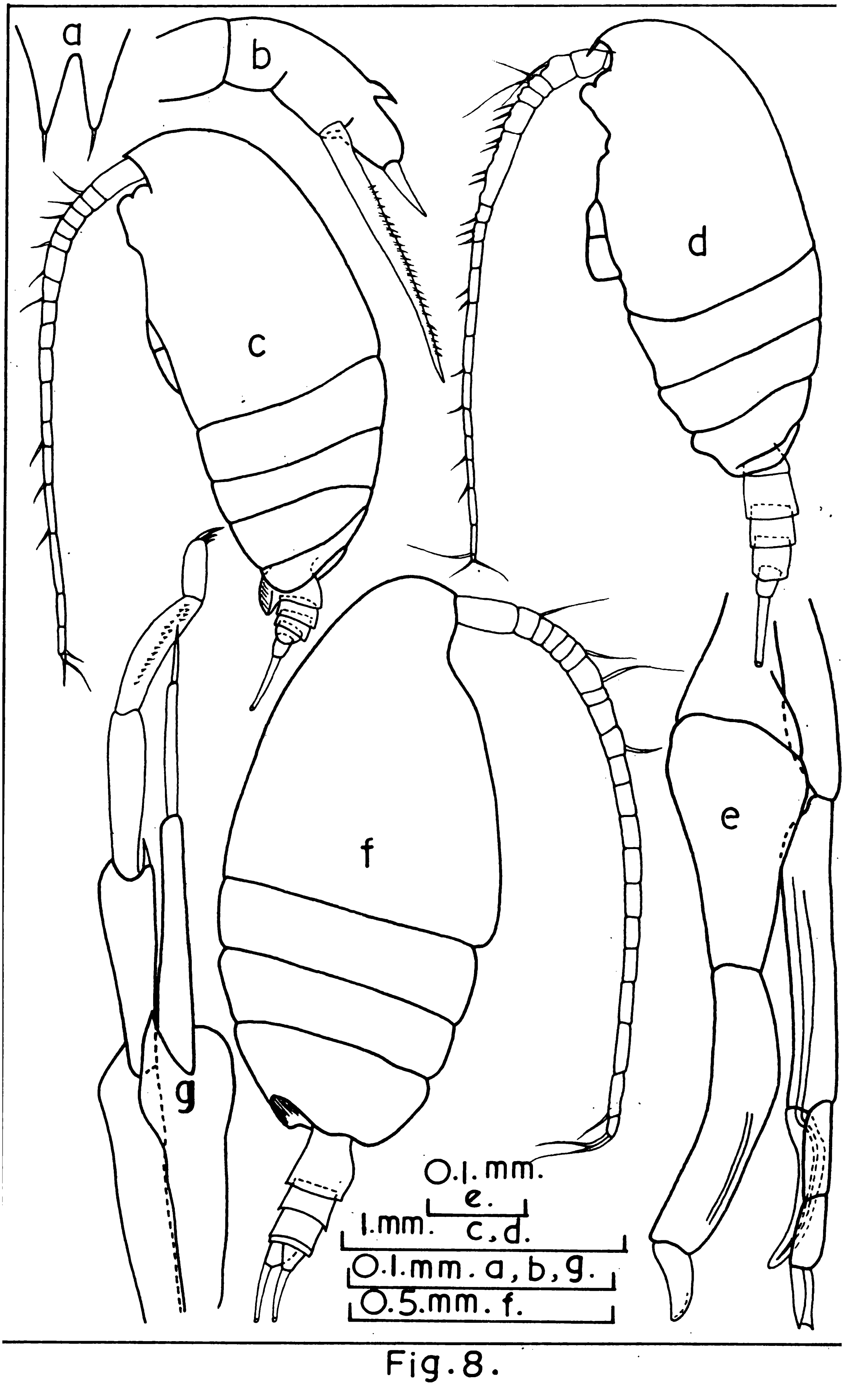


Fig. 8.

Genus *Scolecithricella* Sars, 1903

In this genus 5th pair of legs present in female, 1-jointed, flat, lamelliform and with short spines. Head without crest. Cephalothorax short, wide and usually convex.

Scolecithricella bradyi (Giesbrecht)

Scolecithrix bradyi Giesbrecht, 1892, p. 266.

Female: (Fig. 9 b) Length, 1.2 mm. This species can be very easily identified by its characteristic general appearance. Head and last thoracic segment fused. Last 2 thoracic segments separate. Postero-lateral corners of the 1st thoracic segment narrowly rounded, the one on the right side is more produced posteriorly thereby making the last thoracic segment asymmetrical (Fig. 9 c). Rostrum prolonged and with fine filaments (Fig. 9 d). Abdomen 4-segmented. The genital segment along its lateral margin on the left side is swollen. First antenna 19-segmented and reaches the tip of the last thoracic segment. Fifth leg highly reduced and asymmetrical (Fig. 9 e).

Male: (Fig. 9 f) Length, 1.42 mm. Head and 1st thoracic segment fused. Last two thoracic segments separate. In 5th leg (Fig. 9 g) right endopod is reduced, terminal

Fig. 9.

a. *Scolecithrix nicobarica* : Male - Lateral view.

b. *Scolecithricella bradyi* : Female - Lateral view.

c. " " : Female - Posterior aspect.
Dorsal view.

d. " " : Female - Rostrum.

e. " " : Female - 5th pair of legs.

f. " " : Male - Lateral view.

g. " " : Male - 5th pair of legs.

h. *Scolecithricella vitata* : Female - Lateral view.

i. " " : Female - 5th leg.

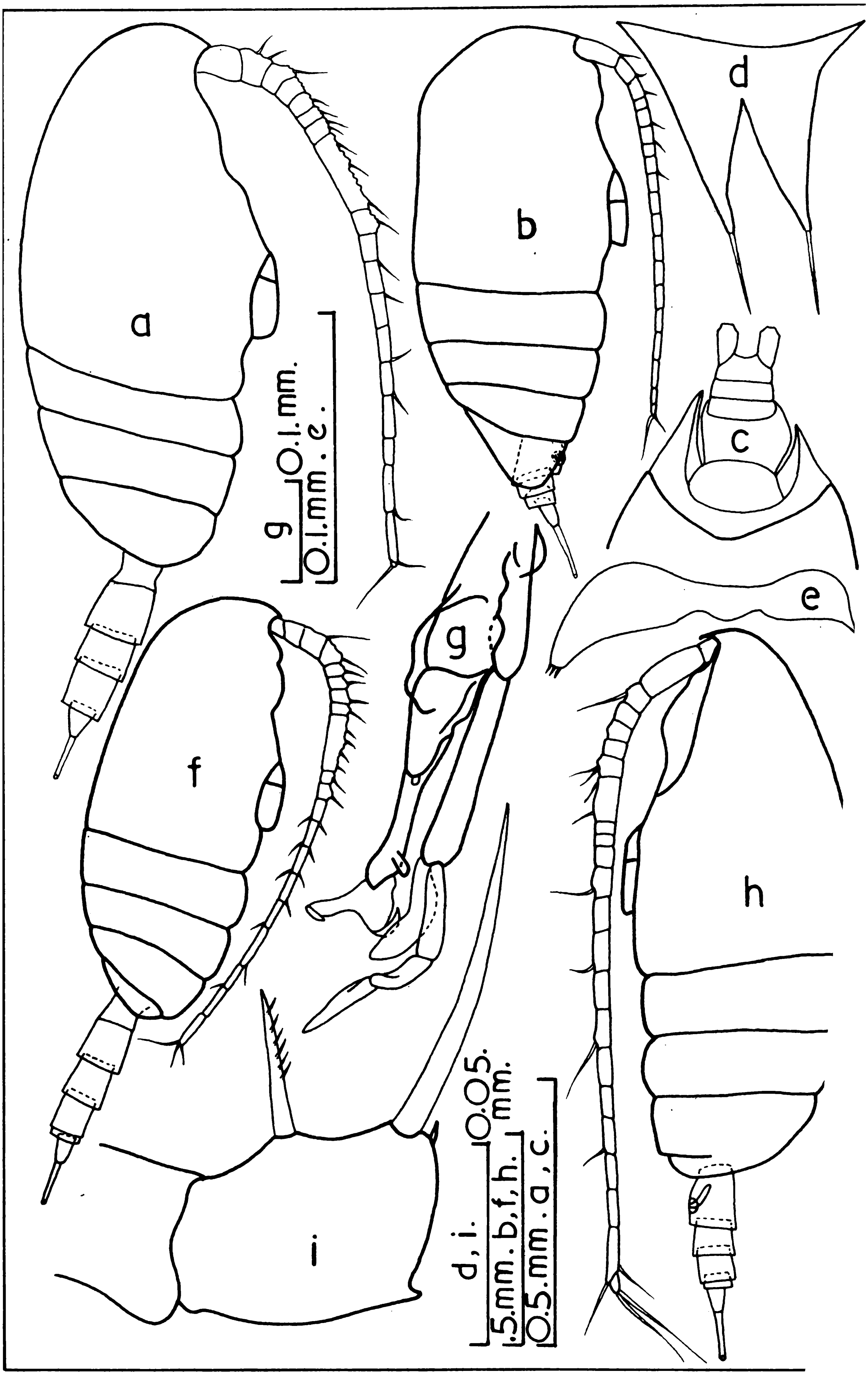


Fig. 9.

segment of the exopod is forked. In left leg endopod is broad. Exopod 3-segmented.

Occurrence: 804 males, 2,649 females and 1,278 juveniles. Present in 63.6% of the total stations and constituted 6.5% of the total Scolecithricidae.

Scolecithricella vitata (Giesbrecht)

Scolecithrix vitata, Giesbrecht, 1892, p. 266.

Female: (Fig. 9 h) Length, 1.65 mm. Head and 1st, 4th and 5th Thoracic segments fused. Line of fusion between 4th and 5th thoracic segments visible. Postero-lateral corners of the last thoracic segment broadly rounded. Abdomen 4-segmented. Genital segment not swollen below. First antenna reaches up to the caudal furca. Fifth leg (Fig. 9 i) single jointed, flat, with a long apical spine. At the base of the apical spine there is a short spine.

Male: (Fig. 10 a) Length, 1.64 mm. Head and 1st, 4th and 5th thoracic segments fused. In 5th leg (Fig. 10 b) 2nd segment of the exopod of the right leg with 2 protuberances, one on the middle and the other near the dista end. Third segment ends up in a bud-like structure. In left leg endopod is slightly longer than the 1st joint of the exopod.

Occurrence: 9 males, 275 females and 91 juveniles. Present in 17.1% of the total stations and constituted 0.5% of the total Scolecithricidae.

Scolecithricella dentata (Giesbrecht)

Scolecithrix dentata, Giesbrecht, 1892, p.266.

Female: (Fig. 10 c) Length, 1.35 mm. Head and 1st, 4th and 5th thoracic segments fused. Line of fusion in both cases visible. Postero-lateral corners of the last thoracic segment broadly rounded. Rostrum deeply notched and filaments are shorter than the notch (Fig. 10 d). Abdomen 4-segmented. Genital segment not swollen below. First antenna 23-segmented, extends up to the tip of the last thoracic segment. Fifth leg 1-jointed, plate-like (Fig. 10 e). Apical spine and inner marginal spine are short and stout, inner marginal spine the largest.

Male: In general appearance like the female. In 5th leg (Fig. 10 f) right endopod is very short, terminal segment of the exopod with a small spine at the tip. In left leg endopod is slightly shorter than the 1st joint of the exopod, 2nd and 3rd segments of the exopod with fine hairs.

Occurrence: 161 males, 1,609 females and 912 juveniles. Present in 34% of the total stations and constituted 3.7% of the total Scolecithricidae.

Scolecithricella abyssalis (Giesbrecht)

Scolecithrix abyssalis, Giesbrecht, 1892, p.266.

Female: (Fig. 11 a) Length, 1.8 mm. Head and 1st, 4th and 5th thoracic segments fused. Posterolateral corners of the last thoracic segment broadly rounded. Abdomen 4-segmented. Genital segment not swollen below. First antenna 22-segmented, reaches up to the caudal furca. Fifth leg (Fig. 11 b) single jointed, plate-like. Apical spine and inner marginal spine short and stout, of the two inner marginal spine is the largest.

Occurrence: 1,688 females and 922 juveniles. Present in 43.4% of the total stations and constituted 3.6% of the total Scolecithricidae.

Scolecithricella tenuiserrata (Giesbrecht)

Scolecithrix tenuiserrata, Giesbrecht, 1892, p.266.

Female: (Fig. 10 g) Length, 1.1 mm. Head and 1st, 4th and 5th thoracic segments fused. Postero-lateral corners of the last thoracic segment angular. Abdomen 4-segmented. Genital segment not swollen below. First antenna 19-segmented, reaches up to the tip of the genital segment. Fifth leg 1-jointed (Fig. 10 h). As agianst the plate-like structure of the female 5th leg in the genera, in

Fig. 10.

a. *Scolecithricella vitata* : Male - Lateral view.

b. " " : Male - 5th pair of legs.

c. *Scolecithricella dentata* : Female - Lateral view.

d. " " : Female - Rostrum.

e. " " : Female - 5th leg.

f. " " : Male - 5th pair of legs.

g. *Scolecithricella tenuiserrata* : Female - Lateral view

h. " " : Female - 5th leg.

i. " " : Male - 5th pair of legs.

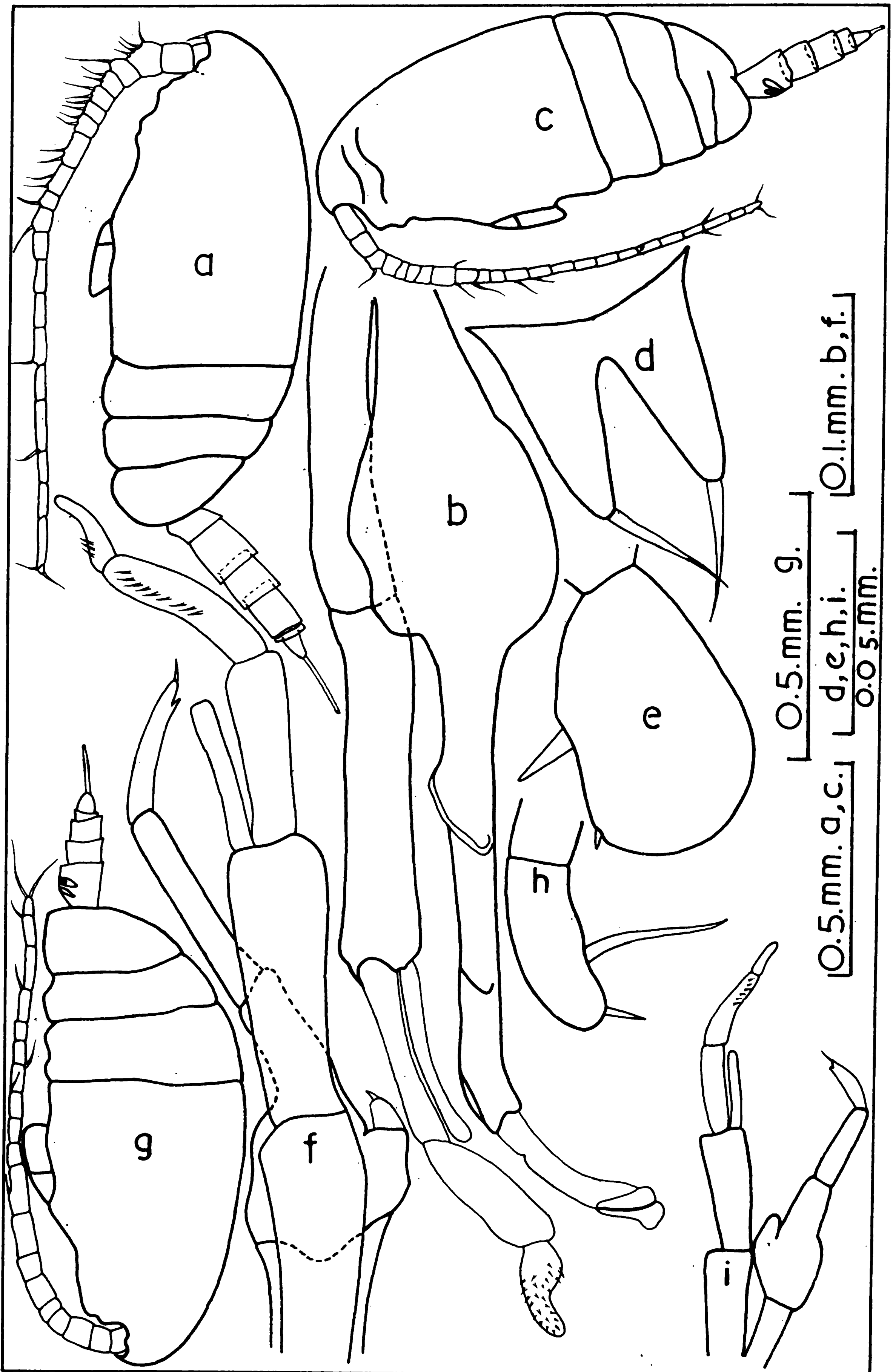


Fig. 10.

this case the joints are slightly cylindrical. One small apical spine and a long inner marginal spine on the terminal joint. In male 5th leg (Fig. 10 i) endopod of right leg is very small. Distal segment of exopod is transformed into a short spine. Endopod of the left leg slightly smaller than the 1st joint of the exopod. Exopod 3-segmented. Second segment with small hairs at the distal end. Third segment very small.

Occurrence: 134 males, 2,818 females and 234 juveniles. Present in 49.1% of the total stations and constituted 4.4% of the total scolecithricidae.

Scolecithricella tropica Grice

Scolecithricella tropica, Grice, 1962, p. 211.

Female: (Fig. 11 c) Length, 1.2 mm. Head and 1st, 4th and 5th thoracic segments fused. Postero-lateral corners of the last thoracic segment narrowly rounded and notched. In 5th leg (Fig. 11 d) joints are slightly cylindrical. Terminal segment with 2 approximately equal spines, which are with fine spinules on the outer margin. The similarities between *S. tropica* and *S. beata* (Tanaka, 1962) are so obvious that the existence of the latter as a distinct species becomes doubtful. It can be considered as a synonym of *S. tropica*.

Fig. 11.

a. *Scolecithricella abyssalis* : Female - Lateral view.

b. " " : Female - 5th leg.

c. *Scolecithricella tropica* : Female - Lateral view.

d. " " : Female - 5th leg.

e. *Scolecithricella ctenopus* : Female - Lateral view.

f. " " : Female - 5th leg.

g. " " : Male - 5th pair of legs.

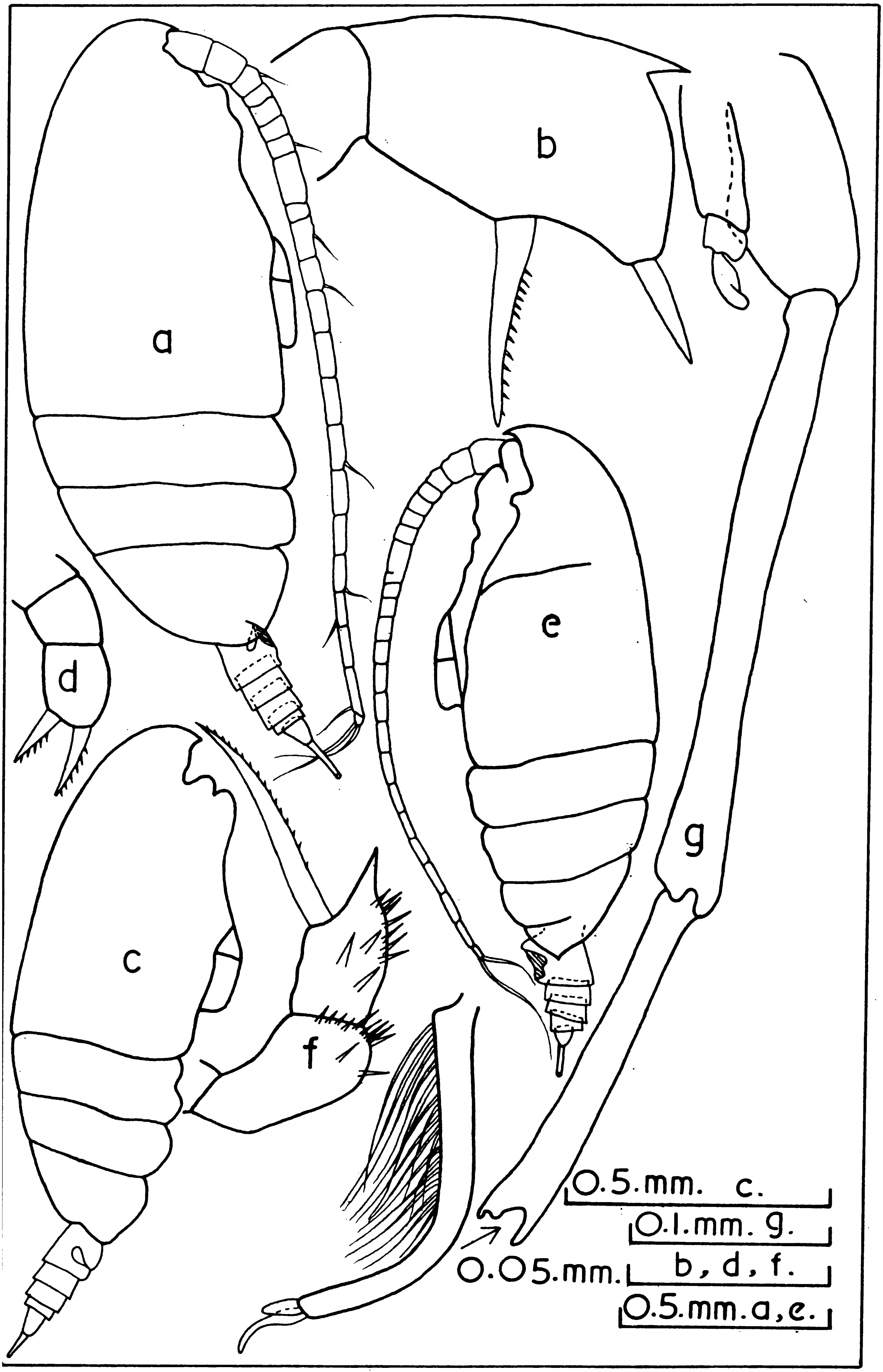


Fig. 11.

Occurrence: 95 females. Present in 3.1% of the total stations and constituted 0.1% of the total Scolecithricidae.

Scolecithricella ctenopus (Giesbrecht)

Scolecithrix ctenopus, Giesbrecht, 1892, p.266.

Female: (Fig. 11 e) Length, 1.45 mm. Head and 1st, 4th and 5th thoracic segments fused. Line of fusion in both cases clearly visible. Postero-lateral corners of the last thoracic segment produced into small pointed spines. Abdomen 4-segmented. Genital segment swollen on the ventral side. First antenna 23-segmented, extends up to the posterior end of the abdomen. Fifth leg with 2 free joints. The terminal segment ends in a strong spine, with an inner marginal spine which has got spinules on the outer margin. Both the joints are provided with spinules on the surface and are slightly cylindrical as against the usual plate-like nature in the genus (Fig.11 f).

Male: (Fig. 12 a) Length, 1.53 mm. Head and 1st thoracic segment fused. Fourth and 5th Thoracic segments separate. Postero-lateral corners of the last thoracic segment not pointed. First antenna 20-segmented. Fifth leg (Fig.11 g) with characteristic shape. Right leg very small. Left leg is very long and slender, without endopod, distal segment with 2 apical spines, of which outer one is long and curved. Distal segment bent at the middle and the proximal portion with a row of spines which is comb-like.

Occurrence: 1,191 males, 2,238 females and 310 juveniles. Present in 31.7% of the total stations and constituted 5.1% of the total Scolecithricidae.

Scolecithricella ovata (Farran)

Scolecithrix ovata, Farran, 1905, p.37.

Female: (Fig. 12 b) Length, 1.7 mm. Head and 1st, 4th and 5th thoracic segments fused. Postero-lateral corners of the last thoracic segment rounded and slightly indented. Abdomen 4-segmented. Genital segment slightly swollen below. First antenna reaches up to the posterior end of the abdomen. Fifth leg (Fig. 12 c) oval in outline, plate-like, with a strong inner marginal spine and an apical spine which is smaller.

Occurrence: 250 females and 66 juveniles. Present in 14.3% of the total stations and constituted 0.4% of the total Scolecithricidae.

Scolecithricella marginata (Giesbrecht)

Scolecithrix marginata, Giesbrecht, 1892, p. 266.

Female: (Fig. 12 d) Length, 1.0 mm. Head and 1st thoracic segment fused. Fourth and 5th thoracic segments separate. Postero-lateral corners of the last thoracic segment rounded. Abdomen 4-segmented. Genital segment slightly swollen on the ventral side. First antenna 18-segmented and reaches up to the end of the cephalothorax. Fifth leg (Fig. 12 e) highly reduced, segments slightly cylindrical. Free joint with a very small outer marginal spine, slightly longer apical spine and still longer and stouter inner marginal spine. The inner marginal spine is with spinules on the outer margin.

Occurrence: 707 females and 14 juveniles. Present in 13.8% of the total stations and constituted 1% of the total Scolecithricidae.

As all these species were already described by previous authors elsewhere, the illustrations and descriptions were done here only briefly, restricting them to the general appearance and the structure of the 5th pair of legs in male and female; and other important characters with which they can be easily identified.

Fig. 12.

a. *Scolecithricella ctenopus* : Male - Lateral view.

b. *Scolecithricella ovata* : Female - Lateral view.

c. " " : Female - 5th leg.

d. *Scolecithricella marginata* : Female - Lateral view.

e. " " : Female - 5th leg.

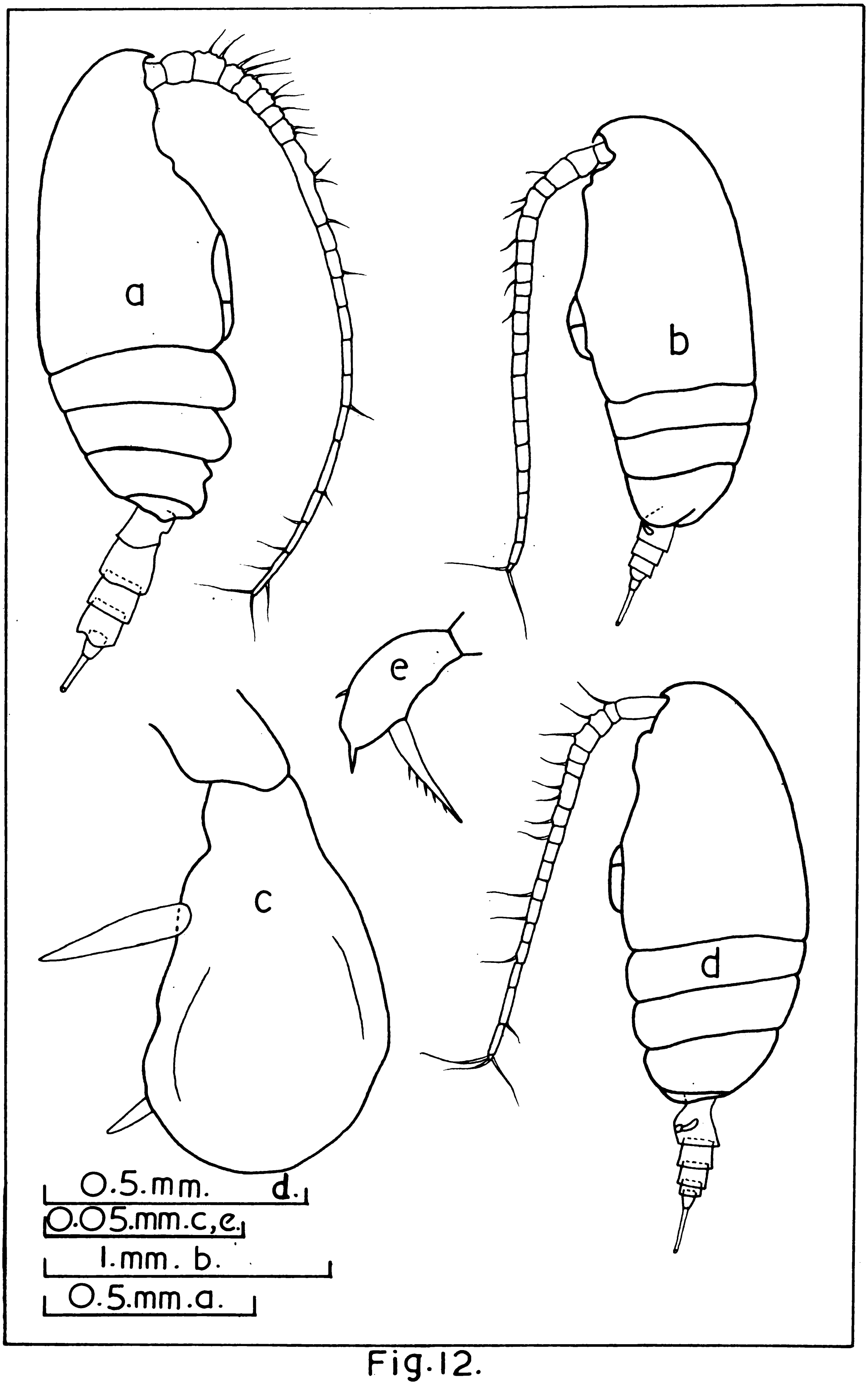


Fig.12.

5. ZOOGEOGRAPHY AND DIVERSITY.

5. ZOOGEOGRAPHY AND DIVERSITY.

5.1. Species-wise distribution.

Distribution of total Scolecithricidae.

Total distribution comprising of 27 species of Scolecithricidae identified from 385 stations sampled during IIOE from 1960-1965 is shown in Figure 13. The 27 species included nonmigrant species such as *S. viata* and *M. cochinensis*, near surface inhabitants those which undergo extensive migration such as *S. ovata*, *S. dentata*, *L. frontalis* and *S. securifrons* which are inhabitants of mid, intermediate and deep water and few undergoing reverse migrations like *S. danae* and *S. bradyi* which are surface inhabitants.

Areas with highest density of more than 800 specimens/haul were located as patches only along the African coast off Mozambique in the Mozambique Channel, in offshore areas of Somalia extending far off upto 60°E meridian and along the offshore areas of Arabian coast, along 80°E meridian in the mid ocean waters, along Java coast and along west coast of Australia. A continuous area along African and Arabian coast as noted for total copepods was not seen. High density areas with 201-800/haul were also confined as large patches along African coast from Port Elizabeth to northern tip of Mozambique, from Zanzibar to Ras Hafun, extending upto 60°E meridian, in Gulf of Aden and along northeast coast of Arabia extending to central Arabian Sea, in the mid ocean waters along 80°E meridian upto 10°S and along east coast of Indian Ocean from northern waters of Bay of Bengal to northern coast of Australia extending to Timor Sea. Thus the areas of abundance were mainly confined to western boundary currents and to a large extent with the eastern boundary currents. Also they were present along the mid ocean waters on either side of equator.

The low density areas of 51-200/haul occupied vast areas of Indian Ocean limit bounded at south by the 20°E parallel in the oceanic areas. Boundary currents extended the low density areas to farther south along west and east coasts of Indian Ocean. Very low density areas having upto 50 specimens/haul occupied as patches in the northern Arabian Sea and northeastern Bay of Bengal and in the entire subtropical zone. From the distribution it appeared to be a tropical circumglobal group having gone flow along South African coast and Indo-Pacific waters.

Fig. 13 a. Distribution of total Scolecithricidae in the Indian Ocean. Density distribution (in nos.).

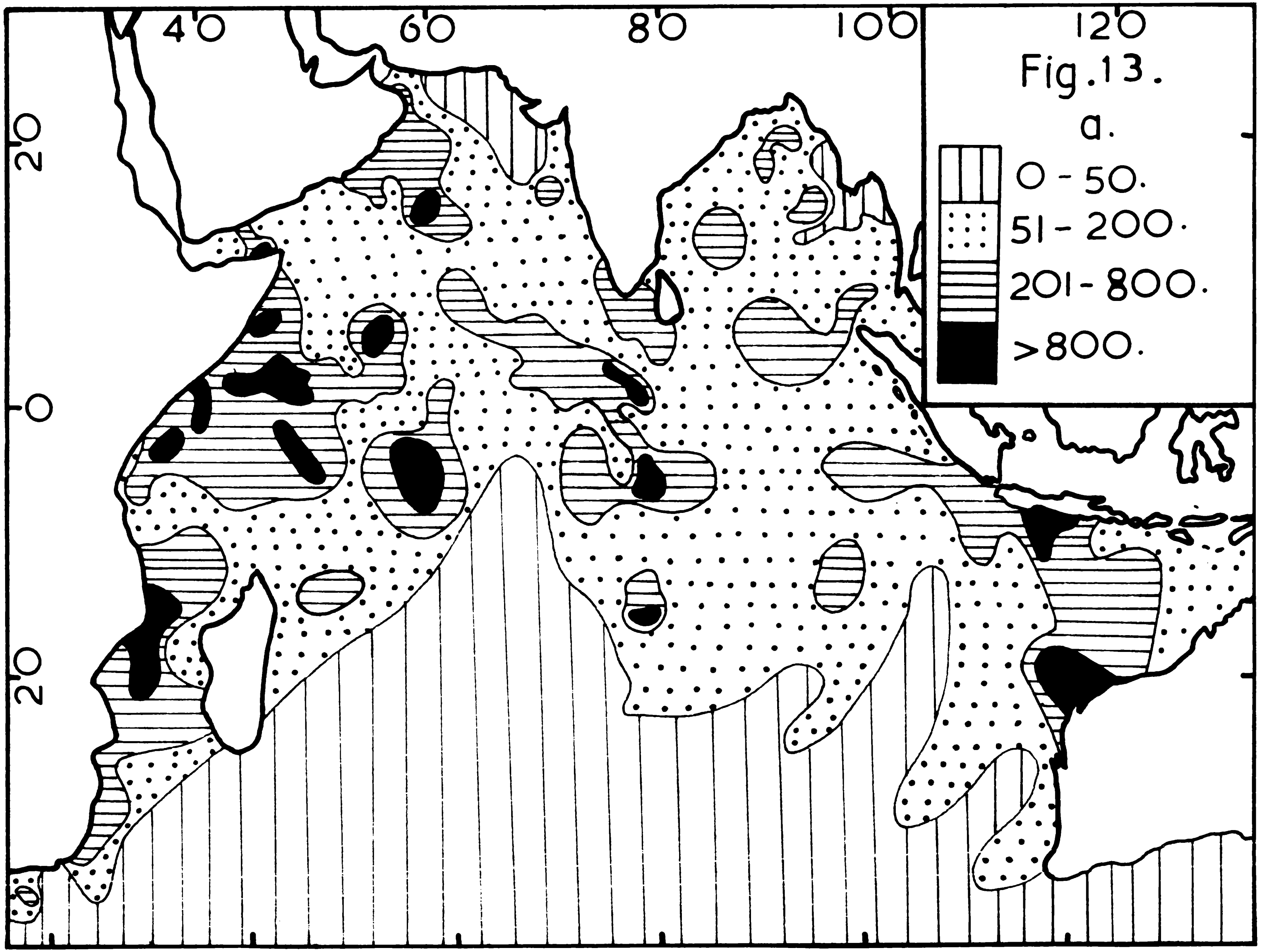
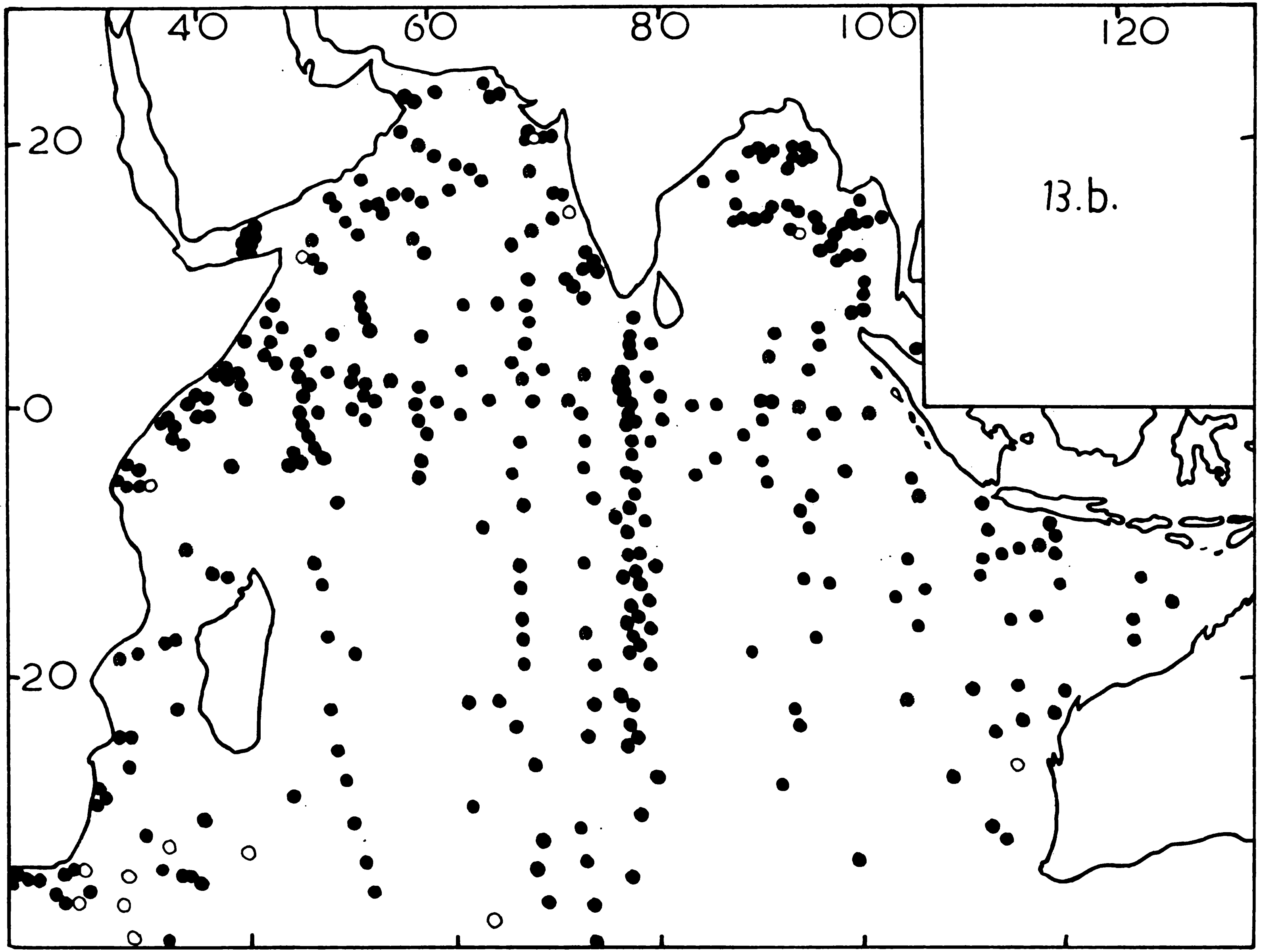


Fig. 13. a.

Fig. 13 b. Distribution of total Scolecithricidae in the Indian Ocean. Closed circles : Present. Open circles: Absent.


40
60
80
100
120
20
0
20
13.b.

In general, areas of high density populations corresponded with areas of high copepod and high zooplankton standing stock. Abundance was restricted to coastal areas as in the case with many other zooplankton. High density areas in general covered areas of intensive upwelling, such as Somalia coast, Arabian coast and Java coast. The abundance was more during the Northeast monsoon period and also during night. The opposing monsoons in the Indian Ocean apparently shifted the Scolecithricidae populations, by way of the current systems. Such changes were found in the latitudinal extensions, particularly on the west and east sides of the Indian Ocean similar to the one noticed for Globoquadrina (Be and Tolderlund, 1971) and Pseudeuphausia latifrons (Brinton and Gopalakrishnan, 1973).

Scolecithrix danae.

This is the most abundant species occurring in the surface waters of the Indian Ocean with a frequency of 82.3%. A total of 43,687 specimens were identified from 325 stations out of 385. The numerical abundance varied from 0 to 2,078 giving an average of 126 for Southwest monsoon and 104 for Northeast monsoon and

110 for night stations and 117 for day stations. Day and night variations in the collections were not prominent as it was present in 156 day and 169 night stations. It is likely that it is present in the euphotic zone throughout the Indian Ocean. Histogram studies revealed its abundance in the equatorial waters between 15°N and 15°S. A gradual increase in the population was noted from east to west and from northern and southern waters to the equator. The distribution is wide spread from 25°N to 40°S (Fig. 14). As noted for other copepods the highest densities (>450/haul) occurred in patches only, confined to areas west of 80°E longitude especially along the African coasts. Starting from Mozambique coast, they occurred north coast of Madagascar, Kenya coast, Somali coast, off Arabia in the central Arabian Sea and as three patches along 78 - 80°E longitudes south of equator. The next range of 151 to 450/haul was widespread all along the African coast upto 55°E longitude. In addition a strip off north Arabian coast extending to central Arabian Sea, four patches along 78 - 80°E longitude and three long patches in the eastern Indian Ocean - one in the southern Bay of Bengal waters, one in Timor Sea and one off Indonesia - represented the high densities. Areas with low densities

(51-150/haul) dominated the eastern and central Indian Ocean area upto 20°S latitude. The northern and central Bay of Bengal waters, NE Arabian Sea waters and southern waters south of 20°S represented lowest densities of 50/haul. But for the lowest densities of the Arabian Sea and Bay of Bengal waters, the distribution pattern was more or less similar to that of total copepods. S. danae is widespread in the seasonally changing monsoon gyre and the south hemispheric subtropical anticyclonic gyre. However the high density areas of occurrence of this species is confined to tropical waters characterised by the presence of comparatively high and medium salinity (35 - 35.5 ‰) waters. The comparative decrease in population towards the northern part of the Arabian Sea may be due to the increase in salinity towards the north and in the Bay of Bengal may be due to the decrease in salinity towards the northern and central Bay of Bengal water suggesting to preference to medium and comparatively high salinities. This indicates avoidance of waters of very high and very low salinity by this species. The highest surface salinities of the water in the subtropical anticyclonic gyre are found in a belt between 25°S and 35°S, upto 500 m depth. This seems to restrict abundance of S. danae population south of 25°S. Similarly the reduction noted south of 35°S latitude may be due to the low salinity waters of the southern Indian Ocean. The high density areas have a production rate of 50 to 120 mg C/m^3/day. The hydrochemical front at 10°S, more pronounced in sub-surface waters may act as a factor limiting its abundance south of it.

In the Indian Ocean this species has been previously recorded from Gulf of Aden (A. Scott, 1902); Ceylon Pearl Banks (Thompson and A. Scott, 1903; Sewell, 1914); Arabian Sea (Cleve, 1904); Maldive and Laccadive Archipelago (Wolfenden, 1906); Malay Archipelago (A. Scott, 1909); south of Madagascar (Wolfenden, 1911); Bay of Bengal and central portion of Indian Ocean (T. Scott, 1912); coast of southern Burma (Sewell, 1912); Durban Bay (Brady, 1914-1915); several "Investigator" collections in the Indian Ocean (Sewell, 1929); inshore waters off Trivandrum coast (Saraswathy, 1961); Durban to Cape Town area (De Decker and Mombeck, 1964) and western Indian Ocean (Grice and Hulsemann, 1967).

The geographic distribution of this species in the other oceans is very wide. It occurs in the tropical and subtropical parts of all oceans including the Mediterranean Sea. It extends from about 35°N to 35°S

Fig. 14 a. Distribution of *Scolecithrix danae* in the Indian Ocean. Density distribution (in nos.)

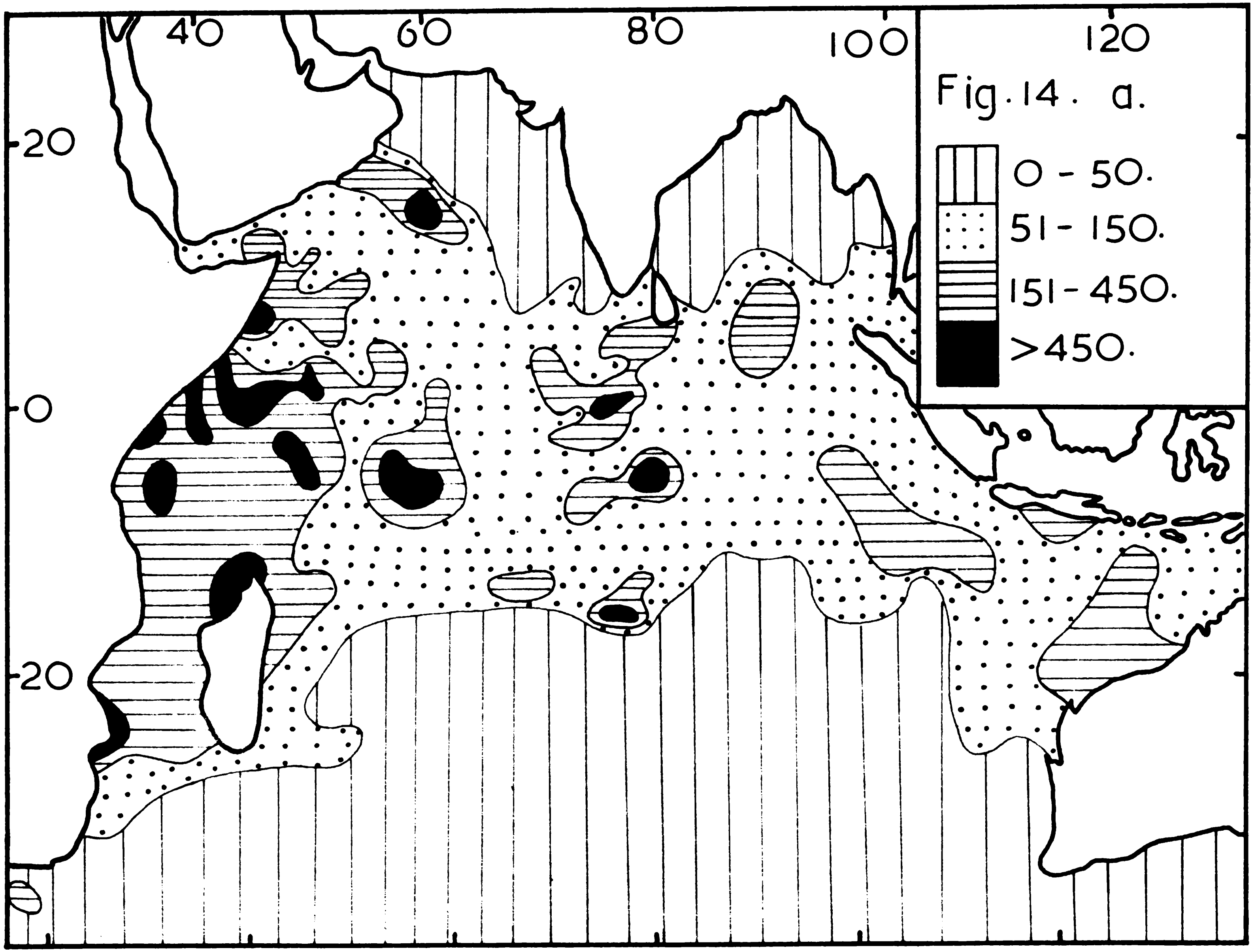
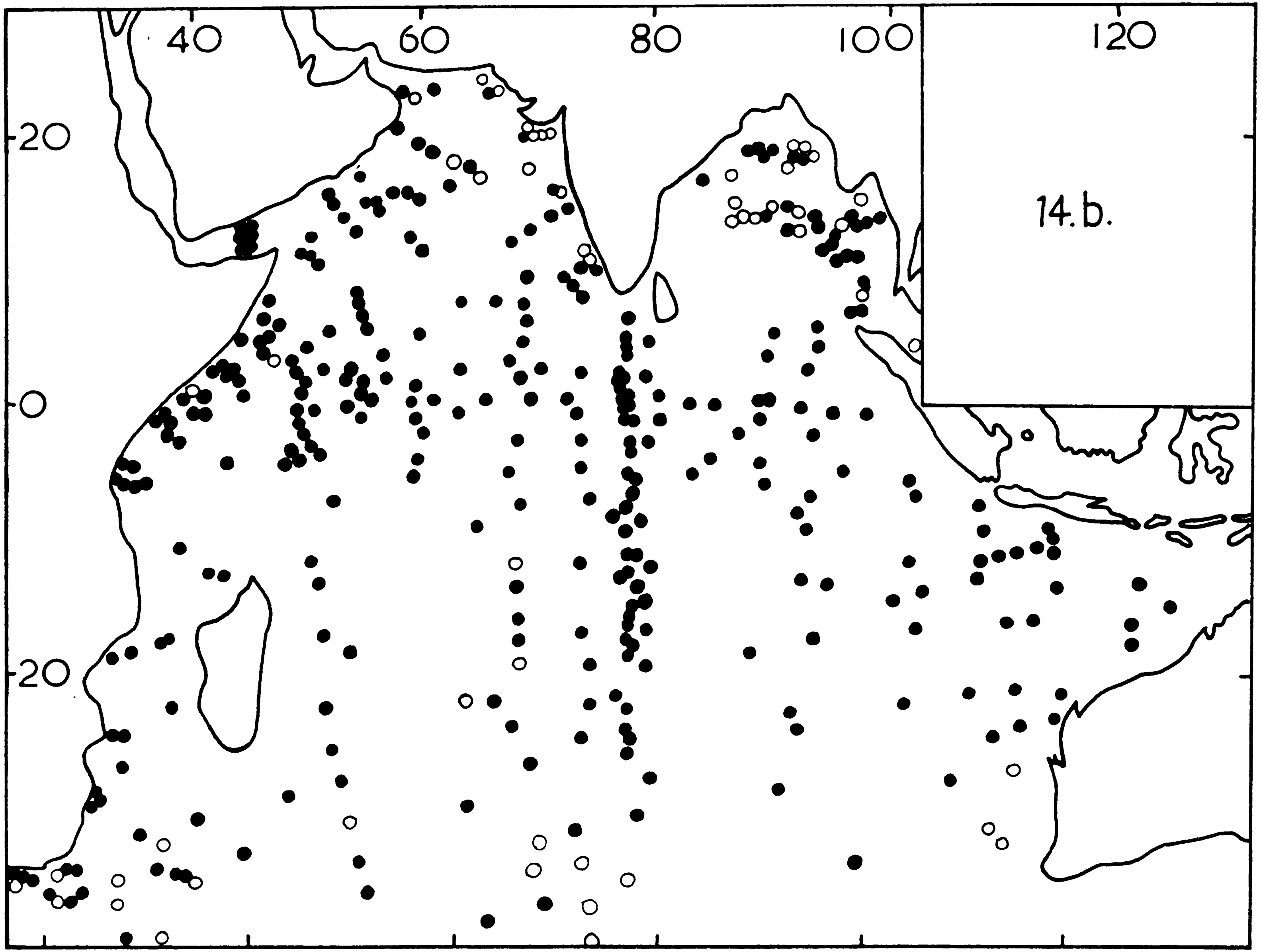


Fig. 14. a.

