

4. Standing Stock and Distribution of Zooplankton

4.1

Zooplankton Studies in the Indian Ocean

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There are a number of papers dealing with the distribution of different species and groups of zooplankton from the coastal areas of the Indian Ocean, particularly adjacent to India, Australia and South Africa. However, for many reasons these studies are not comparable to the observations made on the present IIOE collections. Firstly, with a few exceptions, the IIOE collections were taken from the open ocean and secondly they were collected over a period of 6 years (1960–1965) from a wide area of the Indian Ocean. Most of them were collected with the Indian Ocean Standard Net, IOSN (CURRIE, 1963)

Table 1. Indian Ocean Stations (prior to IIOE)

Ship	Date	No. of Stations ^a
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. "Scalark"	1905	23
7. "Planet"	1906–07	57
8. "Möwe"	1912–13	7
9. "Dana"	1928–30	171
10. "Snellius"	1929	25
11. "Discovery II"	1930, 32, 35, 38	124
12. "Mabahiss"	1933–34	80
13. "William Screschy"	1935, 36, 50	60
14. "Albatross"	1947–48	22
15. "Charcot"	1948–49	10
16. "Galathea"	1950–52	48
17. "Umitaka Maru"	1956	32
18. "Guillard"	1961	77
	Total:	<u>924</u>

^a The information under this column is not complete and does not include stations south of 45° S latitude.

vertically from 200 m depth to the surface. Table 1 shows the work done before the IIOE. Table 2 indicates the density of samples taken during the IIOE for 4 different seasons. Tables 3 and 4 respectively give the seasonal coverage of selected areas and areas of poor zooplankton sampling during the IIOE. Figs. 1–3 illustrate the sampling coverage by area and time.

Table 2. International Indian Ocean Expedition (1960-1965), density of samples

Areas	Limit	Total No. of 5° Sq.	Total No. of samples No. of % Samples ^a	Poor coverage		Moderate coverage		Good coverage								
				Without samples No. of % 5° Sq.	1-5 samples No. of % 5° Sq.	6-10 samples No. of % 5° Sq.	11-20 samples No. of % 5° Sq.	No. of No. of % 5° Sq.								
North Indian Ocean	25° N-5° S 35° E-105° E	69	1. 304	61.3	23	33.3	21	30.4	14	20.3	11	15.9	-	-		
			2. 303	61.9	26	37.7	25	36.2	8	11.6	7	10.1	7	10.1	3	4.3
			3. 279	54.9	22	32.0	26	37.2	15	21.7	5	7.2	5	7.2	1	1.4
Central Indian Ocean	5° S-25° S 30° E-120° E	69	4. 261	60.8	30	43.5	19	27.5	12	17.4	7	10.2	1	1.4		
			1. 119	24.0	41	59.4	21	30.4	5	7.3	5	7.3	2	2.9	-	-
			2. 120	24.5	42	60.9	21	30.4	1	1.4	1	1.4	5	7.2	-	-
South Indian Ocean	25° S-45° S 20° E-120° E	77	3. 131	25.8	34	49.3	27	39.1	7	10.2	1	1.4	-	-		
			4. 100	23.3	42	60.8	22	31.9	5	7.2	5	7.2	-	-	-	-
			1. 073	14.7	53	68.8	20	26.0	3	3.7	3	3.7	1	1.3	-	-
Indian Ocean	25° N-45° S 20° E-120° E	215	2. 066	13.6	54	70.2	19	24.7	3	3.9	1	1.3	-	-		
			3. 098	19.3	48	62.4	22	28.5	6	7.7	6	7.7	1	1.3	-	-
			4. 068	15.9	48	62.2	26	33.8	3	3.9	3	3.9	-	-	-	-
Indian Ocean	20° E-120° E	100	1. 496	100	117	54.4	62	28.9	22	10.2	14	6.5	-	-		
			2. 489	100	122	56.7	65	30.2	12	5.6	13	6.0	3	1.4	-	-
			3. 508	100	104	48.4	75	34.9	28	13.0	7	3.3	1	0.4	-	-
			4. 429	100	120	55.8	67	31.2	20	9.3	7	3.3	1	0.4		

^a Numbers in column 5 indicate periods as follows:

1. January-March (NE monsoon)
2. April-June (Transitional)
3. July-September (SW monsoon)
4. October-December (Transitional)

Table 3. The incomplete seasonal coverage of selected areas covered in greater detail during the IIOE

Area	Incomplete months during the period of IIOE
1. West Coast of India and Pakistan 07° 00' N—25° 00' N 65° 00' E—77° 00' E	January, April, June, July, September and October
2. Somali Coast 06° 00' N—12° 00' N 40° 00' E—55° 00' E	February, March, April, May, June, September, October and November.
3. South Arabian Coast 12° 00' N—25° 00' N 47° 00' E—65° 00' E	January, March, April, August and September.
4. West Bay of Bengal 10° 00' N—21° 00' N 80° 00' E—91° 00' E	February, August, October, November and December.
5. East Bay of Bengal 05° 00' N—21° 00' N 90° 00' E—100° 00' E	January, February, May, July, October, November and December.
6. Equatorial Zone 06° 00' N—06° 00' S 40° 00' E—100° 00' E	March
7. West Australian Coast 12° 00' S—45° 00' S 104° 00' E—114° 00' E	March, June, and November

