

T. S. SATYANARAYANA RAO

12

**Zoogeography of the Indian Ocean**

Introduction—Environmental conditions, physical and chemical aspects—Overall zoogeography of the Indian Ocean—Patterns of zooplankton distribution—Zoogeographical patterns—The Red Sea—The Agulhas Current Region—Conclusions

**Introduction**

Distribution of zooplankton in the Indian Ocean has become of great interest, particularly since the publication of the results of the INTERNATIONAL INDIAN OCEAN EXPEDITION (IIOE, Collected reprints, 1965-1972 by UNESCO).

Besides, the INDIAN OCEAN BIOLOGICAL CENTRE, COCHIN, has summarised zooplankton data in a series of IIOE atlases and handbooks (1968-1973), of great value for studies on zones of occurrence and abundance of zooplankton.

Prior to the IIOE, Sewell (1948) gave an account of the distribution of the planktonic Indian Ocean Copepoda collected by the JOHN MURRAY EXPEDITION, also discussing latitudinal variation and endemic species. He compared species distribution in different oceans and concluded that the Indo-Pacific copepod fauna is quite distinct from the Atlantic Ocean one.

Other important contributions are the 'Fauna and geography of the Laccadive Archipelago' by Gardiner (1906), Hydromedusae by Kramp (1957, 1961), Copepoda by Steuer (1904), and Sewell (1929, 1932), Mysidae by Tattersall (1939), Chaetognatha by Fowler (1906) and Burfield & Harvey (1926), Pteropoda and Heteropoda by Tesch (1948, 1949, 1950), Tunicata by Apstein (1906) and Sewell (1953), Appendicularia by Lohman (1931) and fish eggs and larvae of the Java Sea by Delsman (1921, 1938).

More recent papers include studies on: zooplankton from the Strait of Singapore by Wickstead (1961, 1962), zooplankton from S. African waters by De Decker (1962, 1964, 1973), plankton biomass by Bogorov & Vinogradov (1961), Prasad (1969a, b), Foraminifera by Belijaeva (1962), Bé & Tolderlund (1971), Hydromedusae by Vannucci & Navas (1973a, b), Polychaeta by Peter (1969), Cladocera by Della Croce & Venugopalan (1972, 1973), Copepoda by Grice & Hulsemann (1967), Fleminger & Hulsemann (1974), Vinogradov & Voronina (1961), Euphausiidae by Gopalakrishnan & Brinton (1969), Weigmann (1970), Mysidae by Pillai (1973), Decapoda larvae by Menon et al. (1969), Menon & Williamson (1971), Chaetognatha by Rao (1958, 1962), Nair (1969, 1972), Silas & Srinivasan (1970), Pierrot-Bults (1974), Pteropoda (Euthecosomata) by Sakthivel (1969, 1972), Heteropoda by Aravindakshan (1969) and Appendicularia by Fenaux (1964b, 1969, 1973).

Besides these there are the papers read at: the BIOLOGY OF THE INDIAN OCEAN

SYMPOSIUM (Kiel, 1971) (Zeitzschel, ed., 1973), the INTERNATIONAL SYMPOSIUM ON THE INDIAN OCEAN (Cochin, 1971) and the SYMPOSIUM ON WARM WATER ZOOPLANKTON (Goa, 1976), Special publication NIO/UNESCO, India, 1977.

### Environmental conditions, physical and chemical aspects

The Indian Ocean is separated from the northern oceanic circulation by the huge Asiatic land mass. The interaction between the land mass and the N. Indian Ocean results in monsoon winds which bring about contrary changes in hydrology and biology of the area. During the South-West (SW.) monsoon (June - September), cyclonic circulation in the surface waters of the Arabian Sea and the Bay of Bengal is generated, in the equatorial region a strong eastward drift occurs, and off the African (Somali), Arabian and W. Indian coasts intense upwelling takes place. When the wind direction is reversed during the North-East (NE.) monsoon (December - March), the circulation in the Bay and the Arabian Sea is anticyclonic and the N. Equatorial Current flows westwards like in the Atlantic and Pacific Oceans (Fig. 1).

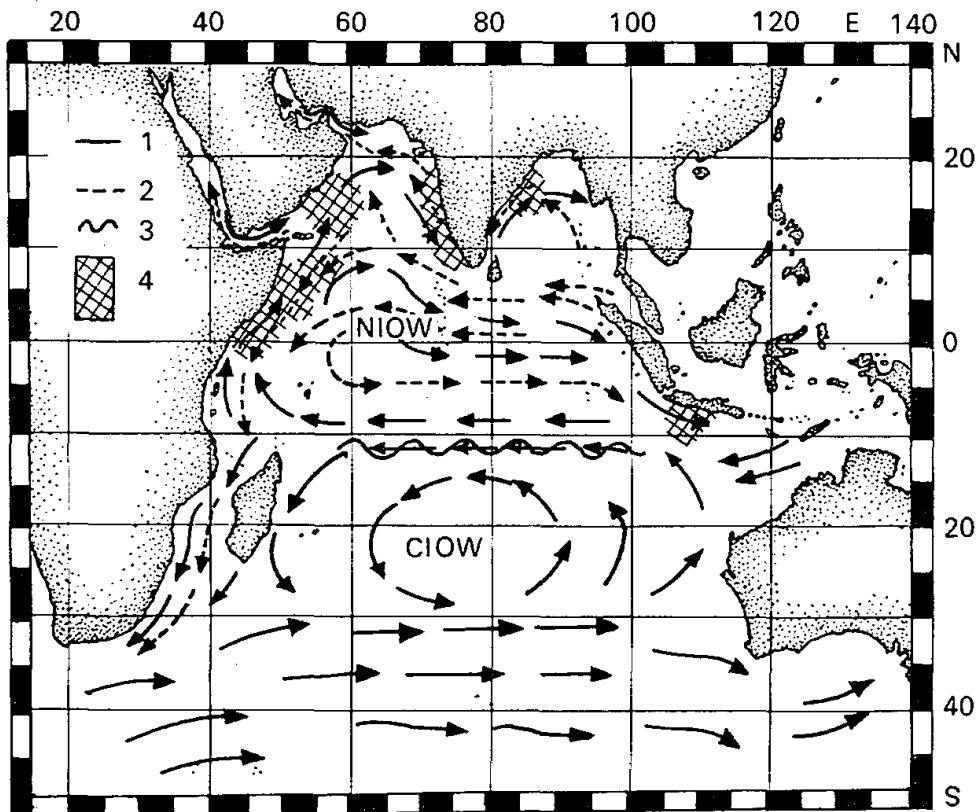


Fig. 1. Surface currents in the Indian Ocean. 1 = SW. monsoon, 2 = NE. monsoon, 3 = Hydrothermal Front, 4 = Upwelling.

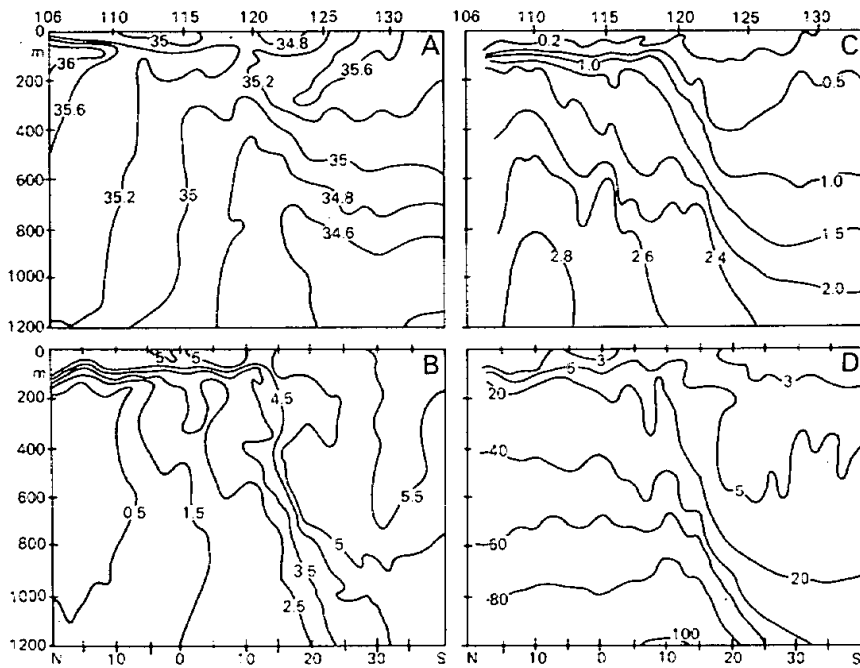


Fig. 2. Distribution of: A) Salinity in ‰, B) O<sub>2</sub> contents (ml/L), C) PO<sub>4</sub>-P contents (μg at/L), D) SiO<sub>4</sub>-Si contents (μg at/L), along 70°E during May-June, showing steep gradients constituting the hydrochemical front between 10°S-25°S (after Wyrski, 1973).

Below 10°S there is no monsoon effect and the typical subtropical anticyclonic surface circulation is dominant throughout the year. Its components are the westward flowing S. Equatorial Current, the Agulhas Current off Mozambique, the eastward current bordering the Subtropical Convergence and the feeble W. Australian Current. S. of the Subtropical Convergence, the hydrographical conditions are similar all over the Antarctic Ocean.

Wyrski (1973) described the hydrochemical front in between about 10°S and 25°S (Fig. 2); this band of low salinity water stretches along 10°S from Timor to the N. of Madagascar, at depths of 100 to 500 m. North of these waters the Arabian Sea and the Bay of Bengal are found, with high salinity, low oxygen and high nutrient values, and to the south, waters with high salinity, high oxygen and low nutrient values. The southern edge of the E. Equatorial Countercurrent, during the NE. monsoon of November - March, and the northern edge of the westward flowing S. Equatorial Current, are also found at 10°S. Salinity, oxygen, phosphates and silicates form steep vertical gradients across the latitudes 10°S-25°S, thus forming a barrier as far downwards as 200 m, for many organisms (cf. also Ovcinnikov, 1961; Ivanov-Franskevic, 1961).

The Red Sea and the Persian Gulf are relatively shallow, narrow seas surrounded by arid land masses with negligible rainfall. The high rate of evaporation results in very high salinities in these basins. The Red Sea has nearly isothermal water below 200 m (21.7°C; 40‰ S). In the Persian Gulf salinities range from 37 to 40‰ and from 42 to 60‰ in coastal areas. These waters sink and spread into the Arabian Sea becoming part of the meridional circulation, particularly in winter.

In the Arabian Sea, salinity is high ( $> 35\text{‰}$ ) throughout the year. However, off the deltas of major Indian rivers and off the W. coast of India freshwater influx causes lower salinities during the SW. monsoon (June to November).

In the Bay of Bengal, with important river-outflow from the Indo-Burmese sub-continent, salinities are low, particularly in the north ( $< 33\text{‰}$ ) and along the E. coast of India from August to October. In fact, the bay can be considered as a mammoth estuary opening into the Equatorial Indian Ocean.

Lack of intense cooling during the northern winter, causes a weak deepwater circulation in the Arabian Sea and the Bay of Bengal. As a result, a layer, very poor in oxygen, develops between 100-1500 m, a unique feature of great biological significance.

The coastal areas of the Arabian Sea are major zones of upwelling during the SW. monsoon (Currie, Fisher & Hargreaves, 1973). Particularly off the Arabian coast upwelling is observed to extend 400 km offshore and it parallels the coast for nearly 1000 km. This area shows the maximum abundance of zooplankton in the Indian Ocean.

Off the S.W. coast of India, upwelling starts even before the onset of the SW. monsoon and continues till its end in September (Sharma, 1968). Major features of the upwelling are the lifting of the  $20^{\circ}$  isotherm by nearly 100 m and the invasion of the shelf off the west coast by oxygen depleted waters. These changes favour the occurrence of very rich zooplankton and enormous shoals of clupeid fish (particularly sardines and mackerels).

Also off the E. coast of India, particularly off the Visakhapatnam coast, upwelling occurs. The main feature of this upwelling is the reduction of surface temperatures by about  $4-5^{\circ}\text{C}$  and the development of rich plankton blooms (La Fond, 1957; Varadachari, 1961).

Uda (1966) described upwelling of great intensity at c.  $15^{\circ}\text{S}$  in the E. Indian Ocean near the Wharton Basin. Wyrski (1962) and Rochford (1962) reported upwelling off Java and Sumbava, in the Arafura, Flores and Banda Seas, during the SE. monsoon (May-September). This region is characterised by high inorganic phosphate concentrations at the bottom of the euphotic layer and by high plankton biomass.

Deep Water circulation in the Indian Ocean is weaker than that in the Atlantic Ocean (Wyrski, 1973). Both Bottom and Deep Water are derived from the Atlantic Ocean. There is no real evidence for the formation of Bottom Water in the Indian Ocean along the Antarctic Continent. Antarctic Bottom Water formed in the Weddell Sea partly spreads over the bottom into the Indian Ocean, filling its deep basins with cold water ( $1.2^{\circ}\text{C}$  in the Arabian Basin,  $1.0^{\circ}\text{C}$  in the Central Indian Basin,  $0.7^{\circ}\text{C}$  in the NW. Australian Basin). The Deep Water originates from N. Atlantic Deep Water (salinity  $34.84\text{‰}$ , temperature  $2.2^{\circ}\text{C}$ ,  $\text{O}_2$  content of  $5 \text{ ml l}^{-1}$ ); it enters the Indian Ocean rounding the Cape of Good Hope at depths of 2500-3200 m. The course of this water can be followed as a salinity maximum to the north of Madagascar and into the NW. Australian Basin. Its further northward spreading into the Arabian Sea and Bay of Bengal is by diffusion rather than by real flow.

The Arabian Sea is filled with highly saline water originating in the Red Sea and the Persian Gulf. Even at 2000 m depth the salinity is as high as  $34.8\text{‰}$  and this large mass of highly saline water may be considered N. Indian Intermediate Water which is also traced in the Bay of Bengal. Isolation and stagnation of the

N. Indian Intermediate Water causes the development of a thick layer with very low oxygen concentration. Everywhere north of  $3^{\circ}\text{N}$ , from 200 to 1200 m depth, the  $\text{O}_2$  content is below  $1.0 \text{ ml l}^{-1}$ . The Antarctic Intermediate Water originates from the Antarctic Surface Water by sinking at the Polar Front. It sinks rapidly to about 1000 m and spreads northwards below the subtropical water and gradually rises to 700 m depth near  $10^{\circ}\text{S}$ .

### Overall zoogeography of the Indian Ocean

The Indian Ocean is a subregion of the Indo-W. Pacific area which is one of the main regions of warm water fauna. It is limited to the north by the Asiatic continent, to the south by the Subtropical Convergence ( $35-40^{\circ}\text{S}$ ), to the west by the African continent and to the east by the Indo-Malayan region and Australia. In the Indian Ocean and adjacent seas the following zoogeographic regions can be recognized: Red Sea and Persian Gulf; Arabian Sea (S. limit placed at  $10^{\circ}\text{N}$ ); Bay of Bengal (S. limit placed at  $10^{\circ}\text{N}$ ); equatorial region (between  $10^{\circ}\text{N}$  and  $10^{\circ}\text{S}$ ); Indian Ocean Central Waters between  $10^{\circ}\text{S}$  and  $35^{\circ}\text{S}$ ; Somali Current region; Agulhas Current region; the entire Indian Ocean down to Subtropical Convergence; the Subtropical Convergence; the Antarctic part of the Indian Ocean.

These geographical areas are characterized by special faunal associations though they also share taxa with adjacent areas. Boundaries between these regions are no barriers for a large number of species which migrate into or out of the areas, depending on the prevailing currents. The local abundance of species is strictly a bio-hydrographical feature while the occurrence or absence of a species is a matter of historical zoogeography of the area. The most important factor which delimits the distribution of species is temperature, next in importance is salinity. A literature review revealed that usually numerical abundance is used to indicate the main centres of distribution and since most literature is based on expedition data, the conclusions can only be provisional. The data give incidental information and the number of stations made during an expedition programme can hardly be considered representative neither in space nor in time. Still, the earlier expeditions and the more recent combined efforts of various countries during the IIOE give a unique opportunity to study the zoogeography of various zooplankton groups over a wide area.