Fig. 14 b. Distribution of *Scolecithrix danae* in the Indian Ocean.
Closed circles : Present.
Open circles. : Absent.



14.b.

(Vervoort, 1965). It has been recorded as far north as 41.5°N in the Atlantic carried by the Gulf Stream (Lyshholm, Nordgaard and Wiborg, 1945). It is an inhabitant of surface and sub-surface water layers undergoing reverse migration to intermediate waters during night.

Scolecithricella bradyi .

This is a surface inhabitant present in 245 stations out of 385 (63.6%) showing a wide distribution (Fig. 15). In the frequency of occurrence S. bradyi ranks next to S. danae. In total, 4,731 specimens were sorted out from 245 collections. Numerical abundance varied from 0 to 150 giving an average of 15 in night collections and 10 in day collections; 12 in Southwest monsoon and 13 in Northeast monsoon. It being present in 128 night and 117 day collections, its distribution is wide throughout the euphotic zone in spite of the downward nocturnal migration exhibited. Histogram studies revealed an increase in population towards south; east-west difference was not significant. Its highest density (>40/haul) was located as twelve patches widely scattered from equator to 25°S latitude. It was found near Port Elizabeth, near Mozambique, off Mombasa, in the northern

Arabian Sea, off Cape Comorin along equator and south of equator, off Java, and near northwest coast of Australia. The next range (21-40/haul) covered in addition to areas around the above patches, the Mozambique Channel, northern tip of Somalia, and patches in the central equatorial waters. The low density areas (11-20/haul) was comparatively wide-spread as three large long patches, along east coast of Africa, north western coast of Australia and along 70-80°E longitude, however restricted to areas below equator and above 30°S. Rest of the Indian Ocean area especially above 5°N and oceanic waters were occupied by lowest densities of less than 10/haul. S. bradyi was more abundant in the equatorial water mass of the Indian Ocean north of the hydrochemical front at 10°S. The subtropical cell of high salinity water beginning from 25°S appears to restrict its distribution in abundance. Numerical abundance was reduced considerably in the upwelling areas of Somalia and Arabia. In general S. bradyi was found not favouring waters of very high or very low salinity eventhough it was abundant in the low salinity waters of Sumatra and Australia. The salinity tolerance of S. bradyi is almost similar to that of S. danae, being less populated in waters of very high and very low salinity.

Previous records of this species from the Indian Ocean are from Red Sea (Giesbrecht, 1896); Malay Archipelago

Fig. 15 a. Distribution of *Scolecithricella bradyi*
in the Indian Ocean.
Density distribution (in nos.)

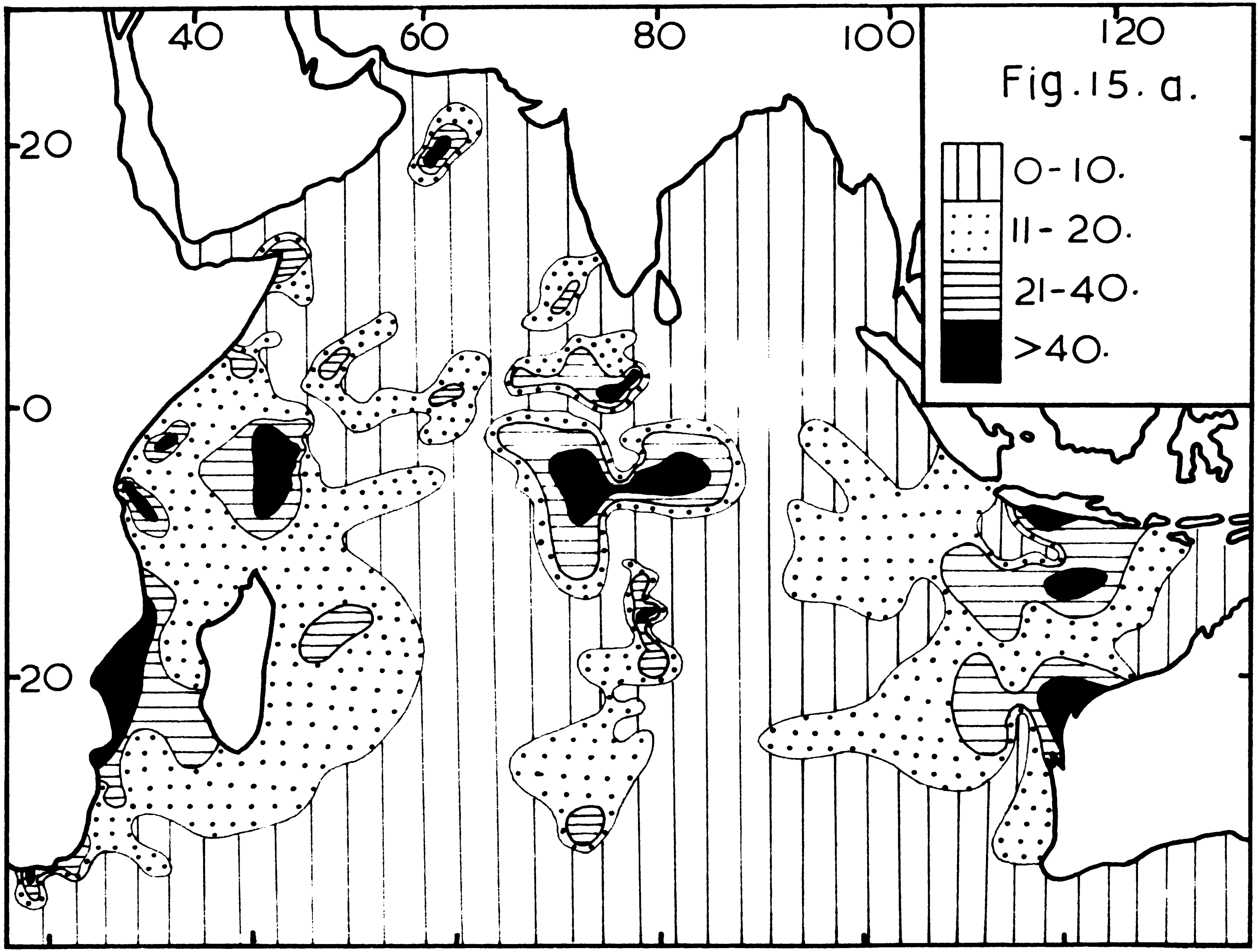
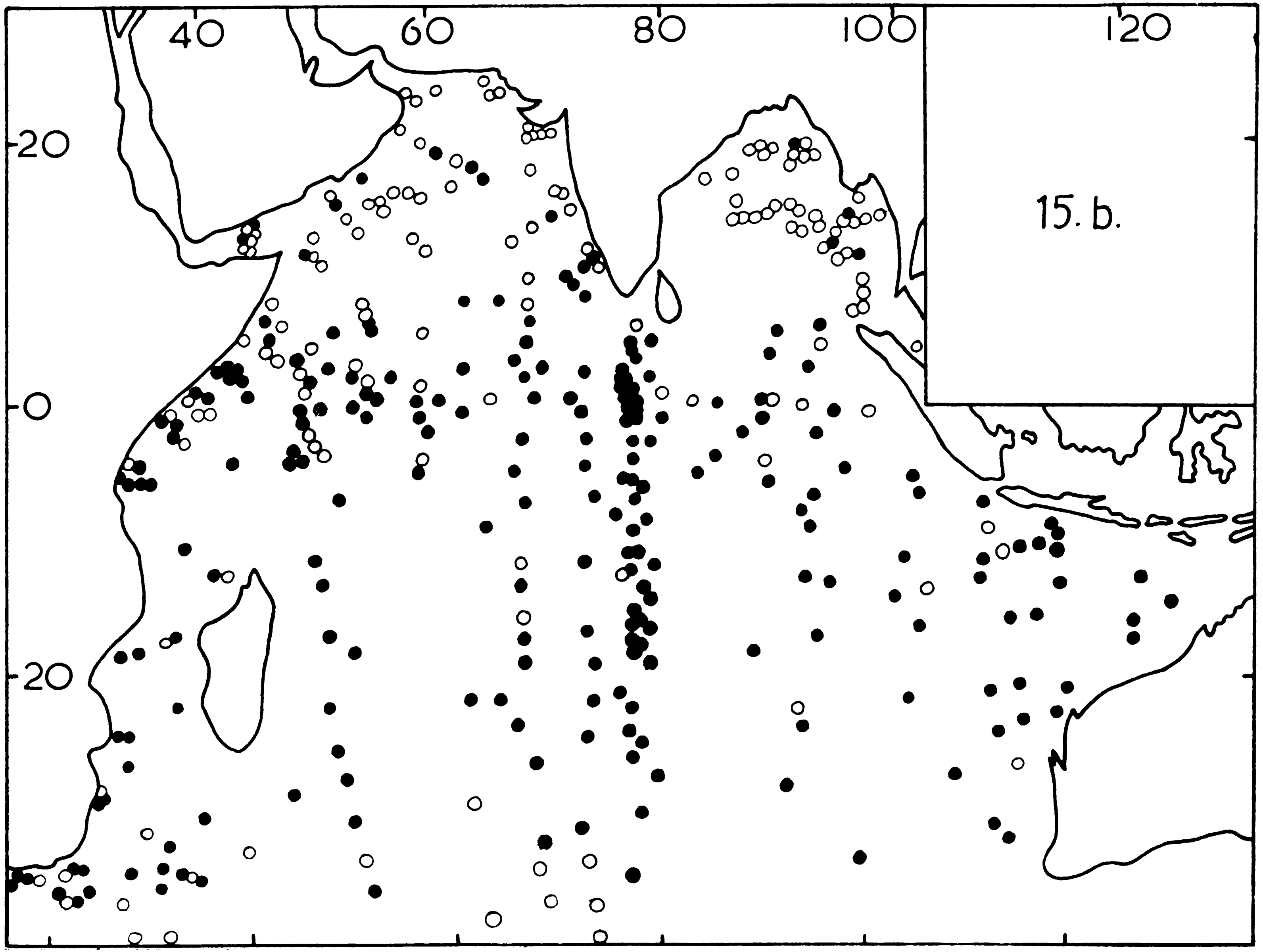

40
60
80
100
120
Fig. 15. a.
20
0
20
0-10.
11-20.
21-40.
>40.

Fig. 15 b. Distribution of *Scolecithricella bradyi*
in the Indian Ocean.
Closed circles : Present.
Open circles : Absent.



15. b.

(Cleve, 1901, A. Scott, 1909); Ceylon Pearl Banks (Thompson and Scott, 1903); south of Madagascar (Wolfenden, 1911); off South African coast (De Decker and Mombeck, 1964) and western Indian Ocean (Grice and Hulsemann, 1967). Geographically this species is also very widely distributed as in the case of _S. danae_. _S. bradyi_ is also an inhabitant of tropical and subtropical oceans including the Mediterranean. In the Atlantic this species is observed in the north as far as 48.5°N (Lyshholm, Nordgaard and Wiborg, 1945). This is also a subsurface species coming to the surface during night.

Scaphocalanus echinatus.

Though this species occurred only in 34.3% of the collections it was widely distributed in the Indian Ocean (Fig. 16), being present in 132 out of 385 stations. Of these 122 were night collections compared to only 10 day collections. On an average night hauls had 24 specimens and day hauls 1 specimen; 9 for Southwest monsoon and 14 for Northeast monsoon. This indicated the bathypelagic nature of the species, undergoing vertical migration at night. A total number of 4,558 specimens were identified from 132 stations and their numerical abundance varied from 0 - 317. Histogram studies revealed an increase in population from south to north and east to west. Abundance was more in northwestern Indian Ocean. The highest density areas (>40/haul) were confined to 15 small to large patches in the western Indian Ocean, compared to one small patch in the south Andaman Sea. But for a very large patch in the area around the southwest peninsular India rest of the patches were restricted along east coast of Africa, off south Africa, off Mozambique, off Somali coast, central Arabian coast, and in the central and south Arabian Sea. The high density range of 21 - 40/haul was noted around the above patches in addition to 2 small patches in the Timor Sea and one large patch in the west wind drift off Australia. Low densities (11 - 20/haul) were confined to far off areas such as off Madagascar, off Somalia, patches in north Arabian Sea and northern Bay of Bengal waters, in the Timor Sea and off the west coast of Australia. Very low densities (0 - 10/haul) prevailed in majority of the Indian Ocean area especially south of 30°S latitude. This species is found associated with upwelling areas. S. echinatus has been found in abundance in the equatorial water mass, mainly confined to western Indian Ocean. It seems not to the low saline warm tropical waters of the Bay of Bengal.

It is less in the central and less saline Indo-Australian water mass. The hydrochemical front at 10°S identified by low salinity waters and low nutrient (phosphate) content of 0.4 ug at/l, also appears to restrict its southern distribution. Its abundance at night revealed its occurrence in large numbers below the euphotic layer, in the mesopelagic zone. As such its association is more with the subsurface and intermediate water masses. It is abundant in the upwelling areas of Somali, Arabian and Java coasts. Associated with the high production (2,000 mg C/m^2/day) area of the Wadge Bank at the southern end of India, a very large patchy concentration of *S. echinatus* occurred, probably related to its behaviour in hydrochemical factors.

Previous record of this species from the Indian Ocean is only from the western region of the Indian Ocean (Grice and Hulsemann, 1967). However it was recorded from the other oceans namely from Atlantic slope, New Zealand region, Great Barrier Reef of Australia and Japanese waters. In the Izu region of Japan this species is common in the deep waters (Tanaka, 1961).

Fig. 16 a. Distribution of *Scaphocalanus echinatus* in the Indian Ocean. Density distribution (in nos.).

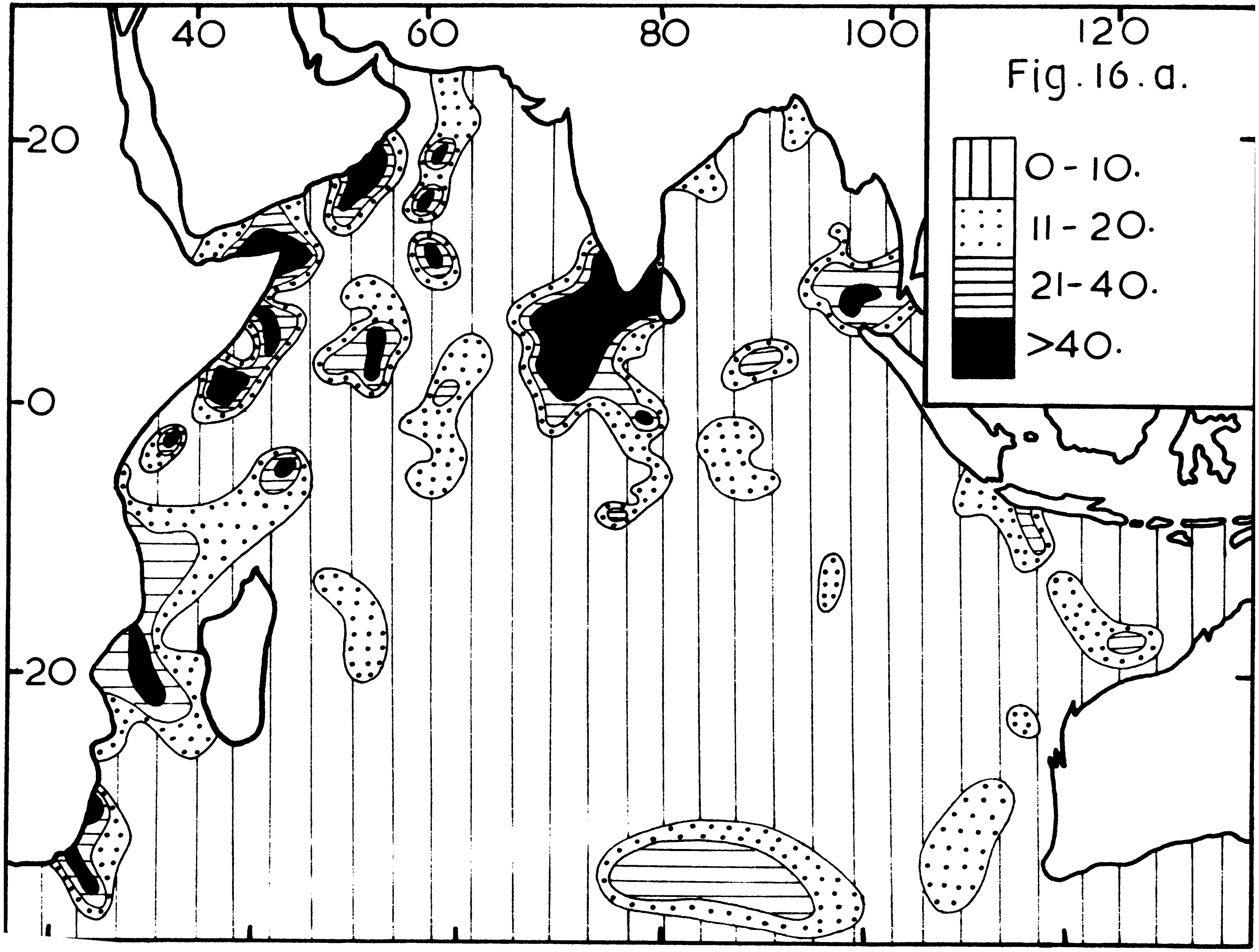
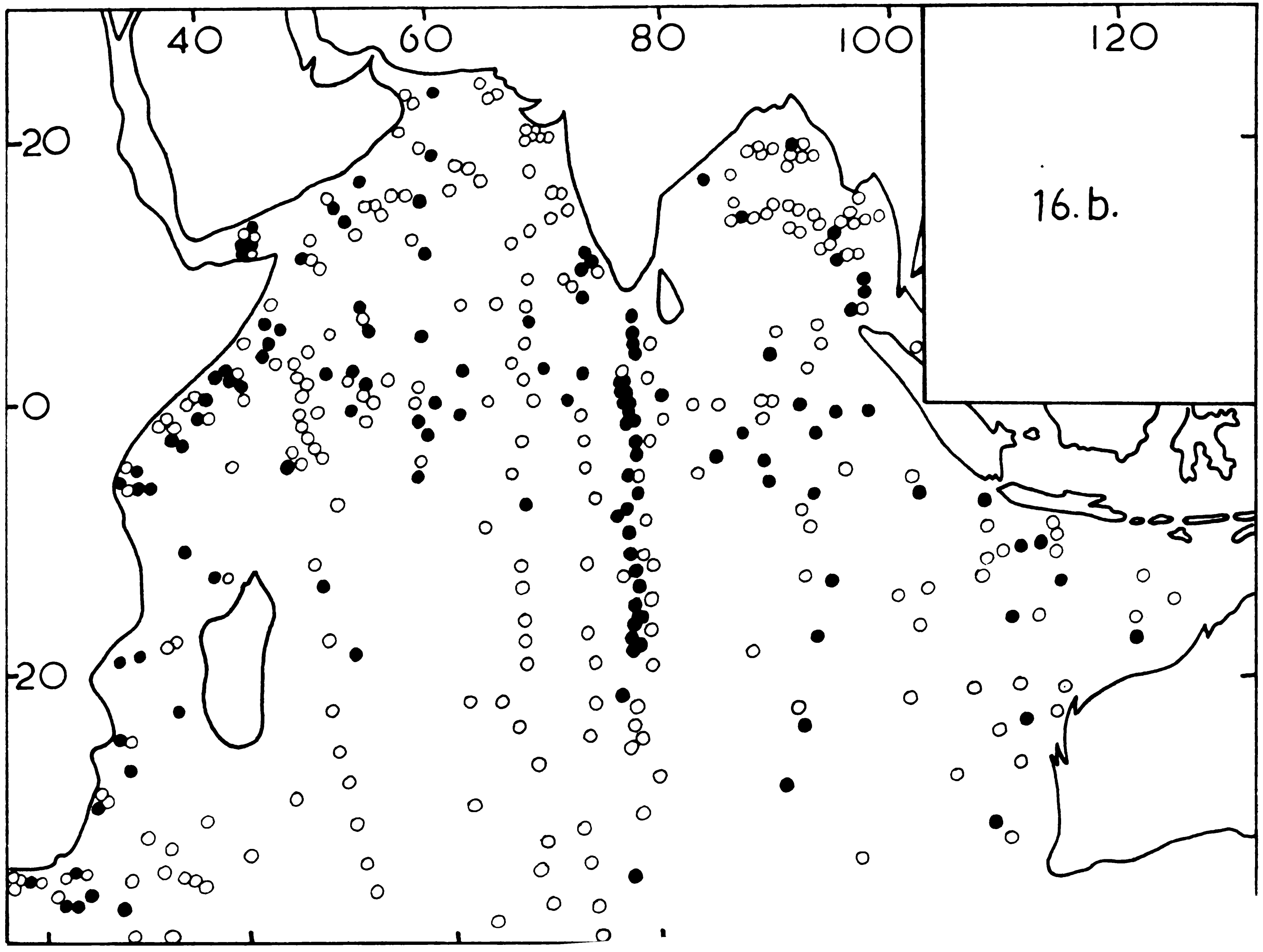


Fig. 16. a.

<u>Fig. 16 b</u>. Distribution of *Scaphocalanus echinatus* in the Indian Ocean.

Closed circles : Present.

Open circles : Absent.


40
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80
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120
20
0
20
16.b.

Scolecithricella ctenopus.

This species is present in 122 out of 385 stations studied (Fig. 17). Though the frequency of occurrence was only 31.7%, the distribution appeared wide up to 20°S latitude. A total of 3,739 specimens were identified. Numerical abundance varied from 0 - 230 with an average of 10/night and 9/day haul; 11/Southwest monsoon and 9/Northeast monsoon. It was present in 62 night (33%) and 60 day (30%) hauls, indicating rare chances of diurnal vertical migration. Histogram studies showed an abundance in the northern Indian Ocean leading to a more or less endemic distribution. Also a west to eastward increase in population can be noted. Very high density patches of > 40/ haul were confined to central Arabian Sea and northern and central Bay of Bengal as very large patches and a small patch in the northwestern corner off Australia. High density areas of 21 - 40/haul occurred around the above 3 patches in addition to 2 small patches in the southern tropical oceanic areas. Low density patches of 11 - 20/ haul marked the southern boundaries of northern Arabian Sea and Bay of Bengal water in addition to 5 small patches along the 10°S hydrographic front and 2 small patches off south African coast. Oceanic waters south of 10°N was characterised by very low densities of 0 - 10/haul.

S. ctenopus is a euryhaline species being present in high densities in high salinity (34 - 37‰) waters of Arabian Sea and low salinity (30 - 33‰) warm tropical waters of Bay of Bengal. Its abundance in Eastern Indian Ocean revealed its preference to less saline waters. Also it was located along the equatorial waters. It was more abundant in oceanic waters. Its occurrence south of the hydrographic front at 10°S was meagre. Thus this can be identified as an equatorial species endemic to Arabian Sea and Bay of Bengal with respect to Indian Ocean. It was almost absent in the upwelling areas of Somalia and Arabia. Lack of a clear variation in nocturnal abundance indicated its occurrence in the euphotic zone. Yet it may be present in the North Indian Ocean high saline (35 - 36 ‰) sub-surface waters occurring in depths of 150-900 m.

In the Indian Ocean *S. ctenopus* has been previously recorded from Malay Archipelago (A. Scott, 1909) and Bay of Bengal (Sewell, 1929). Among the other oceans this species is well distributed in the Pacific as far north as 15°N (Giesbrecht, 1888, 1892; Brodsky, 1962). Izu region Japan, Seas of Japan, equatorial Pacific, Great Barrier Reef of Australia, in the Atlantic from Gulf of Guinea. This is essentially a tropical species.

Fig. 17 a. Distribution of *Scolecithricella ctenopus* in the Indian Ocean. Density distribution (in nos.).

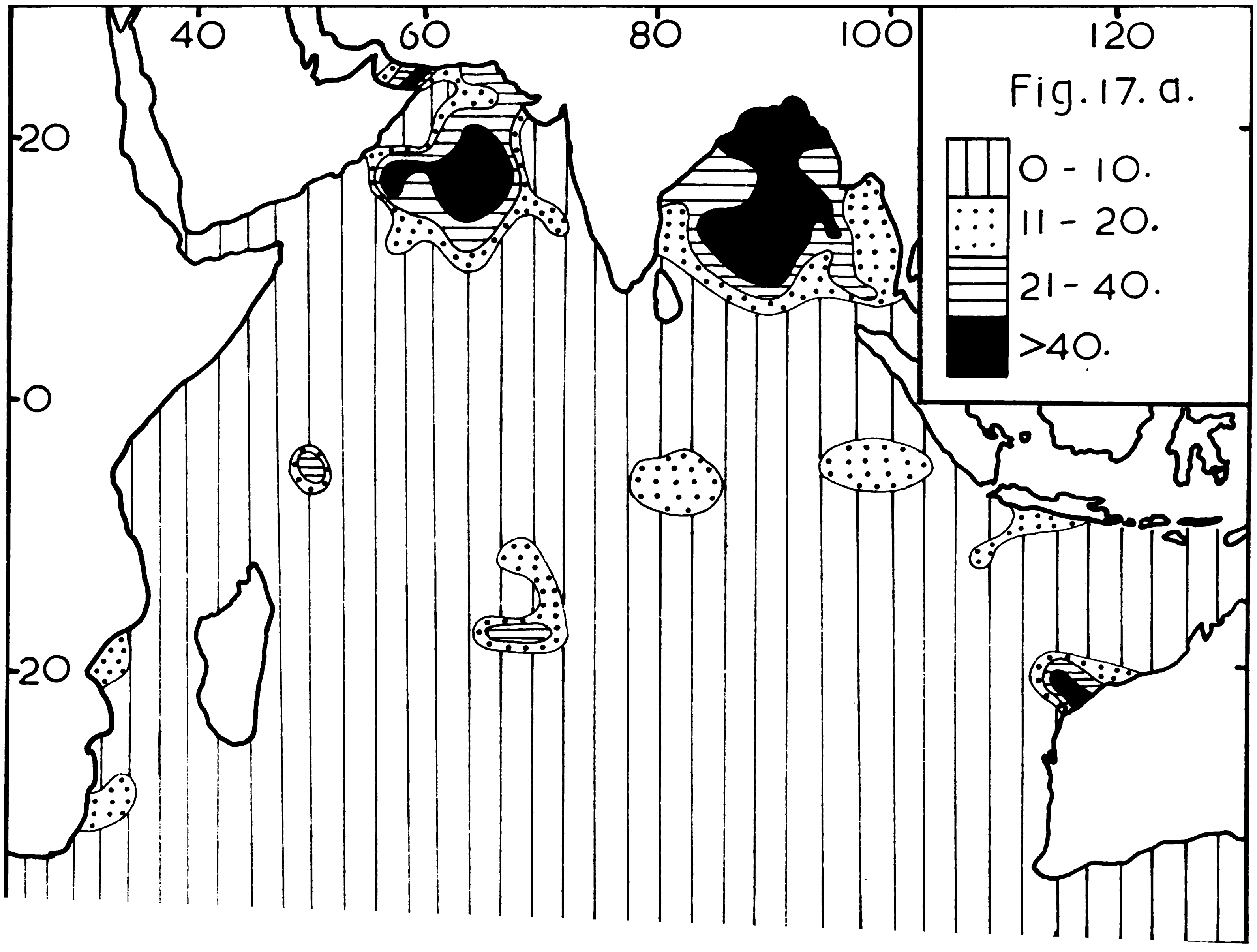
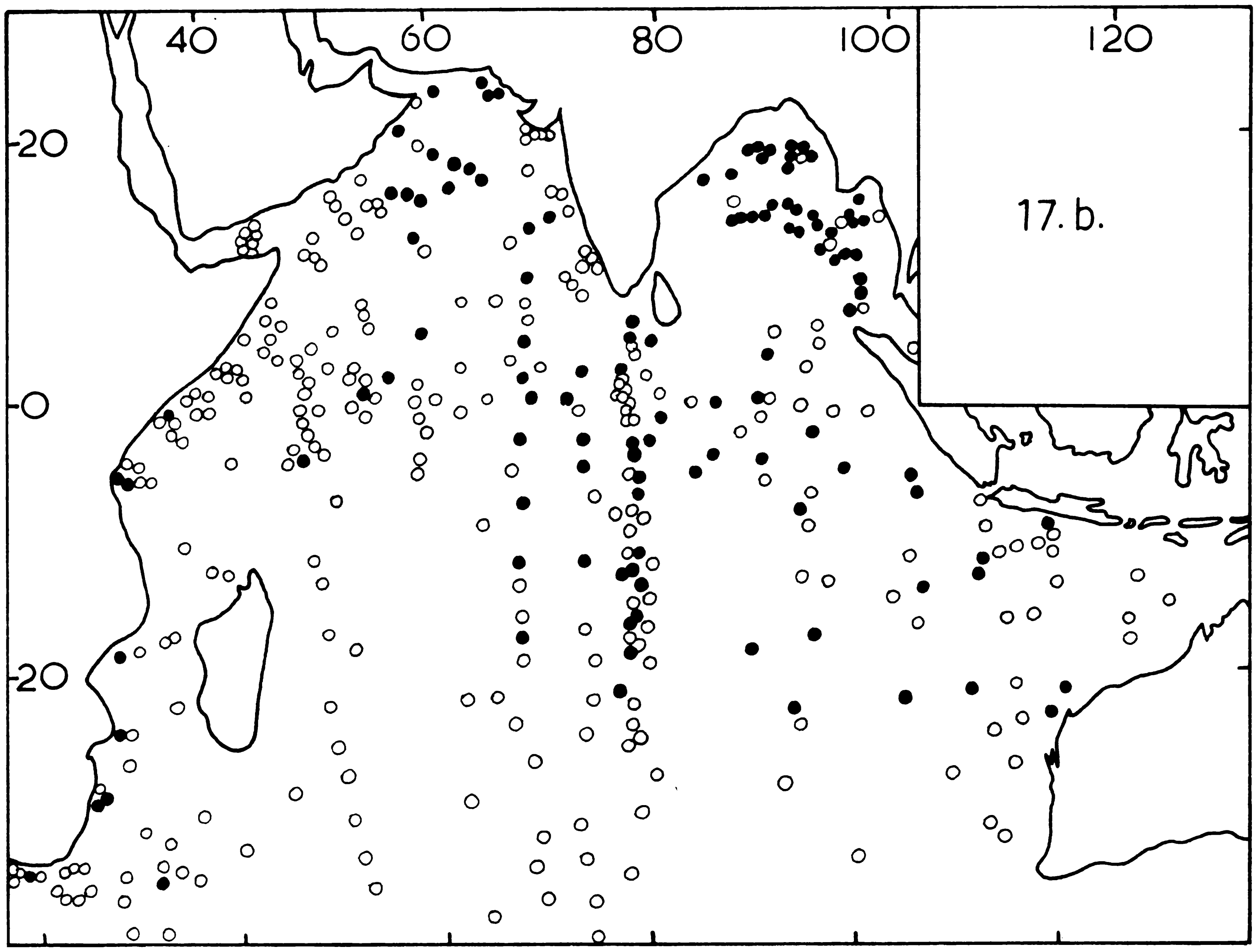


Fig. 17. a.

Fig. 17 b. Distribution of *Scolecithricella ctenopus* in the Indian Ocean.

Closed circles : Present.

Open circles : Absent.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17. b.

Scolecithricella tenuiserrata.

This species is present in 189 out of 385 stations, with a frequency of occurrence of 49.1% (Fig. 18). Its numerical abundance varied from 0 to 178 with an average of 10 for night and 7 for day; 6 for Southwest and 10 for Northeast monsoon. A total of 3,186 specimens were identified. Numerically this is the fifth in abundance. Histogram studies showed its abundance in the north and south of equator. A gradual reduction in population from east to west and north to south occurred. Highest densities (> 40/haul) were located as 9 patches - one in the Gulf of Oman, 2 off north Arabian coasts extending to central Arabian Sea, 3 in the Bay of Bengal northern and central waters, one off Java and 2 in the central Indian Ocean. High density areas with 21 - 40/haul covered in addition to the above areas, a small patch each near Mozambique, off Somali coast, near Laccadive Island, off Cape Comorin, near Timor Sea and 2 patches in the central eastern Indian Ocean along 20°S latitude. Low density (11 - 20/haul) areas included a wider patch off northeast coast of Madagascar, northwestern Bay of Bengal waters, off Java coast, northeastern offshore areas of Australia and 5 patches in the central Indian Ocean. Rest of the Indian Ocean showed very low densities of 0 - 10/ haul. Average catch of 10/haul at night compared to

Fig. 18 a. Distribution of *Scolecithricella tenuiserrata* in the Indian Ocean. Density distribution (in nos.).

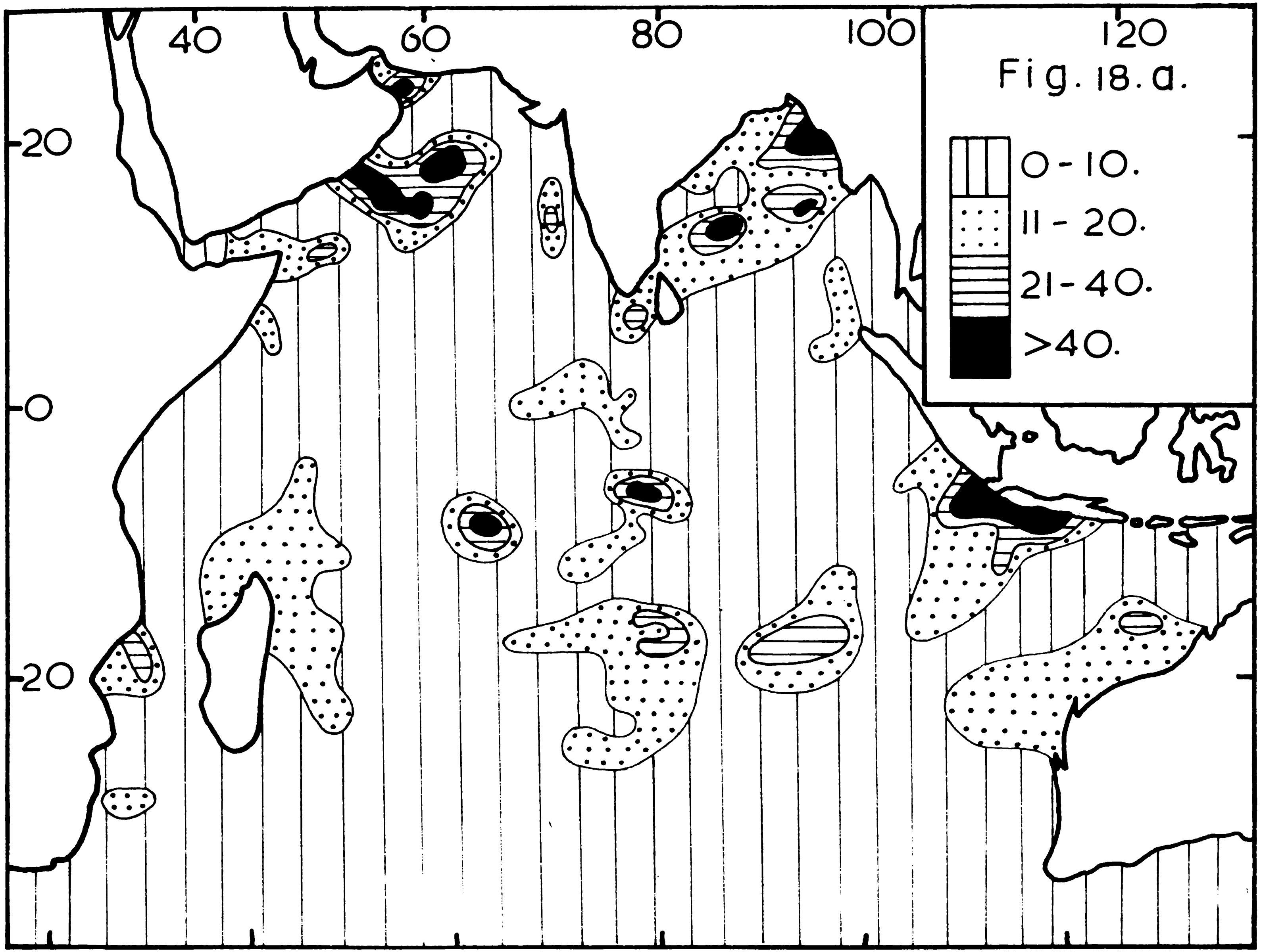
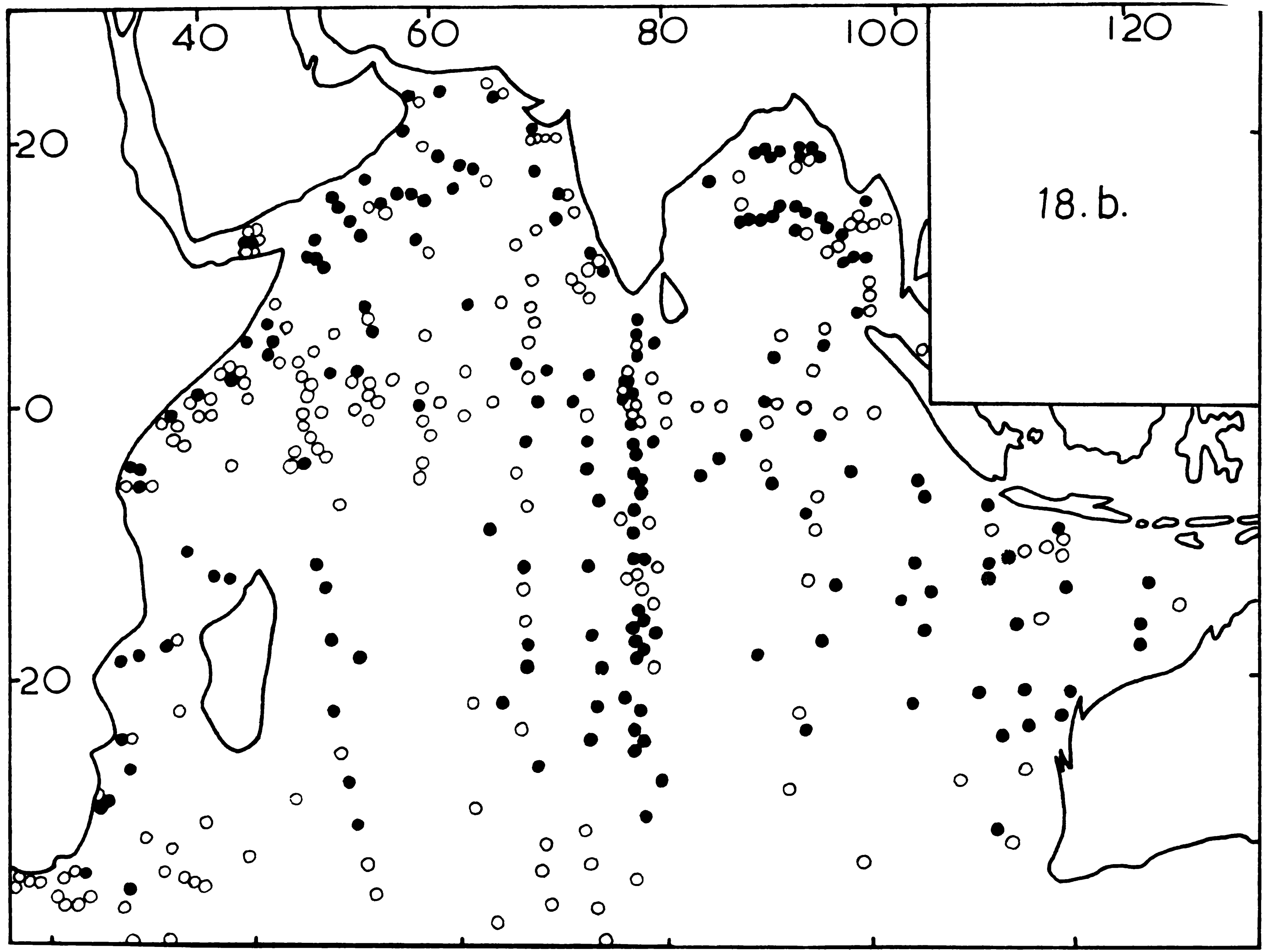


Fig. 18.a.

Fig. 18 b. Distribution of *Scolecithricella tenuiserrata* in the Indian Ocean.

Closed circles : Present.

Open circles : Absent.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18. b.

7/haul during day indicated slight vertical migration. Areas of abundance were confined to south of the hydrochemical front at 10°S in the nutrient poor high oxygen water and north of highest salinity water belt of subtropical gyre. It was more abundant in the high saline upwelling waters of Arabian Sea and warm tropical low saline surface water of the Bay of Bengal. Java upwelling areas also showed abundance. S. tenuiserrata seems to be an oceanic than a coastal species. Also it is euryhaline in occurrence. Boundary currents contain only sparse populations. Previous record of this species from the Indian Ocean is only from the northern part of the Arabian Sea (Sewell, 1947). It is reported from the western part of the Mediterranean, Bermuda area between Bermuda and New York, Great Barrier Reef, central equatorial Pacific, Sagami Bay - Japan and from off Ghana. This species inhabits intermediate depths to surface.

Scolecithricella dentata.

This species numbering 2,682 were identified from 131 out of 385 stations (Fig. 19) leading to a frequency of occurrence of 34%. Its numerical abundance varied from 0 - 256 giving an average of 7 specimens/haul. It was present in 94 night hauls (51%) and 37 day hauls (18%).

In all 2,068 specimens were collected during night and 614 during day hauls giving an average of 11 and 3 for night and day respectively. These figures clearly demonstrated large scale nocturnal migration undertaken by it. Of the 2,682 specimens collected, only 558 belonged to Southwest monsoon period whereas Northeast monsoon period had 2,124 specimens giving an average of 3 and 10 specimens for the Southwest and Northeast monsoons respectively. Of the collections 37 stations during Southwest monsoon period and 94 stations during Northeast monsoon had this species. This indicated its abundant production during the Northeast monsoon period. This species was absent north of 10°N especially in the Arabian Sea and Bay of Bengal. Gradual increase in numerical abundance was noted from east to west and towards equator from south and north as revealed by histogram studies. Areas of high density of > 40/haul were located as 7 small patches along west African coast; 4 similar patches were present along 75 - 80°E longitude. In the eastern Indian Ocean only one small patch near Java and one far off in the open ocean along 100°E longitude were noted. The next grade of high density of 21 - 40/haul followed the same areas as above in addition to one patch near Somalia, one in Andaman Sea and two along north and west Australian coasts. Low density areas of 11 - 20/haul covered African coasts, a large patch extending from Southern tip of India to 20°S along 75 - 80°E longitude, a large patch off Sumatra and an oceanic patch in offshore areas of west Australia. Rest of the Indian Ocean area between 10°N and 40°S latitude showed very low density of 0 - 10/haul. S. dentata population preferred medium salinity waters avoiding very high and very low saline waters of Arabian Seaand Bay of Bengal respectively. These mesoplanktonic copepods occupied mainly sub-surface waters and undertook vertical nocturnal migrations. Its distribution towards northern Indian Ocean was restricted by the biogeographical boundary at 8 - 10°N limiting Arabian Sea and Bay of Bengal from the rest of the Indian Ocean. It was abundant in the equatorial waters south of 10°N especially in the western Indian Ocean. But for its abundance along 75 - 85°E longitude oceanic occurrence was scarse compared to high densities in the offshore areas. The southern area of its distribution was limited by the sub-tropical high salinity cell of water mass between 25°S and 35°S belonging to the sub-tropical gyre. Upwelling areas of Arabia and Somalia were devoid of this species.

S. dentata was previously reported from the Indian Ocean from the area between Durban and Cape Town in the South African coast (De Decker and Mombeck, 1964), from

Fig. 19 a. Distribution of *Scolecithricella dentata* in the Indian Ocean. Density distribution (in nos.)