Table 4. Areas of poor coverage of zooplankton sampling during the IIOE

1. Mozambique Channel	11. East Bay of Bengal
2. 5° S — 50° S	16° N 22° N
40° E — 53° E	91° E — 99° E
3. 5° S — 22° S	12. 10° N — 12° N
59° E — 64° E	82° E — 90° E
4. 7° N — 50° S	13. 6° N — 8° N
72° E — 75° E	83° E — 91° E
5. 5° S — 50° S	14. Off Sumatra Coast
80° E — 90° E	5° N — 7° S
6. 7° S — 50° S	15. 5° N — 10° N
95° E — 99° E	53° E — 58° E
7. 7° S — 50° S	16. 13° N — 15° N
100° E — 104° N	60° E — 70° E
8. 9° S — 20° S	17. 20° N — 25° N
114° E — 117° E	61° E — 66° E
9. Gulf of Mannar	18. 10° N — 13° N
10. Coastal areas of Bay of Bengal	70° E — 74° E
18° N — 22° N	19. Persian Gulf
85° E — 99° E	20. Red Sea

I. Biomass

Plankton biomass distribution in the Indian Ocean formed the subject matter for Vol. I, fascicles 1 and 2, of the Plankton Atlas issued by the IOBC (IOBC, 1968 a, b). (PRASAD (1966, 1970) has given a detailed account of the distribution of the biomass