The water masses in the Indian Ocean can be better distinguished by using communities of species than indicator species. Over large areas temperature is important in limiting species distribution while in sub-areas, where temperature variation is small, salinity variations restrict distribution. In the Indian Ocean there is also a regular decrease in the number of species from E. to W. and from N. to S. The Red Sea and Persian Gulf show minimum numbers of species and pronounced endemism in a few cases. In the south, however, off S. Africa, the Agulhas Current, the W. Wind Drift and the Benguela Current meet. As a result, the Agulhas Bank plankton is a mixture of zoogeographical elements from the Indo-Pacific, Atlantic and Antarctic Oceans. The Agulhas Current transports Equatorial Indian Ocean forms and the Benguela Current cold water (subantarctic) forms into this area. The prevailing upwelling brings mesopelagic forms to the surface. In the east, the Indonesian Archipelago provides pathways for the transport of Indo-Pacific elements from the Indian Ocean to the W. Pacific

and vice-versa, depending on the prevailing monsoons.

The SW. and NE. monsoons in the Arabian Sea and Bay of Bengal initiate a reversal of currents both in the equatorial region and to the north along the coastal areas of N.E. Africa, Saudi Arabia, India and Malaysia. Thus the monsoons influence zooplankton distribution in two ways. There is a shift of populations either to the east or to the west depending on the prevailing monsoon, and, by its reversal, the Somali Current transports zooplankton meridionally across the equator both in southern and in northern directions. This effect is enhanced by the Mozambique and Agulhas Currents particularly during the NE. monsoon. A similar situation exists off Java and the W. Australian coasts. Meso-plankton- and bathyplankton distributions provide evidence for the fact that Atlantic Intermediate Water, Antarctic Intermediate Water and Antarctic Bottom Water flow into the Indian Ocean.

### **Patterns of zooplankton distribution**

#### The coastal area of the Indian Peninsula in relation to monsoons and upwelling

The neritic and inshore waters off India are characterized by a rich and abundant plankton fauna, with typical seasonal variation related to monsoons and upwelling. Throughout the coastal area zooplankton development is, in general, bimodal, with two peak periods: February-April and September-October. Off the E. coast of Waltair January-February and June-July are the peak periods for Chaetognatha, particularly for *Sagitta enflata* (Rao, 1958). In the Madras plankton an abundance of Copepoda from November to March and a second increase in August were recorded (Menon, 1931). The standing crop of zooplankton in the Gulf of Mannar and Palk Bay shows two peaks, a high peak in March (in the Gulf of Mannar) and April (in Palk Bay) and a low peak in September-October in both areas (Prasad, 1958). These data were based on averages for 5 years (1954-1958). Off the Trivandrum coast a regular succession of plankton communities takes place and zooplankton (copepod) maxima occur from January to February, with swarms of *Sagitta enflata* from July to September; this species is rare from October to November (Menon, 1945).

Subramanyan (1959) gave average values for a 5-year period and found a peak in zooplankton abundance from June to August and smaller peaks in January-April off Calicut. The population of Chaetognatha along the Malabar coast shows the highest abundance in November and between May and June, and the lowest in August (George, 1952). For Bombay harbour January-March are the most favourable months for the occurrence of plankton swarms (Bal & Pradhan, 1945). At Bombay, *Sagitta enflata* was found to be abundant in November and December (Lele & Gae, 1936), off Calicut in October and November, and at Trivandrum from July till September. On the E. coast off Waltair and Madras, the peak periods occur during May-August and in the Gulf of Mannar during November and December. It seems that there is a N. to S. shift in the peak periods of plankton off the E. coast and an opposite shift, i.e. from S. to N., off the W. coast. At the same latitude off the E. and off the W. coasts of India, zooplankton populations show highest abundances during different months.

Table I. Hydrobiological conditions and plankton east and west of India

area	period	water mass	salinity (‰)	temperature (°C)
Bay of Bengal E. coast of India, Lawson's Bay	Aug.-Dec.	northern dilute water of the southern current	20.79-32.97	25.00-27.90
	Jan.-Aug.	southern Bay of Bengal water of the northern current	30.06-34.57	24.33-29.80
Arabian Sea: W. coast of India, off Calicut	May-Oct.	surface water of the northern Arabian Sea; near the coast this water flows below less saline waters formed as a result of heavy precipitation during this period; the surface current is southerly	33.0-36.5	26.0-29.5 (lowest values in July near the coast, due to upwelling)
	Nov.-April	surface water of the Indian equatorial region; the currents are northerly up to the end of January and thereafter they become southerly	33.0-35.75	25.0-29.5 (decreasing northward)

Also for phytoplankton such a regular succession of the peak periods is found (Ganapati & Rao, 1958).

In the Arabian Sea and the Bay of Bengal differences in temperature, in salinity range, in periods of upwelling and in surface currents appear to be related to the influence of the prevailing monsoon. The principal movement of plankton off the W. coast is from S. to N. Along this coast upwelling prevails between 7-16°N during the period August to early October (Panikkar & Jayaraman, 1966), but it is not known whether it occurs all at once over the entire stretch. It would appear from the succession of plankton peaks that off the W. coast upwelling is initiated in the south and then progressively moves northwards. Sharma (1968) was already of the opinion that upwelling starts in the south and gradually extends to the north. Off the E. coast upwelling is only reported near the Visakhapatnam coast during March (La Fond, 1954). High plankton values are recorded from the area from April to July. Further to the south off the E. coast of India, no data are available on upwelling. If one can infer physical events from biological processes, it could be stated that peak development of plankton points to enrichment by nutrients in April and May near Madras and in August and September in the Gulf of Mannar.

On the W. coast the SW. monsoon, with heavy rainfall, is strongest from May-September. Consequently, the lowest salinity values off this coast are found from June to August. Large scale upwelling also brings about lowering of temperature in the nearshore areas. However, on the E. coast lower salinities are encountered from September to November which is more due to river outflow than to rain. Low temperatures are found here between December and February.

The average values for salinity as well as for temperature in the Bay are much

---

 plankton
 

---

minor plankton blooms, chaetognaths are low in number and diversity; the tunicates *Fritillaria formica*, *Cyclosalpa pinnata* and *Pegaea confederata* are common

major plankton blooms, very rich chaetognath populations of a.c. *Sagitta pacifica*; the tunicates *Fritillaria borealis*, *F. sargassi* and *F. pellucida* occur in great numbers

phytoplankton abundant; copepods scarce; peak periods for *Sagitta enflata* and *S. neglecta* start in October

phytoplankton scarce; copepods most abundant; chaetognaths *S. enflata*, *S. bedoti* and *S. robusta* continue to be dominant throughout this period

---

lower than those for the Arabian Sea. As already stated, the periods of low salinity and low temperature occur later in the year in the Bay as compared to the Arabian Sea. Such fundamental differences must have a marked influence on development and fluctuation of plankton populations along the two coasts. Ganapati & Rao (1958) (Table I) have summarised the differences in the hydrobiological conditions during the two periods August-December and January-August off the two coasts. Prasad (1969a, b), Panikkar & Rao (1973) and Rao (1973) have given a detailed account of the distribution of the biomass (wet zooplankton displacement volumes expressed as ml per haul taken by the 10s Net) in the Indian Ocean based on the data from 110E samples, also included in Panikkar's 110E atlas (1968a, b).

Prasad (1969a, b) observed the highest volumes in the Arabian Sea between 10 to 25°N and 50 to 65°E, more particularly in the area off the Somali and Saudi Arabia coasts. Average values were noted as high as 54.7 ml (under 1 m<sup>2</sup> for 200 meter column) off Arabia, between 15 and 35 ml off Somali and about 15 ml all over the S.E. region of the Indian Ocean, in the northern Bay of Bengal and S. of Java. The rest of the Indian Ocean shows values below 15 ml/haul. From December to February, during the height of the NE. monsoon 20-39.9 ml biomass was measured in the region of the Gulf of Aden and N. of Mombasa. A few patches providing high values, i.e. 80 and more, were located off Madras in the Bay of Bengal and off Goa on the W. coast of India. The rest of the area showed low values (0.1-9.9 ml). March-April is a transitional period; both the Arabian Sea and the Bay of Bengal show patches of average values (10-32.9 ml) against a surrounding of low biomass (0.1-9.9 ml). Large patches in the Central Arabian Sea and E. Indian Ocean show values from 10 to 19.9 ml.



In May - June the SW. monsoon starts. Patches of high biomass values are scattered, E. of Ceylon 20-39.9 ml is found and a similar patch occurs in the Gulf of Aden. Most of the samples of this season exhibit low values (10 ml). From July to September the SW. monsoon is fully established all over the N. Indian Ocean. High biomass values (40 ml and more) are found at stations off Somalia (between Garad and Ras Mabber), near Cape Guardafui and off the Oman coast. Values ranging from 20-39.8 ml are present S. of the Andaman Sea, near 5°N 90°E, off Cochin, S. of Ceylon and also along 110°E. October and November are transitional months marked by the end of the SW. monsoon and the beginning of the NE. monsoon. The only region having a biomass value of 20-30.9 ml is off the Saudi-Arabian coast. The rest of the areas all show low values.

Though the samples did not cover the entire area for each period mentioned, it is evident that the seasonal distribution of biomass in the areas adjacent to the Saudi-Arabian coast shows consistently very high productivity during the prolonged SW. monsoon period. The eastern and western parts of the Indian Ocean become highly productive during the NE. and SW. monsoon respectively. There is also an overall increase in productivity in the area during the SW. monsoon. In this respect the Saudi Arabian coast is unique. The persistent easterly component of the currents in the Arabian Sea from May to August (Wooster et al., 1967) favours large-scale upwelling off the Saudi Arabian coast. Off this coast the lowest temperatures (23-25°C) are measured in July - September. Salinity is high and constant throughout the year. Nutrients (phosphates and nitrates) show high values for this area, even at the surface (1.61 and 21.1 µg at/l resp.), which is unique for the Indian Ocean. The combination of all these circumstances make the Saudi Arabian coast the area with the richest zooplankton production in the N. Indian Ocean.

Upwelling off Saudi Arabia and S. of Cape Guardafui is active from May to October, the intensity and the actual area may shift with the seasons. Off the W. coast of India July to October is considered the period of upwelling, exact knowledge about this shallow water is not available. During the NE. monsoon upwelling was traced off Bombay (Carruthers et al., 1959), off Ceylon (Kabanova, 1968), off Karachi, in the Gulfs of Persia and Aden. These seem to be the centres from which biological productivity radiates and the abundance and pattern of zooplankton is chiefly governed by the current patterns prevailing at the time of the upwelling. This is proved by the spatial and seasonal distribution of the various zooplankton groups discussed in this paper. The perfect correlation in the Arabian Sea and the Bay of Bengal between temperature, phosphates, primary production, copepods and fish larvae both during the NE. and SW. monsoon is shown in fig. 4a. The dynamics of upwelling, the enrichment of the surface layers, the initiation of the primary production followed by zooplankton production, the timing of spawning and development of fishes all constitute a biological unit and the various factors mentioned are interlinked to form a single ecosystem (Cushing, 1971).

In the S. Indian Ocean there are few samples available. However, a series of cruises along 110°E gave good samples and the ship 'Africana' worked a grid of 19 stations in the Agulhas Bank area for 18 months. The study of the biomass at these stations is very interesting. At 32°S 100-112°E hydrographical observations reveal that conditions were highly stable in August. Temperature (19°C), salinity (35.7‰) and oxygen (5.0 ml/l) show practically no variation throughout

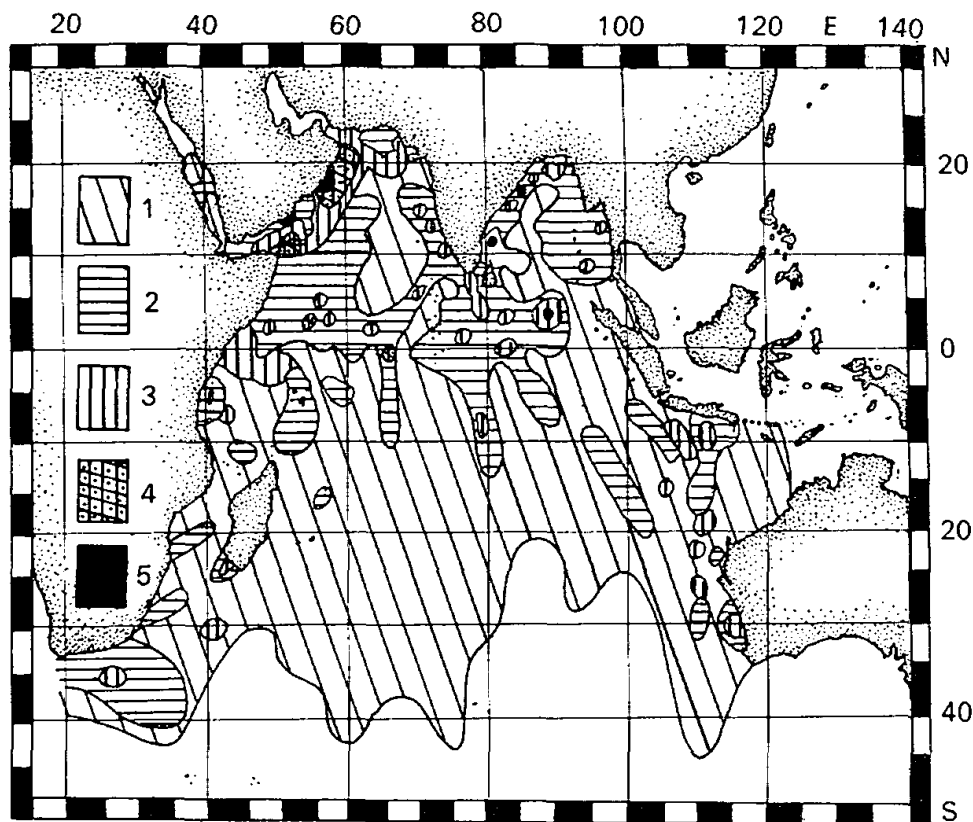
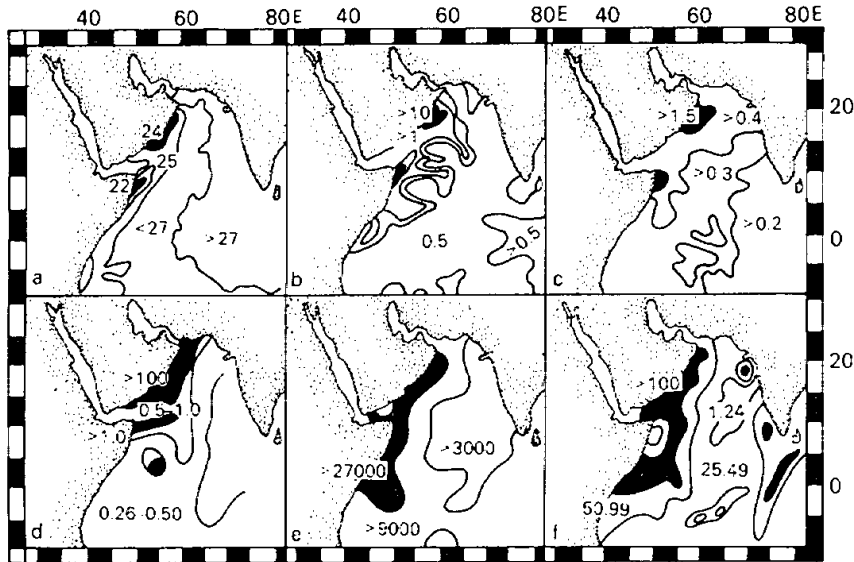


Fig. 3. Zooplankton biomass in the Indian Ocean, 1=0.1-9.9, 2=10-19.9, 3=20-39.9, 4=40-79.9, 5=80 and more (after Rao, 1973).

