

ZOOPLANKTON INVESTIGATION IN INDIAN WATERS AND THE ROLE OF THE INDIAN OCEAN BIOLOGICAL CENTRE

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ABSTRACT

A brief review of the investigations made in the Indian coastal waters since 1930 is given, with special emphasis to the work done at the Indian Ocean Biological Centre. The salient features in the distribution of different zooplankton taxa in the Indian Ocean are presented on the basis of the study so far made on the International Indian Ocean Expedition Collections. In the distribution of zooplankton the occurrence of high density patches of the different groups at considerable distances from the coast has been noticed. The coastal waters off Somalia, Arabia, the southwest coast of India, the Orissa coast and some areas in the equator and in the Java Sea are confirmed to have rich zooplankton population. Bay of Bengal has emerged as an important area for fish eggs and larvae and also for juvenile cephalopods. The Somali-Saudi Arabian offshore upwelling areas, the Malabar upwelling system and the upwelling areas off the Orissa coast are likely to be the main centres for spawning and growth of pelagic fisheries in the north Indian Ocean.

INTRODUCTION

The study of zooplankton forms an important aspect of biological oceanography. This is because of the role played by zooplankton in the food web of the sea, where it constitutes an intermediate level between the primary producers such as phytoplankton and the larger fish and whales. Besides, the myriads of organisms constituting zooplankton, by themselves form a complicated ecological system worthy of special attention.

Contributions from Indian waters on the zooplankton are considerable and a bibliography of plankton of the Indian Ocean prepared by Prasad (1964) cites 881 publications. These include studies on phytoplankton also. Subsequent to this, a large number of papers have appeared, and some of these are referred to elsewhere in this paper. In the following account a brief review of work done (since 1930) at the different Indian coastal areas is given together with a discussion on the zooplankton ecology of the Indian Ocean and the part played by the Indian Ocean Biological Centre since its establishment in 1962 at Cochin.

Madras area

The credit for pioneering researches in the field of marine biology in general and zooplankton in particular goes to the Madras University and the Madras State Department of Fisheries with its substations at Ennore, Krusadai, Tuticorin and West Hill (Calicut). Menon (1931) gave a preliminary account of the Madras plankton followed by Aiyar *et al* (1936) who described the

plankton records for the year 1929 and 1930 off Madras. The Scyphomedusae and Hydromedusae of the Madras and neighbouring coast were described by Menon (1930, 1932). Panikkar (1936) gave a general account of the Anthozoan larvae and some of their developmental stages. John (1933, 1937) described the *Sagitta* of the Madras coast and seasonal variation in the distribution. Menon (1933, 1937, 1940) gave accounts of decapod larvae from the Madras plankton. Alikunhi (1949, 1951, 1967) gave accounts of the metamorphosis of phyllosoma and stomatopod larvae from the Madras plankton. Krishnaswamy (1953, 1957) described the copepods. The Amphipods of the Madras coast were described by Nayar (1959). Nair (1946-52) studied the fish eggs and larvae of the Madras plankton. Nair and Aiyar (1943) also studied the Thaliacea of the Madras plankton. It would appear from this that we have a fairly good account of the important components of zooplankton from the Madras area.

Andhra area

To the north of Madras, the Andhra University at Waltair started its oceanographic activities in 1952. Ganapati and his colleagues made significant contribution to our knowledge of the zooplankton from this area in a series of contributions. Ganapati and Rao (1958) made a quantitative study of plankton off Lawson's Bay. La Fond

summarised oceanographic work done at the Andhra University in 1957. Ganapati and Nagabhushanam (1958) described the seasonal distribution of the Hydromedusae of the Visakhapatnam coast. The distribution of physalia in Indian waters was given by Ganapati and Rao (1962). Ganapati and Rao (1954) started studies on the various aspects of the distribution of Chaetognaths from the Indian waters (see also Rao, 1958 a & b, 1962). Ganapati and Radhakrishna (1958) gave an account of the Polychaeta larvae in the plankton off the Waltair coast. Ganapati and Rao (1959) noted the feeding habits of *Ianthina janthina* and Ganapati and Bhavanarayana (1958) studied pelagic tunicates as indicators of water movements off Waltair coast. Ganapati and Santakumari (1962) studied the distribution of Copepods at Lawson's Bay. Attention was also given to the studies on fish eggs and larvae by Ganapati and Raju (1961, 1963) and Raju and Ganapati (1969). Chandramohan and Rao (1969) studied the Copepoda of the Godavari estuary.

The contributions from the Andhra University are important in the sense that the studies made here include data collected from regular oceanographic cruises on board Indian Naval Minesweepers. Prof. La Fond of the Naval Electronics Laboratory, San Diego started these cruises when he was visiting the university as a Fulbright Scholar in 1952 and again in 1955. The Memoirs in Oceanography Vol. I and II published by the Andhra University form an important landmark in the development of oceanography in Indian waters.

Krusadai and Mandapam

Krusadai is a small island off the east coast of India. The Madras State Fisheries Department has been maintaining a substation for research and the nearby inshore areas are extremely rich in marine life which includes the fascinating coral reefs. Chacko (1950, 1956, 1959) in a series of reports has given an account of the plankton in and around Krusadai Islands. The Central Marine Fisheries Research Institute commenced functioning at Mandapam from 1947 and since then this Centre and its field stations at various places along the Indian coast have substantially contributed to the knowledge of plankton. Prasad *et al.* (1952)

and Prasad (1954, 1956, 1958) have given accounts of the plankton in the nearby Gulf of Mannar. Prasad (1954) has also described the Hydromedusae from the same gulf. Varadarajan and Chacko (1943) described the arrow worms of Krusadai. Ummerkutty (1960, 1961) has added to our knowledge of copepods from this area. Devanesan and Varadarajan (1940) have reported on the occurrence of Tornaria larvae at Krusadai. Sudarsan (1961) made observation on the Chaetognatha of the waters around Mandapam.

The annual reports of the Madras Fisheries Department and its substations contain information on the plankton in the waters off Tuticorin, Ennore and West Hill (Calicut) (Chacko, 1956, 1959).

Porto Novo

The Annamalai University at Chidambaram has a marine biological station at Porto Novo which is situated further south on the Madras coast. This laboratory has been doing some plankton work, though not in a sustained manner. Krishnamurthy (1961) published a paper on the daily variations in marine plankton from Porto Novo.

Kerala Coast

The important centres of plankton research on the Kerala coast are the University laboratories at Trivandrum and Cochin and the substation of the Central Marine Fisheries Research Institute at West Hill (Calicut). Menon (1945) studied the seasonal distribution of the plankton of the Travancore coast. George (1952, 1953) described the marine plankton of the coastal waters of Calicut with observations on the hydrographical conditions and gave an account of the Chaetognaths from the area. George (1958) made observations on the plankton of the Cochin backwaters. Nair (1946, 1951, 1954) described the medusae of the Travancore coast and their correlation with inshore fishing. Pillai (1944) gave an account of the Chaetognatha of the Travancore coast. He also in a series of papers (1955, 1957, 1961, 1964, 1966 a & b) dealt with pelagic crustacea of Travancore namely decapod larvae, Schizopoda, Amphipoda and Mysidacea. Balakrishnan (1959, 1961) gave an account of the fish eggs and larvae of the Kerala coast. Subramanyan (1959) made a detailed study of the relationship between phytoplankton and zooplankton of the west coast of India. Sudarsan

(1968) studied the Brachiopod larvae from the west coast of India. Mukundan (1967) reported on the plankton of the Calicut area.

At the Indian Ocean Biological Centre investigations on the Cochin backwater zooplankton were made to study the total zooplankton biomass and faunal composition (Nair and Tranter, 1971 and Menon *et al.* 1971). Detailed studies on the ecology of hydromedusae, (Santhakumari, 1970, Vannucci *et al.*, 1970 and Santhakumari and Vannucci, 1971), seasonal fluctuations of Chaetognaths (Vijayalakshmi, 1971 a&b) and coexistence of species of the copepod family Acartiidae (Tranter and Abraham, 1971) were also made. From a series of collections taken along the south west coast of India Vannucci and Santhakumari (1969) pointed out new records of hydromedusae and Nair (1972) recorded an amphipod swarm.

Bombay

Off the Bombay coast, the biology department of the Institute of Sciences and the research department of the Maharashtra State Fisheries Department have been active in plankton research. Lele and Gae (1936) gave an account of the common *Sagitta* of the Bombay harbour. Bal and Pradhan (1945) published a preliminary note on the plankton of Bombay harbour and followed it up (1952) with records of zooplankton during 1944-47 and progress report of fish eggs and larvae in Bombay waters. Chopra (1960) made notes on a sudden outburst of ctenophores and medusae in the waters of Bombay. Chhapgar (1956) described the breeding habits and larval stages of some crabs of Bombay. Desai (1961) gave a preliminary account of the eggs and larvae of some marine mollusca of Bombay. Sudarsan (1964) made observations on the plankton and trawler catches off Bombay. To the north of Bombay and for the Gujarat coasts we have hardly any publication dealing with the plankton, the exception being that of Ramamurthy and Dhawan (1963) who described the characteristics of the plankton at Kandla in the Gulf of Kutch during 1958-60.

We have hardly any information from the Orissa and Bengal coasts except for a few publications by Devasundaram and Roy (1954) and Dutta *et al* (1954) from Hooghly estuary. While the foregoing account of the work for the different areas does not claim to include every published paper, it is

clear that centres of activity are in the south and as years go by more and more papers are appearing on the zooplankton in the Indian coastal waters.

International Indian Ocean Expedition and the Establishment of the Indian Ocean Biological Centre at Cochin

The International Indian Ocean Expedition took place during the period 1960-65 and the role played by the Special Committee on Oceanic Research and the Unesco, with the active support of many nations including India in organizing the expedition, is now part of the history of Oceanography in the Indian Ocean. The scientific activities generated by this expedition greatly benefitted India and the most important of this is the establishment firstly of the Indian Ocean Biological Centre at Cochin in 1962 and subsequently the establishment of the National Institute of Oceanography in India in 1966.

Since 1960 oceanographic activities in the Indian waters have greatly increased and in this paper the role played by the Indian Ocean Biological Centre is considered in detail.

The Indian Ocean Biological Centre came into existence in 1962 as a result of the desire of many of the participating nations who wanted a sorting centre to process the large number of zooplankton samples to be collected during the Expedition (see Hansen, 1966). The proposal was first discussed informally at the first Oceanographic Congress in New York between Mr. Robert Snider, Prof. Roger Revelle and Dr. N. K. Panikkar. Definite proposals for its establishment were introduced by the Indian Ocean Working Group in Copenhagen (1960) and again at a meeting of SCOR in Helsinki (IOC 1962-INCOR 1962) and supported by India's representative (Dr. N. K. Panikkar). Tranter (1969) has given a full account of the IOBC - its establishment, activities etc - in the guide to the IOBC issued by the Unesco. The Proceedings of the Unesco Consultative Committee which was responsible for handling of the zooplankton samples collected during the expedition have appeared in the IIOE news letters issued by Unesco and also in the reports published by INCOR and NIO (India.)

The principal functions envisaged for the IOBC are:-

1. Maintenance of named reference collections of Indian Ocean material.

2. Sorting of zooplankton samples taken by standard methods.
3. Examination of the sorted material and sending it to specialists throughout the world.
4. Sorting of zooplankton samples at the request and expense of participating laboratories and
5. Training.

The Unesco Curator with the concurrence of the Advisory Committee defined the systematic groups to be used in subdividing the plankton samples. After measuring the total displacement volume and removing all larger organisms including fish eggs, fishes, cephalopods and larger medusae, a subsample of 3-5 ml was separated out of the total sample for sorting. If the sample was smaller than 3-5 ml, a standard fraction of 10% was stored as 'archive' and the rest sorted. The number of plankton groups sorted was 63 and each one of these was counted separately and preserved. The subsamples were stored in coded groups and data entered in scheme 'C' sheets (Appendix I).

The sorting and subsorting of total number of 1927 samples took nearly 7 years to complete and in 1968 it became clear that the staff at IOBC had developed sufficient expertise to carry out research on most of the zooplankton groups and also prepare handbooks and atlases using the coded data available at the IOBC, as recommended by the Intergovernmental Oceanographic Commission at its sixth meeting in 1968. Subsequently the IOBC has published 5 volumes of atlases dealing with the distribution of zooplankton biomass, copepods and decapod larvae, fish eggs and larvae, mollusca and other groups in the Indian Ocean and 3 volumes of handbooks dealing with the station list, environmental data and proceedings of workshop on plankton methods. The next volumes (IV and V) of handbooks will deal with comprehensive papers on the International Collections both by the IOBC staff and specialists.

Now that the Indian Ocean Biological Centre is well established and made a permanent division of the National Institute of Oceanography (CSIR) its future is assured and the staff are continuing their studies on the International Collections without any break. Besides, a new programme of

research has been initiated to study the variability and ecology of the tropical zooplankton, population dynamics of some selected species and their life cycles and ecological succession of zooplankton in the backwaters.

The IOBC is also participating in the Pelagic Fishery Survey of the Arabian Sea under the United Nations Development Project. It has been agreed that the plankton samples taken by the Survey will be turned over to IOBC where total biomass will be measured and studies will be made on the zooplankton.

In the introduction to this paper, an account on the work done in recent years (1930 onwards) on zooplankton in the coastal areas is summarised. Most of these papers (Bibliography of the Indian Ocean, 1971) deal with the systematics of the different groups of zooplankton with frequent reference to hydrography.

The significance of studies on the zooplankton in the open Indian Ocean is altogether different. Contributions mainly come from occasional

Table 1
Indian Ocean Stations (Prior to IIOE)

Ship	Date	No. of Stations*
1. Novara	1857-59	52
2. Challenger	Dec. 1873-Mar. 1874	6
3. Gazelle	1874-76	37
4. Valdivia	1898-99	67
5. Gauss	1902-03	26
6. Sea lark	1905	23
7. Siboga	1906	272
8. Planet	1906-7	57
9. Mowe	1912-13	7
10. Dana	1928-30	171
11. W. Snellius	1929	25
12. Discovery II	1930, 32, 35, 38	124
13. Mabahiss	1933-34	80
14. William Scoresby	1935, 36, 50	60
15. Albatross	1947-48	22
16. Charcot	1948-49	10
17. Galathea	1950-52	48
18. Umitaka Maru	1956	32
19. Guillard	1961	77
Total:-		1196

* The information under this column is not complete and does not include stations south of 45°S Latitude.

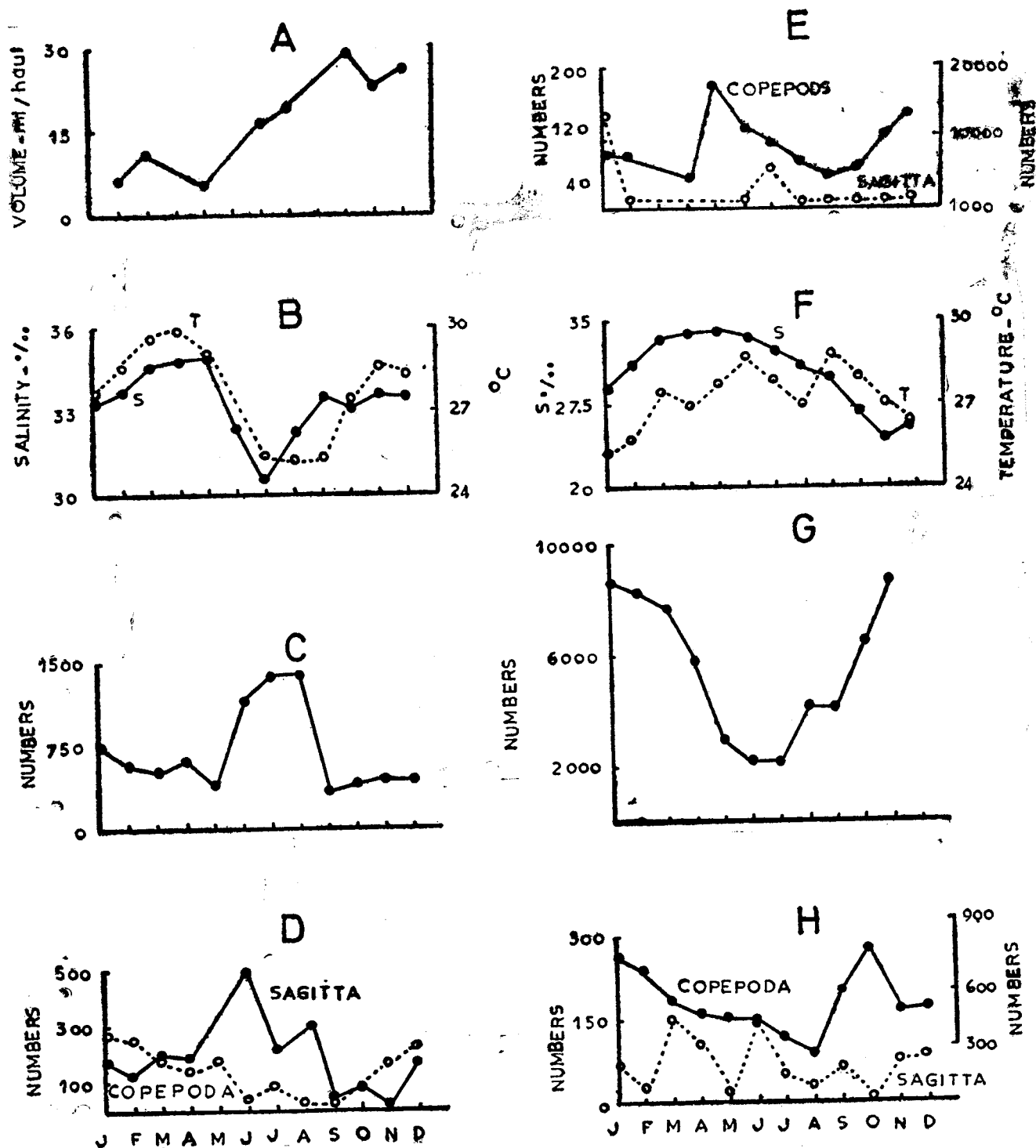


Fig. 1. A. Annual variation of zooplankton volume ml/haul off Bombay, 1963. Sudarsan, 1964.
 B. Salinity & temperature variation during the period 1950 - '54 (5 year - average), off Calicut. Subramanyan, 1959.
 C. Zooplankton variation. 5 year average (1950 - '54). Off Calicut. Subramanyan, 1959.
 D. Annual variation of *Sagitta* and Copepods off Trivandrum 1939. Menon, 1945.
 E. Annual variation of *Sagitta* and Copepods off Waltair 1951 - '52. Rao, 1951.
 F. Salinity and temperature variation off Waltair 1952. Rao, 1958.
 G. Annual variation. Total Copepods off Madras during 1929 - '30 (2 year average). Menon, 1931.
 H. Annual variation of *Sagitta* and Copepods off Mandapam, 1950. Prasad, 1954.

expedition reports and during the past 100 years about nineteen important expeditions have worked in the Indian Ocean (Table 1). The reports from these expeditions include some of the most comprehensive papers on the different components of zooplankton. Mention may be made of Kramp's work (1957, 1961) on Hydromedusae, on Copepods by Steuer (1904) and Sewell (1929, 1932, 1947), Tattersall's report on Mysidacea (1939), Pteropods and Heteropods by Tesch (1948, 1949, 1950), Apstein (1906), Sewell (1953) on Tunicates, Lohmann (1931) on Appendicularians, Fowler (1906) and Burfield and Harvey (1926) on Chaetognaths, and Delsman (1921-1938) on fish eggs and larvae of the Java Sea. Besides we have also some papers on zooplankton from the straits of Singapore and Kenya waters (Wickstead, 1961, 1962). From South Africa, we have a series of contributions from de Decker (1964) and de Decker & Mombeck (1965).

