BIOLOGICAL PRODUCTIVITY IN THE EXCLUSIVE ECONOMIC ZONE (EEZ) OF INDIA

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STATEMENT

As required under the Goa University Ordinance No. 0.413, I state that the present thesis entitled "Biological productivity in the Exclusive Economic Zone of India" is my original contribution and that the same has not been submitted for any degree of this or any other University on any previous occasion. To the best of my knowledge, this is the first comprehensive study of its kind from this area.

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CONTENTS

1. INTRODUCTION

1. INTRODUCTION

Since time immemorial the seas are being used mainly for navigation i.e. transport of men and material and fishing. Today the sea has varied uses and can supply most of the things the land can such as minerals, mineral oil, food, drugs, accommodation, recreation, energy etc. But still one of the most important item we depend upon, is fish and edible items termed as food from sea or marine living resources. Not only marine food augments the food production but is sure and cheaper source of protein and represents about 20 percent of the world supply of animal protein (Holt, 1973). Seventy percent of marine fish catch was directly used as human food in 1981 as per the FAO reports (1981) while rest was used in the preparation of fish meal for poultry or piggery. An estimate shows that 4-5 percent or 5 million tonnes of protein comes from sea (Dalal,1984). Still millions of people are undernourished due to protein deficiency, this is particularly true for third world developing countries. With increasing population the demand of protein *vis-a-vis* the requirement of marine fish catch would be 10 million tonnes in the Indian Ocean region alone by the turn of the century.

India is flanked by seas on its three sides and a large population in coastal areas depend upon marine food as their staple diet. It has a coastline of about 7517 kms with all the islands considered together. Most of the coastal population is far below the living standard in many respects like education, health, income etc. Their standard of living can be raised when marine activities are increased and the sea is used for revenue. This in turn depends upon the knowledge of the sea which include the physical, chemical and biological characteristics of sea water, the processes occurring there, the energy conversion into higher levels etc. The most important and priority area for study is the nearshore waters, continental shelf and margin which has the highest relevance to the exploitation of the marine food resources. The nearshore waters and its ecosystem is complex also since it is this area which is most affected by monsoon, river- run-off, pollution, currents, tides, intrusion of "foreign" waters and other man made changes. The final result has to be studied and known. Therefore, it is necessary to study the various factors and the biological processes which itself have to be studied in order to understand the ecosystem and assess the productivity and to estimate the potentials of the living resources of the Exclusive Economic Zone.

The concept of Exclusive Economic Zone (hereafter called EEZ) came very late in 1970 although it has antecedents going back to several decades. The EEZ is a maritime zone beyond the limits of the territorial sea within which the coastal state has complete jurisdiction over (a) all living and non-living resources in the water and/or under the sea-bed and (b) all activities relating to these resources.

As per the United Nations Conference on the Laws of the Seas (UNCLOS III), the EEZ should not extend beyond 200 nautical miles from the base line from which the breadth of the territorial sea is measured. The UNCLOS convention further states that the state has : (a) Sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or non-living, of the bed, subsoil and the super adjacent waters; (b) Exclusive rights and jurisdiction with regard to the establishment and use of artificial islands, installation and structures; (c) Exclusive jurisdiction with regard to : (i) other activities for the economic exploration and exploitation of the zone, such as production of energy from the water, currents and winds; (ii) scientific research; (d) jurisdiction with regard to the preservation of the marine environment including pollution control and abatement; (e) other rights and duties provided for in the convention (Anon., 1978).

The EEZ involves a distance of 200 miles from the coast. The EEZ is also sometimes referred to as the patrimonial sea (Anon, 1978). With this definition about 3,77,50,000 sq. miles of sea would be within national control, (i.e. EEZ) leaving 67,517,000 sq. miles as international waters. All these activities and conventions are governed by UNCLOS duly agreed by the respective countries. The importance of the EEZ is illustrated by the fact that 90% of the world fish catch and 87% of the globe's known as submarine oil deposits come from the EEZ. In 1986, the world's catch of fish, crustaceans and molluscs from the sea was 80.345 million metric tonnes (95% of which came from the EEZ and 70% of which was destined for human consumption) valued nearly 25.63 million dollars (FAO, 1986). This is only about a tenth of the value of the hydrocarbons which are non-renewable while biological resources are renewable and we have to exploit living resources judiciously. Likewise the EEZ of India measuring 2.01 million sq. km. along the coastline of 7517 kms is very important from the point of view of living resources.

From the above, it emerges that the study of biological productivity in the EEZ is of considerable importance to explore and exploit the marine food resources. The term biological productivity is a broad one and may include the complete marine food chain including the environmental parameters affecting the production. In the present work are included the more important physical and chemical oceanographic parameters, the chlorophyll, the primary production, the secondary production and the benthic production. On the basis of these, the EEZ has been characterized and fishery potentials estimated.

The oceanographic studies in the Indian waters were conducted very sporadically before early 60's. It was Seymore Sewell who first studied the sea as a naturalist. Many expeditions have been undertaken in the Indian Ocean. These are Challenger (1872-1876); Investigator (1884-1925); Vityaz (1886- 1909); Valdivia (1898-1899); Gauss (1901-1903); Planet (1906); Dana (1920-1927); Snellius (1929); Discovery II (1929-1933); John Murray (1933-1934) and Galathea (1951). These expeditions had their limitations and mostly covered the Indian Ocean but failed to bring out conclusive results in time and space for all the oceanographic parameters. Later, few Universities like Bombay, Madras, Travancore initiated marine biology work in coastal areas. This work was further strengthened with the establishment of a Central Marine Fisheries Research Station at Mandapam to conduct studies in coastal as well as territorial waters of India. For example, in the Arabian Sea, works of Prasad (1954); Prasad & Nair (1963); Prasad et al. (1970); Jayaraman & Gogate (1957); Jayaraman *et al*. (1959); Banse (1959); Ramasastry and Myrland (1959); Ramamritham and Jayaraman (1960) and of La Fond (1954); Balarammurthy (1958); Varadachari (1958); Ganapati (1964); Ganapati and Murty (1955) and Ganapati & Rao (1959) in the Bay of Bengal may be mentioned. But the real impetus to the Indian Oceanography was given by International Indian Ocean Expedition (1961-65) organised by UNESCO through which systematic studies were made in various disciplines viz. physical, chemical, biological and geological oceanography. In this expedition many countries including, USA, USSR, U.K., France and Germany had participated. Based on its work hundreds of research papers, reports and atlases have been published, of which three atlases are very comprehensive and useful. They are Wyrtki's (1971) on physical parameters, Krey and Babenard's (1976) on some aspects of biological work and Ramage *et al.* (1972) on meteorological parameters. The Indian Ocean Biological Centre now a Regional Centre of NIO at Cochin also published a series of zooplankton atlases which describe the distribution of zooplankton in the Indian Ocean including the Exclusive Economic Zone of India. Many workers then took up the work on biological productivity of Indian Ocean that included the EEZ of India as well. These workers included Panikkar, Qasim, Raghu Prasad, Dwivedi, Nair, Parulekar, Goswami, Bhargava, Devassy, Radhakrishna and Bhathathiri but none of them covered exclusively the EEZ of India. Qasim (1977, 1978, 1982) and Qasim *et al.*, (1978) while characterizing the waters from various angles, gave an estimate of fisheries potential as 16 million tonnes in the entire Indian Ocean. Nair and Gopinathan (1981), however, estimated 5.5 m. tonnes in the EEZ. Very recently Desai *et al.* (1990) gave an estimate of 3.66 m tonnes for the EEZ of India. A concise account of biological and oceanographic differences between Arabian Sea and Bay of Bengal has been given earlier by Panikkar and Jayaraman (1966).

The environmental parameters directly or indirectly influence the biological processes *vis-a-vis* the biological production. Therefore, environmental aspects form important part of the study. The main parameters discussed in this document are temperature, salinity, dissolved oxygen, phosphate, nitrate and nitrite. Considerable work has been done after the establishment of National Institute of Oceanography in 1966 particularly after acquiring the Research Vessel *Gaveshani* and later *Sagar Kanya*. Technical reports on the work done in Andaman Sea and Lakshadweep Sea have also been brought out and provide a good information on biological and related parameters about the sea.

The different authors have given different estimates of fish production from Indian Ocean. This varies from 7.8 to 16.00 m tonnes or even more. Since 46% of Indian Ocean production comes from Indian EEZ (Qasim, 1975). The estimates from EEZ varied from 3.59 to 7.36 m tonnes. Desai *et al.* (1990) on the basis of EEZ data alone have inferred 3.66 m tonnes. The present fish catch is about 1.6 m tonnes and there is a definite possibility of increasing this to more than double.

The last one and half decade has generated much more information on the productivity of Indian Seas and hence it is time now to review the whole situation in order to get the fullest advantage of these studies in characterizing the EEZ of India in order to exploit the living resources. In this thesis, an attempt has been made to analyse the data collected for over twenty five years including that of my own.

2. DESCRIPTION OF THE AREA

2. DESCRIPTION OF THE AREA

The Indian Peninsula is flanked by two arms of the Indian Ocean i.e. Arabian Sea on the west and Bay of Bengal on the east. The whole area of the Indian EEZ falls in these two seas. The EEZ is chosen for the detailed study as most of the resources particularly living resources, come from this area. The area of the Indian EEZ is 2.01 m sq. km around the Indian coastline of 7517 kms including that of Andaman and Nicobar Islands. This area is spread over as follows (Fig. 1):-

Regions	Area (million Km^2)	% of Total
EEZ along west coast	0.6983	34.74
EEZ along east coast	0.5155	25.64
EEZ around Andaman and Nicobar Island	0.5665	28.18
EEZ around Lakshadweep	0.2300	11.44
TOTAL	2.0103	100.00

The EEZ around Lakshadweep is contiguous with the area along west coast off Mangalore, Calicut and Cochin and therefore is considered as single unit. However, for study and characterization separate account is given at several places for specific purpose. Geographically the area falls between lat. 24°N to 4°N on both the sides while between long. 66° to 77°E on the west coast and 77° to 90°E on the east coast. The EEZ around Andaman & Nicobar Island is spread between lat. 14° to 5°N and long. 89° to 95°E. This whole area has been divided into a grid of 1° square and there are about 249 such squares in the EEZ of India. The Indian EEZ is about two third (66%) of India's landmass and 4.2% of the Indian Ocean.

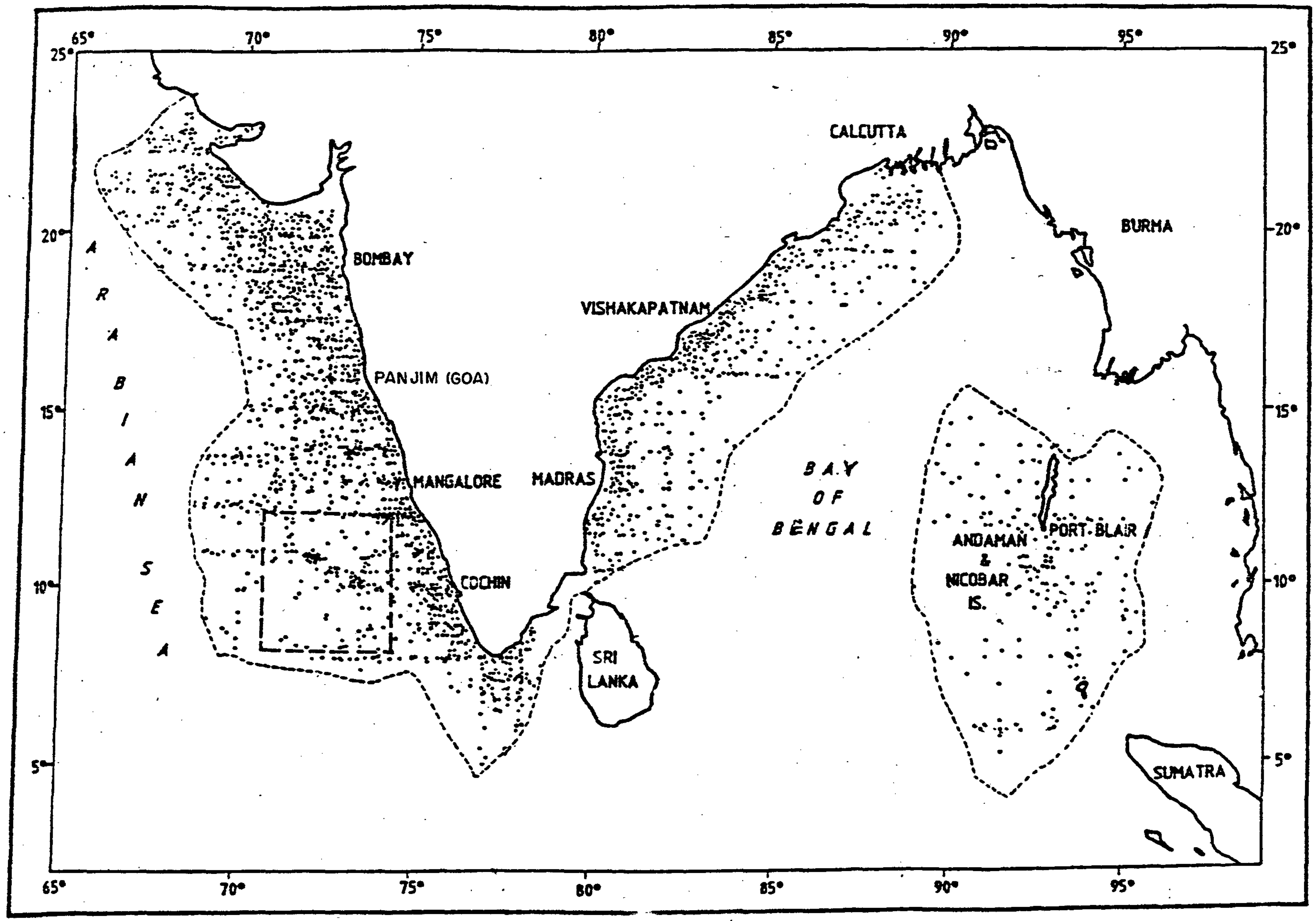


Fig.1 Map of India showing the Exclusive Economic Zone and the location of stationsoccupied in it The area in square is considered as Lakshadweep sea.