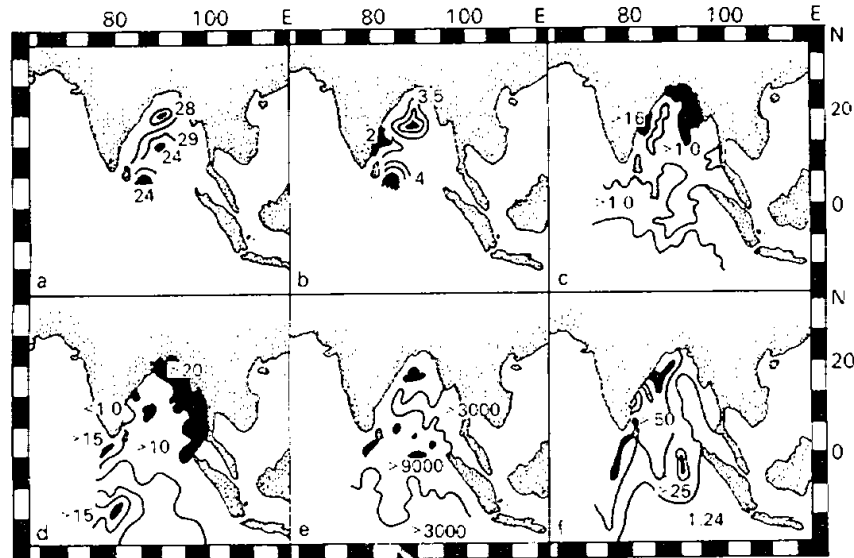
the 200 m column. The nutrients are low throughout the period, the maximum values for  $\text{PO}_4\text{-P}$  being  $0.70 \mu\text{g at/l}$ , in July. The biomass at this station is very low and shows a bimodal fluctuation, high values are observed in February and August.

In the 'Africana' collections the biomass values are higher than at the  $32^\circ\text{S}$ - $100^\circ\text{E}$  station and variable ( $0.9$ - $21.7 \text{ ml per } 100 \text{ m}^3$ ). A clear relationship exists between the prevailing current and the plankton populations. Both Copelata and Chaetognatha come from the east and drift south-westwards with the Agulhas Current (Chandrika & Pannampunayil, 1973).

On the Malabar coast primary production is highest during July-August which is also the period of upwelling, but zooplankton peaks start in October and November. The biological activities between the two monsoons are complementary and the effects of the SW. monsoon are perhaps not fully realised until the NE. monsoon. Another point is that the areas of zooplankton productivity extend hundreds of miles from the zones of upwelling, mostly in the direction of the prevailing surface currents. Cushing (1971) stated: 'at  $\frac{1}{2}$  knot, an upwelling which took 30-60 days to rise through the photic zone might drift 300-600 miles before the decay process was complete'. Cushing also expects that the width of the zone of biological production covers two and a half times the width of physical



A



B

Fig. 4A. Correlation between biohydrographical factors in the Arabian Sea. a) Surface temperatures, Aug. 1963, b) Nitrate-nitrogen  $\mu\text{g at/l}$ , c) Phosphate-phosphorus  $\mu\text{g at/l}$ , d)  $\text{ge/m}^2/\text{day}$ , e) Copepoda No./haul, f) Fish larvae No./haul.

Fig. 4B. Correlation between biohydrographical factors in the Bay of Bengal. a) Temperature at 50 m, b) Oxygen ml/l at 50 m, c) Phosphate-phosphorus  $\mu\text{g at/l}$  at 100 m, d) Nitrate-nitrogen  $\mu\text{g at/l}$  at 100 m, e) Copepoda No./haul, f) Fish larvae No./haul (after Rao, 1973).

upwelling. Off Ras Maber and near  $8-10^\circ\text{N}$ , the Somali Current deflects eastward causing an intense divergence and upwelling. Here the contour for highest copepod density extends up to nearly 600 miles from the coast.  $\text{PO}_4\text{-P}$  ( $\mu\text{g at/l}$ ) values at the surface very clearly correlate with the density distribution of copepods (Wooster et al., 1967) (Fig. 18). The highest value of phosphorus is found

along the shores of Somalia and Arabia and the contour lines of values above  $0.75 \mu\text{g at/l PO}_4\text{-P}$  neatly coincide with the highest densities of copepods.

### Zoogeographical patterns

It is problematic to consider the zoogeography of various species belonging to different groups in relation to a certain geographic area, for the simple reason that hydrographical boundaries are not distinct. Vannucci & Navas (1973a) stated that with the increasing knowledge on the distribution of species over a wide area, the boundaries between various geographical regions have become more and more vague, while the ecology of the species becomes more clear. Besides, there are more species common to the entire Indian Ocean than the few which are endemic to an area. In the present review, the distributional patterns of various zooplanktonic groups are given for the entire Indian Ocean. It is felt that such a treatment is more meaningful than going by areas and geographical names.

The following description is a summary of findings on some of the important zooplankton groups for which reports are available; in most cases the data come from the IIOE. It appears that each author gives different distributional patterns and I have endeavoured to point out here their main findings of zoogeographical significance for the Indian Ocean and adjacent areas. The groups are arranged in systematic order.

#### Foraminifera

Planktonic Foraminifera represent a group very sensitive to environmental changes which makes them good ecological indicators. During the SW. monsoon all Foraminifera are highly abundant off E. Africa and Saudi Arabia, off E. Ceylon and in the Java Sea. Hence, there is a reduction in abundance in these areas during the NE. monsoon (Figs. 5a-b). The distribution of *Orbulina universa* points to a division of the Indian Ocean into a northern section, N. of the  $10^\circ\text{S}$  hydrothermal front and a region S. of it. Near  $10^\circ\text{S}$  an abrupt change in shell diameter and porosity occurs. The equatorial forms are characterised by high porosity, large size and thin walls, while the southern central group has low porosity, small size and thick walls. These changes are found both in plankton and sediment records. However, for the latter, the transitional zone is located further south (Fig. 7) (Hecht, Bé & Lott, 1976).

Bé & Tolderlund (1971) have described the distributional patterns of relative abundance of 27 species of living planktonic Foraminifera from the different oceans. The following summary is based on their paper (Fig. 7). *Globigerina pachyderma* is the best indicator of Polar Waters ( $0-9^\circ\text{C}$ ). *Globigerina quinqueloba* prefers Subantarctic and Antarctic Waters ( $1-21^\circ\text{C}$ , greatest frequency in  $1-5^\circ\text{C}$ ). *Globigerina bulloides* occurs between  $40-55^\circ\text{S}$  ( $0-27^\circ\text{C}$ , peak abundance between  $3-19^\circ\text{C}$ ). *Globorotalia inflata* is an excellent indicator of the Subtropical Convergence and in the southern hemisphere it occurs in a distinct latitudinal belt (roughly between  $35^\circ\text{S}$  and  $45^\circ\text{S}$ ) which nicely defines the zone of Transitional Waters (peak abundance between  $13-19^\circ\text{C}$ ). *Globorotalia truncatulinoides* occurs mainly in the subtropical region of the Central Indian Ocean between  $20^\circ\text{S}$  and  $50^\circ\text{S}$  (peak abundance from  $17^\circ\text{C}$  to  $22^\circ\text{C}$ ). *Globigerinoides ruber* is the most success-

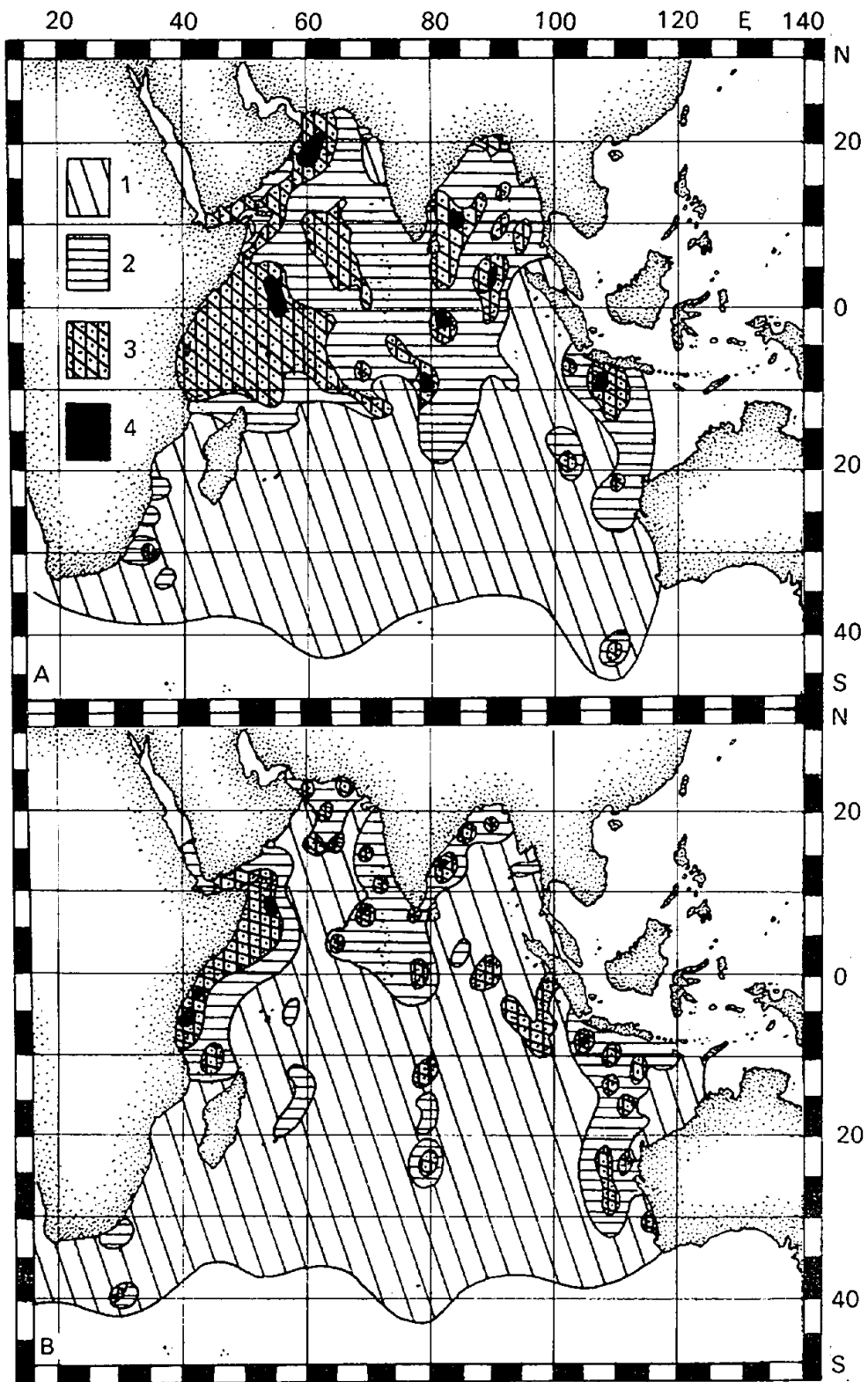


Fig. 5. Foraminifera distribution, A) during SW. monsoon, B) during NE. monsoon. 1 = 1-99, 2 = 100-499, 3 = 500-2499, 4 = 2500 and more (after IIOE Plankton Atlas 5 (2), 1973).

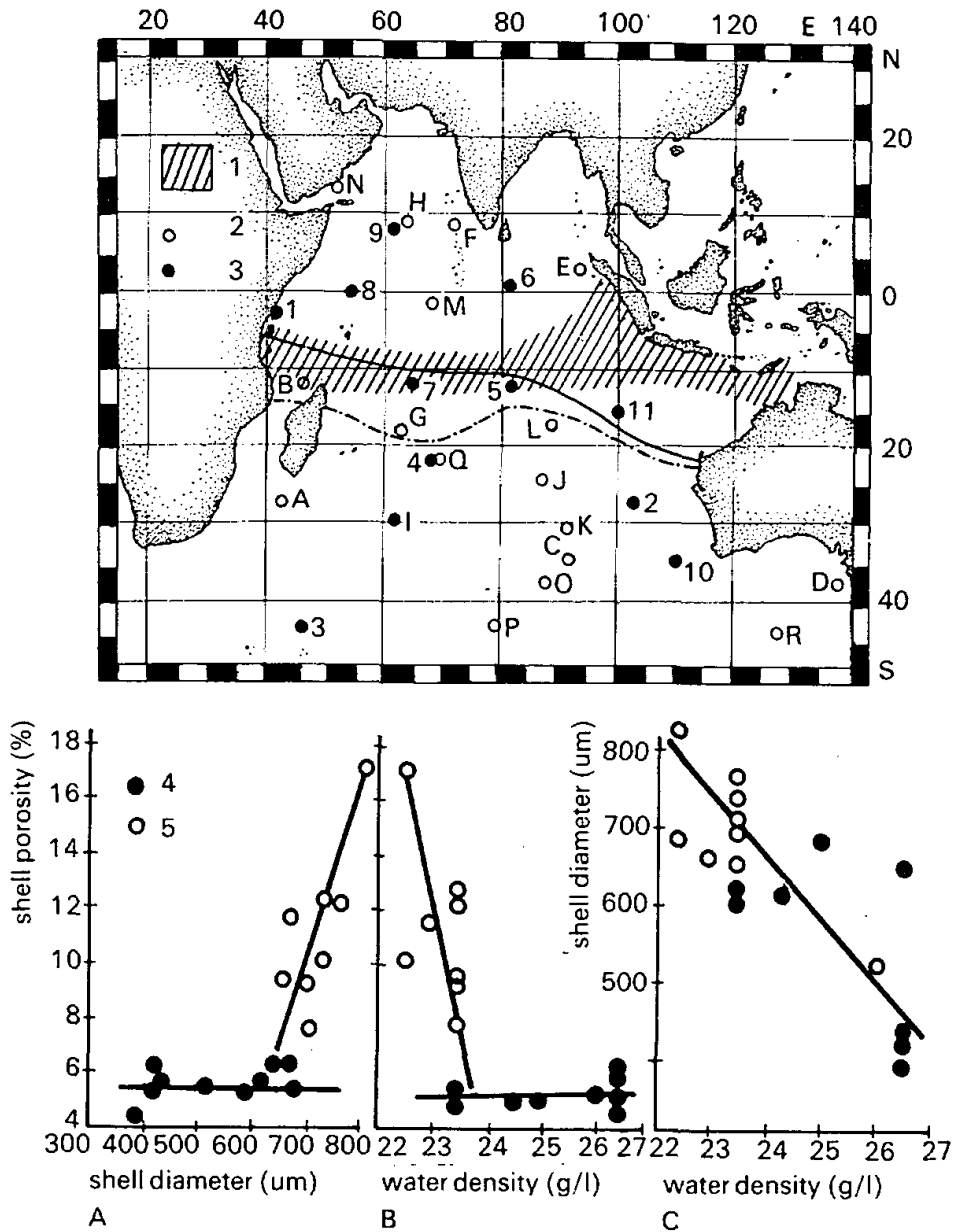


Fig. 6. Geographic limits of plankton and sediment in the Indian Ocean 1 = 10°S hydrographic front, 2 = Sediment samples, 3 = Plankton tows, 4 = Equatorial group, 5 = Central group (after Hecht, Bé & Lott, 1976).

ful warm water species in terms of distribution and abundance. It occupies the entire Central Water mass between 10°N and 30°S (peak abundance in southern central gyre). *G. sacculifer*, though more abundant in the N.E. quadrant, has a similar distribution, while *G. ruber* is found more in the south. It seems that salinity plays an important role in the distribution of these species. *Globoquadrina dutertrei* is particularly abundant in major current systems near continents. Highest frequencies are encountered particularly in the Somali and Madagascar areas and

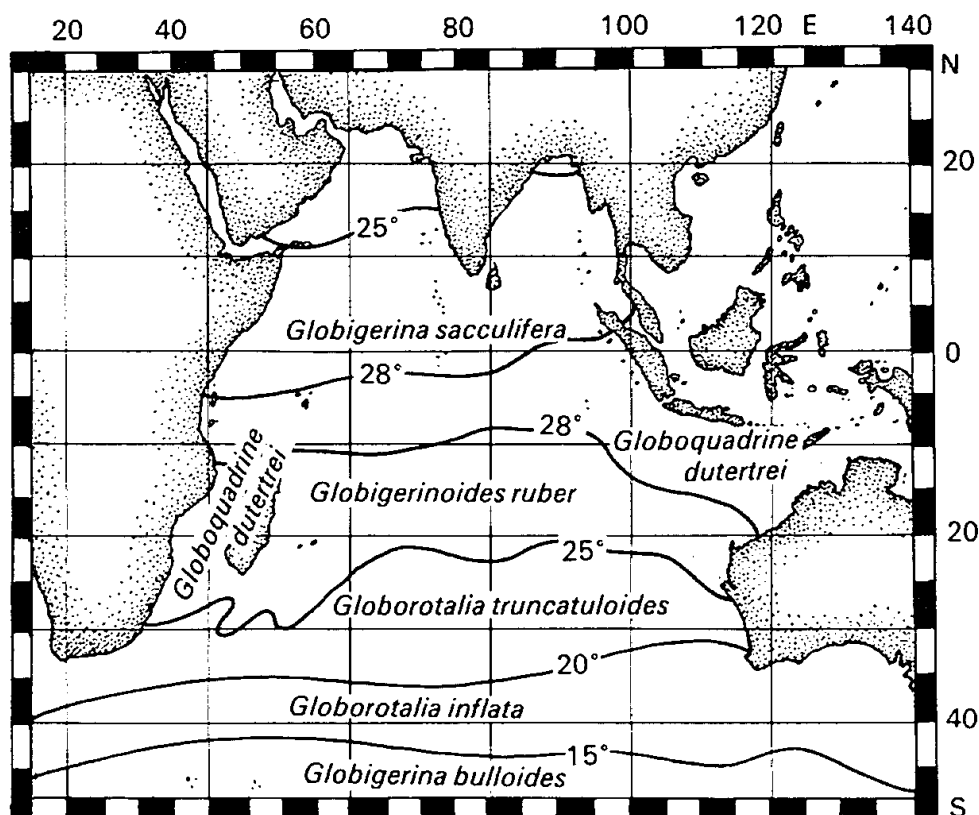


Fig. 7. Idealized centres of distribution of some species of Foraminifera (based on Bé & Tolderlund, 1971) with February isotherm.

