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Present Status of Oceanographic Studies and Characteristics of the Exclusive Economic Zone of India.

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ABSTRACT

The EEZ of India includes four seas viz: Arabian Sea, Lakshadweep Sea, Bay of Bengal and Andaman & Nicobar Sea. All the seas except the Andaman & Nicobar Sea are extensively surveyed. The total number of cruises undertaken in the EEZ are 178. More than 50% of the coverage was done by R.V. Gaveshani (1976-86) and 75% area is covered under the National Oceanographic Programmes. In general, monthly coverage shows a maximum during March and June and seasonally, the maximum is during the pre-monsoon period. Latitudinally study shows maximum coverage between 14-15°N and longitudinally maximum coverage is in between 73-74°E of the EEZ boundaries. Oceanographic stations and Geophysical survey coverage are greatest on the west coast. More gaps exist in the Andaman & Nicobar Sea followed by Lakshadweep and the Bay of Bengal. The oceanographic characteristics show that the surface coastal water of the Bay of Bengal is little warmer than the Arabian Sea, the range being 22.5°C to 30.5°C. At 200m it varies from 13°C to 17°C. Salinity decreased from north to south in the Arabian Sea whereas it was vice-versa in the Bay of Bengal and Andaman & Nicobar Sea. In surface waters of the EEZ, the Maximum (6.1 ml/l) & minimum (3.8 ml/l) values of oxygen concentration were noticed in the EEZ portion of the Arabian Sea. Low values of nutrients are observed in the surface waters of the northern Arabian Sea and the northern part of Bay of Bengal. The surface primary production varied from 0.3 to 86.7 mgC/m²/day. The surface production per unit area is marginally higher along the west coast waters than in the east coast waters whereas column production is much higher in the waters of the eastern coast than the western coast. From the primary, secondary and benthic production the total fish potential has been estimated to be 4.25 million tonnes per year.

Introduction

India has a vast Exclusive Economic Zone (EEZ) measuring about 2.01 million sq.km. along an extensive coastline of nearly 6535 km. This area includes parts of four seas viz; The Arabian Sea and Lakshadweep Sea on the west coast and the Bay of Bengal and Andaman & Nicobar Sea on the east coast of India. Geographically they are quite different and therefore to understand the oceanographic characteristics of the Indian EEZ, an extensive coverage of all the four seas, is required.

Exclusive Economic Zones (EEZ), worldwide cover about 105 million square nautical miles and form 30% of the earth's ocean

surface. These areas account for over 90% of the world's fish catch and 87% of the globe's known submarine oil deposits. The EEZ of India is equivalent to about 66% of its land mass and 4.2% of the Indian Ocean. The area of EEZ on the west coast is 0.97 million sq.km., Andaman & Nicobar Sea 0.55 million sq.km. and the east coast an area of 0.49 million sq.km (Sarupria, 1986).

The oceanographic information is the major requirement for planning and executing the future scientific research and proper utilization of ocean resources. It also helps in establishing trends, extremes and average values of marine environmental parameters. Oceanographic information can play an important role in the economic development of any country.

In this communication, the coverage of the oceanographic studies of the EEZ is presented and oceanographic characteristics are discussed broadly without going into the details of interpretation and reasoning which are beyond the scope of this paper. A summary of the ranges and mean conditions of oceanographic parameters like temperature, salinity, dissolved oxygen, nitrate, phosphate, primary productivity, zooplankton, zoobenthos and fish potential are presented here.

1. Source of Data

The data and information available in the Indian National Oceanographic Data Centre of the NIO form the basis of this paper. The details of the source are stated hereunder.

A total of 178 cruises have been carried out in the EEZ area since 1960. Their distribution is: 103 cruises by R.V. Gaveshani, 48 cruises during IIOE period by 23 ships, 22 cruises by ORV Sagar Kanya and 5 cruises by INS Darshak. Details are shown in Table 1. Seasonal coverage shows that 62 cruises are undertaken during the monsoon period (June-September) followed by 60 cruises during the pre-monsoon (February-May) and 56 cruises during the post-monsoon period (October-January). Ship coverage is by R.V. Gaveshani (57.7%), IIOE (26.9%) and ORV Sagar Kanya (12.3%) (Sarupria, 1986). The information source for the coverage and gaps is IIOE (1960-1966), R.V. Gaveshani (1976-1986), ORV Sagar Kanya (1983-1986) and INS Darshak (1973-1974) as mentioned in Table 1 & 2. The data source for oceanographic characteristics is the data collected by R.V. Gaveshani during 1976-1980 from 779 stations in 34 cruises. The number of observations varied from 131 to 622.

TABLE - 1

Seasonal cruise coverage in the EEZ of India (uptil 1986)

	Pre-monsoon	Monsoon	Postmonsoon	Total
IIOE (1960-65)	18	19	11	48
INS Darshak (1973-74)	3	-	2	5
R.V. Gaveshani (1976-86)	33	34	36	103
ORV Sagar Kanya (1983-86)	6	9	7	22
Total	60	62	56	178

2. Present status of coverage and gaps in the EEZ

2.1 Coverage

The EEZ of India includes four seas out of which three seas are covered substantially except the Andaman & Nicobar Sea. The total number of stations occupied within the EEZ is about three thousand and on an average about 1000 stations are analysed for physical, chemical and biological parameters except primary production as shown in Table - 2. In general, yearly studies show that maximum coverage is during 1986 along the east coast and in Andaman & Nicobar Sea (Fig.1). They also show that maximum stations have been occupied for physical and chemical parameters during 1976, 1979 and 1986 and for biological parameters during 1980 and 1985 (Fig.2). The most geological samples (Fig.2) were collected from the west coast during 1977 and 1980 and greatest geophysical coverage was along the west coast during 1978, 1980 and 1981. Monthly study shows maximum coverage during March and June and seasonal coverage is greatest in the pre-monsoon period followed by monsoon and post-monsoon periods. Geographically, maximum coverage is between 14-15°N and between 73-74°E within the boundaries. Geophysical coverage is more extensive on the west coast than on the east coast while Andaman & Nicobar Sea are not surveyed (Fig.3).

Seasonal study (Fig.4) shows that the west coast is extensively covered during pre-monsoon and post monsoon periods, whereas the east coast is covered during the monsoon period only. Andaman & Nicobar Sea is partially covered during the post monsoon. A total of 3964 stations have been occupied during 62 cruises during monsoon, 3846 stations in 60 cruises during pre-monsoon and 3687 stations in 56 cruises during post monsoon periods for physical, chemical and biological parameters (Sarupria 1985-86) (Table 2).

Data from 3600 stations have been collected for XBT & MBT from the east coast and the west coast during monsoon and post monsoon periods. Biological data on primary production and zooplankton biomass have been collected from more than 900

stations on the west coast during pre-monsoon and post-monsoon periods whereas the east coast is covered during the monsoon only. As far as Nansen cast and chemical parameters are concerned the west coast is extensively covered during all the three seasons whereas the east coast is only covered during the monsoon and post monsoon periods. Andaman & Nicobar Sea is covered in post-monsoon and very little in pre-monsoon periods.