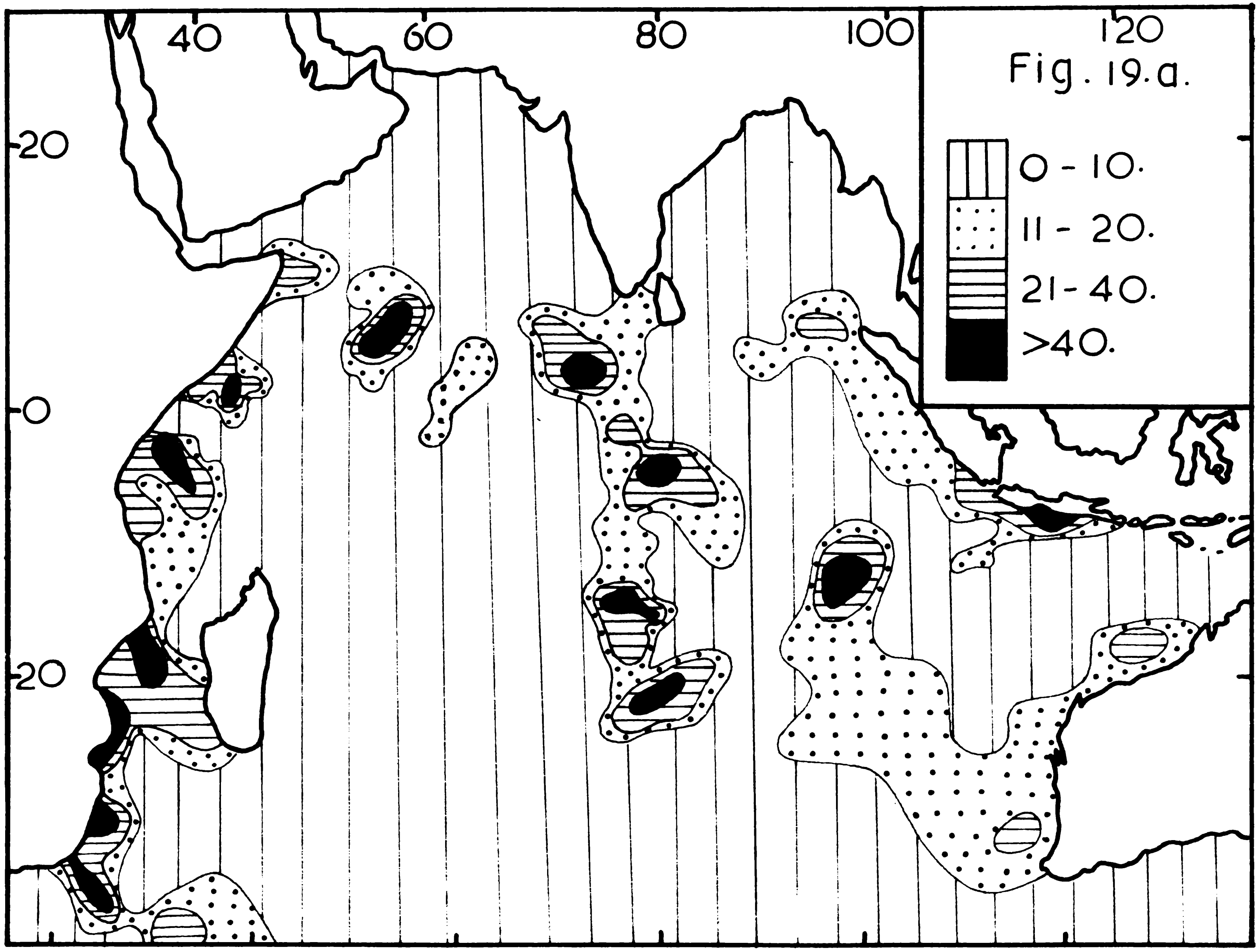
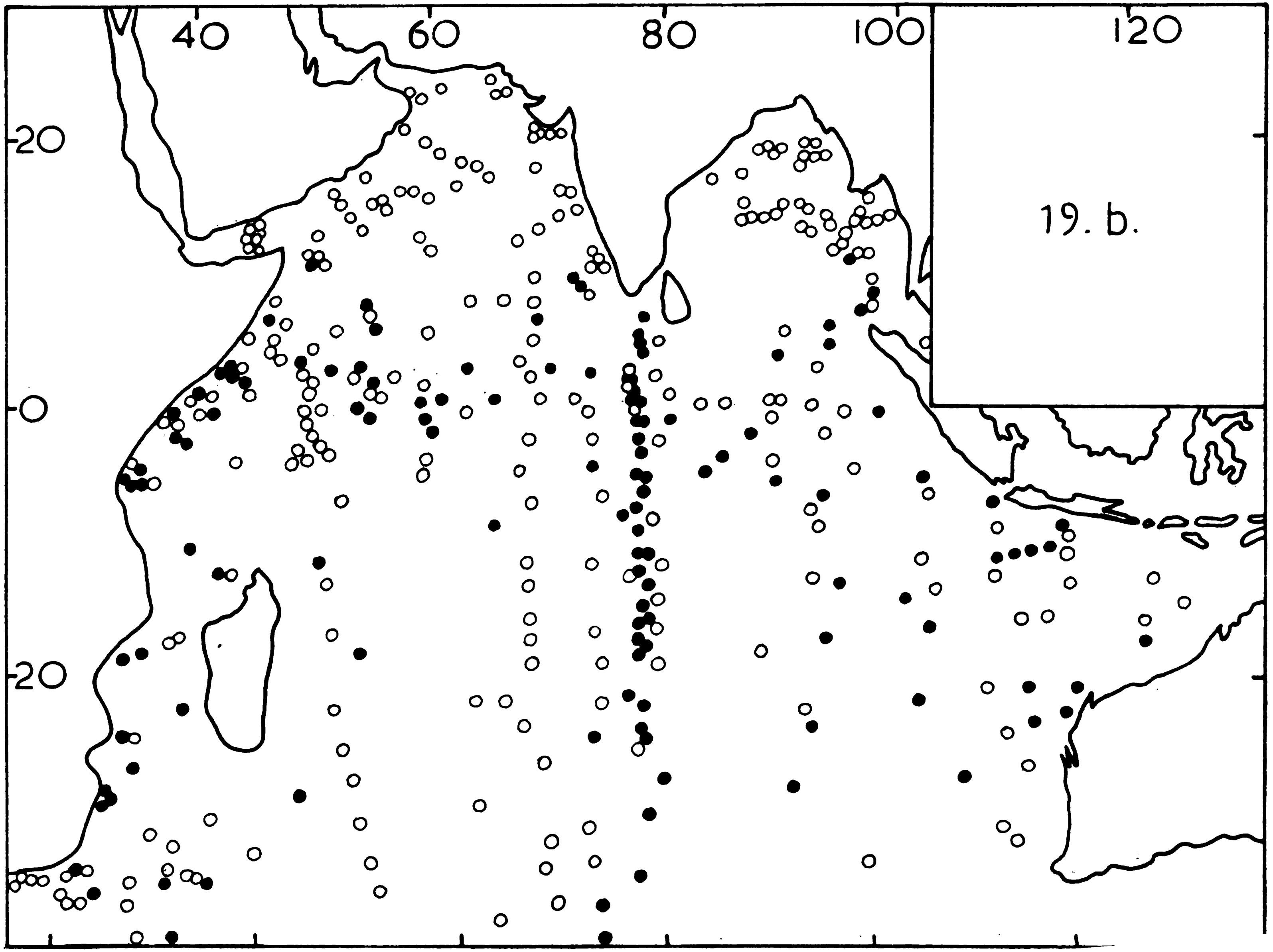


Fig. 19.a.

Fig. 19 b. Distribution of *Scolecithricella dentata* in the Indian Ocean.

Closed circles : Present.

Open circles : Absent.



19. b.

western Indian Ocean (Grice and Hulsemann, 1967). Among the other oceans this species had a wide distribution in the Atlantic and Pacific and has been recorded from Atlantic slope, Bay of Biscay, Atlantic, Mediterranean, Great Barrier Reef and Japanese waters. This is an inhabitant of surface and intermediate waters.

Scolecithricella abyssalis.

This species was present in 167 stations out of 385 indicating 43.4% frequency of occurrence (Fig. 20). It was present in 87 night and 80 day collections indicating absence of large scale diurnal migration. A total of 2,610 specimens were identified giving an average of 9 per nigl haul and 5 per day haul indicating vertical migration to a certain extent. Average number of specimens for Southwest and Northeast monsoons were 4 and 9 respectively. Numerical abundance varied from 0 - 131/haul. Histogram drawings showed a gradual increase from south to north latitudes. East west variations were not much. Though the species is widely distributed up to 20°S latitude, areas of abundance appeared scattered. Very high density patches of 40/haul were located as 6 small patches - off Mogadishu in the Gulf of Aden, in the Wadge Bank, near Minicoy Island and far off Sumatra in the eastern Indian Ocean.

High densities (21 - 40/haul) are confined to 15 small patches - in the Mozambique Channel, off Kenya, off Somalia, off north Arabian coast, an extended area from Capecomorin, in Andaman Sea, patches along the equator, off Java coast and northwest Australian coast. Low density areas (11 - 20/haul) covered wider areas. A large patch from north Arabian coast and Gulf of Oman extended to southwest coast of India and equator. Along equatorial waters 4 patches were noted. Similar large patches occurred around Andamans and in the area between Java and Australian coasts. Barring the above patchy distribution the entire Indian Ocean areas south of equator up to 20°S latitude and Bay of Bengal waters were represented by the lowest densities (< 10/haul).

This species was present mainly in the monsoon gyre. The hydrographical front at 10°S characterised by low nutrient (phosphate 0.4 ug at/l) and a surface salinity minimum layer seemed to restrict its distribution to southern areas of Indian Ocean. In the monsoon gyre it is abundant inthe Indo-Australian water and high salinity Gulf of Aden and Arabian Sea waters of equatorial water mass exhibiting euryhaline nature. However, it do not prefer warm tropical low saline waters of Bay of Bengal.

Fig. 20 a. Distribution of *Scolecithricella abyssalis* in the Indian Ocean. Density distribution (in nos.)

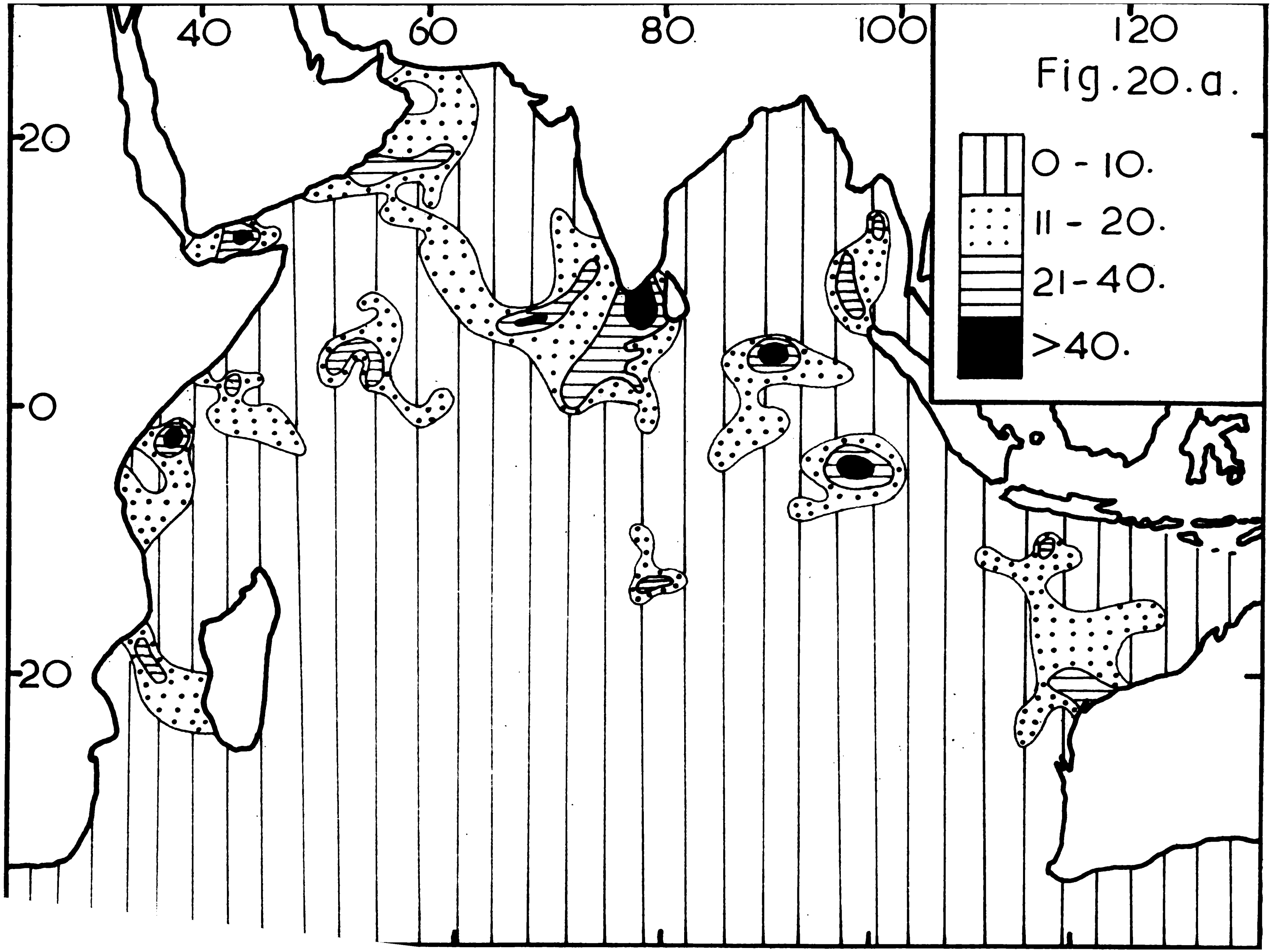
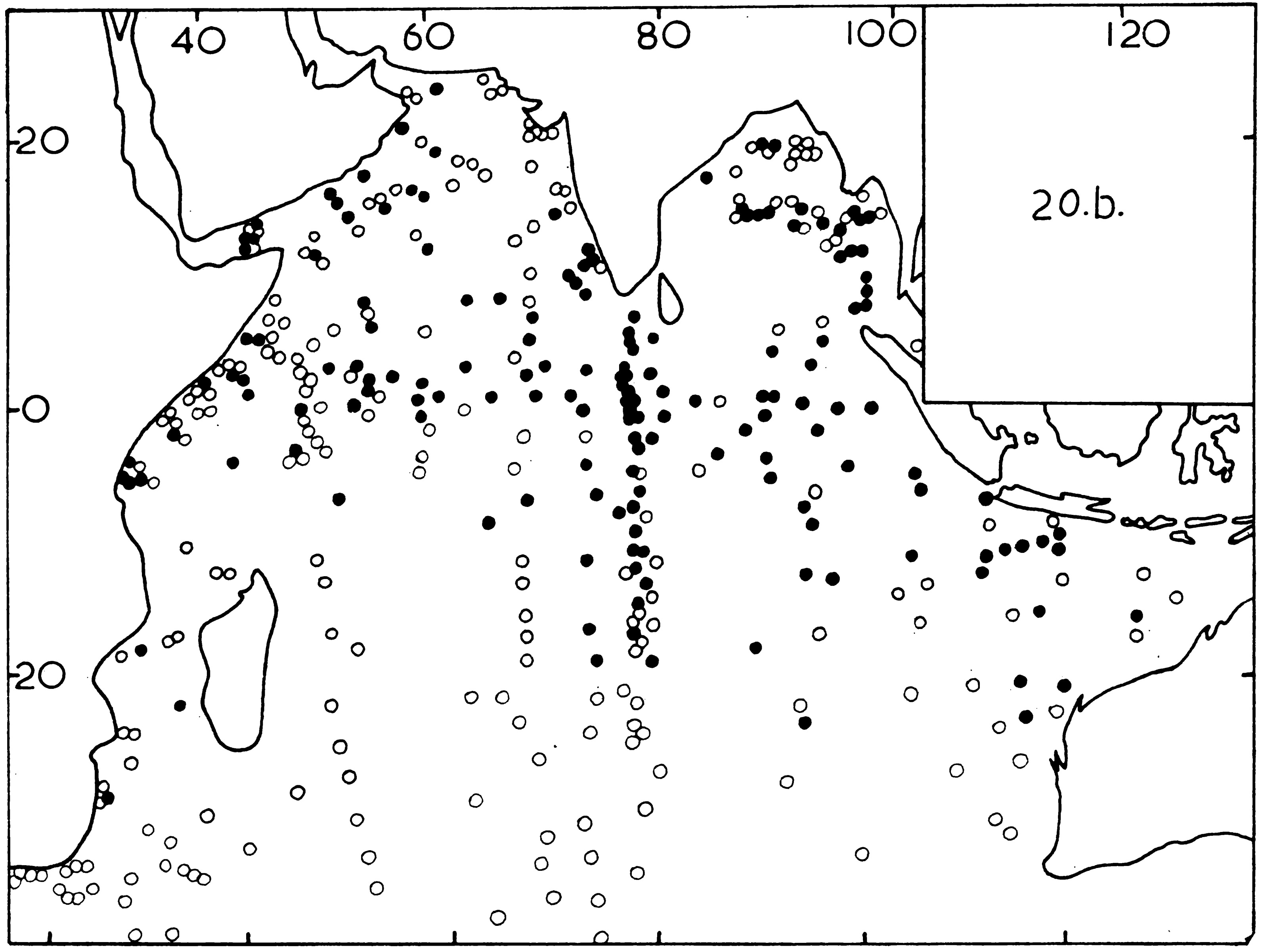


Fig.20.a.

Fig. 20 b. Distribution of *Scolecithricella abyssalis*
In the Indian Ocean.
Closed circles : Present.
Open circles : Absent.


20.b.

The day and night difference in occurrence revealed its occurrence in the meso and bathypelagic layers of the sub-surface and deep water masses especially the North Indian high salinity waters occurring at depths of 150 - 900 m, with a temperature of 22 - 26°C. However it was less abundant in the upwelling areas of Arabia and Java and almost rarely present in the Somali upwelling.

The only previous record of this species from the Indian Ocean is that of A. Scott (1909) from the Malay Archipelago. It was reported from Mediterranean, Pacific - between 11 and 14°N, in the eastern and tropical regions, Japanese waters, equatorial Pacific - and from the temperate part of Atlantic. This is almost an abyssal species occassionally migrating to the surface waters having a depth up to 50 m.

Scaphocalanus curtus.

This species was present in only 35.1% of 385 collections. Yet this species showed a wide distribution (Fig. 21), in the Indian Ocean. A total of 2,459 specimens were identified from 135 collections. The numerical abundance varied from 0 - 163 with an average of 9 for night and 4 for day; 3 for Southwest and 9 for Northeast monsoons. In spite of the day and night variations indicating diurnal vertical migrations, it was present in 68 night and 67 day collections. S. curatus in general shows a north-south and west-east abundance as revealed by histogram studies. (Fig. 32). Distribution showed a patchy nature - 2 patches off Tanzania, 1 off Mogadishu, 1 off North Arabia, 1 in Gulf of Oman and 4 along the equatorial waters of western Indian Ocean and one off Java represent areas of highest densities (> 40/haul). High densities (21 - 40/haul) are located in larger areas surrounding above patches in addition to one patch south of Madagascar and 2 patches off northwestern Australian coast. Low density (11 - 20/haul) patches cover in addition to the above areas, a patch along Mozambique coast, southwestern coast of India, a patch in the Arabian Sea and a large patch extending from Java to Australia. Rest of the major part of the Indian Ocean represents the lowest density range of 0 - 10/haul. From the distribution map this species appears to be more a neritic one than an oceanic. S. curtus mainly occurred in the equatorial water mass of the western Indian Ocean. It was rarely present in the Indian Ocean Central Water Mass of southern Subtropical Anticyclonic Gyre except in the low salinity waters between Java and Australia. It was present in comparatively large numbers in the upwelling areas off Arabia and Java. Similar to S. bradyi it was rarely

Fig. 21 a. Distribution of *Scaphocalanus curtus* in the Indian Ocean. Density distribution (in nos.)

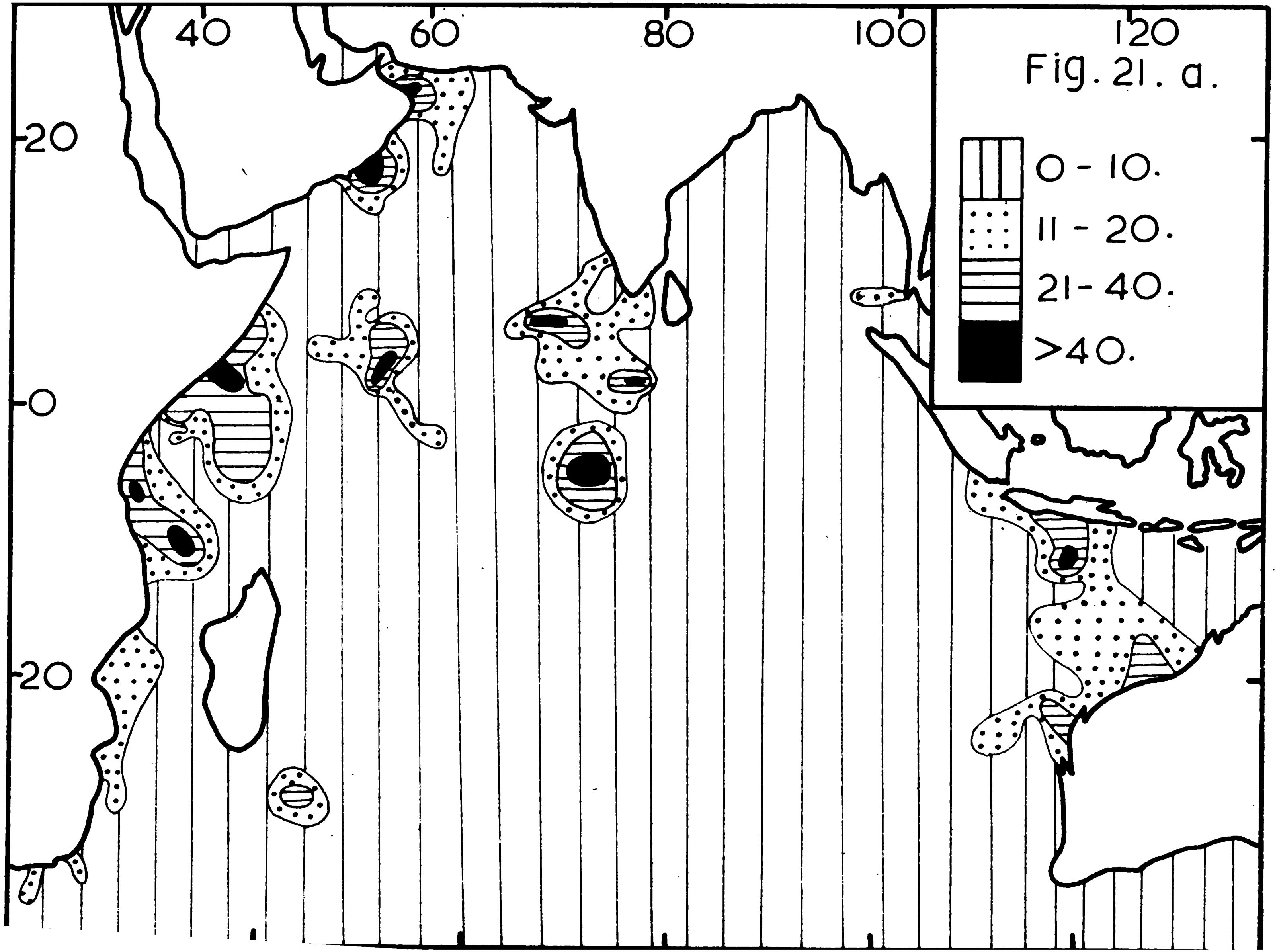
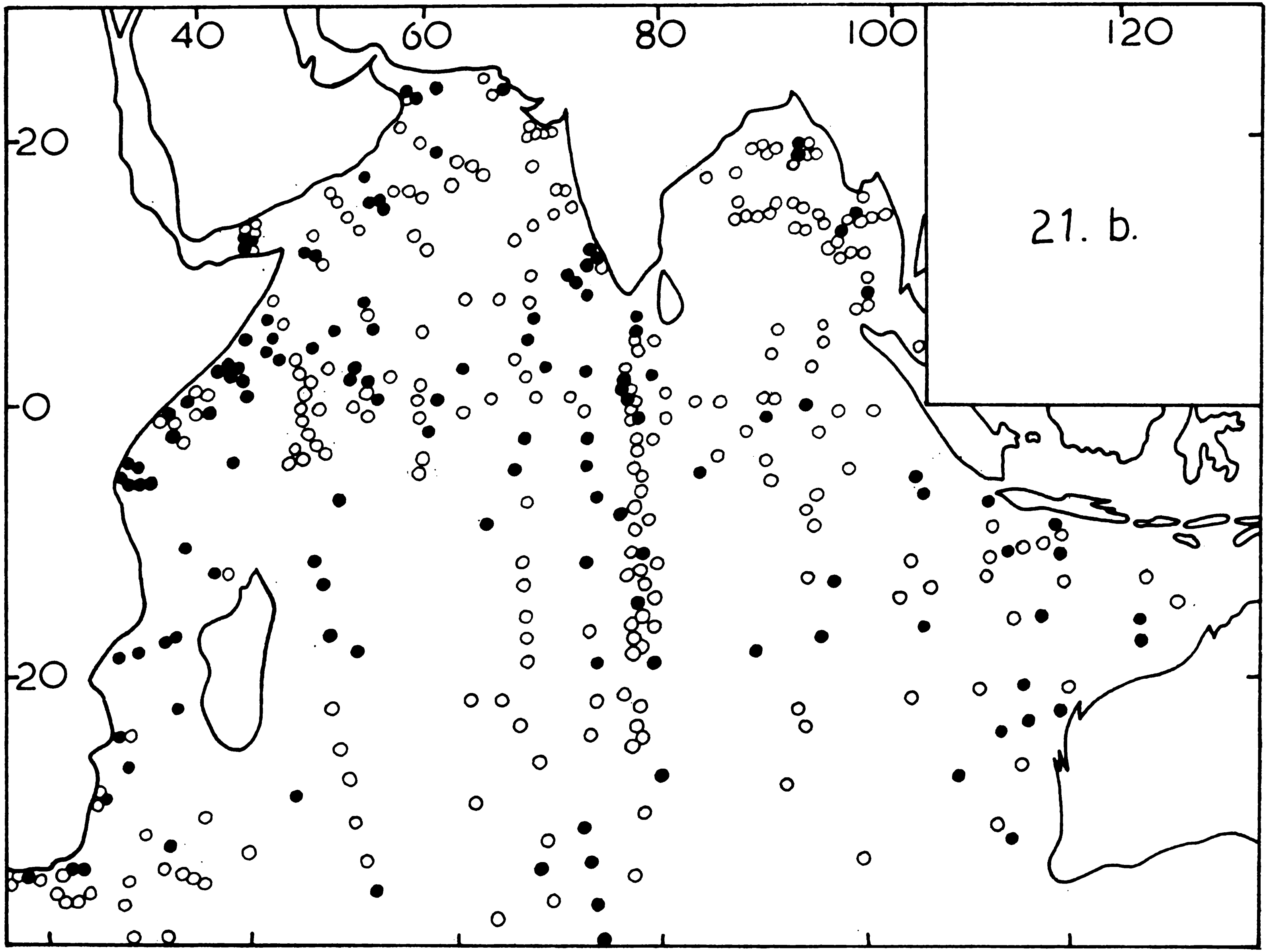


Fig. 21 b. Distribution of *Scaphocalanus curtus* in the Indian Ocean.

Closed circles : Present.

Open circles : Absent.



21. b.

present in the very high or very low saline waters.

Previous record of this species from the Indian Ocean is from the western Indian Ocean (Grice and Hulsemann, 1967). It has been reported from Bay of Biscay, intermediate and surface waters of New Zealand and Japanese waters.

Scolecithrix nicobarica.

A total of 1,181 specimens of S. nicobarica were identified from 75 stations out of 385 leading to a frequency of occurrence of 19.5% (Fig. 22). Its numerical abundance varied from 0 - 230 with an average of 3 per haul. The species was present in 40 night (22%) and 35 day (17%) collections giving a mean occurrence of 3 each in night and day collections. Thus eventhough nocturnal abundance was not noticed, the increase in frequency of occurrence at night indicated diurnal vertical migration to a limited extent. During the Southwest monsoon while an average of 2 specimens were present in a haul, an average of 4 specimens were collected during Northeast monsoon. Thus Northeast monsoon was found more favourable for the production of S. nicobarica. Histogram studies (Fig. 32) indicated a south to north increase associated with a decrease in population from east to west.

The highest density of > 40/haul was located as 3 small patches along the equator near the Somali coast, far off southern tip of India and in southern border of Bay of Bengal. The next range of 21 - 40/haul was confined in addition to the above 3 areas in 3 more areas along the equatorial waters in between 65 and 75°E longitude and off Sumatra. The low range of 11 - 20/haul occurred as small patches off Saurashtra, and off Wadge Bank and as a large patch in the southern Bay of Bengal (Andaman Sea) and off Sumatra. A small patch was present off the north western end of Australia. Rest of the Indian Ocean area was occupied by the lowest range of 0 - 10/haul. It was totally absent in the Arabian Sea and south of 20°S.

<u>S</u>. <u>nicobarica</u> was confined mainly to the monsoon gyre of the Indian Ocean including the hydrochemical front at 10°S. The species seems to have a continuous distribution in the Indo-Pacific waters. Its areas of abundance were confined along equatorial waters especially to the Indo-Australian water. It was totally absent in the high salinity water of Arabian Sea and the highest salinity water belt of the sub-tropical cell, as well a s in the low salinity areas of northern Bay of Bengal. Upwelling areas were devoid of this species. Being

Fig. 22 a. Distribution of *Scolecithrix nicobarica* in the Indian Ocean. Density distribution (in nos.)

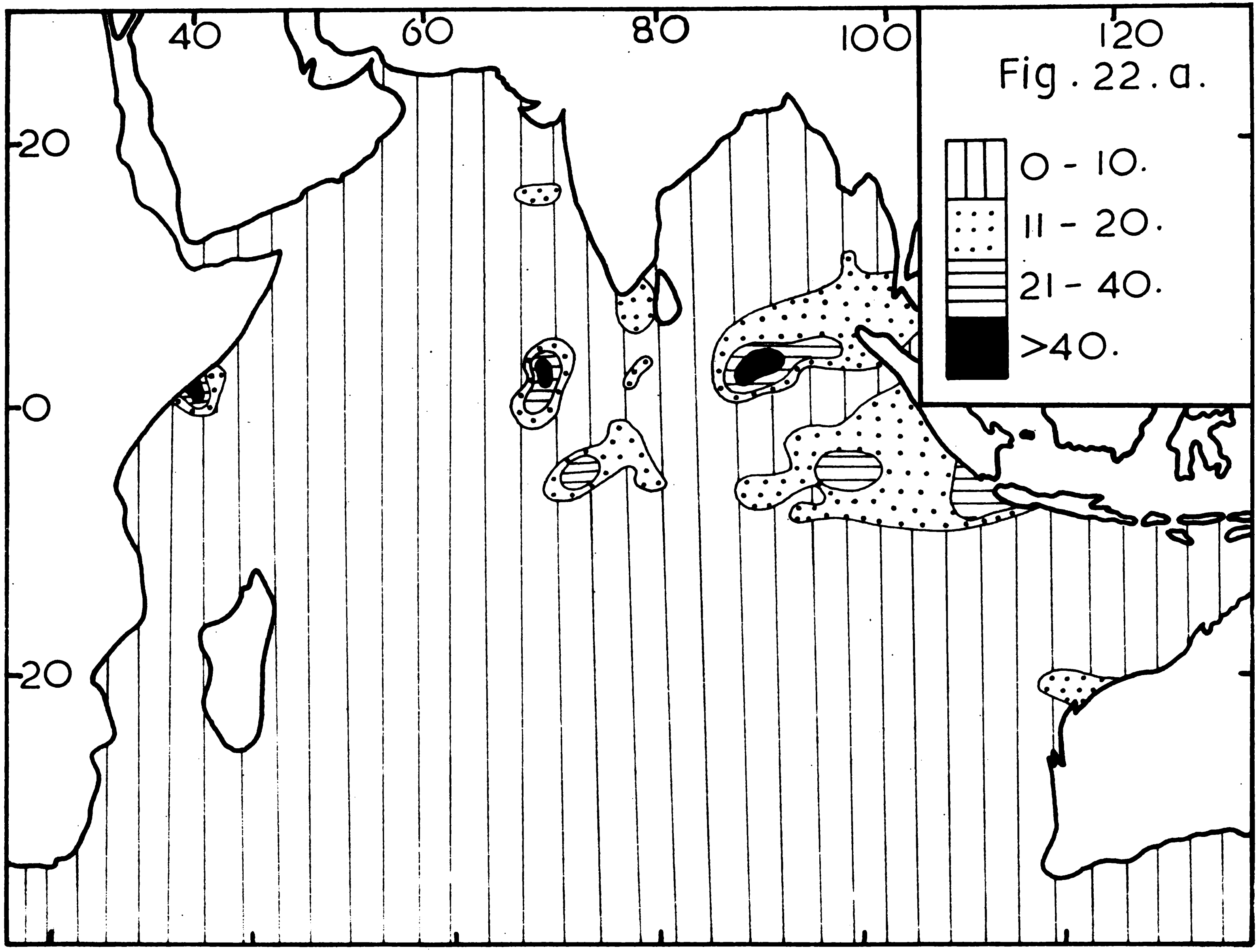
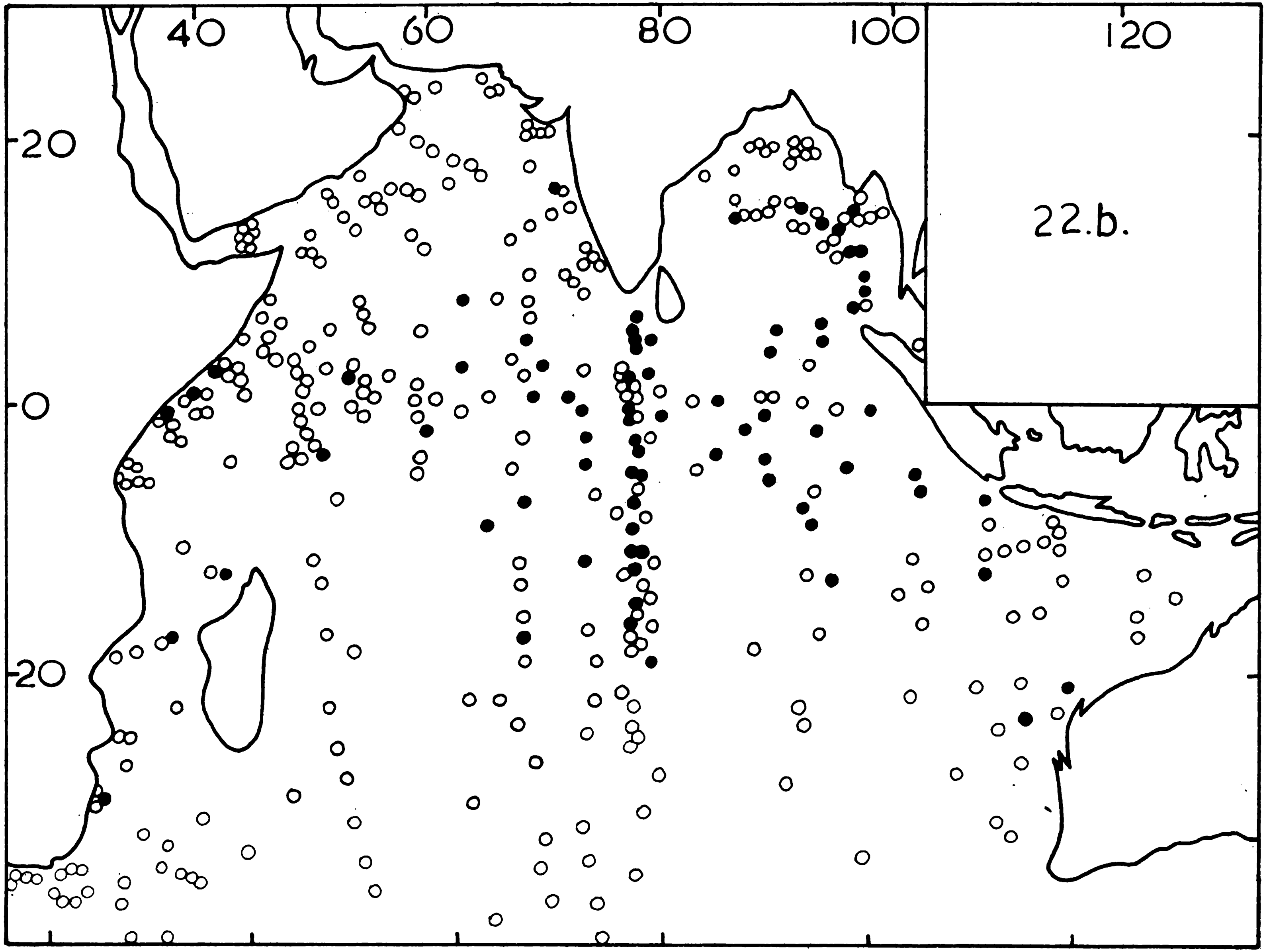


Fig. 22. a.

Fig. 22 b. Distribution of *Scolecithrix nicobarica*
in the Indian Ocean.
Closed circles : Present
Open circles : Absent.



22.b.

migratory to a certain extent it may be traced in the sub-surface waters of Bay of Bengal and equatorial waters.

S. nicobarica has been described originally from Naukurin Harbour in the central group of Nicobar Islands by Sewell (1929) and from western Indian Ocean by Grice and Hulsemann (1967). Other than Indian Ocean it has been recorded from Great Barrier Reef and Japanese waters. It is an inhabitant of sub-surface water layers.

Lophothrix angusta.

This species is present in 106 stations out of 385 with a frequency of occurrence of 27.5% (Fig. 23). Its numerical abundance varied from 0 - 43 leading to an average number of 2/haul having collected a total of 822 specimens. Of the 822 specimens 616 were collected during night and 206 during day hauls giving a mean of 3 and 1 for night and day hauls respectively. Also its presence in 65 night stations (35%) and 41 day stations (20%) indicated the extent of diurnal nocturnal migration undertaken by it. It was present in 46 (27.4%) stations during Southwest monsoon and 60 (27.7%) stations during Northeast monsoon. Of the 822 specimens collected 296 were during Southwest and 526 during Northeast monsoons, giving an average of 2 and 3/haul respectively. This clearly indicated its abundance during Northeast monsoon period. Histogram studies revealed an increase towards south and eastern half of the ocean. The highest densities of > 20/haul were located as small patches, one along African coast near equator and 3 patches in the central Indian Ocean along 75 - 80°E longitude. Two patches along Mozambique coast, 2 patches near Port Elizabeth, 6 patches along 70 - 80°E longitude and 4 patches off north west coast of Australia showed high density (11 - 20/haul) areas. The low density (6-10/haul) areas occupied as large patches along the Mozambique coast, a tongue-like extension off west Australia up to 95°E longitude and a long north-south patch along 75 - 80°E longitude. The lowest densities of 0 - 5/haul occupied the rest of the Indian Ocean. The species was totally absent north of 5°N including the Arabian Sea and Bay of Bengal waters. <u>L. angusta</u> was present mainly in the circulation of sub-tropical anticyclonic gyre, characterised by nutrient poor high oxygen waters. It was very rare in areas north of the hydrochemical front at 10°S and sparse south of the sub-tropical cell of high salinity. <u>L. angusta</u> being a mesoplanktonic species undertakes vertical migrations regularly. As such it is abundant in waters of salinity 34.5 - 35.5 ‰. It is

Fig. 21 a. Distribution of *Lophothrix angusta* in the Indian Ocean. Density distribution (in nos.),

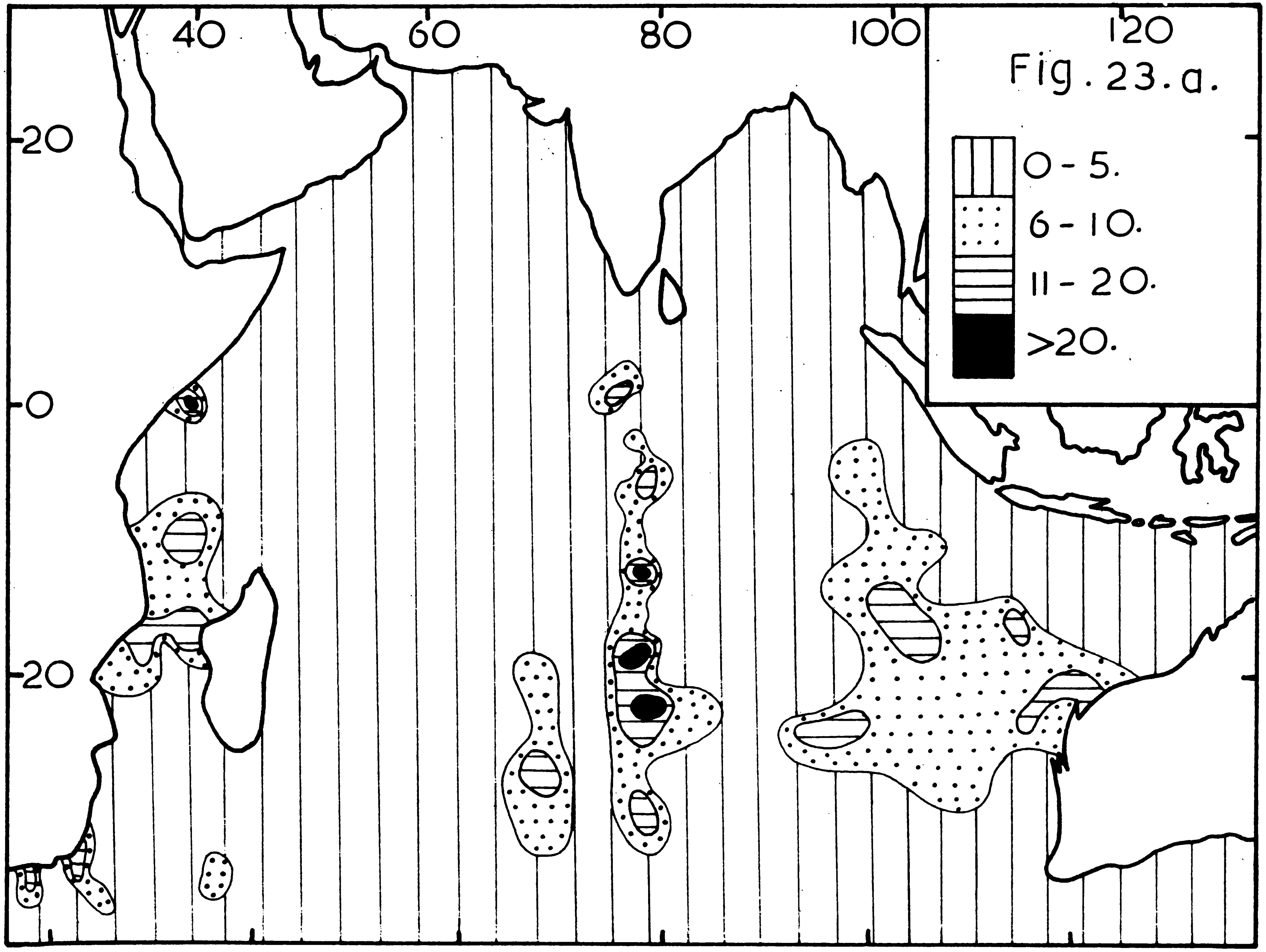
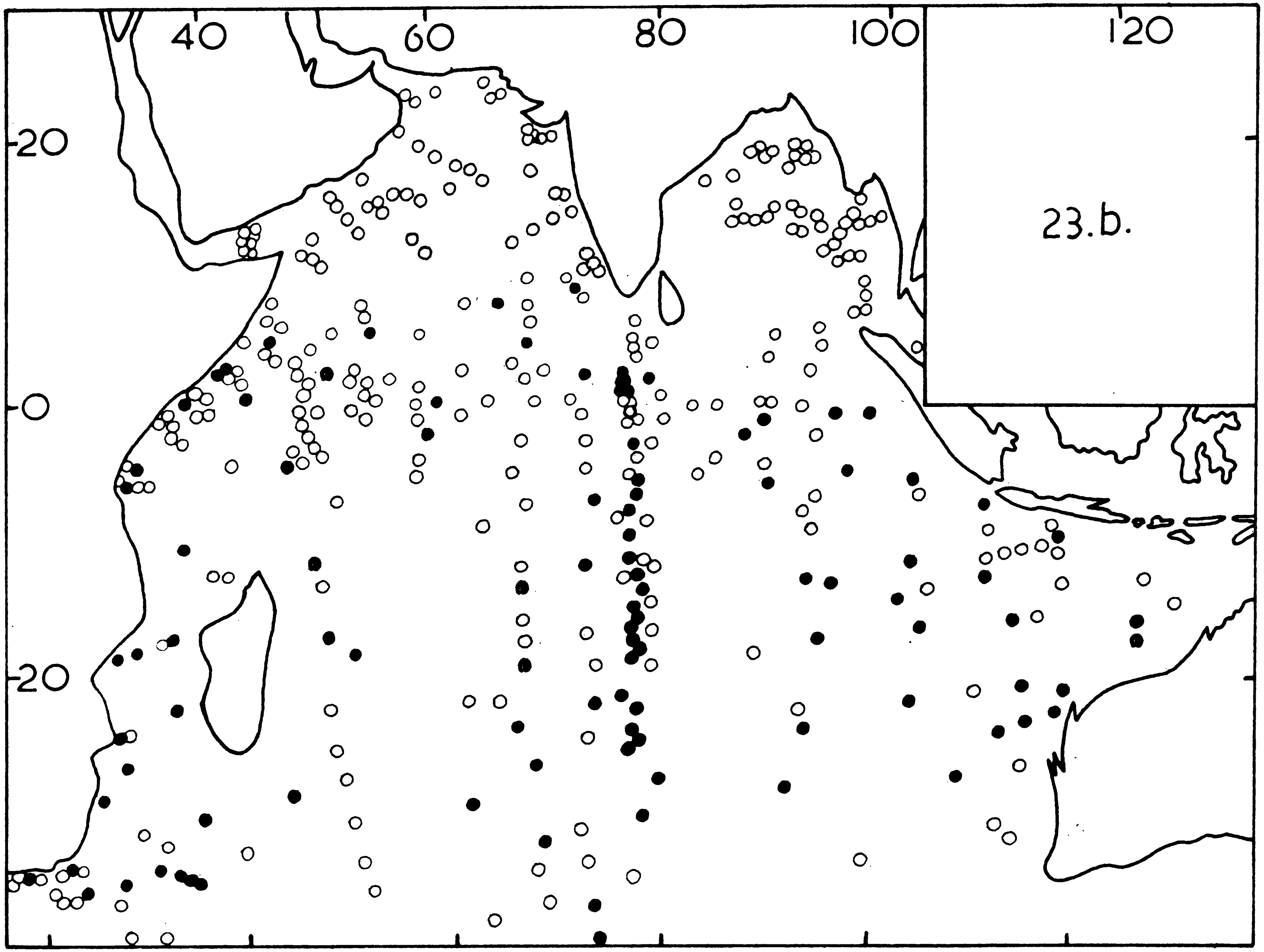


Fig. 23.a.

Fig. 23 b. Distribution of *Lophothrix angusta* in the Indian Ocean.

Closed circles : Present.

Open circles : Absent.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80
100
120
20
0
20
23.b.

totally absent from the upwelling areas of Somalia, Arabia and west coast of India. This may be due to its preference to oxygen rich waters. In Madagascar Channel and generally along east coast of Africa its presence may be attributed to the flow of water from South Equatorial Current. Its abundant occurrence along 75 - 80°E longitude suggested its oceanic nature.

In the Indian Ocean it has been recorded only from off South African coast (De Decker and Mombeck, 1964). Among the other oceans, it has been recorded from northern temperate Atlantic, western Atlantic, coast of Portugal, Bay of Biscay, Gulf of Guinea, Mediterranean, in the Indo-Pacific from Philippines region, Great Barrier Reef, off New Zealand and off San Diego. It is a bathypelagic species which rises to the surface during night.

Scolecithricella marginata.

This species was collected from 53 out of 385 stations studied (Fig. 24). It had a frequency of occurrence of 13.8%. A total of 721 specimens were sorted out. Its numerical abundance varied from 0 - 93, giving an average of 2/haul. It was present in 31 night (17%) and 22 day (11%) stations giving an average of 3 for night and 1 for day stations respectively. Its occurrence in more night stations than in day stations and higher numerical nocturnal abundance was characteristic of the vertical migration undertaken by the species. It was present in 22 stations (13.1%) during the Southwest monsoon and in 31 stations (14.3%) during Northeast monsoon giving an average of 1 and 3 per haul respectively. This indicated its preference for the Northeast monsoon period. Histogram studies revealed a south to north abundance as well as an east to west increase. Compared to the previous species, numerically S. marginata occurred in few numbers. Areas of abundance in the high density range of > 20/haul were located as 5 small patches - one off the coast of Maharashtra, one in Gulf of Cambay, one off Cape Comorin along equator, two in the northern Bay of Bengal and a large patch in the Andaman Sea. High density areas of 11 - 20/haul were located around the above patches in addition to a small patch along 78°E longitude and 5°N latitude. Low density areas of 6 - 10/haul were confined to 6 large patches - one off Maharashtra coast, one off Wadge Bank along the equator, one each in the east and north Bay of Bengal, one in Andaman Sea and one off Sumatra along the equator. Rest of the major India n Ocean were almost devoid of this species. Yet the lowest densities of 0 - 5/haul were present along Mozambique coast, near Java and along 70-80°E longitude near 20°S latitude. S. marginata was generally

Fig. 24 a. Distribution of *Scolecithricella marginata* in the Indian Ocean. Density distribution (in nos).