S. of Java (peak abundance between 16-24°C). *Orbulina universa* is an ubiquitous species particularly abundant in upwelling systems. It is predominant in the eastern half of the Central Water and off the E. coast of Africa. *Globigerina aequilateralis* shows the same distribution as *O. universa*. However, the former is more abundant in the Agulhas-Somali Current region. *Globoquadrina conglomerata* is a typically Indo-Pacific species, reported from the Agulhas Current.

#### Hydromedusae

In an extensive report on the ecology of Hydromedusae in the Indian Ocean, Vannucci & Navas (1973a) have given several instances of species distribution in relation to ecology and geography of various water masses. The following is a summary of their findings.

Deep and Intermediate Water Hydromedusae apparently belong to cold Bottom Waters of antarctic origin (< 2°C and salinity < 35‰). Many of these forms, like *Solmissus marshalli*, *Tetrorchis erythrogaster*, *Aequorea pensilis*, *Protiara tropica*, *Vannucci forbesi* etc., are euryhaline, eurybathic and oxygen tolerant. *Merga reesi*, *Aglantha elata* and *Tetrorchis erythrogaster* are deep water species not yet recorded from the Antarctic, perhaps because of scarce sampling. There are many antarctic species, like *Botrynema brucei*, *Solmissus marshalli*, *Cunina duplicata*, *Pegantha*

*martagon* and *Aeginura grimaldi* which submerge near the Antarctic and Subantarctic Convergences to disperse further north, even N. of the Subtropical Convergence in the Indian Ocean. Though these species are cold tolerant, they are neither restricted to cold nor to deep waters. *Solmissus marshalli* and *Cunina duplicata* were found in the upwelling waters in the E. Bay of Bengal, in the W. Arabian Sea and in the Central Indian Ocean near the equator. The presence of deep water or antarctic species in relatively shallow depths in the Arabian Sea and the Bay of Bengal is noteworthy.

Indian Ocean Central Water Hydromedusae prefer or tolerate temperatures up to about 19°C and salinity between 34.5 to 36.0‰. In the Arabian Sea, many species of this group, like *Sibogita geometrica* and *Amphogona apiceta* are absent because of the low oxygen content, while in the Bay of Bengal the low salinity water excludes them.

Because of the peculiar hydrographical conditions of the Bay of Bengal, peculiar associations of Hydromedusae are found. The Bay of Bengal surface water has high temperatures and a decreasing salinity gradient from S. to N. and besides, it overlies relatively cold waters (< 19°C). Neritic species such as the cosmopolitan *Liriope tetraphylla* and *Cunina tenella* are widely distributed in these surface waters. Some of the Bay of Bengal species such as *Pandeopsis scutigera*, *Phialucium condensum*, *Helgicirrata medusifera* are found in coastal and estuarine areas of the Arabian Sea. These forms have a wide distribution in the Bay of Bengal, but a restricted one in the Arabian Sea. The more abundant species in the Arabian Sea are *Aglaura hemistoma* and *Solmundella bitentaculata*.

Vannucci & Navas (1973a) recognise a separate group of species characteristic of the surface layers of the equatorial region of the Indian Ocean (34-34‰ S, 26-27°C, 3.40-7.46 ml/l O<sub>2</sub>). These species such as *Euphysora furcata*, *Bougainvillia fulva*, *B. platygaster*, *Laodicea fijiana*, *Eirene viridula*, may also spread to adjacent areas, dependent on the cyclical circulation of the Equatorial Currents.

In conclusion, five groups of species are recognised. They are: a) rare species with scattered geographic distribution; b) Deep and Intermediate Water species that are not antarctic; c) antarctic and subantarctic species, usually stenothermal; d) species specific of the Indian Ocean Central Water system with temperature range of 8-20°C and e) species of the Indian Ocean Equatorial system which are confined to waters with temperatures above 20°C. The above ecological classification of the Hydromedusae cuts through most of the geographical areas of the Indian Ocean.

#### Cladocera

Distribution of Cladocera in 110E samples was studied by Della Croce & Venugopalan (1972, 1973). Studies by Dolgopolskaja (1958) showed that *Evadne tergestina* occurs in coastal waters of the whole Indian Ocean, except for the Arabian Sea. However, 110E samples showed a seasonal hiatus in the neritic distribution of this species in the Arabian Sea. Its presence in the Central Arabian Sea and adjacent waters between 0-20°N suggests that a seaward transport may take place during the inter-monsoon period. In March and April this species is found all over the Bay of Bengal. Further south up to the equator, the species has been recorded from August to December and discontinuously in the other months. Between 0-20°S it is continuous from Africa to Java and Australia. In



December and January, its distribution in this area is continuous from 70°E to Australia. *E. spinifera* is rare in the Indian Ocean, restricted to the Agulhas Bank in January, to the W. Australian coasts from December till May and to the north-eastern waters of the Arabian Sea in May and November. *Penilia avirostris* is distributed all over the Indian Ocean (8.7-30.17°C). In the Arabian Sea it is mainly found in neritic waters off India and Pakistan, off Cape Agulhas and off Zanzibar during different periods, and there are a few scattered records in the S. African and Australian waters.

### Copepoda

The areas with highest Copepoda densities are located along the African coast N. of Mombasa, continuing along the Arabian coast they occupy a large area of the N. Arabian Sea (Fig. 8 a-b). The Wadge Bank, the Gulf of Mannar, an area off Madras, the northern Bay of Bengal including the Orissa coast and some patches along the equatorial region also show high densities. Areas with low densities cover the central Arabian Sea and central Bay of Bengal. During the SW. monsoon low copepod densities occur along the W. coast of India as far north as Baluchistan, whereas during the NE. monsoon higher values are recorded in the same region. Production of copepods is thus much more intensive during the NE. monsoon than during the SW. monsoon and it covers large off-shore areas in and around upwelling regions.

In the Bay of Bengal a rich patch is found off the N. Andhra and Orissa coasts, extending right up to the centre of the northern Bay during the SW. monsoon. Local upwelling off Visakhapatnam (La Fond, 1954) alone cannot explain the occurrence of such dense populations far offshore. There must be large-scale upwelling off the Orissa coast but no data are available for this region. During the NE. monsoon dense patches of Copepoda are present off Madras and off the southern tip of India, probably because of upwelling. In the Java Sea and in areas off W. Australia denser patches of Copepoda are more extensive from October to April (corresponds to northern winter) than from April to October. In all upwelling areas extensive production of copepods takes place during the NE. monsoon and it is suggested that, although primary production values are highest during the SW. monsoon, there is some time-lag for the development of zooplankton populations.

Sewell (1948) gave a comprehensive account of the world-wide zoogeography of planktonic copepods with particular reference to the Indian Ocean. He followed Steuer's subdivision into two geographical areas namely 1) a tropical zone N. of c. 10°S, a subregion of Indo-Pacific nature and 2) a southern subtropical zone encompassing the Central and S. Indian Ocean extending from about 10°S to the Subtropical Convergence (35-40°S). South of the Subtropical Convergence, the subantarctic region shows similar characteristics all around the southern hemisphere. To summarise Sewell's findings for Copepoda, it may be stated that the largest number of species in the Indian Ocean is of Indo-Pacific nature. There is a decrease in species diversity from E. to W., finally reaching very low diversity in the N. Red Sea and Persian Gulf. There is also a gradual decrease in the number of species from northern latitudes towards the Subtropical Convergence, and one with increasing depth. Exchange between the copepod fauna from the Indian Ocean and from the Pacific Ocean takes place

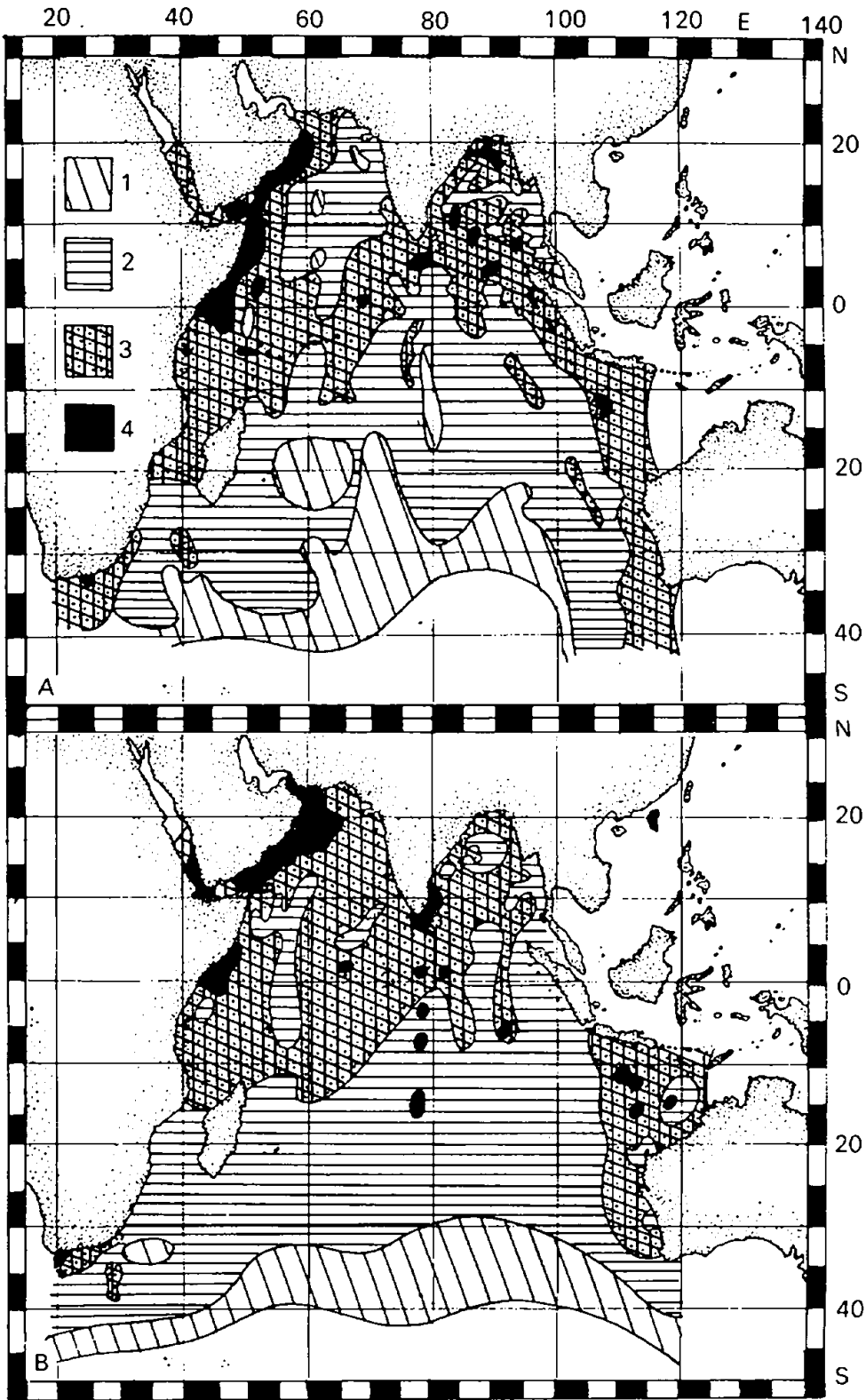


Fig. 8. Copepoda distribution, A) during SW. monsoon, B) during NE. monsoon. 1 = 1 - 2999, 2 = 3000 - 3999, 3 = 4000 - 26999, 4 = 27000 and more (after IIOE Plankton Atlas 2 (1), 1970).

Table II. Patterns of Candaciidae in the Indian Ocean

name	general distribution	areas of abundance
<i>Candacia bradyi</i>	neritic (north of 10°N)	Red Sea and W. Arabian Sea
<i>Candacia tuberculata</i>	neritic (north of 19°N)	E. Arabian Sea
<i>Candacia discaudata</i>	neritic	E. Bay of Bengal and Indonesian waters
<i>Candacia norvegica</i>		Arabian coast (from one single station)
<i>Candacia samassae</i>	restricted	Arabian Sea and Bay of Bengal
<i>Candacia curta</i>	restricted	off Somali coast and Arabian coast
<i>Candacia bipinnata</i>	restricted	off Somali coast
<i>Paracandacia simplex</i>	restricted (mostly south)	Mozambique coast and Agulhas area
<i>Paracandacia truncata</i>	widely (north of 10°N)	mostly equatorial
<i>Candacia catula</i>	widely (north of 10°N)	mostly equatorial
<i>Candacia pachydactyla</i>	widely (north of 10°N)	high productivity water
<i>Candacia bispinosa</i>	widely (north of 10°N)	southern areas - central gyre also upwelling areas
<i>Candacia ethiopica</i>	widely (south of 10°N)	southern areas - central gyre along equator
<i>Candacia longimana</i>	widely (south of equator)	
<i>Candacia varicas</i>	widely (south of equator)	

mainly through the Malacca Strait and S. of Java through the Timor Sea; the Agulhas Current transports copepods and other planktonic organisms southwards and around the Cape of Good Hope into the S. Atlantic area (Sewell, 1948).

In a few instances, the dispersal of species from E. to W. by the Agulhas Current brought about slight structural taxonomic changes giving rise to separate Indo-Pacific and Atlantic forms (see chapter 5 & 7).

About 165 deep water Copepoda are recorded both from the Atlantic and the Indian Oceans and this is attributed to the flow of the Atlantic Intermediate Water into the Indian Ocean or to the influence of Antarctic Intermediate Water

(Sewell, 1948). The occurrence of species like *Pareuchaeta hanseni*, *Valdiviella insignis* and *Bathycalanus bradyi* in the Arabian Sea at depths of 2000 m is probably due to Antarctic Bottom Water reaching these areas. Of the 96 S. Atlantic species taken in the Antarctic, 46 were taken in the Indian Ocean.

Table II gives the zoogeographical patterns of Candaciidae in the Indian Ocean. Lawson (1977) recognized two recurrent groups (RG) in the Indian Ocean: RG 1 includes *Paracandacia truncata*, *Candacia catula* and *C. pachydactyla*, which is characteristic of the Equatorial Gyre; RG 2 includes *P. bispinosa* and *C. ethiopica*, which is dominant in the Central (southern) Gyre. Transitions between Candaciidae faunas are found at 10°N (approximate southern limit of the Arabian Sea and Bay of Bengal), at 0° (minor Transitional Zone) at 10°S (hydrographic front separating Equatorial and Central Waters) and at 35-45°S (southern edge of the Central Water at the Subtropical Convergence). Along E. and W. coasts, the boundary currents extend the ranges latitudinally, for many groups (Fig. 9). Sympatry is illustrated by the RG of Candaciidae. In RG 1, *C. pachydactyla* is the largest epipelagic form. *C. catula* is the smallest and *Paracandacia truncata* is intermediate in size; these three species belong to different morphological species groups.