TABLE - 2

Seasonwise station coverage in the EEZ of India (uptil 1986)

	Pre-monsoon	Monsoon	Post-monsoon	Total
Temperature	RVG 338	RVG 474	RVG 503	2671
	DK 20	DK -	DK 8	
	IIOE 236	IIOE 278	IIOE 367	
	SK 38	SK 326	SK 83	
Salinity	RVG 352	RVG 426	RVG 489	2524
	IIOE 307	IIOE 262	IIOE 359	
	SK 38	SK 218	SK 73	
Oxygen	RVG 362	RVG 320	RVG 355	1997
	IIOE 269	IIOE 219	IIOE 216	
	SK 62	SK 128	SK 66	
NO ₃ ⁻ N	RVG 334	RVG 238	RVG 260	1202
	DK 43	DK -	DK 21	
	IIOE 59	IIOE 14	IIOE -	
	SK 98	SK 115	SK 20	
PO ₄ ⁻ P	RVG 305	RVG 317	RVG 313	1459
	IIOE 149	IIOE 60	IIOE 40	
	SK 97	SK 112	SK 66	
Primary production	RVG 146	RVG 126	RVG 152	686
	DK 14	DK -	DK 2	
	IIOE 104	IIOE 16	IIOE 11	
	SK 62	SK 29	SK 24	
Zooplankton	RVG 245	RVG 238	RVG 237	958
	IIOE 60		IIOE 2	
	SK 108	SK 48	SK 20	
Total	3846	3964	3687	11,497

RVG Research Vessel Gaveshani
 DK INS Darshak
 IIOE International Indian Ocean Expedition
 SK ORV Sagar Kanya

2.2 Gaps

The Indian EEZ comprises approximately 245 one degree grid squares. Fifteen of these are not covered in any season as shown in Fig. 5. These include eleven in the Andaman & Nicobar Seas, one in the east coast and three on the west coast. The seasonal station coverage shows maximum gaps (36.5%) during the monsoon period followed by the post monsoon (29.3%) and pre-monsoon (28.5%) (Sarupria, 1986). In all the three seasons Andaman & Nicobar Sea is either partially covered or not covered. Maximum gaps are noticed along the east coast during the pre and post monsoon and along the west coast during the monsoon period. Gaps exist for biological parameters, particularly primary production and zooplankton, on the east coast and Andaman & Nicobar Sea during pre-monsoon and post-monsoon and in the Arabian Sea and Andaman & Nicobar Sea during the monsoon period (Fig.4). Nansen cast data for temperature, salinity and chemical parameters shows that significant gaps exist in the Bay of Bengal and the Andaman & Nicobar Seas during the pre-monsoon, followed by Andaman & Nicobar Sea and partially along the west coast during the monsoon period and also partially in the Andaman & Nicobar Sea and the west coast between 5-10° N latitude of the EEZ during the post monsoon period. The BT data collection shows that the EEZ area has been covered in all three seasons but gaps exist partially during the pre-monsoon period on the east coast and Andaman & Nicobar Sea, during the monsoon on the west coast and Andaman & Nicobar Sea and during the post monsoon period on the eastern part of Andaman & Nicobar and southern west coast between 5-10° N latitudes.

The monthly data shows that there are no studies in the EEZ of Andaman & Nicobar Sea and the west coast during August of any year, and in the eastern EEZ during February and May of any year (Sarupria, 1986). Further, the Andaman & Nicobar Sea is also not covered during April, July, August and December of any year since 1966. The EEZ along the east coast is not studied in February, May and partially studied in October. The west coast is partially covered during September since 1960. The data is staggered and discontinuous and therefore it is difficult to draw any valid conclusions. Therefore future cruises have to be planned in such a way that complete seasonal cover is obtained to allow a proper understanding of the EEZ areas.

3. Oceanographic characteristics - A resume

3.1 Methods of data collection and analysis

Water samples were collected using Nansen bottles and Van-Dorn bottles. Temperature was read with reversing thermometers and salinity was determined using an inductive salinometer or an Autosol (Model 8400). Samples for the various chemical analyses were collected and analysed on board as per the standard procedures mentioned by Sen Gupta, Pondekar, Sankaranarayanan and De Souza (1975) and Sankaranarayanan (1978). Samples were collected by Van Dorn bottles for primary productivity. Zooplankton biomass was estimated from the samples collected by

the Indian Ocean Standard Net (IOSN) and Benthic biomass was obtained from the samples collected using a snapper, a grab or a dredge. The procedures adopted for benthic biomass are explained by Parulekar et.al (1982) and for primary production by Bhattathiri et.al (1980).

To describe the oceanographic conditions in the EEZ, the parameters selected depths have been sorted from the data base. In this paper four depths, namely surface, 50, 100 and 200 meters are selected for the presentation of the various variables. Values are plotted at each selected depth by taking the average value in each one degree square grid to draw isopleths. Isopleths intervals were selected by taking into consideration the whole range of the particular parameter and its variation with depth. In order to show the horizontal distribution of the parameters synoptically, closed curves which are of small magnitude have been omitted and smoothed curves were made as far as possible.

Temperature

The temperature regime of the EEZ from 0 to 200m is shown in Fig.6. At surface the temperature ranged from 22.5° to 30.0°C in the Arabian Sea and 28.5° to 30.5°C in the Bay of Bengal, the high values being reported from coastal waters off Orissa and a small pocket off Cochin. The lowest temperatures are recorded in northern parts of the Arabian Sea. The variations in surface temperatures in the Arabian Sea are well marked compared to the Bay of Bengal, with a general increase from north to south particularly in the Arabian Sea. At 50m depth, the temperature varied from 25 to 28°C and at this depth, the southern parts of the two seas are warmer compared to northern parts. The same is noticed even at 100m depth with a variation from 16.5 to 27°C. At 200m depth, the temperature varies from 13 to 17°C. At this depth, there is a decrease in temperature from north to south in the Arabian Sea as reported by Qasim (1982) and a tongue of warm water persists in the Central Bay of Bengal (Rao, et.al 1981). The general surface warming from north to south may be due to cooling of the land mass in the northern region and a general flow of cold air from the land causing cooling of the sea close to the land (Sankaranarayanan, 1970). Surface temperature ranged between 27 - 28.5°C in the waters around Andaman & Nicobar Island.