The area under study is influenced by many factors such as fresh water discharge from rivers, sediment transport, intrusion of water masses, water circulation and monsoon rainfall which can all be called as the effects of "monsoon gyre". On the west coast about 350 km^3 of fresh water is discharged annually into the Arabian Sea (Rao, 1975). This does not include the heavy run-off from river Indus. Similarly, the input of fresh water into Bay of Bengal is about 1300 km^3 excluding that of rivers Irrawaddy and Salween into Andaman Sea. The river Irrawaddy alone brings on an average about 13560 m^3 per second (Coleman, 1968). Rao (1975) estimated a discharge of 39400 m^{-3} sec^{-1} into eastern EEZ from rivers Ganges, Brahmaputra, Mahanandi, Godavari and Krishna. Similarly, approximately 363 million tonnes of sediment are carried annually by river Irrawaddy into Andaman Sea (Groves and Hunt, 1980). The other rivers too carry large amount of sediment thus making the water turbid and affecting the photosynthesis and production of living matter. The fresh water discharge and the rainfall lowers the salinity of these areas that is why the salinity of waters along the east coast is lower than that of the west coast of India.

Many factors like salinity, circulation and intrusion of water masses depend upon different season. The west coast is more affected by south-west monsoon (June-September) while north-east monsoon (November-January) is more effective on the east coast and Andaman Sea.

The high salinity water masses from Red Sea & Persian Gulf are known to enter the Arabian Sea. However, their influence is gradually reduced by the time they reach the coastal waters of India. There are also reports that the Bay of Bengal waters also reach the Arabian Sea after the cessation of SW monsoon (Sarma *et al.* 1986).

The EEZ includes the entire continental margin i.e. shelf, slope and rise. On the west coast, the shelf is very wide as much as 150 kms off Gulf of Kutch and it narrows down from north to south. On the east coast the continental margin is not more than 15 kms. The shelf region is always said to be more productive which decreases exponentially from shore towards offshore.

In the Lakshadweep Sea, there are shallow water lagoons whose productivity has been worked out by Qasim *et al.* (1970, 1971, 1972). These waters dominated by corals and coral reefs, influences the environmental conditions and biological productivity.

As far as we know neither coherent data is available nor any systematic integrated study has been made for the EEZ of India. Hence, this effort has been made so that the waters of our EEZ could be better understood on the basis of data collected so far in order to further explore the living resources and later properly exploit the sea for the benefit of millions of our countrymen.

3. COVERAGE AND DATA COLLECTION

3. COVERAGE OF THE AREA AND DATA COLLECTIONS

The work presented here is based on the data available in the Indian National Oceanographic Data Centre including my own work. The centre acquires the data from different organizations, agencies and individual scientists. Most of the data have been deposited by the scientists of the National Institute of Oceanography collected since 1976 in the EEZ of India.

The EEZ has been studied during many expeditions including the International Indian Ocean Expedition (1962-65) organised by UNESCO and IOC in which 40 countries including India participated. Since then many ships have traversed but the ships which worked in this area and for which data are available at the Data Centre are INS *Darshak*, R.V. *Gaveshani* and ORV *Sagar Kanya*. Another ship *Sagar Sampada* has recently been deployed and its data are yet to be made available. A total of 220 cruises have been carried out between 1960 and 1988. Their distribution is as follows:-

23 ships during IIOE	48 cruises
INS *Darshak*	5 cruises
R.V. *Gaveshani*	132 cruises
ORV *Sagar Kanya*	35 cruises

For generalization of results, it is necessary that these data are collected during various times of the year. For the sake of description, the year has been divided into three seasons - the Premonsoon (February-May); Monsoon (June-September) and Post monsoon (October-January). However, this division is based on south-west monsoon which is active only along the west coast of India and Lakshadweep Sea. While the east coast and Andaman Sea are affected by rains of north-east monsoon in November-December months. The seasonwise cruises undertaken are shown in the following Table 1 :-

Table 1 : Seasonwise cruise coverage in the EEZ of India (April 1988

Ships (Period)	Pre-Monsoon	Monsoon Monsoon	Post	Total
IIOE (1960-65)	18	19	11	48
INS *Darshak* (1973-74)	3	2	5	
R.V. *Gaveshani* (1976-88)	42	45	45	132
ORV *Sagar Kanya* (1983-88)	10	14	11	35
TOTAL	73	78	69	220

The table shows that the seasons are almost equally covered. The coverage is 57.7% by *Gaveshani*, 26.9% during IIOE and 12.3% by *Sagar Kanya.*

The EEZ of India includes four regions of the sea, out of which three viz. Arabian Sea, Bay of Bengal and Lakshadweep Seas have been well covered while the fourth i.e. Andaman & Nicobar Sea has not been covered adequately. The total number of stations occupied within the EEZ is more than three thousand and on an average about 1000 station's data have been analysed for physical, chemical and biological parameters (Table 2). Yearwise, as it can be seen, maximum coverage is done during 1986 along the east coast and in the Andaman Sea while maximum stations have been occupied for physical and chemical parameters during 1976, 1979 and 1986 and for biological parameters during 1980 and 1985. March and June and premonsoon months are covered maximum followed by monsoon and post monsoon period. Geographically, the maximum coverage is between 14-15^{0}N and 73- 74^{0}E within the EEZ boundaries.

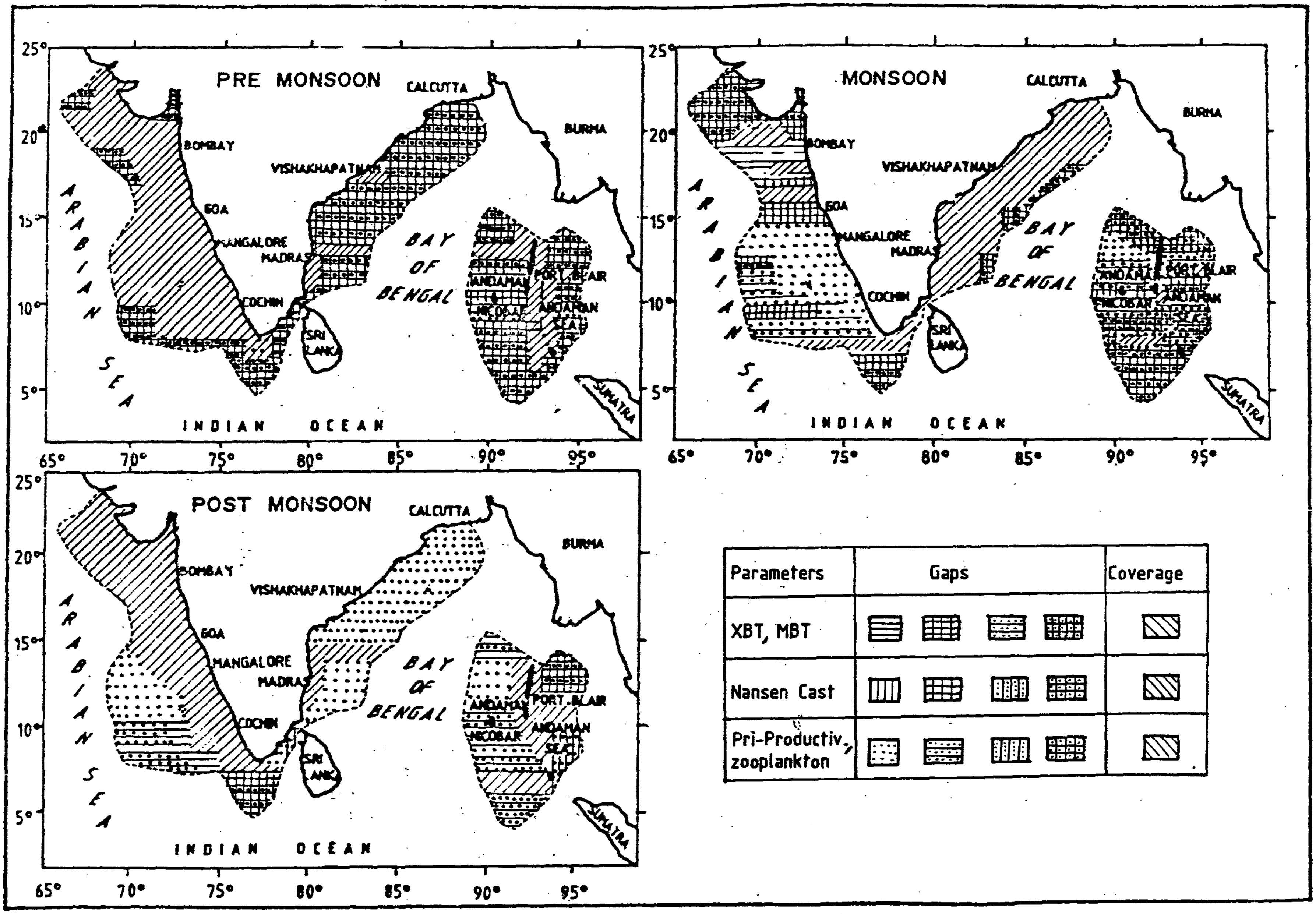
Figure 2 shows that the west coast is extensively covered during pre-monsoon and post monsoon periods whereas the east coast is covered during monsoon. A total of 3964 stations have been occupied during 78 cruises during monsoon, 3846 stations in 73 cruises during pre-monsoon and 3687 stations in 69 cruises during postmonsoon period for physical, chemical and biological parameters (Table 2). Biological data on primary production and zooplankton biomass have been collected from over 900 stations on the west coast during pre and post monsoon and very little in monsoon whereas much of this data from east coast belongs to monsoon

Table 2 : Seasonwise stations coverage in the EEZ of India.

Parameter	Source	Pre-Monsoon	Monsoon	Post Monsoon	Total
Temperature	IIOE	236	278	367	
	DK	20	-	8	
	RVG	513	699	567	3318
	SK	38	451	132	
Salinity	RVG	352	426	489	
	DK	-	-	-	
	IIOE	513	613	557	3453
	SK	38	343	122	
Dissolved Oxygen	IIOE	269	219	216	
	RVG	491	386	415	2424
	SK	96	217	115	
NO_3-N	IIOE	59	14	-	
	DK	43	-	21	
	RVG	466	388	320	1682
	SK	98	204	69	
PO_4-P	IIOE	149	60	40	
	RVG	427	461	354	1904
	SK	97	201	115	
Primary production	IIOE	104	16	11	
	DK	14	-	2	
	RVG	170	195	180	807
	SK	62	29	24	
Zooplankton	IIOE	60	-	2	
	RVG	387	384	355	1364
	SK	108	48	20	

IIOE - International Indian Ocean Expedition (1960-65)
DK - INS *Darshak* (1973-74)
RVG - Research Vessel *Gaveshani* (1976-1988)
SK - *Sagar Kanya* (1983-1988)

period. As far as nansen cast and chemical data are concerned the west coast is well covered in all the three seasons while east coast is covered more during monsoon and post monsoon.



Parameters	Gaps	Coverage
XBT, MBT		
Nansen Cast		
Pri-Productiv, zooplankton		

Fig. 2 . AREAS SHOWING SEASONAL GAPS AND COVERAGE OF OCEANOGRAPHIC STUDIES .

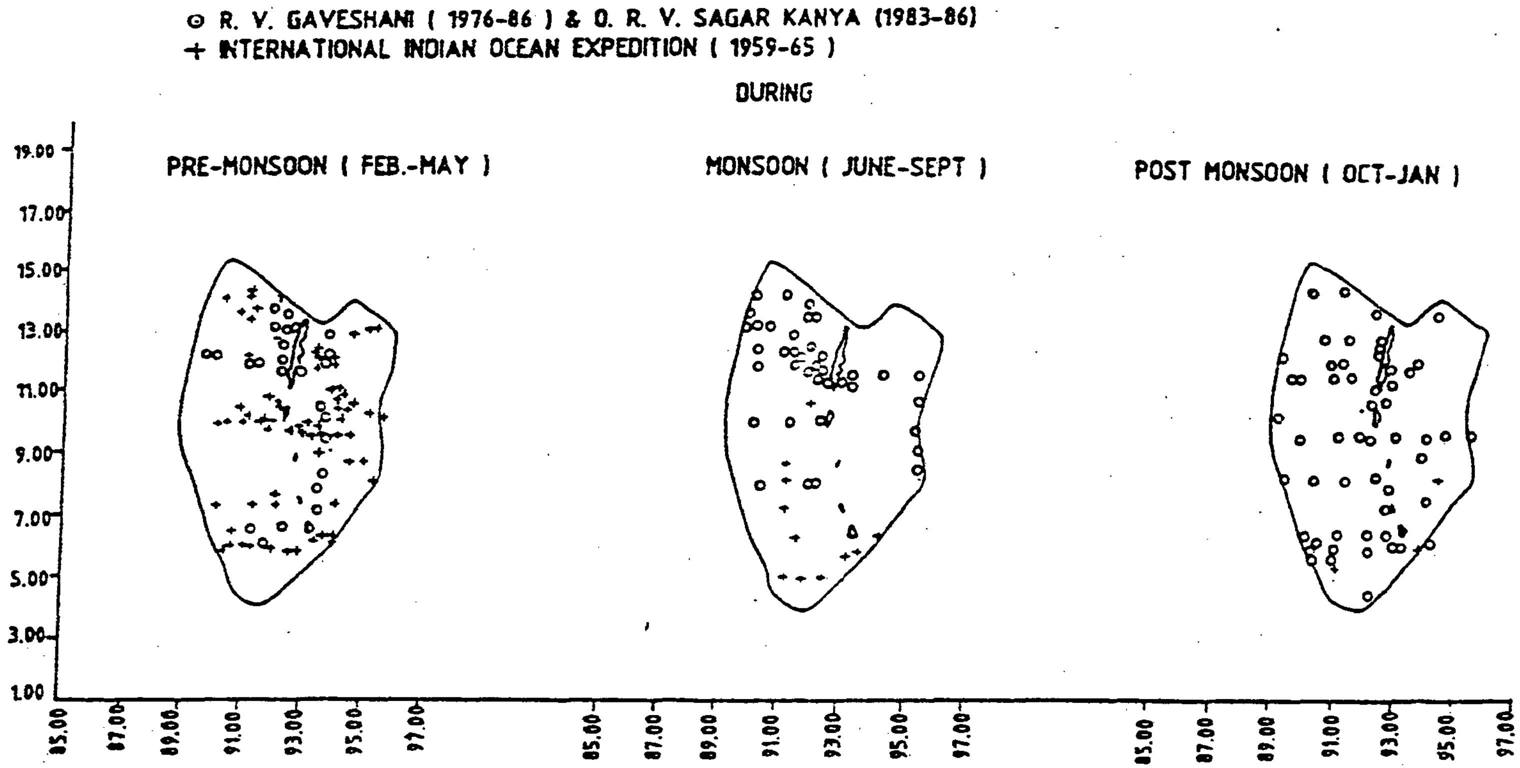


Fig. 3 Location of stationsoccupied in each season in Andaman sea.