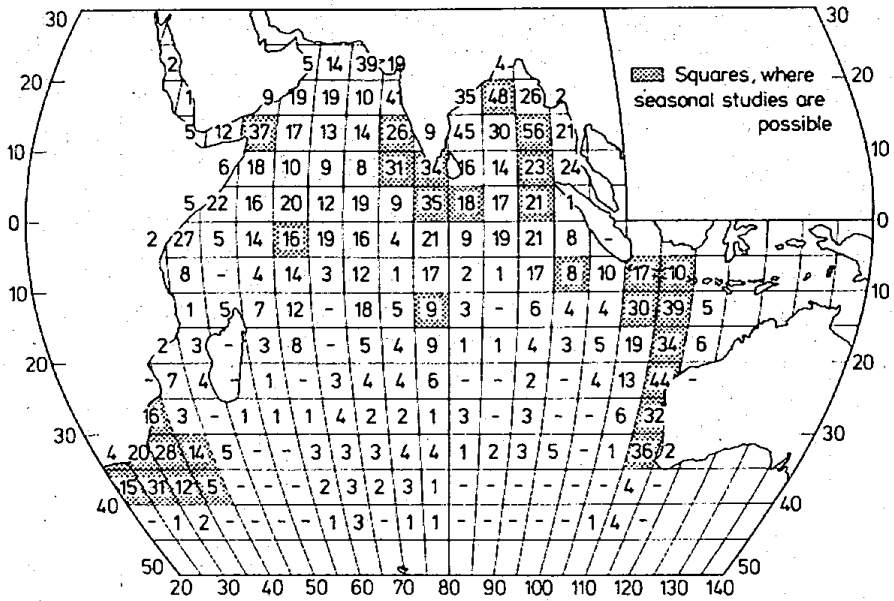


Fig. 1. Number of collections in each 5° square

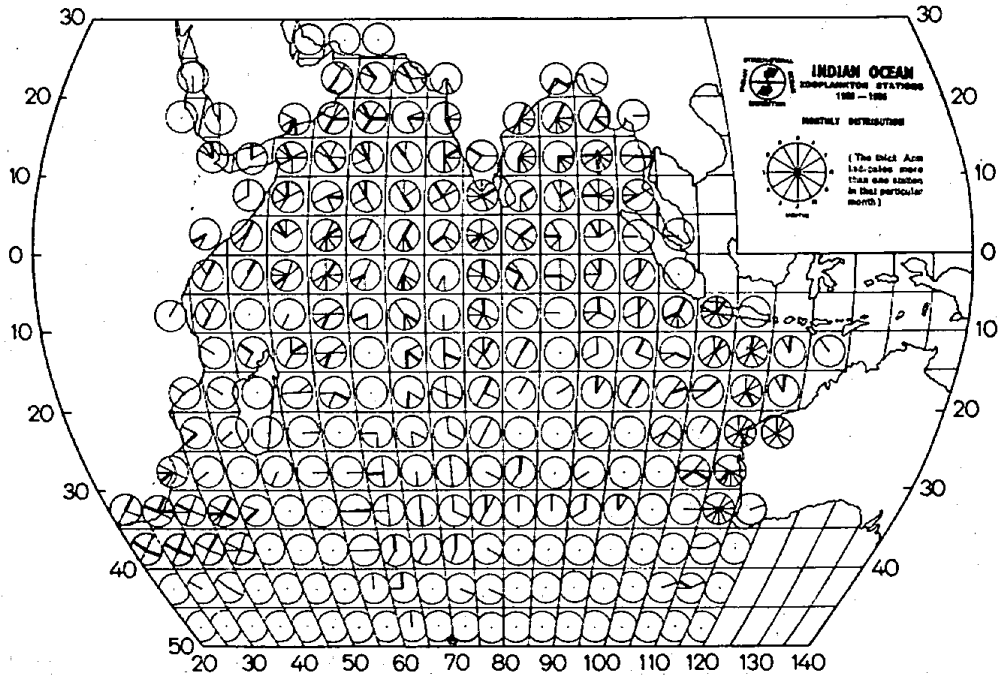


Fig. 2. Monthly coverage of zooplankton stations

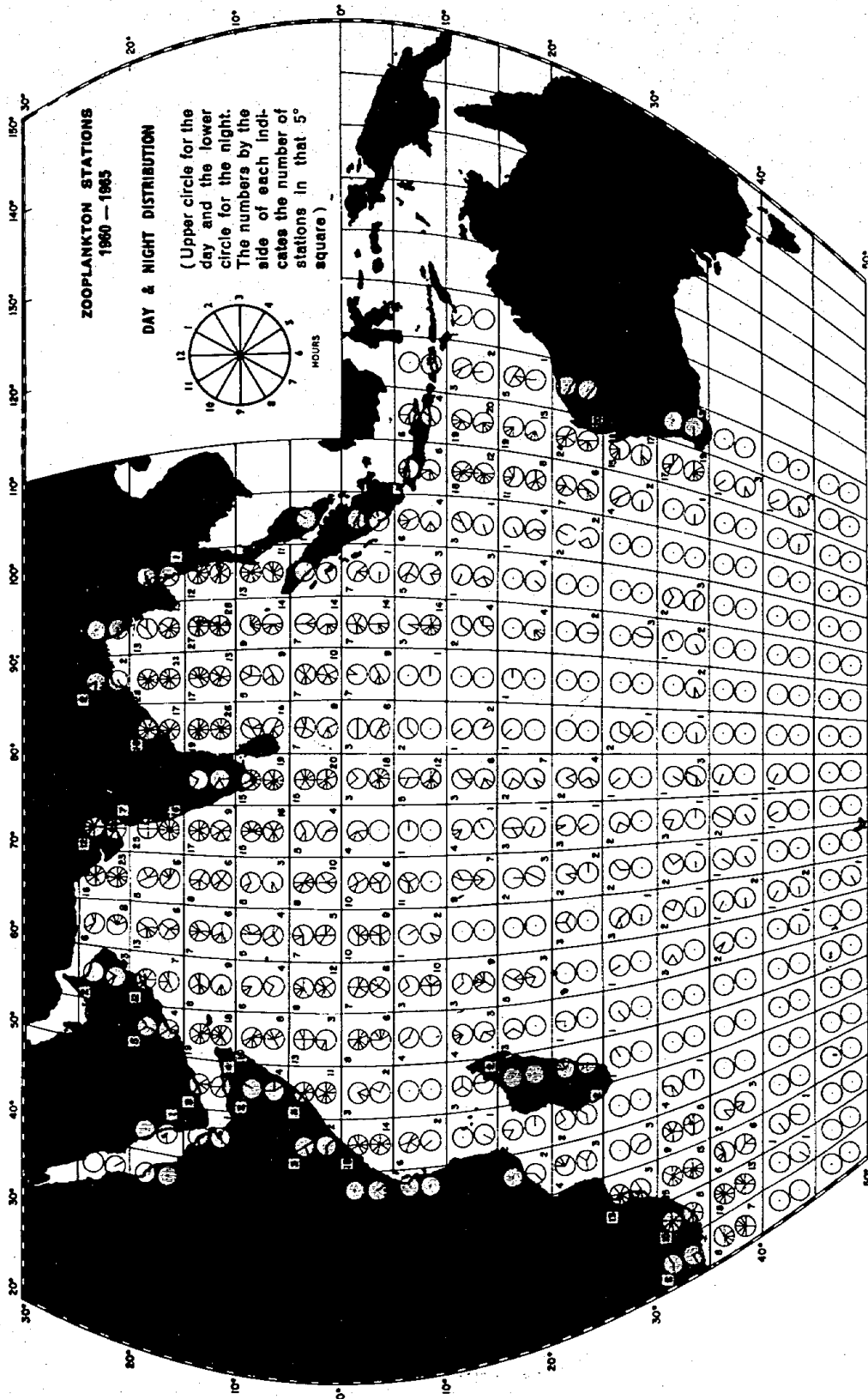


Fig. 3. Day, night and hourly coverage of zooplankton stations

(wet zooplankton displacement volumes expressed as ml per haul taken by the IOSN) in the Indian Ocean based on the data from 1622 samples included in the above atlas (see map on the inside of the front cover).

PRASAD observes that the volumes are highest in the Arabian Sea between lat. 10° to 25° N and long. 50° to 65° E, more particularly in the area off the Somali coast and the coast of Saudi Arabia. Average values as high as 54.7 ml m^{-2} (for 200 m column) were noted off Arabia, with Somali showing 15–35 ml and ± 15 ml all over the southeastern 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 per haul.