Salinity

The distribution of salinity is shown in Fig. 7. The surface salinity varied from 34 to 36.5 x 10⁻³ in the Arabian Sea (except a small pocket in coastal Gujarat waters, 33.5 x 10⁻³) and as low as 23.5 to 34 x 10⁻³ (except a small pocket off Visakhapatnam, 35.2 x 10⁻³) in the Bay of Bengal. Salinity decreased from north to south in the Arabian Sea whereas it is just reverse in the Bay of Bengal. Around Andaman and Nicobar Island salinity varied from 31.5 to 33.5 x 10⁻³ and increased from north to south. At 50m and 100m, the Bay of Bengal waters are well mixed whereas in the Arabian Sea high saline water is

confined to northern portion (Qasim, 1982). At 200m depth, salinity varied from $35-36 \times 10^{-3}$ on the Arabian Sea whereas in the Bay of Bengal it varied from $34-35 \times 10^{-3}$. The high salinity in the northern Arabian Sea is perhaps due to the inflow of highly saline water from the Persian Gulf (Qasim, 1982). As the study is limited to 200m depth and also to the EEZ area, the reasons could not be established for higher salinity values in this region, however earlier studies by Venkateswaran (1956) and Warren, Stommel and Swallow (1966) indicate that the high salinity in the north west Arabian Sea is due to the, excess annual evaporation in this region. Studies by Verma, Das and Gouveia (1980) revealed the inflow of Persian Gulf waters to be responsible for high salinity generally present at 300m depth. They found that this water do not persists along the west coast of India. The low surface salinity of the west coast of India, particularly south of $20^{\circ}N$ is not due to rainfall or land runoff as no major rivers enter this area and the rainfall in the region is quite low. The low salinity water, largely confined to the surface layers in this area, is due to the intrusion of Bay of Bengal waters into the Arabian Sea (Wyrcki 1971). A possible driving mechanism for this intrusion from Bay of Bengal was explained among others by Pankajakshan et.al (1987) using the recent theory of Mc Creary et.al (1986). The high river discharge in the form of land run off into the northern Bay of Bengal from the Krishna, Godavari, Mahanadi, Ganges and Brahmaputra influences the salinity of Bay of Bengal waters.

Oxygen

The oxygen concentration at the surface ranged from 3.8 to 6.1 ml/l in the Arabian Sea and 4.3 to 5.5 ml/l in the Bay of Bengal. At 50m, it decreased to 1 ml/l in both the seas with a variation from 1 to 5 ml/l. At 100m it showed a variation from .5 to 4 ml/l. It was noticed that dissolved oxygen concentration is more in coastal waters of the Arabian Sea than the Bay of Bengal and in either seas the concentration decreased from the coast to off-shore waters. At 200m it further decreased to .2 ml/l with a variation from .2 to .7 ml/l. The details are shown in Fig. 8.

Nutrients

Nitrate - Nitrogen: In surface waters nitrate concentration (Fig. 9) varied from 0.1 to 1.0 $\mu\text{g-at/l}$ almost in the entire EEZ waters. Surface coastal waters of West Bengal on the east coast and in between Goa & Mangalore along the west coast showed maximum concentration of about 1 $\mu\text{g-at/l}$. At 50 and 100m, the concentration is more or less the same as that of surface waters. In surface water around Andaman it varied from .04 to .4 $\mu\text{g-at/l}$. The high concentration around these islands are explained by Sen Gupta et.al (1980). At 200m, the highest concentration was observed at southern part of Andaman & Nicobar Sea and off Goa and Mangalore on the west coast. In general, the nitrate concentration increases from north to south along the western coast of the EEZ and Andaman & Nicobar Sea whereas on the east coast it increases from south to north.

Phosphate - Phosphorus

Phosphate at surface and 50m varied from nil to $1.0 \mu\text{g-at/l}$ (Fig.10) and was found to be highest off Bombay, Goa, between Madras and Visakhapatnam and Calcutta, the minimum range of phosphate in surface waters found between Mangalore and Cochin whereas the range at 100m varied from 0.8 to 1.8 and at 200m it varied from 1.8 to $2.6 \mu\text{g-at/l}$. The minimum concentration of phosphate was observed at 100m and 200m depth off Bombay and Cochin on the west coast, off Visakhapatnam and Calcutta on the east coast and on the eastern part of Andaman & Nicobar Sea. Maximum phosphate was found at 100m and 200m between Orissa and Visakhapatnam region. In general, variation in surface water and at 50m depth is almost matching and low while at 100 and 200m the values are higher.

Primary production

Surface and water - column production rates are shown in Fig. 11. Surface production ranged from 0.3 to $86.7 \text{ mgC/m}^2/\text{day}$. Productivity is high in the coastal waters of Bombay, Mangalore and most of the areas along the east coast of India. Maximum production is reported in West Bengal waters and minimum in central and southern coastal waters of Arabian Sea. Around Andaman & Nicobar Island, the production rate is somewhat low. In general, the productivity is more in coastal waters of the Bay of Bengal and the Arabian Sea as compared to other areas. An estimation by Qasim (1977, 1982) suggests that surface production is of the order of 24.6×10^6 tonnes carbon/yr in the Arabian Sea and out of this 50% is from northern Arabian Sea only. The surface production per unit area along the west coast is marginally higher than that of the EEZ of the east coast whereas the column production is much greater in the east coast than of the west coast. The average surface production in EEZ is $12.39 \text{ mgC/m}^2/\text{day}$. The total surface production in the EEZ is 9.11 million tonnes of C/year. The maximum production is seen off Orissa, between Madras & Visakhapatnam, Gujarat, Bombay, Goa and Cochin. The lowest production is in the Andaman & Nicobar Sea. The average column production is 132.30 tonnes carbon/ km^2/year in the EEZ area. Column production on the east coast is higher which may be due to nutrient rich water, higher chlorophyll and lower salinity and high temperature as compared to the west coast.

2

Column production varied from 10 to $100 \text{ mgC/m}^2/\text{day}$ in the entire EEZ area. Coastal waters in the Bay of Bengal are more productive compared to the Arabian Sea waters.

Zooplankton Biomass

The distribution of zooplankton biomass is shown in Fig. 12(A). The variation in biomass was found to be of the order of 0.01 to 3.2 ml/m^3 . The biomass is very poor in the Bay of Bengal waters including the Andaman & Nicobar Seas. Maximum biomass was reported from the northern and central Arabian Sea. Maximum zooplankton biomass was observed off Gujarat, Bombay, Goa, Mangalore and Cochin along the west coast and off Madras and

Visakhapatnam along the east coast of the EEZ.

Benthic biomass

The distribution of benthic is shown in Fig. 12(B). The distribution varied from 0.1 to 23.2 gm/m². The coastal waters in between Mangalore and Cochin on the west coast side and in between West Bengal and Orissa in the east coast showed higher concentrations. The distribution is moderate around Andaman & Nicobar Island. The northern Arabian Sea and central Arabian Sea areas showed very low concentration.

Fish potentials of the EEZ

Based on the data available, it has been possible to estimate the fishery potential of the EEZ of India. Taking into consideration the primary, secondary and benthic production, the total fish potential has been estimated to be about 4.25 million tonnes per year. Since the present catch from the Indian coast is around 1.6 million tonnes a year, an increase of 2.8 times can be envisaged (Desai et.al, 1987).