In the EEZ around Andaman and Nicobar Islands, the studies are not very comprehensive. In this sea there are 68 one degree squares. Out of which 11 squares have not been covered at all. The location of stations worked out in this sea is shown in Fig. 1. while the seasonwise number of stations occupied are shown in Fig. 3. Out of a total of 223 stations, 144 are covered by R.V. *Gaveshani*, 35 by *Sagar Kanya* and 44 during IIOE. The biological work has been done in 17 cruises which include 7 by *Gaveshani* & 10 during IIOE. In Andaman Seas, it is seen that minimum work has been done in monsoon followed by post and pre monsoon.

Summarising the above information we see that out of 249 one degree squares in Indian EEZ, fifteen squares have not been covered in any season. These include eleven in Andaman Sea, one along east coast and three on the west coast. The seasonal station coverage shows maximum gaps during monsoon followed by post monsoon and pre monsoon. Gaps exist for biological parameter particularly primary production and zooplankton, on the east coast and Andaman Sea during pre monsoon and post monsoon and in Arabian Sea during monsoon. The EEZ along the east coast is inadequately studied in February, May and October while the west coast is partially covered during September.

Besides this, general state of coverage and gaps and the data used in this document for different parameters are given in the respective chapters.

4. DATA ANALYSIS AND DISCUSSIONS

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4.1 *Environmental parameters:*

The environment plays a big role in the biological process affecting the production. The major parameters dealt with here are light, temperature, salinity, dissolved oxygen, phosphate- phosphorus and nitrate-nitrogen. The other factors which are known to affect the processes are nitrite, ammonia, silicate, pH

and other trace elements. Besides these, productivity in the sea is also affected by upwelling which is almost an yearly phenomenon on Indian Coast. In upwelling the bottom waters with low temperature but high nutrients come up and help in increasing production of living matter. It is, therefore, touched upon here.

In a study like this it will be out of scope to describe in detail the horizontal or vertical distribution in a particular year and hence are given only the values and characteristics on a wider sense so as to know the nature of environment in different seasons. And since the primary production is limited to euphotic zone which is about 90m depth, the study and values are restricted to this depth.

4.1.1 *Light:*

Light is essential for photosynthetic activity whereby living matter is produced and generally light is not a limiting factor in tropical waters. However, the penetration of light in the sea depends upon many factors such as turbidity of waters, intensity of light, surface irradiance, and type of water mass etc. The primary production is restricted upto euphotic zone which in terms of light penetration, it can be taken upto a depth of 1% illumination. The most of the infra-red and ultra-violet rays are absorbed in the surface waters and the visible portion of light penetrates.

Nair *et al.* (1968) reported euphotic zone as about 14m in near shore waters, 50-60m in offshore waters and in clear regions near Andaman & Nicobar Island and Lakshadweep Sea it extends upto 80-90m. In northern Arabian sea the euphotic zone varied from 20 to 60m on the Shelf (Varkey and Das, 1976) and 42m in offshore areas (Radhakrishna *et al.*, 1978). In the south eastern Arabian Sea Bhargava *et al.*, (1978) recorded euphotic zone to vary between 20-40m.

Along the east coast in the Bay of Bengal, the light penetration is of the same order i.e. about 60m. In these areas there is a large influx of river waters which are turbid. As per Sechi disk readings, Rao (1957) found reduced transparency in waters along east coast of India in November and December but it increases from February to April with the reversal of currents and intrusion of more oceanic clear waters.

Many authors have studied the effect of light on photosynthesis and growth of various phytoplankton species from temperate and tropical waters. Some of these authors are Riley, 1946; Ryther, 1956; Talling, 1957; Steeman Nielson and Henson, 1959; Smayda, 1963 & 1969; Yentsch and Lee, 1966; Qasim, *et al.*, 1972; Parsons and

Takahashi, 1973 and Raymont, 1980. The results have shown a complex inter relationship between light, temperature and salinity. It is generally seen that photosynthesis increases with increasing light upto only a certain limit. However, the activity also varies with individual species and the physiological state of phytoplankton. The results of Ryther (1956), Russel-Hunter (1970) and Vishniac (1971) shows that the primary production with the available light should be 5 to 10 times more than what is actually measured indicating that besides light there are other factors responsible for this activity.

4.1.2 *Temperature:*

Every organism prefers a suitable temperature and Indian tropical waters provide the congenial temperature to the organisms. These waters are warmer than temperate and polar waters and therefore help in better and faster metabolic activities.

Temperature data have been compiled for study in different sectors at three depths viz. 0, 50 and 100m upto which photosynthesis occurs. All along the west coast, the surface water temperature ranges between 21.7 to 31.2°C in pre-monsoon; 24.3 to 29.9°C in monsoon and 22.7 to 29.8°C in post-monsoon with respective averages of 27.5°, 28.5° and 27.3° celsius. The variation in monsoon was minimum. Qasim (1982) reported surface temperature to vary from 18.36 to 30.12°C in northern Arabian Sea during June - September. At 50m depth, the temperature was lower than that at 0m. The difference between minimum and maximum increases and it varies from 21.67 to 30.57° (av. 25.93°) in pre- monsoon; 20.21 - 29.52 (Av. 26.17°) in monsoon and 15.16 to 29.8 (Av. 26.36°) in post monsoon. The difference further increases at 100m by as much as 15°C. Surface temperature was found to increase from north to south and away from coast on the western coast of India. A tongue of warm water of about 29.9°C was noticed at 20m depth by Anand *et al.* (1968) off the west coast of India spreading from Gulf of Cambay upto Lakshadweep Sea. Minimum temperature is recorded during August-September while maximum is recorded during April-May. The temperature range and their averages are shown in the Table 3. In Lakshadweep Sea too, the pattern is almost same as on west coast. The maximum temperature of 30.84°C was noticed during February-May followed

Table 3 : Average and range of temperature °C at three depths in four sectors of EEZ

		Pre-monsoon (Feb.- May)			Monsoon (June - Sept.)			Post-monsoon (Oct. - Jan)		
Sector	Depth	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.
West Coast	0	21.70	31.20	27.53	24.32	29.93	28.48	22.71	29.83	27.27
	50	21.67	30.57	25.93	20.21	29.52	26.17	15.16	29.80	26.36
	100	13.49	28.35	23.35	13.09	27.80	20.66	12.60	27.96	21.53
Lakshadweep Sea	0	27.33	30.84	29.39	27.86	29.79	28.60	27.10	29.10	28.39
	50	24.17	29.58	28.41	23.83	29.13	27.70	12.51	28.92	24.38
	100	21.00	27.66	24.85	15.86	27.88	20.71	14.46	23.10	19.26
East Coast	0	20.10	30.10	27.99	25.70	29.90	28.59	24.80	29.00	26.04
	50	11.00	29.75	26.28	12.71	29.29	26.01	20.63	28.00	26.24
	100	9.40	27.53	22.56	12.28	28.07	21.18	15.49	26.50	21.82
Andaman & Nicobar Sea	0	26.34	30.98	28.36	26.73	29.83	28.04	25.68	28.57	27.54
	50	21.58	32.06	26.74	9.79	29.54	27.37	19.85	28.22	25.69
	100	12.70	27.90	21.39	14.46	28.76	22.46	15.00	27.81	19.19

during June- September and minimum of 27.10°C in October-January. Being nearer to equator the averages are higher than that of upper west coast. The surface temperature in this area varied from 27.10 to 30.84°C annually while Bhattathiri (1984) reported the temperature to vary from 28.6 to 30.6°C concluding that the mixed layer in open sea was found between 50 and 60m while in shallow areas the entire column becomes homogenous. Along west coast and Lakshadweep Sea, May and June months are warmer in general.

Along east coast, the temperature at 0m varies from 20.1 to 30.1°C (av. 27.99°) in pre-monsoon; 25.7 to 29.9°C (av. 28.59°) in monsoon and 24.8 to 29.0°C (av. 26.04°C) in post monsoon. However, unlike the west coast the temperature decreases away from the coast showing coastal waters including river waters are warmer. At 50 and 100m depths the temperature decreases, the range increases and at 100m the temperature was observed as low as 9.4°C in February 1979. The average temperature at 100m was found to be 22.56° in pre-monsoon; 21.18° in monsoon and 21.82° in post monsoon period. In the pre-monsoon the difference between minimum and maximum was minimum 10° at 0m, 18.75° at 50m and 18.1° at 100m depth.

In Andaman and Nicobar Sea the temperature at surface was found to vary from 26.34° to 30.98° (av.28.36°) in pre-monsoon; 26.73° to 29.83°C (av. 28.04°) in monsoon and from 25.68° to 28.57°C (av. 27.54°C) in post monsoon season. The difference is of 3 to 4°C. At 50m this difference increases very much. The various ranges are 21.58°-32.06°C in pre-monsoon, 9.79°-29.54°C in monsoon and 19.85° to 28.22°C in post monsoon. At 100m also the range is considerable. The averages for the three seasons being 21.39° in pre-monsoon, 22.46°C in monsoon and 19.19°C in post monsoon. Bhattathiri (1984) reported mixed layer depth between 75 to 80m on western Andaman Sea and from 50 to 75m along eastern side and along 10°N channel the mixed layer depth was 40m.

The temperature isopleths at the surface is shown in Fig. 4 This shows that on the west coast the temperature increases from north to south and as we move away from the shore. There are few small patches having temperature more than 30°C in and around the Lakshadweep Islands. On the east coast, however, high temperature is noticed in nearshore waters and it generally decreases towards offshore. In An-

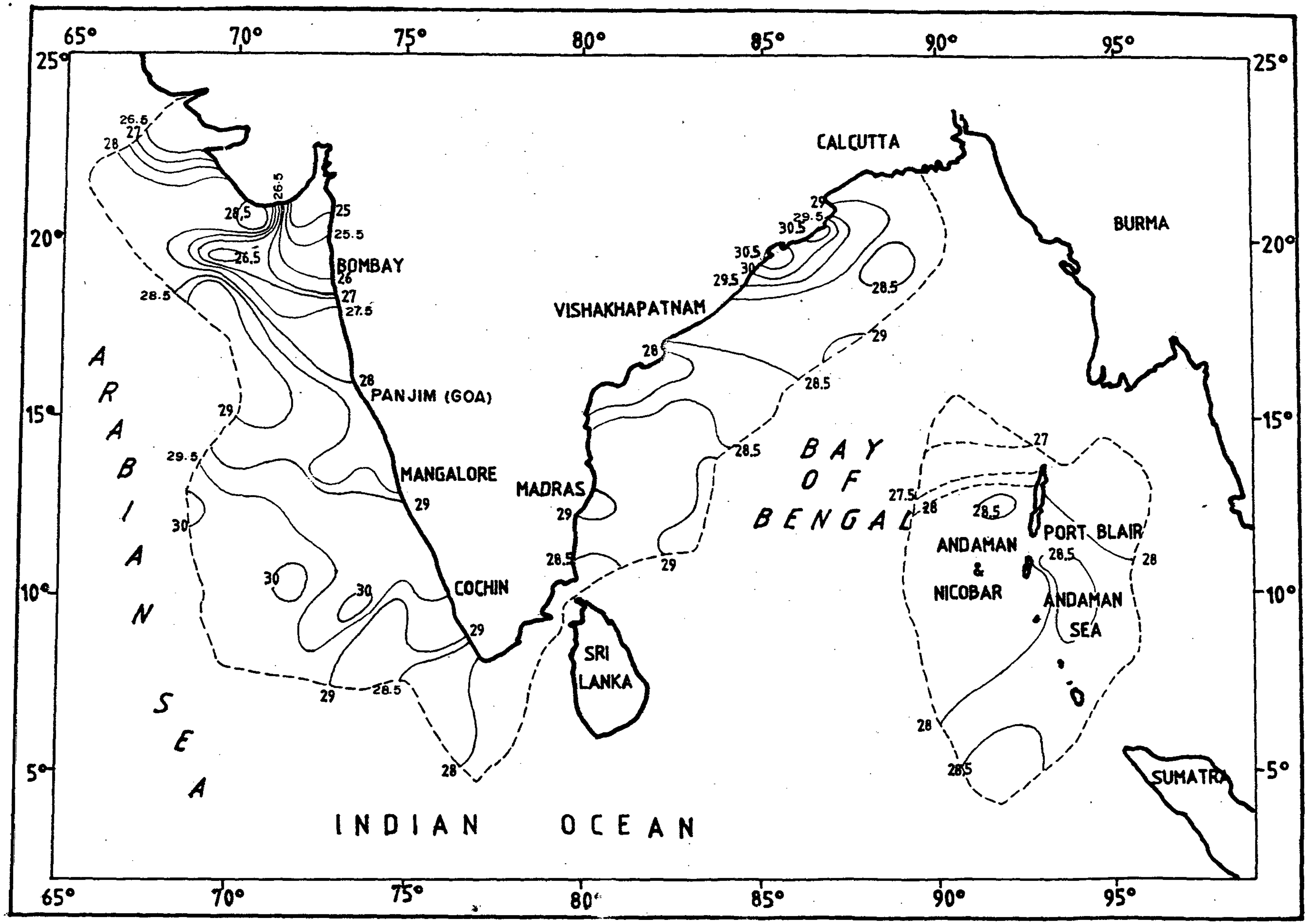

Fig. 4 Distribution of Temperature (°C) at surface.