Since 1960 contributions on the distribution of various planktonic groups in the Indian Ocean has increased, mainly as a result of the activities of the IIOE. Mention may be made of the work on Chaetognaths by Alvarino (1964) and Vijayalakshmi (1969), Pteropods by Sakthivel (1969), Heteropods by Aravindakshan (1969), Foraminifera by Beljaeva (1962), plankton biomass by Bogorov and Vinogradov (1961) and Prasad (1966, 1968, 1969a, 1969b), Fenaux (1964) on Appendicularians, Jacob George (1969) on Ostracods, Gopalakrishnan and Brinton (1969) on Euphausiids, Grice and Hulsemann (1967) on copepods, Menon *et al* (1969), Menon & Williamson (1971) and Menon (1972) on decapod larvae, George Peter (1969), on Polychaetes, Peter (1969a & b) on fish eggs and larvae and Pillai (1973) on Mysidacea of the Indian Ocean.

DISTRIBUTION OF ZOOPLANKTON IN THE COASTAL AREAS OF THE INDIAN PENINSULA

The neritic and inshore waters of the peninsular India are extremely interesting in that they not only support a rich and abundant planktonic life, but also show special features of seasonal variation.

Throughout the Indian coast the general distribution of zooplankton is bimodal, with two peak

periods, one in February-April period and other in September-October (Fig. 1). On the Waltair coast, Rao (1958a) found for the chaetognaths, particularly for *Sagitta enflata*, January-February and June-July to be the peak periods. Menon (1931) found in the Madras plankton, abundance of copepods in November to March and again an increase in August. Prasad (1958) found that in the Gulf of Mannar and Palk Bay the standing crop of zooplankton showed two peaks, a higher peak in March (in Gulf of Mannar) and April (in the Palk Bay) and a lower peak in September-October at both these places. (Figs. 1-3 loc. cit). His data was based on averages for 5 years (1954-58). On the Trivandrum coast Menon (1945) observed a regular succession of planktonic groups and the zooplankton (Copepod) maximum during January to February. He reported swarms of *Sagitta enflata* in July to September and very rare during October to November.

Subramanyan (1959) while discussing the phyto-zooplankton relationship, gave average values for a 5 year period and noted the abundance of zooplankton during June to August and again smaller peaks in January, March and April off Calicut. (See Table XIII loc cit. p. 166). The distribution of chaetognaths along the Malabar coast shows (George, 1952) that their highest numbers are encountered in November and again in May-June. They were lowest in August. Bal and Pradhan (1945) working on the Bombay harbour reported January to March to be the most favourable months of the year for the occurrence of plankton as swarms. At Bombay *S. enflata* was found to be abundant in November-December months (Lele and Gae, 1936), whereas off Calicut it would be October-November and further south at Trivandrum it is much earlier i.e. July-September. On the east coast the peak periods for the species occurs off Waltair and Madras during May-August and in the Gulf of Mannar it is November and December. It would therefore appear that there is some kind of a north to south movement in the peak periods of plankton on the east coast and just the opposite i.e. from south to north on the west coast. Such a regular succession in the peak periods of phytoplankton was also noticed by Ganapati and Rao (1953).

The zooplankton distribution therefore shows abundance during different months both on the east and west coasts of India. Panikkar & Jayaraman (1966) have discussed oceanographic differences between the Arabian Sea and the Bay of Bengal. They point out the differences both in temperature and salinity range as also the periods of upwelling and surface currents. All these appear to be related to the influence of the prevailing monsoon. On the west coast the peak movement of plankton is from south to north. Upwelling is prevalent along this coast between 7°-16° N latitudes during the period August to early October (Panikkar & Jayaraman, 1966), but we do not know whether it occurs all at once over the entire stretch or progressively in any one direction. It would appear from the succession of plankton peaks that on the west coast the upwelling is initiated first in the south and then progressively moves up north. Sharma (1968) is of the opinion that upwelling sets in earlier in the south and gradually extends to the north. Further detailed work is necessary to substantiate this view.

On the east coast upwelling is reported only near the Vishakhapatnam coast (La Fond, 1954) during March. Sure enough high plankton values are reported from the area during April to July. Further to the south on the east coast of India no data is available on upwelling and if one could infer physical events in the sea based on biological processes, it could be stated that replenishment of nutrients resulting in peak periods of plankton takes place in April-May near Madras and August-September in the Gulf of Mannar.

On the west coast the southwest monsoon is strongest and under its influence heavy rainfall occurs during May-September. Therefore the lowest values of salinity on this coast are found in June to August months. Large scale upwelling also brings about lowering of temperature in the near-shore areas. However, on the east coast lower salinities are encountered during September to November months which is more due to river run off than rains. Low temperatures are found here during the period December to February, which is a winter phenomenon.

The average values for salinity for the Bay is much lower than in the Arabian Sea. However, the temperature shows much higher range in the Arabian Sea than in the Bay. Besides these dif-

ferences, as already stated the periods of low salinities and temperature are later in the year in the Bay as compared to the Arabian Sea. Such fundamental changes are bound to have marked influence on the development and fluctuation of plankton populations all along the two coasts.

Ganapati and Rao (1958) found clear differences in the hydrobiological conditions off the Waltair coast during the two periods namely August-December and January-August. The nature of the differences are summarised below:

**In the Bay of Bengal
(East coast of India-Lawson's Bay)**

Period	- August - December
Water mass	- Northern dilute water of the southern current
Salinity ‰	- 20.79 - 32.97
Temperature °C	- 27.90 - 25.00
Plankton	- Minor plankton blooms, the chaetognaths are few in number and variety. Among the pelagic tunicates <i>Fritillaria foramina</i> , <i>Cyclosalpa pinnata</i> and <i>Pegia confoederata</i> are common.
Period	- January - August
Water mass	- Southern Bay of Bengal water of the northerly current.
Salinity ‰	- 30.06 - 34.57
Temperature °C	- 24.33 - 29.80
Plankton	- Major planktonic blooms. very rich chaetognath populations are represented by <i>Sagitta serratodentata</i> and others. Among the Pelagic tunicates, <i>Fritillaria borealis</i> , <i>F. sargassi</i> and <i>F. pellucida</i> occur in large numbers.

In the Arabian Sea (West Coast of India)

Period	- May to October
Water mass	- 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 the period. The surface current is southerly.

Salinity ‰	- 36.5 - 33.0
Temperature °C	- 29.5 - 26.0 (lowest values in July near the coast due to upwelling).
Plankton	- Phytoplankton abundance. Copepods are scarce; peak period for <i>Sagitta enflata</i> and <i>S. neglecta</i> commences in October.
Period	- November - April
Water mass	- Surface water of the Indian equatorial region. The currents are northerly upto the end of January and thereafter they become southerly.
Salinity ‰	- 35.75 - 33.0
Temperature °C	- 29.5 - 25.0 (northward reduction)
Plankton	- Phytoplankton is scarce. Copepods are most abundant. Species of chaetognatha like <i>S. enflata</i> , <i>S. bedoti</i> , <i>S. robusta</i> continue to be dominant throughout this period.

As already stated the general picture of zooplankton distribution all along the Indian coast presents a bimodal oscillation with two peak periods, one early in spring and the other late in autumn. The usage of words spring and autumn are not very appropriate for the Indian waters since the magnitude of seasonal variations of hydrographical as well as biological factors are not marked except for salinity in coastal areas from one season to the other. Sometimes even the daily range in air temperature, water temperature, wind force and dissolved oxygen is almost equal in magnitude to the annual range of these factors on these tropical coasts (Rao and Rao 1962). Against such a background of environmental conditions fluctuations in plankton populations during a day, month or year in these waters could be sometimes of the same magnitude and therefore the picture cannot be generalised.

Zooplankton Biomass

Zooplankton biomass distribution in the Indian Ocean formed the subject matter for the Vol. I - Fascicles 1 and 2 of the Plankton Atlas prepared by Prasad and issued by the IOBC (Gen.

Ed. Panikkar, 1968a&b). Prasad (1968, 1969a & b) has given a detailed account of the distribution of the biomass (wet zooplankton displacement volumes expressed as ml per haul taken by the IOS net) in the Indian Ocean based on the data from 1622 samples included in the above atlas.

Prasad observes that the volumes are highest in the Arabian Sea between the latitudes 10° to 25° N and longitudes 50° to 65° E, more particularly in the area off the Somali coast and coast of Saudi Arabia. Average values as high as 54.7 ml. (under 1 sq. meter for 200 meter column) were noted off Arabia, with Somali showing 15-35 ml and + 15 ml all over the South eastern region of the Indian Ocean and again in the northern Bay of Bengal and South of Java. The rest of the Indian Ocean shows values less than 15 ml/haul.

The data for the atlases mentioned above were based on average values calculated from all the stations for every 5° square.

In order to obtain a more realistic picture of the distribution of the biomass, data from 1548 standard IOSN samples were replotted on 5 different charts (Figs. 2-6) to show the biomass distribution for five different monsoonal periods recognized by Duing (1970), for the northern Indian Ocean.

During the height of the north east monsoon (WM) (December to February) data from 431 samples indicate the occurrence of 20-39.9 ml biomass in the region of Gulf of Aden and north of Mombasa. A few spots indicating highest range ie. 80 and above were located off Madras in the Bay of Bengal and off Goa along the west coast of India (Fig. 2). Rest of the area shows low values from 0.1-9.9 ml.

March-April is a transitional period with 238 samples but the Somali and Arabian coasts are not covered (Fig. 3). Both the areas show patches of middle range values (10-32.9 ml) against a background of low biomass (0.1-9.9). Large patches in the central Arabian Sea and eastern Indian Ocean show values from 10-19.9 ml.

May-June period witnesses the commencement of the S. W. monsoon. Here also we have no data from the Somali and Arabia coasts nor from eastern Bay of Bengal (Fig. 4). Patches of high values are scattered with a rich patch of biomass

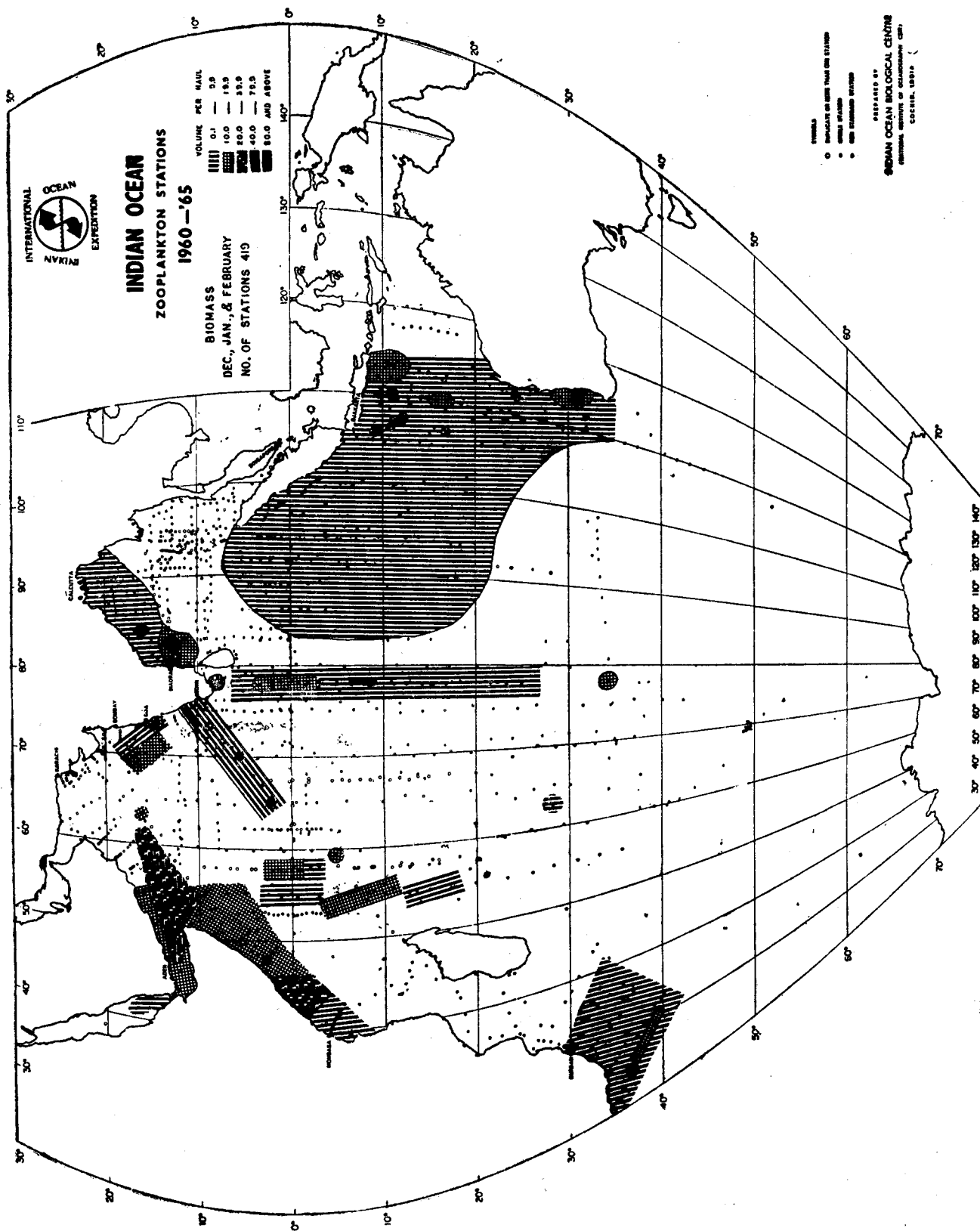
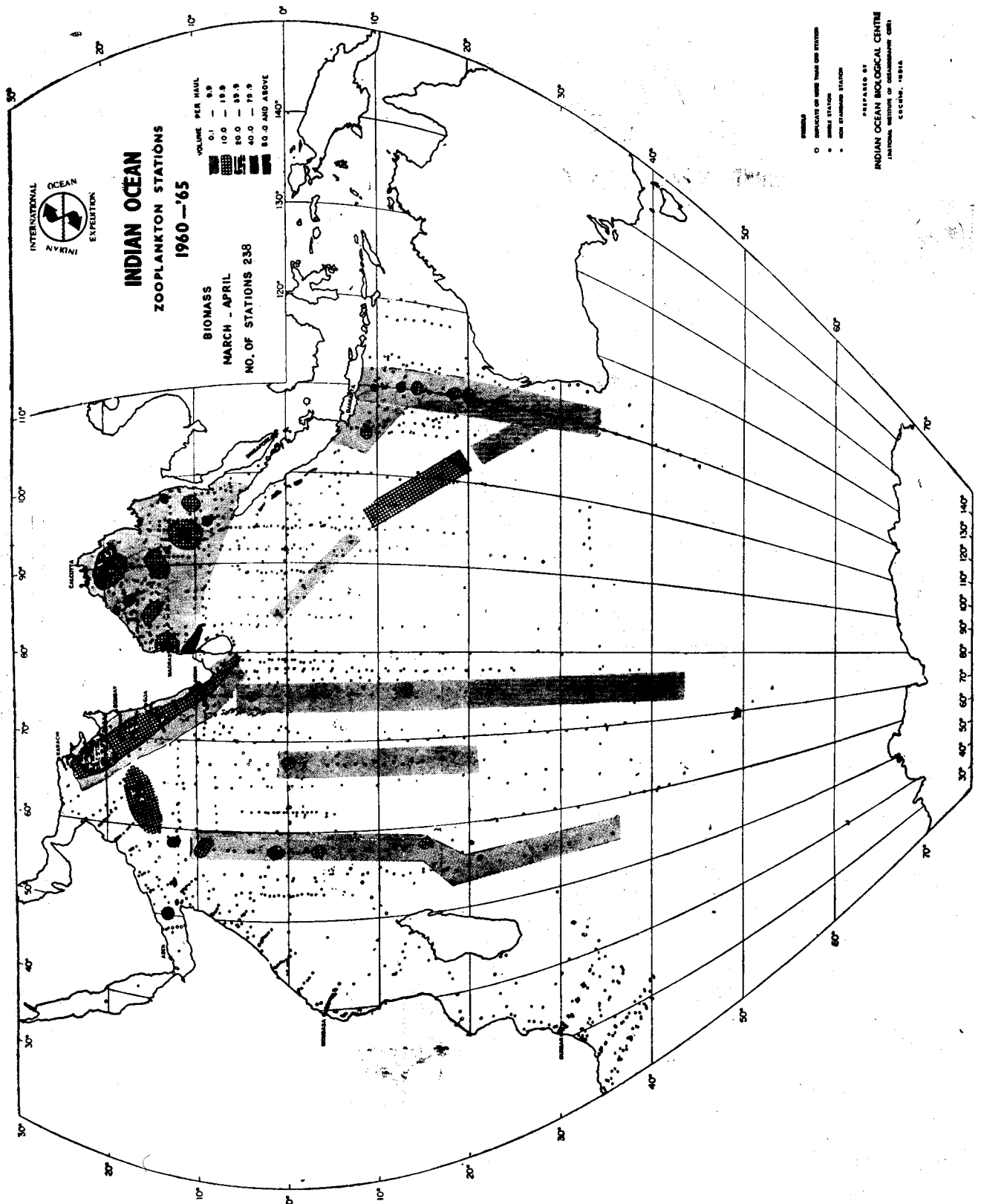