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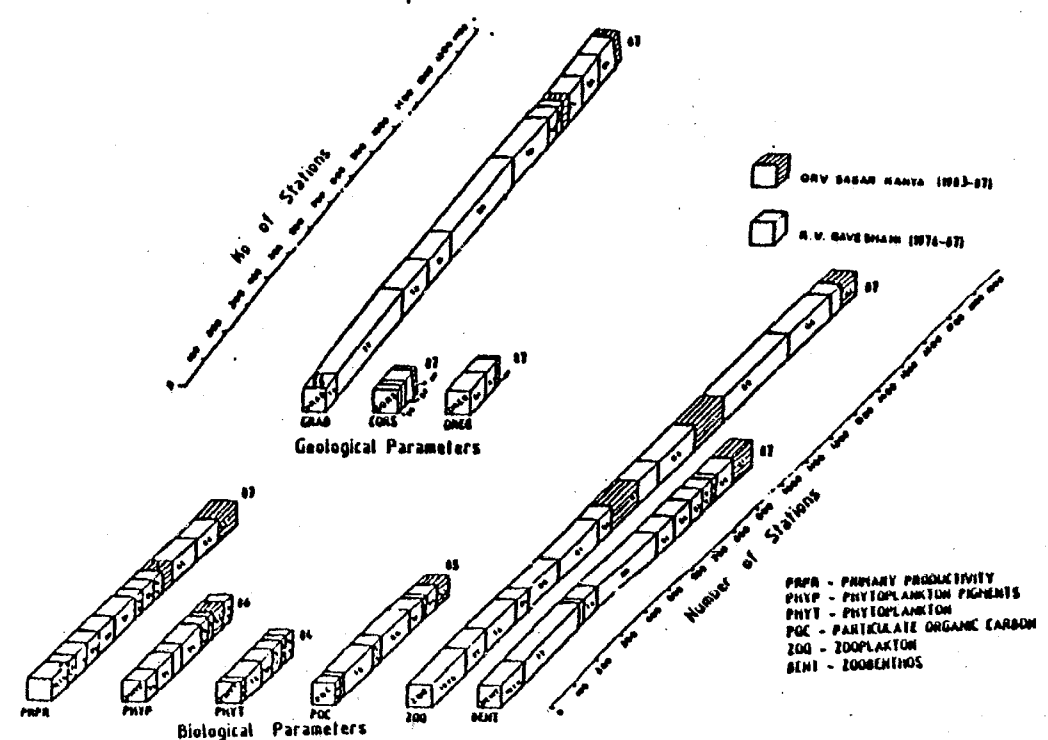
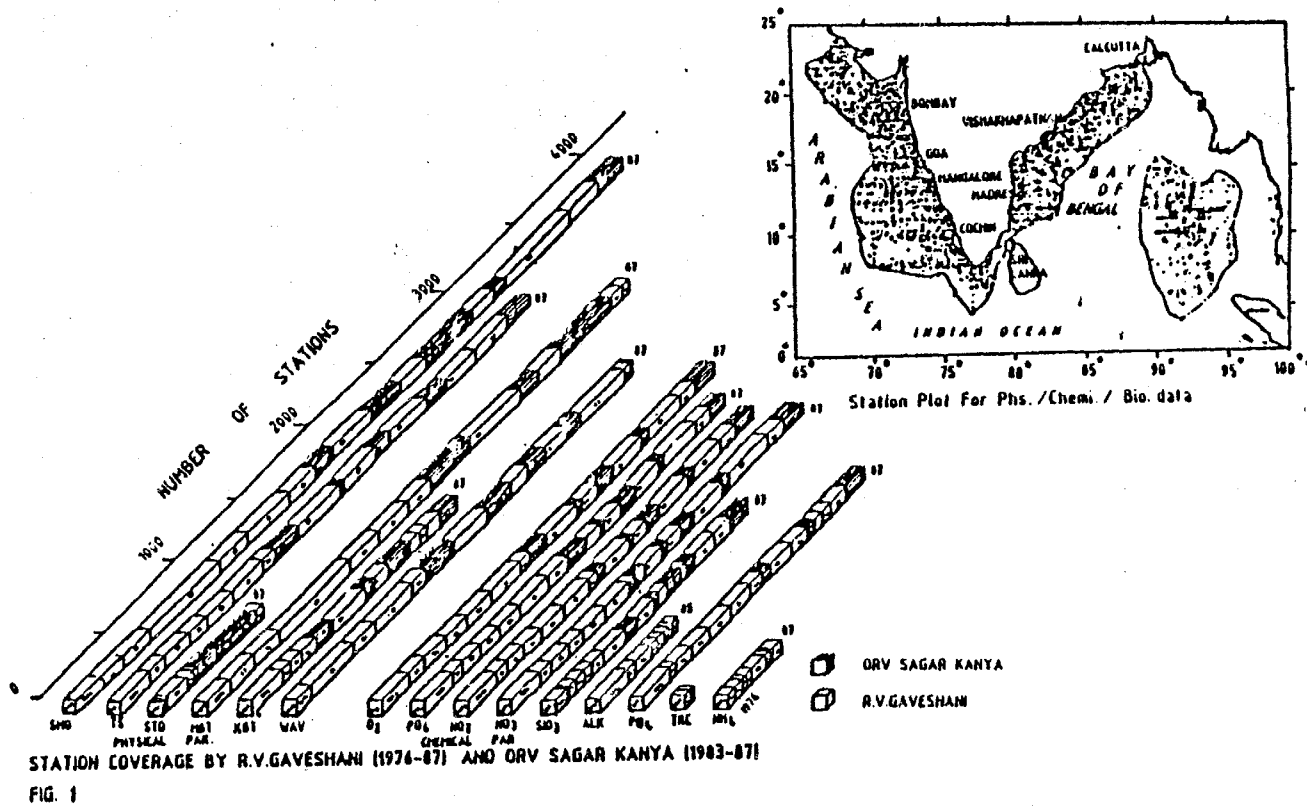
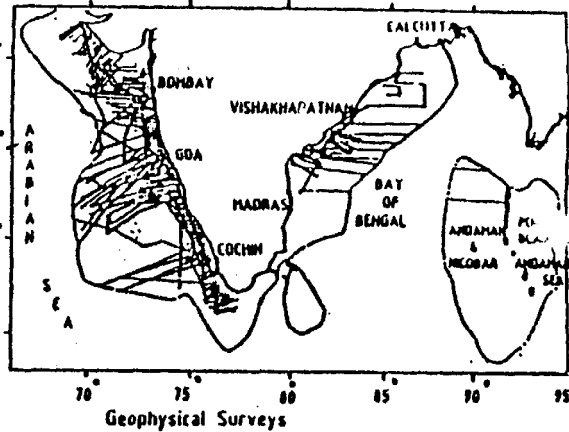
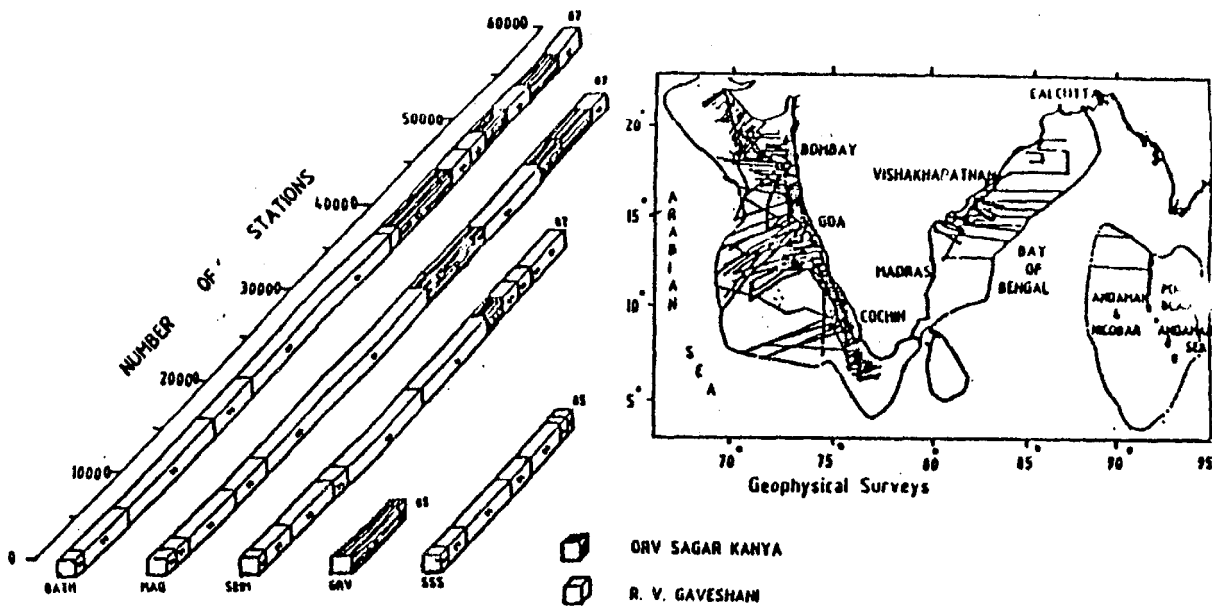