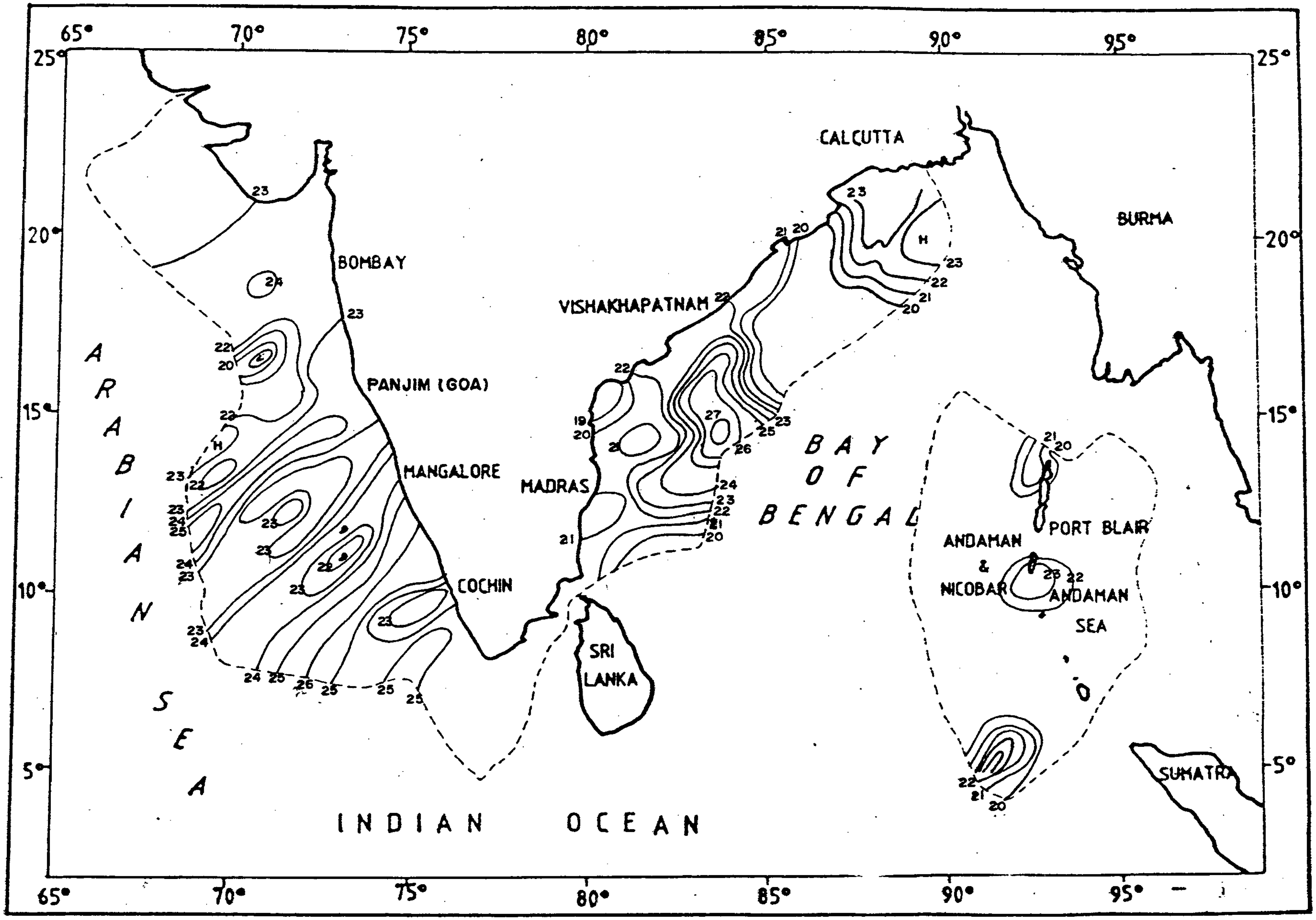

Fig. 5 Distribution of temperature (°C) at 100m depth.

daman waters, the temperature is uniform. The temperature contours show a large variation at 100m depth with no uniform pattern and hardly any horizontal mixing (Fig. 5).

4.1.3 *Salinity:*

The range and average salinity in the different sectors is shown in Table 4. The salinity along western EEZ was always more than that along eastern border. In the western waters the minimum during pre-monsoon was 21.70×10^{-3}, which was unusually low, and maximum was 37.06×10^{-3} with an average of 35.37×10^{-3}. During monsoon it ranged between 28.93 to 36.92×10^{-3} (av. 35.1×10^{-3}) while during post monsoon the variations in salinity values were noticed from 29.90 to 36.91×10^{-3} with an average of 34.94×10^{-3}. At 50 and 100m depths the values increased slightly and the average for these three seasons were 35.80, 35.93 and 36.06×10^{-3} at 50m and 35.89, 35.59 and 35.59×10^{-3} at 100m. In northern Arabian Sea, Qasim (1982) reported surface salinity between 35.04 and 36.89×10^{-3} during June-September. In the adjacent Lakshadweep Sea the variations were similar but average was slightly less at all the three depth during pre-monsoon probably because the rains set in there a little early. In other seasons it is comparable with that of west coast. At surface, the average salinity was found to be 34.94, 35.69 and 35.54×10^{-3} during pre-monsoon, monsoon and post monsoon respectively. In the whole year, at the three depth the salinity ranged between 33.08 and 36.8×10^{-3}. It is seen that high salinity water from Arabian Sea is found around 100m depth. Sarma *et al.* (1986) identified a depth range of 200-300m at 15^{o}N and 65^{o}E as the zone of maximum salinity exceeding 35.9×10^{-3} during December 1982.

Along the east coast, however, the salinity was less than that at west coast a Lakshadweep Sea. It varied between 20.50 and 35.85×10^{-3} among the three depths in the entire year. At 0m the average in all the seasons was less being 33.41×10^{-3} in pre-monsoon, 32.45×10^{-3} in monsoon and 32.36×10^{-3} in post monsoon the period when east coast is affected by north east monsoon rains. At 100m the averages were 34.67×10^{-3} in pre- monsoon, 34.83×10^{-3} in monsoon and 34.71×10^{-3} during post monsoon. At 50m the averages were in between the two indicating that the salinity gradually increases from surface to subsurface. Surface salinity is less because of

Table 4: Average and range of salinity (10^{-3}) in different sectors in three seasons

Sector	Depth (m)	Pre-Monsoon (Feb. - May) Min.	Max.	Av.	Monsoon (June - Sept.) Min.	Max.	Av.	Post-monsoon (Oct. - Jan.) Min.	Max.	Av.
West Coast	0	21.70	37.06	35.37	28.93	36.92	35.10	29.90	36.91	34.94
	50	33.70	36.57	35.80	28.23	36.82	35.93	34.40	36.98	36.06
	100	34.09	36.85	35.89	31.83	36.65	35.59	34.83	36.83	35.59
Lakshadweep Sea	0	33.57	35.84	34.94	33.08	36.13	35.69	34.33	36.40	35.54
	50	34.78	36.02	35.33	35.38	36.44	35.96	34.30	36.80	35.74
	100	35.12	36.24	35.72	35.04	36.00	35.53	35.11	35.82	35.40
East Coast	0	31.09	35.50	33.41	20.50	35.51	32.45	28.67	34.65	32.36
	50	23.11	35.00	33.82	32.50	35.85	34.32	31.83	34.70	33.71
	100	33.92	35.43	34.67	33.78	35.48	34.83	34.06	34.98	34.71
Andaman & Nicobar Sea	0	30.78	34.27	32.71	30.00	34.54	32.98	26.19	34.74	30.87
	50	25.60	34.99	33.56	31.51	35.00	33.47	32.55	35.10	33.93
	100	33.49	35.01	34.52	33.73	35.20	34.56	33.39	35.02	34.63

heavy river runoff in Bay of Bengal. Bhattathiri (1984) reported salinity less than 30 x 10^{-3} in the head of Bay of Bengal while it increases to 34 x 10^{-3} towards southern part during the months of June to September. At the river mouths along the east coast, Lafond (1954) observed as low as 18 x 10^{-3} or even less.

In the Andaman & Nicobar Sea, the salinity at surface varied from 30.78 to 34.27 x 10^{-3} (av. 32.71) in February-May, from 30 to 34.54 x 10^{-3} (av. 32.98) during June-September and between 26.19 and 34.74 x 10^{-3} (av. 30.87) during October-January. Its averages are slightly lower than salinity averages at corresponding depth along the east coast of India. Here also the salinity values increases with depth, being more at 50 and 100m depth. At 100m depth the range of salinity was found between 33.49 x 10^{-3} and 35.01 x 10^{-3} (av. 34.52) during February-May, 33.73 to 35.[illegible] x 10^{-3} (av. 34.56) in June-September and 33.39 to 35.02 x 10^{-3} (av. 34.63) in October-January. The salinity was found to increase from north to south on western coast and vice- versa on eastern coast. Bhattathiri (1984) reported salinity inversions also. He observed vertical and horizontal gradients in the upper 100m layers.

Salinity variations have its own effect on production. Qasim *et al.* (1972a) found out that phytoplankton grow better in low saline waters. The favourable salinity was reported to be between 15-25 x 10^{-3}. Above 35 x 10^{-3} salinity, diatom growth is adversely effected. However, these observations are based on experimental work in the laboratory but its applicability in a dynamic marine environment is not well understood.

The general pattern of distribution of salinity at surface is shown in Fig. 6. The west coast waters show the salinity not less than 34 x 10^{-3} except at small area along Gujarat coast. Along northern and central west coast the salinity also increases offshore while along southern side of west coast there is uniform salinity over a large area except a patch of high salinity off Cochin. Along eastern coast the salinity is comparatively lower but increases in offshore. At 100m depth the upper western half is having more or less uniform salinity between 36-37 x 10^{-3} while lower half between has 35 to 36 x 10^{-3} (Fig. 7).

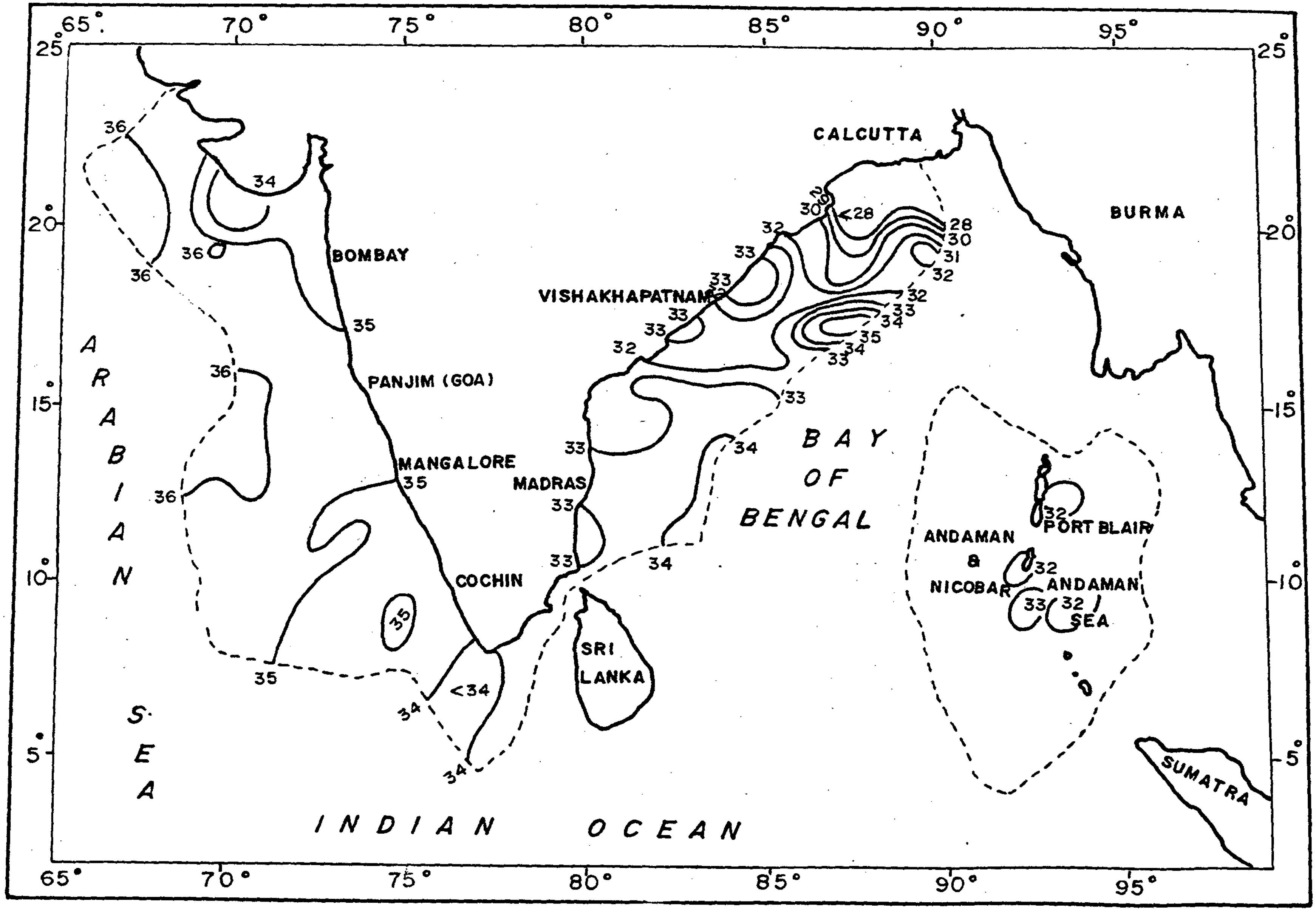

Fig. 6 Distribution of salinity (‰) at surface.