The data for the atlases mentioned above were based on average values calculated from all the stations in every 5° square. The area was divided into 2 monsoon seasons,

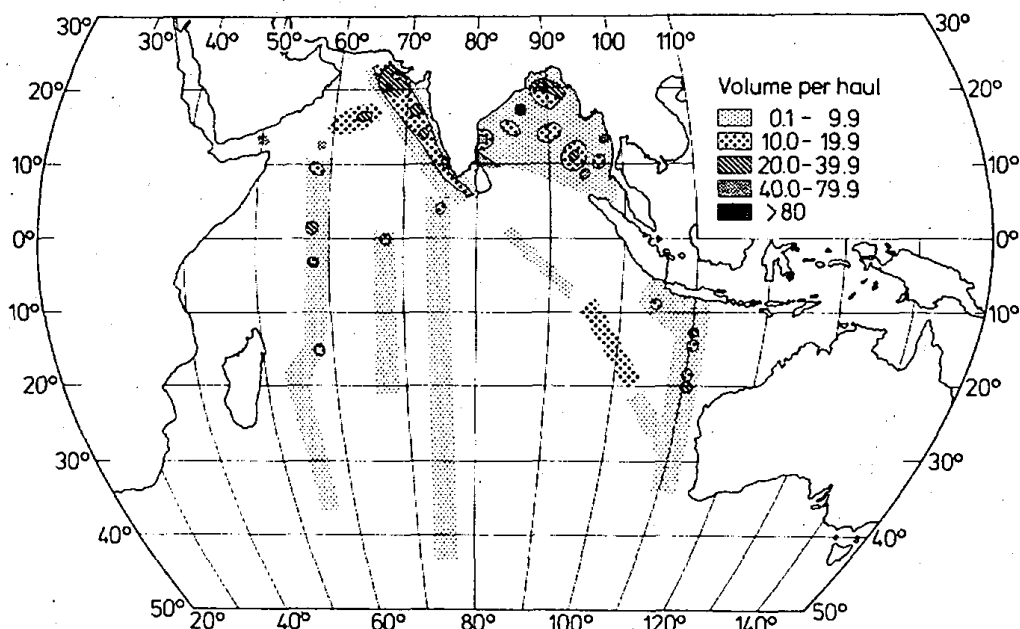


Fig. 4. Biomass distribution in the Indian Ocean, March–April in ml m^{-2} for 200 m column (Premonsoon season with variable conditions)

the SW monsoon extending from 16 April to 15 October, and the NE monsoon from 16 October to 15 April. Day and night treatment was also attempted. During the SW monsoon 3 centres of high biomass (50–60 ml) were noted in the Arabian Sea, located off the Somali, Oman and Kerala coasts. In the Bay of Bengal a similar region was present at the head of the Bay with an average value of around 20–40 ml. During the NE monsoon high values off the Somali coast and Kerala coast were not present, but off the Saudi Arabian coast the peak areas had shifted westward and nearer to 10° N latitude as compared to the situation during SW monsoon when it was in the vicinity of 20° N latitude. The night values were generally higher than day values.

In order to obtain a realistic picture of the biomass, the available data from 1548 standard samples were replotted on 5 different charts (Figs. 4–8) to show the biomass distribution for 5 different periods, as described by DÜING (1970). The different seasons are based on winds and surface currents of the Indian Ocean.