Fig. 2 STATIONS COVERAGE R.V.GAVESHAN (1976-87) AND O.R.V.SAGAR KANYA (1983-87) FOR BIOLOGICAL AND GEOLOGICAL PARAMETERS



COVERAGE BY R.V. GAVESHANI (1976-1987) & ORV SAGAR KANYA (1983-87) FOR GEOPHYSICAL PARAMETERS

Fig. 3

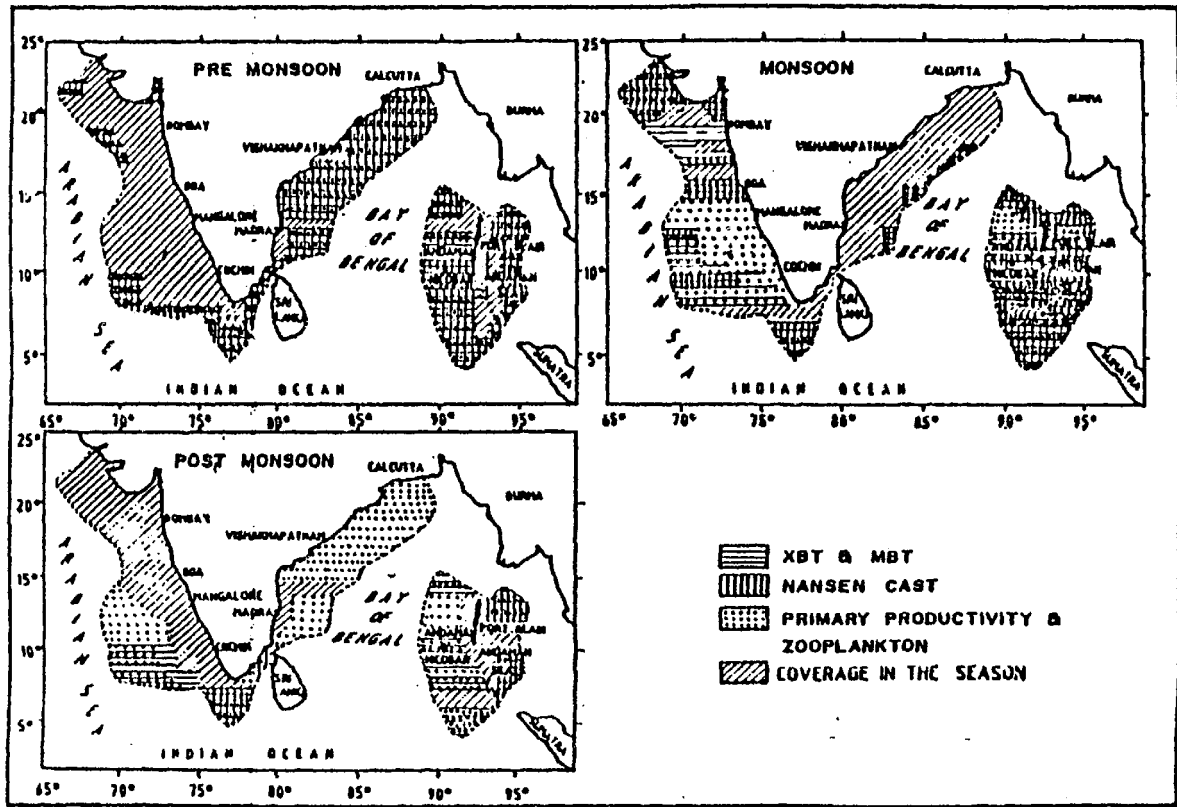
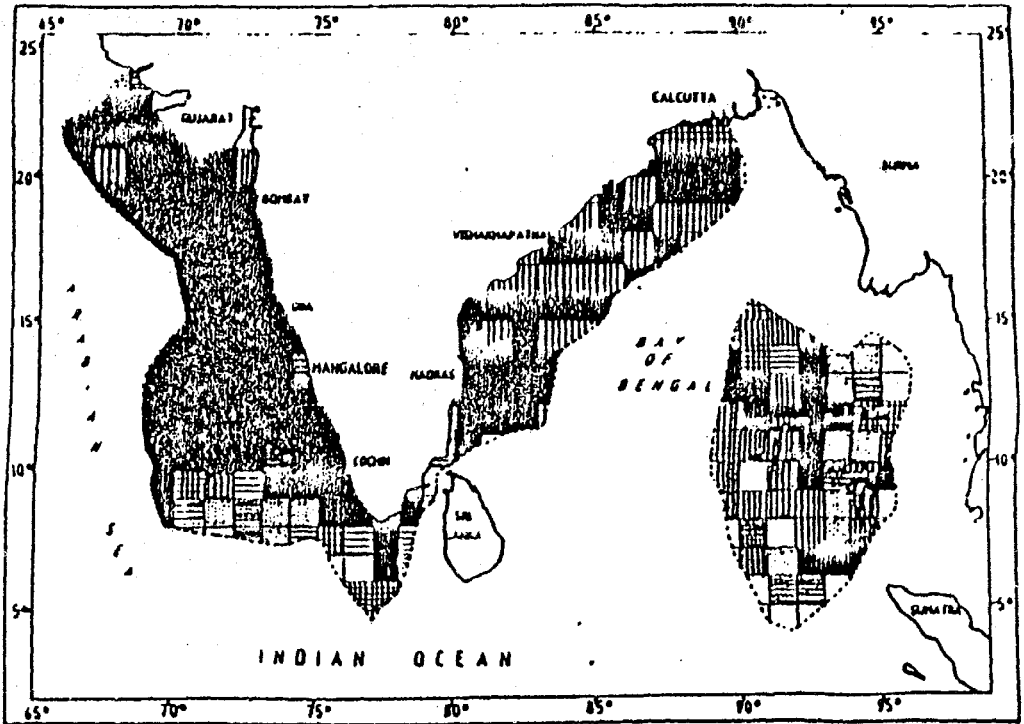