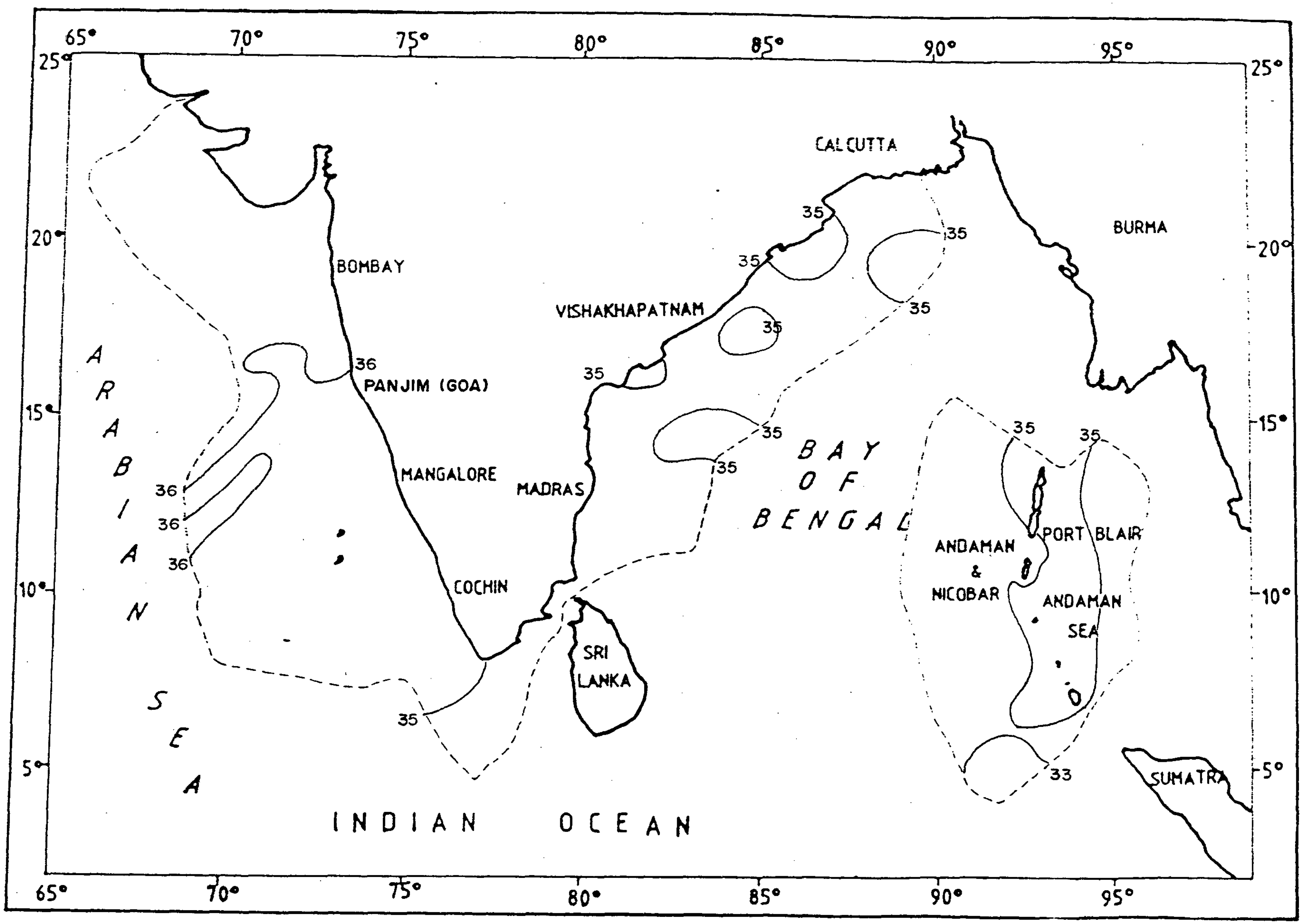

Fig.7 Distribution of salinity (‰) at 100m depth.

4.1.4 *Oxygen distribution*

The O_2 distribution is of great interest in biological studies. The phytoplankton evolves O_2 during photosynthesis while animal life need it for their survival. As a general rule the O_2 concentration goes down with increasing depth.

As shown in the Table 5, the O_2 at 0m (surface) on west coast varies between 2.63 and 6.58 mll^{-1} (av. 4.69) in pre- monsoon, 3.40-8.48 mll^{-1} (av. 4.68) in monsoon and from 0.3 to 6.84 mll^{-1} (av. 4.56) during post monsoon. At 50m the averages are slightly less being 4.33, 3.48 and 3.28 mll^{-1} in the respective three seasons but at 100m there is a sharp decrease. The minimum concentration reaches as low as 0.1 mll^{-1} in March 1965. The maximum of 4.95 mll^{-1} was also noticed in March but in 1981. This shows the dynamic nature of the sea waters. The average O_2 concentration was calculated to be 2.48 in pre- monsoon, 1.62 in monsoon and 1.44 mll^{-1} in post monsoon.

In Lakshadweep Sea, the O_2 concentration at 0 and 50m was very similar with west coast distribution but showed a little higher values at 100m depth. The average in pre-monsoon at 0, 50 and 100m was 4.47, 4.46 and 2.49 mll^{-1} with a range from 0.73 to 5.37 mll^{-1}. In monsoon, the surface values ranged from 4.16 to 4.75 mll^{-1} 50m values were found to be between 2.88 and 4.42 mll^{-1} while at 100m these were 0.34 to 4.06 mll^{-1}. Their averages were 4.44, 3.62 and 1.31 mll^{-1} at 0, 50 and 100m depth. In post monsoon the averages of O_2 values were 4.64 mll^{-1} at 0m, 4.06 mll^{-1} at 50m and 1.03 mll^{-1} at 100m depth. The results of Bhattathiri (1984) shows that during October the layer between 10 and 50m was supersaturated but in December it was 20 to 50m layer which was supersaturated with O_2.

The O_2 concentration along east coast also shows the same trend. The maximum being at surface and decreasing at depths with sharp decline at 100m. The range at surface (0m) was 3.7-5.38 mll^{-1} in pre-monsoon (av. 4.6), 2.69 - 6.21 mll^{-1} (av. 4.57) in monsoon and 4.15 - 5.15 mll^{-1} (av. 4.65) in post monsoon. It declines to an average of 1.34 mll^{-1} (0.13-4.33 mll-1, 1.22 mll^{-1} (0.16-5.15) and 0.84 mll^{-1} (0.15-3.88 mll^{-1}) in pre-monsoon, monsoon and post monsoon seasons at 100m depth while at 50m depth it was in between but more nearer to surface values.

Table 5: Average and range of dissolved oxygen ($ml l^{-1}$) in three seasons at three depths

Sector	Depth (m)	Pre-Monsoon (Feb. - May) Min.	Max.	Av.	Monsoon (June - Sept.) Min.	Max.	Av.	Post-monsoon (Oct. - Jan.) Min.	Max.	Av.
West Coast	0	2.63	6.58	4.69	3.40	8.48	4.68	0.30	6.84	4.[illegible]
	50	1.44	6.17	4.33	0.83	5.76	3.48	0.37	5.35	3.2[illegible]
	100	0.10	4.95	2.48	0.31	3.70	1.62	0.19	4.75	1.44
Lakshadweep Sea	0	3.93	5.37	4.47	4.16	4.75	4.44	4.23	5.22	4.[illegible]
	50	3.00	5.50	4.46	2.88	4.42	3.62	1.43	5.50	4.[illegible]
	100	0.73	4.30	2.49	0.34	4.06	1.31	0.15	3.85	1.[illegible]
East Coast	0	3.71	5.38	4.60	2.69	6.21	4.57	4.15	5.15	4.6[illegible]
	50	1.43	5.41	4.05	0.18	5.86	3.51	1.65	4.84	4.[illegible]
	100	0.13	4.33	1.34	0.16	5.15	1.22	0.15	3.88	0.[illegible]
Andaman & Nicobar Sea	0	3.51	4.69	4.46	3.13	5.35	4.41	4.35	4.91	4.6[illegible]
	50	1.60	5.21	4.11	1.77	4.65	3.94	0.46	4.58	2.73
	100	0.34	4.68	2.00	0.39	4.07	1.75	0.28	4.37	1.2[illegible]

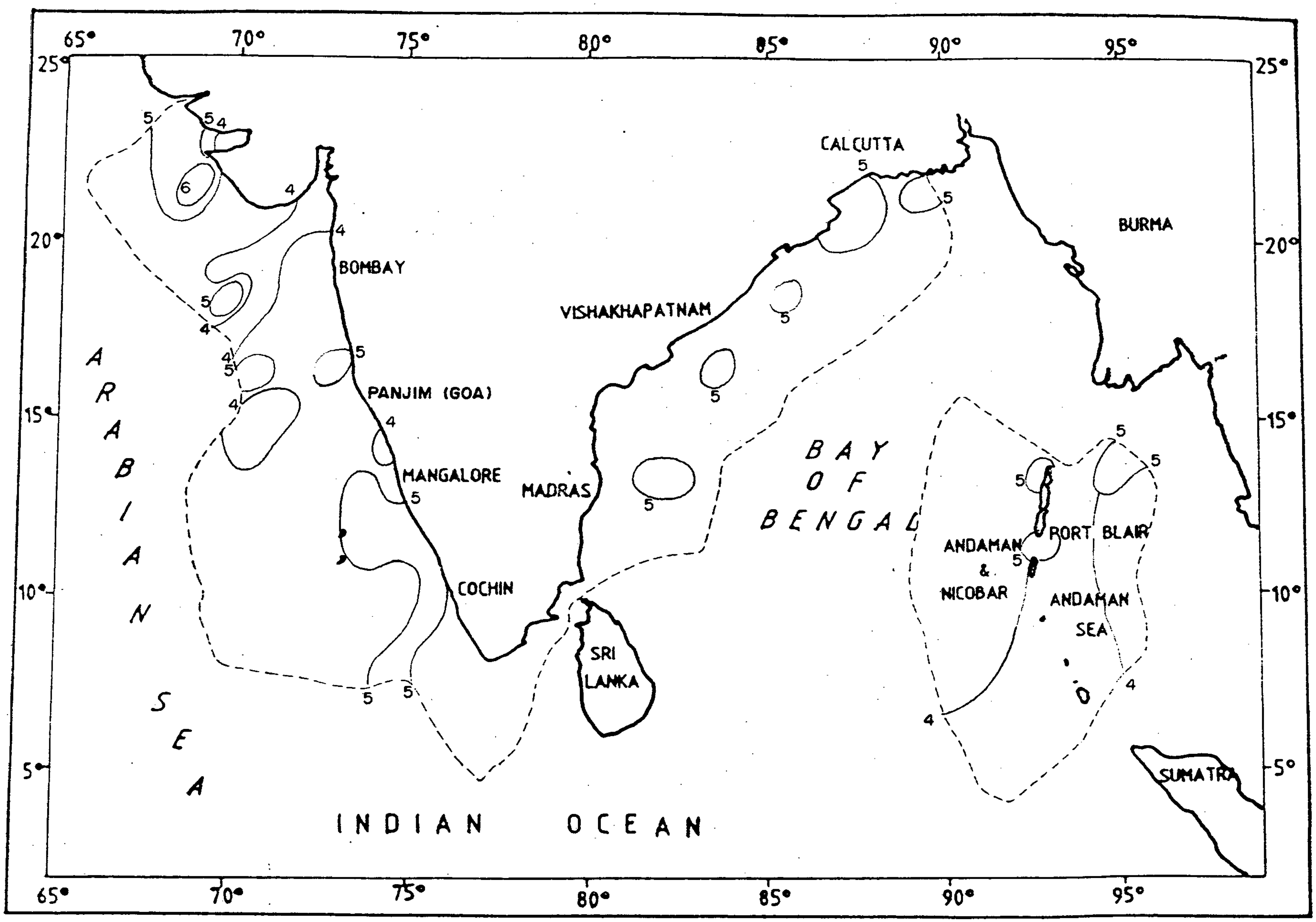

Fig. 8 Distribution of dissolved oxygen ($ml l^{-1}$) at surface.

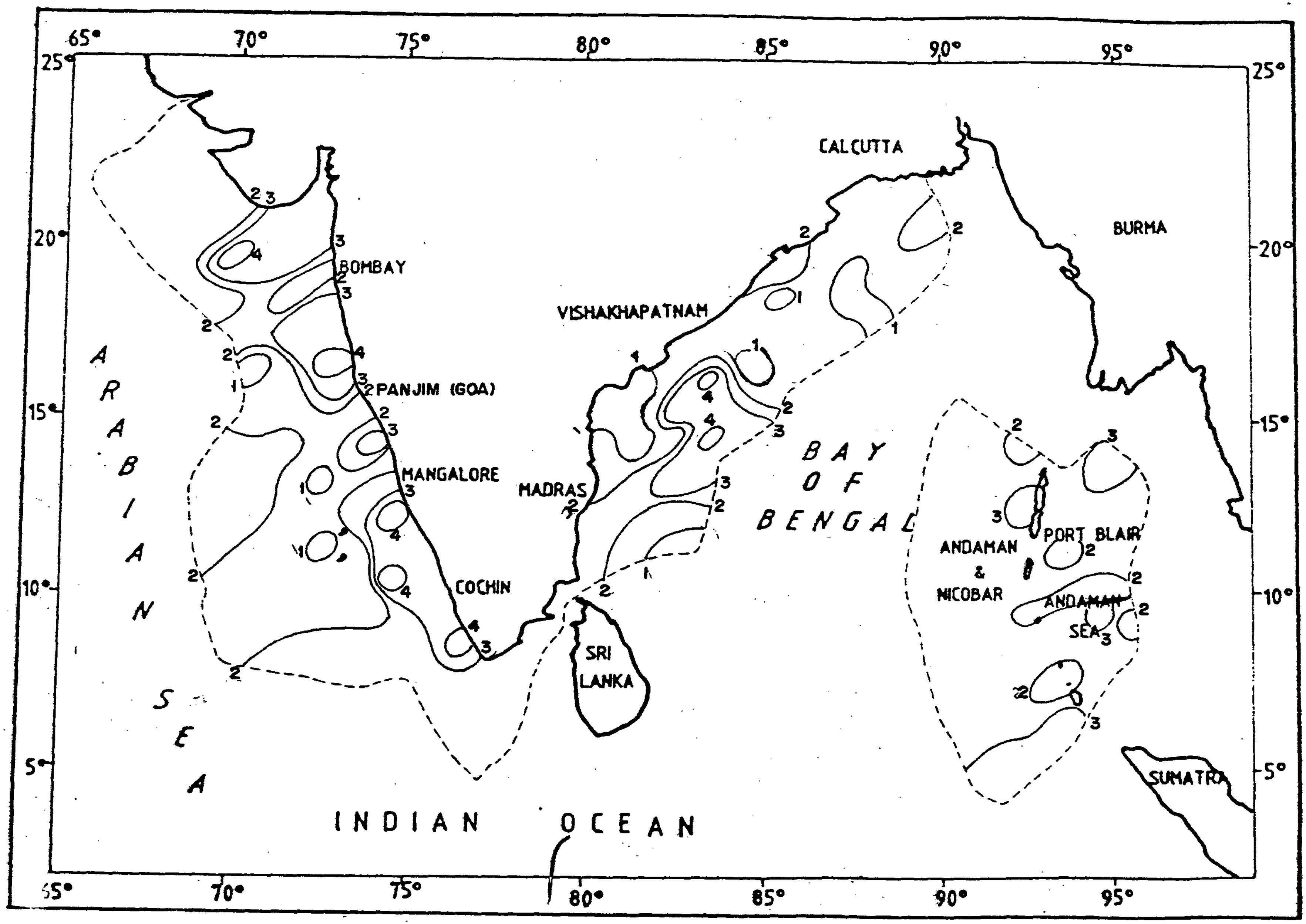

Fig. 9 Distribution of dissolved oxygen ($ml\,l^{-1}$) at 100m depth.