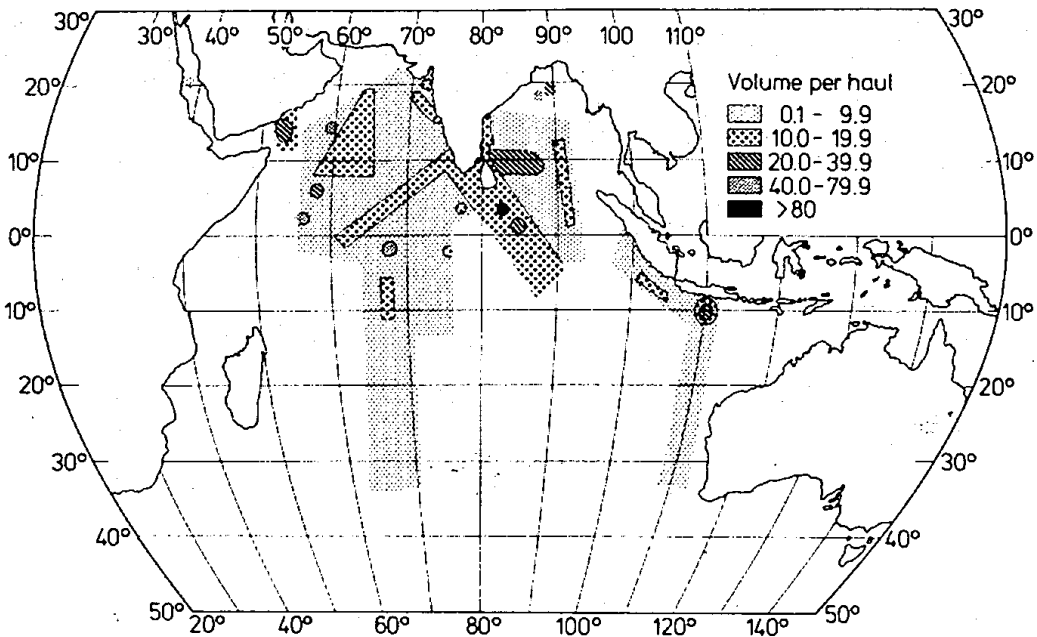


Fig. 5. Biomass distribution in the Indian Ocean, May–June in ml m^{-2} for 200 m column (Beginning of the SW monsoon)

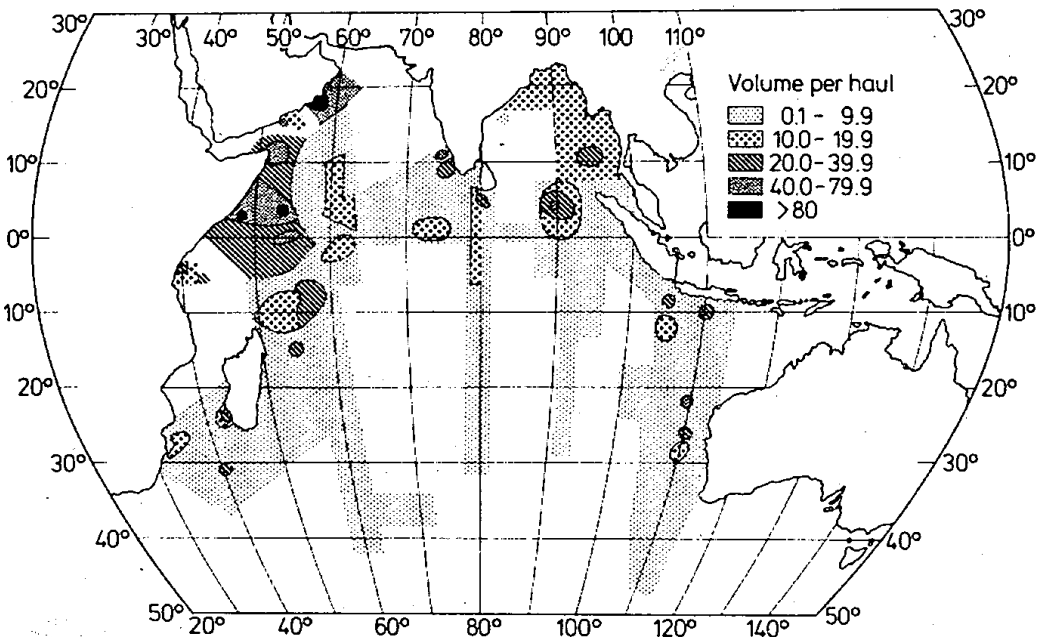


Fig. 6. Biomass distribution in the Indian Ocean, July–September in ml m^{-2} for 200 m column (SW monsoon, well stabilized all over the area)

During the height of the NE monsoon (December to February) data from 431 samples indicate the occurrence of 20–39.9 ml m^{-2} biomass in the region of the Gulf of Aden and north of Mombasa. A few spots indicating highest range, i.e. 80 ml and above, were

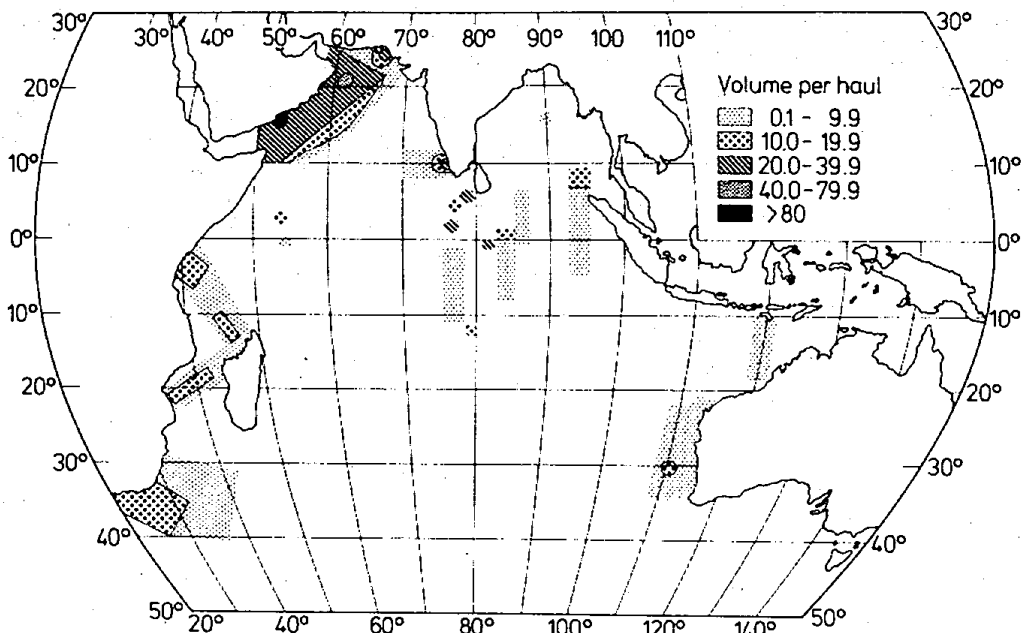


Fig. 7. Biomass distribution in the Indian Ocean, October–November in ml m^{-2} for 200 m column (Postmonsoon season with variable conditions and beginning of NE monsoon)