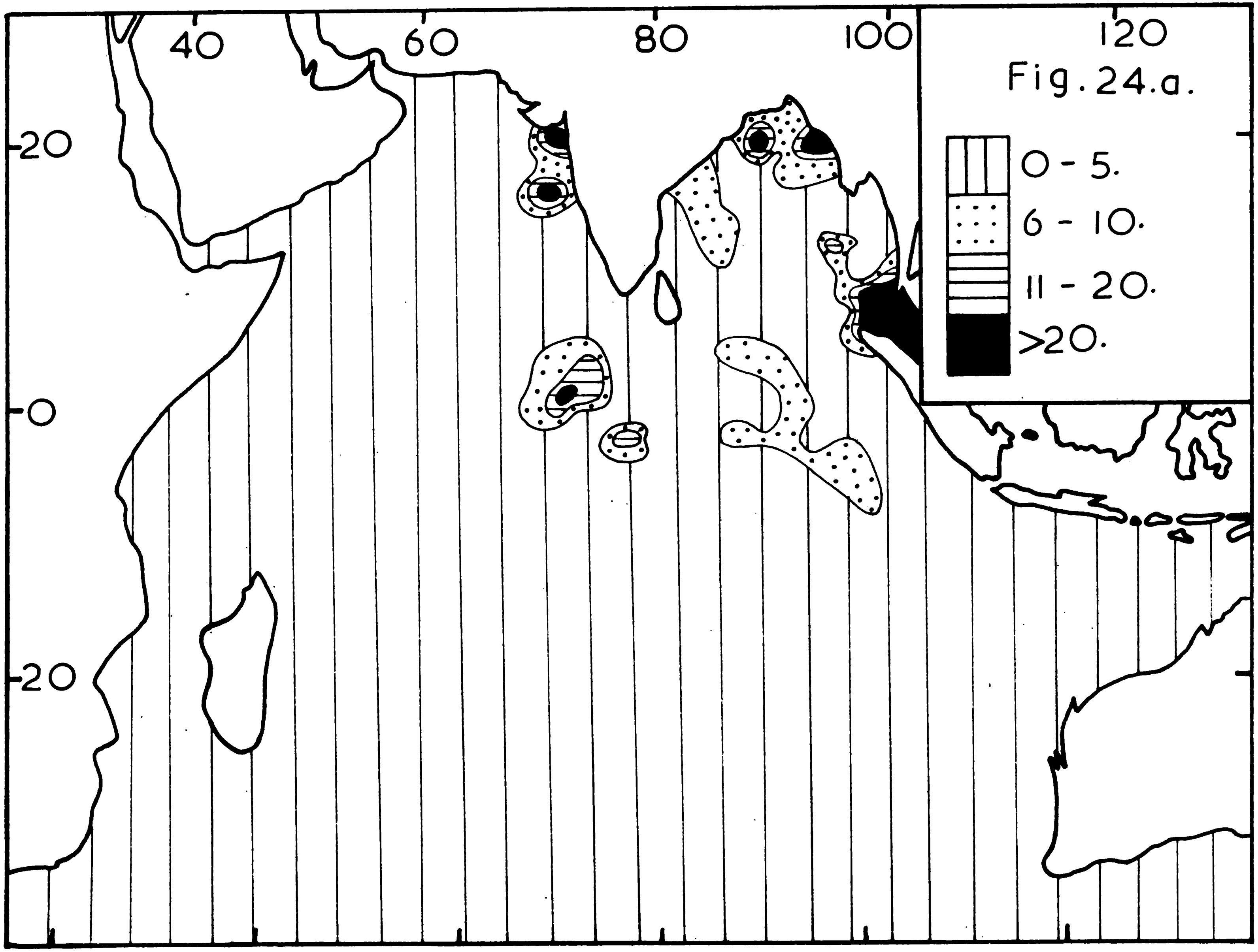
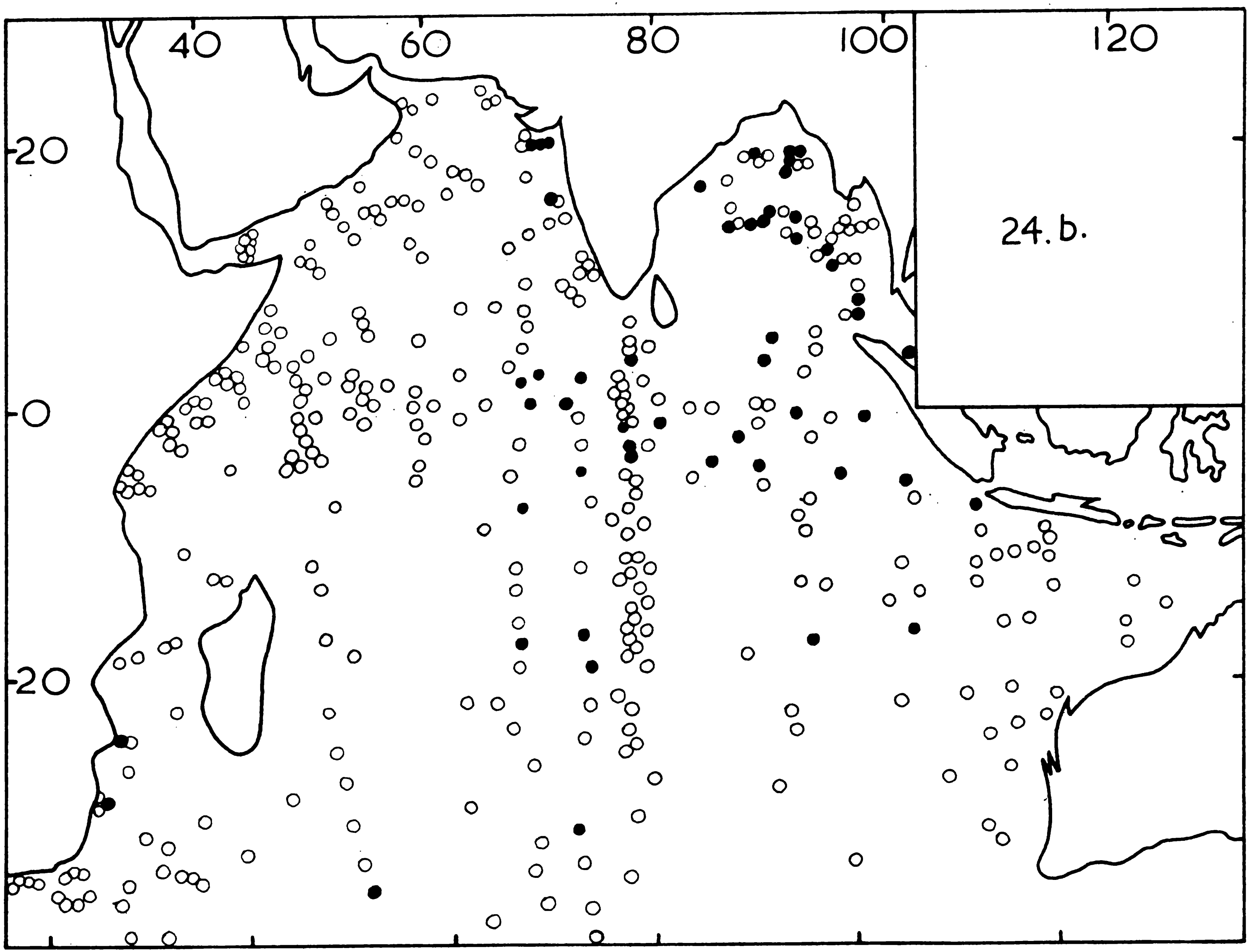


Fig. 24.a.

Fig. 24 b. Distribution of *Scolecithricella marginata* in the Indian Ocean.

Closed circles : Present.

Open circles : Absent.


40
60
80
100
120
20
0
20
24.b.

found in the monsoon gyre of the Indian Ocean up to equator. Its occurrence in the Sub-tropical anticyclonic gyre was rare. In the monsoon gyre it was mainly confined to low saline (30 - 33 ‰) waters of the Bay of Bengal. It was totally absent in the upwelling areas of Somalia and Arabia. Its presence in the Gulf of Cambay may be due to the comparatively low saline waters present there. Thus this species appears to be a stenohaline one as it was generally absent in waters of high salinity except that from high salinity water of Agulhas Current. This may be with the result of expatriation. In Bay of Bengal as the salinity increases in a north-south direction, the species abundance also was reduced in proportion. It was also present in less saline waters off Sumatra.

The first and only record of *S. marginata* from the Indian Ocean was that of A. Scott (1909) from the Malay Archipelago (Indo-Pacific). This species was also reported from the equatorial Pacific.

Amallothrix indica.

The distribution of this species is illustrated in Fig. 25. This species had a frequency of occurrence of 8.6% as this was obtained from only 32 stations out of 385. A total of 539 specimens were identified. Its numerical abundance varied from 0 - 91 with an average of one per station. Of the 539 specimens 387 were collected during night and 152 during day time. It was present in 28 (15%) night hauls and 5 (0.02%) day hauls, giving an average of 2 and 1 respectively. Barring the single day station with 91 specimens, its occurrence during day hauls was found rare. This indicated its nocturnal abundance and subsequent vertical migration. As such it was epipelagic and bathypelagic in occurrence. A. indica was obtained from 13 out of 168 stations during Southwest monsoon and 20 out of 217 stations during North-east monsoon. A total of 268 and 271 specimens were collected during the two seasons respectively. Thus North-east Monsoon showed a slightly higher production. Histogram studies revealed an increase towards north and from east to west. It occurred in high densities (>20/haul) as 3 patches - one off Maharashtra coast, one small patch in the central Bay of Bengal and one in the Andaman Sea. Extended areas around the above patches and a patch along 20°S latitude in the central Indian Ocean covered the next high density (11-20/haul) areas. Low density areas (6-10/haul) occupied central Arabian Sea, a long patch extending from southern tip of India to equator and a large patch covering north eastern Bay of Bengal. Very low density areas (< 5/haul) extended to areas north of 10°N in the Arabian Sea and Bay of Bengal, and equatorial region along 80°E longitude, above equator. From the distribution this appears to be purely an endemic species restricted to northern Indian Ocean north of equator. Its geographical centres of abundance was in the Arabian Sea, Bay of Bengal and north of equator. A. indica was mainly confined to the northern part of the monsoon gyre of the Indian Ocean. Its distribution was controlled by the cyclonic and anticyclonic circulation of the Arabian Sea and the Bay of Bengal. In spite of the hydrographical differences noted for the Arabian Sea and Bay of Bengal waters, its occurrence in both waters showed its ability to tolerate wide fluctuations during migratory movements. It was mainly occupants of the sub-surface and North Indian Ocean High Salinity Waters of the meso and bathypelagic regions. It was rare in the upwelling areas.

A. indica has originally been described from the Laccadive Sea (Sewell, 1929). It has also been described from the northern and central part of the Arabian Sea (Sewell, 1947) and from western Indian Ocean (Grice and Hulsemann, 1967).

Fig. 25 a. Distribution of *Amallothrix indica* in the Indian Ocean. Density distribution (in nos.).

Fig. 25 a. Distribution of *Amallothrix indica* in the Indian Ocean. Density distribution (in nos.).

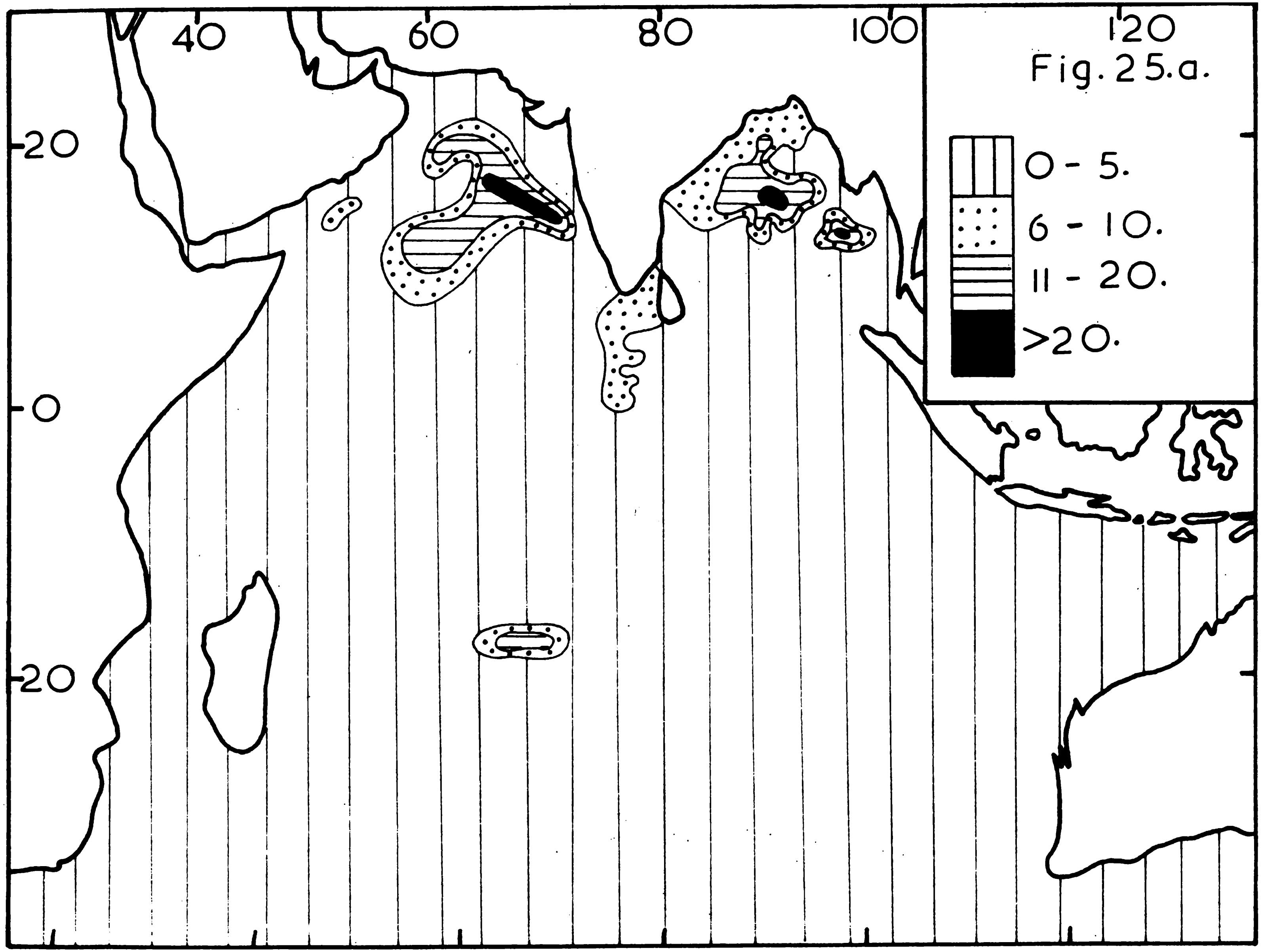
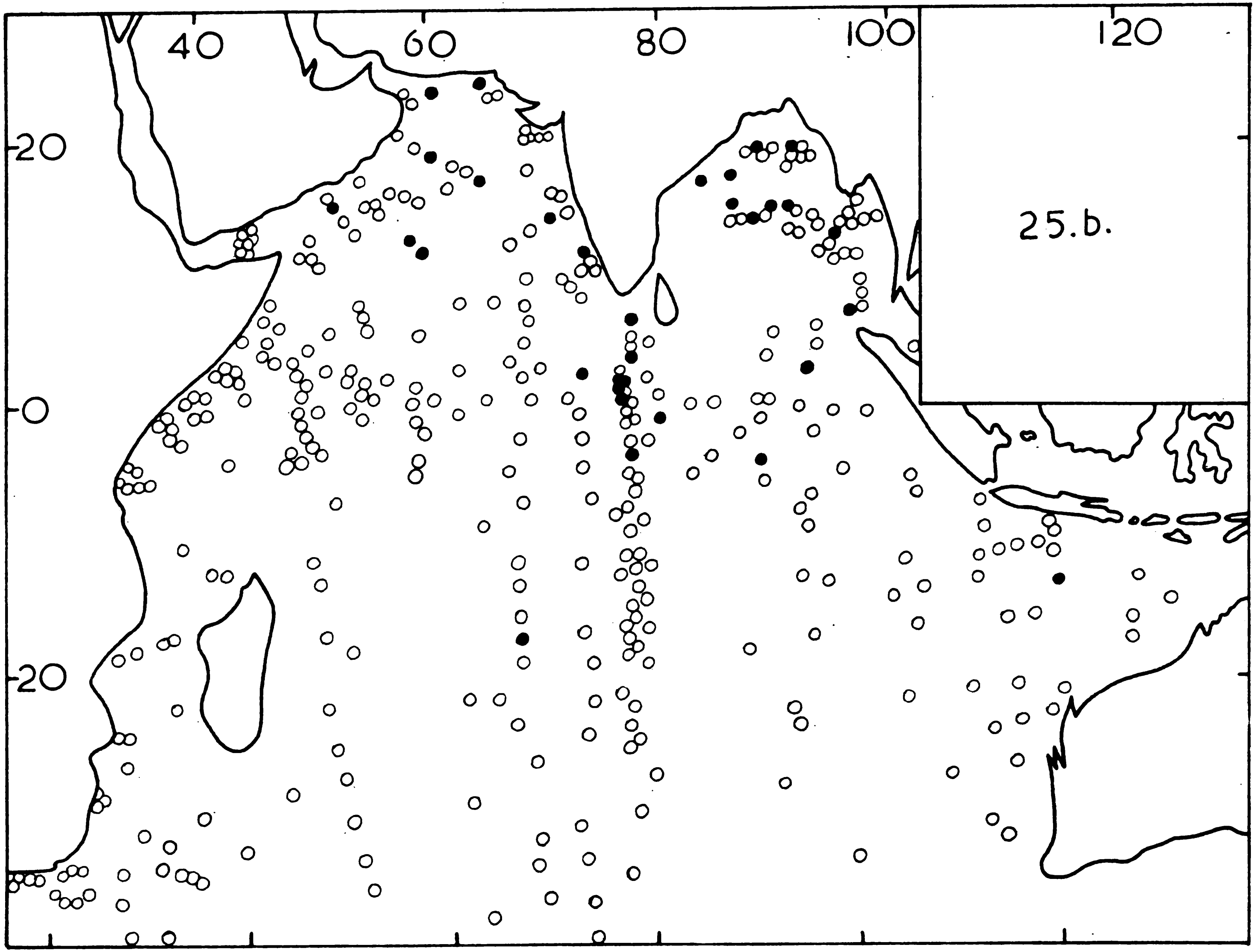

40
60
80
100
120
Fig. 25.a.
20
0
20
0 - 5.
6 - 10.
11 - 20.
>20.

Fig. 25 b. Distribution of *Amallothrix indica* in the Indian Ocean.
Closed circles : Present.
Open circles : Absent.


25.b.
40
60
80
100
120
20
0
20

Scolecithricella vitata.

This species is present in 65 out of 385 stations in the Indian Ocean. The frequency of occurrence is 17.1% (Fig. 26). A total of 375 specimens were identified. Its abundance varied from 0 - 29 giving an average of one per haul. Of the 375 specimens 189 (50%) were collected during night and 186 (50%) during day hauls, giving an average of one each for night and day. It was present in 36 night (20%) and 30 day (15%) hauls. These observations indicated *S. vitata* as a non-migrant near surface species, abundant in euphotic zone. *S. vitata* occurred in 22 stations (13%) during Southwest monsoon and in 44 stations (20%) during Northeast monsoon; 106 specimens during Southwest and 269 specimens during Northeast monsoons respectively; their mean being less than one and more than one. Thus seasonal abundance showed an increase in Northeast monsoon. Histogram studies revealed an increase towards southern areas, as much from east to west.

The areas with highest densities (20/haul) were located as 5 small patches - near Cape Guardafui, in the south Mozambique Channel, off north east coast of Madagascar, north west Australia and near Cocos Island. Areas surrounding the above patches, in addition to a patch off south-eastern coast of Madagascar and off Perth showed high densities of 11 - 20/haul. Low density (6 - 10/haul) areas were located as 6 small patches - along African coast near Port Elizabeth and near Mogadishu, in the southern Mozambique Channel, south of Java, as 3 small patches along 80°E longitude and a patch covering the west coast of Australia. Rest of the Indian Ocean were occupied by lowest density of less than 5 per haul. The species was not present north of equator including Arabian Sea and Bay of Bengal.

S. vitata was not represented in the upwelling areas of northern monsoon gyre. It was mainly present in the circulation of sub-tropical central gyre. Its southern boundary coincided with the high salinity water of southern sub-tropical gyre. It was rarely present north of equator. This species preferred Indian Ocean Central Water Mass of high oxygen and poor nutrients. It preferred a salinity range of 34.5 - 35.5 ‰. Earlier record of this species from the Indian Ocean is from off the South African Coast only (De Decker and Mombeck, 1964). It has been recorded from Bay of Biscay, Atlantic, Mediterranean, Great Barrier Reef of Australia, equatorial Pacific and Japanese waters. It was a more or less deep water species coming to the surface during night.

Fig. 26 a. Distribution of *Scolecithricella vitata* in the Indian Ocean. Density distribution (in nos.).

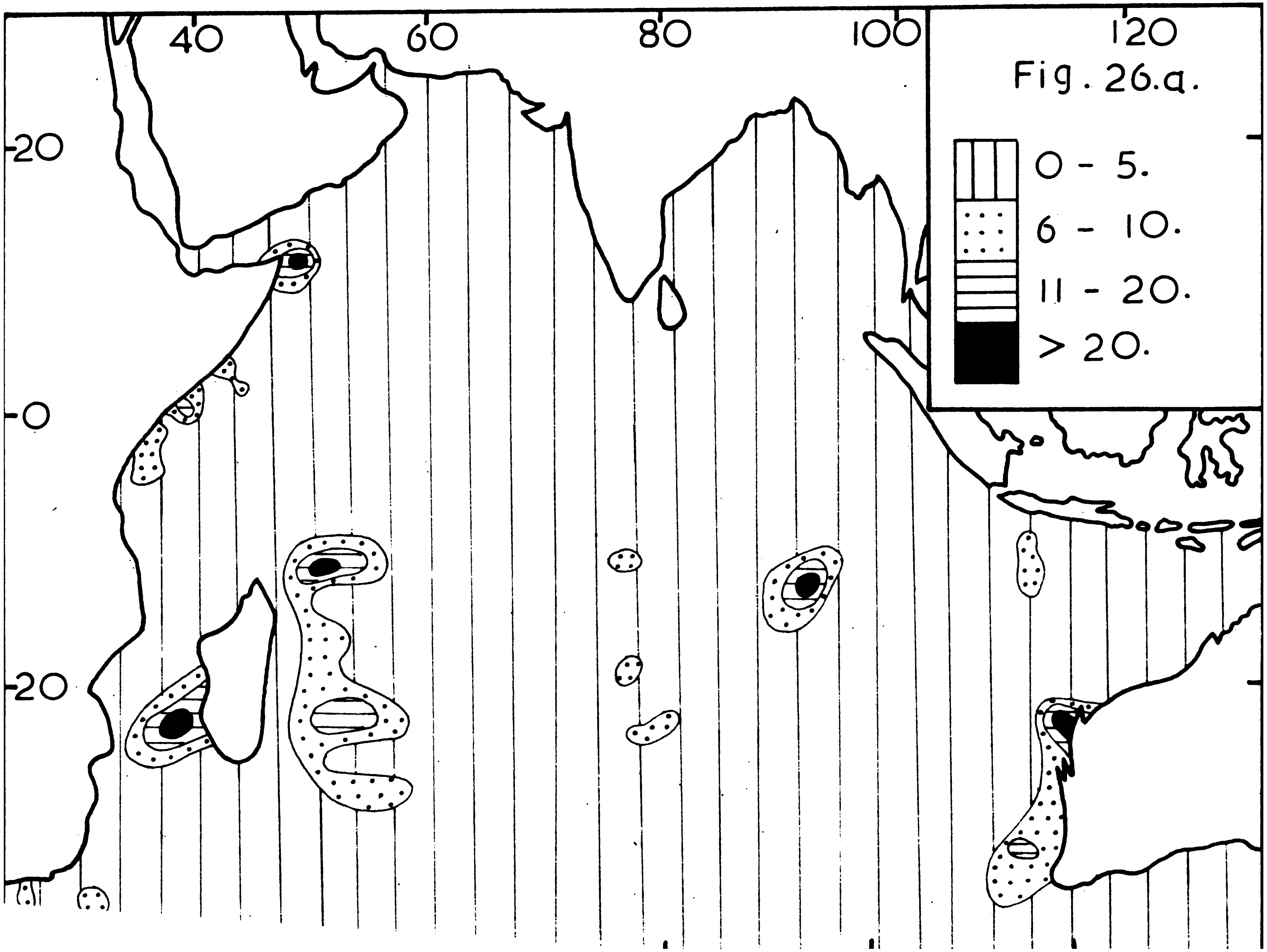
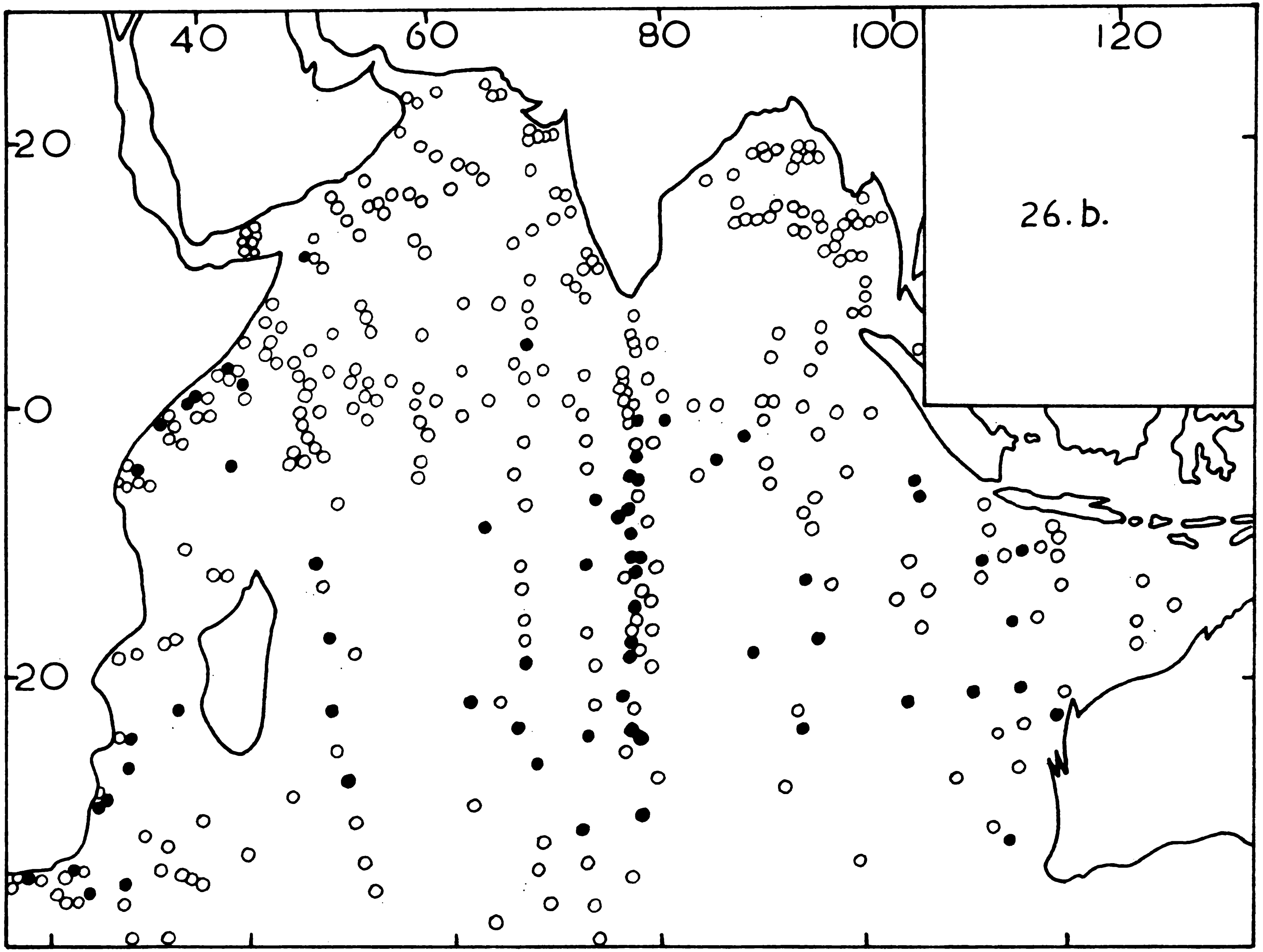

40
60
80
100
120
20
0
20
Fig. 26.a.
0 - 5.
6 - 10.
11 - 20.
> 20.

Fig. 26 b. Distribution of *Scolecithricella vitata* in the Indian Ocean.
Closed circles : Present.
Open circles : Absent.



26.b.

Scottocalanus dauglishi.

The distribution and abundance of this species is shown in Fig. 27. A total of 364 specimens were identified from 385 stations giving an average of one per station. Its frequency of occurrence was 7.3% being an endemic species. Its numerical abundance varied from 0 - 38. Of the 184 night collections it was present in 26 (14%) with an average of 2 per night haul having collected 331 specimens at night. During day time only 33 specimens were collected from 2 day hauls (1%) out of the total of 201 day stations. The collection of 91% of specimens during night indicated its almost nocturnal abundance and the large scale nocturnal vertical migration undertaken. Of the 364 specimens collected 273 (75%) were during Northeast monsoon and only 91 (25%) were collected during Southwest monsoon. It was present in 18 out of 217 stations of Northeast monsoon and in 10 out of 168 stations of Southwest monsoon. This revealed its slight abundance during the Northeast monsoon. Histogram studies showed its abundance north of equator and a west to east increase. The high density (>20/haul) areas were confined as small patches off Somalia near equator, along north Arabian coast, 3 patches in the Andaman Sea and as a large patch south of peninsular India. The next high density range (11-20/haul) occurred in the south central Arabian Sea, in addition to surrounding high density areas shown above. Low density areas (6-10/haul) occurred off Mogadishu, off south western tip of India and in the Andaman Sea. The lowest density of less than 5/haul was confined to 20°S latitude along 70°E longitude. Thus the species was totally absent in the rest of the Indian Ocean especially south of equator. It was totally absent in upwelling areas other than Arabian coast. Its geographical centre of abundance was confined to Arabian Sea and along 78°E longitude south of India upto equator. The species was confined to limited areas of monsoon gyre of the Indian Ocean. Distribution was mainly controlled by the north equatorial current. Being almost nocturnal it was the inhabitants of the North Indian Ocean high salinity intermediate waters and deep waters. It preferred low saline Bay of Bengal waters more than high saline surface waters of the Arabian Sea.

This species is originally described from the Indian Ocean - in the Laccadive Sea (Sewell, 1929) and from the western Indian Ocean (Grice and Hulsemann, 1967). S. dauglishi is endemic to Indian Ocean.

Fig. 27 a. Distribution of *Scottocalanus dauglishi* in the Indian Ocean. Density distribution (in nos.)

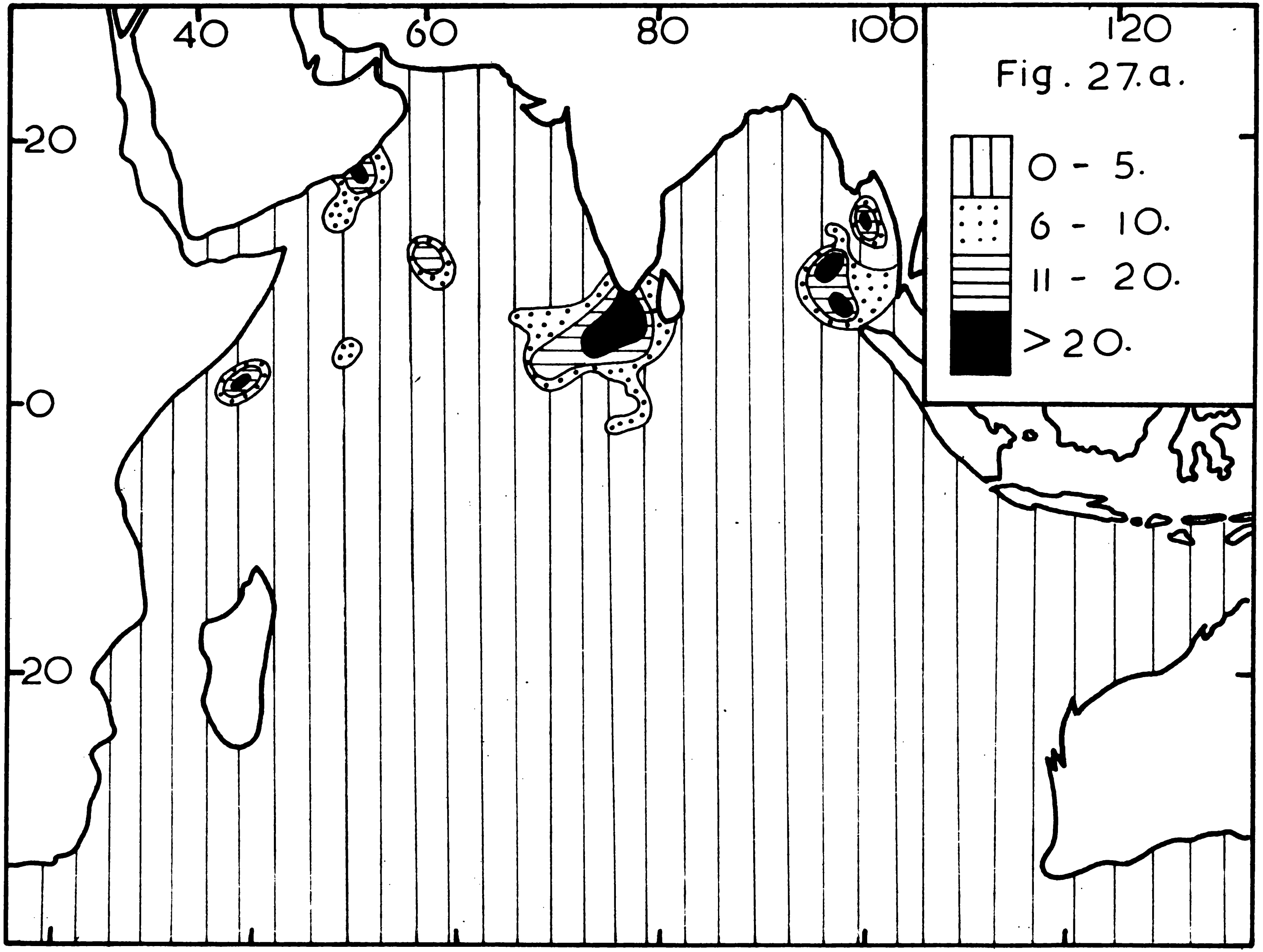
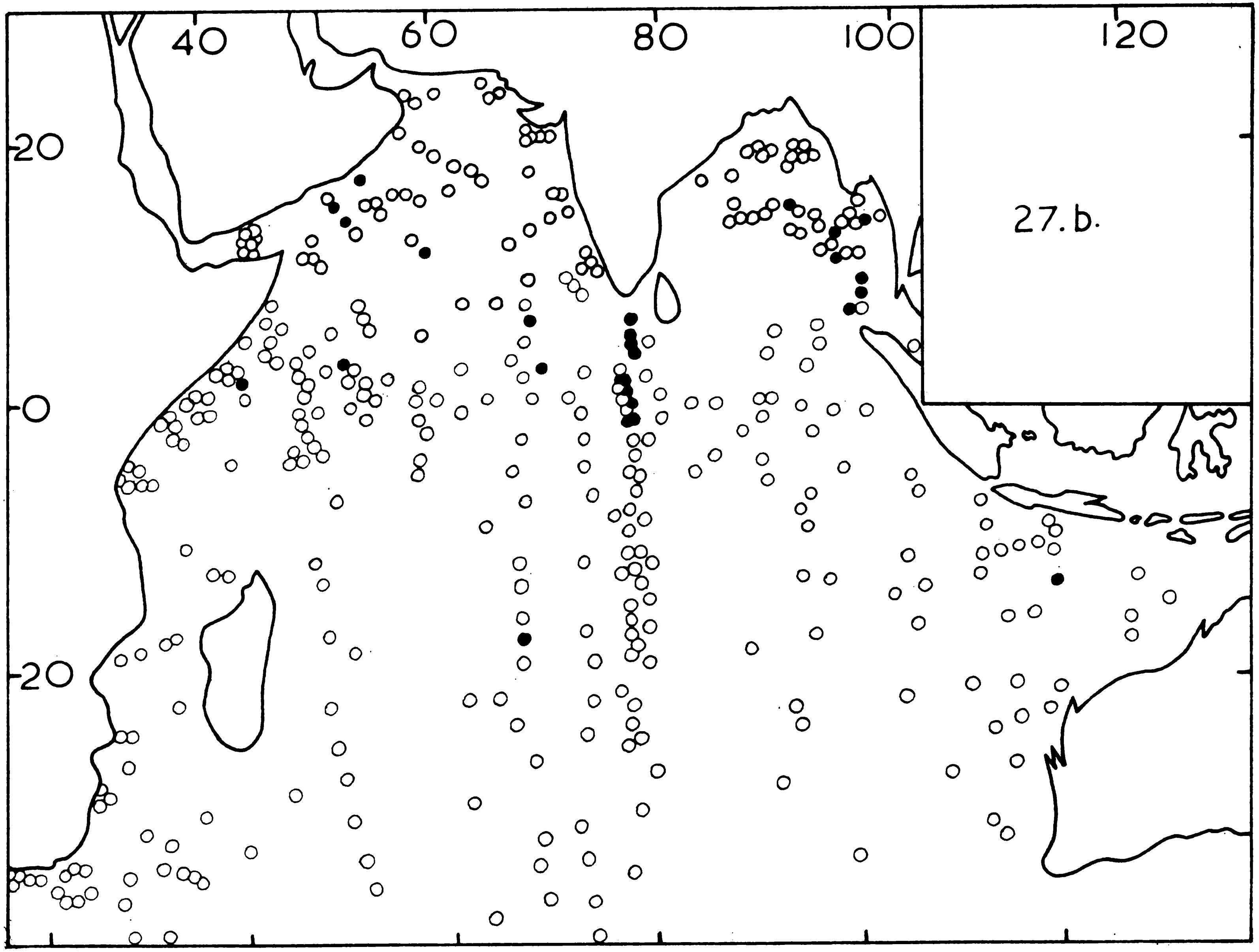


Fig. 27.a.

Fig. 27 b. Distribution of *Scottocalanus* *dauglishi* in the Indian Ocean.
Closed circles : Present.
Open circles : Absent.



27.b.

Scottocalanus securifrons.

The distribution and abundance of this species is shown in Fig. 28. This species was present only in 38 out of 385 stations having a frequency of occurrence of 11.2%. In all 325 specimens were identified. Its numerical abundance varied from 0 - 66 with an average number of one per haul. Of the 325 specimens only 6 were collected during day haul whereas 319 were from night hauls. It was caught only from one day station whereas it was present in 42 (23%) night stations. This distribution clearly demonstrated its noctumal abundance in the meso and bathypelagic zones and rare presence in the epipelagic zones during day time. While Southwest monsoon contributed 64 specimens from 168 stations, 261 specimens were from 217 stations of Northeast monsoon.

This indicated higher occurrence during Northeast monsoon. Histogram studies showed an increase from south to north with its peak between equator and 10°Nlatitude and east to west. Two small patches representing highest density of > 20/haul were located - one near equator along Somali coast and another off Somali along 55°E longitude. The next grade of high density (11-20/haul) covered a small patch along the equator near Somali coast, 2 patches offshore of Somali coast, one patch in the central western Indian Ocean and another patch along 80°E longitude and 35°S latitude. The low intensity range of 6 - 10/haul was represented by 12 patches located at southern end of South Africa, in the Mozambique coast, Kenya coast, off Somali coast, 3 oceanic patches along the equator and 2 patches in the Timor Sea. Rest of the Indian Ocean was represented by the lowest gradient (0-5/haul). The species was conspicuously absent in the Arabian Sea (except Gulf of Aden) and Bay of Bengal. This species having almost nocturnal abundance is an inhabitant of deep waters. It preferred warm tropical waters from equator to 20°S. It was present in large numbers in the subsurface salinity maximum waters extending throughout the Subtropical Anticyclonic Gyre. Its presence in the Gulf of Aden high saline waters revealed its occurrence in the subsurface salinity maximum of Arabian Sea water also.

Previous records of this species in the Indian Ocean are from the central and southern parts of the Arabian Sea (Sewell, 1947), off South Africa (Cleve, 1904a, De Decker and Mombeck, 1964) and Malay Archipelago (A. Scott, 1909). This species has a wide distribution in the other oceans and has been reported from Pacific, Atlantic, Far Eastern and Polar Seas and Japanese waters. This has been recorded previously as an inhabitant of deep and intermediate water layers.

Fig. 28 a. Distribution of *Scottocalanus securifrons* in the Indian Ocean. Density distribution (in nos.).

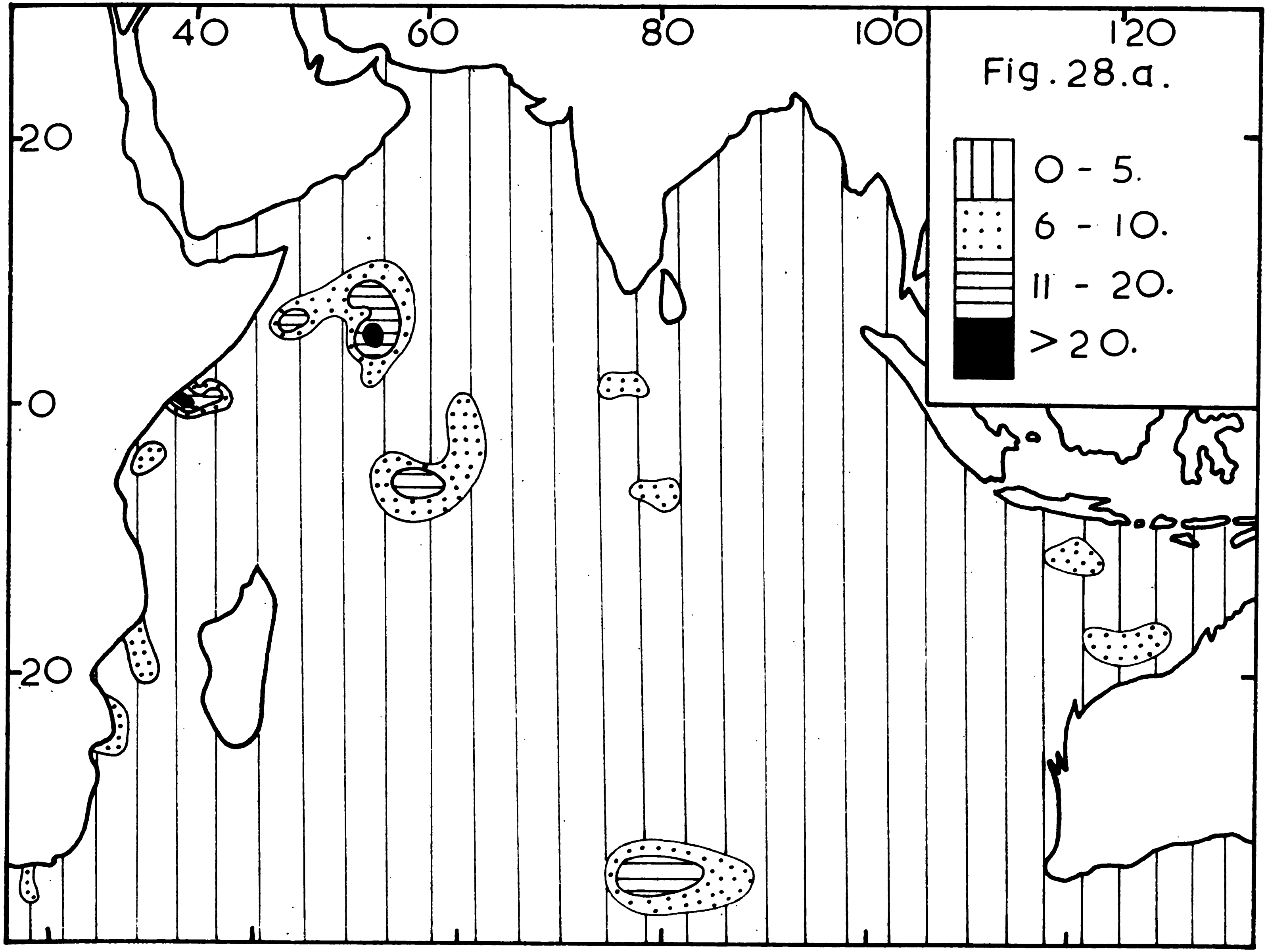
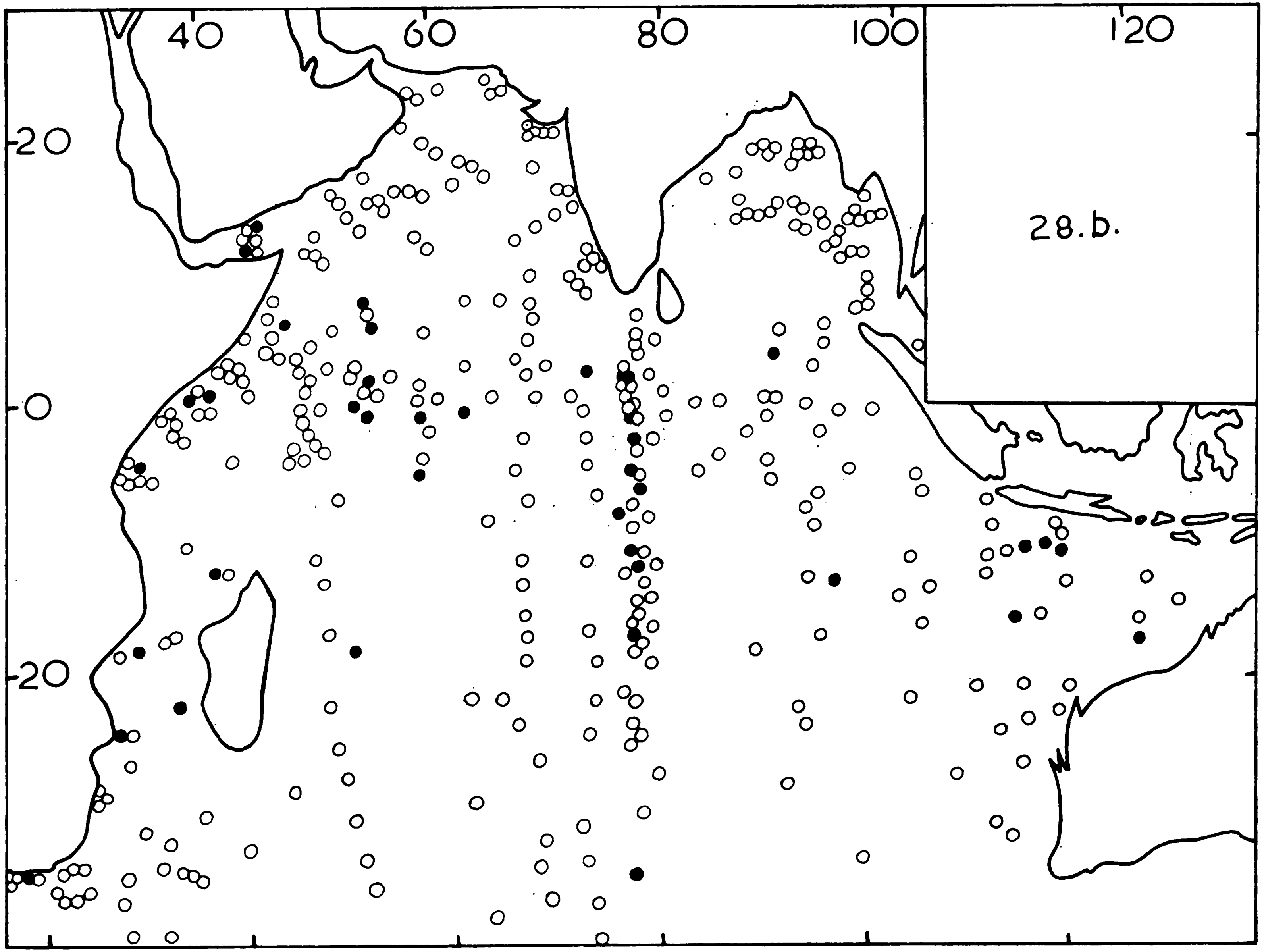


Fig. 28.a.