Fig. 4 PARAMETERWISE & SEASONAL DATA GAPS IN EEZ OF INDIA



□ Gaps in all seasons ▨ Gaps during monsoon ■ Coverage in three seasons
 ▤ Gaps during pre-monsoon ▧ Gaps during postmonsoon

Fig. 5 Distribution of Seasonal coverage in one degree grid of EEZ

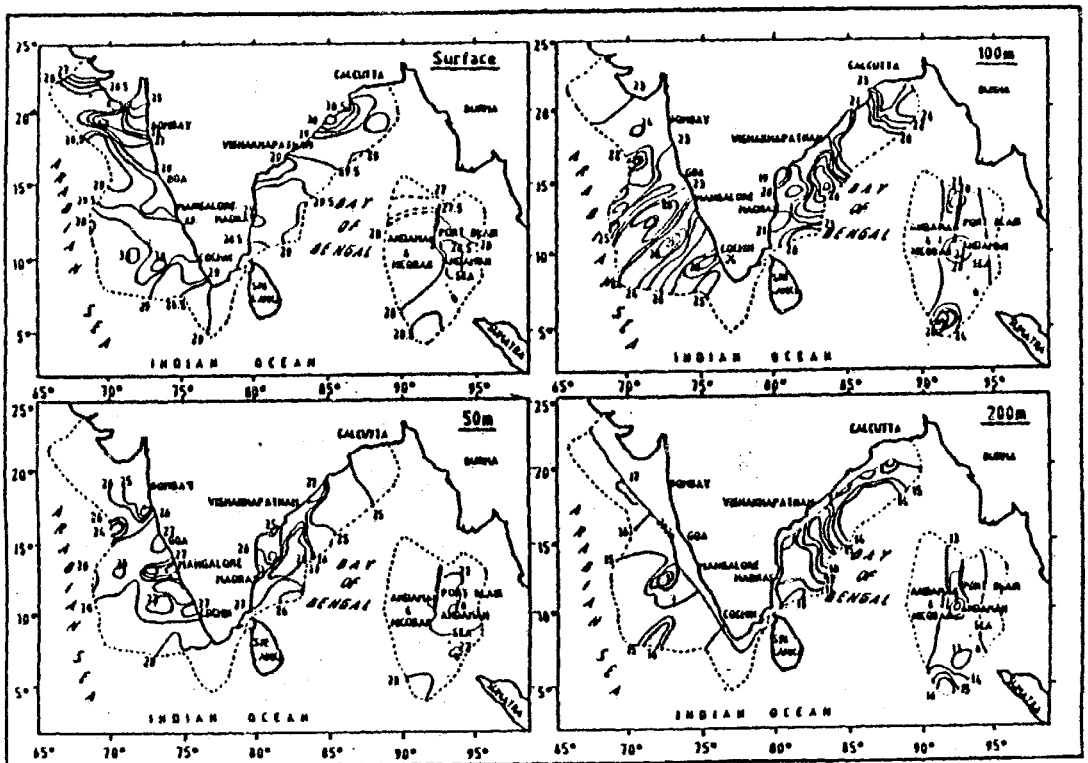


Fig. 6 Distribution of Temperature ($^{\circ}\text{C}$) at four different depths
4-48