located off Madras in the Bay of Bengal, off Goa along the west coast of India. The 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. The west coast of India and the Bay of Bengal are well covered.

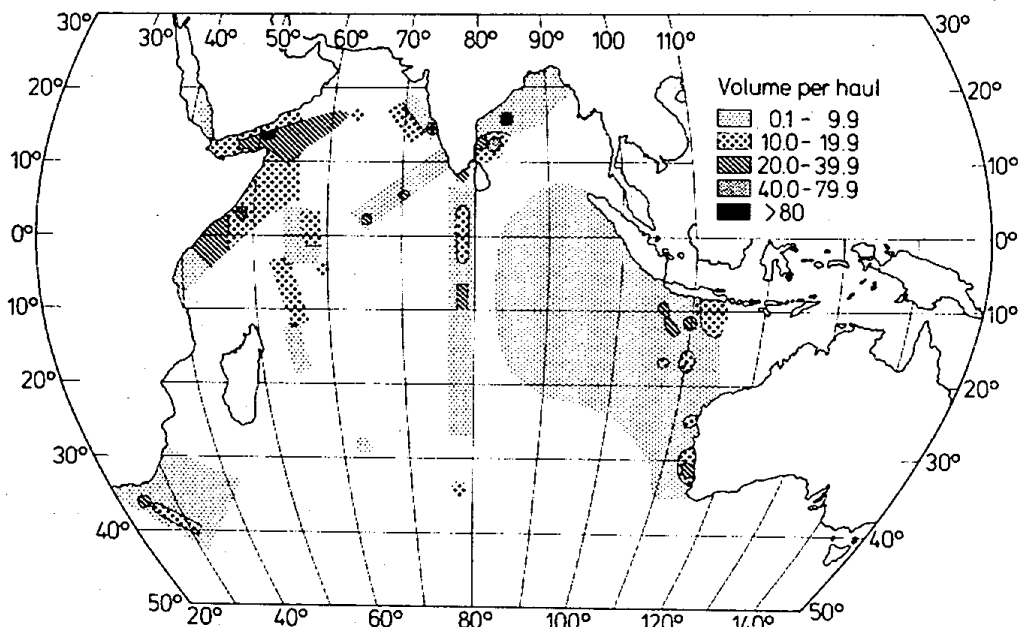


Fig. 8. Biomass distribution in the Indian Ocean, December–February in ml m^{-2} for 200 m column (NE monsoon, well established all over the area)

Both the areas show patches of middle range values (10–39.9 ml) against a background of low biomass (0.1–9.9 ml). Large patches in the central Arabian Sea and eastern Indian Ocean show values from 10–19.9 ml.

The May–June period witnesses the commencement of the SW monsoon. Here also we have no data from the Somali and Arabian coasts nor from the eastern Bay of Bengal. Patches of high values are scattered with a rich patch of biomass (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 when the SW monsoon is fully established all over the north Indian Ocean. There are 451 samples for this season but unfortunately

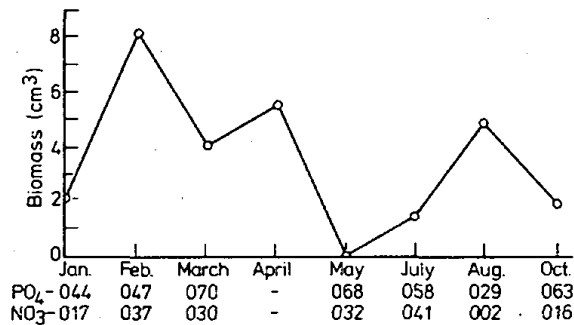


Fig. 9. Biomass, phosphate and nitrate data at the reference station at 32° S and 110° E. Nutrient concentration $\mu\text{g-at l}^{-1} 10^{-2}$

there are no data for most of the west coast of India north of Mangalore and the Madras coast. High biomass values, 40 ml and above, are found in stations off Somalia (between Garad and Ras Mabber) adjacent to Cape Guardafui and off the Oman coast. Values ranging from 20–39.8 ml 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 is the transition period and marks the end of the SW monsoon and the beginning of the NE monsoon. There are 180 samples for this period, mostly off the Saudi Arabian coast. This is the only region having biomass values of 20–39.9 ml. The rest of the areas have 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 SW monsoon period. A comparison of the biomass distribution with the surface thickness layer distribution makes clear that high biomass values overlap areas of no 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, SCHAEFER and ROBINSON, 1967) creates divergent conditions off the Saudi Arabian coast and thus favours large-scale upwelling. In July, August and September the lowest temperatures on this coast are 23°–25° C. Salinity is high and constant throughout the year. Distribution of nutrients indicates high values for this area. All these circumstances combine to make the Saudi Arabian coast the richest area for secondary production in the north Indian Ocean.