Table III shows that closely related taxa are allopatric to avoid competition. The three paracandaciids *P. truncata*, *P. bispinosa* and *P. simplex* for example, form one

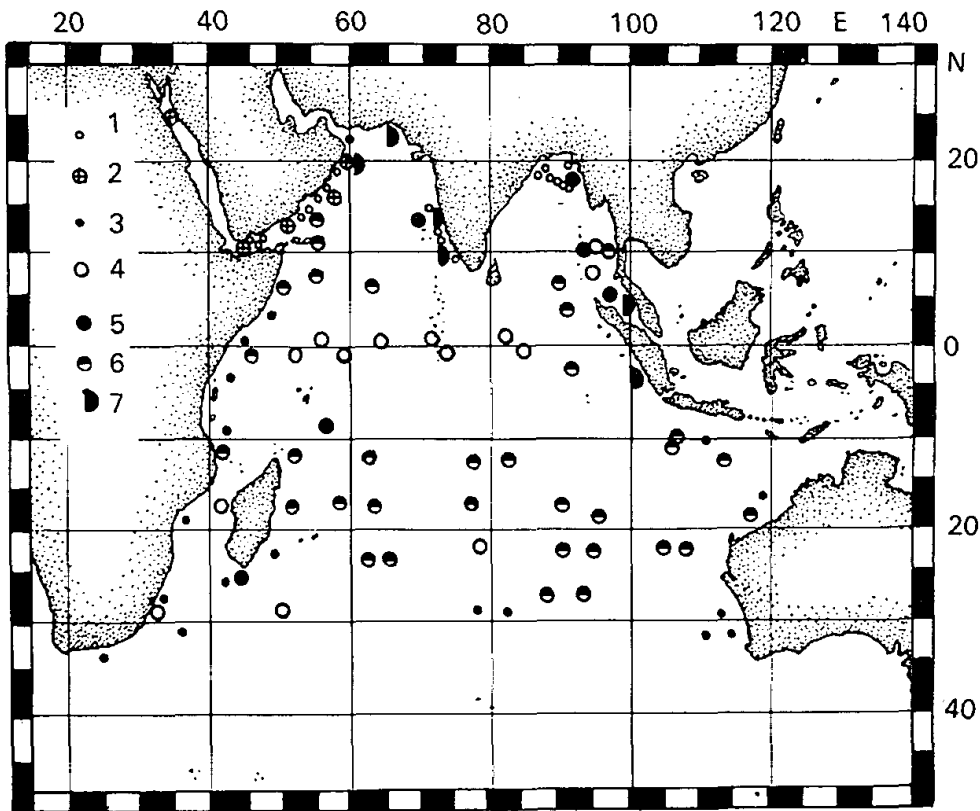


Fig. 9. Distribution of some Copepoda. 1 = *C. samassa*, 2 = *C. bradyi*, 3 = *P. simplex*, 4 = *C. longirama*, 5 = *C. discaudata*, 6 = *P. bispinosa*, 7 = *C. tuberculata* (based on Lawson, 1977).

Table III. Geographic displacement in *Candacia* and *Paracandacia* groups

species-groups	species	geographic centres of abundance in the Indian Ocean
1	<i>P. truncata</i>	northern gyre
	<i>P. bispinosa</i>	central gyre, 20-30°S
	<i>P. simplex</i>	south, periphery of central gyre
2	<i>C. bradyi</i>	Red Sea, W. Arabian Sea
	<i>C. tuberculata</i>	N. and E. Arabian Sea
	<i>C. discaudata</i>	Bay of Bengal
3	<i>C. ethiopica</i>	central gyre, 20-30°S
	<i>C. longimana</i>	central gyre
	<i>C. curta</i>	western upwelling regions
	<i>C. pachydactyla</i>	northern gyre
4	<i>C. sarassae</i>	Arabian Sea, Bay of Bengal, Red Sea
	<i>C. varicans</i>	central gyre
	<i>C. bipinnata</i>	African coast, western Equatorial
	<i>C. cheirura</i>	south

morphological species group and because of morphological and size similarities they are potentially strong competitors. To avoid this, they occupy different ranges. *P. truncata* is widely distributed N. of 10°S. *P. bispinosa* has a more southern range S. of 10°S and along the W. African coast. *P. simplex* is mostly confined to southern latitudes around 30°S with some N-S. dispersal on either side of the Indian Ocean.

The northern neritic species *Candacia bradyi*, *C. tuberculata* and *C. discaudata* are also similar in morphology and size. They are allopatric along the E-W. salinity gradient at northern latitudes.

Based on the distribution of the copepod family Candaciidae, Jones (1966a, b) divided the W. Indian Ocean into 3 main planktonic provinces. North of about 20°S equatorial species predominate. In the W. these species are carried southward by the Agulhas Current. *Candacia pachydactyla*, *C. catula* and *Paracandacia truncata* are equatorial forms from the Indian and Atlantic Oceans, but the populations are separated by the Benguela Current S. of Africa (Fig. 10). In fact, this area forms the barrier for the transport of Indo-Pacific forms into the S. Atlantic. *Candacia guggenheimi* has apparently a discontinuous distribution, occurring in the W. Indian Ocean and then again in the Central Pacific (Jones, 1966a, b). Reporting on the distribution of the epiplanktonic calanoids of the Indian Ocean, Fleminger & Hulsemann (1973) found two biogeographical phenomena significant for epiplankton of the Indian Ocean. a) Species breeding between 40°N and 40°S (e.g. *Pontellina plumata*), tend to be circumglobal in distribution and probably maintain gene flow around S. Africa. b) Species breeding between 30°N and 30°S (e.g. *Eucalanus elongatus*) are provincial and may have tropical cognates in other oceans.

The epiplanktonic *Gaussia sewelli* (Copepoda—Metridiidae) is endemic to the

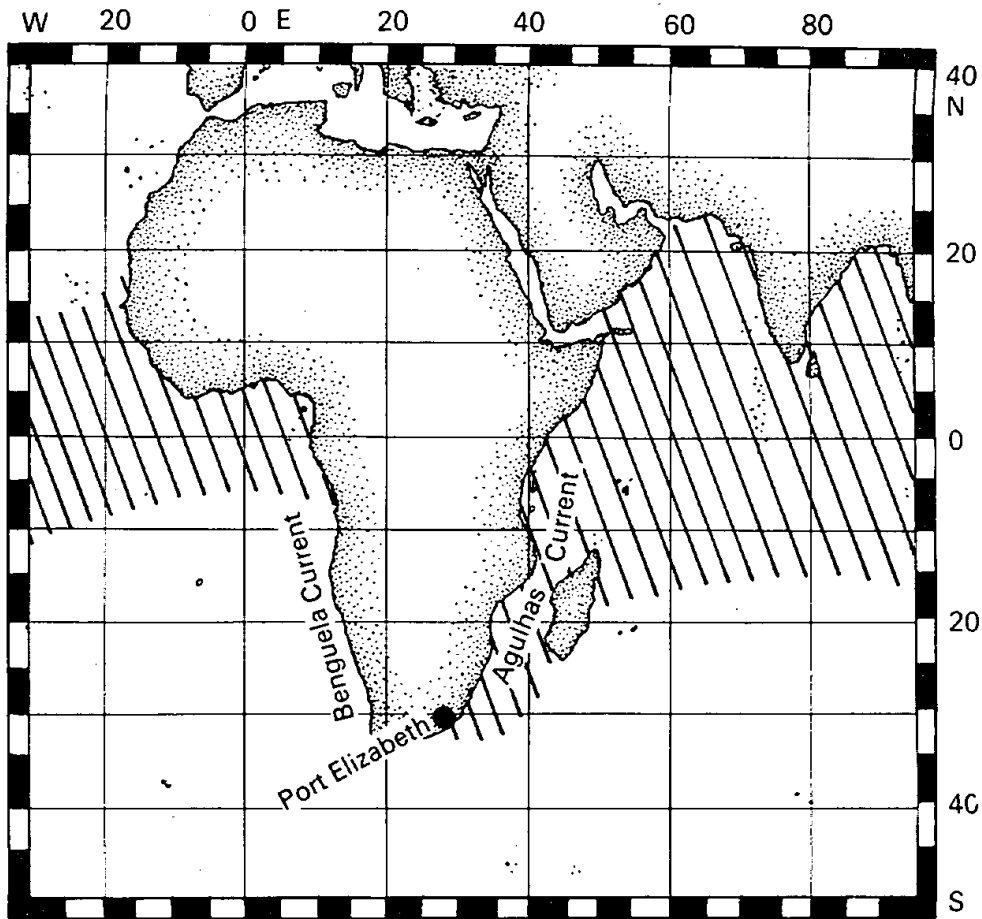


Fig. 10. Discontinuous distribution of *C. pachydactyla* in Indian and Atlantic Ocean. (Jones, 1966).

N. Indian Ocean, particularly to the Arabian Sea and Bay of Bengal (Saraswathy, 1973). *G. scotti* occurs between 200 and 3000 m depth, S. of the equator as far S. as 41°S. This is the most widely distributed species of the genus found also in other oceans. So far, the genus has not been recorded from the northernmost areas of either the Arabian Sea or the Bay of Bengal. The species inhabiting the northern areas of the Indian Ocean is a separate species. Recognition of a species endemic to the N. Indian Ocean is important, as it may point to a certain degree of isolation of this area. In *Chauliodus slomi* at least two populations exist: a denser one N. of the frontal zone (about 10°S) (cf. p. 256) and, separated by a sterile region, a less dense one S. of about 23°S (Gibbs & Hurwitz, 1967).

*Pleuromamma* is abundant in the Arabian Sea and the Bay of Bengal and in certain restricted areas it is the only representative of the genus, like in the vicinity of the mouth of the Gulf of Oman and in the central Bay of Bengal, the Persian Gulf, the Gulf of Aden and the Red Sea. A few specimens from the Pacific and the Atlantic coasts of Africa have been recorded (Saraswathy, unpubl.). Off the Karachi coast *Pleuromamma indica* is mainly found at shallow depths (6-23°C, < 1 ml/l). The highest concentration of this species was found near the continental margin and inside the area of the Indus Outflow in November when deep

penetration of cool and O<sub>2</sub> deficient water was recorded (Haq et al., 1973).

### Euphausiidae

Euphausiidae are omnivorous, consuming diatoms, zooplankton and detritus, and they form an important food source for fish and whales. Gopalakrishnan & Brinton (1969), Weigmann (1970) and Ponomareva (1964) dealt with the Euphausiacea of the Indian Ocean.

As in Copepoda, the highest densities of Euphausiidae (1250/haul) is confined to patches along the African and Arabian coasts, two patches in the Central Indian Ocean S. of Ceylon, a large one off Madras, one N. of the Island Andaman, three patches in the Java Sea and one off Perth. The next range of density (250/haul) is widely distributed along the E. African coast, chiefly N. of Mombasa, and as a tongue into the Central Indian Ocean. There are similar density bands right across the Central Indian Ocean, separated by patches of low density (Fig. 11a, b)

During the SW. monsoon, high density patches appear off Somalia, Saudi Arabia and off Madras. These patches extend for hundreds of miles off shore. Except for a band of low density, the whole Bay of Bengal shows values similar to those of the African coast. Very low densities of euphausiids off Bombay and Gujarat persist even during the NE. monsoon. However, during this monsoon the Bay of Bengal has lower densities and off Madras and Ceylon the patches of highest density disappear. Densities of more than 250/haul are found for Euphausiidae over a much wider area, extending from the African to the Australian coast, during the NE. monsoon than in the SW. monsoon. In terms of biomass, here again, the NE. monsoon period is more productive than the SW. monsoon. Euphausiid distribution as reported by Brinton & Gopalakrishnan (1973) confirms the patterns already given for Copepoda. *Euphausia distinguenda*, *Pseudeuphausia latifrons* and *Stylocheiron indicum* are characteristic of the area N. of 10°N, including the Bay of Bengal and the Arabian Sea. The northern boundary of eight tropical, subtropical circumglobal species also coincides with 10°N. *Euphausia pseudogibba* and *Thysanopoda aequalis* occupy the 0-10°N zone including the Andaman Sea. However, in the Pacific, these species occur more to the south and occupy the Central Water mass (Brinton, 1963).

The equator forms the southern boundary for *E. pseudogibba* and *T. aequalis* and the northern limit for *E. brevis*, *T. subaequalis* and *E. similis*; these three species decrease in numbers N. of the equator. Many northern species, particularly those of subsurface levels, and the equatorial species *E. diomedea*, *Nematoscelis gracilis*, *Stylocheiron microphthalmum* and *E. paragibba* sharply diminish in numbers south of 10°S.

The zone of 25-30°S forms the southern boundary of some of the subtropical species that occur S. of the equator, like *E. brevis*, *E. mutica*, *S. suhmii* and *Thysanopoda subaequalis* and of a number of more widely ranging tropical and subtropical species such as *E. tenera*, *N. microps*, *N. tenella*, *T. tricuspidata*, *T. monacantha*. This zone is the northern limit for some of the southern species like *E. similis* and *Thysanoessa gregaria*. The boundary region between subtropical and temperate zones at 40-45°S is the southern limit of *E. recurva*, *N. megalops* and *E. hemigibba*.

An interesting feature of the zoogeography of the Indian Ocean is that species both in the east and west have a wider N-S. range than in between. This is caused

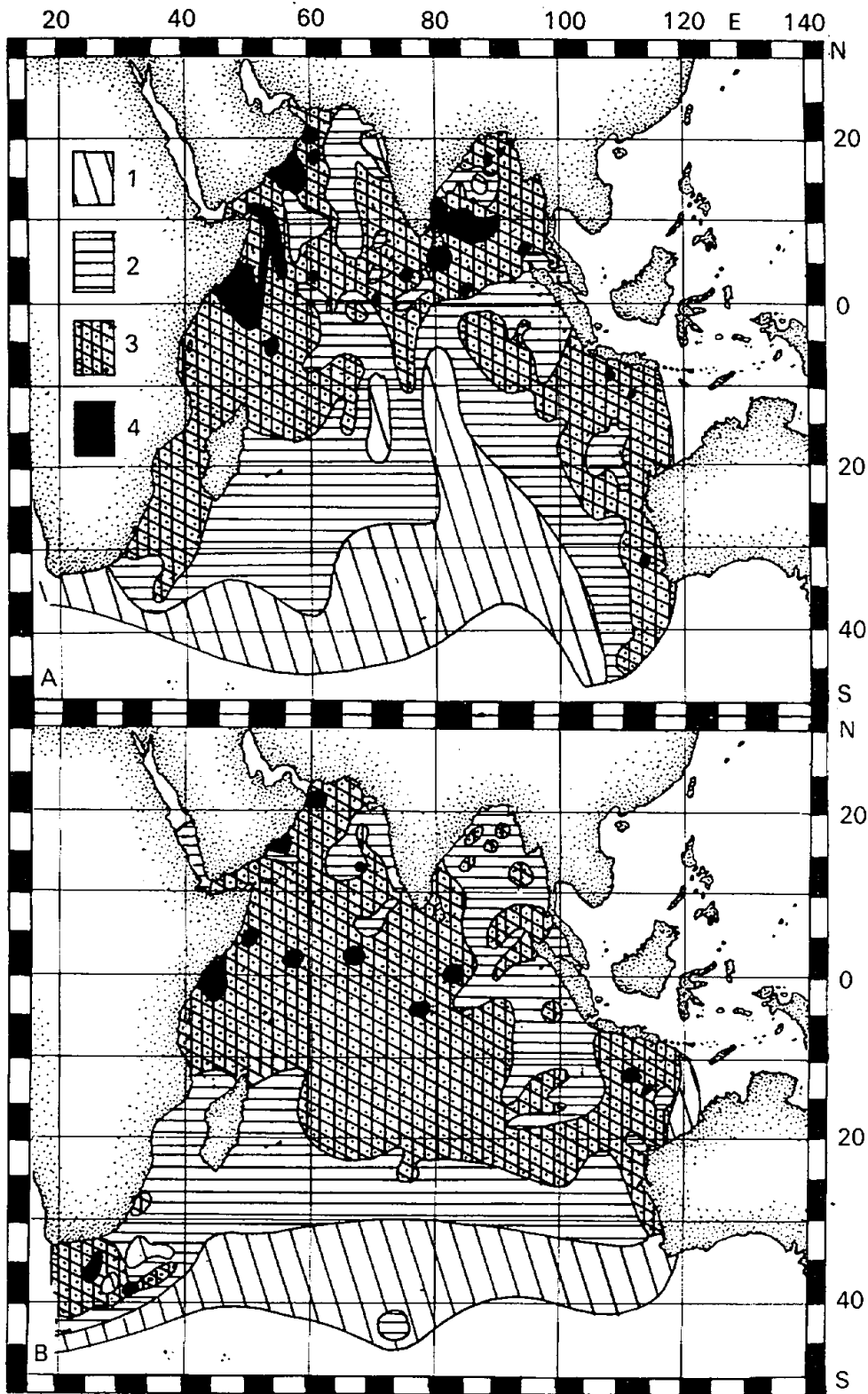


Fig. 11. Euphausiidae distribution, A) during SW. monsoon, B) during NE. monsoon. 1 = 1-50, 2 = 51-250, 3 = 251-1250, 4 = 1251 and more (after IIOE Plankton Atlas 3 (1), 1972).