In Andaman Sea, the O_2 concentration ranges from 3.51 - 4.69 mll^{-1} (av. 4.46) in pre-monsoon, 3.13 - 5.35 mll^{-1} (av. 4.41) in monsoon and 4.35 - 4.91 mll^{-1} (av. 4.65) in post monsoon period. At 50m the averages are 4.11, 3.94 and 2.73 mll^{-1} while at 100m depth these average were found to be 2.0, 1.75 and 1.28 mll^{-1} in the seasons respectively which again shows a decline more so from 50 to 100m depth. In western Andaman, the supersaturation was found upto 50m in February 1979 but not so in the eastern Andaman Sea.

Fig. 8 shows the contour of oxygen distribution in the EEZ at surface. Along the entire area there are pockets of high oxygen concentration ranging between 5-6 mll^{-1} otherwise it ranges between 4-5 mll^{-1} in most of the area. At 100m high concentration is observed near the coast on the western EEZ but low oxygen near the coast on the eastern side (Fig. 9). In Andaman waters there does not seem to be any regular pattern.

4.1.5 *Nutrients:*

The nutrients play a very significant role in the process and a few of them may be the limiting factors. Very important among them are phosphate, nitrate and nitrite which provide phosphorus and nitrogen for the activity. The nutrients are replenished either by upwelling, mineralisation or river runoff.

(a) *Phosphate-Phosphorus* : The range and average of phosphate- phosphorus at various places are given in the Table 6. Along the west coast the values at surface range between 0.02 - 1.39 $\mu g - atl^{-1}$ (av. 0.24) during premonsoon, 0.06 - 0.97 μg-atl^{-1} (av. 0.35) in monsoon and 0.03-1.08 μg-atl^{-1} (av. 0.42) during post monsoon. The averages for 50 and 100m depth are higher. At 100m the averages are 1.05, 1.55 and 1.73 μg-atl^{-1} during the three seasons respectively. Higher values are seen during monsoon months when there is lot of river runoff and mixing. The next best is during post monsoon period. In the south west Arabian Sea, Bhargava et al. (1978) noticed during October-December the PO_4-P concentration to range from 0 - 1.04 μg-atl^{-1} while in northern Arabian Sea during December and May, Radhakrishna et al. (1978) recorded its concentration between 0 - 2.18 μg-atl^{-1} in the shelf regions and further decreased offshore. Qasim (1977) reported high concentration of PO_4-P along east and west coast of India and also in northern Bay of Bengal. He calculated the

Table 6: Average and range of PO_4 -P (μg-atl^{-1}) in three seasons at three depths

Sector	Depth (m)	Pre-monsoon (Feb. - May) Min.	Max.	Av.	Monsoon (June - Sept.) Min.	Max.	Av.	Post-monsoon (Oct. - Jan.) Min.	Max.	Av.
West Coast	0	0.02	1.39	0.24	0.06	0.97	0.35	0.03	1.08	0.42
	50	0.05	2.39	0.37	0.13	2.10	0.78	0.03	2.04	0.52
	100	0.06	2.15	1.05	0.74	2.23	1.55	0.81	2.94	1.73
Lakshadweep Sea	0	0.04	0.53	0.19	0.16	0.97	0.30	0.30	1.23	0.55
	50	0.07	0.53	0.23	0.26	0.78	0.58	0.31	1.23	0.55
	100	0.10	1.49	0.72	0.48	2.07	1.67	1.08	1.86	1.34
East Coast	0	0.08	1.03	0.24	0.02	1.30	0.45	0.09	0.17	0.11
	50	0.09	1.10	0.34	0.09	1.58	0.49	0.12	0.27	0.18
	100	0.37	1.60	0.91	0.28	4.69	1.69	0.27	1.92	1.23
Andaman & Nicobar Sea	0	0.05	0.52	0.22	0.07	0.18	0.12	0.09	0.17	0.13
	50	0.05	1.03	0.31	0.11	0.61	0.32	0.09	0.18	0.14
	100	0.35	2.25	1.21	1.00	2.10	1.57	0.25	0.28	0.27

concentration to range between 80 - 100 μg-atl^{-1} along north-west coast of Indian. This is the integrated value for the entire 100m column.

In Lakshadweep Sea, the concentration of phosphate during pre-monsoon is lower at all the three depths than in the western coast. During monsoon the values at 0 and 50m are less but at 100m it is more than at the respective depths along west coast while during post-monsoon the average concentration of PO_4-P at all the depths is higher. At surface the averages during three seasons are 0.19, 0.30 and 0.55 μg-atl^{-1} while at 100m the corresponding figures are 0.72, 1.67 and 1.34 μg-atl^{-1} and without any deviation the values at 50m fall in between. The low values of PO_4-P at surface during monsoon is possible either due to its utilization since the primary production during these months is high on an average or dilution by rain water.

The PO_4-P concentration along the east coast on the whole is lower than that of west coast. At the 0m depth it ranged from 0.08 to 1.03 μg-atl^{-1} (av. 0.24) in pre monsoon, 0.02 to 1.30 μg- atl^{-1} (av. 0.45) in monsoon and 0.09 to 0.17 μg-atl^{-1} (av. 0.11) during post monsoon. It is observed to increase upto 100m depth where the averages for 0, 50 and 100m depths are 0.91, 1.69 and 1.23 μg-atl^{-1} in pre monsoon, monsoon and post monsoon respectively. Inspite of the river runoff in coastal waters of Bay of Bengal, the phosphate-phosphorus values are not higher than those in the west coast. The October-January months were particularly poor in PO_4-P concentration specially in 0 and 50m depth zone.

The Andaman and Nicobar Seas were not very different from the eastern coast. The surface values were low throughout the year not exceeding 0.52 μg-atl^{-1}. The concentration at surface varied from 0.05 - 0.52 μg-at/l (av. 0.22), 0.07 - 0.18 μg-atl^{-1} (av. 0.12) and 0.09 - 0.17 μg-atl^{-1} (av. 0.13) during pre monsoon, monsoon and post monsoon respectively. At 100m depth the mean concentration is better in pre monsoon and monsoon but low during post monsoon. The respective averages being 1.21, 1.57 and 0.27 μg-atl^{-1}.

The values and mean concentration indicate an increasing trend with depth all along the two coasts, and the islands waters.

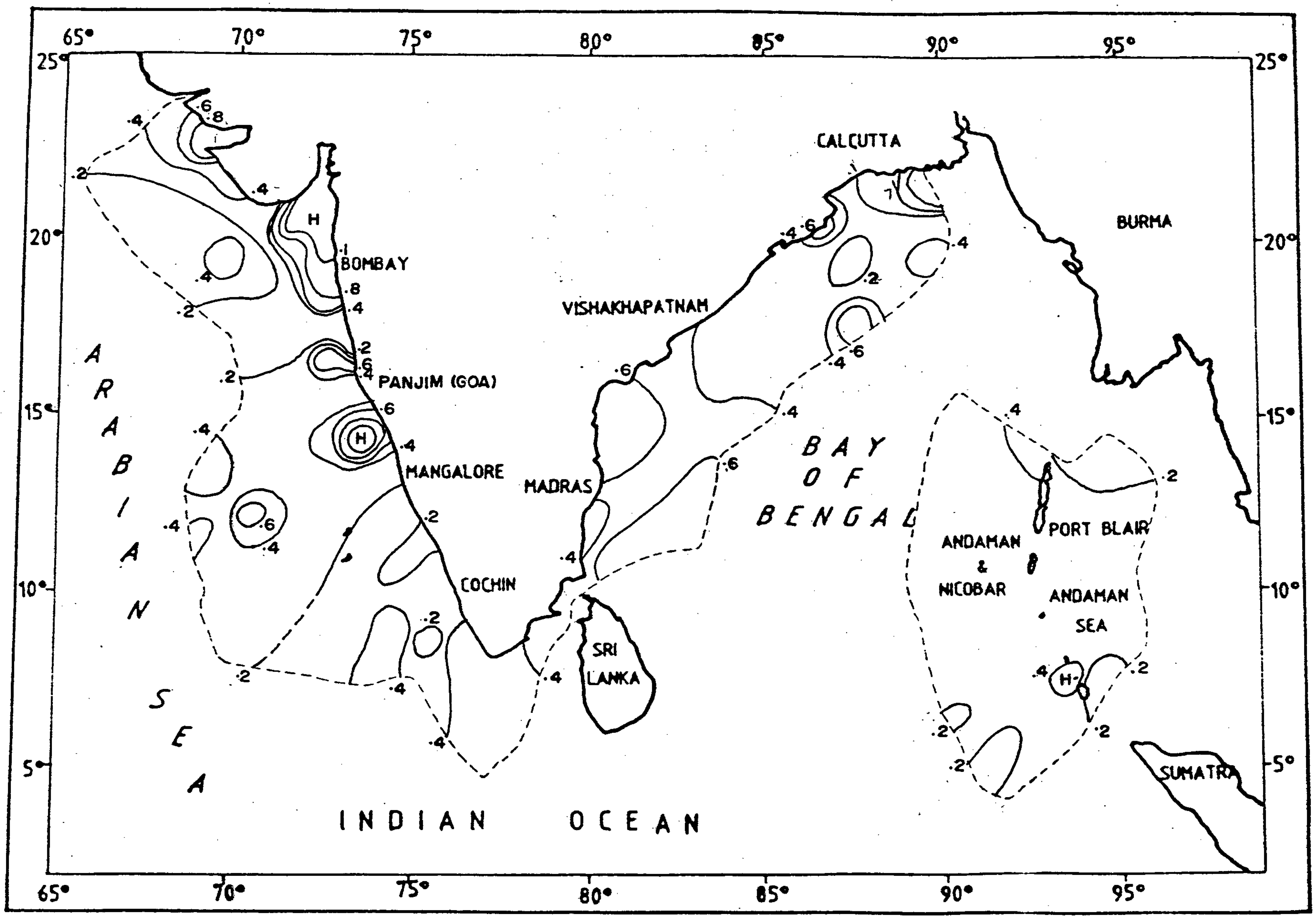

Fig. 10 Distribution of PO4-P ($\mu g-at\ l^{-1}$) at surface

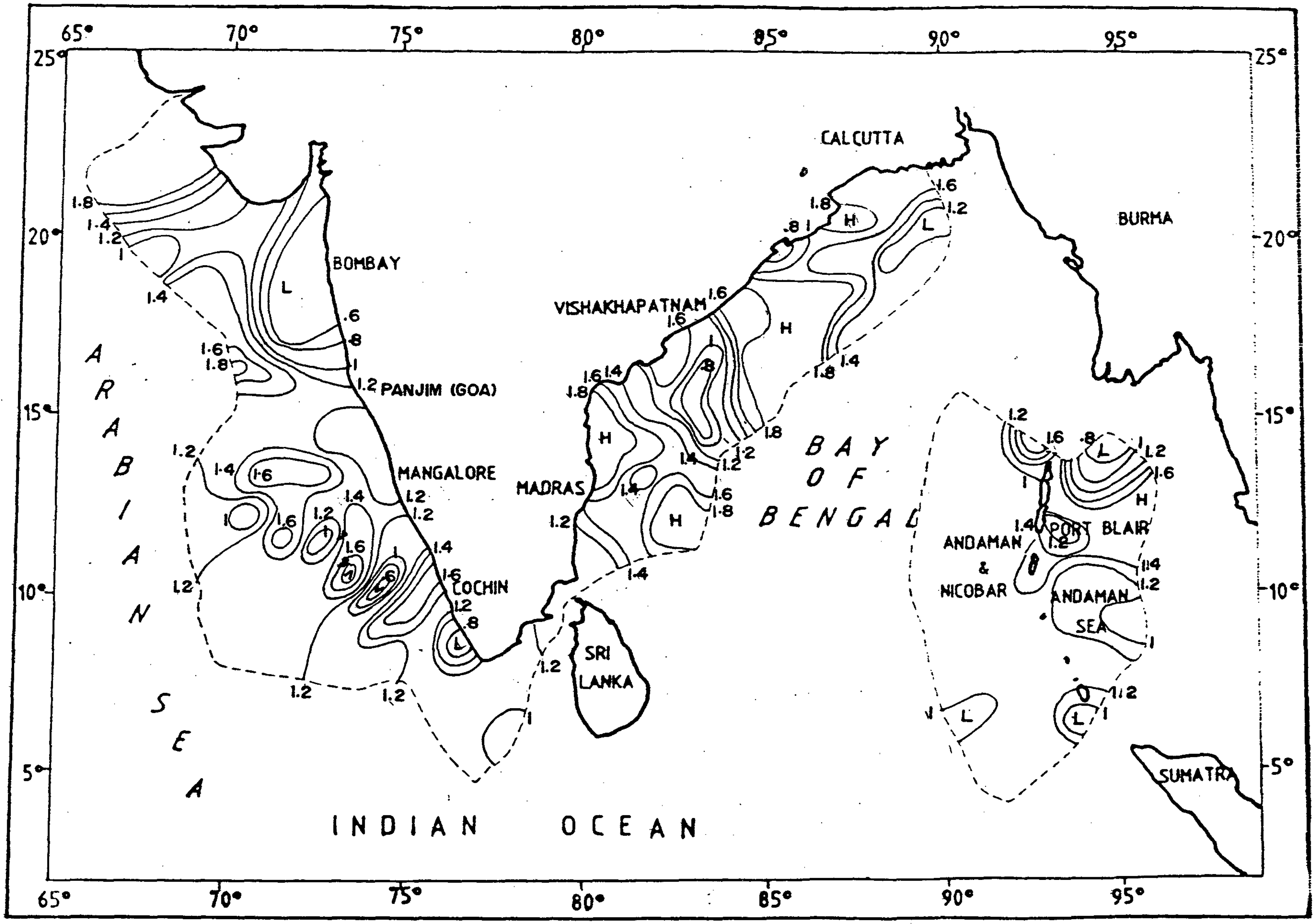

Fig.11 Distribution of PO4-P (μg-at l^{-1}) at 100m depth.