Fig. 2. Biomass distribution December - February



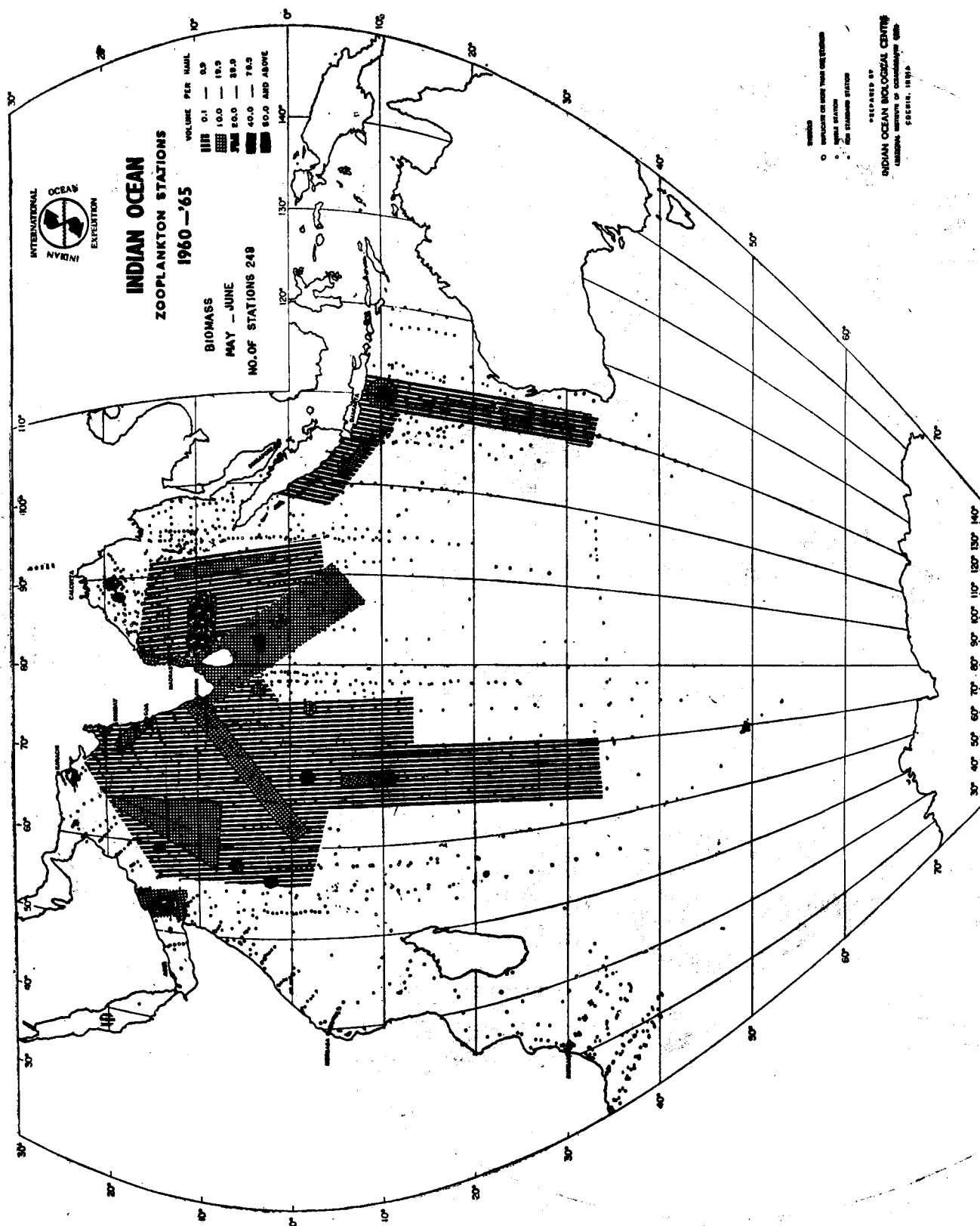


Fig. 4. Biomass distribution May - June.

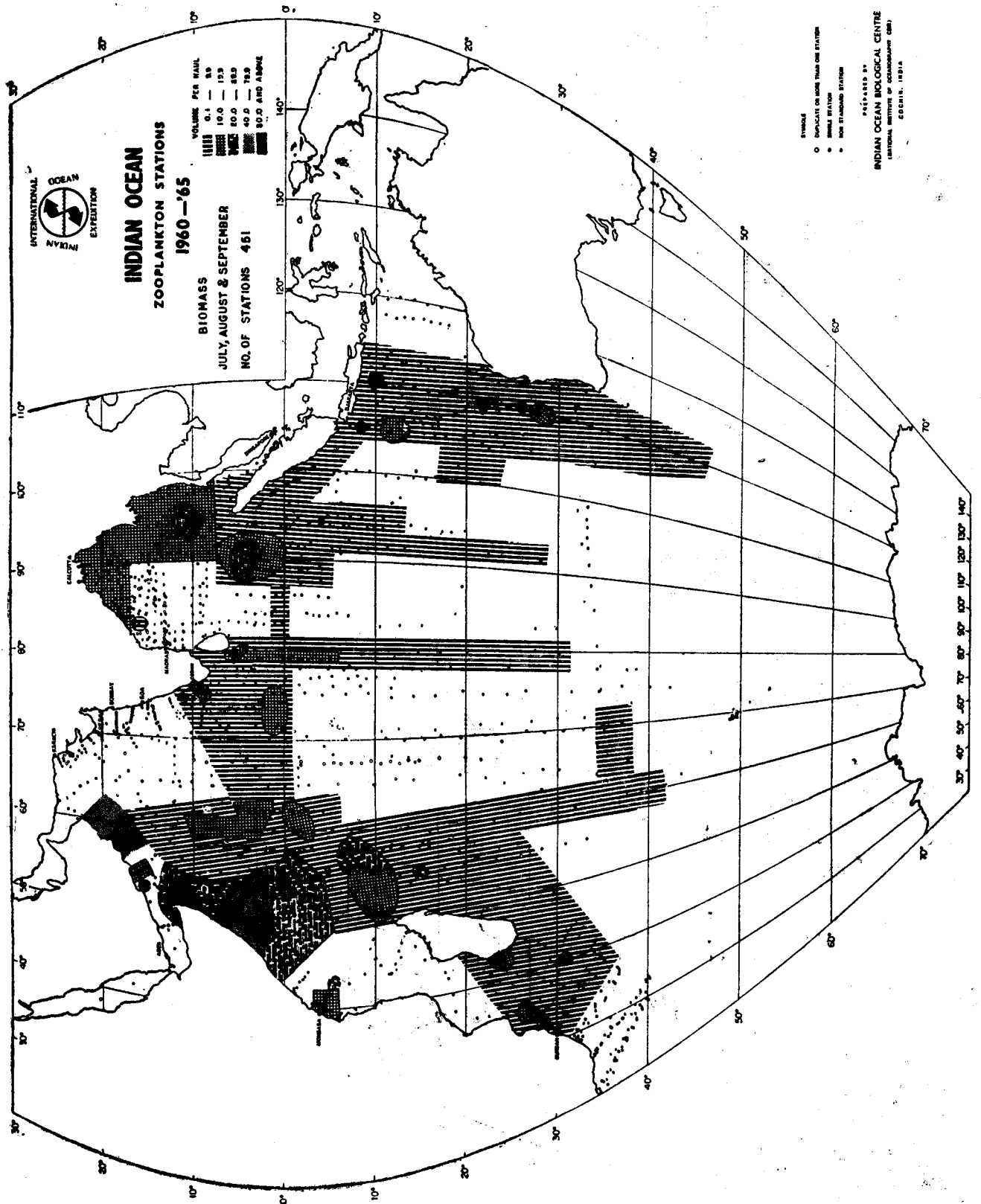


Fig. 5. Biomass distribution July - September.

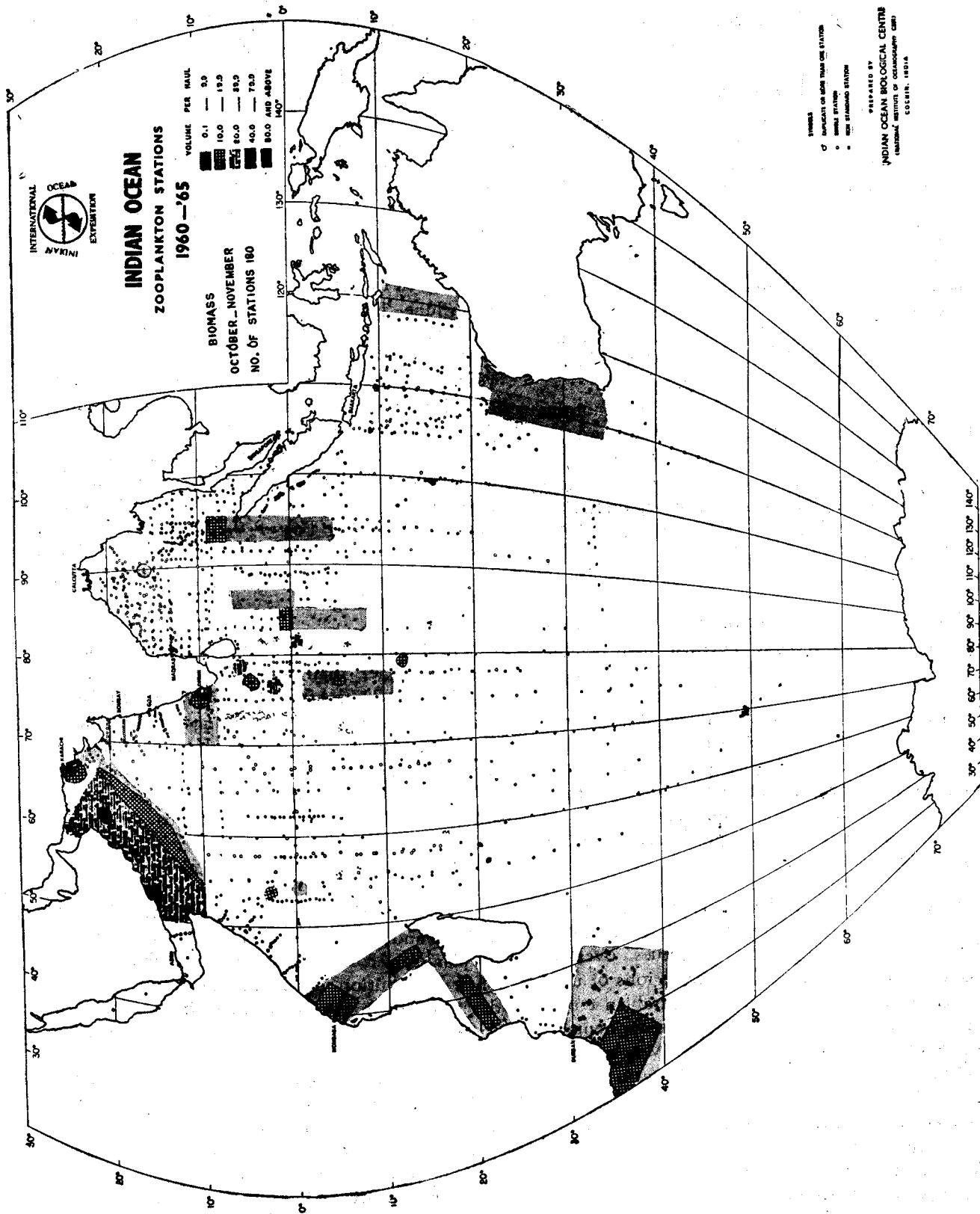


Fig. 6. Biomass distribution October - November.

(20-39.9 ml) to the east of Ceylon and a similar patch in the Gulf of Aden. Most of the samples out of the 248 for this season exhibit low values (10 ml).

July-August and September are the months where the south west monsoon is fully established all over the north Indian Ocean. There are 451 samples for this season and unfortunately most of the west coast of India north of Mangalore and Madras coast have no data (Fig. 5). High biomass values, 40 ml and above are found at stations off Somalia (between Garad and Ras Mabber) adjacent to Cabo Guardafui and off Oman coast. Values ranging from 20-39.8 are present south of the Andaman Sea, around 5°N and 90°E, off Cochin and south of Ceylon and also on 110°E.

October-November are transition months and mark the close of the S.W. monsoon and the beginning of north east monsoon. There are 180 samples for this period mostly off the Saudi Arabian coast (Fig. 6). This is the only region having a biomass value of 20-39.9 ml. The rest of the areas have all low values. No data are available for the Bay of Bengal.

From the above account of the seasonal distribution of the biomass, it is evident that the areas adjacent to the Saudi Arabian coast consistently show very high ranges of productivity during the prolonged south-west monsoon period. It may also be stated that the eastern portion of the Indian Ocean becomes highly productive during the northeast monsoon and the western portion during the southwest monsoon. There is also an overall increase in the area of productivity during the southwest monsoon.