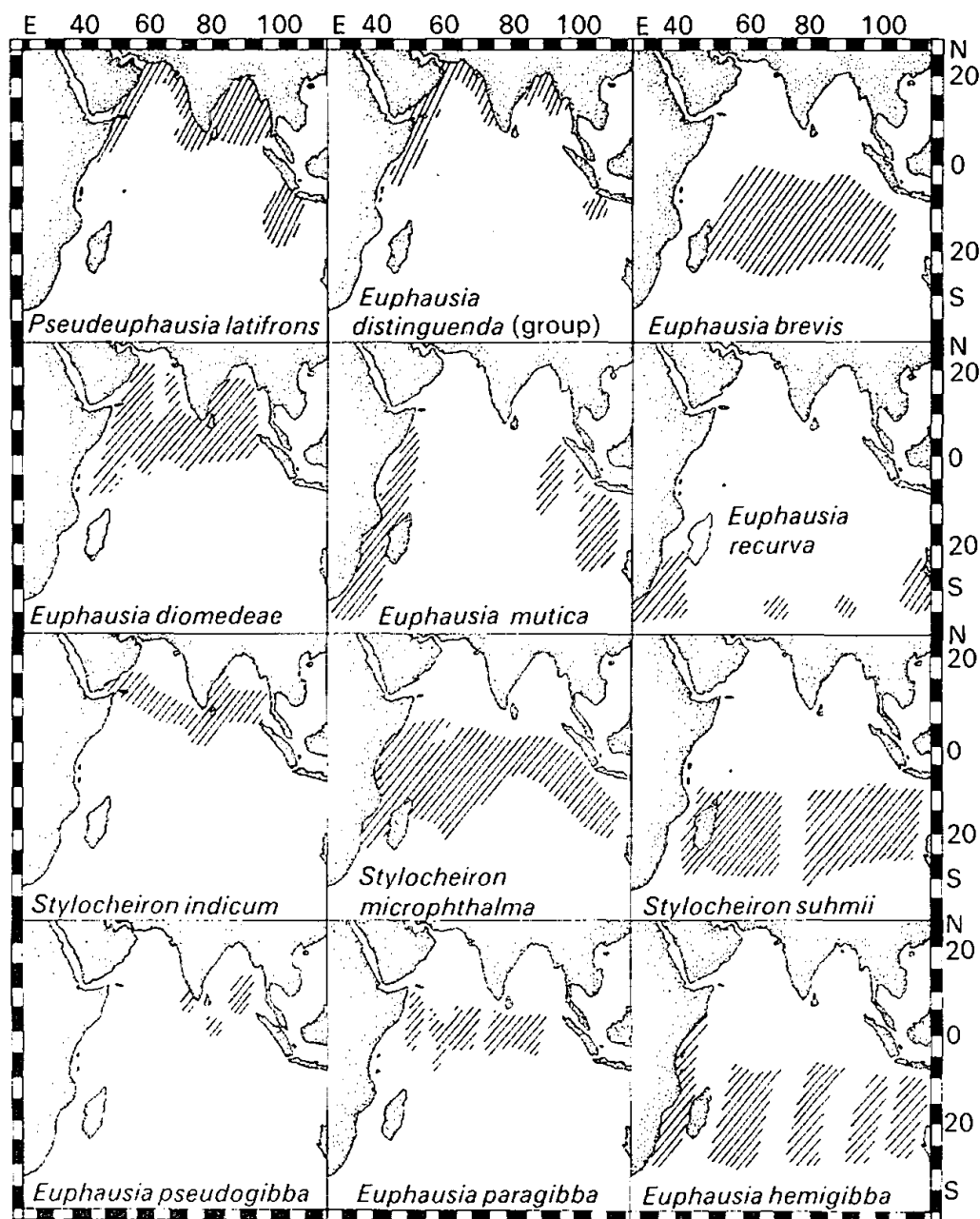


Fig. 12. Distribution of some euphausiid species in the Indian Ocean, hatched areas indicate major concentration of species. (based on Brinton & Gopalakrishnan, 1973).

by the monsoon effect which reverses the Somali Current and brings species both northward and southward of the equator; a similar situation exists off W. Australia and Java. In the west, *Pseudeuphausia latifrons* ranges from the Persian Gulf to Madagascar, *E. sanzoi* occurs from 25°N to 30°S, *E. distinguenda* occurs in the Bay of Bengal down to the waters off S. Java, and *Stylocheiron insulare* occurs in the Andaman Sea and also S. of Java. On the west side a number of subtropical

species are found N. of the equator, along the Somali coast, particularly during the SW. monsoon when the current runs northward (Brinton & Gopalakrishnan, 1973). Species with this pattern are *Euphausia mutica*, *E. brevis*, *Nematoscelis microps*, *N. fenella*, *Stylocheiron suhmii*, *E. hemigibba*, *Thysanopoda subaequalis* and *E. similis*; they do not become abundant in the Somali region and do not replace the Somali Current community which is characterised by *E. distinguenda*, *F. diomedae*, *E. tenera*, *Nematoscelis gracilis*, *Stylocheiron affinis*, *S. carinatum* and *Thysanopoda tricuspidata*.

In the Agulhas Current region off S. Africa we find the southward transport of tropical species, e.g. *E. diomedae* (to 31°S), *N. gracilis* (to 27°S), *S. microphthalmus* (to 33°S) and *E. paragibba* (to 29°S) and subtropical species, e.g. *E. brevis* (to 38°S), *N. microps* (to 38°S), *N. tenella* (to 32°S), *E. tenera* (to 31°S) and *Thysanopoda tricuspidata* (to 31°S).

### Mysidacea

The Indian Ocean comprises 36 mysid species (Pillai, 1973), the most abundant ones are: *Pseudanchialina pusilla*, *P. inermis*, *Siriella thompsoni*, *S. gracilis*, *Hemisiriella parva*, *H. pulchra*. All these species have a wide distribution in the tropical and subtropical areas of the Indo-Pacific. Next to these come species like *Anchialina typica*, found in all the oceans. *Doxomysis quadrispinosa* and *Siriella gracilis* are absent from the Atlantic Ocean. These two species cannot tolerate cold water so that they are unable to round the Cape of Good Hope into the Atlantic. Of the other species of *Siriella*, *S. jonesi* is confined to the Arabian Sea, *S. dubia* is mostly a shallow water form recorded from the N. Indian and W. Pacific Oceans, but absent from the Atlantic, and *S. aequiremis* and *S. thompsoni* have a very wide distribution in all the oceans.

Restricted in distribution are *Lophogaster affinis*, confined to the Red Sea, and *Paralophogaster indicus*, collected from the Red Sea, Middle Arabian Sea and off Ceylon. All six species of *Paralophogaster*, except *P. glaba*, are collected from the Red Sea or the adjacent part of the Arabian Sea. *Leptomysis capensis* is restricted to the S. African waters. *Afromysis dentisinus* appears to be confined to the coastal waters of the Arabian Sea. Most of the other species belonging to the genera *Pseudanchialina* and *Euchaetomera* appear to have very wide distributions in all the oceans.

### Sergestidae

Omori (1977), studying the zoogeography of the genera *Lucifer* and *Acetes* concluded to three overall zoogeographical phenomena found in warm water epipelagic plankton.

- 1) a) Tropical species found roughly between 30°N and 30°S tend to show restricted distribution due to continental and hydrological barriers. These species are restricted to Atlantic, Indo-W. Pacific and Tropical E. Pacific Waters.
- b) Tropical—warm/temperate water species living between 40°N and 40°S tend to be circumglobal in distribution.
- 2) There are more warm water neritic species in the Indo-W. Pacific than in other seas and their number is maximal in the Malayan Archipelago—S. China Sea region.

3) The present-day distribution and dispersal is mostly attributed to the Late Tertiary changes, namely land formation between Asia and Africa and between N. and S. America and climate changes.

### Chaetognatha

The chaetognath fauna is rich in the W. Arabian Sea, along N.E. Africa and S. Arabia, in the Bay of Bengal and S. of Sumatra and Java. Population maxima are found off the Somali and Arabian coasts, which agrees with the findings for the Copepoda. A general decrease in population density is observed in southern latitudes. During the SW. monsoon the high density ranges of chaetognaths are confined to coastal areas off Somalia, Arabia, W. India and to the eastern part of the Bay of Bengal and Java Sea. During the NE. monsoon there is an apparent shift westward in the abundance, presumably due to prevailing westward current. Ecologically, Chaetognatha are more at the end of the food chain, which starts in the upwelling, and as a consequence centres of high density of Chaetognatha are removed from these areas of upwelling. Late secondary and tertiary production are displaced from the centre of upwelling over a distance dependent on the speed of the current and the generation time of the species concerned. Alvarino (1964b) described two well-defined zoogeographical boundaries between 8°S and 42°S in the Indian Ocean: one between 5°S and 15°S and one in the area of the Subtropical Convergence. Between them, three main regions are distinguished; the equatorial, central and the subantarctic regions.

*Sagitta enflata* is the commonest species in offshore areas, *S. bombayensis* is considered endemic to inshore areas along the Indian coast (Tokioka, 1962). While *S. hexaptera*, *S. lyra*, *S. gazellae* and *S. serratodentata* are distributed widely and far into the S. Indian Ocean, *S. maxima*, *S. planctonis*, *S. macrocephala* and the three species of *Eukrohnia* are chiefly confined to the S.W. Indian Ocean. The southern form of *S. planctonis* extends into the Pacific by the S. Australian route. *Eukrohnia bathypelagica*, previously recorded at great depths in the Pacific, was once found in the N.W. Indian Ocean at 2179 m.

The hydrochemical front at 10°S and the Subtropical Convergence near 40°S appear to divide the chaetognath fauna into three zoogeographical provinces.

The typically Indo-Pacific species-*Krohnitta pacifica*, *Sagitta bedoti*, *S. neglecta*, *S. pulchra* and *S. robusta* are mainly confined to the N. Indian Ocean, N. of 10°S.

From 10°S to roughly 40°S is the Subtropical Gyre, dominated by the cosmopolitan species of the Pacific, Atlantic and Indian Oceans and by widely distributed Indo-Pacific species like *S. pacifica*, *S. regularis* and *S. ferox*. The species typical of Atlantic and Subantarctic Waters are restricted to the area S. of the Subtropical Convergence. *S. decipiens* is known to be abundant in deeper waters but its distribution is continuous throughout the Indo-Malayan waters. *Eukrohnia fowleri* dominates the bathyplanktonic zone in the N. and is replaced by *E. hamata* in the Subtropical Waters (Nair, 1978). The epiplanktonic *Krohnitta subtilis*, *S. hexaptera* and *S. minima* are rare in the N. Indian Ocean and common in the south. Species typical of the S. Indian Ocean, namely *S. serratodentata* and *S. tasmanica* are recorded up to 15°S.

The SW. monsoon appears along the W. coast in early June and gradually moves northward; on the E. coast its effect is first felt in the Waltair area and subsequently further south. *S. enflata* develops peak abundance along the W. coast in July -

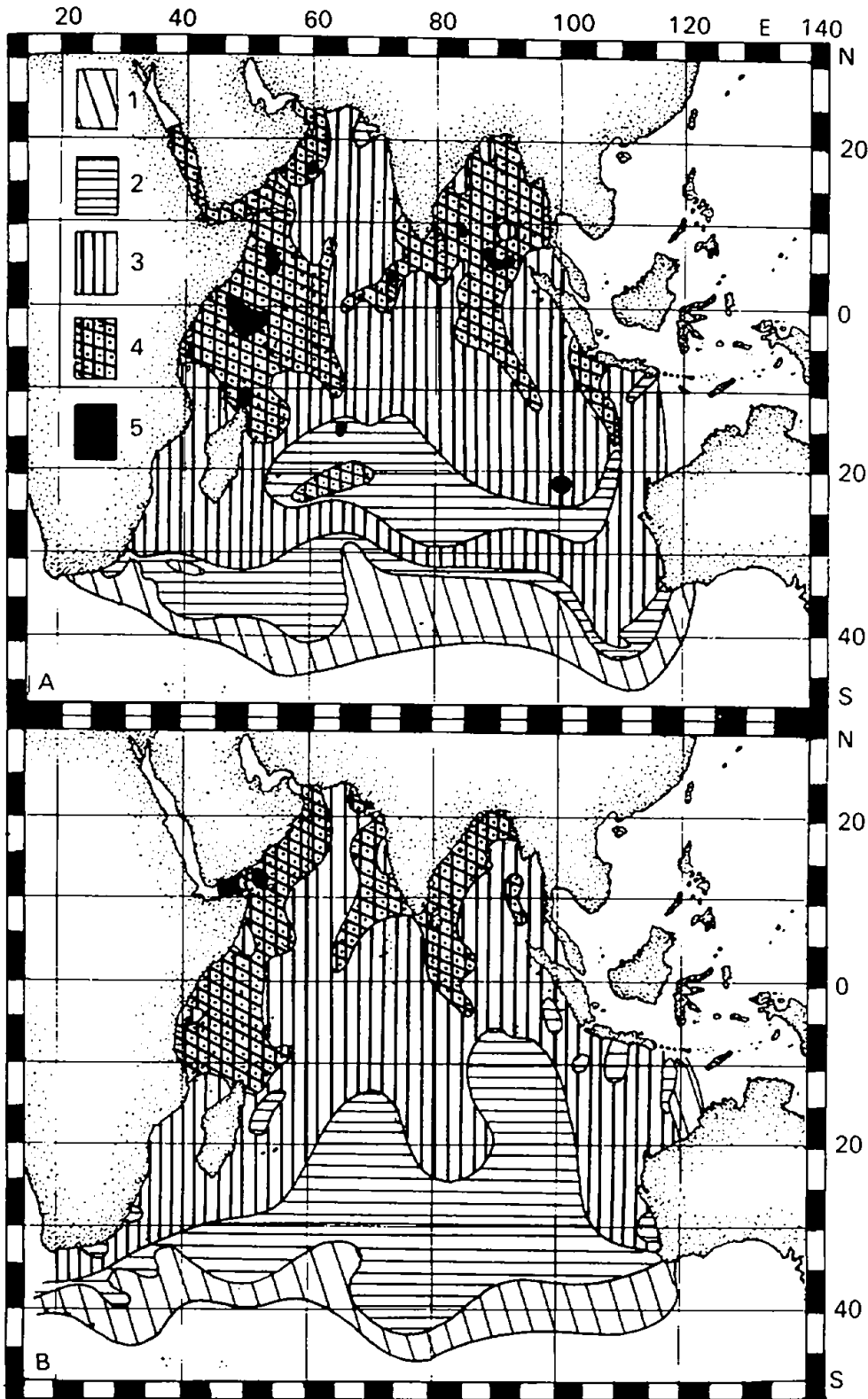


Fig. 13. Chaetognatha distribution, A) during SW. monsoon, B) during NE. monsoon. 1 = 1-99, 2 = 100-399, 3 = 400-1599, 4 = 1600-6399, 5 = 6400 and more (after IIOE Plankton Atlas 4 (2), 1973).

September at Trivandrum, during October and November at Calicut and near Bombay during November and December; near the E. coast at Waltair in July, at Madras in September and it becomes common in the waters of the Gulf of Mannar in November and December (Rao, 1958). Phytoplankton shows a similar pattern in relation to the two coasts and the monsoon.

*Sagitta bedoti* is considered an indicator of inshore water and *S. neglecta* and *S. pacifica* of offshore waters. The latter is an indicator of oceanic waters brought to the coast under the influence of prevailing currents. *Pterosagitta draco* is an indicator of upwelling during February - April, particularly off the Waltair coast. The S.E. Asia-Indonesia region includes the highest number of tropical-equatorial Chaetognatha of which eight species reach the E. Pacific, while ten or more are endemic to the Indo-Malayan region. Five species, viz. *Sagitta bruuni* (neritic, Gulf of Thailand), *S. johorensis* (S. China Sea, Malay regions), *S. nagae*, *S. oecania* and *S. tokiokai* appear to be restricted to the S.E. Asian region.