Fig. 28 b. Distribution of _Scottocalanus securifrons_ in the Indian Ocean.

Closed circles : Present.

Open circles : Absent.


40
60
80
100
120
20
0
20
28.b.

Scolecithricella ovata.

The abundance and distribution of this species is shown in Fig. 29. This species having a frequency of occurrence of 14.3%, sorted out only from 55 stations out of 385. A total of 316 specimens were obtained. Its numerical abundance varied from 0 - 17 with an average of about one per haul. Of the 316 specimens 221 were collected during night hauls while day hauls had only 95 specimens. It was present in 34 (18%) night and 21 (10%) day stations. Low frequency of occurrence in total stations (14.3%) and high frequency of occurrence in night stations indicated that the species was not widespread in the epipelagic zone. Its low nocturnal occurrence revealed a sparse population only. This species underwent vertical migrations. *S. ovata* was present in 17 stations (9%) during Southwest monsoon and 38 stations (19%) during Northeast monsoon. Seventy five specimens (24%) and 241 specimens (76%) were its numerical abundance during the Southwest and Northeast monsoons respectively. This indicated abundance of *S. ovata* during the Northeast monsoon. Histogram studies revealed equatorial abundance and gradual increase from south to equator and east to west. The high density patches (> 15/haul) occurred in the Mozambique Channel, along equator near Somali coast and off southern tip of India and off the coast of Perth. High density (11-15/haul) patches were located as small patches surrounding the above patches. Ten small patches along the equator and north of 10°S showed low densities of 6 - 10/haul. Rest of the equatorial area was represented by very low densities of < 5/haul. But for the equatorial waters the species was totally unrepresented in the northern and southern Indian Ocean. From the distribution it appears to be an Indo-Pacific species. This was mainly found in the southern areas (equatorial zone) of monsoon gyre and only 6 occurrences were recorded from the subtropical gyre. The hydrographic front along 10°S almost restricted its distribution south of this front. The areas of abundance was characterised by low oxygen and high nutrient waters. It mainly occurred in the equatorial counter current, Java coastal current, upper part of south equatorial current. The species was rarely present in upwelling areas. In the mesopelagic region it was abundant in the north Indian Ocean high salinity intermediate waters. Temperature cannot be easily invoked as one determining the geographic distribution of vertically migrating mesopelagic ones.

S. ovata has been previously recorded from the Indian Ocean by Grice and Hulsemann (1967). Among other regions

Fig. 29 a. Distribution of *Scolecithricella ovata* in the Indian Ocean. Density distribution (in nos.)

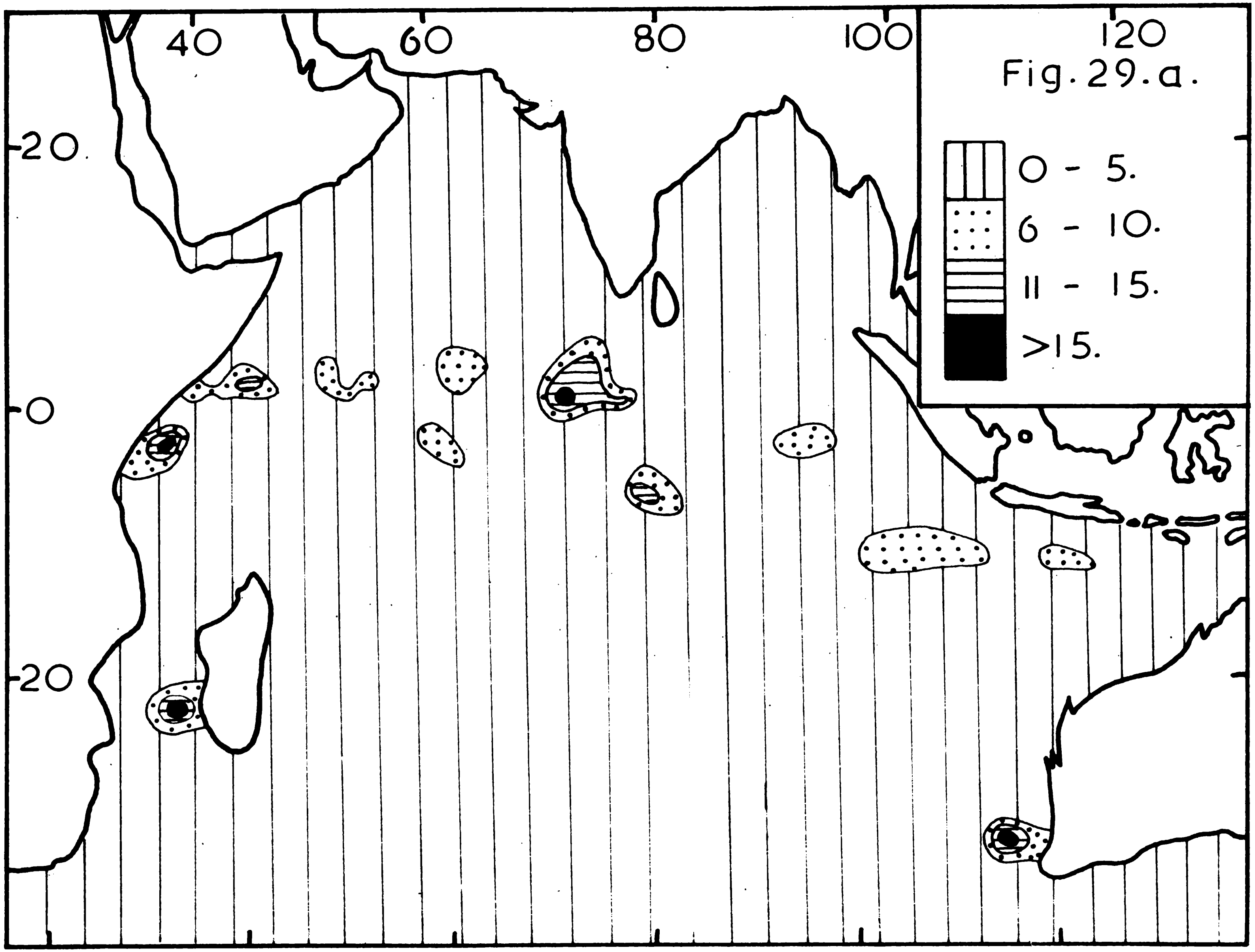
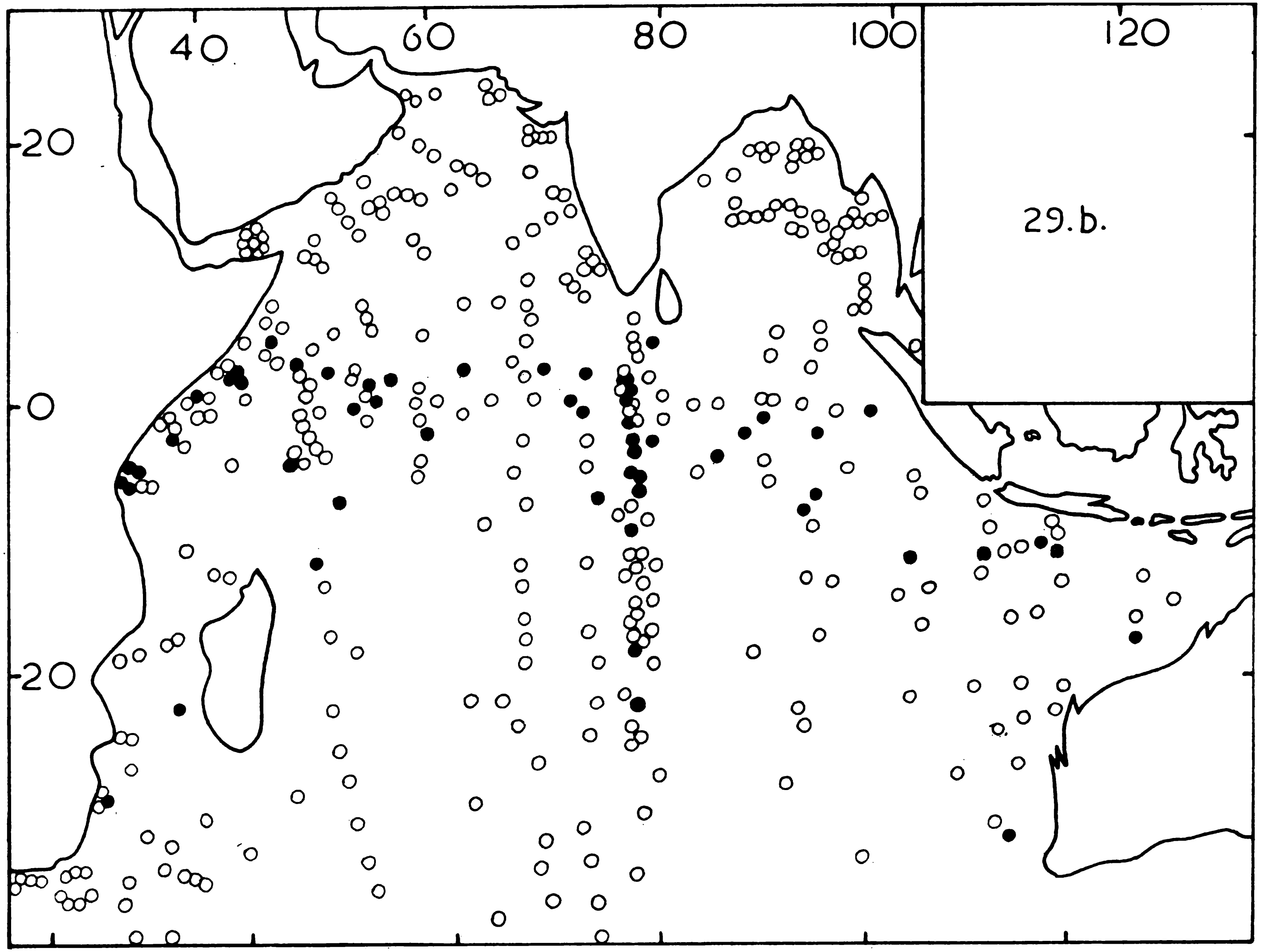


Fig. 29.a.

ig. 29 b. Distribution of *Scolecithricella ovata* in the Indian Ocean.
Closed circles : Present.
Open circles : Absent.


40
60
80
100
120
20
0
20
29.b.

it has been reported from Atlantic, South Pacific, Antarctic, far eastern and Polar Seas and Japanese waters. It is inhabitant of deep and intermediate waters.

Scaphocalanus longifurca.

This species was a rare species collected from only 11 stations out of 385 with a frequency of occurrence of 2.9% (Fig. 30 a). In all 234 specimens were collected. It was present in 5 night (2.7%) and 6 day hauls (3%). While 160 specimens (68%) were collected from 5 night hauls only 74 specimens (32%) were obtained from 6 day hauls. In general it was abundant in night hauls compared to day hauls. Its numerical abundance in many stations indicated its tendency to occur in swarms.

Of the 234 specimens 68 (29%) were obtained during Southwest monsoon whereas 166 (71%) were from Northeast monsoon. This indicated higher production during Northeast monsoon period. It was present in 3 out of 168 stations during Southwest monsoon and 8 out of 217 statio during Northeast monsoon. Histogram studies showed an increasing trend from west to east and south to north.

The geographical areas of abundance were confined to Gulf of Oman, off Karachi, off Kerala coast and northern Bay of Bengal. This species was restricted to northern part of monsoon gyre of the Indian Ocean. It was present in 2 stations in the upwelling areas of Arabia. Its occurrence in the high salinity waters of northern Arabian Sea and low salinity waters of central and northern Bay of Bengal indicated its ability to adjust to waters of salinity 33 - 37 ‰. It was mainly present in the cyclonic and anticyclonic circulation of waters of Bay of Bengal. Its occurrence along the Kerala coast was due to flow of Bay of Bengal waters to eastern Arabian Sea during North-east monsoon. From the distribution map this species appeared to be endemic to northern Indian Ocean waters of tropical area, with respect to Indian Ocean. As it undergoes vertical migrations it was an inhabitant of the North Indian Ocean high salinity intermediate waters occupying in depths of 150 - 900 m.

The previous record of this species from the Indian Ocean was that of Grice and Hulsemann (1967) from the western Indian Ocean only. It is widely distributed in north Pacific and Izu Region of Japan.

Scaphocalanus affinis.

This is also a rare species having collected from only 15 (3.8%) stations out of a total of 385 (Fig. 30 a). In all 93 specimens were identified, 83 (89%) of which were during night hauls and only 10 (11%) specimens during day hauls. Of the 15 stations in which it was present only one day station got 10 specimens, whereas rest of the 83 specimens occurred in 14 night stations. This revealed its almost exclusive nocturnal abundance, by way of vertical migrations from the intermediate and bottom waters. Season-wise study showed 58 specimens (62%) from 8 out of 168 stations during Southwest monsoon and 35 specimens (38%) from 7 out of 217 stations during Northeast monsoon. This indicated its abundance during Southwest monsoon. Histogram studies revealed a south to north increase as well as a west to east increase. S. affinis was present in the monsoon gyre circulation of the Indian Ocean mainly confined to the low salinity waters of northern Bay of Bengal and high salinity waters in areas south of peninsular India upto 10°S. It was totally absent in areas of the hydrochemical front at 10°S. But for 2 records one off Arabian coast and one near Mombasa along the coast of Africa rest were confined to northeastern Indian Ocean. It was very rare in upwelling areas. It was seen in the Equatorial Counter Currents and monsoon currents. Being a migratory species it was confined to the North Indian Ocean high salinity waters in depths of 150 - 900 m, with a temperature varying from 22 - 26°C. This species was restricted to northern tropical Indian Ocean and Arabian Sea and Bay of Bengal waters characterised by high nutrient, low oxygen waters at the surface.

__Fig. 30 a__. Distribution of (I) __Scaphocalanus affinis__
(II) __Scaphocalanus longifurca__
in the Indian Ocean.

(Nos. indicate the number of specimens at each Stns.)

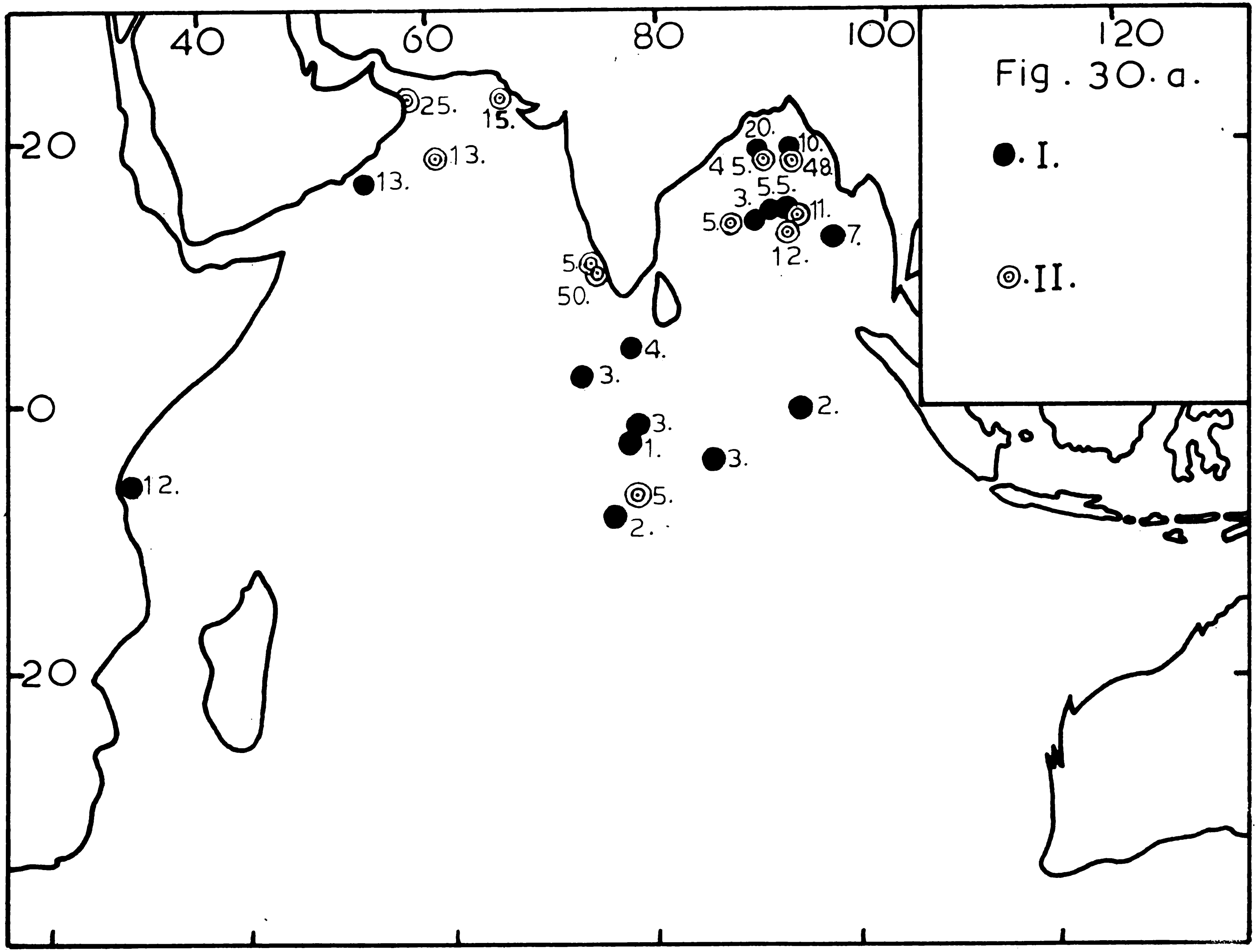


Fig. 30.a.

● I.
◎ II.
40
60
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100
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20
0
20
25.
15.
13.
13.
12.
5.
50.
20.
10.
4
5.
48
5.5.
3.
11.
5.
12.
7.
4.
3.
2.
3.
1.
3.
5.
2.

This species was previously recorded from the Indian Ocean from the Laccadive Sea and central Arabian Sea (Sewell, 1929), western Indian Ocean (Grice and Hulsemann, 1967), south of Madagascar (Wolfenden, 1911) and Malay Archipelago (A. Scott, 1909). Other areas of distribution were North Atlantic (region of Asores and Canary Islands), Gibralter, Gulf of Gascony, Antarctic, South Atlantic, in Pacific northwestern part, the southern part of the sea of Okhotsk, Isu Region of Japan.

Scolecithricella tropica.

This species was identified from only 12 stations (Fig. 30 b) out of 385 having a frequency of 3.1%. It was present in 7 night (3.5%) and 5 day (2.5%) stations. A total of 95 specimens were collected of which 28 (29%) belonged to night stations and 67 (71%) to day stations. Of the 95 specimens 66 (70%) belonged to Southwest monsoon and 29 (30%) to Northeast monsoon. It was collected from 5 stations out of 168 during Southwest monsoon period and 7 stations out of 217 during Northeast monsoon period. Histogram studies revealed an increase to east from west and to south from north. Areas of geographical abundance were confined to south west coast of Africa, Andaman Sea, south of Java and northwestern coast of Australia. Off

Java numerical abundance was very high (50/haul) indicating patchiness. It was present in the seasonally changing monsoon gyre and subtropical anticyclonic gyre circulation. It was associated with North Equatorial Current, Monsoon Current, South Equatorial Current, Java Coastal Current and Agulhas Current. It was not recorded from upwelling areas of western boundary currents of Indian Ocean. Though numerical abundance was very low, it was wide spread.

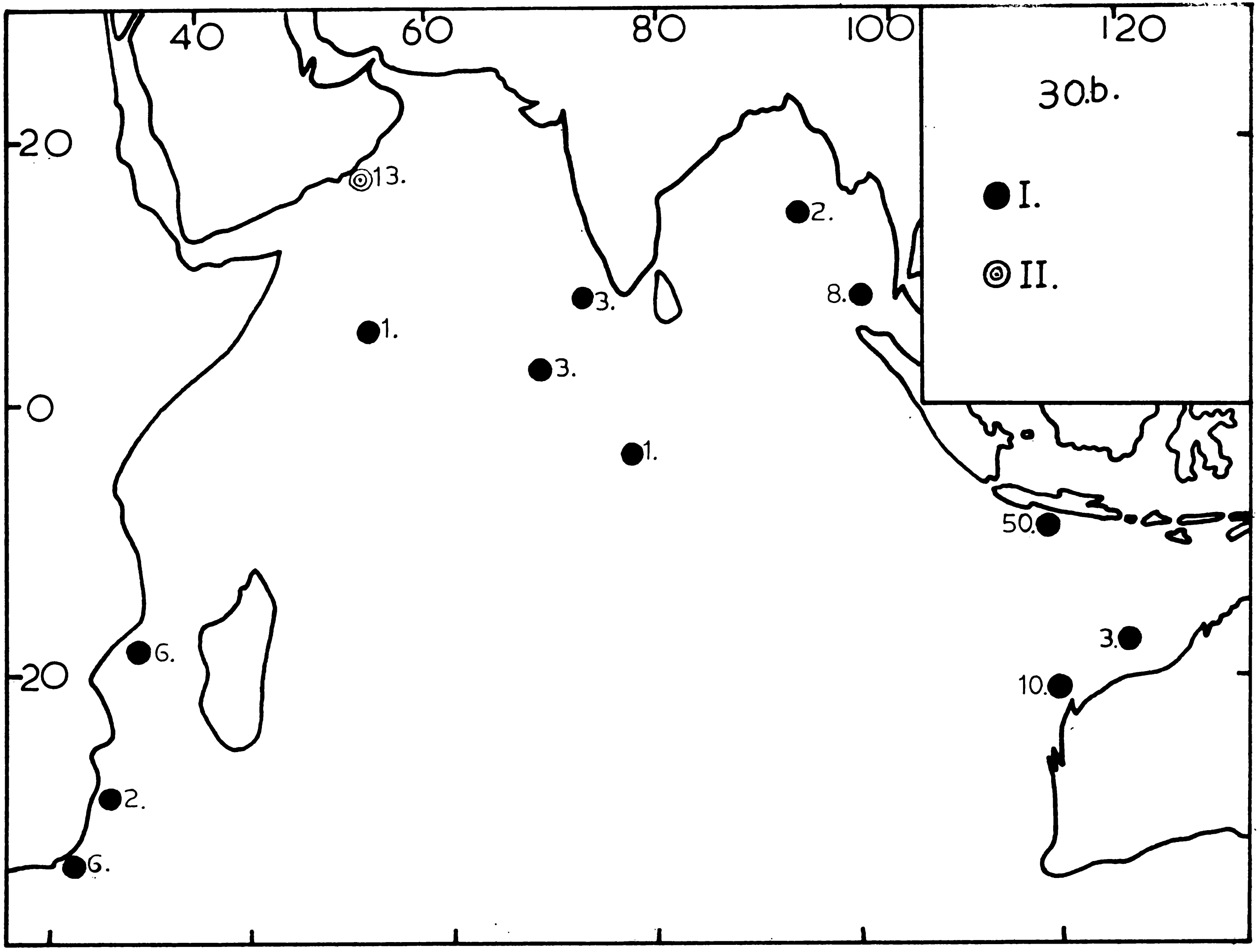
S. tropica has been previously reported from the central and southern Indian Ocean, which was the first record of this species from this area, the description of which was based on the same IIOE material (Gopalakrishnan, 1974). It has been originally described from the equatorial waters of the Pacific (Grice, 1962). *Scolecithricella beata* Tanaka (1962) from the Izu Region Japan can be considered as a synonym of this species.

Amallothrix arcuata.

This species was identified from only a single station located at 17°18'N and 57°09'E in the Arabian Sea. Thirteen specimens were obtained, (Fig. 30 b) sampled by "Discovery" at night during the Southwest monsoon period in the month of July 1963. The station

Fig. 30 b. Distribution of (I) *Scolecithricella tropica*
(II) *Amallothrix arcuata*
in the Indian Ocean.

(Nos. indicate the number of specimens at each Stn.)


30.b.
● I.
◎ II.
40
60
80
100
120
20
0
20
◎13.
1.
3.
3.
1.
2.
8.
50.
3.
10.
6.
2.
6.

was located in the upwelling area of Arabia. The temperature in the station varied from 23.62°C at surface to 15.06°C at 200 m depth. Similarly salinity values varied from 35.76 to 35.57 ‰. Oxygen values decreased from 4.25 ml/l at surface to 0.25 ml/l at 148 m depth.

This species has been previously recorded from the Indian Ocean, from the Laccadive Sea (Sewell, 1929), central Arabian Sea (Sewell, 1947; Grice and Hulsemann, 1967). Other than Indian Ocean, this species had only been recorded from Atlantic (Sars, 1920, 1925).

From the distribution it appears to be a very deep water species occurring in the deep waters of Indian and Atlantic Oceans, rarely coming to the euphotic layer.

Scottocalanus persecans.

This species was caught from only a single station (Fig. 31 a) off Somali coast near equator, located at 02°02'N and 56°03'E, out of 385 stations. Two specimens were collected by "Discovery" in a night haul during the Southwest monsoon in the month of June, 1964. The salin varied from 35.39 at 67 m to 35.01 ‰ at 30 m. Temperatu varied from 29.74°C at surface to 13.67°C at 200 m depth. Surface layer extended from surface to 39 m. Oxygen varied from 4.4 ml/l at 39 m depth to 1.76 ml at 87 m. From earlier descriptions this species appeared to be a regular inhabitant of tropical waters of Atlantic, Pacific and Indian Oceans found at intermediate depths rising to surface at night.

Earlier Indian Ocean records of this species are from off Port Shepstone - Indian Ocean coast of South Africa (Cleve, 1904 a), off South African coast (De Decker and Mombeck, 1964), southern portion of the Arabian Sea (Sewell 1947), Malay Archipelago (A. Scott, 1909). Among other oceans it has been recorded from Atlantic - Woods Hole region, Gulf of Maine, North Atlantic and South Atlantic, Gulf of Guinea, North Pacific, and San Diego region.

Scottocalanus farrani.

This species was identified from only 10 stations out of 385, having a frequency of occurrence of 2.6%, (Fig. 31 a). A total of 109 specimens were collected of which 103 (95%) belonged to 9 night stations (5%) whereas only 6 (5%) were from one day station (0.5%). This clearly indicated its nocturnal abundance as a result of vertical migration. Of the 109 specimens collected 88 (81%) belonged to Southwest monsoon period and 21 (19%) belonged to Northeast monsoon period. It was present in 6 stations during Southwest monsoon and 4 stations during Northeast monsoon. This showed its prevalence during Southwest monsoon. They showed an east to west increase. The areas of occurrence were confined to equatorial waters from African coast to Australian waters. Zones of abundance were western and central equatorial waters. The areas of occurrence were in the monsoon gyre of the Indian Ocean controlled by Agulhas Current, Monsoon Current and South Equatorial Current. But for rare occurrence in Somali upwelling, it was not seen in other upwelling areas. Surface equatorial waters having these specimens were high salinity waters flowing from high saline Arabian Sea water mass. It was an inhabitant of Indian Ocean Central Water, Equatorial Intermediate Water and the North Indian Deep Water. A large patch of 50 specimens per haul indicated its patchiness.

This species has been previously recorded from the Malay Archipelago (A. Scott, 1909) and Chilka Lake region (Sewell, 1913). It has also been recorded from equatorial and other areas in Pacific.

Scottocalanus helenae.

A total of 36 specimens were collected from 8 stations out of 385 sampled (Fig. 31 a). It had a frequency of occurrence of 2.1%. Of the 36 specimens, 30 (83%) were from night hauls and only 6 (17%) specimens were from day haul. This indicated nocturnal abundance as a result of extensive vertical migration to euphotic zone. Five hauls during Southwest monsoon period had 19 specimens and 3 hauls during Northeast monsoon contained 17 specimens. Thus Southwest monsoon had a slight increase only over the Northeast monsoon production. Distribution of this mid-water species was confined to equatorial waters south of equator showing an increase in population from west to east. Areas of abundance were confined to central and southern equatorial waters. But for one statio it was not seen in the upwelling areas. This tropical species was present in the southern part of monsoon gyre and northern part of subtropical anticyclonic gyre of circulation. Distribution was controlled by Java coastal current and the south equatorial current. It was generally present in the less saline tropical surface waters especially in the surface salinity minimum layer of the hydrochemical front at 10°S. It was the inhabitant of Indian Ocean Central Water, Equatorial Intermediate Water and North Indian Deep Water.

S. helenae has been previously recorded from the Indian Ocean from Laccadive Sea (Sewell, 1929), Maldive region (Sewell, 1947) and southwestern Indian Ocean (Grice and Hulsemann, 1967). It has a wide distribution in Atlant and Pacific. It is known to occur in sub-tropical Atlantic

Fig. 31 a. Distribution of (I) *Scottocalanus persecans*

(II) *Scottocalanus farrani*

(III) *Scottocalanus helenae*

in the Indian Ocean.

(Nos. indicate the number of specimens at each Stn.)

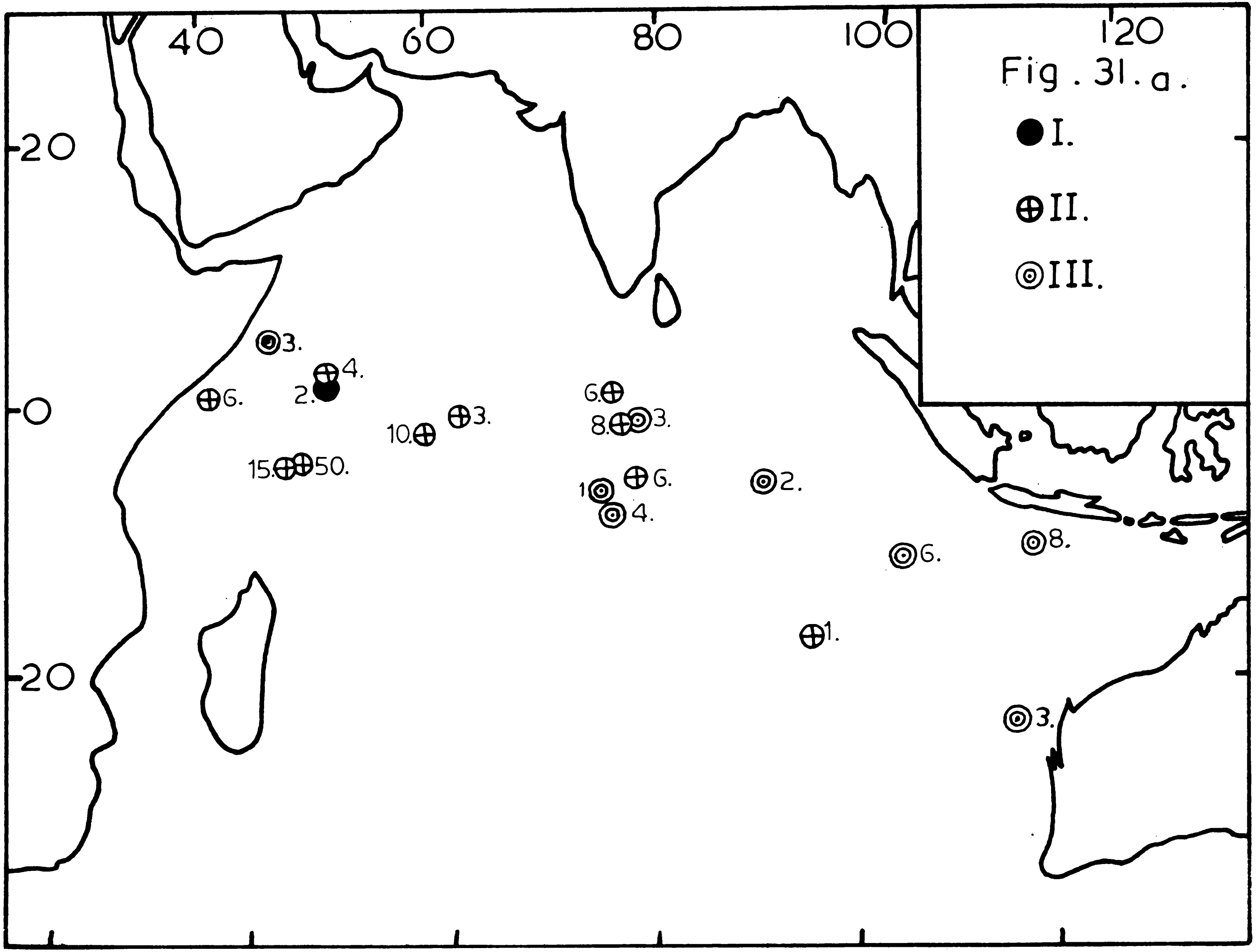


Fig. 31. a.

Gulf of Guinea. It is also recorded from the Great Barrier Reef of Australia and Izu region of Japan.

Lophothrix frontalis.

This species was identified from 10 stations only out of 385 having a frequency of occurrence of 2.6% (Fig. 31 b). Its numerical abundance varied from 0-26 per haul. It was present only in the night hauls. Of the 184 night hauls studied it was present in 10 (18.4%). A total of 72 specimens were collected. Its total absence in day hauls indicated its nocturnal occurrence in surface waters as a result of diurnal vertical migration. All the 72 specimens belonged to Northeast monsoon, surprisingly not a single specimen was collected from 168 Southwest monsoon samples, it being present in 10 out of 217 stations sampled during Northeast monsoon. Histogram studies revealed an east to west and south to north abundance in population. Areas of abundance were confined to off Mombasa coast, Gulf of Aden, along 78°E longitude off the southern tip of India up to equator, Andaman Sea, southwest coast of Java. The species was mainly confined to the southern areas of the monsoon gyre of the Indian Ocean. The 10°S surface salinity layer restricted its movement to southwards. Similarly it was totally absent in the Arabian Sea and Bay of Bengal waters. The distribution was controlled by North Equatorial Current, Monsoon Current and the South Equatorial Current. But for a patchiness occurred in the Gulf of Aden and a small patch off Java rest of the upwelling areas were devoid of this species. It was mainly present in the equatorial waters from 10°S to 10°N. It was an inhabitant of north Indian Ocean high salinity intermediate waters and deep waters, rarely visiting the euphotic layers.

L. frontalis is a widely distributed species. Its previous Indian Ocean records are Bayof Bengal (Sewell, 1929), Gulf of Aden and Arabian Sea (Sewell, 1947), south-western Indian Ocean (Grice and Hulsemann, 1967), off South African coast (De Decker and Mombeck, 1964) and Malay Archipelago (A. Scott, 1909 and Snellius Expedition). Among other areas of distribution it has been recorded from Pacific-Phillipine region, Fiji region, Japanese waters, northern Pacific up to Gulf of Alaska. It is widely distributed in the north and south Atlantic. It is a deep and intermediate water form arising to the surface layers during night.

Macandrewella cochinensis.

This is an endemic species to the northern Indian Ocean, recorded in good numbers, off the south west coast of India (Gopalakrishnan, 1973) (Fig. 31 b). This species

Scottocalanus thomasi.

This species was present in the Indian Ocean in only 4 out of 385 stations (Fig. 31 b). It has a frequency of occurrence of 1%. A total of 23 specimens were identified. All of them belonged to 4 night hauls only, out of 184 night hauls. Absence of even a single specimen in the 201 day hauls indicated its complete absence in the euphotic layer during day time. Its noctumal abundance showed vertical migration undergone by it. Of the 23 specimens no one belonged to the Northeast monsoon period. It Belonged mainly to the southern sub-tropical gyre and partly to southern areas of monsoon gyre circulation. The Agulhas current, Equatorial Counter Current and the monsoon current seemed to control its distribution. Areas of occurrence were confined to south of equator in the western part of the Indian Ocean. It was collected from the Mozambique Channel and equatorial waters of northern Indian Ocean. It was an inhabitant of mesopelagic and bathypelagic waters of the equatorial region and deep waters of Agulhas eddy.

In the Indian Ocean this species has been previously described from the Bay of Bengal (Sewell, 1929) and from Indo-Pacific in Malay Archipelago (A. Scott, 1909 and Snellius collection). Among other oceans it has been was present in only 4 stations out of 385 giving a frequency of occurrence of only 1%. In all, 177 specimens were identified. They all belonged to 4 day (0.5%) stations only. This indicated its occurrence in large numbers in the surface layers and lack of diurnal migration. Of the 177 specimens, 175 (98%) belonged to Northeast monsoon period. Only 2 specimens were collected during Southwest monsoon. The above indicated Northeast monsoon periods to be the most productive. It showed an increase from east to west and south to north. The areas of abundance were confined to southern end of Mozambique coast, southwest coast of India and in the Andaman Sea. But for the 2 specimens from the Madagascar Channel rest belonged to northern Indian Ocean above 10°N. It appeared to be an epipelagic species very rarely undergoing vertical migrations. It belonged to the northern gyre of the Indian Ocean, limited to surface waters of Bay of Bengal and eastern Arabian Sea. One single station sampled by "R.V. Conch" contained 157 specimens from an area 10°10'N, 75°46'E showing its patchy occurrence. The species appeared to be a neritic one as it occurred in near shore collections only.

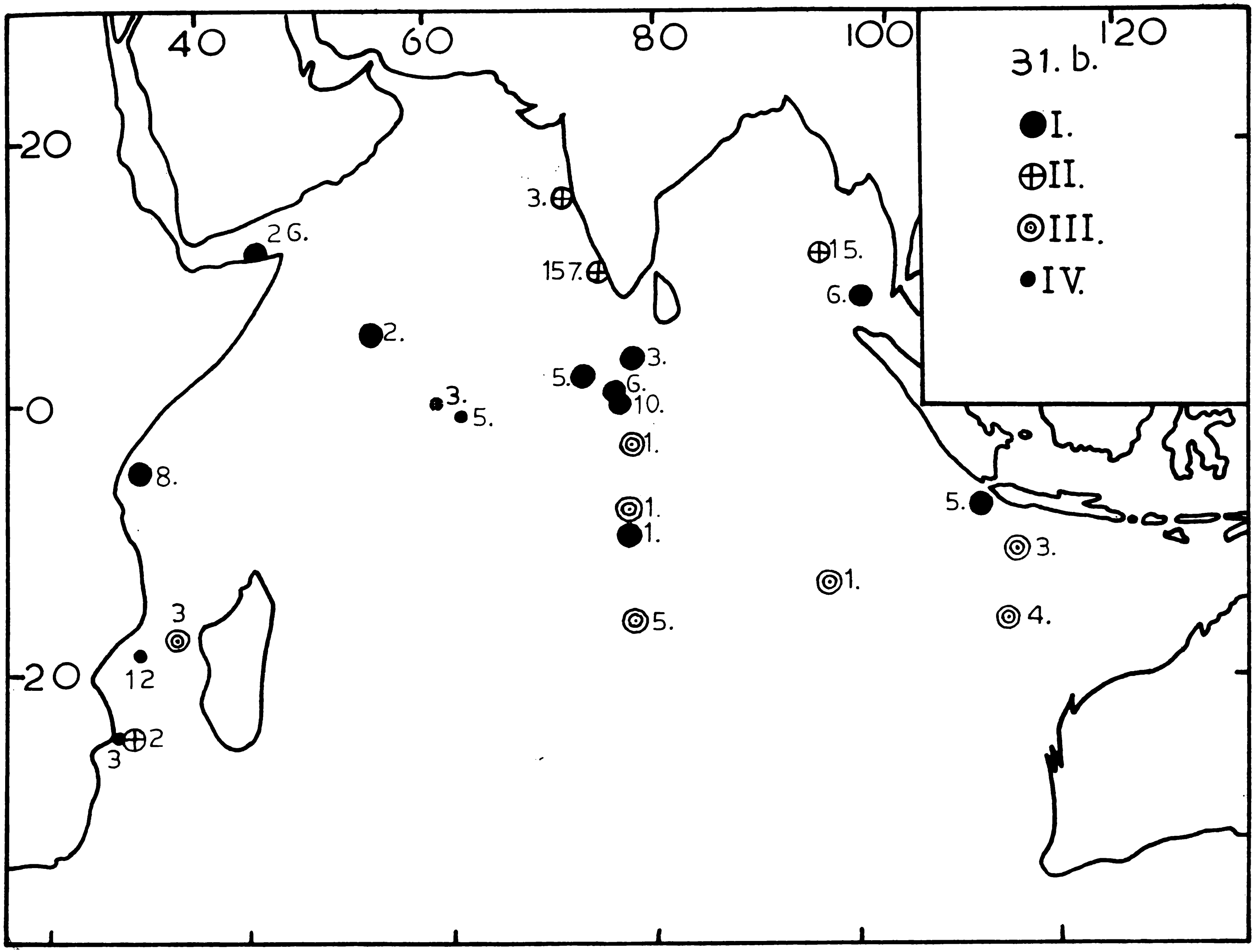
recorded from Hawaiian Islands region, Philippine Islands region in Pacific and Gulf of Guinea in Atlantic.

Scottocalanus australis.

This species was present in only 7 stations out of 385 (Fig. 31 b). It has a frequency of occurrence of 1.8%. A total of 18 specimens were obtained from 7 stations all belonging to the night collections only (3.8%). Absence of any specimen during day hauls indicated its nocturnal abundance as a result of vertical migrations. Of the 18 specimens 3 were from Southwest monsoon period (from only one station) and 15 were from 6 stations of Northeast monsoon. This revealed its abundance in the Northeast monsoon period. It showed a reduction of population from south to north and east to west. Areas of occurrence were confined to the southern sub-tropical anticyclonic gyre circulation. Northern boundary coincided with the hydrochemical front at 10°S and that of southern boundary with the sub-tropical cell of high salinity water at 25°S. Thus it was confined to the southern tropical zone. Its distribution was controlled by the South Equatorial Current, Agulhas Current and Java coastal current. It was not present in the upwelling areas. It was an inhabitant of mesopelagic

Fig. 31 b. Distribution of (I) *Lophothrix frontalis*
(II) *Macandrewella cochinensis*
(III) *Scottocalanus australis*
(IV) *Scottocalanus thomasi*
in the Indian Ocean.

(Nos. indicate the number of specimens at each Stn.).


31. b.
● I.
⊕ II.
◎ III.
• IV.
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60
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100
120
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20
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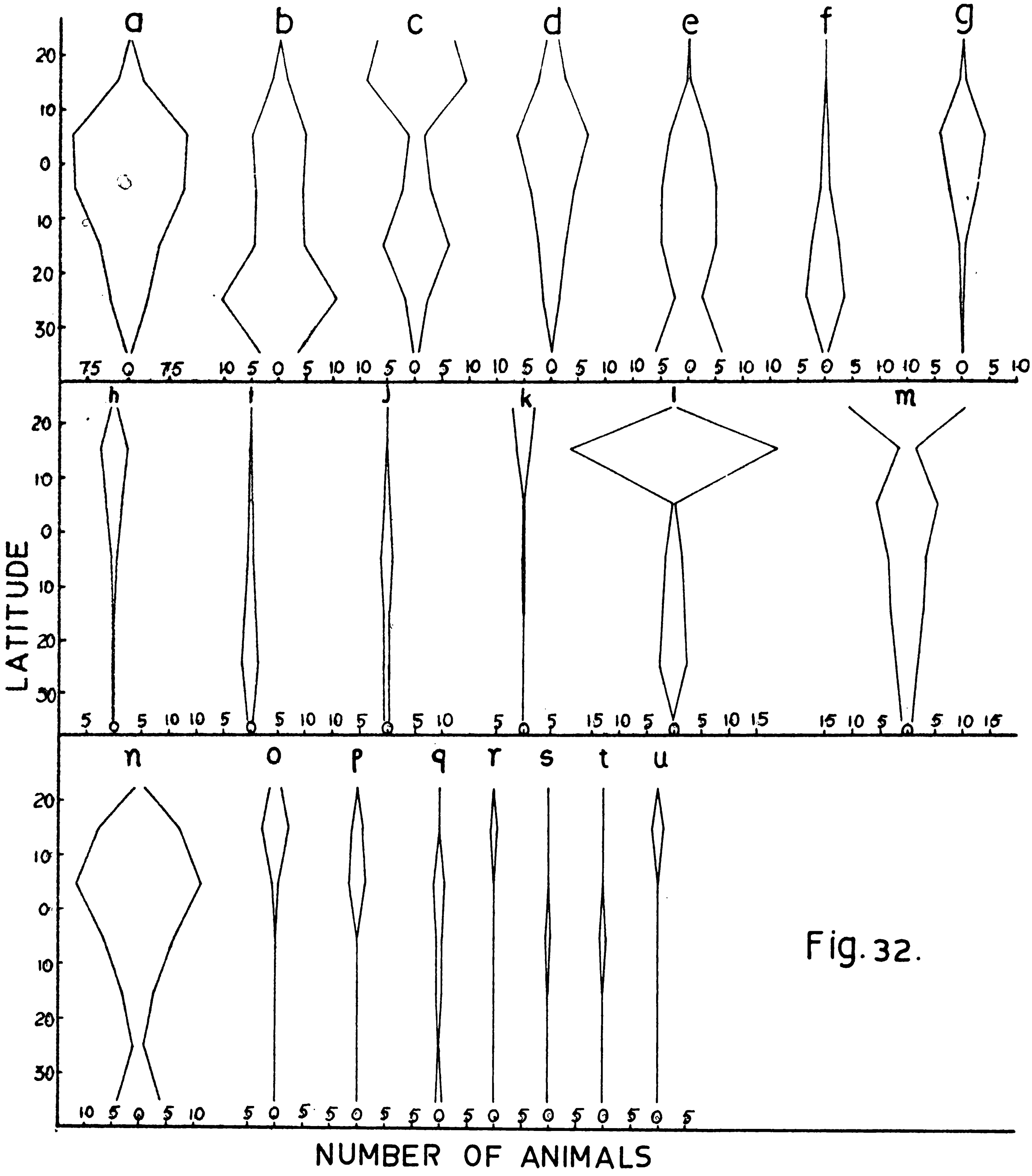
1.
5.
3.
157.
15.
6.
5.
3.
1.
4.
8.
3
12
2
3

Fig. 32. Histogram showing average number of each species per standard haul at different latitudes.

a. *S. danae*
b. *S. bradyi*
c. *S. tenuiserrata*
d. *S. abyssalis*
e. *S. dentata*
f. *L. angusta*
g. *S. nicobarica*
h. *S. marginata*
i. *S. vitata*
j. *S. ovata*
k. *S. longifurca*
l. *S. ctenopus*
m. *S. curtus*
n. *S. echinatus*
o. *A. indica*
p. *S. dauglishi*
q. *S. securifrons*
r. *S. affinis*
s. *S. tropica*
t. *S. farrani*
u. *M. cochinensis*.


a
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m
n
o
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q
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s
t
u
20
10
0
10
20
30
7.5 0 7.5
10 5 0 5 10
5
10
15
LATITUDE
NUMBER OF ANIMALS

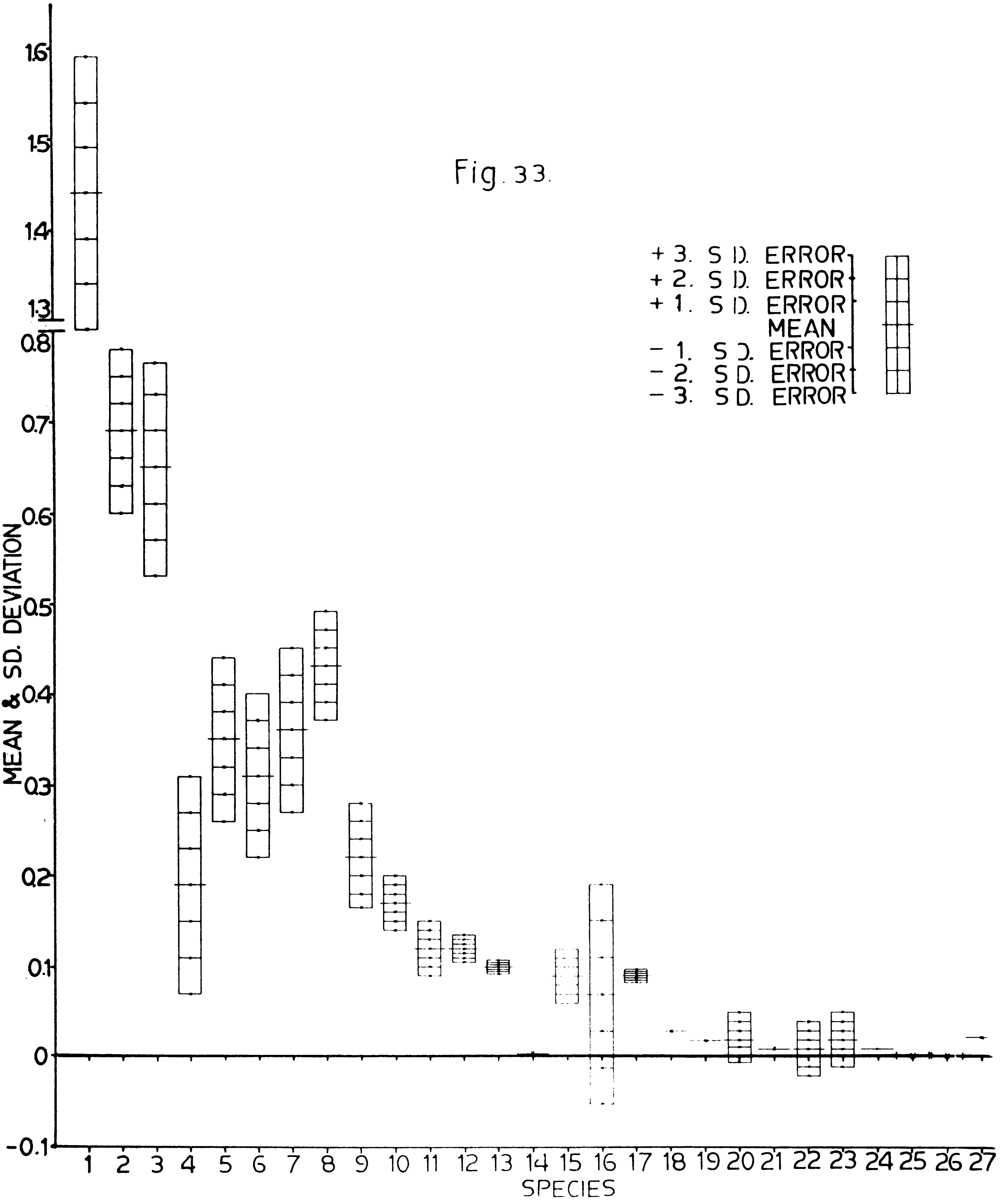
Fig. 32.