In the southern Indian Ocean the number of samples available for analysis are few. There are 2 exceptions, the seasonal repetitive cruises along 110° E (TRANter, 1973)

and the "Africana" cruises off South Africa (DE DECKER, 1973). At 32° S 100–112° E there are 14 observations made by Australian scientists covering 8 months of the year. The biomass at this station is very low and shows a bimodal fluctuation, high values being observed during February and August (Fig. 9).

In the "Africana" collections the biomass values are higher than at the 32° S–100° E station, and variable (0.9–21.7 ml for 100 m³). Most of the stations here are located on the continental shelf and the data here are excellent for correlation with hydrographical parameters. 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.

II. Distribution of Copepoda

As the copepods form a good percentage of the zooplankton both in volume and numbers, the pattern of distribution of biomass already described (IOBC, 1970 a), reflects to a large extent the distribution of copepods and in fact many other groups such as amphipods, chaetognaths, cladocerans, fish eggs and larvae, etc. In the Bay of Bengal there is a high-density region in the head of the Bay during the SW monsoon (April 16–October 15) which disappears during the NE monsoon season. It is also clear from these charts that the area of high density of the copepods spreads out from the area of upwelling in the direction of the prevailing currents. *Gaussia princeps* (T. SCOTT) studied by SARASWATHY (1973) reveals that this bathypelagic species exists in areas of the Indian Ocean where intermediate waters come up within 200 m of the surface. *Haloptilus acutifrons* (GIESBRECHT) studied by ROSAMMA and SARALADEVI (personal communication) considered to be a deep water species, presents a pattern of distribution suggesting that it is euryphagous, eurythermal and euryhaline and was taken in stations where the O₂ was not less than 1.5 ml l⁻¹ and seems to avoid salinities higher than 36‰.

III. Decapod Larvae

The total distribution of decapod larvae (IOBC, 1970 a) shows the interesting feature that while off the Somali, Indian and Burmese coasts high numbers (301–900 per haul) occur adjacent to the coast, off Saudi Arabia they occur at a great distance (150–200 miles) from the shore. They are also distributed much more extensively during the SW monsoon than in the NE monsoon. The occurrence of a dense patch of larvae south of Java (over 2,700 per haul) and a large patch of high value (300–2,700) south of the Andaman is noteworthy.

Very high concentrations of the larvae are met with at one station each in the western and eastern Indian Ocean, off Port Elizabeth and south of Java respectively, and 3 stations off the west coast of India (mostly brachyuran larvae). In the central Indian Ocean south of 10° S latitude there is very little representation of these larvae in the plankton.

The larvae of penaeid prawns show a maximum concentration around the southern extremity of the Indian peninsula and off the Somali coast. Similar patterns of distribution are found for other families of decapod larvae.

IV. Fish Eggs and Larvae

Taking the distribution of fish eggs as an indication of spawning areas, the IOBC Atlas (IOBC, 1970 b) reveals that such centres are located adjacent to the Saudi Arabian coast and the northeastern Bay of Bengal. These areas are consistently rich and show a high range (100 per haul) throughout the monsoons and also in the day and night distribution of eggs and larvae. PETER (1967) has recorded for the first time early stages of the mackerel at 3 stations, one at the head of the Bay of Bengal, the other off Madras and a third in the Gulf of Oman. It is clear that the IOSN samples have not shown the existence of a sufficient number of larvae to distinguish the breeding grounds of commercially important fisheries, particularly sardines and mackerel. While the oceanic zone is dominated by the larvae of bathypelagic fishes such as gonostomids, stomiatids, myctophids, etc., the intermediate zone towards the coastal areas is found to be the richest for fish larvae of economic importance. The families *Thunnidae*, *Scomberomoridae*, *Carangidae*, etc. are all well represented here.

In conclusion it may be stated that the emergence of the northeastern Bay of Bengal as an area of fish spawning is an important discovery of the IIOE. The poor catches of fish in the Bay of Bengal should not mislead us and make us overlook the possibilities of finding rich fishery resources here as indicated by IIOE data on fish eggs larvae and biomass distribution.

V. Mollusca

The family *Cavolinidae* (*Clio*, *Creseis*, *Styliola*, *Hyalocylix* and *Cuvierina*) seems to be densely distributed off the Somali coast, in the Red Sea, off the south of Java, the southwest coast of India and the northern part of the Bay of Bengal; the highest peak is in the Red Sea, the maximum number being 3160 at "Discovery" station 5002 A. The same station is noted for its peak abundance of *Limacinidae*, *Peraclidae* and *Cymbulidae* (the highest number is 6920). This is also true in the case of meroplanktonic gastropods (the maximum number being 3360). *Limacinidae*, *Peraclidae* and *Cymbulidae* are abundant in the Red Sea and western Arabian Sea off Mauritius, including the Mozambique Channel to the Persian Gulf. During the NE monsoon rich areas of *Limacinidae*, *Peraclidae* and *Cymbulidae* extend to the west coast of India and also along the meridians between 75° E and 85° E for a long distance in the central Indian Ocean.