A comparison of the biomass distribution with the surface thickness layer distribution (Fig. 7) makes it clear that high biomass values overlap areas of shallow surface layer or regions of upwelling. 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) creates divergent conditions off the Saudi Arabian coast and thus favour large scale upwelling. In July, August and September this coast has lowest temperatures around 23°-25°C. Salinity is high and constant throughout the year. Distribution of nutrients (phosphates and nitrates) indicate high values for this

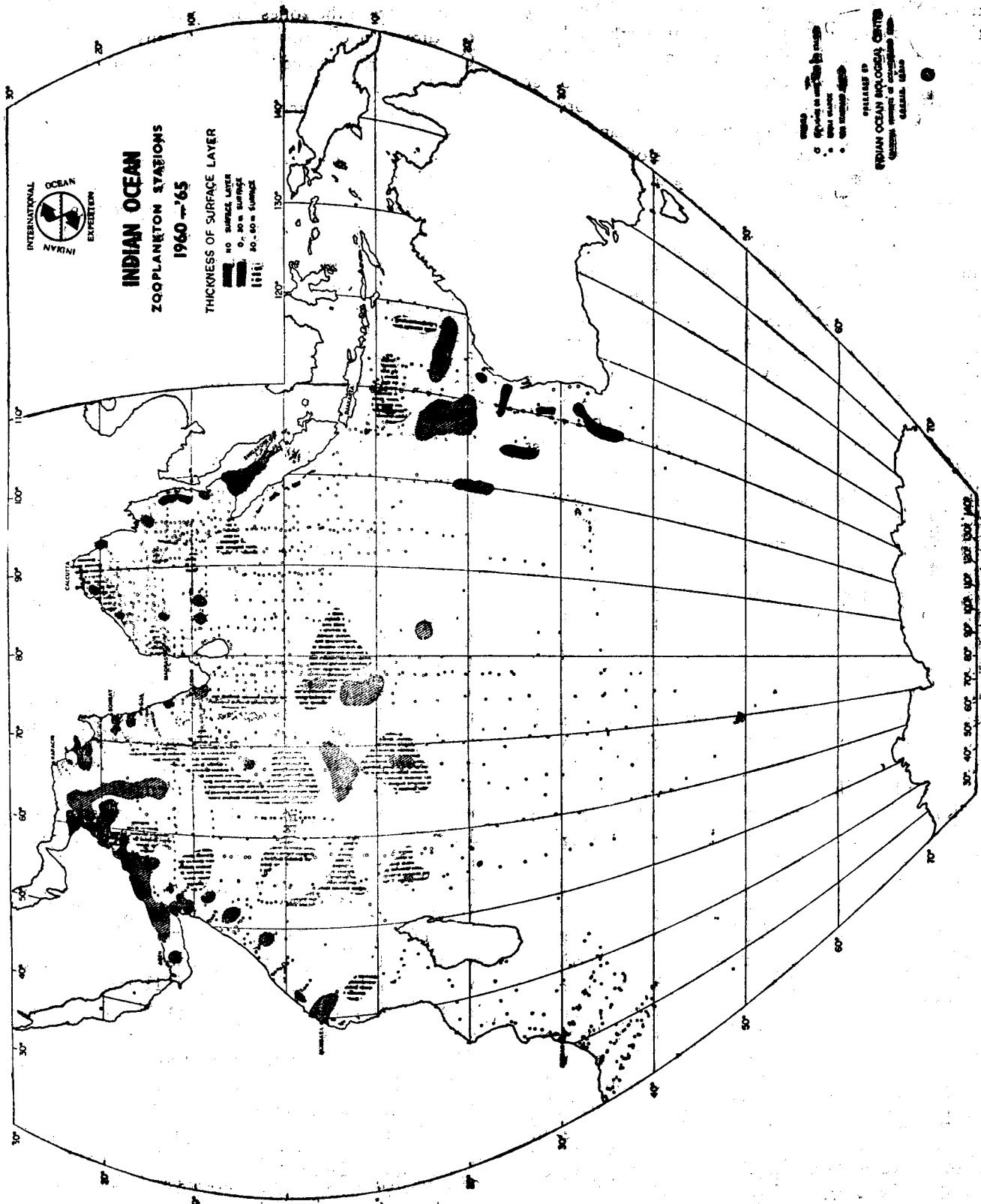
area. Even at the surface, phosphates and nitrates show very high values of 1.61 and 12.1 ug/at/1 respectively which is nowhere else to be seen in the Indian Ocean. All these circumstances combine to make the Saudi Arabian coast the richest area for zooplankton production in the north Indian Ocean.

In the southern Ocean the number of samples available are few. This is however, made up by a series of cruises occupying same stations by Australia and again by South Africa whose ship 'Africana' worked a grid of 19 stations in the Agulhas bank area for 18 months from June 1965. Study of the biomass at these stations is very interesting. At 32°S 100-112°E we have 14 observations covering 8 months of the year. The hydrographical data from these stations reveal that conditions were highly stable during August. Temperature (19°C), salinity (35.7‰) and oxygen (5.0ml/l) show almost no variation throughout the 200 meter water column. The nutrients are low throughout the period, the maximum values being $\text{Po}_4 - \text{P}$ 0.70 ug at/1, in July. The biomass at this station is very low and shows a bimodal fluctuation, high values observed during February and August.

In the 'Africana' collections the biomass values are higher than at 32°S-100°E station and variable (0.9-21.7ml for 100m³). A clear relationship exists between the prevailing current and the plankton populations. Both Copepoda and Chaetognaths come from the east and drift westwards and southwards with the Agulhas current (Chandrika and Pannampunayil 1973)

Copepoda (Fig. 8)

These are the main herbivores among the zooplankton and constitutes nearly 70-80% of total zooplankton collected at most of the stations. Their distribution during the two monsoons and day and night are represented in the plankton Atlas Vol. II, Fasc. 1 published by the IOBC (1970). Areas of highest density are located all along the east African coast north of Mombasa and continue along the Arabian coast and occupy a large area of the northern Arabian Sea. Then again the Wadge bank and gulf of Mannar, an area off Madras, head of the Bay of Bengal including the Orissa coast and some patches along the equatorial region show high densities. Low value



areas cover the central Arabian Sea and the Bay of Bengal. During the summer monsoon it is interesting to note low copepod densities along the west coast of India to as far north as Baluchistan, whereas in the winter monsoon higher values are recorded in the same region. In other words production of copepods is much more extensive during the winter monsoon than in the summer monsoon and covers large offshore areas including and away from regions of well known upwelling.

In the Bay of Bengal a rich patch is seen off the northern Andhra and Orissa coasts and this dense area extends right upto the central portions of the northern Bay during the summer monsoon. La Fond (1954) has reported upwelling off Visakhapatnam in March, but this local phenomenon alone cannot explain the occurrence of such dense populations far offshore. There must be large scale upwelling taking place off the Orissa coast and unfortunately no data is available from this region. In Fig. 7 the distribution and thickness of the surface layer is shown in the Indian Ocean and it is clear that shallow surface layers exist all along the north eastern coast of India and also cover a greater part of the head of the Bay. During the winter monsoon dense patches of copepods are present off Madras and southern tip of India and upwelling may take place there too. In the Java sea and in the seas off western Australia denser patches of copepods are more extensive during October-April (corresponds to northern winter) than in April-October. Wyrki (1961, 1962) and Rocheford (1962) have described upwelling areas off Java and northwest Australia and in the Flores, Banda and Arafura Seas during the months of July-August.

In all these areas extensive production of copepods takes place during the winter monsoon (corresponding months in areas of south of the equator) and it is suggested that although primary production values are highest during the summer monsoon, there is some time lag for the development of zooplankton populations. For example on the Malabar coast primary production is highest during July-August which is also the period of upwelling, but zooplankton peaks commence in October-November. In this way the biological activities between the two monsoons are complementary and the effects of the summer monsoon is perhaps, fully realized during the winter monsoon.

Another important point is that the areas of zooplankton productivity extends hundreds of miles from the zones of upwelling, mostly in the direction of the prevailing surface currents. Cushing (1971) stated that "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 (zooplankton quantity) would be about two and a half times the width of physical upwelling. Off Ras Maber and around the northern latitudes of 8-10°N, the Somali current deflects eastward and an intense upwelling region develops at this divergence and here highest density contour for copepods extends upto a distance of nearly 600 miles from the coast. PO_4-P (μg at/1) values at the surface as summarized in Wooster *et al* (1967) very clearly correlates with the density distribution of copepods (Fig. 18). The highest values of phosphorous is along the shores of Somalia and Arabia and the contour lines of values above 0.75 μg at/1 PO_4-P neatly coincide with the highest densities of copepods, in this region.

At the IOBC special attention is also paid to the study of species for geographical distribution. Analysis of the 1927 samples received at the IOBC during the IIOE, yielded specimens of *Gaussia* (Copepoda-Metridiidae) from 19 stations (Saraswathy, 1973). At all these positive stations the sampling was from the upper 200m of water and excepting one, all the other stations were either in the Arabian Sea or the Bay of Bengal. Examinations of specimens of *Gaussia* collected from deeper levels in the Indian Ocean revealed that the species inhabiting the northern areas of the Indian Ocean can be separated from the type species. Recognition of a species endemic to the northern Indian Ocean is important, because it is beginning to be felt that there is a certain degree of isolation of fauna in this area. Gibbs and Hurwitz (1967) have also shown that in the case of *Chauliodus sloani* there appears to be at least two populations, a denser one north of the frontal zone (about 10°S) and less denser one further south of about 23°S, the two separated by a sterile region. The concept of a frontal zone separating the northern part of the Indian Ocean from its southern part, has been recognized by many workers and Ovcinnikov (1961) observes that north of frontal zone the Arabian Sea water characterized by a minimum

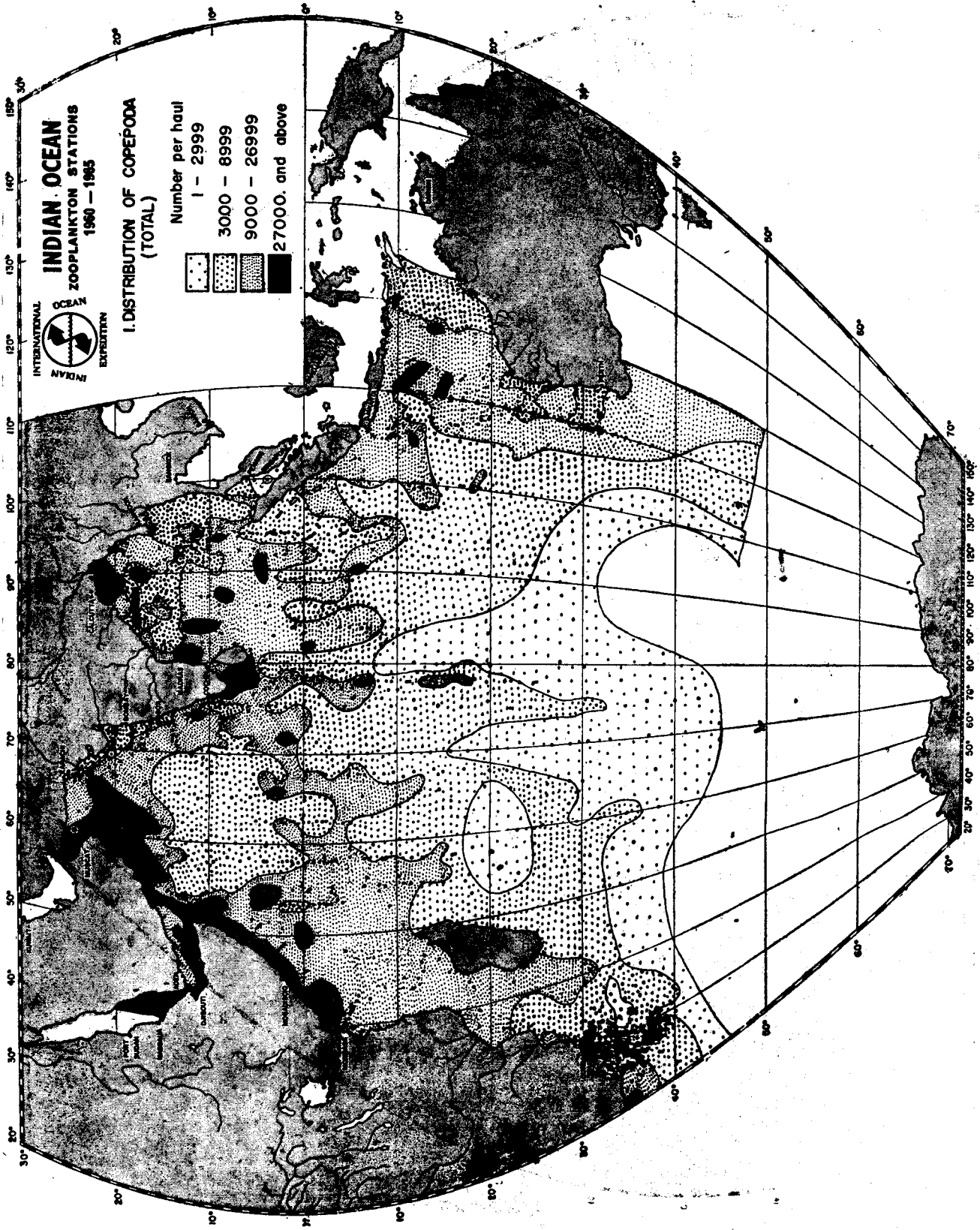
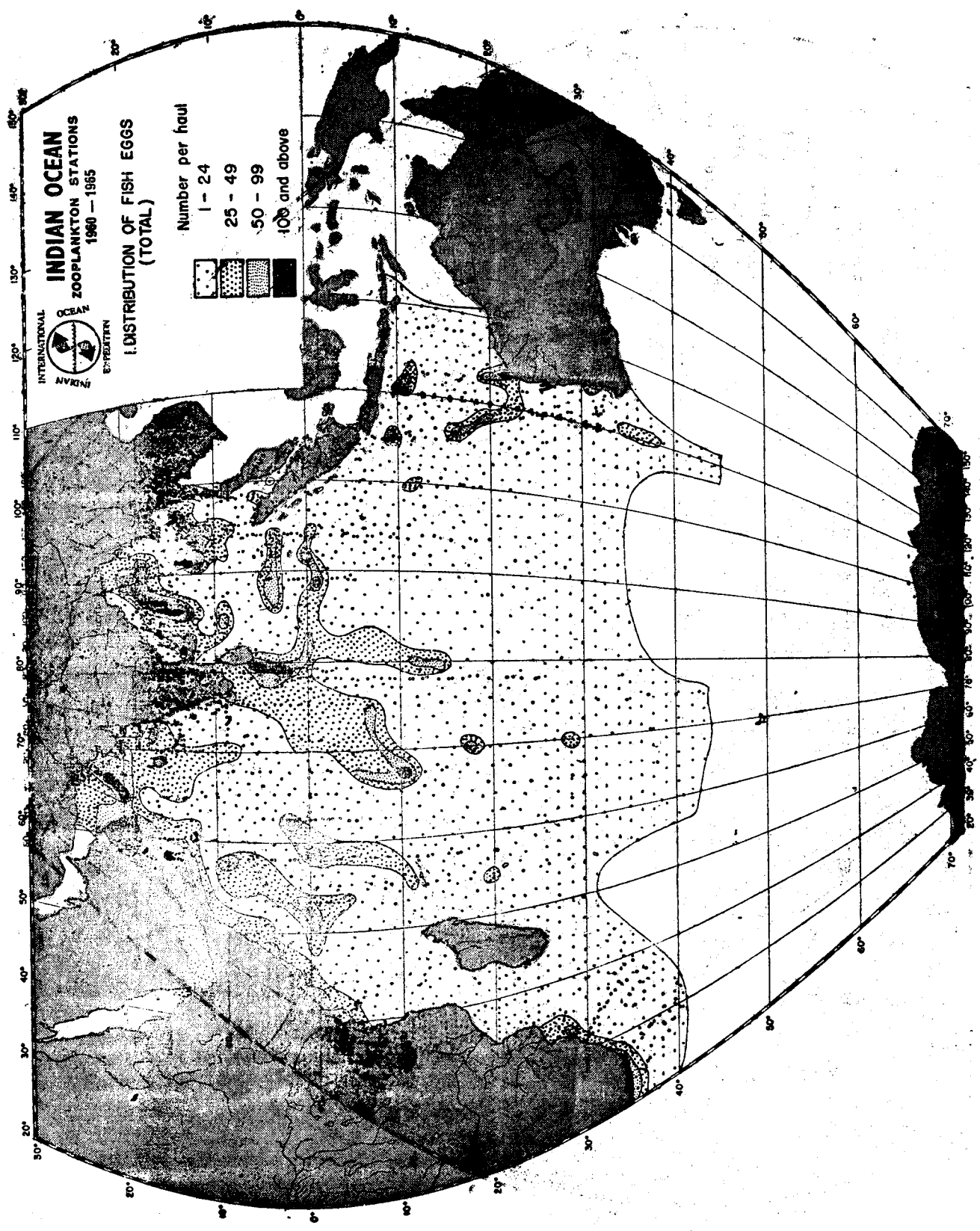


Fig. 8. Distribution of Copepoda (total) in the Indian Ocean.