Fig. 33. Diagram showing the mean and the 3 standard error limits.

Order of species:

1. *S. danae*
2. *S. bradyi*
3. *S. tenuiserrata*
4. *S. abyssalis*
5. *S. ctenopus*
6. *S. curtus*
7. *S. dentata*
8. *S. echinatus*
9. *L. angusta*
10. *S. nicobarica*
11. *S. marginata*
12. *S. vitata*
13. *S. ovata*
14. *S. longifurca*
15. *A. indica*
16. *S. dauglishi*
17. *S. securifrons*
18. *S. affinis*
19. *S. tropica*
20. *S. farrani*
21. *S. australis*
22. *S. helenae*
23. *L. frontalis*
24. *S. thomasi*
25. *S. persecans*
26. *A. arcuata*
27. *M. cochinensis*

Fig. 33.



+ 3. S D. ERROR
+ 2. S D. ERROR
+ 1. S D. ERROR
MEAN
− 1. S D. ERROR
− 2. S D. ERROR
− 3. S D. ERROR
MEAN & SD. DEVIATION
1.6
1.5
1.4
1.3
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
1
2
3
4
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7
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27
SPECIES

zone coming to the euphotic zone only at night. It was present in the Indian Ocean Central Water, Equatorial Intermediate Water and North Indian Deep Water.

Eventhough S. australis is considered as a synonym of S. helenae by Vervoort (1965) the present specimens agree well with the description and figures given by Farran (1936) in the original description. Thus, by giving it the status of a distinct species, this becomes the first record of this species from the Indian Ocean. It has been originally recorded from the deep waters of the Great Barrier Reef of Australia. It is also present in the Izu region, Japan.

5.2. Occurrence and abundance at species level.

The abundance of a species is a measure of its success and relative abundance is an important aspect of community structure. For identification studies, a total of 73,169 specimens including 24,758 juveniles, 13,399 males and 35,012 females sorted out from 385 stations, were used. The numerical abundance (Table 4) varied from 0 - 2,078 per collection with a mean of 191. They were totally absent in only 14 collections. Basic statistics of Scolecithricidae in the Indian Ocean is given in Tables 7 to 14. Of about 45 species of Scolec thricidae known from the Indian Ocean, only 27 species belonging to 7 genera were present in the IIOE collections. Of these, 24 species had been previously reported from the Indian Ocean, 2 are new records (*Scolecithricella tropica* and *Scottocalanus australis*) and one has been described as a new species - (*Macandrewella cochinensis*). Distribution maps include total Scolecithricidae copepods (Fig. 13) obtained during the 6 year period (1960-'65). Figures 14 - 31 show distribution maps for 27 species incorporating the values for the same period. Numerically *S. danae* is the most abundant comprising of 59.7% of the total specimens identified. Seven less abundant species - *Scolecithricella bradyi*, *S. ctenopus*, *S. tenuiserrata*, *S. abyssalis*, *S. dentata*, *Scaphocalanus echinatus* and *S. curtus* together constituted only 33% of the total specimens. Rest of the 19 species accounted for the remaining 7.3% only, indicating their very low numerical abundance. This may be due to the inadequate sampling because they were rare or neritic or are not typically inhabitants of the upper 200 m of water sampled for these studies. Seven species - *Scolecithrix danae*, *Scolecithricella tenuiserrata*, *S. abyssalis*, *S. bradyi*, *S. ctenopus*, *Scaphocalanus curtus* and *S. echinatus* were widely distributed in the Indian Ocean, *S. danae*, *S. curtus* and *S. echinatus* were most abundant in equatorial waters.

S. bradyi was abundant south of equator while *S. tenuiserrata* and *S. ctenopus* were abundant north of equator. However the Indian Ocean circulation and pattern of currents (Wyrtki, 1973) transported these 7 species far south and north of their normal range. *S. dentata* which was profusely abundant in the southwestern Indian Ocean and mid ocean and *Lophothrix angusta* abundant in the mid southern Indian Ocean were totally unrepresented in the Arabian Sea and Bay of Bengal. *Amallothrix indica* present in the northern Indian Ocean was abundant in central Arabian Sea and central Bay of Bengal whereas *Scottocalanus dauglishi* was abundant in the Andaman Sea and south of Peninsular India. *Scolecithricella marginata* and *Scolecithrix nicobarica* occurring in the Bay of Bengal and equatorial waters were abundant in the Andaman Sea and southern bay waters respectively. *S. securifrons* and *S. ovata* characteristic of equatorial waters were numerically few in number when present. *Lophothrix angusta* and *S. vitata*, fewer in number, when present, had their area of occurrence south of hydrographic front at 10°S. *L. angusta*, *S. dentata*, *S. securifrons*, *S. ovata* and *S. vitata* were totally absent north of 10°S. These 5 species can be identified with the central gyre. *S. securifrons* and *S. ovata* also appeared to be typical of equatorial waters. The rare *Amallothrix arcuata* (13 specimens) was obtained from only one station off the Arabian coast (Fig. 30 b). Similarly *Scottocalanus persicans* (4 specimens) was identified from a single station (Fig. 31 a) along the equator off Somali coast. *S. farrani*, *S. helenae* and *S. thomasi* were collected from the equatorial waters only. *S. tropica* and *S. australis* were confined to central gyre waters, whereas *S. affinis*, *S. longifurca* and *M. cochinensis* were present in the northern gyre waters. Thus in all, 2 species were widespread in the northern and central gyre, 11 species in northern gyre, 7 species in central gyre and 7 species in equatorial waters. *S. echinatus*, *S. tenuiserrata*, *S. ctenopus*, *S. tropica* and *S. affinis* occurring in large abundance along upwelling areas may be regarded as species indicators of upwelling. *S. vitata*, *L. angusta* and *S. australis* were associated with low productivity waters. As noted for *Candacea pachydactyla* by Jones (1962) and Vinogradova and Voranica (1965), *S. tenuiserrata* and *S. echinatus* have been found associated with high productivity waters. The northern limit of abundance for *S. dentata*, *L. angusta*, *S. securifrons*, *S. ovata*, *S.vitata* and the rarely occurring species as *L. frontalis*, *S. helenae*, *S. farrani*, and *S. tropica* were south of 10°N only. *S. marginata* was abundant in the faunistically "peculiar" Andaman Sea as noted for *Candacia longimana* (Lawson, 1977) and for euphausids *Euphausea gibboids* and *Stylocheiron insulare* (Brinton and Gopalakrishnan, 1973). *Amallothrix indica* and *Scolecithricella ctenopus* and the rare species *S. longifurca* were offshore forms of Arabian Sea and Bay of Bengal having their counterparts in the endemic euphausid *Stylocheiron indicum* and candacid *Candacia samasse*. The distribution of the nonsonally disttributed species as *S. vitata* and *S. tropica*, predominantly found in the boundary currents of southern hemisphere also had counterparts in *Euphausia mutica* (Brinton and Gopalakrishnan, 1973) and *Paracandacia simplex* and and *Candacia bipinnata* (Lawson, 1977).

Two recurrent groups were identified. These were composed of *S. abyssalis*, *S. echinatus*, *S. tenuiserrata*, *A. indica* and *S. longifurca*, species typical of northern monsoon gyre and *S. bradyi*, *S. dentata*, *L. angusta* and *S. vitata* typical of central waters. A broad zone of overlapping could be noticed between these two groups. *S. danae* was wide spread in both gyres. Rest of the 16 species were restricted to various water masses. However 6 of these species were found typical of equatorial waters only. They were *S. ovata*, *S. securifrons*, *S. nicobarica* and and *S. dauglishi* in addition to the rare species *L. frontalis*, and *S. farrani*. The sonally restricted distribution of Scolecithricidae resembled thatof euphausids (Brinton and Gopalakrishnan, 1973) and Candacids (Lawson, 1977). They also observed extended distribution of species along meridian beyond the zonal boundaries as a result of boundary currents as observed in the present studies. South of 20°S all species of Scolecithricidae were found decreasing in abundance and occurrence.

Similar to the euphausid faunistics, copepods revealed zonal characteristics (Table 6) in oceanic region and meridional characteristics in the boundary regions. The zonal characteristics related primarily to the paralle of latitude 10°N, equator, 10°S, 20°S, 30°S, and 40°S. 10°N parallel enclosed the tropical, paired semi-enclosed basins of Arabian Sea and Bay of Bengal, peculiar to India Ocean. The abundance of *S. tenuiserrata*, *S. ctenopus*, *A. indica*, *S. marginata*, *S. longifurca* and *M. cochinensis* indicated coastal water quality. Compared to tropical ocean this part (north of 10°N) had only 6 species of Scolecithricidae in abundance. Thus these species were associated with high productivity low oxygen waters. 10° parallel bound on the north a number of tropical-subtropical circumglobal species such as *S. bradyi*, *S. dent* *S. nicobarica*, *S. securifrons*, *S. ovata*, *S. vitata*, *S. tropica*, *S. farrani*, *S. helenae*, *L. frontalis* and

M. cochinensis. Equator along with the southern edge of north equatorial current lies in the northern limit of *S. australis* and *S. thomasi* and the southern limit of *A. indica*, *S. dauglishi* and *M. cochinensis*. 10°S, the southern limit of easterly equatorial counter current and northern limit of westerly south equatorial current diminished sharply the extension to south of equatorial species such as *S. affinis*, *S. farrani*, *L. frontalis* and possibly *S. marginata* and *S. longifurca*. 20°S, 30°S and 40°S were regions of the southern boundary of tropical-sub-tropical species. A feature of the zoogeography of both the eastern and western Indian Ocean is the extensive north-south ranges of coastal species. Thus *S. echinatus*, *S. bradyi* and *S. dentata* ranged from the Gulf of Oman to waters off Port Elisabeth, particularly from 25°N to 40°S. Coastal species on the eastern side ranged from Bay of Bengal to waters of southwest Australian coast as illustrated by *S. abyssalis*, *S. curtus*, *S. echinatus*, *S. tenuiserrata*, *S. ctenopus*, *S. tropica* and *S. dentata*. In the western boundary coasts - Agulhas Current and Somali Current transported Scolecithricidae species to far north (11°N) and south up to 38°S. Distribution of species along an east-west salinity gradient from the high salinities of the Red Sea Gulf of Aden to the lower salinities of the eastern Bay of Bengal and East Indies is an evidence for allopatric speciation to avoid competition among morphologically similar species identical in size also as noted for Candacids by Lawson (1977).

Patchiness is well known in plankton distribution, already thought by Wynne Edwards (1962) not to be accidental but the effect of a normal subdivision in more or less discrete populations. As patchiness is the result of animal behaviour, hydrophysical and hydrochemical factors it can very well be considered the basis of populations. Large scale patterns of aggregates of populations could be discovered only by comparison of the distributional patterns of 27 species of Scolecithricidae. Of the several instances of numerical abundance analysed, only 3 occurrences of S. danae - 2,078, 1,975, 1,326/haul - without any of the other 26 species, can be considered as patchy as rest of the instances with numerical abundance less than 1,000/haul were associated with other species of Scolecithricidae. Occasionally the plankton population seems to explode with disastrous results. The oxygen depletion, the toxicity and the fouling of fish gills causes great ecological damage. In 1957 a plankton bloom in the Arabian Sea was estimated to have killed the equivalent of the entire world catch of fish for an year.

5.3. Diurnal migration and vertical distribution.

According to Mc Laren (1963) the adaptive value of vertical migration may depend upon the lower temperatures generally found in deeper waters. The vertical migration by zooplankton according to Hutchinson (1967) is most likely to avoid visual predation,having a residence away from the surface by day. Mc Alister (1969) suggested that vertical migration may give the additional advantage of better utilisation of the growth potential of the zooplankton, as well as permitting the unimpeded growth of plants during the day light hours. Kerfoot (1970) argued that vertical migration or orientation in the water column as "an unavoidable correlate of the use of light as a frame of reference" optimised the transfer of phytoplankton production to zooplankton populations. Roe (1972 c) found a degree of sexual vertical segregation occurring in Scolecithricella major, S. brevicornis and Metrida venusta. By day the males of all these species were distributed mainly above their respective females. By night the distribution of the non-migratory S. major remained unchanged. The males of S. brevicornis and M. venusta were also largely non-migratory, but the females of both species migrated so that they became distributed both above and below their respective males.

The above explanation of the adaptive values of vertical migration by zooplankton are difficult to express in terms of individual fitness. So Mc Laren (1974) analysing the demographic strategy of vertical migration of a marine copepod, Pseudocalanus minutus in their normally stratified waters worked out a metabolic model. This model conferred a demographic advantage to zooplankters in which size and fecundity are negative functions of temperature. Copepods in general exhibited remarkable diurnal variations in spatial abundance. There are some indications that diurnal migration (Vinogradov and Voronina, 1961) may play some part in the vertical distribution in the upper strata. Roe (1972 c) studying the vertical distribution and diurnal migration of 27 species of calanoid copepods found that some species were extensive migrators, whereas few showed little or no migration and the rest possibly had reversed (downward) migrations. Of the 27 species of Scolecithricidae studied (Tables 2 and 4), S. danae and S. bradyi were mainly surface inhabitants and so they undertookdownward migrations. This is the reason why they were present in 82.3 and 63.6% respectively of 385 stations studied. In numerical abundance they formed 59.7% and 6.7% of the total respectively. Vertical segregation between congeneric species was shown by species of Scolecithricella. S. securifrons was common in mid-water which by night extended its depth range to surface. Thus while only 6 specimens were caught from one out of 201 day stations, 319 specimens were obtained from 42 out of 184 night stations showing their abundance below 200 m in day time. Vervoort (1965) observed S. securifrons as an inhabitant of deep and intermediate water layers by night. Wolfenden (1904) recorded this at 549 m (as Lophothrix securifrons) and Farran (1926) found adult male in the upper 183 m by night and suggested that by day the depth range was between 640 and 457 m. Park (1970) recorded it between 1,000 and 102 m, Roe (1972 c) recorded from a depth of 940 to 100 m. Males exhibited an increase in nocturnal collections. A maximum of 66 specimens were identified from a night station at 6°44'N, 57°59'E showing their swarming in the euphotic zone of equatorial waters. S. helenae was a very common species of mid-water having a very restricted depth range. Of the 184 night collections it was present only in 7 stations (36 specimens) and of the 201 stations it was present in only one station with 6 specimens. This species was relatively very rare in the 200 - 0 m column and males predominated the night catch. This was recorded by Owre and Foyo (1964) between 877 and 584 m. Grice and Hulsemann (1965) found it at one station between 100 and 500 m and Owre and Foyo (1967) found a single specimen at 127 m. Park (1970) recorded it from a depth range of 940 to 100 m.

L. frontalis was rather uncommon species exhibiting a fairly distinct vertical distribution. As it was recorded from a depth range of 940 - 360 m he concluded that it was distributed below 500 m depth by day and had a moderate vertical migration by night to between 460 and 360 m. As such not a single specimen was collected from the 201 day stations though 72 specimens were obtained from 10 out of 184 night stations. According to Vervoort (1965) this is a widely distributed deepwater species. It was recorded by Wolfenden (1904) at 914 m, Grice (1963 a) between 1,200 and 620 m and Owre and Foyo (1964) from 1,000 to 584 m. S. echinatus was the abundant common species in midwater. A total of 4,381 specimens were collected from 122 out of 184 night stations and only 177 specimens from 10 out of 201 day stations. A maximum of 317 specimens were collected from a single sample obtained at night from 13°N and 92°E. Roe (1972 c) recording this species in the depth range of 950 - 50 m revealed its abundance in mid-water by day and the extensive migration by night with specimens reaching a depth of 50 m. Occasionally this was found at the surface. It seemed mainly to be an inhabitant of intermediate water. Farran (1926) found specimens between 1,829 and 274 m by day and by distinct vertical migration specimens reaching surface at night. Grice and Hulsemann (1965) recorded it from 1,000 and 180 m (Park, 1970) between 1,000 and 102 m and Wheeler (1970) between 4,100 and 2,200 m. S. ovata was a fairly common mid-water species (Vervoort, 1957) at all depths between 940 and 350 m, bulk of the specimens having a distinct upward migration by night, reaching a depth of 100 m (Roe, 1972 c). Farran (1926) recorded it by day between 1,829 and 183 m, with specimens reaching surface at night. Grice (1963 a) recorded it from 1,200 m, Grice and Hulsemann (1965) between 1,000 and 180 m and Park (1970) between 1,000 and 487 m. S. ovata numbering 221, was present in 34 out of 184 night stations and 95 specimens in 21 out of 201 day stations. A maximum of 17 specimens were obtained from one night station. This indicated their rare occurrence in the euphotic layer even at night. S. vitata was abundant in the near-surface hauls being numerically a very important member of the upper water layers; 189 specimens were identified from 36 out of 184 night collections and 186 specimens from 30 out of 201 day stations. As the day and night distributions were very similar as observed by Roe (1972 c) there was little evidence for vertical migration. Roe (1972 c) recorded it by day from the depth range 570 - 85 m and by night from 550 - 100 m. Farran (1926) found them between 1,372 and 914 m, Owre and Foyo (1964) at 170 m, Grice and Hulsemann (1965) between 200 and 95 m and Park (1970) between

200 and 100 m. S. dentata was common in mid-water and surface layers with a depth range of 625 - 400 m by day and 700 - 50 m by night. As the majority of population moved upwards to a depth of 50 m at night, 2,068 specimens were collected from 94 out of 184 night stations while only 614 specimens were obtained from 37 out of 201 day stations as they preferred to remain below the euphotic zone during day. Swarms of these populations numbering 256 and 133 were collected from 2 night stations in the euphotic zone. It appeared to be a fairly common inhabitant of the upper water layer. Farran (1926) recorded them between 914 and 0 m by day and between 183 and 46 m by night. Grice and Hulsemann (1965) found it between 960 and 190 m, Owre and Foyo (1967) between 171 and 32 m, Vilela (1968) between 50 and 0 m, Park (1970) between 1,900 and 0 m and Wheeler (1970) between 4,100 and 2,200 m.

S. danae, numerically the most abundant and widespread species, was fairly common in the surface and subsurface layers by both day and night. Roe (1972 c) observed its depth range by day from 150 - 40 m and by night from 100 - 50 m. Males formed a slightly increased abundance than females. Of the 43,687 specimens identified 20,233 were from 156 out of 184 night collections and 23,454 from 169 out of 201 day collections, giving an average of 110 and 117 for night and day respectively. Swarms of them numbering 730 - 2,078 per collection were recorded in euphotic layers. Roe (1972 c) suggested a possible reversed migration as he found great increase in numbers caught by night. Vervoort (1965) found S. danae inhabiting intermediate and subsurface layers, being found at the surface by night and in comparatively deep water by day. The present day records similar to observations by Roe (1972 c) are not in accordance with this account. Disagreeing with Roe (1972 c) and Vervoort (1965) during the present study, S. danae was found abundant during day suggesting a possible migration downwards by night. The species was recorded by Owre and Foyo (1964) from 1,316 - 10 m, Grice and Hulsemann (1965) from 45 - 0 m, Seguin (1966 a) from surface, Vilela (1968) from 50 --0 m, Park (1970) between 200 - 0 m and Wheeler (1970) between 4,100 and 2,200 m.

S. bradyi was fairly common in the surface hauls having a vertical distribution very similar to that of S. danae. S. bradyi is a sub-surface form, characteristic of all warm seas (Vervoort, 1965). Roe (1972 c) recorded them by day from a depth range of 85 - 40 m and by night from 100 - 50 m. A total of 2,663 specimens were collected from 128 out of 184 night stations and 2,068 specimens from 117 out of 201 day stations, giving an average of 15 and 10 respectively for night and day. Swarms of 125 - 150 per haul were recorded during the present study. The increase in the number caught at night suggested a reversed migration. Its decrease in numerical abundance in spite of its occurrence in 63.6% of stations can be a reflection of its small size range of 1.2 - 1.4 mm, possibly not being caught in the 330 micron net used for the collections. This was recorded by Owre and Foyo (1964) between 1,000 and 292 m, Grice and Hulsemann (1965) from 200 - 100 m, Vilela (1968) between 50 - 0 m and Park (1970) from 1,900 - 0 m.

Congeneric species exhibiting vertical segregation when they migrated upward at night as noted by Roe (1972c) were the following - _S_. _ovata_, _S_. _dentata_, _S_. _vitata_ and _S_. _tenuiserrata_. These four species formed one recurrent group.

5.4. Seasonal variations.

The Indian Ocean being a seasonal ocean (Ramage, 1969; Wyrtki, 1973) in order that some general features of seasonality may be considered, distributions were studied for 2 time periods, April 16 to October 15 (corresponding to Southwest monsoon in the northern half of the ocean) and October 16 to April 15 (corresponding to Northeast monsoon). Data within a season, but for the several years of the expedition, were studied together.

More detailed consideration of seasonal changes in distributions was probably not yet justified for the ocean as a whole, in view of the limited temporal geographical coverage presented by even this extensive collection of samples.

Of the 73,169 copepods of the family Scolecithricidae identified, 31,107 (42.4%) were collected from 168 stations during the Southwest monsoon and 42,062 (57.6%) from 217 stations during the Northeast monsoon period giving a mean value of 185 and 194 respectively. This indicated only a slight increase in population during the Northeast monsoon period.

Studies on the total copepod distribution in the Arabian Sea revealed more intensive production during the Northeast monsoon than during the Southwest monsoon, also it covered large offshore areas in and around the upwelling regions. However total scolecithricid copepods showed a slightly higher production during the Southwest monsoon in the Arabian Sea mainly contributed by the major species S. danae. But, rest of the 19 abundant species were more during the Northeast monsoon following the total copepod pattern. Scolecithricidae distribution along the west coast of India revealed same values in both seasons. In the Bay of Bengal, areas of production of S. danae and S. ctenopus were more during Southwest monsoon than during Northeast monsoon. However rest of the 17 major species had more or less similar production rate. Bay of Bengal also noted same population of total copepods during Southwest monsoon perhaps due to local upwelling. Dense patches were present off Madras and off the southern tip of India during Northeast monsoon probably related to upwelling. Equatorial region showed a considerable increase in the production of total Scolecithricidae during Southwest monsoon mainly contributed by the major species *S. danae*. Moreover 17 other species present in the equatorial region occurred in higher densities during the Northeast monsoon. In southwest Indian Ocean area, of the 13 species present including the major species *S. danee* monsoon effect on the abundance was negligible. Contrary to this in the southwest Indian Ocean area production of 13 Scolecithricidae species including *S. danae* was considerably higher during the Northeast monsoon. This area also indicated denser extensive patches of total copepods off west Australia and in the Java Sea during the Northeast monsoon period. The number of species present in the Indian Ocean also showed a higher number during the Northeast monsoon period. Thus, but for the southwest Indian Ocean area rest of the area showed a considerable increase in the production of Scolecithricidae during the Northeast monsoon period. Total Scolecithricidae distribution decided by S. danae was more in the Southwest monsoon period except for the southeast Indian Ocean area. Thus the extensive production of Scolecithricidae except S. danae suggested a time lag for the development of zooplankton population eventhough primary production values were high during Southwest monsoon as observed for the distribution of total copepods.

Table 2 shows the overall seasonal changes in the average number of 27 species of Scolecithricidae in four different areas of the Indian Ocean.

5.5. Zoogeography of neritic and oceanic species.

The environment of marine zooplankton consists of two essentially different sections - the neritic province covering the shelf area and the oceanic province covering the areas off the shelf edge deeper than 200 m - which are characterised by physical, chemical and ecological properties. Each have specific pattern of speciation and special plankton fauna. The oceanic province is far more extensive (about 80-84%) than the neritic province. The species diversity of the oceanic plankton is generally richer than the neritic plankton.

The predominance, throughout the temperate and tropical areas, of copepod genera such as *Paracalanus*, *Oithona*, *Acartia*, *Eurytemora* and *Labidocera* principally in the neritic waters and the rich variety of species of the genera *Calanus*, *Candacia* and *Paracandacia* in the oceanic waters are generally known. Many of the neritic copepods are collected in swarms at night and rarely during day time. This is because the main population of these copepods stay just above the bottom in a hyperbenthic state in the day time due to diurnal vertical migration. Also the neritic species are euryhaline and eurythermal compared to the stenohaline and stenothermal oceanic species. Compared to the restriction of majority of marine cladocerans, medusae and mysids to the neritic waters, Scolecithricidae copepods in the present collections were abundant in the oceanic waters similar to the oceanic calanoid *Calanus helgolandicus* (Vucetic, 1966). The following 8 out of 27 species of Scolecithricidae studies belonged to the neritic province, as they were adapted to the highly fluctuating conditions of the region. They are *S. curtus*, *S. echinatus*, *S. ctenopus*, *S. marginata*, *S. tropica*, *A. arcuata*, *S. longifurca* and *M. cochinensis* with a mean size of 1.4, 1.8, 1.4, 1.0, 1.2, 2.5, 1.5 and 2.9 mm respectively. These neritic species of Scolecithricidae are evidently smaller than the oceanic species, as is the general rule with most zooplankton groups. Most neritic species showed a general trend towards endemism. These endemic species were comparably more numerous in the Indo-Pacific than in the Atlantic. In copepods, generally the number of typically neritic species is much fewer than that of the oceanic species. The occurrence of large number of oceanic species shows their long lasting separation from the neritic province. Many of the neritic Scolecithricidae species were observed from the oceanic waters, though sparsely, as the sea currents do not constitute absolute and solid barriers. The drifting of neritic species into the oceanic province had occurred as seen in the Figs. 16, 17, 21, 24, 25, 27, 30a, and 31 b. S. danae, S. dentata, S. tenuiserrata and S. bradyi which were the commonest oceanic Scolecithricidae were found in neritic waters also. The islands of Indian Ocean may also play an important role in the distribution of neritic forms as shown in the case of pontellid copepods by Sherman, 1964.

5.6. Speciation - boundaries and barriers.

One of the most striking features of plankton species is their vast distributional ranges, since insurmountable barriers are hard to detect in the marine environment. Yet the continents themselves acting as distinct barriers appear to prevent circumglobal distribution of planktonic animals. Compared to the Atlantic the separation of the Indian and Pacific Oceans is not strict, as the warm water belt is nearly continuous through the Indonesian Archipelago. Johnson and Brinton (1963) found the direction of the migratory movements mainly eastwest. Thus majority of the Scolecithricidae species (24 spp.) found in the warm water belt are found having a continuous distribution with Pacific species. Those species restricted to the Indo-Pacific are - *Scolecithrix nicobarica*, *Scolecithricella marginata*, *Scaphocalanus longifurca*, *Scolecithricella tropica*, *Scottocalanus farrani* and *Scottocalanus australis*. Yet strictly tropical, stenohaline species such as *Scolecithricella ctenopus*, *S. marginata*, *Scolecithrix nicobarica*, *Amallothrix indica*, *A. arcuata*, *Scottocalanus dauglishi*, *Scaphocalanus longifurca*, *S. affinis* and *Macandrewella cochinensis* are found to occur, in their high density ranges, in the northern Indian Ocean. These taxa for which the continental isolating mechanism is effective, usually occur in the upper 200 m and are roughly limited by the 20°C mean year isotherm

Fleminger and Hulsemann (1973, 1974) proved that tropical copepods show different species in the Atlantic and Indo-Pacific Oceans, whereas tropical and sub-tropical species, breeding regularly from 40°N to 40°S are monotypic and circumglobally distributed, due to the possibility of maintaining gene flow around the South African continent. Thus Scolecithricidae species found in the tropical-subtropical Indian Ocean (25°N - 40°S) having a circumglobal distribution are - *Scolecithrix danae*, *Scolecithricella bradyi*, *S. tenuiserrata*, *S. abyssalis*, *S. ctenopus*, *S. dentata*, *S. vitata*, *S. ovata*, *Scaphocalanus curtus*, *S. echinatus*, *S. affinis*, *Lophothrix angusta*, *L. frontalis*, *Amallothrix arcuata*, *Scottocalanus securifrons*, *S. persicans*, *S. helenae* and *S. thomasi*. However the 6 Indo-Pacific species listed above, having a 25°N to 40°S distribution is not seen in Atlantic, not confirming the above phenomenon. Occurrence of identical species in the tropical areas of all oceans known as a sibling species is not encountered among Scolecithricidae species. Those species belonging to the tropical Indo-Pacific areas alone being not seen in tropical Atlantic are -

Scolecithrix nicobarica, *Scolecithricella marginata*, *S. tropica*, *Scaphocalanus longifurca*, *Scottocalanus farrani* and *S. australis*. Those found only in the Indian Ocean are - *Amallothrix indica*, *Scottocalanus dagglishi* and *Macandrewella cochinensis*. The land locked northern Indian Ocean thus may act as a distinct barrier in the formation of speciation.

Carter (1961) recognised no effective barrier other than distance isolation in the deep sea, characterised by the great homogenity of the environment. Thus the meso and bathypelagic species of Scolecithricidae collected from euphotic zone of the Indian Ocean during their nocturnal migration, are widely distributed in the deep waters of all oceans. However bottom topography may act as a barrier. The strait of Bab-el Mandeb (100 m depth) may not act as a bottom topographical barrier in the migration of shallow Scolecithricidae species from Arabian Sea to Red Sea, since many of them are present in the Gulf of Aden. The Indonesian Archipelago except for the Timor Corridor may cause a hindrance for the passage of other than shallow species in the Indonesian Archipelago. Thus speciation in Scolecithricidae of the Indian Ocean due to the presence of a distinct continental barrier is expected only in tropical Indian Ocean species.

Being unable to overcome water movements by its own mobility, zooplankton is transported by surface currents acting as indistinct barrier. Water circulation by surface currents in the Indian Ocean cause separate subsystems like an extensive central anticyclonic gyre and a small equatorial-cum-northern cyclonic gyre. Scolecithricidae species abundant and specific to northern gyre, north of 10°S are - *Scolecithricella abyssalis*, *S. ctenopus*, *S. marginata*, *Scolecithrix nicobarica*, *Scaphocalanus curtus*, *S. longifurca*, *S. affinis*, *Amallothrix indica*, *A. arcuata*, *Scottocalanus dauglishi*, *S. echinatus*, *S. tenuiserrata*, *S. longifurca*, *S. persecans*, *Lophothrix frontalis* and *Macandrewella cochinensis*, and those specific to central gyre are - *Scolecithricella ovata*, *S. vitata*, *S. bradyi*, *S. securifrons*, *S. thomasi* and *Lophothrix angusta*. Also the boundary currents along the edges of the oceanic water masses may provide indistinct barrier for the epiplanktonic copepods. As noted for fish transported by currents (Harden-Jones, 1968), planktonic copepods seem to be able to maintain their geographical positions instead of being merely transported by currents. Copepods undertake diurnal vertical migrations to prevent specimens from being transported and thus to maintain geographical stability to the population. Thus *Scolecithricella vitata*, *S. australis* and *Lophothrix angusta* are good examples of the effects of currents which keep them in the southern Indian Ocean, south of 10°S.

A special type of vertical distribution is noted for enlargement of distribution into areas with strongly differing conditions as in the case with a number of Chaetognaths, Pteropods, Euphausids, Ostracods and Copepods which are epipelagic in higher latitudes becoming meso to bathypelagic in lower latitudes. Thus occupying different depth zones at different latitudes they find suitable conditions over large geographic areas. This may explain absence of northern species of Scolecithricidae in the southern waters as collections are not made below 200 m. Thus sparseness of 8 species (listed above as abundant in the northern Indian Ocean) in the southern waters can be confirmed only after deep collections below 200 m are examined. Species with a wide vertical range usually show a wide latitudinal range and vice versa. When species are unable to cross a barrier, the result will be probably (monotypic) species with restricted ranges, coinciding with water masses as in the case with *Scolecithrix nicobarica*, *Scolecithricella marginata*, and *Scottocalanus dauglishi* being abundant in equatorial water mass and *Lophothrix angusta*, *Scolecithricella vitata* and *S. ovata* being abundant in central water mass. This point is in agreement with the view of David (1963) who discussed the influence of barriers on speciation in chaetognaths.

When species are able to cross a barrier more or less unrestrictedly it will probably result in a widely spread species with different infraspecific taxa or formae in different water masses, as in the pteropods (Vander Spoel, 1967, 1976) or it will result in clinal variation becoming discontinuous in the boundary regions as in salps (Van Soest, 1975). Scolecithricidae species having such unrestricted distribution are *Scolecithrix danae*, *Scolecithricella tenuiserrata*, *S. bradyi*, *Scaphocalanus curtus* and *S. echinatus*. However infraspecific/clinal variations were not studied in the case of Scolecithricidae. During the present study a general trend noticed was a decreased abundance in the barrier zones suggesting speciation process.

Temperature may be considered as an indistinct barrier for Scolecithricidae copepods, since in a number of cases a more or less latitudinal pattern of distribution can be noticed from histogram studies (Fig. 32) which seems to be correlated with temperature. The tropics can form a barrier between taxa from sub-tropical, temperate and sub-polar waters due to temperature, nutrient concentration, currents, ecological competition etc. Thus the well known phenomenon of bipolarity (called biantitropical by Brinton, 1962) showing isolation between populations of the northern and southern hemisphere is found among euphausids (Brinton, 1962), copepods (Frost and Fleminger, 1968, Fleminger and Hulsemann, 1973), pteropods (Van der Spoel, 1967) and chaetognaths (David, 1963, Pierrot Bults, 1976). This tropical sub-tropical belt separating the faunas of higher latitudes however form a barrier only for epipelagic species living above the thermocline. The water masses between the sub-tropical convergences only show endemic species above the thermocline as shown by Reid _et al_. (1978) who state that species living permanently above or within the thermocline appear to be bound to either sub-tropical (being antitropical) or equatorial systems. A barrier like the Antarctic convergence may act in different ways on a taxon or even within one group of animals complete, partial or by a change in the vertical range. Pierrot-Bults (1976) came to the conclusion that distributional patterns show no correlation with taxonomic categories. The meso-plankton is less affected by boundary currents, tropical belt and Antarctic Convergence. They also perform extensive diurnal migrations. However permanent thermocline may act as a barrier as noted in ostracods (Angel, 1978).

The most extensive boundary zone is probably that between the oceanic and neritic environment. The neritic zone is populated by more tolerant species than oceanic zone. Oceanic species are adapted to the more stable oceanic habitat and as such are unable to cope with changing neritic conditions. In this case there is an ecological barrier, for the neritic species towards the ocean and a physical barrier for the oceanic species towards the neritic waters. Scolecithricidae species classified as neritic are *S. ctenopus*, *S. curtus*, *S. marginata*, *A. arcuata*, *S. echinatus*, *S. longifurca*, *S. tropica* and *M. cochinensis*. Rest are oceanic species. The special biotope forming the broad boundary zones occurring in boundary currents around the central gyre between neritic and oceanic zones is called transition zone and is occupied by special taxa. The pattern of transition zone species guided by gyral currents does not always fit the scheme of water mass distributions.

The open ocean is a vast area and the mere fact of a great distance can act as a barrier for the successful dispersal of planktonic organisms. Species are not found evenly distributed but form local populations, swarms and patches as noted by Wynne Edwards (1962) and Endler (1977). Thus the four density grades used for depicting species abundance and distribution are widely scattered (Figs. 13-29), less densly populated areas occur in between high populations. The faunal differences between east west noted in the Indian Ocean may be caused by such distance or may be due to the physical conditions as oxygen concentration. The east-west faunal differences noted among Scolecithricidae are shown in Figs. 13-29. The effect of the distance depends on the changes in ecological conditions over that distance.

North-south diversity in Scolecithricidae species: Next to land masses hydrographical barriers exist in the pelagic realm dividing the Indian Ocean into water masses each with its own characteristic physico-chemical conditions and trophic properties. These masses cross the north-south path in accordance to the north-south temperature gradient caused by the dynamic system of ocean currents and gyres. Major barriers of the above types present in the surface layer of the Indian Ocean are at 25°N (land locked boundary of tropical gyre), at 10°S (boundary between tropical and sub-tropical gyres in the southern hemisphere), at 41°S (sub-tropical convergence) and at 55°S (Antarctic convergence). Last two convergences exhibit large temperature drop over a small area. In mid water depths fewer boundaries such as sub-tropical convergence and Antarctic convergence exist. No latitudinal barrier exists in the bathyal zone due to deepest circulation.

The effectiveness of north-south hydrographical barriers in restricting the distribution pattern of Scolecithricidae species, can be explained by the diversity of species along the north-south gradient. Van Soest (1979) included 215 oceanic out of 1,200 species of copepoda in addition to other 724 species forming 17 higher taxa for his studies on distribution along a north-south gradient. He divided them based on latitudinal boundaries as follows: (a) widely distributed at all latitudes (b) moderately widely distributed (50°N-50°S), (c) restricted to mid latitudes (50°-30°N, 30°-50°S), (d) restricted to high latitudes (50°N & 50°S) and (e) restricted to low latitudes (30°N-30°S). From the above analysis of the 93 species of epipelagic copepods, Soest found 3 species widely distributed, 64 moderately wide and 26 restricted to low latitudes. This makes it clear that most common epipelagic distribution is the moderately wide distribution (69%) i.e. most species occur in tropical and sub-tropical convergence (25°N-45°S). The next pattern represented is the restricted warm water distribution (confined to sub-tropical and tropical waters) with 28% of the species observed. Studies on continuous wide distribution of species revealed presence of only such 3 copepod species (3%). They are *Paracalanus parvus* (Claus, 1863), *Clausocalanus arcuicornis* (Dana, 1849) and *Scolecithricella minor* (Brady, 1883). Of the 108 mesopelagic copepod species, 21 were widely distributed, 74 moderately distributed, one restricted to high latitudes and 12 to low latitudes. Similarly among the 12 bathypelagic species 3 were widely distributed, 7 moderately wide and 2 restricted to low latitudes. Similar analysis of north-south distribution of 27 species of Scolecithricidae in the Indian Ocean revealed the following patterns:

(1) 25°N - 40°S: *S. danae*, *S. curtus* and *S. bradyi* - Tropical + Sub-tropical. (2) 25°N - 30°S: *S. echinatus* and *S. tenuiserrata*. (3) 25°N - 20°S: *S. abyssalis*, *S. ctenopus* and *S. nicobarica* - mostly tropical. (4) 25°N-10°S: *S. marginata* and *S. longifurca*. (5) North of equator

(Arabian Sea and Bay of Bengal): *A. indica*, *S. dauglishi* and *M. cochinensis*. (6) 10°N - 40°S: *S. dentata*, *S. tropica* and *L. angusta*. (7) 10°N - 30°S: *S. vitata*. (8) 10°N - 20°S: *S. securifrons*, *S. ovata* and *S. helenae*. (9) 10°N - 10°S: *S. affinis*, *S. farrani* and *L. frontalis* - purely tropical. (10) South of equator to 20°S: *S. australis* and *S. thomasi*. Due to restricted collections made upto 40°S only are available, Soest classification could not be followed. Yet the most common epipelagic distribution is the restricted warm water distribution i.e. most Scolecithricidae species in the Indian Ocean occur in tropical and atleast in part of sub-tropical waters of the Indian Ocean. Scolecithricidae species appear to be confined by the subtropical convergence (45°S).

S. danae, *S. curtus* and *S. bradyi* were widespread from 25°N - 40°S. *S. echinatus* and *S. tenuiserrata* were mostly wide upto 30°S. *S. abyssalis*, *S. ctenopus* and *S. nicobarica* were less wide as they were not present south of 20°S. While *S. dentata*, *S. tropica* and *L. angusta* were distributed upto 40°S, they were not seen above 10°N. *S. securifrons*, *S. ovata* and *S.helenae* were restricted to southern tropical zone only - 10°N - 20°S. *A.indica* and *S. dauglishi* were restricted to the northern Indian Ocean only, as they were not sampled south of equator. The rare species *M. cochinensis* was also restricted to this area. *S. affinis*, *S. farrani* and *L. frontalis* may be considered as purely tropical species occurring from 10°N - 10°S. *S. australis* and *S. thomasi* were mainly collected from south of equator to 20°S. While *S. marginata* and *S. longifurca* were collected mostly from 25°N - 10°S, *S. vitata* mainly occurred between 10°N and 30°S. *A. arcuata* and *S. persegans* were present in only one station each. Thus the above study indicated the effectiveness of latitudinal oceanic barriers in limiting the distribution of Scolecithricidae species inspite of the fact that many species are meso and bathypelagic inhabitants coming to the surface only as part of diurnal migration.

The number of Scolecithricidae species in general decreased from low latitudes (equator) to high latitudes. In the tropical zone of 20°N - 20°S their number did not vary much. This general trend strongly suggests that the place of origin of most Scolecithricidae species is to be found primarily in the surface waters of the lower latitudes.

5.7. Sympatric, allopatric and parapatric speciation.

The biological species concept states that species are groups of natural populations which actually or potentially reproduce and which do not reproduce with other such groups. Speciation is usually accepted as being the result of special isolations and local adaptations. Thus a low speciation rate should be parralled by special distribution phenomena. According to Pierrot-Bults and Van der Spoel (1979)since boundaries and barriers such as varying temperature, oxygen and food in the ocean cannot completely isolate species of morphologically same nature, allopatric speciation as described by Mayr (1963) cannot hold good. They also found sympatric speciation based on ecological isolation without geographical isolation as advocated by Connell and Orias (1964), made possible due to presence of different niche combined with different ecological behaviour of organisms, unable to explain speciation among zooplankton. However David (1963), Van der Spoel (1967), Van Soest (1975) and Pierrot Bults (1976) noticed formation of new plankton species resulting from absolute geographic isolation caused by a variety of environmental conditions. Further studies by Endler (1977) and White (1977) found that selective pressure due to environmental conditions is

different in various parts of distribution for wide range species. This caused partial isolation between populations which according to them was named parapatric speciation. For holoplanktonic animals an environment in which numerous different niches occur at short distances is hard to imagine. One may even wonder whether "niche" is a concept applicable in planktonology. In the sea, areas with special biological and physical conditions are never so small and nowhere do they form mosaics which could be compared to the terrestrial and fresh water niches. The physical structure of the open ocean is much less complex than that on the land and parallel with this phenomenon, the community structure is less complex. The marine environment covering 70% of the earth but only 40% of all taxa living in it have some very specific characters. They are its uniformity and stability in environmental conditions, its three dimensional space and its vastness. Changes in the marine environment are gradual, both in time and space, Distribution ranges of organisms are usually extensive.
Mc Gowan (1971) concluded that there are less niches per unit of space in the open ocean than on the land. One can state, therefore, that the diversification of the biosphere of the ocean has not reached the level at which

niches develop and water masses are thus only biotopes. Under these conditions ecological variation and speciation may lead to parapatric speciation and often to infraspecific variation as seen in polytypic species. According to Pierrot Bults and Vander Spoel (1979) evidence for sympatric speciation or ecological isolation in interbreeding groups has never been given for oceanic holoplankton, so only allopatric and parapatric speciation are found to occur. Lawson (1977) during his study of community interaction in oceanic copepod Candacids found size as well as morphological differences within recurrent groups to prevent hybridization and competition for food etc., feeding on 10 different chaetognath species out of 24 from Indian Ocean (Nair and Rao, 1973). This he considered as a typical instance of sympatric speciation. Lawson also noted morphologically identical species and of similar size occupying different areas varying in temperature and oxygen leading to allopatric speciation. The pattern of distribution identified for Scolecithricidae species (Table 6) also perhaps indicate their speciation as a result of allopatry and sympatry. From the distribution pattern, the Scolecithricidae would now appear to be in biological equilibrium with minimum competition among them.

Niche formation: Niches of the species are compared using Hutchinson's multidimensional hyper volume as a model and described in terms of environmental variables (temperature, salinity, oxygen, biomass and space) measured at stations where the species was abundant. Mean niche adaptations of most of the species was separable from congeners along atleast one niche variable, to escape sympatric interference. Centre of abundance of a species was defined as where the species is found in abundance, greater than the median abundance. These high density stations numbering half the total occurrences of a particular species (Tables 2 and 4) were taken into consideration in studying niche separation. Taking into consideration of species centres of abundance relative to maximum temperature in upper 200 m, *S. ovata*, *S. securifrons* and *S. nicobarica* preferred surface waters than 25°C, whereas *L. angusta* and *S. vitata* were southern species preferring cooler waters. *S. echinatus*, *S. bradyi*, and *S. dentata* were displaced towards cooler temperatures. *S. marginata*, *S. longifurca*, *S. abyssalis*, *S. curtus*, *S. ctenopus*, *A. indica*, *S. dauglishi*, *S. affinis* and *M. cochinensis* were more displaced towards warmer temperatures. *S. danae*, *S. tenuiserrata* and *S. echinatus* appears to be eurythermal. *S. echinatus*, *S. tenuiserrata*, *S. bradyi* and *L. angusta* appears to prefer high food concentrations. *S. ctenopus*, *L. angusta*, *S. vitata*, *S. ovata* and *A. indica* preferred low concentrations of biomass. In general rest of the species preferred a biomass range of $10^{0.3}$ to $10.^{0.4}$ $cm^3/200$ m^3. Most of the species were confined within a salinity range of 14.5 to 35.5 ‰. *S. marginata*, *S. nicobarica* and *S. affinis* occurred at somewhat lower salinities as low as 32 - 34 ‰. No species was found at salinities of 35.5 ‰ or higher. Species distribution was related to oxygen minimum (ml/l) in upper 200 m. *A. indica* and *S. ctenopus* were confined to areas where sub-surface waters were extremely depleted of oxygen. *S. dentata*, *S. vitata* and *L. angusta* occurred in well oxygenated waters.