The Arabian Sea comprises 19 Chaetognatha species, all belonging to the Indo-Pacific fauna. Of these, *S. bombayensis* is the only species exclusive to this area

Table IV. Zoogeography of Chaetognatha

epiplanktonic	Atlantic, Indian and Pacific Oceans	<i>Krohnitta subtilis</i> (15°N-30°S); <i>Pterosagitta draco</i> (20°N-30°S); <i>Sagitta bipunctata</i> (20°N-30°S); <i>S. enflata</i> (25°N-40°S); <i>S. hexaptera</i> (20°N-43°S); <i>S. minima</i> (0°-40°S)
	Indian and Pacific Oceans	<i>K. pacifica</i> (20°N-10°S); <i>S. bedoti</i> (20°N-10°S); <i>S. ferox</i> (10°N-10°S); <i>S. neglecta</i> (20°N-10°S); <i>S. pacifica</i> (20°N-30°S); <i>S. pulchra</i> (20°N-10°S); <i>S. regularis</i> (20°N-30°S); <i>S. robusta</i> (20°N-10°S)
	endemic to the Indian neritic waters	<i>S. bombayensis</i>
	typically cold water species	<i>S. tasmanica</i> (35°S-45°S)
	typically Atlantic species	<i>S. serratodentata</i> (35°S-45°S)
mesoplanktonic	Atlantic, Indian and Pacific Oceans	<i>S. decipiens</i> <i>S. lyra</i> <i>S. zetesicus</i>
bathyp planktonic	cosmopolitan	<i>Eukrohnia fowleri</i>

and the Bay of Bengal. Of the 15 epiplanktonic species, seven, viz. *S. bedoti*, *S. ferox*, *S. neglecta*, *S. pacifica*, *S. pulchra*, *S. regularis* and *S. robusta* are endemic to the Indo-Pacific region.

*S. gazellae* is a circum-antarctic and subantarctic species, the northernmost record in the Indian Ocean is at 40°30'S-90°E (David, 1956), and for young specimens at 37°49.6'S-85°21.7'E (Alvariño, 1964b). These records are an indication of northward extension of Subantarctic Waters in the Indian Ocean. *Sagitta tasmanica* populates the Atlantic and southernmost parts of the Indian Ocean, the Subtropical Convergence is a barrier for its northward dispersal in the Indian Ocean. *S. lyra*, a typically Atlantic taxon, is found in small numbers in the W-Central Indian Ocean, indicating the penetration of Atlantic Intermediate Water.

On the basis of spatial and bathymetric distribution the following groups (with latitudinal dispersal) were recognised in the Indian Ocean by Nair (1977).

The species composition indicates the dominance of Tropical Indo-Pacific elements in the fauna. The typically Indo-Pacific species seem to be carried into the offshore regions of the Agulhas Bank. The W. Wind Drift sustains a free exchange of cold water species between the Atlantic and Indian Oceans. In the 'Sagitta serratodentata group' *S. tasmanica* occurs between 35°S and 65°S in all the oceans; *S. pacifica*, totally absent from the Atlantic Ocean, is present in the Indian and Pacific Oceans between 40°N and 40°S (Pierrot-Bults, 1974).

Stratification of Chaetognatha in the Indian Ocean showed that maximum density was confined to the upper 125 m (Nair, 1978). Species diversity decreased from the epiplanktonic towards the bathyplanktonic domain. Maximum species diversity observed at 250-125 m is attributed to the mixing of the meso- and epiplanktonic species at this level. Most of the mesoplanktonic and bathyplanktonic species occupy their respective domain in the N. and Central Indian Ocean but they reach more shallow depths towards the Subtropical Convergence. Latitudinal quantitative and qualitative variations indicated that in the Indian Ocean N. of the equator, maximum species diversity is found.

*Krohnitta subtilis*, *Sagitta hexaptera* and *S. minima* are rare in the epiplankton of the N. Indian Ocean but they become common towards the south.

#### Planktonic Mollusca

The Indian Ocean distribution of Thecosomata resembles that of Copepoda and Chaetognatha. Rich patches are found mostly in the W. Indian Ocean and locally during the SW. monsoon, in the Bay of Bengal. Their general abundance increases during the NE. monsoon (Fig. 14a, b). Sakthivel (1972) reported on the Indian Ocean distribution of the Euthecosomata. The epiplanktonic zoogeography of this group reveals 10 patterns mainly related to temperature zonations:

- 1 Cosmopolitan distribution (tropical, subtropical, subantarctic) (25°N-65°S): *Limacina inflata*, *Clio pyramidata*. *C.p. convexa* is more common in the north while *C.p. lanceolata* is more abundant in the equatorial zone, *C.p. antarctica* and *C. sulcata* in the Subantarctic and Antarctic.
- 2 Tropical and Subtropical, I (incl. Red Sea, Persian Gulf, Gulf of Oman) (25°N-40°S): *Limacina trochiformis*, *Creseis virgula*, *C. acicula*. They reach peak abundance in the vicinity of the coasts which points to a neritic distribution.
- 3 Tropical and Subtropical, II (excl. Red Sea, Persian Gulf, Gulf of Oman)

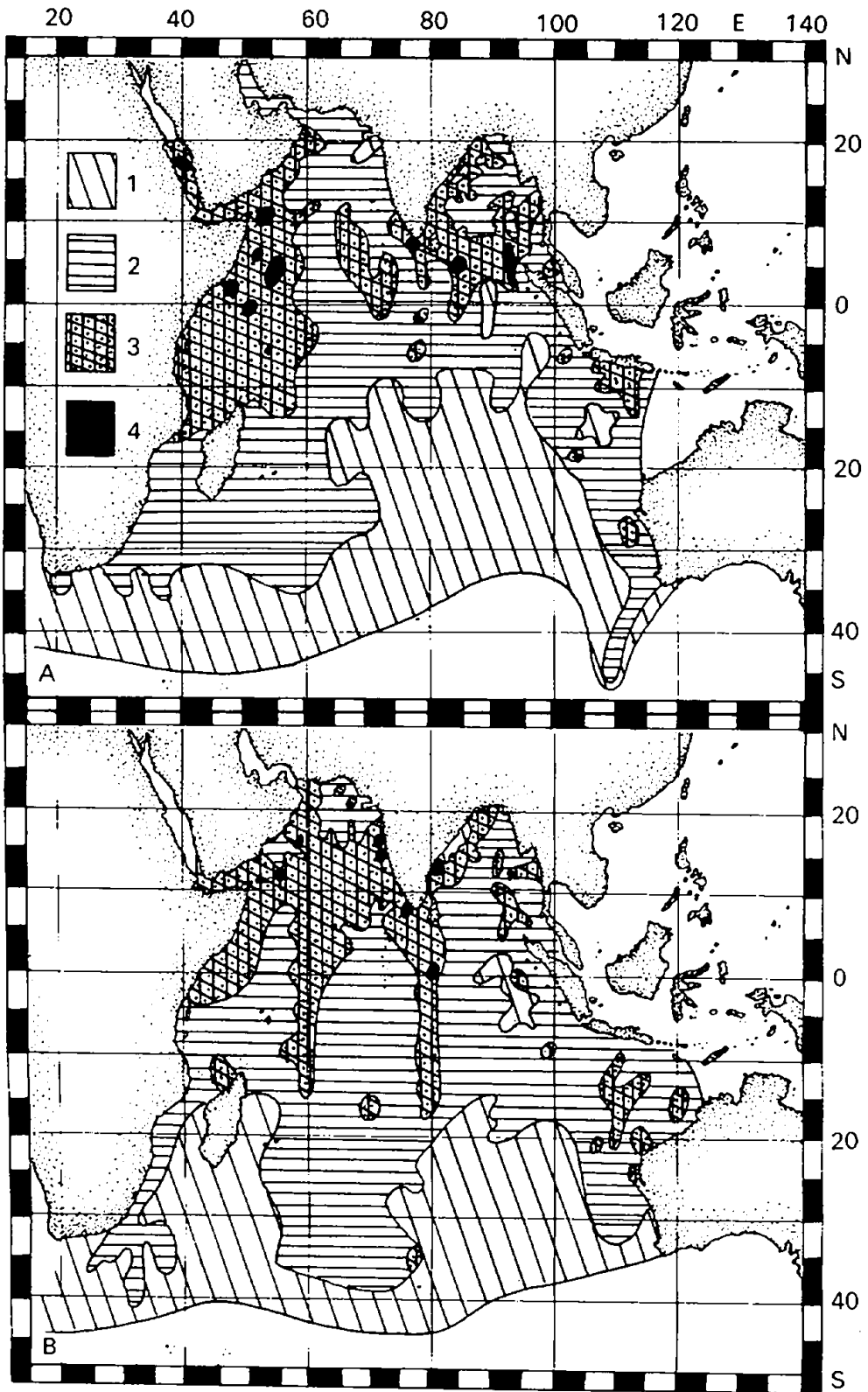


Fig. 14. Thecosomata distribution (Limacinidae, Peraclididae, Cymbuliidae), A) SW. monsoon, B) NE. monsoon. 1 = 1-9, 2 = 10-99, 3 = 100-999, 4 = 1000 and more (after IIOE Plankton Atlas 3 (2), 1971).

(25°N-40°S): *Limacina bulimoides*, avoiding high salinity, demarcating a well-defined N.E. area in the Arabian Sea, inclusive of the Persian Gulf and the N.W. coast of India, by way of its northern boundary. Species composition of this region is slightly different from the rest of the Arabian Sea, as only a fauna tolerating high salinity (> 36‰) and an oxygen minimum in the subsurface layers (upto 0.2 ml/l) can survive here.

4 Tropical, I (Bay of Bengal, E. Arabian Sea, Equatorial, Java Sea) (20°N-20°S): *Cavolinia uncinata* demarcates the northern Bay of Bengal where those species not tolerating low salinity (< 34‰) and low oxygen content in the sub-surface layers (upto 0.2 ml/l) are absent.

5 Tropical, II (Equatorial, Java Sea, Agulhas Current) (10°N-30°S): *Cavolinia globulosa*, an equatorial Indo-Pacific species absent in the Atlantic, transported upto 30°S by the Agulhas Current. Sub-surface oxygen minima in combination with high salinity of the Arabian Sea and low salinity in the Bay of Bengal act as a well-defined northern boundary (10°N) for equatorial species like *Styliola subula*, *Cuvierina columnella* and *Cavolinia globulosa*. There is some indication that these species are often transported to the north by the Somali Current.

6 Subtropical and Equatorial (10°N-40°S): *Styliola subula*, a subtropical species absent N. of 10°N and continuous in the equatorial and subtropical parts of the Indian Ocean. The Subtropical Convergence (40°S) forms the southern boundary for the tropical and subtropical species and the northern boundary for the antarctic species.

7 Subtropical and Transitional (10°S-50°S): *Limacina lesueuri*. There is a weak boundary near 10°S due to the flow of low salinity water from the E. Indies towards the west; it separates the equatorial fauna from the subtropical one and forms the northern boundary of *Limacina lesueuri* and the southern limit of *Cavolinia uncinata*.

8 Transitional (40°S-50°S): *Limacina helicina rangi*.

9 Subantarctic and Antarctic (50°S-70°S): *Limacina retroversa australis*, *Clio sulcata*.

10 Antarctic (60°S-70°S): *Limacina helicina antarctica*.

The Heteropoda, Atlantidae excluded, comprise 14 species in the Indian Ocean. *Carinaria lamarcki lamarcki*, *C. l. challengerii*, *C. cristata* and *C. galea* are not frequently found. *C. cithara* is more common in the Indian Ocean, especially off the Arabian coast, the other species are neither found in the Arabian Sea nor in the Bay of Bengal.

*Pterosoma planum*, widely distributed in the equatorial belt and frequently found in the Bay of Bengal is absent in the Arabian Sea. *Cardiapoda placenta* is very common all over the Indian Ocean while *C. richardi* is only found in the southern part. *C. placenta* is very abundant in the Bay of Bengal and in the equatorial belt, it has only a scattered distribution in the Arabian Sea.

Of the four species of *Pterotrachea*, *P. coronata* has a wide distribution in the Indian Ocean (Aravindakshan, 1977). It is absent, however, from the E. Arabian Sea (except for one record at the southernmost part off the W. coast of India), in the northern and northwestern parts of the Bay of Bengal and in the central zone of the S. Indian Ocean. It is a tolerant species occurring in Tropical and Subtropical Waters. *P. hippocampus* is predominantly distributed in the equatorial region in the Indian Ocean, and in the seas N.W. of Australia; it is abundant in the E. Andaman Sea and relatively common off E. Ceylon. It is completely



absent in the N.E. part of the Arabian Sea. *P. scutata*, absent in the Arabian Sea and the Bay of Bengal, is only represented by two records. *P. minuta*, absent from the Arabian Sea, is mainly distributed along the Equatorial Region, with only one record from the Bay of Bengal.

*Firoloides desmaresti*, with highest concentrations in the Bay of Bengal, is the most common species in the Indian Ocean; in numbers it exceeds the total of all other species together.

### Appendicularia

According to Fenaux (1973) the most abundant appendicularian species are, in decreasing order: *Oikopleura longicauda*, *Megalocercus huxleyi*, *O. rufescens*, *O. fusiformis*, *O. cophocerca*, *Fritellaria borealis* and *F. pellucida*. *M. huxleyi* is only abundant off the Somali coast. As in other groups there is a clear evidence for the decrease in number of specimens from north to south.

Fenaux (1973) found 23 species in the Arabian Sea, 19 species in the Gulf of Aden and the Oman Sea; the Gulf of Oman had 12 species and the Persian Gulf only 6 species. In the epipelagic fauna of the Bay of Bengal indigenous species are not very common and most of this fauna is transported from the equatorial areas by the prevailing currents (Fenaux, 1969). One or two species form the bulk: *Oikopleura longicauda* represents 50% of the total number collected, followed by *O. rufescens* 14% and *Megalocercus huxleyi* 8%; the other taxa are not abundant. Starting with 21 species in the south, there were only two species in the N. of the Bay of Bengal. This is presumably due to low salinity prevailing in the area during most of the year (Fenaux, 1973).

### Red Sea

The Red Sea occupies the deep rift between Arabia and Africa, a long and narrow basin with a sill (depth 100 m) connecting it with the Arabian Sea. Because of the general aridity prevailing in the area, both salinity and temperature are high, in fact they are the highest for the Indian Ocean and adjacent areas. Surface salinity ranges between 37-41‰ and temperatures from 17.9-32°C. The deeper waters below 200 m are nearly homothermal (21.7°C) and homohaline (40.5-40.6‰). As a result, the Red Sea developed an endemic fauna as is evidenced by the distribution of flagellates, tintinnids, copepods and chaetognaths.

Current direction in the Red Sea is determined by prevailing monsoons, the SW. monsoon generates a flow in clockwise direction along the Saudi Arabian coast towards the W. coast of India. During this period, from May to October, there is a net flow of surface waters into the Gulf of Aden. During the NE. monsoon, an anticyclonic circulation in the Arabian Sea develops and the surface current flows from the Gulf of Aden into the Red Sea. During this October - March period many zooplankton species enter the southern Red Sea. A similar situation occurs in the Persian Gulf. When compared to the adjacent areas, these two water bodies show lower values for both zooplankton and phytoplankton.

Kabanova (1964) estimates primary productivity values (expressed as mg/m<sup>2</sup>/day) for the Gulf of Aden and Saudi-Arabian region to be 88-270, for the eastern part of the Indian Ocean (Andaman Sea) 114-176, and for the open parts of the Indian Ocean 10-20.

Table V. Endemic Red Sea species

Cubomedusae	<i>Charybdea alata</i>
Rhizostomiae	<i>Mastigins gracilis</i>
Coronatae	<i>Paleophyra antiqua</i>
Leptomedusae	<i>Gastroblasta timida</i>
Nacromedusae	<i>Pegantha aureola</i>
Anthomedusae	<i>Dicodonium cornutum</i>
Dinoflagellata	<i>Dinophysis caudata</i> f. <i>marisrubri</i> <i>D. miles</i> f. <i>marisrubri</i> <i>D. miles</i> f. <i>triposoides</i> <i>Gymnodinium galaeformis</i> ? <i>Ceratium egyptiacum</i>
Ostracoda	<i>Cyprindina dorsocurvata</i> <i>Palicmedes polae</i> <i>Asterope mariae</i> <i>A. arabica</i>

Zooplankton has unequal distribution in the Red Sea. South of 20°N it is more abundant than in the northern part. Delalo (1966b) found a biomass in the upper meters of up to 47.7 mg/m<sup>3</sup> in the northern part, and of maximal 571 mg/m<sup>3</sup> in the Gulf of Aden. The N.E. Mediterranean was very poor with 24 mg/m<sup>3</sup> in the same layer.