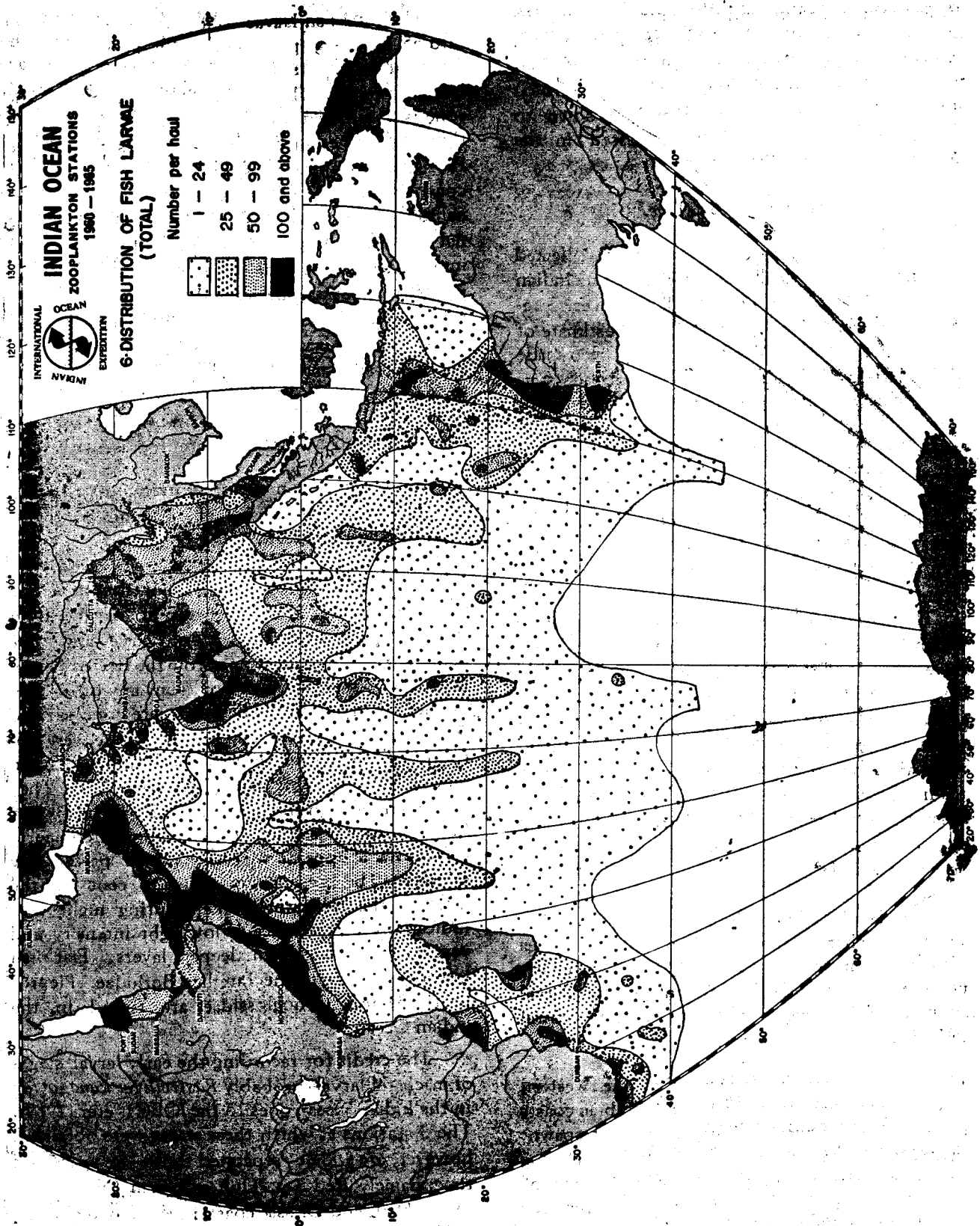


Fig. 10. Distribution of Fish larvae (total) in the Indian Ocean.

oxygen layer is present and the central water mass further to the south of 10°S has high oxygen content. Ivanov - Franskevic (1961) also stresses the importance of the frontal zone (at 10° - 12°S) which marks a clear boundary spreading down to 2000 m and is more sharply expressed in the eastern part of the Indian Ocean.

Fish eggs and larvae (Figs. 9-10)

Of the 1927 zooplankton samples collected and sent to the IOBC during International Indian Ocean Expedition, the eggs and larvae were present in about 87% of the samples. An estimate of abundance of fish eggs and larvae has been made on the basis of actual number present at each station. 10 charts were prepared and published by the IOBC in Plankton Atlas Vol. II - Fasc. 2 in 1970. These charts show total distribution and distribution during the two monsoon periods, day and night. The highest was about 2300 eggs per haul from the vicinity of the central Arabian coast ($14^{\circ}21'\text{N}$ - $58^{\circ}18'\text{E}$) and larvae about 1600/haul from the Malabar coast ($11^{\circ}00'\text{N}$ - $74^{\circ}35'\text{E}$).

The pattern of distribution of fish eggs is extremely interesting. Higher numbers (100 and above) are found over an extensive area along the Saudi Arabian coast, southern coast of South Africa, some patches along the equator, an elongated patch radiating from Ceylon downwards along the 80° longitude, and in an extensive area in the western Bay of Bengal away from the Indian coast. Such a type of distribution persists both during the two monsoons as well as during the day and night.

The larval distribution overlaps the eggs; however, higher values cover an extensive area particularly in the east African-Arabian coasts and the Bay of Bengal. In contrast low larval numbers are found over most of the central Arabian Sea.

It is clear from these charts that the western Arabian Sea adjacent to African and Arabian coasts and the Bay of Bengal emerge as important spawning areas for fish in the Indian Ocean. During the southwest monsoon most of the coast of India shows low values for eggs. However, for larvae the Malabar and the Ceylonese coasts are rich and this rich zone continues into the Bay of Bengal during both the monsoons.

The total fish larvae collected were subsorted into 55 groups (upto the family level) and the distribution charts for the various families are being prepared. The results show that the oceanic zone is dominated by larvae of deep sea and bathypelagic fishes such as Goniostomids, Stomiids, Paralepids, Scopelarcids, and Myctophids. The coastal zone includes larvae of strictly coastal fishes such as anchovies, sardines, lizard fishes, flat fishes, gobies and scorpionid fishes. The intermediate zone consists of a mixture of bathypelagic and coastal species and, as is to be expected, this zone is the richest for the variety of fish larvae. Most of the larvae of economically important fishes of families Thunnidae, Scomberomoridae, Carangidae and Gobiidae are collected from the zone. Even larvae of certain fishes such as Engraulids and Synodontids are represented here.

Investigations on the quantitative distribution of the flat fish larvae (Lalithambika Devi, unpublished) indicate that compared to other plankton taxa, the larvae of Heterosomata are represented only in very small numbers and that too only in about 11 per cent of the IIOE samples. In general, the flat fish larvae are more abundant in the collections from the Bay of Bengal than from the Arabian Sea or from any other part of the Indian Ocean. The larvae are concentrated in the neritic region. The flat fish larvae were not found in the central and southern Indian Ocean (about 52°E to 100°E and 10°S to 45°S). They were seen more in the northern half of the Bay of Bengal. As the salinity in this region is comparatively low, it appears that the larvae prefer low salinity. The presence of 65 per cent of the larvae in the collections taken during night may indicate their preference to low light intensity and vertical migration from deeper layers. Flat fish larvae belonging to the families Bothidae, Pleuronectidae and Cynoglossidae are found in the Indian Ocean.

The credit for recording the early larval stages of mackerel larvae (probably *Rastrelliger kanagurta*) in the Indian Ocean goes to the IOBC (Peter, 1969). The 3 stations at which these stages were obtained, however, are widely separated both in space and time; namely Red Sea, Gulf of Oman (November-December) and Orissa coast in the Bay of Bengal (May). It may not be prudent to make comments on the spawning areas of the mackerel based on these collections, but the presence of these larvae

in only 3 collections out of the large number of IOBC samples perhaps indicates that early stages of the larvae of such fishes are not present in the upper two hundred metres, since most of the samples come from this layer. In the case of the flying fish (Balasubramanyan *et al.*, 1969) the indications are that they spawn around the coasts of Ceylon. More detailed work on the fish larvae is in progress and charts showing the distribution of these families in the Indian Ocean are under preparation.

Decapod larvae (Fig. 11)

These larvae form an important constituent of the zooplankton. Out of the 1548 standard samples studied, 1518 samples contained decapod larvae. The distribution of these larvae are presented in 6 maps in the IIOE Plankton Atlas Vol. II Fasc. 1 (1970).

Very high concentrations of the larvae (over 2700/haul) are met with at one station each, off Port Elizabeth and south of Java and 3 stations off the west coast of Indian peninsula. In the central Indian Ocean south of 10°S latitude there is very little representation of decapod larvae. Except for the head of the Bay of Bengal, the brachyuran component of the decapod larvae is found distributed all over the Indian Ocean along with the rest. This may be due to the prevailing low salinity conditions off the mouths of Ganges and Brahmaputra.

During the southwest monsoon season the decapod larvae have a wider distribution and high density areas include Somali and Arabian coasts, west coast of India and the entire east coast of India including Ceylonese waters and a large patch west of Sumatra. During the northeast monsoon, the waters around the southern Indian peninsula has good representation and most of the east coast of India north of Madras has low concentration.

Another interesting feature is that the decapod larvae has lower concentrations close to the Saudi Arabian and Somali shores, while offshore areas has dense patches, nearly 300-400 miles from the coast. Ecologically speaking, the decapod larvae come late in the sequence of production commencing from phytoplankton, and they would therefore be located at places away from the actual upwelling areas (see discussion under copepods).

The concentration of the high density areas around the Indian coasts during the northeast

monsoon into the southern region of the peninsula as compared to their occurrence all along both the coasts during the southwest monsoon, perhaps, indicate that spawning of some of the economically important families of decapods takes place all along the Indian coasts during the southwest monsoon and with the onset of more stable conditions of hydrography during the northeast monsoon, they all migrate and develop into rich fisheries along the Malabar, Madras and Ceylonese coasts. The distribution of fish eggs and larvae also suggests a similar pattern.

Preliminary notes on the decapod larvae of the Arabian Sea based on expedition material has already been published (Menon *et al.*, 1969). The trends in distribution of the larvae of the major groups of decapods are also under study. The larvae of penaeid prawns, Paguridae and Callinassidae, show a maximum concentration around the southern extremity of Indian peninsula, off Madras and off the Somali coast. However, the latter two families are equally abundant in the Gulf of Cambay region. In the case of Brachyuran larvae the greatest numbers occur in the region surrounding the Indian peninsula, northern part of Somali coast, Andaman Sea and off the western Australian coast. Caridean larvae are abundant near South African coast and also south of Java in the eastern Indian Ocean.

The data on the distribution of the larval stages of several families of decapod crustaceans from the material obtained from IIOE collections have been analysed. Larval stages of *Thalassocaris* spp. were described (Menon & Williamson, 1971). Larval development of *Heterocarpus* spp. has also been traced (Menon, 1972). The complete larval history of one of the forage species of pasiphaeid prawns *Leptochela robusta* has been worked out by George and Paulinose (1973). The development of one of the penaeid prawns which is of commercial importance in Indian waters namely, *Penaeopsis rectacuta* is known (Paulinose, 1973). The abundance of penaeid larvae in the IIOE collections have been analysed to study it as an index of penaeid prawn resources in Indian Ocean (Paulinose & George, in press).

Ostracoda (Fig. 12)

A preliminary report on the distribution and abundance of planktonic Ostracoda has already been published (George, 1969). The ostracods are an important group next among import-

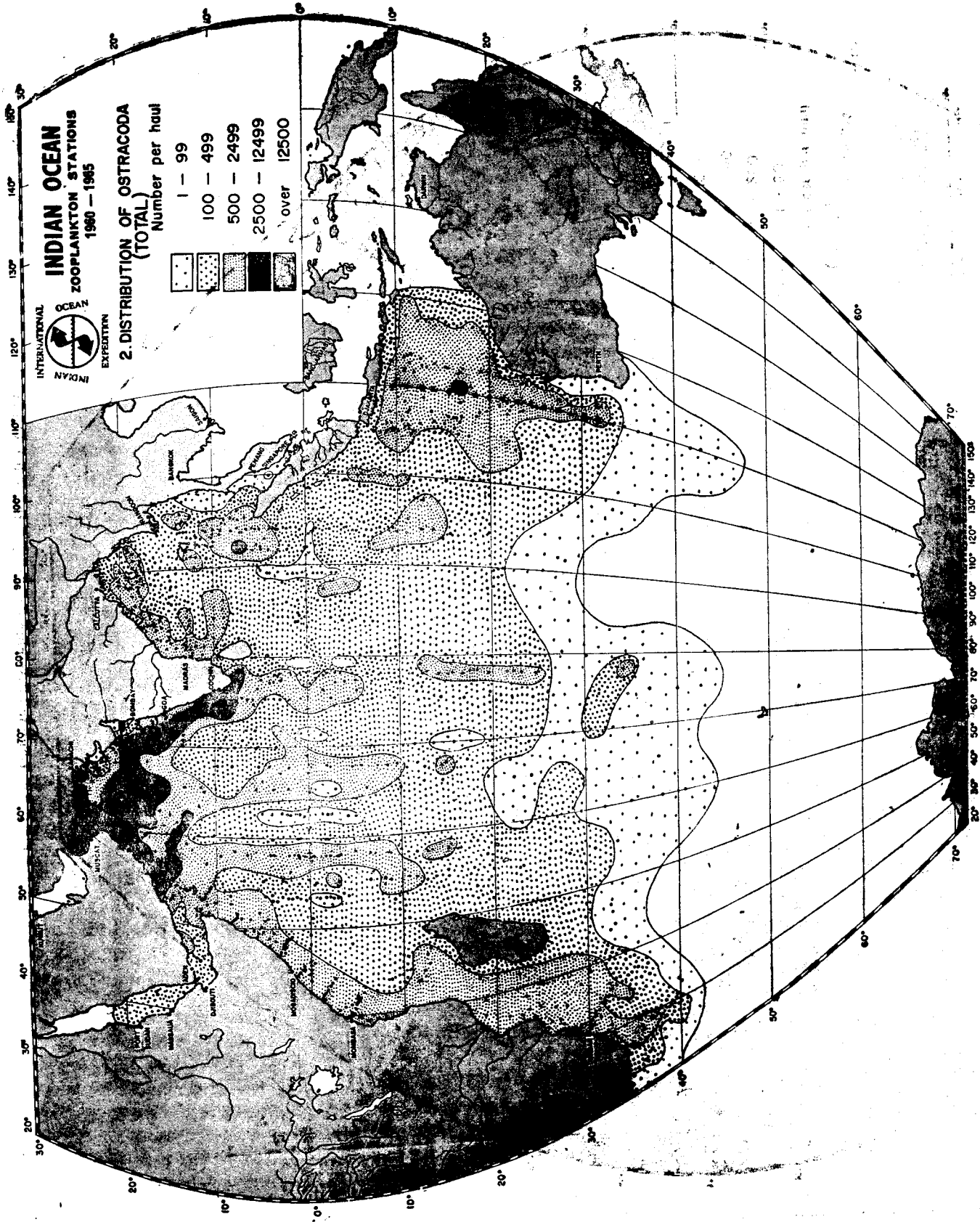
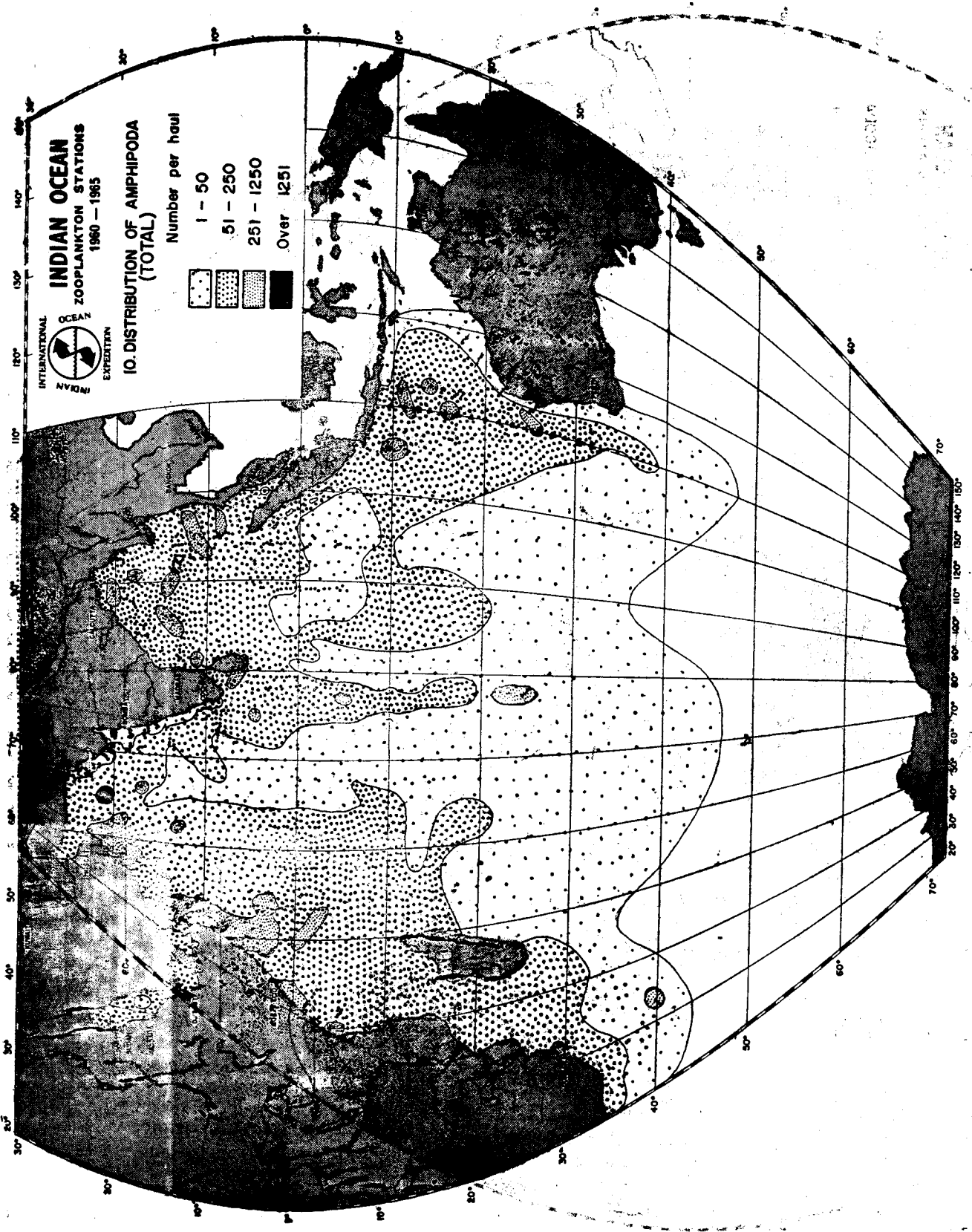


Fig. 12. Distribution of Ostracoda (total) in the Indian Ocean.