Bivalve larvae are densely distributed around the Somali coast and the southern coast of Arabia, the SW coast of India, north of Sumatra and south of Java with dense patches scattered in these areas. Maximum abundance was in the Gulf of Aden. Bivalve larvae are sparse along the coastal areas of Australia and South Africa and the east coast of India.

In the case of cephalopod distribution, the areas of highest abundance were observed in the northern part of the Bay of Bengal and also on the western half of the Bay off the Madras and Andhra coasts. In addition, they are well distributed off the Somali coast, Arabian coast, Kutch and south of Ceylon. Here again the Bay of Bengal is outstanding for the abundance of cephalopod larvae.

VI. Other Groups

Amphipods, cladocerans, euphausiids, chaetognaths, medusae, copepods, salps, and doliolids, ostracods, and polychaetes are all under study at the IOBC. The distribution

of most of these groups follows the same pattern as that of the copepods, fish eggs and larvae, the richest region being the Saudi Arabia and Somali coasts. For example, amphipods show a great abundance along the coasts of Oman, Somalia, west coast of Burma and off the southern coast of Java, increasing in general towards the northern part of the Indian Ocean. Their numbers decrease southwards.

Chaetognaths, too, show a similar distribution. The highest density was recorded in the western part of the Arabian Sea and their numbers also decrease southwards. It should be noted, however, that the concentration of these groups overlaps and also radiates from the areas of upwelling. This would be expected because the development of maximum populations of carnivores or omnivorous groups of plankton takes some time in the sequence of biological events in the sea. Firstly, there is local enrichment due to upwelling and as the surface waters get fertilized and spread under the influence of the local currents, the development of the phytoplankton population is displaced in space and time, and by the time copepods and their predators begin their population explosion, they may be located quite some distance from the area of upwelling. This is precisely what happens in the case of distribution and abundance of copepods, fish larvae and chaetognaths, amphipods and other groups in the northern Arabian Sea and the Bay of Bengal (see Plankton Atlases Vols I and II, IOBC, 1968, 1970).

VII. Numerical Distribution

Assuming that each IOSN sample of zooplankton represents the optimal distribution and occurrence in the 192 m³ of water strained through the net, Table 5 was prepared in order to see whether any relationship exists between the different kinds of plankton. A 5° Marsden square (067-4) where we have data for about 5 months was arbitrarily selected and the numerical data were tabulated. Ecologically, the copepods are the major grazers and next come the copelates. The rest of the groups listed are mostly carnivorous or omnivorous; they are also capable of devouring each other or may even be cannibalistic in some cases. The order of dominance appears to be, barring copepods

Table 5. No. of zooplankters % of the total. Marsden square: 067 (4)

Station No.	ABA 3	D1 5251	D1 5012	D1 5089	AB 4A 170	Average Value
Months	Feb.	Mar.	June	Aug.	Oct.	
Copepoda	69.74	73.47	76.91	72.30	75.53	75.59
Chaetognaths	8.41	12.30	3.63	4.06	10.08	6.41
Copelata	0.07	1.13	1.89	2.76	0.66	1.09
Medusa	0.22	0.30	0.13	0.66	0.27	0.26
Polychaeta	0.59	0.62	1.04	1.97	0.39	0.77
Thecosomata	1.97	1.32	2.11	1.37	0.34	1.18
Euphausiacea	1.45	0.92	2.89	5.24	3.20	2.30
Amphipoda	0.54	0.35	0.18	0.17	0.16	0.23
Ostracoda	15.70	7.65	7.01	6.45	1.84	6.44
Decapoda	0.59	1.81	0.91	1.00	0.81	0.85
Salps	0.41	0.35	0.59	3.00	6.33	1.78
Fish larvae	0.30	0.22	0.63	0.82	0.19	0.36
Biomass						
Total No.	75629	54884	29683	19514	55456	39194

which numerically form nearly 70% of the total samples, ostracods, chaetognaths, euphausiids, thecosomates and the rest.

The pattern of distribution of the major components of zooplankton including fish eggs and larvae clearly indicates that some of the Indian Ocean areas, such as Saudi Arabia and the Somalia coasts and the head of the Bay of Bengal are extraordinarily productive and the question uppermost in our minds is how much of this secondary production gets converted into exploitable resources of fish and how much of it goes to waste. PRUTER (1964) and PRASAD (1966) have discussed the potential yield of fisheries in the Indian Ocean. PRASAD estimates that the level of organic production in the Arabian Sea is at least 3 times that of the Bay of Bengal and in the actual fish yield the former is 2.4 times more than the latter. Such estimates are not possible for other areas of the Indian Ocean for want of sufficient data. However, it should be noted that rich patches of zooplankton occur at many places in the Indian Ocean as indicated by the IOBC samples.