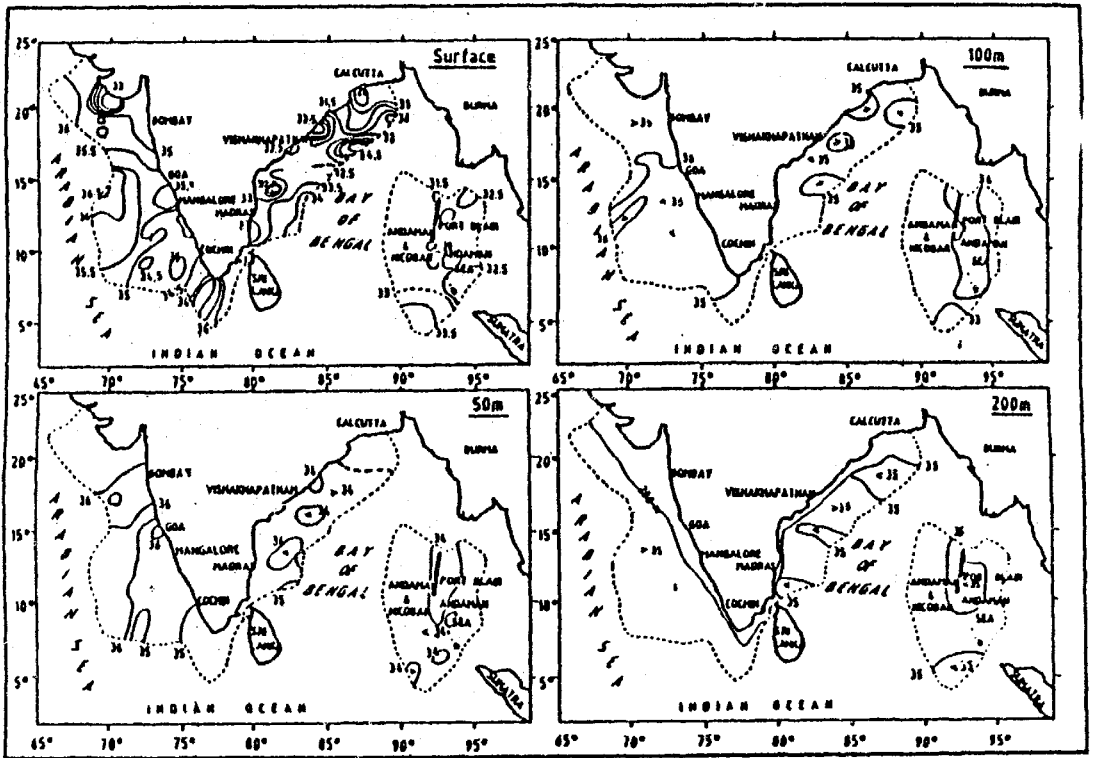


Fig. 7 Distribution of Salinity ($\times 10^{-3}$) at four different depths

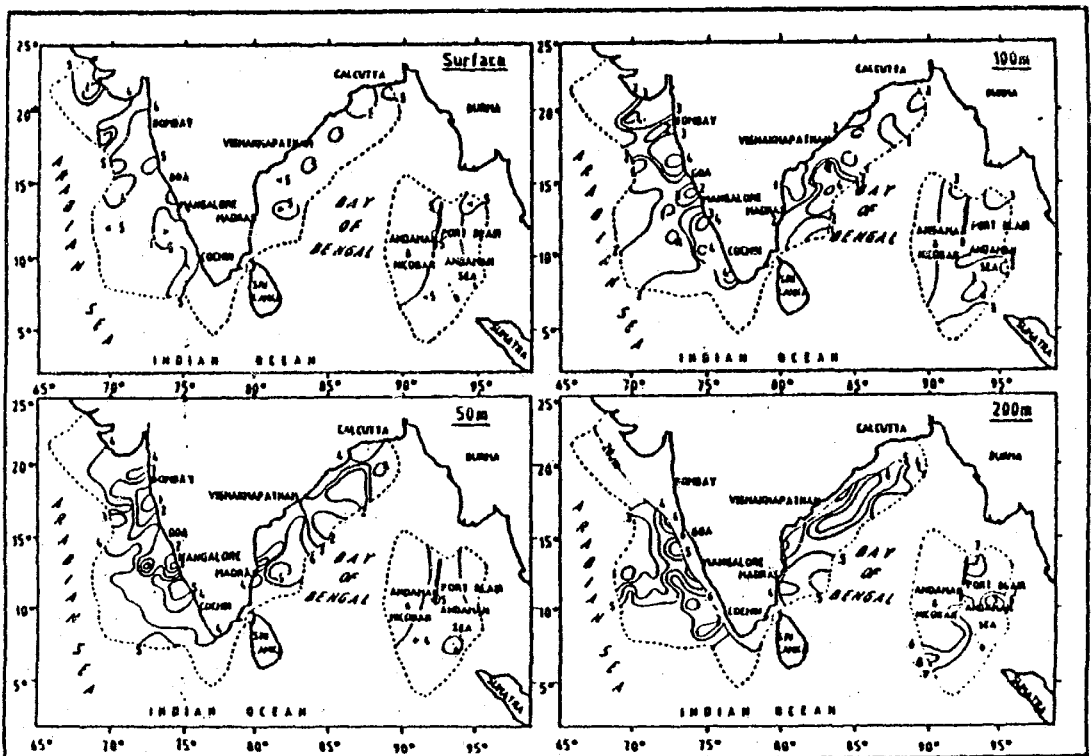


Fig. 8 Distribution of Dissolved oxygen (ml l^{-1}) at four different depths

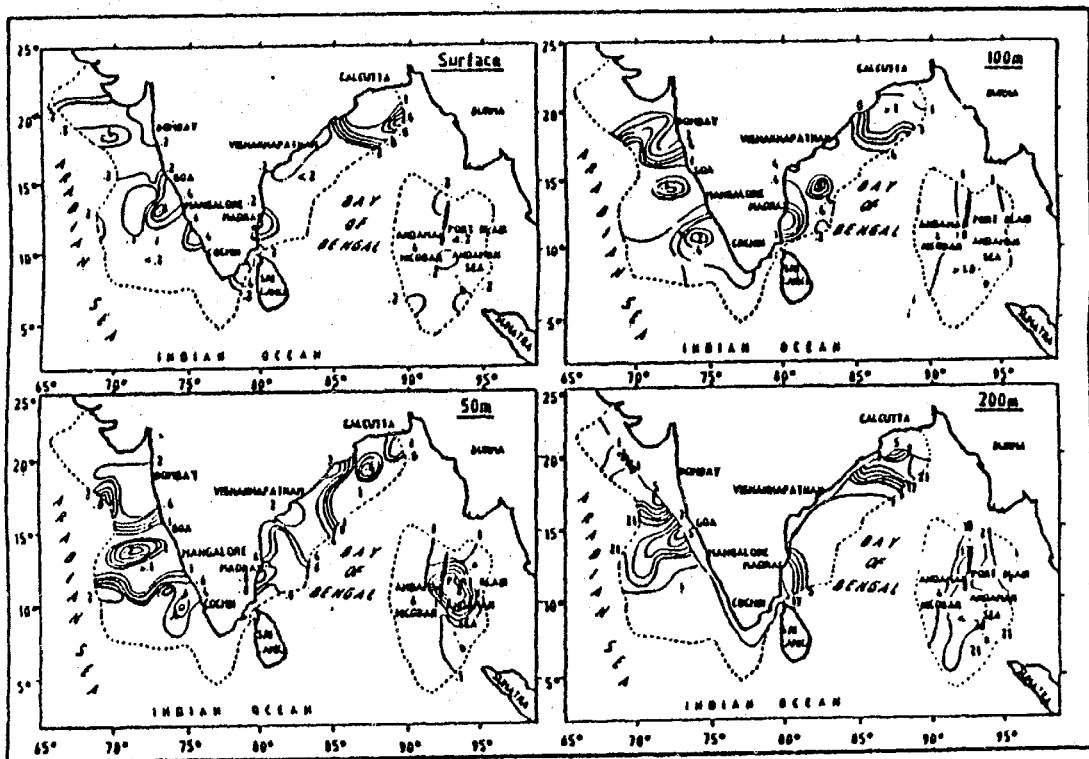


Fig. 9 Distribution of Nitrate-Nitrogen ($\mu\text{g-at l}^{-1}$) at four different depths