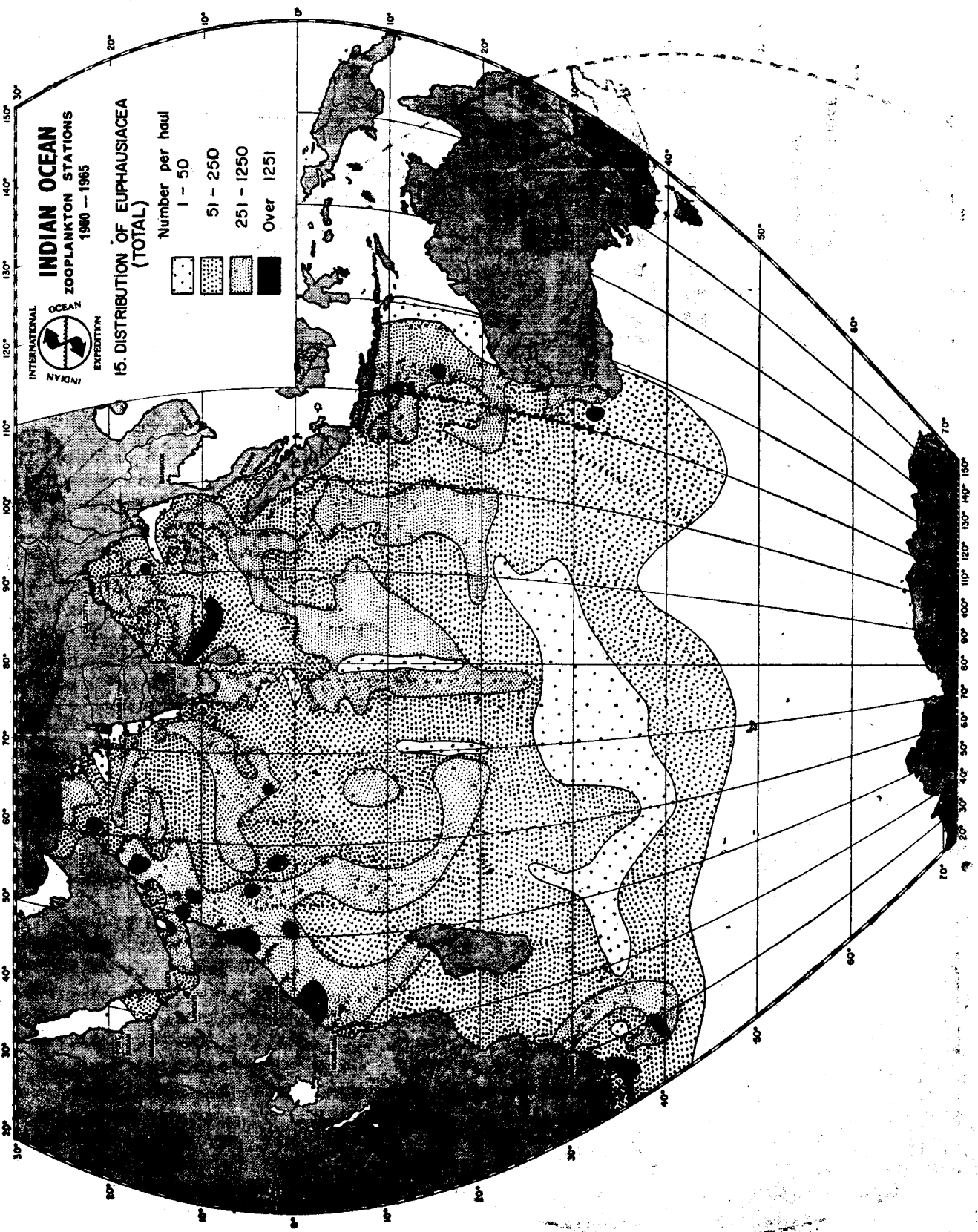


Fig. 14. Distribution of Euphausiacea (total) in the Indian Ocean.

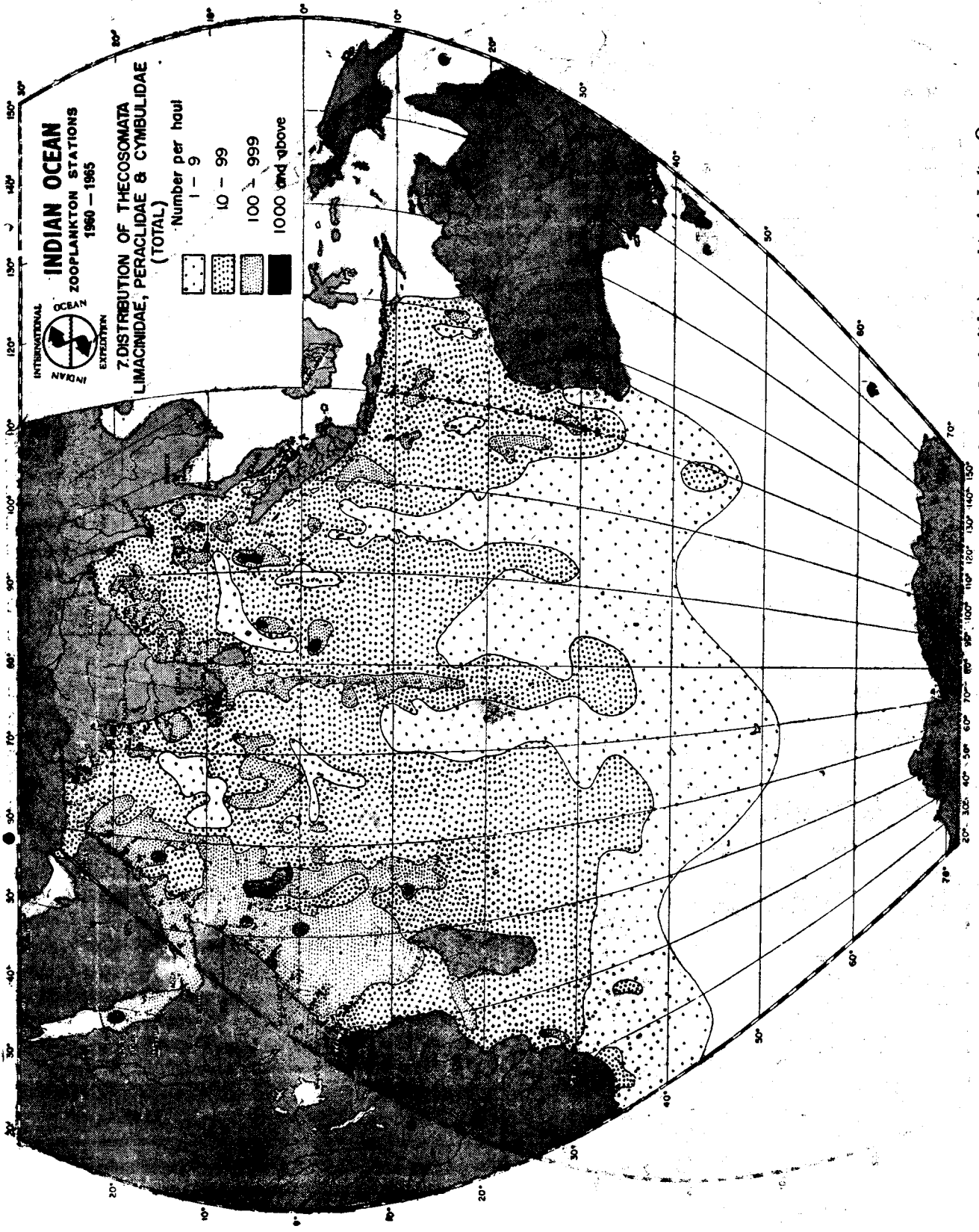


Fig. 15. Distribution of planktonic Mollusca. (Thecosomata - Limacnidae, Peracidae & Cymbulidae) total in the Indian Ocean.

ance to copepods in numerical abundance. The majority of the species belong to the family Halocyprididae.

The distribution charts for the Ostracoda is given in the IIOE Plankton Atlas Vol. III - Fascicle 1 (1972). The total distribution of the ostracods is very interesting. There is a high density patch (2500/haul) originating on the Saudi Arabian coast and this spreads right across the Arabian Sea and extends upto southern extremity of the Indian peninsula; the coastal areas south of Karachi and off Bombay, however, support low density population. Swarms of ostracods (12500/haul) are present off Karachi, Gujarat and Kerala coasts.

During the southwest monsoon northern Arabian Sea north of 13-14°N latitude and excluding the Gulf of Cambay area, has high density ostracods, similarly the Kerala coast. During the northeast monsoon a similar distribution exists, with an extension of the high density patch into the Gulf of Aden. The Burmese and Thai coasts of the Bay of Bengal have low density ostracods during both the monsoons.

The 5° square falling in between 75°-80°E and 10°-15°N has very high densities and contained on an average of more than 10,000 ostracods per haul and this happened during the northeast monsoon period. This area is adjacent to upwelling areas off Saudi Arabia and is also the home of other zooplankton groups, including fish eggs and larvae.

30 species of Ostracods were observed in the IIOE collections from the Arabian Sea. *Bathycorchoecia deeviae* is a new record for the Indian Ocean (George, 1971).

Amphipoda (Fig. 13)

Amphipods are also an important group of zooplankton, but their numbers are not as great as those of ostracods or copepods. They were found in almost all the samples at the IOBC. Their distribution is presented in 5 maps as part of Vol. III - Fascicle 1 of IIOE Plankton Atlas published by the IOBC (1972).

As in other groups, the amphipods also show high density areas along the African and Arabian coasts, isolated patches both in the Arabian Sea and Bay of Bengal and also in the West Australian area. Somehow the entire West Coast of India

has very low densities of amphipods. Another interesting feature is that the dense patches of amphipods are not as extensive as in other groups such as ostracods, copepods, or euphausiids.

During the south west monsoon, high density patches (250/haul) are present adjacent to Somali and Arabian coasts, south of Ceylon and four patches in the Bay of Bengal and one south of Java. While the Somali and Arabian coasts are known for upwelling, nothing is known about the other areas mentioned above, except for Java Sea where upwelling is reported to take place. A reference to Fig. 17 showing the distribution of surface layer, indicates that some of the dense patches of amphipods in the Bay of Bengal are close to areas where the surface layer is thin. During the northeast monsoon, the dense patches off Somalia disappears, while the Saudi Arabian patch is located further east and extends to the Gulf of Oman. A new patch appears at the tip of the Indian peninsula and some patches in the west Australian seas. It is possible that upwelling takes place in the Gulf of Oman (Weigmann, 1970) and also off Ceylon and Australian areas to account for these dense populations during the northeast monsoon.

Most of the species belong to the family Hyperiididae. Two species from the family *Dairellidae* are new records for the Indian Ocean.

Euphausiids (Fig. 14)

These are omnivorous feeders and consume diatoms, other zooplankton and detritus. In turn they form an important food base for fish and whales and the importance of this group as 'krill'—the principal food of the baleen whales of the Antarctic waters is well known. A recent estimate places the annual consumption of the krill by the whales in the Antarctic Ocean alone at 150 million tons/year and Russians are reported to be harvesting these organisms in place of baleen whales which are becoming scarce.

Preliminary observations on the distribution of Euphausiacea from the International Indian Ocean Expedition were made by Gopalakrishnan and Brinton (1969). Weigmann (1970) has given an account of the ecology and feeding habits of the euphausiids in the Arabian Sea based on Meteor collections (1964-65) during the IIOE, at the time

of the northeast monsoon. Ponomareva (1964) has also dealt with the Euphausiacea of the Arabian Sea and Bay of Bengal.

As in the case of copepods and decapod larvae, highest densities of euphausiids (1250/haul) are confined to patches along the African and Arabian coasts, two patches in the Central Indian Ocean due south of Ceylon, a large patch off Madras, one north of Andaman Islands, three patches in the Java Sea and one off Perth. The next range of density (250/haul) is very widely distributed all along the East African coast mostly north of Mombasa and a tongue of this extends into the Central Indian Ocean. There are similar bands right across the Central Indian Ocean separated by low density patches. (Atlas Vol. 3. Fasc. 1)

During the southwest monsoon high density patches appear off Somalia, Saudi Arabia and also off the Madras coast. These patches extend for hundreds of miles off shore. Except for a band of low density, the whole of Bay of Bengal has similar populations as those of the African coast. It is interesting to note very low densities of euphausiids off the Bombay and Gujarat coasts and this persists even during the north east monsoon. However, during this monsoon the Bay of Bengal has lower densities and off Madras and Ceylon the highest density patches disappear. Besides, a much wider area extending from the African to the Australian coast is occupied by the euphausiids in densities of over 250/haul, during the north east monsoon than in the southwest monsoon. Here again we have an instance where biologically speaking northeast monsoon season is more productive than southwest monsoon.

In the geographical distribution of the euphausiids Gopalakrishnan and Brinton (1969) found interesting results. *Nematoscelis microps* and *Euphausia brevis* were present at most stations south of the equator, but not north of it. *Stylocheiron microphthalma* was, on the average 4 times more abundant in the south than in the north and the opposite was the case with *Nematoscelis gracilis*. *Euphausia tenera*, *Thysanopoda tricuspida* and *Nematoscelis gracilis* were dominant forms in the north.

As already referred to, south of the equator a frontal zone is present which effectively separates

the northern Indian Ocean waters from the south. During the 'Lusiad' expedition the characteristics of the southwest monsoon current differed between the western and eastern sides of the ocean. The western side (west of 55°E) had cooler waters (26°C) in the upper 100 metres, with higher salinity, oxygen and inorganic phosphate content, perhaps due to upwelling in these areas. While the frontal zone separates north and the south Indian Oceans across the 10-12°S latitude, upwelling appears to give a special character to the western side as opposed to the eastern side of the Indian Ocean. Gopalakrishnan and Brinton (1969) found *Thysanopoda tricuspida*, *Euphausia diomediae* and *E. tenera* occur in large numbers on the western side and *E. brevis* on the eastern side of the Indian Ocean.

Planktonic mollusca (Fig. 15)

Under this, Thecosomata, Gymnosomata Heteropoda, meroplanktonic gastropoda, Nudibranchia, bivalve larvae and Cephalopoda are included and the distribution of these groups in the Indian Ocean is given in IIOE Plankton Atlas Vol. III- Fascicle 2 (1971).

Sakthivel (1969) has given a preliminary report on the distribution of Euthecosomata in the Indian Ocean based on 395 zooplankton samples collected by research vessels Argo and Anton Bruun. Aravindakshan (1969) has similarly reported on the geographical distribution of two families of Heteropoda, namely Carinariidae and Pterotracheidae. Saraswathy (1972) has given an account of the distribution of bivalve larvae.

All these studies emphasize the fact that southern Indian Ocean is very poor in most of these groups, while in the northern Indian Ocean different groups - particularly their constituent species - have a varied pattern of distribution. In most cases, the east African and Saudi Arabian coasts are rich, while the rest of the Arabian Sea, Bay of Bengal and the eastern Indian Ocean has isolated regions showing higher densities.

In the Family Cavoliniidae (the genera included here are *Clio*, *Creseis*, *Styliola*, *Hyalocylix* and *Cuvierina*) the total group distribution shows high density (>100/haul) areas near East African coast, Red Sea, Arabian coast, large patches in the central Arabian Sea, off Canara and Kerala coasts,

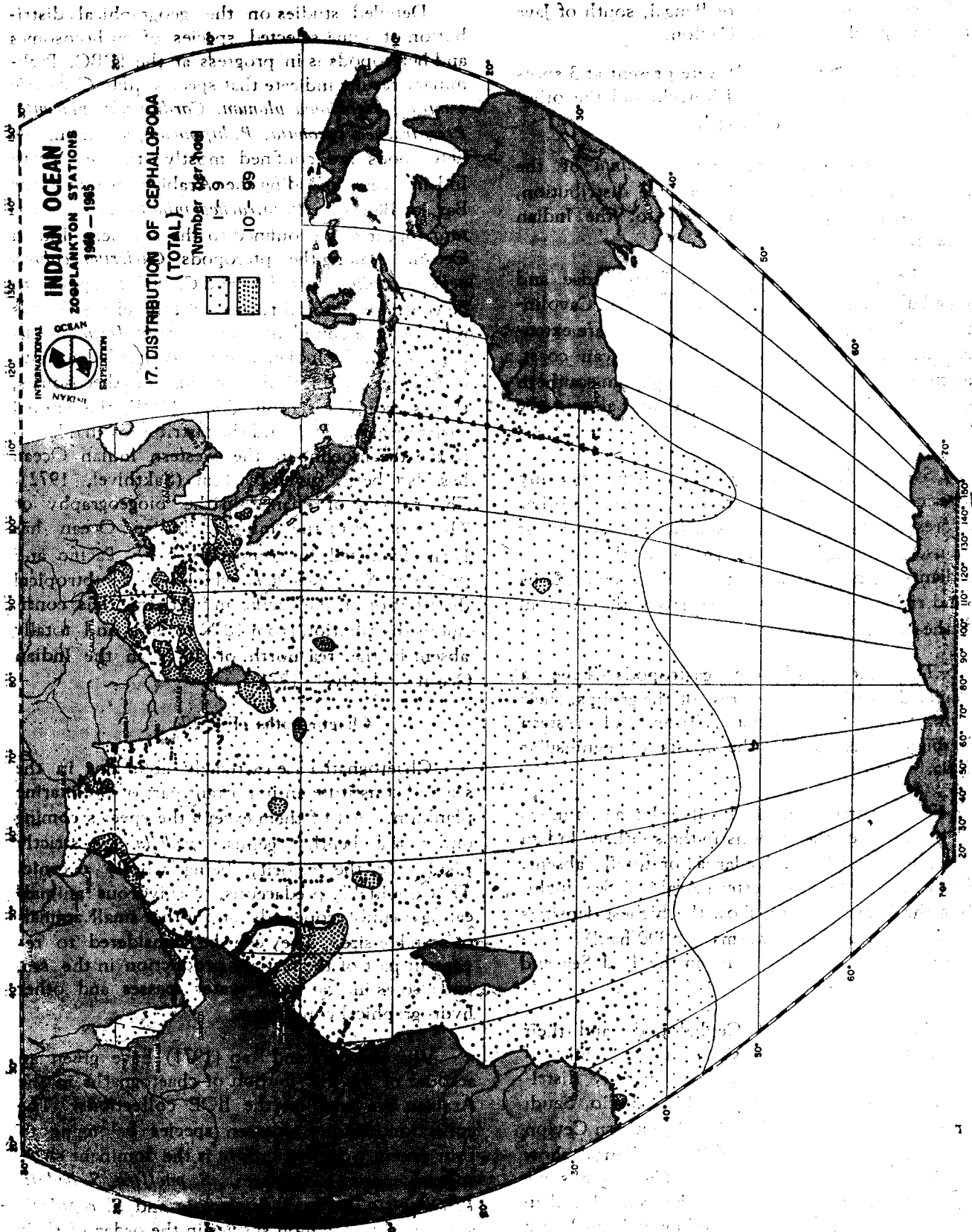


Fig. 16. Distribution of Cephalopods in the Indian Ocean.

off Madras, northern Bay of Bengal, south of Java and two patches south of Ceylon.