Traditionally water masses are determined on their T-S properties, but it is now clear that oxygen content of the water as well as dissolved nutrient ratios aid in identifying its origin (Gardner, 1977). The biological history of a body of water is atleast as important as the abiotic environmental factors in determining the species that occur in it. But the Indian Ocean with its characteristic features as reversal of monsoons renders extensive seasonal interchange of surface waters between the equatorial and central water masses, providing convenient avenues for epipelagic species to rapidly extend their distribution throughout the oceanic basin. Yet distribution studies made by Lawson (1977) on calanoid copepods showed that the calanoid species have maintained discrete patterns of distribution in the Indian Ocean. Distributional studies on Scolecithricidae (Figs. 13-31) also indicated such discrete patterns of distribution in the Indian Ocean. These patterns provide circumstancial evidence that the species are adapted to distinctly different types of environments. The distribution of organisms which live in the surface layers are best described by the surface hydrography. The distribution of planktonic animals mainly epipelagic zooplankton species have been shown to be strongly associated or conforming to boundaries of physical water masses of the world oceans, as recognised by Sverdrup *et al*. (1942) and Wyrtki (1973).

5.8. Zoogeography.

Zooplankton distribution pattern in the world oceans has a simple pattern. They are (a) a tropical-sub-tropical zones showing a certain homogenity of plankton population circumglobally; (b) 2 temperate zones, boreal and antiboreal, which display varying degrees of endemicity and which are more or less circumglobal by northern and southern routes; (c) a circumglobal southern ocean zone; (3) a north Pacific-Arctic Ocean-North Atlantic region and (e) bipolarity. Biogeographic zones when defined strictly in terms of temperature, may have only limited relevance to the living world. But when defined in terms of limits of distribution of biota like the reef building corals the zones may have more meaning. Most of the pelagic taxa contain many examples of circumglobal tropical-sub-tropical species. Fleminger and Hulsemann (1974) studying world distribution of 4 species of Pontellina found only one of them - P. plumata to be circumglobal with slight morphological variations in populations of 3 oceans. There are many warm water plankton which are circumglobal. Concerning warm water plankton, Fleminger and Hulsemann (1973) have concluded, on the basis of calanoid copepod distribution and other evidence (euphausids - Brinton, 1962; bathypelagic fishes - Ebeling, 1962, 1967) that the strictly tropical species are not often circumglobal but tend to be restricted to either (1) the Atlantic Ocean (2) the Indian Ocean and western portion or more of the Pacific Ocean or (3) the tropical (equatorial) Pacific Ocean. Species that are sub-tropical rather than tropical or are found in both tropical and sub-tropical warm water regions, and maintain gene flow around Cape of Good Hope route between Indian and Atlantic Oceans. According to Brinton (1963) oceanic zooplankton occupying waters of the Indo-Australian Archipelago are mainly tropical (equatorial) species common to both the Indian and Pacific Oceans. Ekman (1935) in his synthesis "The Zoogeography of the Sea", could suggest that world-wide patterns of distribution existed for marine fauna and he recognised only 3 major patterns. According to Ekman (1953) the different zoogeographic regions of the shelf areas along the oceans are characterised by special genera and families while the different pelagic regions of the open ocean only show endemism at species level. Based on his analysis of water masses, ocean circulation and species distribution Reid _et al_. (1978) concluded that most zooplanktonic groups show identical distributional patterns. Distributional barriers like the convergences and divergences, making the limits of water masses are found to coincide roughly with boundaries for a number of taxa in a region and thus they constitute a faunal boundary. A critical analysis of zoogeography of various zooplankton groups in the Indian Ocean reported by various authors revealed geographical areas (different latitudinal zones) characterised by special faunal associations. The boundaries recognised are Red Sea and Persian Gulf, Arabian Sea and Bay of Bengal, equatorial region (10°N to 10°S), Indian Ocean Central Water (10°S to 35°S), Somali Current region, Agulhas Current region, entire Indian Ocean upto sub-tropical convergence and the Antarctic part of the Indian Ocean. The present study also indicated the local abundance of species to be strictly a bio-hydrographical feature whereas absence or presence of a species to be a matter of historical zoogeography of the area. Communities of species were found better in identifying water masses than indicator species. The role of reversing monsoons in the northern gyre and boundary currents in the latitudinal transport and shift of populations is worth realising. Occurrence of meso and bathypelagic species of Scolecithricidae of the Atlantic Ocean in the epipelagic zone of the Indian Ocean provide evidence for the influence and flow of Atlantic Intermediate Water, Antarctic Bottom Water and Antarctic Intermediate Water into the Indian Ocean. Using the ecological indicators - the 27 species of planktonic foraminifera - Be and Tolderland (1971) described their distributional patterns stressing the importance of temperature and salinity in the latitudinal zonation of the Indian Ocean. Vannucci and Navas (1973a) recognised 5 groups of Hydromedusae related to water masses irrespective of geographical limits. Brinton and Gopalakrishnan (1973) recognised 5 boundaries for euphausids. Omori (1977) suggested 2 regions for Sergestidae. Nair (1977) recognised 3 zones for chaetognaths. Sakthivel (1972) adopted 10 patterns for Euthecosomata. Stuer (1933) published a scheme of 12 zoogeographic regions in the world oceans based on his study of copepods which formed the basis for much of today's zoogeographic thinking. But Mc Gowan (1971) observed the major patterns seem to repeat themselves from taxon to taxon. Sewell (1948) based on his studies on planktonic copepods divided Indian Ocean into 2 zoogeographical areas namely a tropical zone north of 10°S - a sub region of Indo-Pacific nature - and a sub-tropical zone comprising central and southern Indian Ocean extending from 10°S to subtropical convergence zone at 40°S. Though he established Indo-Pacific nature to the large number of copepod species from the Indian Ocean, only 24 out of 45 Scolecithricidae species described from Pacific Ocean were identified during the present study. From east to west a decrease in species diversity of Scolecithricidae occurred from 27 in the Indo-Pacific area to 7 in the Gulf of Aden similar to the observations made by Sewell (1948) for copepods. Seven species recorded from the Gulf of Aden are *S. danae*, *S. abyssalis*, *S. securifrons*, *S. echinatus*, *S. bradyi*, *S. tenuiserrata* and *L. frontalis*. The number of Scolecithricidae species gradually got reduced from 24 in the northern equatorial latitudes to 13 at the sub-tropical convergence, as observed by Sewell (1948). Owing to the availability of collections only from the euphotic zone, changes in species with depth could not be studied. The high density population found south of Java and off northwestern Australian coast in the Timor Sea and through Malacca Strait may be the result of exchange of Pacific waters with Indian Ocean waters taking place in this sea. The following 6 species - *S. nicobarica*, *S. marginata*, *S. longifurca*, *S. tropica*, *S. farrani* and *S. australis* which are typical of the Indo-Pacific waters were not found in the Atlantic Ocean. The 3 species - *A. indica*, *M. cochinensis* and *S. dauglishi* are endemic to the Indian Ocean. Though Sewell (1948) recorded 165 deep water copepods from the Indian Ocean including deep water Scolecithricidae species, in view of the 200 m depth limit of the collections made, majority of them could not be collected during this study. Significant work on zoogeography of copepods include Fleminger (1975), Fleminger and Hulsemann (1974), Frost and Fleminger (1968) and Lawson (1977). Jones (1966 a & b) divided the western Indian Ocean into 3 main provinces based on distribution of Candacidae copepods. He noted equatorial species abundant in areas north of about 20°S, those species being carried southward by Agulhas Current. These equatorial forms had a discontinuous distribution being found in Atlantic and Pacific waters. However Lawson (1977) studying the zoogeographical patterns of Candacidae from the Indian Ocean recognised 2 recurrent groups characteristic of equatorial waters and central gyres respectively with faunal transitions at 10°N, equator, 10°S and 45°S. Fleminger and Hulsemann (1973) from their studies on epiplanktonic calanoids of Indian Ocean noted 2 features of interest. They are (a) species breeding between 25°N and 40°S such as *Pontellina plumata* tend to be circumglobal in distribution maintaining gene flow around South Africa and (b) those species breeding in between 30°N and 30°S such as *Eucalanus elongatus* which are restricted, having tropical cognates in other oceans. Haq *et al*. (1973) recorded highest concentration of *Pleuromamma indica* near continental margin of Karachi coast, when penetration of deep water which is cool (6-23°C) and oxygen deficient (< 1 ml/l) was recorded. It was also abundant in Arabian Sea and Bay of Bengal waters. Saraswathy (1973) dealing with epiplanktonic Metridiidae copepod found *Gausia sewelli* endemic to northern Indian Ocean and *G. scotti* a most widely distributed species in other oceans being abundant at 200 - 3,000 m depth, south of equator as far as 41°S. Scolecithricidae copepods were found having extended range of distribution latitudinally, to north or south along the east and west coasts of Indian Ocean, controlled by the coastal currents as observed for Candacidae by Lawson (1977). Based on the distributional aspects of Scolecithricidae species from the Indian Ocean, the following pattern appeared to be more meaningful: Scolecithricidae species were sparse in between 20°S and 35°S.

Oceanic circulation carry zooplankton to areas beyond what might normally be thought of as their range to regions of the ocean which are suitable for their existance, but unsuitable for their reproduction. Thus the overall distribution of an oceanic zooplankton can be very misleading unless its total life history is considered. The occurrence of sterile, dead-end populations of animals in the ocean appears to be wide spread and the phenomenon is known as expatriation, recognised first as a general feature in oceanic zoogeography. Grainger (1963) showed <u>Calanus finmarchicus</u> as an expatriate at the northern limits of its range off Labrador. Such expatriation could be noted in the Scolecithricidae distribution (Figs. 14-31).

Based on the above observations, the following 10 patterns were observed (Table 7) in the distribution of Scolecithricidae species of copepods, many of which showing only restricted distribution. There were:

1. 25°N-40°S : *S*. *danae*, *S*. *curtus*, *S*. *bradyi*. Tropical + sub-tropical.
2. 25°N-30°S : *S*. *echinatus*, *S*. *tenuiserrata*.
3. 25°N-20°S : *S*. *abyssalis*, *S*. *ctenopus*, *S*. *nicobarica*. Mostly tropical.
4. 25°N-10°S : *S*. *marginata*, *S*. *longifurca*.
5. North of equator (Arabian Sea & Bay of Bengal: *A*. *indica*, *S*. *dauglishi*, *M*. *cochinensis*.
6. 10°N-40°S : *S*. *dentata*, *S*. *tropica*, *L*. *angusta*.
7. 10°N-30°S : *S*. *vitata*.
8. 10°N-20°S : *S*. *securifrons*, *S*. *ovata*, *S*. *helenae*.
9. 10°N-10°S : *S*. *affinis*, *S*. *farrani*, *L*. *frontalis* - Purely tropical.
10. South of equator to 20°S : *S*. *australis*, *S*.*thomasi*.

The area between 20°S and 35°S turned to be an impoverished area for Scolecithricidae. The hydrographical front at 10°S acted as a boundary between the olygotrophic sub-tropical anticyclonic gyre and eutrophic northern monsoon gyre.

5.9. Species diversity.

No. of sp. present	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
No. of Stations	10	41	44	45	43	47	40	26	28	25	16	12	3	3	1	1

Of the 27 species of Scolecithricidae collected, a maximum of 15 species was present only in one oceanic station located at 02°N, 75°E in the Arabian Sea. The observation indicated a proportionate reduction in number of stations as the number of species in each station increased from 1-15. Stations having 1-6 species ranged from 41-47 numbers whereas stations having 7-9 species ranged from 25-28 numbers; 10, 11, 12, 13 and 14 and 15 species were present in 16, 12, 3, 3, 1 and 1 stations respectively. A detailed analysis of the number of species present in each of the 385 stations sampled indicated that stations with large number of species were located in the oceanic province especially along the mid ocean extending from peninsular India to 32°S parallel. The 10 stations where not a single Scolecithricidae occurred were coastal neritic stations. Many coastal or nearshore stations sampled had only one, two or three species. Thus neritic stations in general had fewer species compared to the oceanic regions. Also, studies on day-night variations in the numerical abundance of species in oceanic areas showed their abundance only in the night stations. Occurrence of few numbers of species in the day stations even in oceanic areas revealed their meso and bathypelagic habitat in oceanic areas below the euphotic zone. Majority of them underwent nocturnal vertical migrations to euphotic zone. Also, more number of species were collected during the October-April period, which revealed, a definite increase of population after the Southwest monsoon, leading to more chances of sampling them. This study throws light on the importance of nocturnal vertical migration in the species diversity of oceanic province.

5.10. Statistical inferences.

Studies on coexistence of Scolecithricidae species showed that of the correlations 21.65% were positive and 58.68% of the correlations were found to be significant at 1% level ($p < 0.01$) and 2.84% were found to be significant at 5% level. About 59.7% of the correlations significant at 1% level were found to be positive. Species

S. danae and *S. abyssalis* were significantly correlated with 75% of the rest and species *S. danae*, *S. bradyi*, *S. abyssalis*, *S. ctenopus*, *S. echinatus*, *L. angusta*, *S. nicobarica*, *S. tropica* and *S. thomasi* were significantly correlated with 60% of the rest (Table 7).

The influence of the parameters studied namely temperature, salinity and oxygen in controlling the occurrence of the species in Arabian Sea and Bay of Bengal, southwest Indian Ocean and southeast Indian Ocean was studied by means of correlation of the species with these parameters in each case. For this, correlation coefficients were calculated. In the Arabian Sea 22.22% of the species were significantly correlated at 1% level with temperature, 37.04% were significantly correlated at 1% level with salinity and 14.82% were significantly correlated with oxygen. In the Bay of Bengal 40.74% were significantly correlated with temperature, 29.63% were significantly correlated with salinity at 1% level, ($P < 0.01$). In southeast Indian Ocean no species was found to be significantly correlated with any one of the above parameters. In southwest Indian Ocean no significant % of the species was found to be significantly correlated with temperature and salinity and 18.52% of the species were significantly correlated with oxygen at 1% level ($P < 0.01$). Bay of Bengal, Arabian Sea, southeast and southwest Indian Ocean were compared for the total occurrence of the species. Comparison was done by testing the hypothesis that there was no significant difference between them and also the total occurrence of species was the same in all the 4 places.

The correlation coefficient matrix of size 27 x 27 revealed the fact that ~~about~~ more than 75% of the species of Scolecithricidae had different environmental requirements, since negative correlations exceeded positive correlations. So we can expect a considerable change in the abundance of species of Scolecithricidae in the regions in course of time provided the environmental conditions vary. From correlation coefficients of the species with the 3 parameters for each region it was found that salinity was the most important factor followed by temperature and oxygen in Arabian Sea, oxygen was the most important factor followed by temperature and salinity in the Bay of Bengal, oxygen was the most important factor followed by salinity and temperature in the southwest Indian Ocean and none of the parameters had significant role in southeast Indian Ocean, in controlling the occurrence of the species of Scolecithricidae. The multiple regression model was -

$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3$. The normal equations obtained by the method of least squares are -

$$\Sigma Y = nb_0 + b_1\Sigma X_1 + b_2\Sigma X_2 + b_3\Sigma X_3 \quad \ldots\ldots\ldots\ldots\ldots (1)$$

$$\Sigma X_1Y = b_0\Sigma X_1 + b_1\Sigma X_1^2 + b_2\Sigma X_1X_2 + b_3\Sigma X_1X_3 \quad \ldots\ldots\ldots (2)$$

$$\Sigma X_2Y = b_0\Sigma X_2 + b_1\Sigma X_1X_2 + b_2\Sigma X_2^2 + b_3\Sigma X_2X_3 \quad \ldots\ldots\ldots (3)$$

and $$\Sigma X_3Y = b_0\Sigma X_3 + b_1\Sigma X_1X_3 + b_2\Sigma X_2X_3 + b_3\Sigma X_3^2 \quad \ldots\ldots (4)$$

b_0, b_1, b_2 and b_3 were calculated. The techniques of the multiple regression model fitted to predict the biomass of species of Scolecithricidae

(1) for the whole was

$$Y = -8.33073 - 0.61129\ X_1 + 25.85218\ X_2 - 139.28992\ X_3$$

(2) For Arabian Sea was

$$Y = 339.0007-1.46207\ X_1+38.51889\ X_2-294.31703\ X_3$$

(3) For Bay of Bengal was

$$Y = 38.87251-1.02051\ X_1+0.82451\ X_2+18.0212\ X_3$$

(4) For southwest Indian Ocean was

$$Y = -10721.8832-148.9770\ X_1+363.5726\ X_2+272.1656\ X_3$$

(5) For southeast Indian Ocean was

$$Y = 66.3457+3.8257\ X_1-0.3246\ X_2-1.2514\ X_3.$$

Table 10 (1) gives the analysis of variance of the regression coefficients and it shows that regression coefficients were all significant at 1% level for the data collected from the whole area ($P < 0.01$) which indicates that fitted regression was capable of explaining a significant part of the variability in the prediction of biomass of the Scolecithricidae collected. But variability explained by the regression model was only 11%. Since unexplained variability far exceeded the explained variability eventhough the regression coefficients were found to be significant we can conclude that still a good part of the variability in the model can be explained by the variables like nitrate-nitrogen, phosphate-phosphorus, current-turbidity, depth stratification, interaction of the above factors etc. which are not included in the model. From Table 10 - $^{(2)}$ it was seen that regression coefficients are all significant at 1% level, for the data collected from Arabian Sea ($P < 0.01$). Here also significance of the regression coefficients does not fully reveal the fact that the fitted regression was capable of explaining a significant part of the variability in the prediction of the biomass of Scolecithricidae collected, since unexplained variability was more than 4 times the explained variability. So it follows that some or all of the environmental factors mentioned above were also to be included in the model to extract or to explain maximum amount of variability present in the prediction equation.

From Table 10 - (3) it was seen that regression coefficients were not significant, for the data collected from Bay of Bengal at 1% level ($P < 0{\cdot}01$) i.e. the parameters-temperature, salinity and oxygen taken at present cannot explain a significant part of the variability in the prediction equation. So it is a must that all environmental factors mentioned above are to be included completely or partially which can be judged by a similar test, so that whole or a significant part of the variability in the prediction can be explained. From Tables 10 - (4) and 10 - (5) it is again seen that regression coefficients were not significant indicating that the parameters included at present were not capable of explaining a significant part of the variability in the regression model used to predict the biomass of Scolecithricidae collected from the southeast and southwest Indian Ocean. So our former conclusion remains true in these two areas also. From Table 11 relative importance of the parameters in the regression model for prediction of biomass in the 4 regions are in the same order as concluded from the table of coefficients. Salinity was the most prominent environmental factor followed by temperature and oxygen in Arabian Sea; while the order was oxygen, temperature and salinity in Bay of Bengal; temperature, salinity and oxygen in southwest Indian Ocean; temperature, oxygen and salinity in southeast Indian Ocean and salinity, oxygen and temperature when we consider the 4 regions together.

Table 13 showed that there was significant difference between the 4 regions and there was significant difference among the species with respect to their total occurrence. This conclusion was quite clear from the relative importance of parameters like temperature, salinity and oxygen in predicting the biomass of Scolecithricidae in the 4 regions.

Diagrams were drawn to show the distribution of the species in the 3 ranges. These showed that first 8 species occurred over a wide range when compared with the rest (Fig. 33).

Table 14 gives the Fisher's species diversity index α and its variance. The values of α ranged from 2.374 to 2.788 which indicated that the type of environment in all areas were more or less of the same kind but neither too old or too new, severe nor unpredictable. It was quite clear from the nature of the coexistance of the species. Further, since the V (α) ranged from 0.0296 to 0.0430 it followed that α calculated will remain almost constant for all the areas.

6. SUMMARY.

6. SUMMARY.

1. The studies on scolecithricid calanoid copepods are based on 385 collections (184 night and 201 day collections: 168 collections during Southwest monsoon and 217 during Northeast monsoon period) of zooplankton from the euphotic zone of the Indian Ocean, during the International Indian Ocean Expedition, 1960-'65.

2. A brief account of the scope and purpose of study of the IIOE zooplankton along with literature survey, taxonomic history of Calanoida, past studies on planktonic Copepoda and studies on zoogeography and species diversity of zooplankton is given in the introductory chapter.

3. The second chapter deals with the material used and methodology involved in processing the data along with statistical methods adopted (Tables 1-3).

4. The chapter on environmental factors of the Indian Ocean deals with the importance of oceanographic parameters such as topography, thermal structure, salinity gradient, oxygen content,

nutrients, water masses, current systems, pattern of circulation, upwelling and phytoplankton production in understanding the biogeography of the Indian Ocean.

5. Taxonomic features of 27 species of Scolecithricidae, belonging to 7 genera, identified from the IIOE zooplankton samples, based on the classification by Sars (1905) are briefly described with illustrations (Figs. 1-12) in chapter four. One of the 27 species viz. *Macandrewella cochinensis* has been described as a new species by the author in 1973 and *Scolecithricella tropica* and *Scottocalanus australis* are new records from the Indian Ocean which are previously known only from the Pacific.

6. Chapter five deals with the inferences made from the distribution of 27 species of Scolecithricidae (Figs. 13-33 and Tables 4-14) and possible discussions arising out of it, regarding their distribution and speciation.

7. The abundant and wide-spread *Scolecithrix danae*, *Scolecithricella bradyi*, *Scaphocalanus echinatus*, *Scolecithricella ctenopus*,

S. tenuiserrata, *S. dentata*, *S. abyssalis* and *Scaphocalanus curtus*, having a frequency of occurrence of 82.3, 63.6, 34.3, 31.7, 49.1, 34.0, 43.4 and 35.1 % in total stations respectively, contributed to 59.7, 6.5, 6.2, 5.1, 4.4, 3.7, 3.6 and 3.4 % of total Scolecithricidae collected respectively.

8. *Scolecithrix*, *nicobarica*, *Lophothrix angusta*, *Scolecithricella marginata*, *Amallothrix indica*, *Scolecithricella vitata*, *Scottocalanus dauglishi*, *S. securifrons* and *Scolecithricella ovata* had low numerical abundance of 1.6, 1.1, 1.0, 0.7, 0.5, 0.5, 0.4 and 0.4 % of total Scolecithricidae respectively, but with a median range of occurrence of 19.5, 27.5, 13.8, 8.6, 17.1, 7.3, 11.2 and 14.3 % respectively in total stations.

9. The following 11 species viz. *Scaphocalanus longifurca*, *S. affinis*, *Scolecithricella tropica*, *Amallothrix arcuata*, *Scottocalanus persicans*, *S. farrani*, *S. helenae*, *Lophothrix frontalis*, *Macandrewella cochinensis*, *Scottocalanus australis* and *S. thomasi* were rare species contributing to 0.3, 0.1, 0.1, 0.02, 0.003, 0.2,

0.1, 0.1, 0.2, 0.02 and 0.03 % respectively of total Scolecithricidae and having very low frequency of occurrence of 2.9, 3.9, 3.1 0.3, 0.3, 2.6, 2.1, 2.6, 1.0, 1.8 and 1.0 % respectively in total stations.

10. *S. danae* and *S. bradyi* are widely spread surface inhabitants undergoing reverse vertical migration. *S. vitata* and *M. cochinensis* are non-migrant, near-surface layer species occurring in the central gyre and monsoon gyre water respectively whereas another non-migrant *S. curtus* from mid waters occurs more in equatorial region. Rest of the 22 species are extensive migrants undertaking nocturnal migrations to the surface in neritic and oceanic waters.

11. The most abundant and widely distributed *S. danae* contributed to a higher production in the Southwest monsoon period, whereas 19 other species showed an intensive production in the Northeast monsoon period.

12. Distribution studies showed continental isolating mechanism as land locked northern

Indian Ocean effective in upper 200 m roughly delimited by the 20°C mean year isotherm, whereas in the deep sea, only the distance factor isolated the species. Role of currents, vertical distribution, temperature and thermocline as indistinct barriers for speciation in Scolecithricidae are discussed. The family Scolecithricidae as such is widespread in the Indian Ocean having a circumglobal distribution, occurring in abundance along the west and east coasts of Indian Ocean (in the boundary currents) and in the mid ocean extending from the southern tip of India to 20°S. Numerical abundance varied from 0 - 2,078 per IIOE standard haul per station. Of the 27 species, 18 are common to Indian, Atlantic and Pacific Oceans, 6 are confined to the Indo-Pacific waters and 3 are endemic to the Indian Ocean. *Amallothrix indica* and *Scottocalanus dauglishi* confined to Bay of Bengal and *M. cochinensis* restricted to Wadge Bank and Andaman Sea are the endemic species in the Indian Ocean. Mid and deep water species *S. nicobarica*, *S. marginata*, *S. tropica* and

S. longifurca and the two deep water forms *S. farrani* and *S. australis* occur in Indo-Pacific waters. The remaining 18 species are common to the three oceans.

13. North-south diversity of Scolecithricidae showed importance of latitudinal hydrographic boundaries in the euphotic zone in restricting the distribution of the species and in explaining species diversity. Most common epipelagic distribution is in the restricted warm water zone.

14. As generally observed with zooplanktonic organisms, the small sized *M. cochinensis* (2.9 mm), *A. arcuata* (2.5 mm), *S. echinatus* (1.8 mm), *S. longifurca* (1.5 mm), *S. curtus* (1.4 mm), *S. ctenopus* (1.4 mm), *S. tropica* (1.2 mm) and *S. marginata* (1 mm) are neritic in abundance. *S. danae* and *S. bradyi* occur in abundance in neritic as well as in oceanic waters. The remaining 17 species may be considered as oceanic.

15. Discrete patterns of distribution indicate speciation as a result of allotropy (geogra-

phical isolation) and sympatry (ecological isolation without geographical isolation). Based on Hutchinson's multi-dimensional hypervolume as a model, niches of the species are compared and using the different environmental variables as temperature, salinity, oxygen and food, niches of each species are described. Mean niche adaptations of most of the species was separable from congeners along atleast one niche variable. Discrete patterns of distribution maintained by semi-enclosed gyres of water masses also provide evidence for their adaptation to distinctly different type of environments.

16. Based on the present studies the following 10 patterns of distribution were observed:

a) 25°N - 40°S : *S. danae*, *S. curtus and S. bradyi* - Tropical and sub-tropical.

b) 25°N - 30°S : *S. echinatus* and *S. tenuiserrata*.

c) 25°N-- 20°S : *S. abyssalis*, *S. ctenopus* and *S. nicobarica* - Mostly tropical.

d) 25°N - 10°S : *S. marginata* and *S. longifurca*.

e) North of equator (Arabian Sea and Bay of Bengal): *A. indica*, *S. dauglishi* and *M. cochinensis*.

f) 10°N - 40°S : *S. dentata*, *S. tropica* and *L. angusta*.

g) 10°N - 30°S : *S. vitata*.

h) 10°N - 20°S : *S. securifrons*, *S. ovata* and *S. helenae*.

i) 10°N - 10°S : *S. affinis*, *S. farrani* and *L. frontalis* - Purely tropical.

j) South of equator to 20°S : *S. australis* and *S. thomasi*.

17. Species diversity increased from neritic to oceanic waters. The maximum number of species found in the neritic waters per haul was 3, whereas upto 15 species were present in a haul in the oceanic realm.

18. Studies on coexistence of species showed that *S. danae* and *S. abyssalis* were significantly correlated with 75% of the rest and species *S. danae*, *S. bradyi*, *S. abyssalis*, *S. ctenopus*, *S. echinatus*, *L. angusta*, *S. nicobarica*, *S. tropica* and *S. thomasi* were significantly correlated with 60% of the rest. The correlation coefficient matrix prepared for the 27 species showed that more than 75% species had different environmental requirements. The coefficient of correlation for 27 species based on temperature, salinity and oxygen data indicated that salinity was the most

important factor followed by temperature and oxygen in Arabian Sea, oxygen followed by temperature and salinity for Bay of Bengal, oxygen followed by salinity and temperature for southwest Indian Ocean, none was significant for southeast Indian Ocean and salinity, oxygen and temperature respectively for the Indian Ocean as a whole. A multiple regression model significant at 1% level was developed indicating that the fitted regression was capable of explaining only 11% of the variables in the prediction of abundance of Scolecithricidae. Calculation of Fisher's diversity index α and its variation indicated that the type of environments in the different areas of the Indian Ocean were more or less of the same kind.

TABLES

Table 1 : Participating nations and the Research Vessels of the IIOE Zooplankton Programme, the general area explored and the number of samples collected during 1960-'65.

Country	Research Vessel	No. of collections per year						Total	General area explored
		1960	1961	1962	1963	1964	1965		
U.S.A.	Anton Bruun	-	-	-	191	118	-	309	Bay of Bengal, Arabian Sea and western half of south Indian Ocean.
	Argo	-	-	94	-	12	-	106	Somali coast, 45°-100°E, 6°N-6°S.
	Pioneer	-	-	-	-	40	-	40	80°-105°E, 21°N-6°S.
India	INS Kistna	-	-	39	153	77	83	352	Bay of Bengal, Arabian Sea and central equatorial zone.
	Varuna	-	-	-	71	-	-	71	West coast of India.
	Conch	-	-	-	6	-	-	6	Off Cochin
Australia	Diamantina	-	-	36	107	36	19	198	South-east Indian Ocean.
	Gascoyne	-	-	15	32	-	-	47	Along the meridian 110°E.
	Patanela	-	-	-	-	21	5	26	60°-115°E, 33°S-51°S.

Table 1 (Contd.)

Country	Research Vessel	No. of collections per year						Total	General area explored
		1960	1961	1962	1963	1964	1965		
Japan	Umitaka Maru	-	-	13	20	15	-	48	78°E, 100°-120°E, 5°-25°S.
	Kayoshima Maru	-	-	-	24	8	-	32	78°E & 86°E, 8°N-25°S.
	Oshoro Maru	-	-	16	45	21	2	84	Off Sumatra and off Java.
	Koyo Maru	-	-	23	18	6	-	47	90°E & 100°E, 8°N-25°S.
U.K.	Discovery	-	-	-	41	162	-	203	40°-70°E, 20°N-20°S.
South Africa	Natal	-	-	100	35	-	-	135	South African Sea.
West Germany	Meteor	-	-	-	-	41	81	122	Gulf of Aden, Somalia, Kenya, and west coast of India.
U.S.S.R.	Vitiaz	14	3	50	-	7	5	79	70°-95°E, 10°N-35°S.
Pakistan	Zulfiquar	-	-	-	-	22	-	22	Off Pakistan.

Table 2 - Total number of each species in the four areas,
two seasons, night and day.

Species	Arabian Sea	Bay of Bengal	SW Indian Ocean	SE Indian Ocean	SW monsoon	NE monsoon	Night	Day
S. danae	29952	4658	5994	3083	21136	22551	20223	23464
S. bradyi	2179	460	1270	822	1925	2806	2663	2068
S. tenuiserrata	1314	921	560	391	981	2205	1814	1372
S. abyssalis	1635	608	178	189	735	1875	1677	933
S. ctenopus	929	2551	152	107	1874	1865	1868	1871
S. curtus	1808	132	293	226	569	1890	1635	824
S. dentata	1126	236	1058	262	558	2124	2068	614
S. echinatus	3248	575	603	132	1542	3016	4381	177
L. angusta	175	29	444	174	296	526	616	206
S. nicobarica	582	532	50	17	362	818	588	593
S. vitata	91	15	175	94	106	269	189	186
S. marginata	243	454	20	4	183	538	510	211
S. ovata	192	29	45	50	75	241	221	95
S. longifurca	113	123	-	-	68	168	76	160
A. indica	232	281	21	5	268	271	387	152

Table 2 (Contd.)

Species	Arabian Sea	Bay of Bengal	SW Indian Ocean	SE Indian Ocean	SW monsoon	NE monsoon	Night	Day
S. *daughlighi*	247	108	4	5	91	273	331	33
S. *securifrons*	245	13	52	15	64	261	319	6
S. *affinis*	38	55	-	-	58	35	83	10
S. *tropica*	8	60	14	13	66	29	28	67
S. *farrani*	108	-	-	1	88	21	103	6
S. *australis*	2	-	8	8	3	15	18	-
S. *helenae*	17	10	-	9	19	17	30	6
L. *frontalis*	61	11	-	-	-	72	72	-
S. *thomasi*	8	-	15	-	23	-	23	-
S. *persecans*	2	-	-	-	2	-	2	-
A. *arcuata*	13	-	-	-	13	-	13	-
M. *cochiensis*	160	15	2	-	2	175	-	177
Total	44728	11876	10958	5607	31107	42062	39938	33231

No. of Stations : Arabian Sea (176), Bay of Bengal (75), SW Indian Ocean (94), SE Indian Ocean (40), SW monsoon (168), NE monsoon (217), Night (184) and Day (201).

Table 3 - IIOE Zooplankton sampling variability.

Gear	Mouth diam. (cm)	Mesh width (mm)	Number of collections Wire out (m)							Total
			10-50	51-100	101-199	200	201-300	301-400	401-500	
IOSN	113	0.33	78	104	35	1047	433	29	2	1728
Organdie	50	0.06	1	1	-	104	4	2	-	112
N 70	70	0.54 + 0.24	4	5	4	49	2	-	-	64
Juday	113 reduced to 80	0.17	-	-	15	1	4	1	1	22
75 M	75	0.06	-	-	-	1	-	-	-	1
Total			83	110	54	1202	443	32	3	1927

Table 5 - Latitudinal variation of each species studied.

Species	25°-20°N	20°-10°N	10°N-0°	0°-10°S	10°-20°S	20°-30°S	30°-40°S	Remarks
S. danae	5.4	42.6	211.6	204.0	106.6	66.9	12.3	
S. bradyi	-	2.7	10.3	18.9	19.9	21.0	7.4	
S. tenuiserrata	13.9	18.4	2.9	5.2	12.0	8.1	0.4	
S. abyssalis	2.3	4.9	13.2	8.4	4.5	3.2	-	
S. ctenopus	13.6	38.4	1.3	3.0	3.7	4.7	0.3	
S. curtus	21.3	3.4	10.5	7.1	5.5	3.8	1.7	
S. dentata	-	0.5	7.3	10.1	10.3	4.7	11.7	
S. echinatus	1.8	15.3	22.6	12.9	5.7	2.0	8.3	
L. angusta	-	-	1.2	1.4	5.4	6.6	2.1	
S. nicobarica	-	0.5	8.2	4.8	0.9	0.5	-	
S. marginata	1.0	4.5	3.0	0.9	0.2	0.3	0.1	
S. vitata	-	0.2	0.4	0.8	2.3	2.7	1.1	
S. ovata	-	-	1.4	1.5	0.9	0.6	0.4	
S. longifurca	4.0	2.4	-	0.1	-	-	-	
A. indica	2.1	5.2	0.9	0.1	0.5	-	-	
S. deuglishi	-	1.6	2.5	0.1	0.2	-	-	
S. securifrons	-	0.1	2.1	0.9	0.7	0.3	0.6	

Table 5 (Contd.)

Species	25°-20°N	20°-10°N	10°N-0°	0°-10°S	10°-20°S	20°-30°S	30°-40°S	
S. affinis	-	0.8	0.1	0.3	-	-	-	
S. tropica	-	0.03	0.2	0.7	0.2	0.3	0.1	
S. farrani	-	-	0.1	1.4	0.02	-	-	
S. australis	-	-	-	0.03	0.3	-	-	Only in 7 stations
S. helenae	-	-	0.03	0.2	0.1	0.1	-	-do-
L. frontalis	-	0.3	0.3	0.3	-	-	-	Only in 10 stations
S. thomasi	-	-	0.1	0.04	0.2	0.1	-	Only in 4 stations
S. persecans	-	-	0.02	-	-	-	-	Only in 1 station
A. arcuata	-	0.2	-	-	-	-	-	-do-
M. cochinensis	-	2.2	-	-	-	0.1	-	Only in 4 stations.

Table 6 - Pattern of distribution of Scolecithricidae species in the Indian Ocean.

Species	General distribution	Areas of abundance
S. *danae*	Widely (north of 40°S)	East coast of Africa. Northern gyre
S. *abyssalis*	" (north of 20°S)	Wadge Bank (southwest coast of India). Northern gyre.
S. *curtus*	" (north of 40°S)	Highly productive waters. Northern gyre.
S. *echinatus*	" (north of 30°S)	Upwelling areas, coast of peniniasular India, Andaman Sea. Northern gyre.
S. *bradyi*	" (north of 40°S)	Mozambique Channel, Timor Sea. Mid ocean waters. Central gyre.
S. *tenuiserrata*	" (north of 30°S)	Arabian and Java coasts, Bay of Bengal. Northern gyre.
S. *ctenopus*	" (north of 20°S)	Arabian Sea and Bay of Bengal. Northern gyre.
S. *dentata*	" (south of 10°N)	East coast of Africa along 80°E meridian. Central gyre.
A. *indica*	Restricted (north of equator)	Eastern Arabian Sea and central Bay of Bengal. Northern gyre.
S. *dauglishi*	" (equator up to 15°N)	Wadge Bank, Andaman Sea. Northern gyre.
S. *marginata*	" (north-east of 10°S)	Gulf of Kutch, northern Bay of Bengal, Malacca Strait. Northern gyre in eastern Indian Ocean.
S. *nicobarica*	" (north of 20°S, absent in Arabian Sea)	Equatorial Bay of Bengal. Northern gyre.
S. *securifrons*	" (5°N to 20°S)	Somali upwelling, southern part of Northern gyre.

Table 6 (Contd.)

Species	General distribution	Areas of abundance
S. ovata	Restricted (equator to 20°S)	Equatorial patches. Southern periphery of Northern gyre.
S. vitata	" (equator to 35°S)	Coastal Madagascar, W. Australian coast. Central gyre.
L. angusta	" (equator to 40°S)	Along 80°E south of equator. Central gyre.
S. affinis	Rare (north of 10°S)	North Bay of Bengal, Arabian coast. Northern gyre.
S. longifurca	" (north of equator)	North Arabian Sea, Bay of Bengal, west coast of India. Northern gyre.
S. tropica	" (equator to 20°N)	Andaman Sea. Northern gyre.
A. arcuata	" (only in one stn.)	North Arabian coast. Northern gyre.
S. persecans	" (" " " ")	Off Somali coast, Northern gyre.
S. farrani	" (equator to 10°S)	Off Somali coast. Periphery of northern gyre.
S. helenae	" (" " ")	Off Java coast. Central gyre.
L. frontalis	" (10°N to 10°S)	Gulf of Aden, southern periphery of Northern gyre.
M. cochinensis	" (5°N to 15°N)	SW coast of India. Northern gyre.
S. australis	" (equator to 20°S)	Along 80°E meridian. Central gyre.
S. thomasi	" (equator)	Along equator. Equatorial.

Serial Order of Species in Tables 7, 8, 9(1), 9(2) and 9(3).

1. *S. danae*
2. *S. bradyi*
3. *S. tenuiserrata*
4. *S. abyssalis*
5. *S. ctenopus*
6. *S. curtus*
7. *S. dentata*
8. *S. echinatus*
9. *L. angusta*
10. *S. nicobarica*
11. *S. marginata*
12. *S. vitata*
13. *S. ovata*
14. *S. longifurca*
15. *A. indica*
16. *S. dauglishi*
17. *S. securifrons*
18. *S. affinis*
19. *S. tropica*
20. *S. farrani*
21. *S. australis*
22. *S. helenae*
23. *L. frontalis*
24. *S. thomasi*
25. *S. persecans*
26. *A. arcuata*
27. *M. cochinensis*

Table 8 - Regression coefficients for the data collected from the 4 regions.

Species	Arithmetic Mean				Standard deviation			
	Arabian Sea	Bay of Bengal	SW Indian Ocean	SE Indian Ocean	Arabian Sea	Bay of Bengal	SW Indian Ocean	SE Indian Ocean
1	1.501910	1.325913	1.037604	1.519376	1.187630	0.764894	0.900484	0.659957
2	0.723787	0.443224	0.818213	1.078192	0.932336	0.572904	0.579664	0.533128
3	0.411341	0.621313	0.489602	0.819276	1.776373	0.627606	0.553323	0.470880
4	0.582812	0.586583	0.145177	0.383546	0.586826	1.063336	0.367773	0.546097
5	0.241610	0.954493	0.132988	0.197984	0.522099	0.794245	0.360177	0.450736
6	0.505502	0.154843	0.250970	0.414287	0.650254	0.304761	0.463838	0.457949
7	0.372069	0.235879	0.457023	0.504281	0.592953	0.461021	0.663453	0.587537
8	0.580531	0.330273	0.330162	0.312057	0.770549	0.594948	0.563663	0.471827
9	1.272830	0.071008	0.432228	0.462427	0.306230	0.203859	0.499188	0.555248
10	0.139135	0.387854	0.083643	0.048814	0.417606	0.561867	0.233163	0.204205
11	0.084859	0.382513	0.041783	0.024408	0.313021	0.534784	0.155528	0.107939
12	0.070652	0.038586	0.244447	0.278259	0.213158	0.151694	0.369302	0.331510
13	0.151907	0.068907	0.046389	0.151259	0.299019	0.188743	0.200510	0.357397
14	0.040867	0.087838	0	0	0.331027	0.437348	0	0
15	0.096716	0.216999	0.014916	0.021032	0.300913	0.519293	0.140713	0.126194

Table 8 (Contd.)

Species	Arithmetic Mean				Standard deviation			
	Arabian Sea	Bay of Bengal	SW Indian Ocean	SE Indian Ocean	Arabian Sea	Bay of Bengal	SW Indian Ocean	SE Indian Ocean
16	0.111141	0.106979	0.007767	0.021032	0.295245	0.341901	0.073271	0.126194
17	0.132266	0.024061	0.075446	0.100405	0.296341	0.089524	0.237904	0.301632
18	0.028729	0.090339	0	0	0.151432	0.263443	0	0
19	0.010501	0.019879	0.024081	0.044419	0.072247	0.243048	0.133493	0.192707
20	0.050836	0	0	0.008135	0.221273	0	0	0.075408
21	0.003500	0	0.015337	0.035165	0.045776	0	0.102575	0.147536
22	0.016320	0.019879	0	0.039114	0.107827	0.124144	0	0.166044
23	0.037387	0.022546	0	0	0.183697	0.133499	0	0.289998
24	0.008025	0	0.019067	0	0.074603	0	0.132102	0
25	0.002774	0	0	0	0.039087	0	0	0
26	0	0	0	0	0	0	0	0
27	0.016284	0.016724	0.005301	0	0.045540	0.140914	0.050011	0

Table 9 (1) - Correlation coefficients of the species with temperature in Arabian Sea, Bay of Bengal, SW Indian Ocean and SE Indian Ocean.

Species	Arabian Sea	Bay of Bengal	SW Indian Ocean	SE Indian Ocean
1	0.038591	-0.550883	0.078298	0.047163
2	-0.036153	-0.536771	-0.183775	-0.207738
3	0.038335	0.613887	-0.104751	-0.213947
4	0.077082	-0.466942	0.202430	0.046235
5	0.023506	-0.314522	-0.057549	0.016946
6	0.064655	-0.678351	0.021482	0.026933
7	0.048149	0.533382	-0.019475	0.000040
8	-0.054274	-0.739536	0.075569	-0.110823
9	-0.042914	-0.076833	-0.119629	0.006620
10	0.201349	-0.538986	-0.070670	0.010418
11	0.362754	0.264993	-0.080494	0.009895
12	-0.439623	-0.868697	-0.222554	0.014386
13	0.249852	-0.348619	0.012691	-0.085439
14	0.046702	-0.001795	0	0
15	0.127379	0.096770	0.000807	0.016910
16	0.421247	0.063993	0.006679	0.016910
17	0.052569	0.032349	0.013040	-0.198949
18	0.017130	0.074499	0	0
19	0.077879	0.003102	-0.063922	0.010728
20	0.053363	0	0	-0.011952
21	0.044393	0	0.014472	0.137048
22	0.036660	-0.045357	0	-0.017328
23	0.044024	0.000607	0	0
24	0.055993	0	0.001089	0
25	0.068162	0	0	0
26	0	0	0	0
27	0.057345	0.025373	0.001127	0

Table 9 (2) - Correlation coefficient of the species with salinity in Arabian Sea, Bay of Bengal, SW Indian Ocean and SE Indian Ocean.

Species	Arabian Sea	Bay of Bengal	SW Indian Ocean	SE Indian Ocean
1	0.682738	-0.751262	0.103367	-0.043540
2	0.577860	-0.825193	-0.004170	-0.001086
3	0.655676	0.670058	-0.229876	-0.071566
4	0.081022	-0.472687	-0.040860	0.100220
5	0.132479	-0.340151	0.001557	0.066340
6	0.014041	-0.665104	0.102147	0.125323
7	0.132735	-0.563144	-0.168964	0.120384
8	0.179782	0.120235	-0.166795	-0.035763
9	-0.921943	0.063436	-0.088418	0.084246
10	0.260244	0.186708	-0.264937	0.035061
11	-0.010485	-0.198757	0.000696	0.032202
12	-0.013013	-0.511741	0.535470	0.123991
13	0.081630	0.025638	-0.000440	0.162554
14	0.175757	0.020158	0	0
15	0.494660	0.042793	-0.001826	-0.003438
16	0.547273	0.184478	-0.009740	-0.003438
17	0.155862	0.051463	-0.000323	-0.082769
18	0.027752	0.033496	0	0
19	0.019481	0.011420	0.058772	0.034049
20	0.034103	0	0	0.018199
21	0.009465	0	-0.002968	0.183585
22	0.022067	-0.043518	0	0.034750
23	0.029416	0.027360	0	0
24	0.014395	0	0.000901	0
25	0.010564	0	0	0
26	0	0	0	0
27	0.047444	0.006936	0.000521	0

Table 9 (3) - Correlation coefficient of the species with oxygen in Arabian Sea, Bay of Bengal, SW Indian Ocean and SE Indian Ocean.

Species	Arabian Sea	Bay of Bengal	SW Indian Ocean	SE Indian Ocean
1	0.508284	-0.555395	0.056924	0.116396
2	-0.200626	-0.405343	0.060194	-0.116619
3	0.127229	-0.148448	0.096090	-0.158020
4	-0.042163	-0.207017	0.029693	-0.019795
5	0.039699	0.215606	-0.087800	0.028457
6	-0.159602	-0.474347	0.024660	-0.178436
7	-0.039690	-0.519534	-0.066153	0.169631
8	-0.257028	-0.367054	-0.470157	-0.278723
9	0.135677	-0.477660	0.284502	0.212626
10	0.209292	0.316348	-0.337873	0.180691
11	0.051417	-0.152002	0.281776	0.175078
12	0.036147	-0.332556	0.053468	0.270067
13	0.040920	-0.536525	0.037692	0.168023
14	-0.400231	0.083166	0	0
15	-0.133897	0.051063	0.043176	-0.213343
16	-0.007484	0.109271	0.043387	-0.213343
17	-0.292368	-0.387677	0.638966	-0.426097
18	-0.011792	-0.015527	0	0
19	0.009742	0.327677	0.019810	0.005170
20	-0.041012	0	0	-0.099223
21	-0.003491	0	-0.001986	-0.197055
22	0.000706	0.013156	0	-0.023838
23	0.009210	-0.192038	0	0
24	-0.012344	0	0.034728	0
25	-0.010222	0	0	0
26	0	0	0	0
27	0.031371	0.369892	0.020507	0

Table 10 (1) - Analysis of variance table to test the significance of the regression Model fitted (1) to the whole data.

Source	Sum of squares	D.F.	Mean sum of squares	F. Ratio
Regression	2611459.4742	3	870486.4914	16.11263*
Deviation	20583562.9414	381	54025.0996	
Total	23195022.4156	384	60403.7042	

Table 10 (2) ....(2) to the data collected from Arabian Sea.

Source	Sum of squares	D.F.	Mean sum of squares	F. Ratio
Regression	3289960.3334	3	1096653.44	15.0509*
Deviation	12532411.4621	172	72862.86	
Total	15822371.7955	175	90413.55	

Table 10 (3) .... (3) to the data collected from Bay of Bengal.