The phosphate-phosphorus contours show that at surface (Fig. 10) high concentration exists off Bombay and Goa on west coast and off Calcutta and in waters between Madras and Visakhapatnam along east coast. Along west coast it decreases offshore but not necessarily so along east coast. The Andaman waters are almost poor in phosphate concentration. On the contrary the PO_4-P occurs in high concentrations at 100m depth in the whole of EEZ area as shown in the map (Fig. 11).

(b) *Nitrate-Nitrogen* : The concentration of NO_3-N in the form of average and range is shown in the Table 7. On the west coast, the concentration ranged between 0.01 & 4.74 μg-atl^{-1} in pre monsoon, 0.01 & 1.03 ug-atl^{-1} in monsoon and 0.01 to 1.24 μg-atl^{-1} during post monsoon with averages of 0.316, 0.205 and 0.256 μg-atl^{-1} in the three respective seasons. At 50m depth the average values were found to be 0.337 μg-atl^{-1}; 0.439 and 0.512 ug-atl^{-1}. In monsoon the lowest limit is almost same but the maximum is much lower than that in pre monsoon the averages being 0.205, 0.439 and 1.031 ug-atl^{-1} at 0, 50 and 100m respectively. The post monsoon values were higher at 50 and 100m depth. The average value at 100m depth was highest among all the seasons.

In Lakshadweep Sea, at surface the average was maximum during post monsoon followed during monsoon and pre monsoon. At 50m depth the average values were again highest during post monsoon while monsoon average was high at 100m depths. Bhattathiri (1984) reported average value of NO_3-N to be 0.78 μg- atl^{-1} at 10m depth. He also reported average column values in Lakshadweep Sea during October which ranged between 1.50 to 4.66 ug-atl^{-1}.

Along the east coast, during pre monsoon the concentration at 0, 50 and 100m ranged between 0.01 - 0.21; 0.18 - 1.36 and 1.14 - 2.03 μg-atl^{-1} respectively with respective averages of 0.122, 0.897 and 1.585 μg-atl^{-1}. The average values during monsoon at 0 and 50m were much higher being 0.963 and 1.634 ug- atl^{-1} but at 100m depth the values were less than that of pre monsoon.

A look at the average values indicate that nitrate-nitrogen increases from 0 to 100m depth in almost all areas and in all seasons. Depending upon the mixing pattern and movement this nutrient can be available for consumption at other depths as well.

Table 7: Average and range of NO_3-N (μg-atl^{-1}) in three seasons at three depths

Sector	Depth (m)	Pre-monsoon (Feb.- May)			Monsoon (June - Sept)			Post-monsoon (Oct. - Jan.)		
		Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.
West Coast	0	0.01	4.74	0.316	0.01	1.03	0.205	1.01	1.24	0.256
	50	0.01	5.45	0.337	0.01	1.53	0.439	0.01	6.77	0.512
	100	0.05	14.61	1.174	0.04	2.61	1.031	0.01	24.00	3.533
Lakshadweep Sea	0	0.01	0.04	0.023	0.03	0.75	0.293	0.01	0.53	0.316
	50	0.01	0.01	0.010	0.01	0.84	0.370	0.04	1.10	0.308
	100	0.04	1.78	0.793	0.46	2.61	1.536	0.25	1.76	0.899
East Coast	0	0.01	0.21	0.122	0.01	8.20	0.963	0.06	2.10	1.204
	50	0.18	1.36	0.897	0.01	19.70	1.634	0.40	6.74	2.650
	100	1.14	2.03	1.585	0.04	2.73	1.038	3.10	12.04	9.248
Andaman & Nicobar Sea	0	0.70	0.70	0.700	0.63	3.48	2.258	0.04	8.64	1.093
	50	0.15	5.10	1.975	0.41	3.91	1.998	0.05	4.07	1.112
	100	1.41	20.60	13.878	10.78	15.56	13.890	1.21	22.80	10.243

Table 8: Average and range of NO_2-N (μg-atl^{-1}) at three depths in three seasons

Sector	Depth (m)	Pre monsoon (Feb.- May)			Monsoon (June - Sept)			Post monsoon (Oct. - Jan)		
		Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.
West Coast	0	0.01	1.47	0.19	0.03	0.31	0.13	0.03	1.85	0.51
	50	0.01	1.53	0.28	0.05	0.32	0.16	0.10	1.95	0.74
	100	0.01	1.83	0.48	0.02	0.32	0.14	0.10	0.74	0.30
Lakshadweep Sea	0	0.01	1.09	0.36	0.04	0.29	0.16	-	-	3.62
	50	0.01	0.36	0.13	0.16	0.62	0.32	-	-	1.81
	100	0.11	4.51	1.27	-	-	-	1.77	2.20	1.98
East Coast	0	-	-	-	0.08	1.99	0.88	-	-	-
	50	-	-	0.11	0.04	1.95	0.65	0.01	0.26	0.11
	100	0.03	0.19	0.08	0.04	1.95	0.72	0.01	0.08	0.04
Andaman & Nicobar Sea	0	-	-	0.72	-	-	0.70	-	-	-
	50	0.05	1.50	0.50	-	-	0.01	-	-	-
	100	0.01	1.92	0.40	-	-	0.10	-	-	-

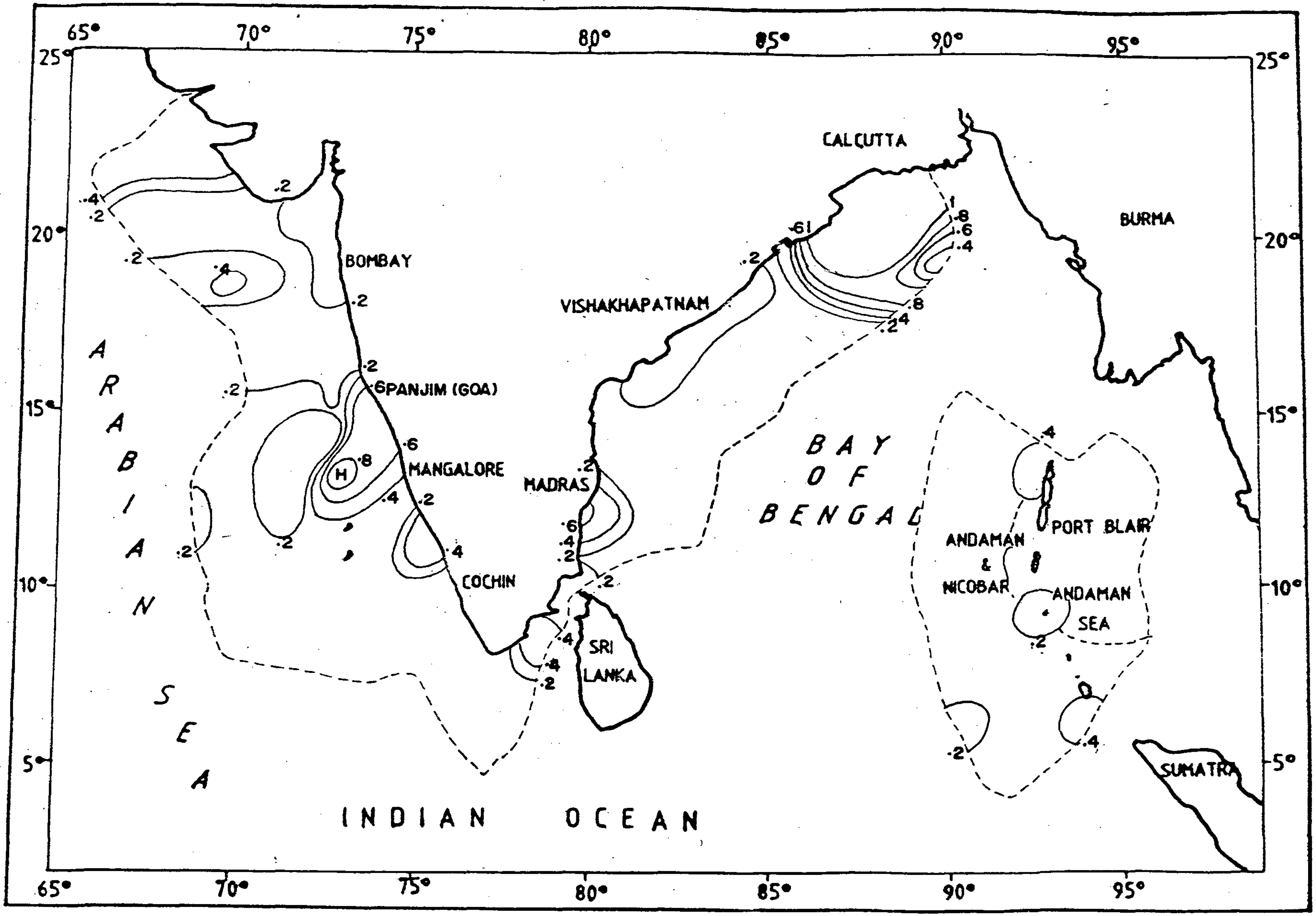

Fig. 12 Distribution of NO_3-N (μg-at l^{-1}) at surface.

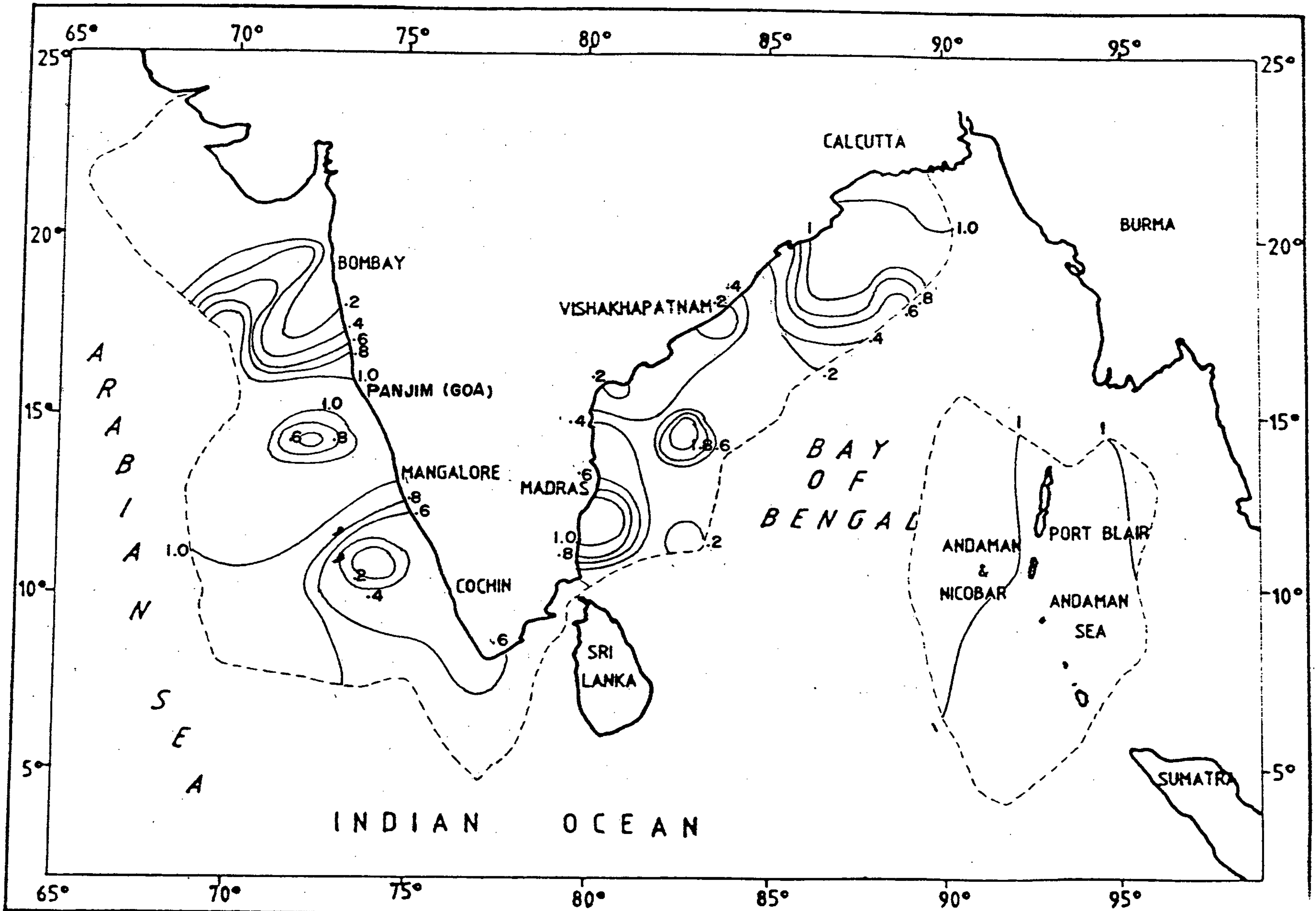

Fig.13 Distribution of NO_3-N ($\mu g - at\,l^{-1}$) at 100m depth.

The present data (Table 7) in the Andaman and Nicobar Sea shows that at surface the highest average (2.258 μg-atl^{-1}) was seen in monsoon followed in post monsoon (1.093) while pre- monsoon average (0.70 μg-atl^{-1}) was lowest but this is the only value available. At 50m depth the values are higher but at 100m the mean values are exceptionally high during all the seasons. The averages are 13.878 μg-atl^{-1} in pre monsoon, 13.89 μg-atl^{-1} in monsoon and 10.243 μg-atl^{-1} in post monsoon.