Swarms (>1000/haul) were present at 3 spots one in the Red Sea, one off Karachi and the other in the northern Bay of Bengal.

The genera *Diacria* and *Cavolinia* of the family Cavoliniidae have also a wide distribution, but their density is low over most of the Indian Ocean.

The families Limacinidae, Peraclididae and Cymbulidae have denser distribution than Cavoliniidae. High density areas (>100/haul) are extensive over a wide area off the East African coast, along 76–78°E longitude extending from southern tip of India, in the Bay of Bengal and also in the eastern Indian Ocean.

Swarms (>1000/haul) are present at many locations far from the coastal areas. Another interesting feature is that during the southwest monsoon the high density patch in the western Indian Ocean is broken, it forms a continuous band right across Arabian Sea from the African to the Indian coast.

The meroplanktonic gastropods have a similar distribution as the rest of the groups, their abundance hugs the east African and western Arabian coasts and also the coasts of peninsular India.

The distribution of bivalve larvae is interesting. Most of the stations in the southern Indian Ocean are poor in bivalve larvae or totally absent. As to be expected the western Arabian Sea including the Somalia region show the highest densities of bivalve larvae. Swarms (>300/haul) were present at two locations, one in the Red Sea and the other near Sumatra.

The distribution of Cephalopoda and their larvae (Fig. 16) is of great significance. While all over the Indian Ocean they are sparsely distributed, an extensive area off Mogadiscio, Saudi Arabian coast, Gulf of Kutch, off southern Ceylon and vast stretches of the Bay of Bengal show densities between 10–99/haul. There are some patches of the same density in the central Indian Ocean. The emergence of the Bay of Bengal as a rich area for Cephalopods is very interesting and should have economic implications.

Detailed studies on the geographical distribution of some selected species of euthecosomes and heteropods is in progress at the IOBC. Preliminary results indicate that species like *Carinaria cristata*, *Pterosoma planum*, *Cardiapoda placenta*, *Pterotrachea coronata*, *P. hippocampus* among the heteropods are confined mostly to the North Indian Ocean including the Arabian Sea and the Bay of Bengal. *Pterotrachea minuta* and *P. Scutata* appear to be confined to the southern Indian Ocean. Among the pteropods *Cuvierina columella*, *Cavolinia globulosa* and *C. inflexa* appear to be central equatorial forms. Sakthivel (1968) has reported the abundant occurrence of *Desmopterus gardineri* in the Indian Ocean. A detailed account on the geographical distribution of thecosomes, their seasonal variation along 110°E, the annual variation along 78°E and the distribution in relation to the thermocline in the western Indian Ocean has also been given by him (Sakthivel, 1972). The pattern of change in the biogeography of Thecosomata of the unipolar Indian Ocean has been elucidated in comparison with Pacific and Atlantic. *Styliola subula* which has bi-subtropical distribution in the Pacific and Atlantic has continuous distribution from 10°N to 40°S and totally absent in the area north of 10°N in the Indian Ocean (Sakthivel, 1971).

Chaetognaths (Fig. 17)

Chaetognatha are extremely abundant in the sea and constitute an important part of the marine plankton. All of them except the species coming under the benthic genus *Spadella* are strictly planktonic, the majority being wholly oceanic. They are highly predaceous, carnivorous animals eating mainly copepods and other small animals of suitable size. They can be considered to represent part of the tertiary production in the sea, and also as indicators of water masses and other hydrographical conditions.

Vijayalakshmi and Rao (1971) have given an account of the distribution of chaetognaths in the Arabian Sea based on the HIOE collections. The collection includes nineteen species belonging to four genera. *Sagitta enflata* is the dominant chaetognath species in this area. *S. pacifica*, *S. bedoti*, *Pterosagitta draco*, *S. bipunctata* and *S. regularis* are the other common species in the order of their numerical abundance. The maximum observed density for most of the species is near Somalia and

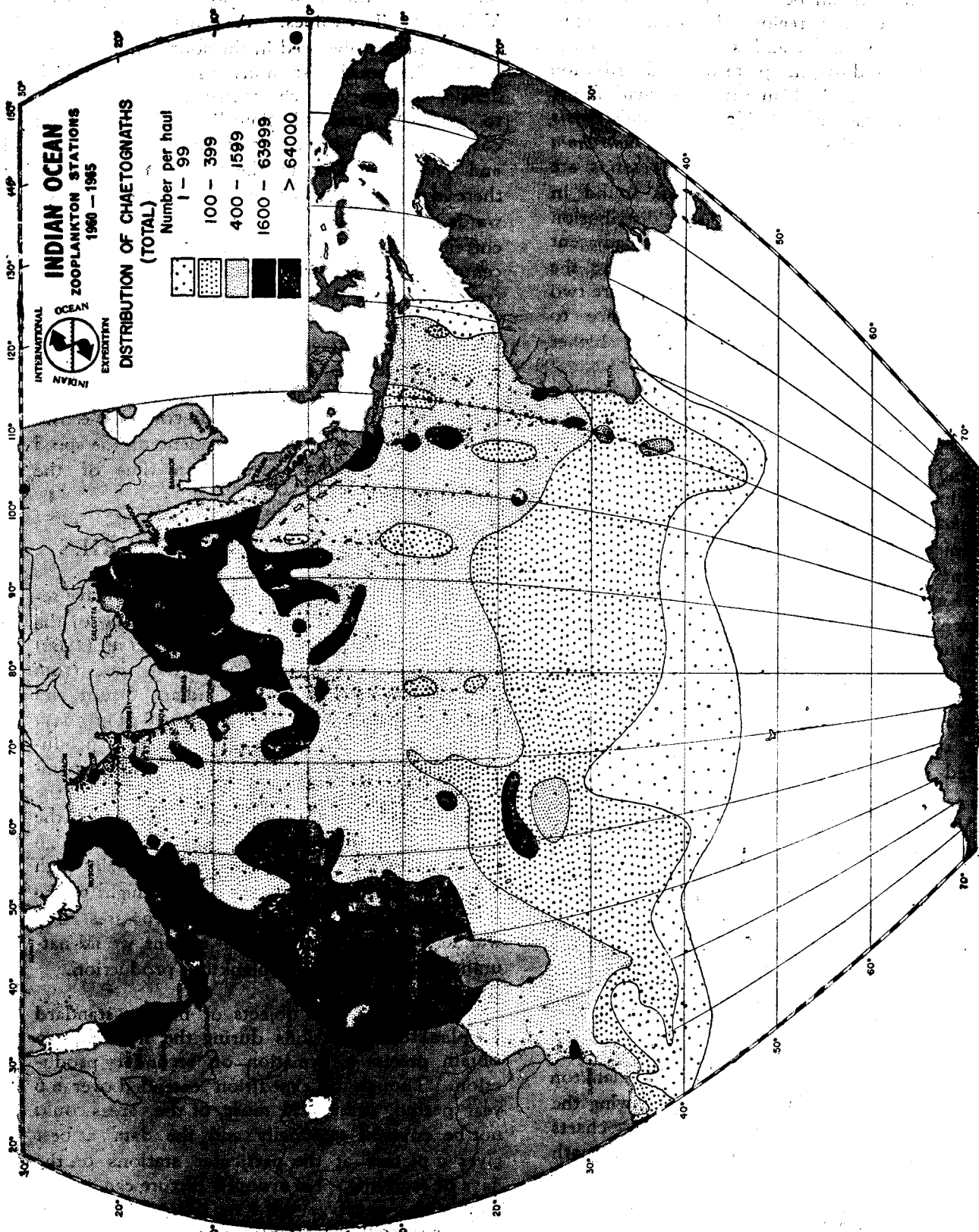


Fig. 17. Distribution of Chaetognaths (total) in the Indian Ocean.

Arabia and this can be attributed to the high productivity of the region. It is interesting to note that the abundance and scarcity of chaetognaths correspond to the pattern of distribution of copepods. The Arabian Sea chaetognath fauna are typical of the Indo-Pacific. *S. bombayensis* is restricted to the coasts of India. *Eukrohnia fowleri*, *S. decipiens*, *S. lyra* and *S. zetesios* are four deep and subsurface water species found in the collections. Variability in the distribution of chaetognaths in the Arabian Sea and adjacent sea is studied in selected localities and along the latitudes (Vijayalakshmi, (1972)). There are two categories of species one having preference to northern latitudes and the other having higher abundance towards the southern latitudes.

Recently Silas and Srinivasan (1969) have reported on the chaetognaths from the Laccadive Seas and off the west coast of India. Their collections include fourteen species of which one—*Eukrohnia minuta* is new to science. Vijayalakshmi and Rao (1971) made a comparative account of the chaetognaths of the Kavaratti and Kalpeni, two atolls in the Laccadive Archipelagoes. *Spadella angulata* recorded from the Kalpeni lagoon is a new record for the Indian waters. Their studies indicate a general impoverishment of the chaetognath population inside the lagoon and the probability of these being utilised by the coral community is pointed out.

Vijayalakshmi (1969) has given a preliminary account on the distribution of the seasonal changes in the abundance of chaetognaths in the Indian Ocean based on the IIOE collections. The period mid April to mid October shows a comparatively higher density of chaetognaths for all areas except the eastern half of the Arabian Sea. In both the periods the areas of highest density are in the western part of the Arabian Sea.

Volume IV—Fascicle 2 of the IIOE Plankton Atlas (1973) includes the charts showing the distribution of Chaetognaths. These charts show the following features. The chaetognath fauna is rich in the western Arabian Sea bordering the northeast Africa and southern Arabia, Bay of Bengal and south of Sumatra and Java. Population maxima are found off the Somali and Arabian coast, agreeing with the similar

findings for the biomass and copepods (Atlas Vol. I & II)—values. A general decrease in population is observed in the southern latitudes. During the southwest monsoon period the high density ranges of chaetognaths are confined to coastal areas off Somalia, Arabia, west coast of India, eastern part of the Bay of Bengal and Java Sea. During the northeast monsoon there is an apparent shift in the abundance westwards, presumably due to the prevailing westerly currents. Another important feature is that centres of high density chaetognaths are removed from the areas of upwelling and this is as it should be, because ecologically chaetognaths appear at a later stage in the chain of biological events that commences with the upwelling in the sea. The time lag involved displaces the late secondary and tertiary production from the centre of upwelling by a distance dependent on the speed of the current and the generation time of the species concerned.

PRODUCTIVITY AND FISHERIES

Prasad (1966) and Kabanova (1968) have reported and discussed on the productivity of the Indian Ocean (see Table 2). Ryther *et al.* (1966) summarized the primary productivity data from 231 stations in the western Indian Ocean and found low levels of productivity (0.10 gc/m²/day) in the eastern part, intermediate levels of productivity (0.26-1.00) in the equatorial and Mozambique area, and high productivity (1.00) in the northern and western portions, particularly in the western Arabian Sea. They attribute this high productivity to the presence of unusually high concentrations of plant nutrients brought to the surface by large scale upwelling processes. No wonder, therefore, the same regions would naturally support high zooplankton production.

One of the main objects of making standard zooplankton collections during the IIOE was to obtain precise information on secondary production. Though the expedition extended over a 6 year period, unhappily most of the areas could not be covered seasonally and the data at best gives a picture at the particular stations on the days of sampling. No synoptic picture can emerge from such a coverage (see Rao, 1971), but the fact remains that all the samples were collected by a standard method and to that extent they are comparable.

TABLE 7.
INDIAN OCEAN
Productivity data (Kabanova 1968)

Northeast monsoon (December-April)	Southwest monsoon (July-September)
<i>Values above 1.45 gC/m²/day.</i>	
Off Tanzania, northwestern Madagascar, Visakhatnam, head of the Bay of Bengal, Rangoon and northwestern Australia.	Off Saudi Arabia, Somalia, east coast of South Africa and central Java Sea.
<i>Values between 0.38 - 1.45 gC/m²/day.</i>	
Coasts of Tanzania and Kenya, east coast of India including Ceylon, whole of the Andaman and Java Seas and a patch along western equatorial region.	Central Arabian Sea with extension into the southwestern Indian Ocean, parts of eastern Indian Ocean extending from Sumatra to western Australia.
<i>Low values - 0.38 gC/m²/day.</i>	
Central parts of the Arabian Sea, Bay of Bengal and most of the southern Indian Ocean.	Central portion of the southern Indian Ocean.
<i>No data</i>	
From west coast of India, coasts of Sumatra, Somalia and Arabian coasts.	West coast of India north of Mangalore, most of Bay of Bengal.
Equatorial region and southern Indian Ocean poorly covered.	Equatorial region and southern Indian Ocean poorly covered.

Cushing (1971) has compiled all the productivity data in his excellent account prepared for the FAO Indian Ocean Fishery Commission on the survey of resources in the Indian Ocean and Indonesian area. He used a factor of 0.065 to convert the zooplankton biomass from the IOSN collections into gC/m² and with some corrections and assumptions, estimated the third trophic level based on 10% of the secondary production or 1% of the primary production. His figures 12 a and 12 b (*loc cit*) are very revealing. The contours indicate 5, 10, 20 and 40 tons x 10⁶ per 5° square. During the northeast monsoon the centre of the south equatorial anticyclone, centres of Arabian Sea and Bay of Bengal had low production values of about 0.5 m. tons/5° square. The west Australian region, an area of southward extension from Cape Comorin and along the equatorial belt extending from the East African coast and between equator and 5° south latitude, the whole of Bay of Bengal have values around 1-2 m. tons/5° square. Highest values indicating more than 2-4 m

tons/5° square are found right across the northern Arabian coast, off Tanzania and in the Mozambique channel, around Andaman Islands and in the Java Sea.