Source	Sum of squares	D.F.	Mean sum of squares	F. Ratio
Regression	156327.2306	3	52109.0769	3.7504
Deviation	986341.9161	71	13892.1397	
Total	1142669.1467	74	15442.1506	

* Calculated F is significant at 1% level i.e. Regression Model fitted is significant at 1% level.

Table 10 (4) - Analysis of variance table to test the significant of the regression Model fitted (4) to the data collected from southwest Indian Ocean.

Source	Sum of squares	D.F.	Mean sum of squares	F. Ratio
Regression	282885.5799	3	94295.1933	2.9544
Deviation	2872510.9095	90	31916.7880	
Total	3155396.4894	93	33928.9945	

Table 10 (5) .... (5) to the data collected from southeast Indian Ocean.

Source	Sum of squares	D.F.	Mean sum of squares	F. Ratio
Regression	32986.0374	3	10995.3458	0.63742
Deviation	620987.5626	36	17249.6545	
Total	653973.6000	39	16768.5538	

Table 11 - Relative importance of the parameters.

	Temperature	Salinity	Oxygen
Total	0.02008	1.05632	0.791910
Arabian Sea	0.02849	0.91125	0.000015
Bay of Bengal	0.05411	0.01978	0.278700
SW Indian Ocean	0.71404	0.57857	0.168540
SE Indian Ocean	0.25115	0.01392	0.023400

Table 12 - The variability explained by the Regression Model in cases it is found to be significant.

	Variability explained	Variability unexplained
Total	10.56 %	89.44 %
Arabian Sea	19.41 %	80.59 %

Table 13 - Two way classification to test Hypothesis that there is no significant difference between 4 areas and between the total number of species in the 4 areas.

ANOVA Table

Source	Sum of squares	D.F.	Mean sum of squares	F. Ratio
Row	8.71916	3	2.90638	11.81743*
Column	29.56181	15	1.97078	8.01325*
Error	11.34852	45	0.24594	
Total	49.84852	63		

* Calculated F is significant at 1% level i.e. Regression Model fitted is significant at 1% level.

Table 14 - Fisher's diversity index α and its Variance V (α).

Region	S	N	α	V (α)
Arabian Sea	27	44728	2.788450	0.04301
Bay of Bengal	22	11876	2.612099	0.03889
SW Indian Ocean	20	10958	2.374158	0.02958
SE Indian Ocean	19	5607	2.456943	0.03438

Fisher's species diversity index α is given

by $S = \alpha \log_e \left(1 + \frac{N}{\alpha}\right)$

$$V(\alpha) = \alpha^3 \left\{ \frac{(N + \alpha)^2 \log_e \left(\frac{2N + \alpha}{N + \alpha}\right) - N\alpha}{(SN + S\alpha - N\alpha)^2} \right\}$$

7. LITERATURE CITED.

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8. APPENDICES I - III : PUBLISHED PAPERS.

Reprinted from I. O. B. C. Handbook Vol. V. 1973 : 180—189

A NEW SPECIES OF MACANDREWELLA (COPEPODA : CALANOIDA) FROM OFF COCHIN, SOUTH WEST COAST OF INDIA

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ABSTRACT

Macandrewella cochinensis is described and compared with other species of the genus. Examination of the specimens revealed that they cannot be assigned to any of the known species of the genus though they had similarities with M. *joanae* and M. *scotti*.

INTRODUCTION

During the course of the studies on the copepod family Scolecithricidae from the International Indian Ocean Expedition collections, some specimens of both sexes belonging to the genus *Macundrewella* were observed in a sample taken by "R. V. Conch" from a station at Lat. 10°10'N, Long. 75°46'E (IOBC Hand book Vol.I, 1969). They were different from the seven known species of the genus and are hence described as new. Specimens belonging to the same species were later collected from a sample taken by "Blue Fin" at Lat. 09° 48'N, Long. 75°39' E (N. I. O., 1969-70).

DESCRIPTION OF SPECIES

Macandrewella cochinensis n. sp.

Female (Fig. la): Head and the first thoracic segment fused together with a faint line of demarcation laterally. Forehead with a lens-like organ at the base of the rostrum. Fourth and fifth thoracic segments completely separated. Posterolateral corners of the last thoracic segment asymmetrical, each side drawn out into a stout curved spine with a distinct tooth at the base. Spine on the left side longer than the spine on the right side reaching the level of the distal margin of the first urosome segment (Fig. lb). Rostrum with a bifurcate base and one filament attached to each ramus.

Abdomen four segmented, genital segment asymmetrical in outline in dorsal view and with a ventral backwardly directed protuberance Fig. 1c). Posterior margin of the second and the third abdominal segments fringed with fine spines. Fourth abdominal segment shortest. Caudal furca almost as long as wide. Five caudal setae attached to each furcal joint. Middle caudal seta on the left side elongated.

Antennules with 23 separate segments. Antennae, mandibles, maxillae and maxillipeds in general structure almost similar to those of the other species of the genus with the following differences. Chewing blade of each mandible carries 8 teeth; inner tooth long, curved and serrated (Fig. 2c). First basal of the maxilliped with a short row of fine curved spines at its proximal end on either side. Second basal just behind the anterior margin, on either surface carries a long row of fine spines, along its entire length. Spines at the centre of this row are short and those at the ends are long (Fig.2f).

Segmentation of legs 1-4 (Figs. 3a,b,c,d) as in *M. Scotti* Sewell, with the following differences. Outer border of exopod 3 of leg 1 even and straight, external spines on the three exopod segments almost subequal. First basal segment of leg 2 with a small spine behind the distal external angle. Exopod segment 2 of leg 2 and 3 with a transverse, crescent-shaped row of spines towards the distal border, segment 3 provided with a group of small spines on the surface towards the middle. Endopod 1 of leg 2 drawn out into a spine at the distal external angle. Endopod 2 of leg 2 with two rows of three spines each. Spines in the outer row almost equal. Spines in the inner row unequal. Endopod segments 1 and 2 of legs 3 and 4 drawn out into spines at their distal external angle, segments 2 and 3 with stout sharp spines on the surface. Spines on the sur-

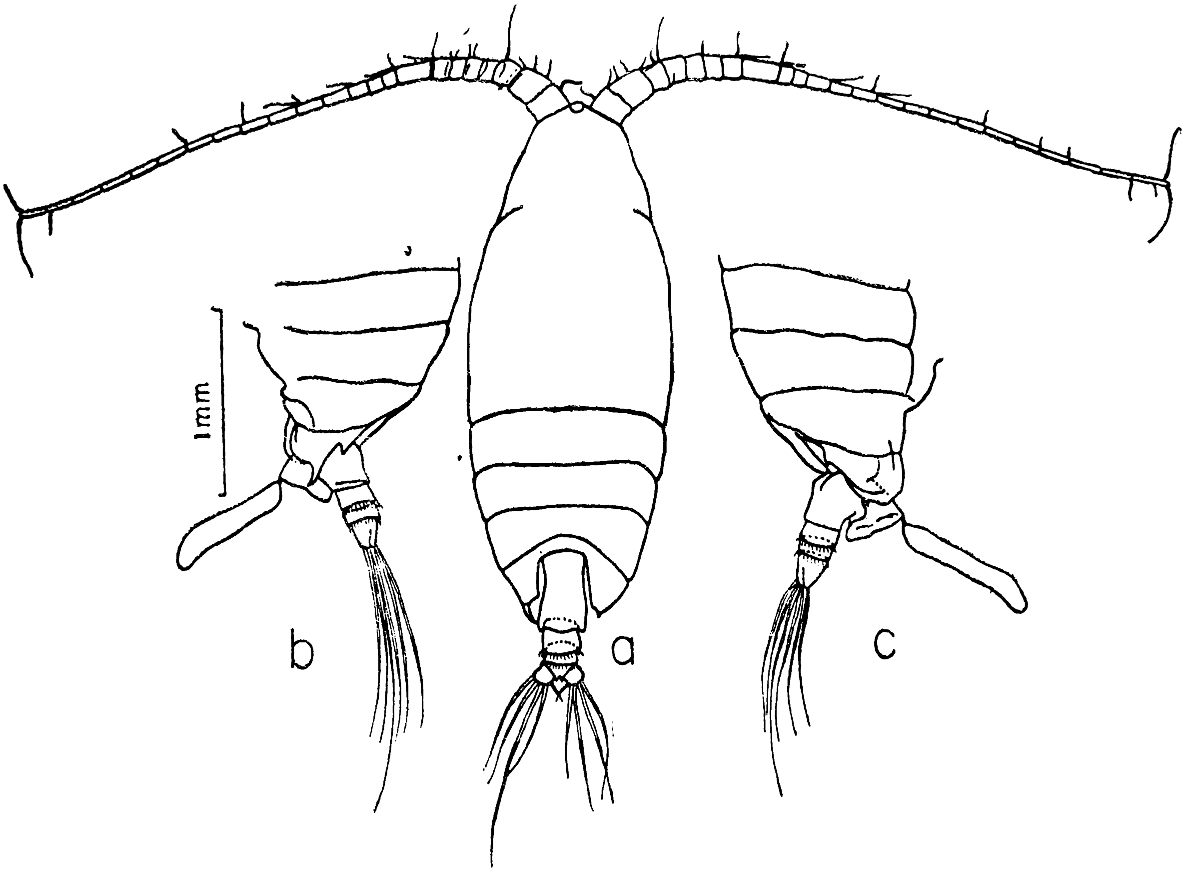


Fig. 1. *Macandrewella cochinensis.* n. sp. Female.
(a) Dorsal view, (b) Lateral view of posterior part from left side, (c) Lateral view of posterior part from right side.

face of segments 2 and 3 of both exopod and endopod of leg 4 arranged in vertical rows. Leg 5 absent.

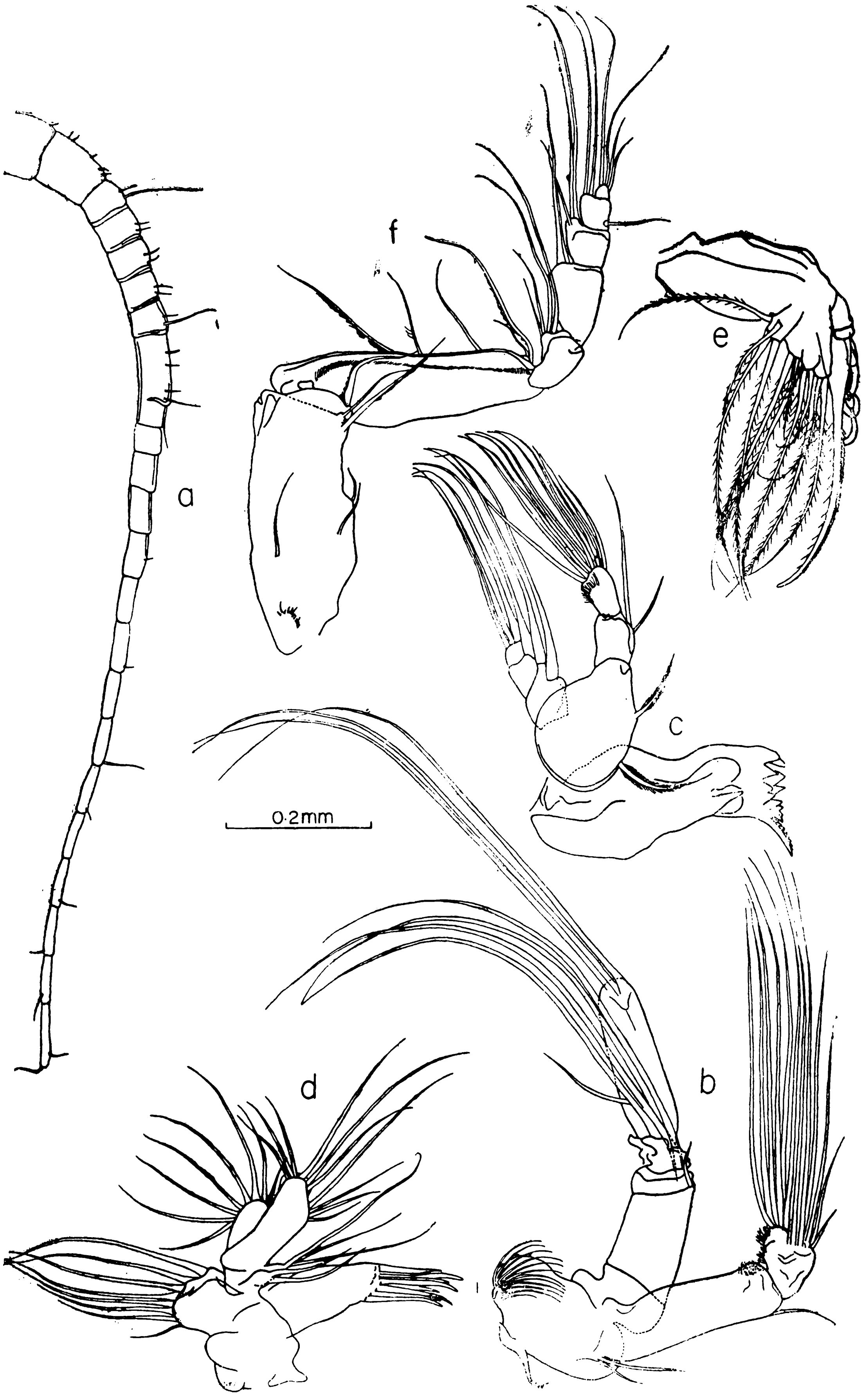
Material examined: Total 25 specimens from the two samples.

Length range· 3.0–3.15mm.

Male (Fig.4a):- Head and first thoracic segment fused together, forehead carries lens-like organ. Posterolateral corners of the last thoracic segment symmetrical, each side with stout curved spines. Abdomen five segmented. Posterior margin of second, third and fourth abdominal segments fringed with fine spines. Four caudal setae on each caudal rami. Antennules with 20 segments on the right side and 21 on the left side. Mouth parts as in female. Legs 1-4 as in female but with reduced armature. Leg 5, in general structure resembles that of the other species in the genus. Right leg with the first basal with an angular expansion towards the proximal one-third; the second basal segment dilated, proximal part of endopod with a curved and blunt distally directed process, a median conical protuberance and a curved tapering distal end; first exopod segment bearing an irregular wing like expansion at the proximal part, a small rounded prominence in the middle and an evenly curved prominent process towards the distal end, second segment with an internally directed club-shaped process almost as long as the entire segment, third segment bent on itself at about the middle with a thin transparent web-like structure connecting the two halves. In left leg second basal longer than first, endopod one-segmented and almost straight, with two triangular expansions and a row of strong teeth distally; exopod two-segmented, tip of second segment with a thin plate-like structure covered with a dense tuft of long cilia and with a thin pointed claw (Fig.4b.).

Material examined : Total 31 specimens from the two samples.

Length range: 2.9 – 2.95 mm.



Fig, 2. ***Macandrewella cochinensis*** n. *sp. female.*
(a) Antennule, (Magnification double that of the other appendages), (b) Antenna, (c) Mandible, (d) 1st maxilla, (e 2nd maxilla, (f) Maxilliped.

Fig. 3. *Macandrewella cochinensis*, *n. sp. female*.
(a) — (d) legs 1 — 4.

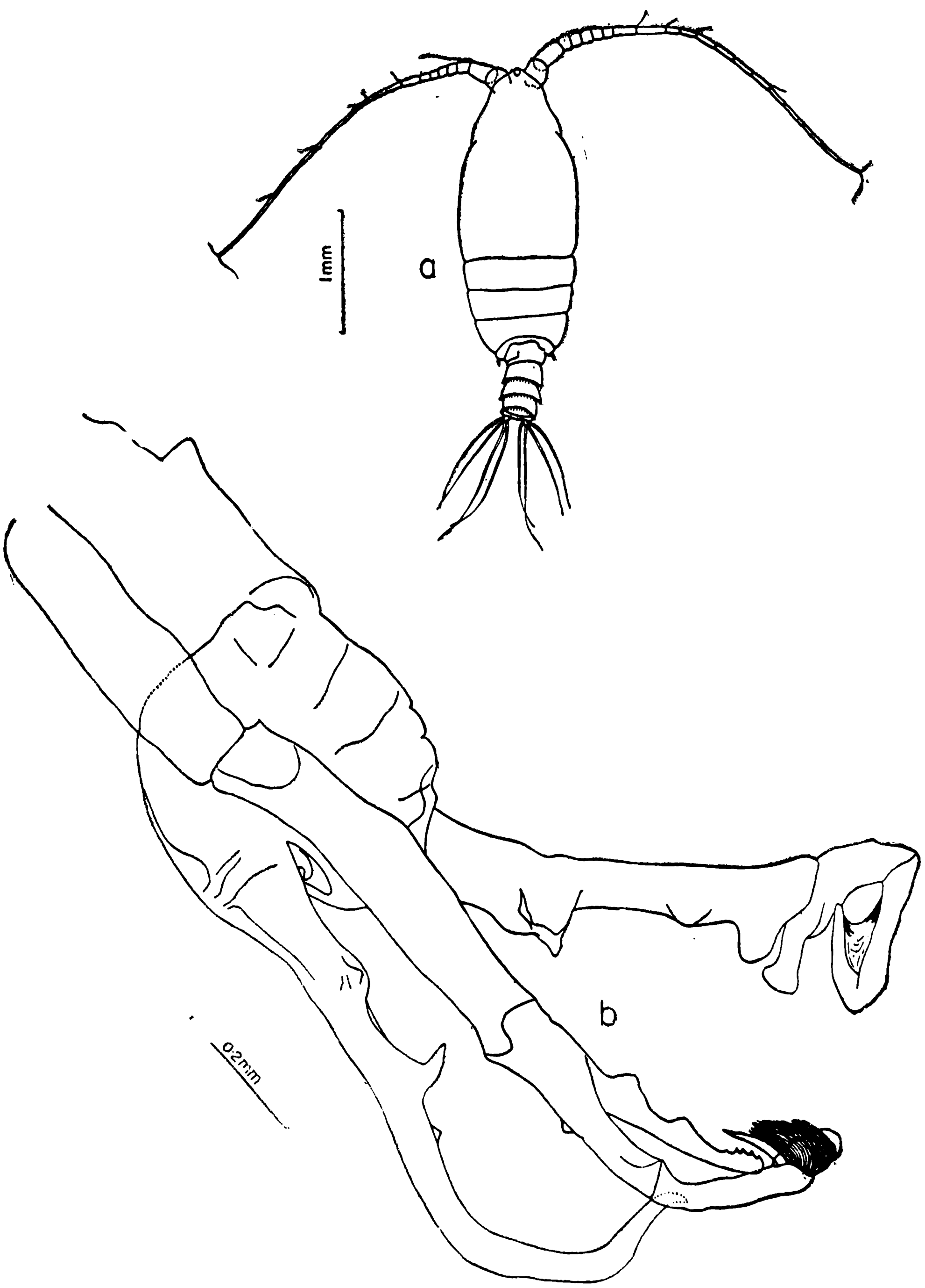


Fig. 4. *Macandrewella cochinensis n. sp.* male.
(a) Dorsal view (b) Leg. 5.

Table: Comparison of *Macandrewella* species

	M. joanae	*M. scotti*	*M. chelipes*	*M. Sewelli*	*M. asymmetrica*	*M. mera*	*M. agassizi*	*M. cochinensis*
Female								
Length (mm)	3.6	3.2	3.5	3.5 - 3.7	3.5 - 3.7	3.84	3.0	3 - 3.15
Posterolateral corners of the last thoracic segment	Asymmetrical with the spine on the left side extending beyond the middle of the genital segment	Symmetrical	Symmetrical	Symmetrical	Asymmetrical with the spine on the left side bent outwards at an angle of about 45°.	End laterally in short sharp points directed slightly inwards. Dorsal to the point on the right side the margin of the segment is produced into a short tooth which bears a few spinules on its margin.	Symmetrical	Asymmetrical with the spine on the left side reaching the level of the distal margin of the first urosome segment.
Genital segment	Asymmetrical in dorsal view. Ventral surface produced posteriorly into a small blunt lobe.	Symmetrical in dorsal view.	Symmetrical in dorsal view.	Asymmetrical with a lobe at the right posterior corner overlapping the next abdominal segment.	Asymmetrical with a swollen lateral projection on the right side slightly overlapping the following segment dorsally and with a ventral backwardly directed thumblike process projecting from the genital boss.	Asymmetrical with a swelling on the right side, a ventral thumblike projection directed backwards from the genital plate.	Dorsal surface strongly elevated along mid line and armed with a stout spine at the posterior end.	Asymmetrical in dorsal view, prominent backwardly directed protuberance on ventral side.
Spines on the posterior margin of abdominal segments	Present on 1st, 2nd and 3rd segments.	Present on 2nd and 3rd segments	Absent	Absent	Absent	Absent	Absent	Present on 2nd and 3rd segments.
Caudal furca	As long as broad	Short and broad	Wider than long	Wider than long	As broad as long	—	Wider than long	As long as broad

Table (Contd)

	M. joanae	*M. scotti*	*M. chelipes*	*M. sewelli*	*M. asymmetrica*	*M. mera*	*M. agassizi*	*M. cochtnensis*
Caudal setae	5 on each side, asymmetrical with middle seta on left side eolngated.	5 on each side, symmetrical.	4 on each side, symmetrical.	4 on each side, symmetrical.	5 on each side, symmetrical	Symmetrical	4 on each side, asymmetrical with 2nd inner seta on left side elongated.	5 on each side, asymmetrical with middle seta on left side elongated.
Leg 5	Present	Absent	Absent	Absent	Absent	Absent	Present	Absent
Male								
Length (mm)	3.4	—	Smaller than female	3.25	3.7	Male not recorded.	2.95	2.9 - 2.95
Spines on the posterior margin of abdominal segments	Present on 2nd, 3rd and 4th abdominal segments.	Present on 2nd and 3rd abdominal segments.	Absent	Absent	Absent	—	Absent	Present on 2nd, 3rd and 4th abdominal segments.
5th leg Right								
Exopod	2 segmented	3 segmented	3 segmented	3 segmented	Similar to that figured by Scott for *M. joanae* and differ only in small details which can be best seen by comparison of the figures.	—	3 segmented	3 segmented.
Exopod 1	Produced internally into a strong curved claw which exceeds the length of the joint, middle inner margin produced into stout tooth.	Fused with second basal, a wing-like projection at proximal end, about the junction of the middle and distal thirds a small rounded lobe, a club-shaped prominence at the distal end.	An angular swelling on the outer margin at the centre, a small knob at the inner distal corner.	Extends beyond the articulation with the second segment as a curved finger-like process.	—	—	A knob at the inner distal corner.	An irregular wing like expansion at the proximal part, small rounded prominence in the middle and an evenly curved prominent process at the distal end.

Table (Contd.)

	M. joanae	M. scotti	M. chelipes	M. sewelli	M. asymmetrica	M. mera	M. agassizi	M. cochinensis
Exopod 2	Forked at the apex	A strong inwardly directed blunt process at the base equal in length to the whole segment.	A curved process at the base and a small straight process near the centre of the inner margin.	Outer side articulated with the inner side of Ist segment, proximal end enlarged into a trilobed knob which extends behind the articulation.	—	—	A sickle shaped process on the inner margin at the base, projects distally beyond the joint with the third segment.	An internally directed club-shaped process almost as long as the entire segment.
Exopod 3	—	Sickle shaped.	Sickle shaped; a knob on the convex margin, point of sickle overlaps the base of the second segment.	Bent at right angles near its centre with a long process, toothed at the tip on the outer angle of the bent.	—	—	Bent at right angles near its centre and the terminal claw-like part overlaps the sickle-like process at the base of the 2nd segment.	Bent on itself at the middle with a thin transparent web-like structure connecting the two halves.
Endopod	One jointed long curved.	One jointed long curved.	Slender, reaches the distal end of exopod 2.	Extends beyond exopod 2, curved and blunt at the tip, a sharp process on the inner margin near the base and another towards the tip.	—	—	One jointed, a single knob near the centre of the outer margin.	One jointed, proximal part with a curved and blunt distally directed process, a median conical protuberance and a curved tapering distal end.
Left leg								
Exopod	2 jointed.	2 jointed	3 jointed	2 jointed.	—	—	3 jointed	2 jointed.
Exopod 2	Short, dilated, apex furnished with a pad of hairs and a spine.	Terminates in a claw-like process with a tuft of hairs.	Equal in length to exopod 1.	Enlarged at its distal end with an outer setose process.	—	—	Somewhat widened.	A thin plate-like structure at the tip covered with dense tuft of long cilia and with a thin pointed claw.

Table (Contd.)

	M. joanae	*M. scotti*	*M. chelipes*	*M. sewelli*	*M. asymmetrica*	*M. mera*	*M. agassizi*	*M. cochinensis*
Exopod 3	—	—	Short and claw shaped.	—	—	—	With a rounded process and a soft pointed filament on its inner surface, rounded tip covered with hairs.	—
Endopod	One jointed, sickleshaped, as long as exopod, distal half of inner margin serrated.	One jointed, curved and with a row of serrations at the distal end. Shorter than exopod.	One jointed, nearly as long as exopod, dentate on its inner margin.	One jointed, shorter than exopod, laminate and truncate at its tip, with a sharp spine at the centre and a row of coarse teeth distal to the spine.	—	—	One jointed, nearly as long as exopod, two angular processes on the outer margin, three minute teeth at the tip.	One jointed, shorter than exopod, almost straight, two triangular expansions, a row of strong teeth distally.

Types:- Holotype 1 female, allotype 1 male and paratypes 2 females and 2 males are deposited in the reference collection at the Regional Centre of N. I. O. (CSIR), Cochin-18, India, Reg. Nos: I. O. B. C. 0146, 0147, 0148 respectively. In the table the distinctive features of the species in the genus *Macandrewella* are summarised.

DISCUSSION

Scott (1909) created the genus *Macandrewella* to accommodate the new species *M. joanae* collected by "Siboga" in the Malay Archipelago. Scott also included in the genus the copepod that Giesbrecht (1896) had described from the Red Sea under the name *Scolecithrix chelipes*. There are seven established species of the genus; *M. joanae*, *M. chelipes* (Giesbrecht 1896), *M. scotti* Sewell (1929), *M. sewelli*, *M. asymmetrica*, *M. mera* Farran (1936) and *M. agassizi* Wilson (1950). Female of *M. cochinensis* resembles *M. joanae* in the extreme asymmetry of the posterolateral corners of the last thoracic segment with the spine on the left side reaching the level of the distal margin of the first urosome segment and in the asymmetrical caudal setae with the middle seta on the left side elongated. But the absence of leg 5 is an important character distinguishing it from the latter species. Leg 5 of male in *M. cochinensis* is distinct, in the structure of the different parts, from the other species, though retaining the basic form in the genus. Sewell (1929) while describing females of *M. scotti* refers in the text to the similarity with *M. joanae* in the shape of the posterolateral corners of the thorax, but from figures it has to be assumed that though there are spinous projections they are not comparable to the distinctly asymmetrical spines of *M. Joanae.* Moreover, Sewell makes special mention of the symmetrical caudal setae. They are asymmetrical in *M. cochinensis* as well as in *M. Joanae.* Apart from the variations in the distribution of spines on the maxilliped and legs 1-4, the straight outer border of exopod 3 of leg 1, instead of a notched border in *M. scotti* is a well marked feature of *M. cochinensis.* Thus *M. cochinensis* though possessing certain characters in common with *M. joanae* and *M. scotti* is quite distinct from them and also from the other species in the genus.

ACKNOWLEDGEMENTS

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PROCEEDINGS
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A REVIEW OF THE COPEPOD *SCOTTOCALANUS SECURIFRONS* (T. SCOTT) AND A NOTE ON ITS SYNONYM *SCOLECITHRIX CUNEIFRONS* WILLEY (CALANOIDA: SCOLECITHRICIDAE)

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Abstract

Scottocalanus securifrons from the International Indian Ocean Expedition Collections is described and compared with that of T. Scott 1893, A. Scott 1909, Tanaka 1961, *Lophothrix securifrons* Wolfenden 1904 and *Scolecithrix cuneifrons* Willey 1918. A thorough examination of the descriptions of *securifrons* and *cuneifrons* and the examination of ♀ syntypes of S. *securifrons* from the British Museum revealed a doubtful existence of *Scolecithrix cuneifrons* as a distinct species. Hence it is considered as a synonym of S. *securifrons* in agreement with Vervoort (1965).

Introduction

While studying the scolecithricid copepods collected during the International Indian Ocean Expedition 1960–65 (IIOE) I encountered a number of specimens of both sexes belonging to the genus *Scottocalanus* Sars. Upon comparing the IIOE specimens with published descriptions of species of *Scottocalanus*, I found good agreement with S. *securifrons* (T. Scott, 1893) and also with S. *cuneifrons* (Willey, 1918). The IIOE specimens are assigned to the older S. *securifrons* and described below.

Scottocalanus securifrons (T. Scott)

(Figure 1 a–g, Figure 2 a–c, Figure 3 a–h)

Scolecithrix securifrons T. Scott, 1893, p. 47, pl. 4, figs. 40–56, pl. 5, fig. 1 [♀ only, ♂ = *Scottocalanus helenae* (Lubbock)].—Giesbrecht and Schmeil, 1898, p. 49.—van Breemen, 1908, p. 76, fig. 88 [♀ only].—Canu, 1896, p. 425.—Thompson, 1903, p. 20.—Norman 1903, p. 137.—Cleve, 1904, p. 197.—Cons. Explor. Mer, 1909, p. 99.—Jespersen, 1940, p. 36.

Lophothrix securifrons Wolfenden, 1904, p. 120, pl. 9, figs. 12–15.

Lophothrix securifrons (T. Scott).—Wolfenden, 1911, p. 268.

Scottocalanus acutus Sars, 1905, p. 7.

Scolecithrix cuneifrons Willey, 1918, p. 194, figs. 17–24.

Scottocalanus securifrons (T. Scott).—Sars, 1905, p. 7 [by implication]; 1912, p. 654; 1924–1925, p. 160–162, pl. 45 figs. 1–8.—Pearson, 1906, p. 19.—Farran, 1908, p. 57; 1920, pp. 18, 21; 1926, p. 267; 1929, p. 251.—Paulsen, 1909, p. 137.—A. Scott, 1909, p. 104, pl. 25 figs. 1–9, pl. 28 figs. 1–9.—Stebbing, 1910, p. 529.—With, 1915, p. 220, pl. 8 fig. 13, text figs. 71–73.—Cons. Explor. Mer, 1916, p. 57.—Lysholm and Nordgaard, 1921, p. 21.—Rose, 1929, p. 26; 1933, p. 144, fig. 144; 1942, p. 148.—Wilson, 1936, p. 91; 1950, p. 340.—Tanaka, 1937, p. 259, figs. 9a–c; 1953, p. 132; 1961, p. 141–143, fig. 106; 1969, p. 275. —Leavitt, 1938, p. 384.—Lysholm, Nordgaard and Wiborg, 1945, p. 26.—Sewell, 1947, p. 143.—Fraser and Saville, 1949a, pp. 61, 63.—Brodsky, 1950, p. 242, fig. 152.—Wiborg, 1955, p. 51.—Hida and King, 1955, p. 11.—Marques, 1956, p. 15; 1958, p. 225; 1959, p. 211. —Heinrich, 1958b, p. 1029.—Vinogradov, 1960, p. 502.—Grice, 1962, p. 213, pl. 19 figs. 12–15.—Grice and Hart, 1962, appendix, tab. —Owre, 1962, p. 492.—Vervoort, 1965, p. 36.—Fleminger, 1967, p. 194.—Owre and Foyo, 1967, p. 63, figs. 98, 400–403, 409, 410. —Park, 1970, p. 476.—Bowman, 1971, p. 34.

Description of the specimens: Female. Length 4.2 mm. Head and first thoracic segment, 4th and 5th thoracic segments fused. Head with high median crest (Fig. 1c). Last thoracic segment produced posteriorly into triangular expansion terminating in sharp pointed spine on either side. Rostrum bifid at tip (Fig. 2 a). Abdomen 4-segmented. Genital segment swollen ventrally at mid-length; its ventral posterior margin overlapping the following segment (Fig. 1 d). Posterolateral margins of genital segment furnished with spines which are absent on dorsal and ventral side (Fig. 1 e). A. Scott (1909) shows spines on the posterior margin of the genital segment present on the dorsal as well as lateral surfaces. Posterior margins of 2nd and 3rd abdominal segments with a hyaline fringe (Fig. 1 e). Anal segment very short. Caudal rami almost as wide as long, each with 4 setae.

First antenna with 23 separate segments, when the partly separated 8th and 9th segments are counted as one (Fig. 1 a). First maxilla with

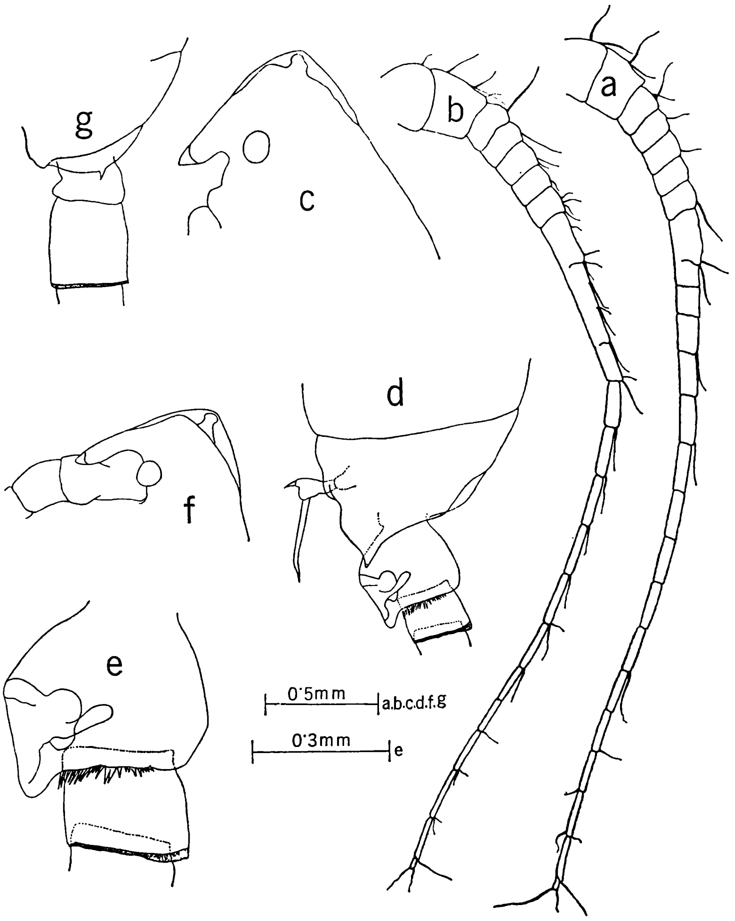

FIG. 1. *Scottocalanus securifrons.* a, 1st antenna ♀; b, 1st antenna ♂; c, frontal profile ♀; d, last thoracic segment and genital segment ♀; e, genital segment ♀, enlarged; f, frontal profile ♂; g, last thoracic segment ♂.

numbers of setae on different lobes as follows (Fig. 2 b): Inner lobe 1 with 12 setae of which 3 are on posterior surface; inner lobe 2 with 2 setae; inner lobe 3 with 3 setae; basipod 2 with 5 setae; endopod segment 1 with 3 setae; endopod segments 2 and 3 together with 4 setae; exopod with 8 setae; outer lobe with 9 setae. Exopod segment with fine surface hairs at distal end. Second maxilla endopod with 4 bud-like and

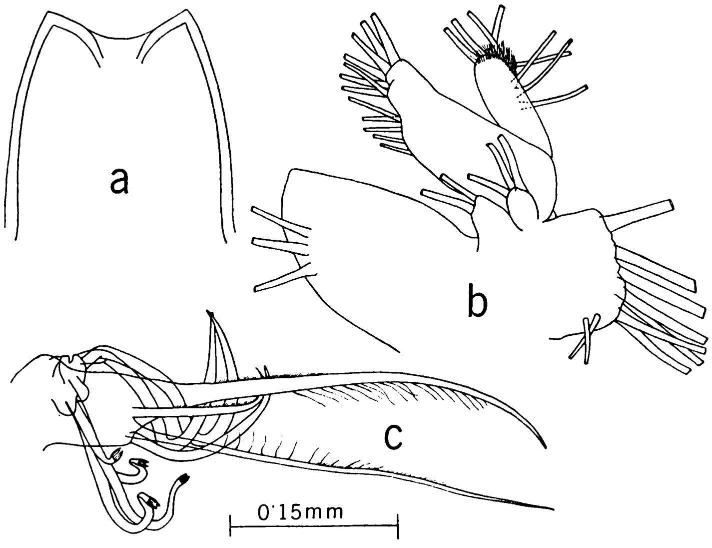

FIG. 2. *Scottocalanus securifrons.* a, rostrum ♀; b, 1st maxilla ♀; c, distal portion of 2nd maxilla ♀.

3 vermiform filaments (Fig. 2 c). Swimming legs 1–4 as shown in figures (Figs. 3 a–d).

Fifth pair of legs asymmetrical; subapical spine of left leg thicker than that of right leg. Subapical spines with two rows of teeth (Fig. 3 e).

Male. Length 4.57 mm. General appearance similar to that of female. Head with high median crest (Fig. 1 f). Last thoracic segment terminating in small spine on either side (Fig. 1 g). Abdomen 5—segmented. Posterior margin of 2nd to 4th abdominal segments with hyaline fringe (Fig. 1 g). First antenna with 20 segments when fused 8th to 12th segments, partly divided by 2 incomplete sutures between segments 8 and 9 and 11 and 12, are counted as one (Fig. 1 b). 5th leg as illustrated (Fig. 3 f–h). The small teeth on the inner margin of the proximal joint of the endopod of the left leg figured by A. Scott are not present in Tanaka's specimens, Willey's specimens or in the IIOE specimens.

DISCUSSION

The IIOE specimens agree well with descriptions of S. *securifrons* by T. Scott (1893, ♀ only), A. Scott (1909), Wolfenden (1904), and Tanaka (1961). They also appear to conform to Willey's (1918) description of S. *cuneifrons*. Willey was aware of the similarity of his S. *cuneifrons* to S. *securifrons*, and stated that he was at first inclined to identify his specimens as S. *securifrons*, but decided to establish a

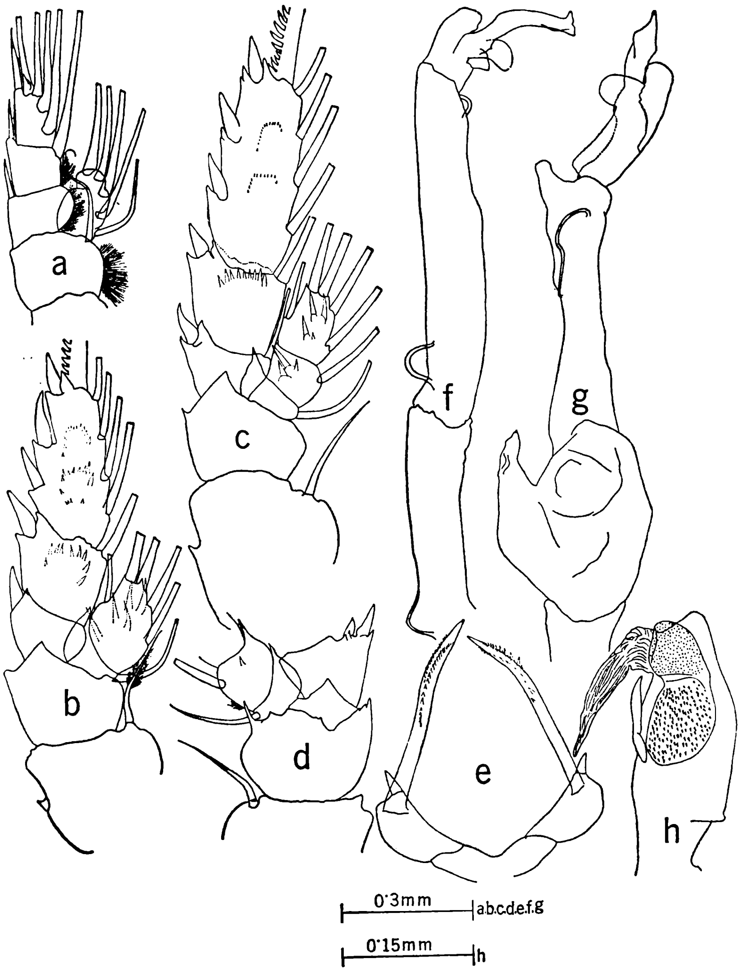

FIG. 3. *Scottocalanus securifrons.* a, 1st leg ♀; b, 2nd leg ♀; c, 3rd leg ♀; d, proximal portion of 4th leg ♀; e, 5th leg ♀; f, left 5th leg ♂; g, right 5th leg ♂; h, left 5th leg ♂, 2nd joint of Re, enlarged.

new species for them because the male fifth legs of his specimens differed from those of *S. securifrons.* Apparently he was referring to T. Scott's male, which is now believed to belong to a different species, *Scottocalanus helenae* (Lubbock), and not to the male described by A. Scott which had a fifth leg very similar to that of *S. cuneifrons.* Curiously, Willey did not cite either T. Scott (1893) or A. Scott (1909) in his bibliography.

In order to be certain about the identity of T. Scott's specimens, I requested a loan of them from The British Museum (Natural History). Although Scott (1893) reported *S. securifrons* from 5 "Buccaneer" stations, Dr. Roger J. Lincoln reported that the British Museum had only 2 females, the male being missing. Upon examining these 2 females, I found that one of them is not *S. securifrons* but another species of *Scottocalanus*, possibly *S. australis* Farran (1936). The remaining female is herewith designated as the lectotype of *Scolecithrix securifrons* T. Scott in order to obviate further confusion.

Distribution: The species has a fairly wide distribution, and has been recorded from the Atlantic, Pacific and Indian Oceans. It has been recorded from the central and southern part of the Arabian Sea (Sewell, 1947), from the Indian Ocean off Port Shepstone, South Africa (Cleve, 1904a), from many localities in the eastern part of the Malay Archipelago (A. Scott, 1909, and Snellius Expedition), from the Philippine Islands region (Wilson, 1950), from the central equatorial Pacific, 00°03'N, 157°00'E (Grice, 1962), from the California Current region (Fleminger, 1967), from Sagami and Suruga Bays, Izu region, Japan (Tanaka, 1937, 1961) from surface waters off Three Kings Islands, New Zealand (Farran, 1929), from many localities in the West-Pacific ranging from off Peru to the Galapagos Islands region (Wilson, 1950) and from the Far Eastern and Polar Seas of the U.S.S.R. (Brodsky, 1950). The specimens described in this paper are from around the central part of the equatorial Indian Ocean (03°29'N, 77°54'E).

In the Atlantic *S. securifrons* is widely distributed over large areas, penetrating at least as far north at the Atlantic slope off Cabot Strait, 42°31'N, 63°31.5'W (Willey, 1918) and 43°18'N, 60°11'W (Rose, 1929). Also known from 47°47'–63°08'N, 8°00'–26°20'W (With, 1915; Lysholm and Nordgaard, 1921); the South coast of Iceland, 63°08'N, 21°30'W; 62°47'N, 15°03'W (Paulsen, 1909; Jespersen, 1940); the Faroe Channel, ± 60°N, 7°W (Norman, 1903; Wolfenden, 1904); 28°–58°N, 7°–50°5'W (Lysholm, Nordgaard and Wiborg, 1945); NNW of Achill Head, Ireland (Norman, 1903); 52°06'–54°33'N, 10°30'–15°53.9'W (Thompson, 1903; Farran, 1908); off the south-west coast of Ireland (Farran, 1920); 27°43'–47°43'N, 8°06'–42°40.5'W (Sars, 1925); Bermuda (Wilson, 1936); 30°08'N, 31°19'W (Sars, 1912); Florida current (Owre, 1962); between Bermuda and New York (Grice and Hart, 1962); Bay of Biscay ± 47°N, 8°W (Farran, 1926); 44°17'N, 4°38'W (Canu, 1896); 20°41'N, 31°53'W; 17°28'N, 29°42'W; 16°24'N, 28°53'W (Wolfenden, 1911); Gulf of Guinea (T. Scott, 1894); off Angola (Marques, 1956, 1958, 1959); 26°59'S, 17°06'W and 35°10'S, 2°33'W (Wolfenden, 1911). It has been captured in the northern part of the North Sea during the periodical plankton investigations, 1902–1908 (Cons. Explor. Mer 1909, Scottish area). It has been recorded from the southeastern United States between Cape Hatteras and Southern Florida (Bowman, 1971).

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A NOTE ON THE OCCURRENCE OF *SCOLECITHRICELLA TROPICA* GRICE (CALANOIDA:SCOLECITHRICIDAE) IN THE INDIAN OCEAN–A NEW RECORD

ABSTRACT

Scolecithricella tropica Grice is reported for the first time from the Indian Ocean. The similarities between the two species *Scolecithricella tropica* and *Scolecithricella beata* are obvious enough to consider them synonymous, hence the specimens recorded here are assigned to the former species which was described first.

Grice (1962) described the species *Scolecithricella tropica* in his account of the Calanoid copepods from the equatorial water of the Pacific Ocean. During the study of copepods from the Indian Ocean, one female specimen from station Ka. II, position 04°57'S, 77°59'E and four female specimens from station Um. 6312, position 21°04'S, 112°50'E (IOBC 1969), collected during the International Indian Ocean Expedition (IIOE) were identified as *Scolecithricella tropica* and these are reported here as the first record of this species from the Indian Ocean.

As described by Grice, these specimens can easily be identified from the structure of the posterior thoracic margin and the fifth pair of feet. There is a notch on the posterior thoracic margin just anterior to the apex (Fig. 1 A, B.) The fifth pair of feet show variations in a few specimens. In some the feet are symmetrical by having two approximately equal terminal spines (Fig. 1 E) Whereas in a few they are asymmetrical with 3 terminal spines on one side and 2 on the other (Fig. 1 F). Average length of the specimen is 1.2 mm.

Tanaka (1962) described the species *Scolecithricella beata* from the Sagami Bay (Izu Region), Middle Japan. On comparing the published descriptions of *Scolecithricella tropica* and *Scolecithricella beata* with those of the present species, a good agreement can be seen between these two and the specimens from the Indian Ocean reported here. The few differences observed are the following.

In the first maxilla (Fig. 1. C.) Grice has shown 8 setae on the first inner lobe, Tanaka has mentioned 11 setae and the specimens recorded here also have **11** setae. The third inner lobe of the same appendage in the specimens from the equatorial water of the Pacific has 3 setae, so also the Indian Ocean specimens, whereas Tanaka has mentioned only 1 seta. On the endopod of the second maxilla (Fig. 1 D) the IIOE specimens have 5 sensory and 3 worm-like appendages as described by Grice. Tanaka has mentioned only about worm-like appendages.

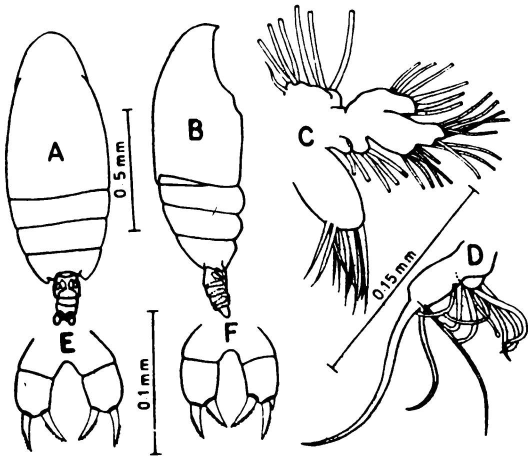

Fig. 1 *Scolecithricella tropica* Grice, 1962, ♀ (A) dorsal view (B) lateral view (C) first maxilla (D) terminal part of second maxila (E) fifth pair of feet (F) fifth pair of feet, abnormal.

The similarities between the two species *Scolecithricella tropica* and *Scolecithricella beata* are obvious enough to consider them synonymous and so, the specimens recorded here have been identified as *Scolecithricella tropica* Grice, which was first described from the Pacific.

The author thanks Dr. G. D. Grice of Woods Hole Oceanographic Institution for confirming the identification.

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