The concentration of Peridinales decreases from the Gulf of Aden through the southern part of the Red Sea to its northern part, with resp. the values 450-950, 200-350 and 130 cells/m<sup>3</sup> (Sukhonova, 1969). The same trend is evident for zooplankton with resp. 571, 81 and 48 mg/m<sup>3</sup> for the same areas (Delalo, 1966b). The diversity of zooplankton in the Red Sea and Persian Gulf follows the same pattern. Of the 270 calanoid species known for the Indian Ocean, 158 species are recorded from the Red Sea and there is evidence that still less species exist in the Gulf of Eilat and at Suez (Halim, 1969).

Of the 22 euphausiid species described from the Indian Ocean (36 according to Brinton & Gopalakrishnan, 1973), only ten epiplanktonic forms are known from the Red Sea, mostly immigrants from the Gulf of Aden. They could easily pass the sill at Bab-el-Mandab (Ponomareva, 1968). According to Weigman (1970), the Arabian Sea proper has 24 species, the Gulf of Aden ten, the Red Sea six, the Gulf of Oman five and the Persian Gulf one species. A few endemic species from the Red Sea, such as *Euphausia sanzoi* and *Pseudeuphausia colosi*, are known. Two or three pteropod species occur in the Persian Gulf, while a large number of species occur in the Gulfs of Aden and Oman (Frontier, 1963a, 1963b). The decreasing trend is also noticed in the distribution of Chaetognatha. According to Furnestin, the Red Sea species are predominantly Indo-Pacific in character (after Nair & Rao, 1973). Fourteen appendicularian species occur in the Red Sea and only three in the Gulf of Eilat (Fenaux, 1966a).

Siphonophora are not well represented in the Red Sea: 27 Indian Ocean species are absent from the Red Sea.

The Scyphomedusae fauna is purely Indo-Pacific in its affinities. *Periphylla hyacinthina* is common in the Gulf of Aden, but has not yet been recorded in the Red Sea. *Cassiopea andromeda* is perhaps the most common species present all over the Red Sea basin, *Pelagia noctiluca* and *Aurelia aurita* are common to the Red Sea and Mediterranean.

Only two Hydromedusae, *Dicodinium cornutum* and *Aequorea pensilis* are recorded from the Red Sea, the other eight Indian Ocean species are absent N. of Bab-el-Mandab (Kramp, 1968).

The ostracod population is of pronouncedly Indo-Pacific origin, but *Cypridina dorsocurvata*, *Philomedes polae*, *Asterope arabica* and *A. mariae* seem to be restricted to the Red Sea. The Gulf of Suez has more ostracod species than the main Red Sea. Two unidentified species of *Philomedes* appear to be restricted to this gulf. Among the Red Sea Cladocera, both *Evadne tergestina* and *Penilia avirostris* are widely distributed inter-oceanic species. *Conchoecia magna*, *Microconchoecia clausii* and *Paraconchoecia oblonga* and several others occurring in the Gulf of Aden are, however, absent from the Red Sea.

Copepods are poorer than in the Indian Ocean. According to Sewell (1948) *Acartia tonsae*, *Calanopia media*, *Candacia samassae*, *Scolecithrix chelipes* and *Tortanus recticauda* are endemic to the Red Sea. There are seven copepods, *Fucalanus attenuatus*, *Scolecithrix auctopecten*, *Acartia dubia*, *A. longiremis*, *Canuella perplexa*, *Metridia lucens* and *Pseudocalanus elongatus*, common to the Red Sea and the Mediterranean but they have not yet been recorded from the Indian Ocean. It may be stated that all the Red Sea copepods are Indo-Pacific fauna elements. 33% of them are not known from the Mediterranean. 78 species are also common in the E. Pacific, 23 in the W. Pacific, but six have not even been recorded E. of the Indian Ocean (Sewell, 1948). The highest number of species is recorded in the S. Red Sea in winter, when, due to the NE. monsoon, a strong flow of surface water from the Arabian Sea and Gulf of Aden crosses the sill at Bab-el-Mandab. The number of species in the Red Sea decreases in summer when the SW. monsoon and NW. winds cause surface water to flow out of the Red Sea into the Gulf of Aden.

Absence in the Red Sea of so many species of the Indo-Pacific fauna may also be due to the fact that conditions in the Red Sea are not favourable. This is dramatically shown in pteropods, transported across the sill at Bab-el-Mandab. The surface currents carry the pteropods across the sill, where they die in great numbers, as is evident from the increase in their shell-deposits across the sill. The Gulf of Suez has only 50% of all the Red Sea species.

Concluding, one may say that zooplankton in the Red Sea and the adjacent gulfs is predominantly of Indo-Pacific origin and there is a trend of decreasing species diversity from the Arabian Sea towards the interior of the Red Sea and the Persian Gulf. The shallow sill at Bab-el-Mandab preventing many bathypelagic and mesopelagic forms from migrating into the Red Sea, and the high temperature and salinities can be held responsible for the low diversity. However, besides Indo-Pacific species the Red Sea also shows endemic forms.

The chances of the Red Sea species to pass into the Mediterranean via the Suez Canal are not great, due to the salinity ranges from 48.5 to 52.2‰ in the Bitter Lakes. Planktonic Copepoda in the Canal show a steady fall in diversity towards Port Said; the number of species found in the Suez Bay, at Port Taufiq, in the Bitter Lakes, in Lake Tumasah and near Kantara are resp. 18, 19, 15, 13 and

4. But further north, there is a slight increase in diversity due to the entry of Mediterranean forms like *Paracalanus parvus* f. *borealis*, *Corycoeus brehmi* and *Centropages ponticus*.

### Agulhas Current region

The Agulhas Current starts N. of Madagascar, off Mozambique, where the S. Equatorial Current is deflected south. As the Agulhas Current moves south it flows very close to the S. African coast from Zululand to Port Elisabeth. According to Derbishire (1964) this system consists of two parts: the cool (17-20°C) Agulhas Water close to the coast and the warm (> 20°C) offshore section. During the NE. monsoon when the Somali Current flows southward, plankton organisms are able to float in a continuous current from the northern latitudes of the Arabian Sea right down to the tip of Africa. Many examples of N-S. extension of species belonging to various groups support this, as shown by the patterns of distribution already described.

In the Agulhas Current, *Sagitta hexaptera*, *S. bipunctata*, *S. neglecta* and *Krohnitta pacifica* are found besides the Indo-Pacific group of *S. enflata*, *S. serratodentata*, *Pterosagitta draco*, *S. regularis*, *S. robusta*, *S. ferox* and *S. bedoti*. The presence of the latter group of species in the Agulhas Current clearly proves their transportation southward along the western boundary of the Indian Ocean (Stone, 1969). *S. friderici*, abundant in the neritic waters off S. Africa is second in abundance to *S. enflata*. The former species is absent in the Arabian Sea and in the Bay of Bengal (Nair & Rao, 1973), but is quite common in the Atlantic and Pacific Oceans and its extension into the neritic S.W. Indian Ocean is an interesting zoogeographical feature.

The Agulhas Bank off S. Africa is the point where the Agulhas Current ends and the Benguela Current begins. It shows a mixed plankton fauna of both cold water and warm water species (De Decker, 1973). Among Chaetognatha, *S. friderici* was again most abundant in the coastal areas. *S. minima*, a species of mixed water, clearly indicates the arrival of the Agulhas Current. In some years, the presence off the west coast of S. Africa of the Indo-Pacific forms *S. enflata* and *S. regularis* points to the transport of epiplanktonic tropical-equatorial forms round the Cape by the prevailing current.

Similar distributions are seen in some of the euphausiid species. *Euphausia lucens* and *Nyctiphanes capensis* are dominant and the latter is only known from the area off SW. Africa and from the Cape Verde Islands (Meira, 1970).

Temporary visitors at the Bank are the two Indian Ocean forms *E. recurva* and *E. diomedae*, which are introduced by the Agulhas Current. The presence of *E. similis* var. *armata* off the W. coast is very interesting as it is absent from other areas; it is considered a cold water form of the Antarctic Intermediate Water. The Indian Ocean element in the copepod fauna of the Bank, transported by the Agulhas Current are e.g. *Candacia truncata*, *Copilia mirabilis*, *Labidocera acuta*, *Temora turbinata*, *Paracalanus aculeatus*. Species like *Metridia lucens*, *Centropages brachiatus* and *Calocalanus tenuis* are of Atlantic origin. Northward penetration of Subantarctic Waters brings *Calanus tonsus*, *Clausocalanus ingens* and *Euchirella rostrata* to the Bank (De Decker, 1973).

The bathypelagic fauna of the seas around S. Africa and the Agulhas Bank is a mixed fauna composed of Atlantic, Antarctic and Indian Ocean elements

(Grindley & Penrith, 1965). Three watermasses are recognised on either side of S. Africa. On the east side, the Agulhas Current forms the surface waters with temperatures above 17°C, below this water down to 700-1300 m S. Indian Central Water is found (5°C; 34.5-35.5‰ S), and below this the Antarctic Intermediate Water (< 5°C) penetrates. On the west side, the upper layer is formed by the warm waters of the S. Atlantic Gyre below which there is the S. Atlantic Central Water and below this, from about 700 m downwards, the Antarctic Intermediate Water is found. In this environment many species are found common to both the Atlantic and Indian Oceans. However, five species, *Plesiope-neus nitidus*, *Aristeomorpha foliacea*, *Gennades gilchristi*, *Acantephyra haeckelii* and *Plesionika longirostris*, are found only in the Indian Ocean samples, while *Solenocera africanum* is only found in the Atlantic. *Sergestes arcticus* is present on the western side only where there is upwelling, near the Cape. West of the Cape Peninsula, *S. gazellae*, an Antarctic deep water form, occurs (Grindley & Penrith, 1965).

### Conclusions

The zoogeography of zooplankton in the Indian Ocean is a reflection of the bi-hydrographical regimes in the different parts of this area. For this study the Indian Ocean was delimited by the Subtropical Convergence occupying a belt between 35°S and 40°S and by the huge land masses of Africa, Asia and Australia. There are connecting passages with the W. Pacific through various straits in the Indo-Malayan Archipelago and S. of Australia. These connections are responsible for the more or less uniform dispersal of the fauna in the area, resulting in the major zoogeographical warm water realm named the Indo-Pacific region. Ekman (1953) stated that the rich Indo-Malayan fauna, particularly fishes and crabs, is distributed over a large part of the Indian Ocean with a decrease of species to the west. Clarke (1936) reported that the W. and S.W. parts of the Indian Ocean have less crinoid species than the E. side. Most of the south-eastern region off Africa contains a subtropical fauna of independent character, though not well established. The Red Sea and the Persian Gulf and their inlets have exceptionally high salinities and temperatures, and as a result these areas support many endemic species (Ekman, 1953).

Sewell's (1948) conclusions support the above remarks by Ekman. He also found that the number of copepod species decreases from E. to W. and from surface to deep waters.

Division of the Indian Ocean into various zoogeographical areas by different authors is mostly based on ecological factors such as temperature, salinity, depth, etc.

The zoogeographical pattern shown by zooplankton biomass mainly reflects the hydrological regimes in the Indian Ocean. Upwelling and divergence areas are highly fertile and the southern and central parts of the Indian Ocean have very low biomass values (Rao, 1973). The opposing monsoons in the Indian Ocean apparently shift the zooplankton populations by way of the current systems. Such changes are also found in the latitudinal extension of many species, particularly on the E. and W. sides of the Indian Ocean as shown by the distribution of e.g. *Globoquadrina dutertrei* and *Pseudeuphausia latifrons*.

Krey (1973) recognized the following eight plankton regions based on climatological and hydrological parameters:

1) Coastal upwelling areas off S. Arabia, W. Australia and Indonesia; 2) Central Arabian Sea and Bay of Bengal; 3) Somali Current region; 4) Mozambique Current region; 5) Equatorial Current region; 6) Southern Subtropical Gyre; 7) region of the W. Wind Drift; 8) Antarctic Gyre upto the Subantarctic Convergence.

The above subdivisions are not followed by students on zooplankton though many of the species are restricted to these areas.

In studies on the Foraminifera dispersal, temperature and salinity revealed a clear latitudinal zonation of the Indian Ocean (Bé & Tolderlund, 1971).

Vannucci & Navas (1973) have mainly related the distribution of Hydromedusae to the water masses, more or less ignoring geographical boundaries. They have recognized the following five groups:

1) Deep and Intermediate Water Hydromedusae; 2) Indian Ocean Central Water Hydromedusae; 3) Bay of Bengal Hydromedusae; 4) Arabian Sea Hydromedusae; 5) Indian Ocean Equatorial Hydromedusae.

Reports on Copepoda have divided the Indian Ocean into many regions and many species show restricted distribution. Lawson (1977) discussed the following areas:

1) Red Sea and W. Arabian Sea; 2) E. Arabian Sea; 3) E. Bay of Bengal and Indonesian Waters; 4) Arabian Sea and Bay of Bengal; 5) Somali and Arabian coasts; 6) Mozambique coast and Agulhas Current; 7) Equatorial area; 8) Southern Gyre; 9) North of 10°N; 10) between 10°N and 10°S; 11) S. of the equator.

Brinton & Gopalakrishnan (1973) recognized the following boundaries for Euphausiidae in the Indian Ocean:

1) Down to 10°N; 2) the equator; 3) 10°S; 4) 25°S-30°S; 5) 40°S-45°S.

Omori (1977) suggests the following two main areas based on Sergestidae:

1) Between 30°N and 30°S; 2) Between 40°N and 40°S.

Nair (1977) recognizes the following three main divisions based on Chaetognatha:

1) Tropical zone 25°N-10°S; 2) Subtropical zone 10°S-38°S; 3) Transitional zone 38°S-45°S.

Sakthivel (1972) recognized the following 10 patterns of zoogeographical distribution for Euthecosomata:

1) 25°N-65°S; 2) 25°N-45°S (Red Sea and Persian Gulf incl.); 3) 25°N-45°S (Red Sea and Persian Gulf excl.); 4) 20°N-20°S; 5) 10°N-30°S (Agulhas Current incl.); 6) 10°N-40°S; 7) 10°S-50°S; 8) 40°S-50°S; 9) 50°S-70°S; 10) 60°S-70°S.

The Red Sea, the Persian Gulf and the Agulhas Current region are separate areas in the distribution of many groups. The central fact, however, in all studies is, that for the vast Indian Ocean, though subjected to monsoons, to reversal of currents in the north and to mixing of water masses causing homogenisation of the background of millions of organisms inhabiting the vast stretches of the multidimensional saline waters, nevertheless different latitudinal zones and coastal areas with special communities are found.

The various reports cited above support the following zoogeographical division of the Indian Ocean:

1) Red Sea and Persian Gulf; 2) Arabian Sea; 3) Bay of Bengal; 4) Equatorial zone (10°N to 10°S); 5) Southern Gyre (10°S to 35°S); 6) Somali Current region; 7) Agulhas Current Region; 8) the entire Indian Ocean down to Subtropical Convergence; 9) Subtropical Convergence; 10) The Antarctic portion of the

Indian Ocean (excluded from the present discussion).

However, the boundaries between these regions do not form inseparable barriers for a vast majority of zooplankton. Particularly the region between 20°S and 35°S turned out to be an impoverished region for zooplankton. There is a definite decrease in the number and diversity of species from the north to the south in the Indian Ocean.

The area between 20°S and 35°S is also a sterile region for radiolarians in pelagic sediment of the Indian Ocean (Nigrini, 1967). The boundary between the two different populations of the Foraminifera species *Orbulina universa* (Fig. 6) is also found in this area. The steep hydrochemical front at 15°S to 25°S forms, perhaps, an effective boundary preventing the rich waters of the N. Indian Ocean and its richer fauna from penetrating the S. Indian Ocean, thus giving rise to the extensive oligotrophic character of the subtropical anticyclonic gyre.

### **Acknowledgement**

I wish to express my sincere thanks to Dr. S. Z. Qasim, Director, National Institute of Oceanography, Dona Paula, Goa, for his useful suggestions and to my colleague Dr. V. R. Nair for her help in the preparation of the chapter.