During the southwest monsoon, the highest values 2-6 m tons/5° square are found over the entire western Arabian Sea, off Tanzania and Mozambique channel, off the southwest coast of India and Ceylon, northern Bay of Bengal, Central Bay and Java Sea. It would appear that the southwest monsoon period makes the whole of the Indian Ocean highly productive except for the central portions of south equatorial gyre. If Cushing's estimate for the tertiary production is nearer the truth, then we have more than 50 million tons available from the Arabian Sea alone. On the west coast of India the two 5° squares adjacent to Kerala and Ceylon are estimated to support more than 8 million tons. How much of this consists of exploitable fish biomass cannot be stated at present. Prasad *et al.* (1970) while discussing the potential yield in the Indian Ocean based on zoop-

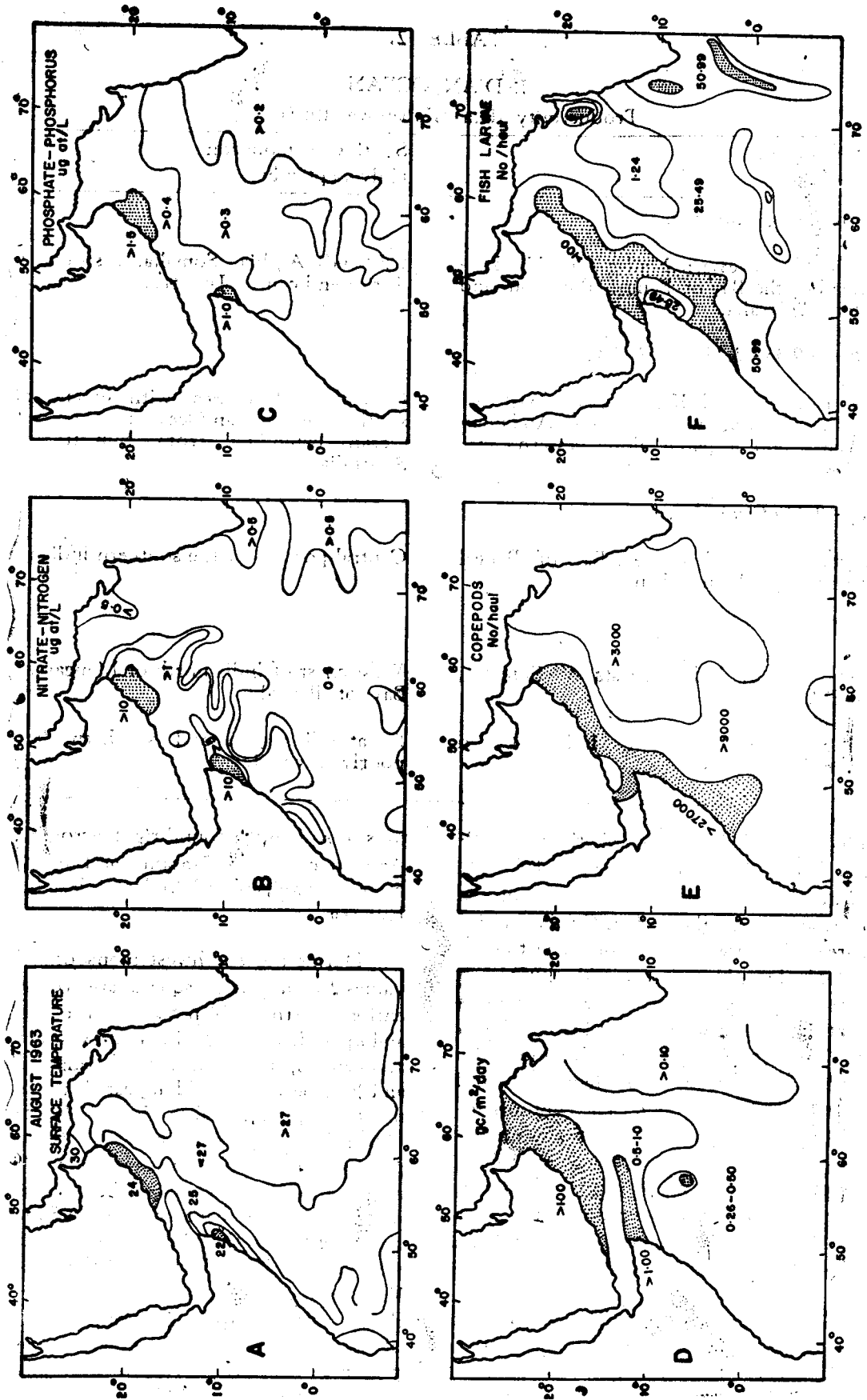


Fig. 18. Hydrobiological conditions during the Summer monsoon in the Arabian Sea.

plankton biomass, estimate that at 10 per cent efficiency of conversion the fish biomass may be in the order of 29 million tons and at 15 per cent efficiency it would be 45 million tons. They further state that such an estimate may be an underestimate since the zooplankton data on which it is based mostly comes from the oceanic areas of the Indian Ocean. However, the above reveals a pleasant picture of estimated production, particularly when it is realised that the total fish landings from the sea for the entire Indian coast was about 1 million tons in 1970.

We have very little data on the actual zooplankton production in the sea. Mullin (1969) has dealt with this problem and suggests that it is desirable to discontinue the practice of treating the whole zooplankton collection as a single entity. This is because a plankton catch represents the sum total of complicated histories of several hundred species, each, perhaps, at a different ecological or trophic level.

DISCUSSION

The picture of zooplankton distribution emerging from the study so far made on the international collection at IOBC and local collections all along the Indian coast, is of great significance for future investigations and also for planning exploratory survey for fishery resources.

The coastal waters upto a distance of a few hundred miles off Somalia, Arabia, the southwest coast of India, the Orissa coast, some areas on the equator and in the Java Sea are confirmed to support very rich zooplankton populations. We had occasion in the previous chapter to discuss broadly the reasons for such a type of distribution, while dealing with the different groups of zooplankton. For more meaningful results further studies based on species of zooplankton are in progress.

The hydrographical condition of the Indian Ocean is now fairly well known, thanks to a large number of papers published recently based on IIOE results. It is now well realized that the northern Indian Ocean north of the 'frontal zone' (10-12°S lat.) is greatly influenced by the alternating monsoons and all variations in hydrography and biology of these waters are monsoon dependent. South of the frontal zone, particu-

larly in the central part of the southern Indian Ocean, the number of stations are few and therefore the results cannot be generalized. However, on either side of the vast stretch of the ocean, the Australians made an excellent seasonal study all along the 110°E longitude and similarly South Africa has a number of stations with seasonal information. We are particularly interested in the Arabian Sea and Bay of Bengal.

Arabian Sea (Fig. 18)

Oceanographically the southern limit of the Arabian Sea could be fixed at 10° south latitude. Intensive upwelling is reported on the African, Arabian and the Indian coasts and the hydrography is well summarised by Wooster *et al* (1967), Gallagher (1966), Banse (1968), Darbyshire (1967), Rama Sastry and Myrland (1959), Swallow and Bruce (1966), Warren *et al* (1966) and many others.

Both the western and eastern parts of the Arabian Sea adjacent to the land masses have become well known for upwelling and Cushing (1971) has discussed the role of upwelling in the production of biomass of zooplankton and fisheries in those upwelling areas.

Upwelling off Saudi Arabia and south of Cape Gaurdafin takes place during May to October, the intensity and the actual area may shift with seasons. Again off the west coast of India, July to October is considered as the period of upwelling. No precise knowledge of this shallow water upwelling is available. During the northeast monsoon upwelling is indicated off Bombay (Carruthers *et al* 1959), off Ceylon (Kabanova, 1968), off Karachi, Gulf of Persia and Aden. It would appear that these are the centres from which biological activity springs and the abundance and location of zooplankton distribution is chiefly governed by the current patterns prevailing at the time of upwelling. This is proved by the spatial and seasonal distribution of the various zooplankton groups discussed earlier in the paper. In Fig 18 are shown the excellent correlation between temperature, phosphates, primary production, copepods and fish larvae both during the northeast and southwest monsoon periods in the Arabian Sea. There is no denying the fact that positive relationship exists between the various factors in upwelling areas of the Arabian Sea. The dynamics of upwelling, the enrichment of



Fig. 19. Hydrobiological conditions in the Bay of Bengal.

the surface layers, initiation of the primary production followed by zooplankton production, the timing of the spawning and development of fisheries against the upwelling background all constitute according to Cushing (1971) a biological unit and the various factors mentioned are interlinked to form a single ecosystem.

The upwelling systems are highly productive. Wooster and Reid (1963) estimate that at least 4 million tons of anchovy are removed by man and birds from the Peruvian upwelling system alone.

we have no precise knowledge from other upwelling areas. The Arabian Sea upwelling systems appear to be extensive and should support a very rich fish population.

Bay of Bengal (Fig. 19)

Panikkar and Jayaraman (1966) have drawn attention to the biological and oceanographic differences between the Arabian Sea and the Bay of Bengal as observed from the Indian region. In spite of the good coverage of the Bay of Bengal during the International Indian Ocean Expedition,

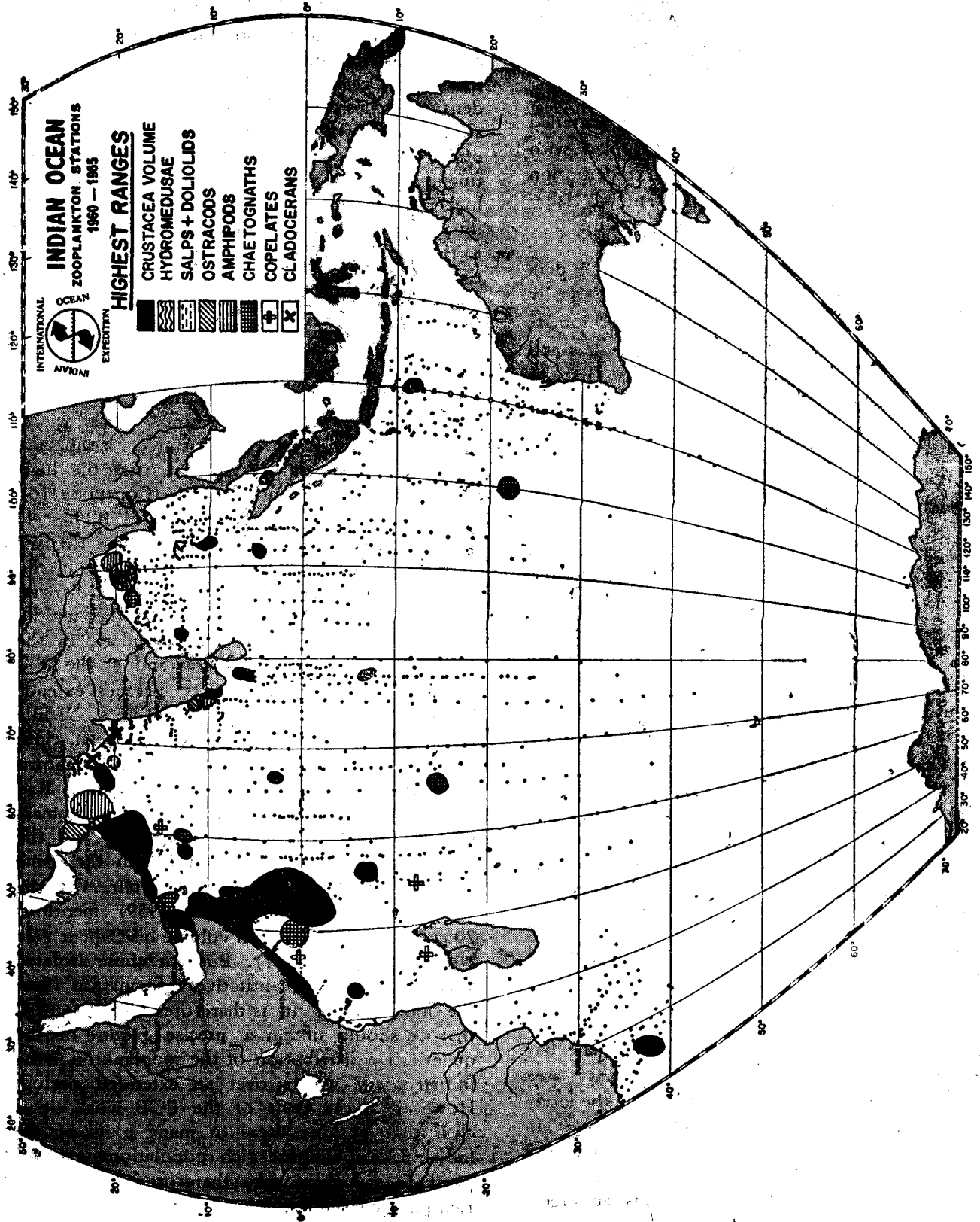


Fig. 20. Distribution of highest range of zooplanktonic groups in the Indian Ocean.

no comparable summary of the data similar to Wooster *et al.* (1967) for the Arabian Sea, is available for Bay of Bengal. No particular oceanographic phenomenon similar to the Somali current or the upwelling systems of the Arabian Sea have been reported from the Bay to attract detailed studies by any ship or country. Coupled with this is the discouraging fact that the contribution from the Bay of Bengal to the total annual fisheries of India is less than 30% (CMFRI, 1970).

However, plankton studies based on IIOE data have revealed that the Bay of Bengal is equally rich in zooplankton production and high biomass areas are present particularly off the Madras and Orissa coasts. La Fond (1954) was the first to report upwelling off Visakhapatnam and subsequently Anand *et al.* (1968) have confirmed upwelling off Madras and Visakhapatnam (June, 1964) and also intense subsurface upwelling off the mouths of Godavari and Kistna. In Figs. 6-7 (*loc cit.*) two low temperature/oxygen cells are present off Madras and Orissa coasts and these may well be centres of upwelling. Sankaranarayanan and Reddy (1969) show evidence for upwelling in the coastal areas of the northwestern Bay as early as in January. La Fond and La Fond (1968) has also reported the occurrence of upwelling off the Burmese coast and off Andamans. Cushing (1971) cites Kabanova (1968) for upwelling off Ceylon. While the intensities, duration and the location of all these upwellings are not precisely known, all these areas mentioned above coincide with high density patches of zooplankton groups in the Bay of Bengal (Fig. 20).

As already mentioned elsewhere, the Bay of Bengal has emerged as an important area for fish eggs and larvae and also for Cephalopods. Further work is necessary to arrive at meaningful estimates as to the biological productivity of the Bay of Bengal and its importance as a spawning area for fish. The reported occurrence of the early larval stages of *Rastrelliger* off the Orissa coast in May supports the view that the upwelling areas off the Orissa coast may be the spawning grounds of this important fish in the Bay. There is an urgent necessity to understand the upwelling processes taking place in the Bay, particularly off the Orissa coast.

CONCLUSION

Perhaps the most important aspect of zooplankton distribution that must be recognized in the Indian Ocean areas is the occurrence of high density patches of the different groups at considerable distances from the coast (Fig 20). In fact most of the IOSN collections are taken beyond the continental shelf and we have already mentioned that higher concentration of zooplankton population during the southwest monsoon period are found to the east of the upwelling areas and in the northeast monsoon they are located to the west of the upwelling areas. Cushing (1971) has noted that the width of the zooplankton production zone would be twice that of the upwelling zone and in the absence of a precise knowledge of the extent of the upwelling zone along the Indian coasts and elsewhere, we can perhaps estimate their width based on the extent of distribution of zooplankton. On the Somali and Arabian coasts the high density patches of zooplankton (Copepoda for example, see IIOE Plankton Atlas Vol. II, Fasc-1, Map 1) extends nearly 200-300 km into the sea as a parallel band to the coast from about the north of Mombasa to the mouth of the Persian Gulf, and this band extends almost to the middle of the northern Arabian Sea. Similarly in the area west of Ceylon, off Madras and at the head of the Bay there are high density patches extending over hundreds of square kilometers. While this description holds good for open ocean, close to the shore, zooplankton production is known only at a few stations. Ganapati and Rao (1958) estimated a very high production biomass of 3107 mg/M³ on 16th February 1956 and the monthly maximum of 1230 mg/M³ in the same month for the whole year off Waltair. On the Malabar coast Subramanyan (1959) mentions 20 cc/M³ for the plankton volume off Calicut (*loc cit.* Table XI, p. 147). But for these isolated values we have no quantitative information from the Indian coasts. It is therefore very essential that we should obtain a precise picture of the quantitative distribution of the zooplankton in the Indian coastal waters over an extended period. However, on the basis of the IIOE work, it is clear that offshore areas in many parts of the Indian Ocean support rich populations of zooplankton and these may therefore also harbour rich pelagic fisheries.

Another important aspect that could be surmised on the basis of zooplankton distribution in

the Indian Ocean is the possible areas of fish spawning. On the Peruvian and Californian coasts, where upwelling systems are studied in detail, fish are known to spawn just about the beginning of upwelling season so that their larvae can make use of the primary and secondary production that follow the upwelling. Cushing (1971) while speaking of the California current system writes that "the extraordinary point is that they (Pacific hake) spawn in the south when the larvae can take advantage of the upwelling and they migrate north to feed in the upwelling off Oregon and Washington much later in the year; so the adults live in the upwelling regions for 6 months or more during the year". A similar situation may be anticipated for the pelagic fisheries of the African and Indian Coasts. It is highly likely that sardines and mackerels spawn in the upwelling areas and follow the dispersal pattern of the zooplankton populations on which they feed. It follows therefore that the Somali-Saudi Arabian offshore upwelling areas, the Malabar upwelling system and the upwelling areas off the Orissa coast are likely to be main centres for spawning and growth of pelagic fisheries of the northern Indian Ocean.

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APPENDIX 1

Log sheet used at the IOBC for maintaining the zooplankton data from the International Indian Ocean Expedition

INDIAN OCEAN BIOLOGICAL CENTRE, ERNAKULAM-6, KERALA, INDIA

<p>Sample Serial No. Ship Cruise No./Name Station No. Lat: Long: Date & Year Collected Time (GMT) Time (Zonal) Day/Night Depth to Bottom</p>	<p>IOSN Gear Other M. Wire paid out Wire Angle Depth of Haul Vol. Water Filtered (V. W. F.) Method used to determine V. W. F. Measurements at time collected:- Biomass (Live weight) mg. Displ. Vol. ml.</p>
<p>Displ. Vol. IOBC ml. Size of subsample sorted % Dates of Sorting: From To Duration of Sorting (Hours) Sorter, Standard Sorting Sorter, Subsorting Supervision: Name Date</p>	

* In the case of Code numbers 23, 30, 47, 62 and 79, place the numbers in 3b or 4b; in all others, in 3a or 4a;
+ § in column indicates that specimens are left in the residue.

Code No.	Group	Number of specimens sorted		No. of specimens left in residue	Total No. in sample	No. per 1000 m ³ water filtered	Percentage of total catch	Condition of specimens & other remarks
		From total	From subsample					
		3a	3b	4a	4b	7	8	9
1	Residue (ml)							
§2	Ellobiopsidae. Preserved with host organism, Yes/No Host organism: Porifera (also spicules) Pillidium							
§5	Rotifera							
§6	Nematoda. Preserved with host organism, Yes/No Host organism: Actinotrocha (Phoronid)							
7	Cyphonautes							