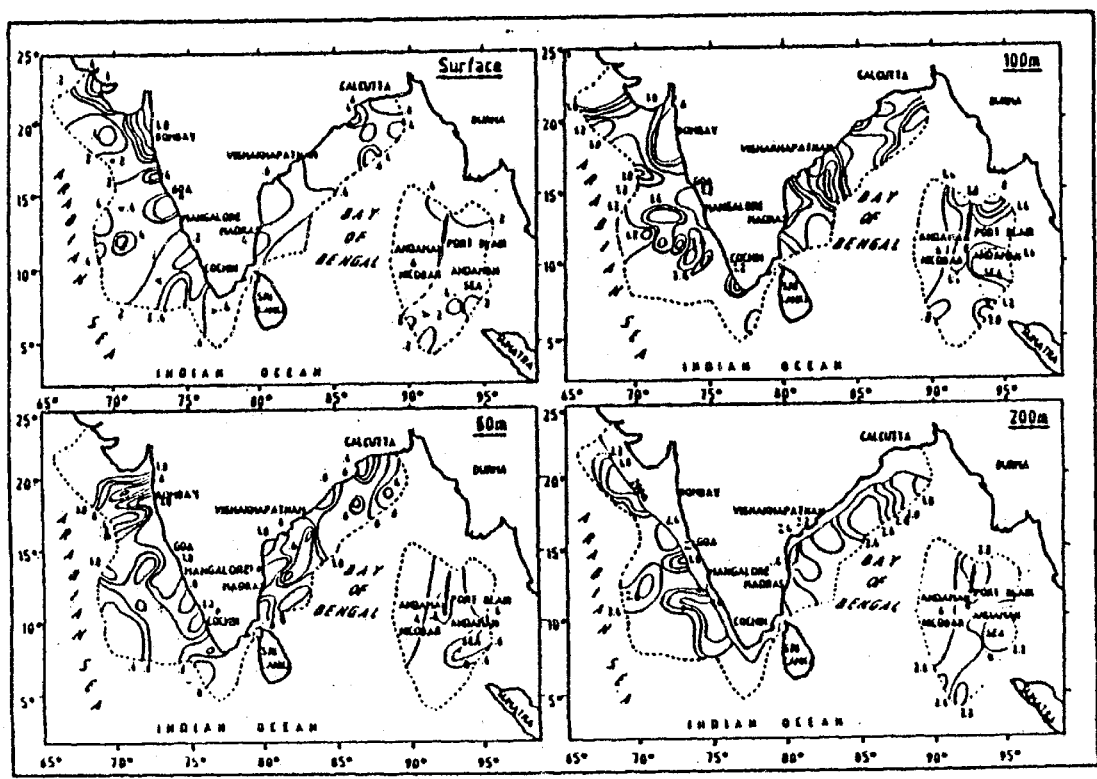


Fig. 10 Distribution of Phosphate ($\mu\text{g-at l}^{-1}$) at four different depths

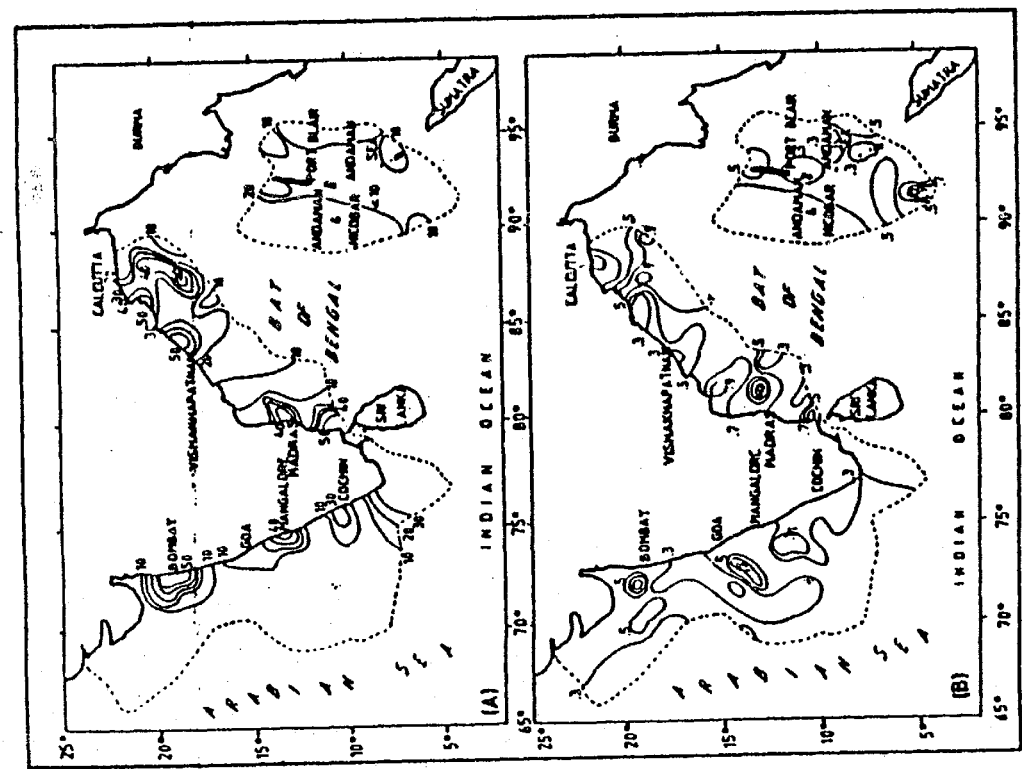


Fig. 11 Rates of primary production (14 C uptake l at the Surface (A) $\text{mg C/m}^3/\text{Day}$ and column (B) $\text{g C/m}^2/\text{Day}$

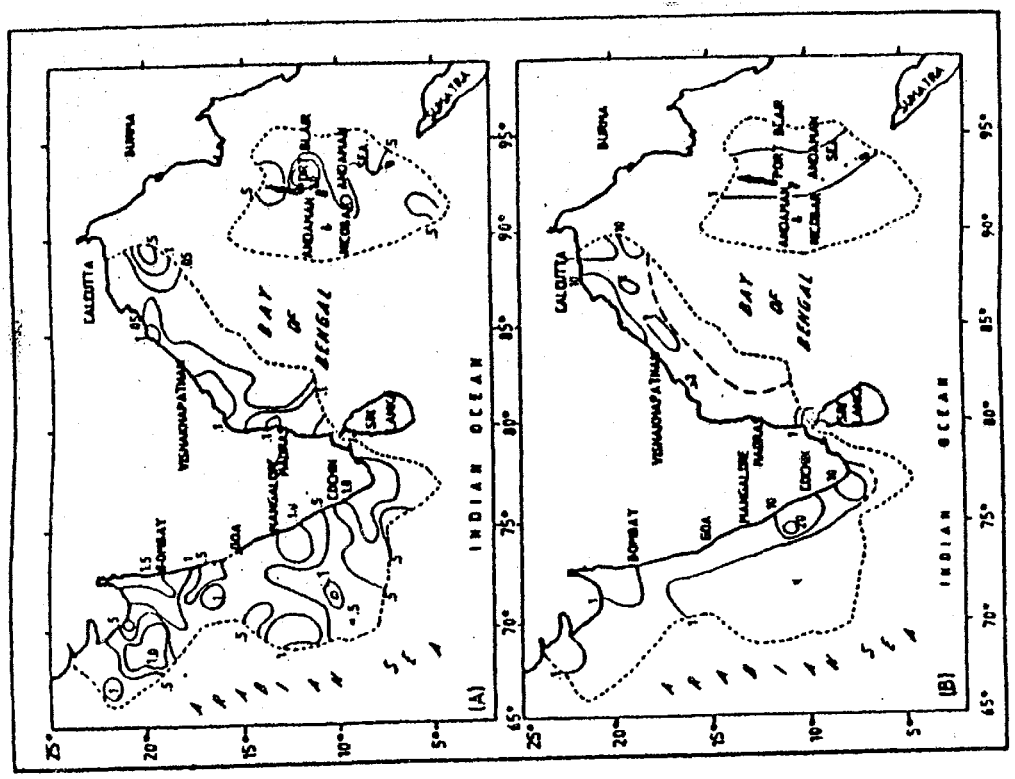


Fig. 12 A. Distribution of Zooplankton biomass (ml m^{-3})
 B. Distribution of Benthic biomass (gm^{-2})