In Andaman Sea, during February, Bhattathiri (1984) reported 0 value at surface and at 50m depth, except at a single station where it was 0.78 μg-atl^{-1} at surface. But 50m depth he reported the presence of NO_3-N. The average concentration, as he reported for 75 and 100m column were 1.66 and 4.46 μg-atl^{-1}.

A contour map (Fig. 12) of NO_3-N distribution shows that off Goa on west coast and in inshore waters off Calcutta on east coast the concentration is higher and it gradually decreases as we move away from the shore. At 100m depth the concentration is high at almost all places on east and west coast except in waters off Gujarat and Bombay (Fig. 13).

(c) *Nitrite-Nitrogen :* The nitrogen is also available in nitrite and ammnonical forms. The range and average of NO_2-N are given in the Table 8. Along west coast the values range between 0.01 - 1.85, 0.01 - 1.95 and 0.01 - 1.83 μg-atl^{-1} at 0, 50 and 100m depths. The post monsoon averages were higher at 0 and 50m depth while at 100m the average concentration was more during pre monsoon. In Lakshadweep Sea also the concentration was higher at 100m depth. Along east coast and Andaman Seas the values are very low but comparable.

4.2 *Biological parameters:*

The biological productivity may be explained as the capacity of the seas to produce the living resources through biological processes - a function of the marine food chain. In the first instance, the living matter is produced from non-living material through primary producers or phytoplankton, which are consumed by small animals called zooplankton. These phyto-and zooplankton, in the presence of nutrients and under some physical conditions, forms the basis of tertiary production which includes nektonic and benthic forms.

In this chapter, some important parameters which are directly responsible for fertility of sea and its potential marine fish yield are considered. The more important factors being chlorophyll concentration, primary production or the rate of production of living matter, the zooplankton production and the benthic production. The primary and the secondary producers i.e. phyto- and zooplankton are the main food for the fishes and are therefore particularly responsible for the fish production and are discussed in detail.

All the four sectors viz. western coast, eastern coast, the Lakshadweep Sea and the Andaman Sea are geographically and environmentally different. Therefore, each parameter has been described for each of these sectors:

4.2.1 *Chlorophyll:*

Among the various green pigments chlorophyll a is most important and is responsible for the photosynthesis vis-a-vis conversion of non-living into living matter. This can, therefore, be taken as one of the indices for the primary production.

In this study, the concentration of chlorophyll at surface and in column has been taken into consideration. Further the observations have been divided seasonwise and sectorwise. A total of 1041 observations have been taken and evaluated. These are as follows:

	Surface				Column			
	Pr.M.	M.	Pt.M.	Total	Pr.M.	M.	Pt.M.	Total
Eastern	453	83	1	137	32	84	1	117
Western	117	36	137	290	111	17	83	211
Lakshadweep	20	8	18	46	15	8	21	44
Andaman	115	4	19	138	43	2	23	58
TOTAL	305	131	158	611	201	111	107	430

(Pr.M = Pre-monsoon; M = Monsoon; Pt.M = Post Monsoon

This table shows that the distribution of observations is fairly good except in eastern part during Post Monsoon and in Andaman Sea during Monsoon.

These observations have been made over a period of more than 10 years on different ships. The methodology therefore differs. During the period of IIOE the chlorophyll used to be estimated spectrophotometrically while lately the Flourometers are used which provide direct value and is more sensitive. However, the unit is same and the differences are under experimental errors. The source of data are the cruises during IIOE (1960-65), cruises of INS *Darshak* (1973-74), R.V. *Gaveshani* (1976-87) and ORV *Sagar Kanya* (1983-85). The observations have been made at various depths in the euphotic zone which is determined either by Sechi Disc or Photometer. The values from the different depths are then integrated into a column value. The euphotic zone varies from place to place and rarely exceeds 90 meters in exceptional cases. In this study, the surface and the column values have only been discussed.

In the entire EEZ, the chlorophyll a at surface varied from 0.017 to 7.16 mgm^{-3} with an annual average of 0.250 mgm^{-3}. The seasonal averages being 0.229 mgm^{-3} in pre-monsoon (range 0.01- 7.16); 0.45 mgm^{-3} in monsoon (range 0.01-5.72) and 0.137 mgm^{-3} in post monsoon (range 0.0017-1.5). During this period the maximum was recorded in May 1981 and minimum was in December 1987. The sector and seasonwise values are shown in Table 9.

In the western sector, the annual average is 0.253 mgm^{-3} with a maximum mean value being 0.626 in monsoon in the range of 0.032 to 3.183 mgm^{-3}. The second best average of 0.225 was recorded during pre-monsoon between the range of 0.01 to 3.80 mgm^{-3} while minimum was noticed in post monsoon where it ranged between 0.017 and 1.50 with an average of 0.154 mgm^{-3}.

In the seas around Lakshadweep Island which is within the boundary of EEZ of the west coast, the annual average is not different from the other part of western sector. It is 0.2313 mgm^{-3}, but the maximum value (7.16 mgm^{-3}) and average (0.436 mgm^{-3}) is in pre-monsoon. Minimum remaining the same at 0.01 mgm^{-3}.

The average in monsoon and post monsoon being 0.074 and 0.071 mgm^{-3} respectively. The range of surface chlorophyll in monsoon was found to be 0.04 to 0.187 mgm^{-3} and in post monsoon it was 0.043 to 0.18 mgm^{-3} - a very poor concentration. Barring ten observations, the values are low which coincide with the

Table 9: Average and range of chlorophyll a valuesatsurface in different seasons and sect

Sector	Pre-monsoon (Feb.-May)		Monsoon (June-Sept)		Post monsoon (Oct.-Jan)		Annual average
	Range	Aver.	Range	Aver.	Range	Aver.	
West Coast Lat. 65-78° N Long. 4-24° E excluding Lakshadweep Sea	0.01 3.80	0.253	0.032 3.183	0.626	0.0017 1.50	0.154	0.253
Lakshadweep Sea Lat.8-12° N long.71-74° E	0.01 7.16	0.438	0.04 0.187	0.074	0.0043 0.18	0.071	0.2313
East Coast Lat[illegible]-22° N Long.78-91° E	0.01 1.60	0.242	0.01 5.72	0.429	0.26	0.26	0.358
Andaman Sea Lat. 4-16° N Long.88-96° E	0.01 1.21	0.162	0.02 0.08	0.055	0.02 0.40	0.074	0.147

Data source - IIOE (1960-65), Darshak (1973-74), Gaveshani (1976-87) (1983-85) fact that in coral reefs which are abundant in the Lakshadweep Sea, the phytoplankton are poor and hence low chlorophyll values are observed. The observed maximum value of 7.16 mgm^{-3} in May 1981 seems to be due to some bloom condition.

The chlorophyll a concentration along east coast was high among all the four sectors. The annual average was 0.358 mgm^{-3}. Among the three seasons monsoon average was topping with 0.429 mgm^{-3} ranging between 0.01 to 5.72 mgm^{-3}. This was followed during post monsoon with 0.26 - a single observation in 25 years, and pre-monsoon with 0.242 mgm^{-3} as an average from a range of 0.01 and 1.60 mgm^{-3}.

In the Andaman Seas, the annual average was lowest being 0.147 mgm^{-3}. The maximum average value of 0.162 mgm^{-3} was noticed in pre-monsoon. In post monsoon, the average was minimum with a value of 0.074 mgm^{-3} while the average in monsoon was 0.055 mgm^{-3}. As is shown in Table the values range between 0.01-1.21 in pre-monsoon, 0.02-0.08 in monsoon and 0.02 to 0.40 mgm^{-3} in post monsoon.

The more important is column concentration of chlorophyll a which is the integrated value for the entire euphotic zone and is the direct indication for productivity. A total number of 430 observations have been taken into account and the average and ranges are shown in Table 10. The annual average for the entire EEZ is 11.814 mgm^{-2} with a minimum of 0.08 and maximum of 100.61 mgm^{-2}. The maximum was in May 1981 which coincided with maximum at surface also. The average for different seasons are pre- monsoon - 14.172 ranging between 0.16 and 100.61; monsoon average 12.75 for values ranging between 1.108 and 93.15 mgm^{-2} while for post monsoon, the average worked out to be 7.299 within a range from 0.08 to 59.575 mgm^{-2}. This shows that the chlorophyll is maximum in the months of February to May showing favourable conditions particularly, in February, March and April. This is followed by monsoon and post monsoon values.

Along the west coast the best season for column chlorophyll was found to be pre-monsoon when the average was 18.025 mgm^{-2} and values ranged from 0.16 to 92.85 mgm^{-2}. This was followed by post monsoon and monsoon when the respective averages of column chlorophyll concentration were 8.265 and 7.898 mgm^{-2} respectively. The values were higher during monsoon when they ranged between 1.447

Table 10: Average and range of column chlorophyll a in different seasons and sectors (mgm^{-2})

Sector	Pre-monsoon (Feb - May)		Monsoon (June-Sept)		Post monsoon (Oct- Jan)		Annual Average
	Range	Aver.	Range	Aver.	Range	Aver.	
West Coast	0.16 92.85	18.025	1.447 96.44	7.898	.08 59.575	8.265	13.370
Lakshadweep Sea	1.418 100.61	14.537	1.631 3.293	2.45	0.12 16.71	4.311	7.459
East Coast	1.0 34.0	8.084	1.108 93.15	14.78	-	22.0	13.010
Andaman & Nicobar Sea	0.43 34.0	8.631	6.0 14.0	10.0	0.48 16.32	5.904	7.749

Source : IIOE (1960-65), Darshak (1973-74), R.V.Gaveshani (1976-87) and Sagar Kanya (1983-85).

and 96.44 mgm^{-2} while in post monsoon the values ranged from 0.08 to 59.575 mgm^{-2}.

In the Lakshadweep Sea, the trend remained the same - the highest average of 14.537 mgm^{-2} in pre-monsoon (range 1.418 - 100.61 mgm^{-2}), next in post monsoon having average 4.311 (range 0.12 - 16.71 mgm^{-2}) and minimum average of 2.45 mgm^{-2} in monsoon within the range of 1.631 - 3.293 mgm^{-2}.

The data of the various sectors indicate that the maximum annual average of column chlorophyll is along the west coast (13.37) very closely followed along east coast (13.01), then comes the Andaman Sea with a value of 7.749 and minimum in Lakshadweep which is 7.459 mgm^{-2}.

The concentration of column chlorophyll a along east coast is very close to that of west coast as stated above. The seasonal averages show that it was maximum (22.0 mgm^{-2}) in the post-monsoon but this was the only observation recorded. More observations are required here during this season for arriving at a reasonable average. The monsoon average was 14.78 mgm^{-2} within a range of 1.108 to 93.15 mgm^{-2}. However, the lowest concentration was in pre-monsoon with an average of 8.084 and range of 1.00 to 34.0 mgm^{-2}.

In the neighbouring Andaman Sea the pre-monsoon figures are comparable to the values of east coast. The post monsoon average was found to be 5.904 mgm^{-2}. The monsoon values were quite less than those of east coast the average being 10.0 mgm^{-2} and range 6-14 mgm^{-2}. The pre-monsoon average was 8.631. mgm^{-2} and range was from 0.43 to 34.0 mgm^{-2}.

The comparison of seasonal concentration along east and west coast will not be of much relevance since the two differ in environmental characteristics.

Chlorophyll a concentration has been calculated during various expeditions and cruises in different areas. Krey and Babenard (1976) and Qasim (1978) have summarised the chlorophyll values in the entire Indian Ocean taking into account the data collected by various ships. Average chlorophyll a concentration was found to be more than 0.5 mgm^{-3} IMC for 50m column along the west coast of India. Bhattathiri (1984) considered west coast as fertile area during December - March when chlorophyll a values were more than 0.5 mgm^{-3}. He also observed values between 0.1 and 0.15 mgm^{-3} in the Bay of Bengal whereas the values recorded here ranged between 0.01 to 1.61 mgm^{-3} during the same period.

Qasim (1978) reported the values, based on IIOE data, between 0.16 and 1.0 mgm^{-3} with average for Arabian Sea & Bay of Bengal being 0.244 and 0.224 mgm^{-3} respectively while in the present study, the average on the basis of all data comes to 0.25 and 0.264 mgm^{-3} respectively. Except little higher value observed for the Bay of Bengal the values are comparable. In the north eastern Arabian Sea during November, Radhakrishna *et al.* (1978) reported the values of surface chlorophyll a to vary between 0.02 to 1.5 mgm^{-3} and column values between 4 and 28.8 mgm^{-2}. In the present study the average column value along west coast was found to be 13.37 mgm^{-3} for the entire year and varied between 0.16 and 96.44 mgm^{-2}.

In the nearshore waters of central west coast of India, Dehadrai and Bhargava (1972) reported surface chlorophyll values between 0.75 to 18.8 mgm^{-3} between September and May showing nearshore waters to be more productive.

In the Bay of Bengal, Bhattathiri *et al.* (1980) reported surface chlorophyll during southwest monsoon of 1978 to vary from 0.01 to 1.02 mgm^{-3} and column values to vary from 1.11 to 50.65 mgm^{-2}. The present data show that surface and column chlorophyll a values vary from 0.01 to 5.72 mgm^{-3} and 1.108 - 93.15 mgm^{-2} showing much higher values. A slight difference may be due to the values of pheopigments included in IIOE data. This may be about 10% of the values (Banse, 1988).

In the Lakshadweep Sea, Bhattathiri (1984) had estimated chlorophyll a concentration in October, December, March and April. The surface values he reported ranged from 0 to 0.578 mgm^{-3} with maximum in December and minimum in March/April. During the same period the column values varied from 89 to 18.86 again maximum in December.

An interesting feature he noticed was increase in chlorophyll values with the depth and secondly the average value in March and April was less but the productivity was higher. In the present study, the surface values were found to be higher in pre-monsoon but in post monsoon including December, the values were found to be low. The column values of chlorophyll a were higher than those observed by Bhattathiri (1984). His values from October to April ranged between 0.89 to 18.86 mgm^{-2}. As noticed here, high values were found during February - May. The lowest average was in monsoon months though individual lowest values were recorded in January 1984 and highest (100.61 mgm^{-2}) in May 1981.

In Andaman Seas, more observations have been made in pre- monsoon (February - May) and very few in monsoon and post monsoon. Qasim (1978), based on IIOE, data reported average surface chlorophyll a in Andaman Sea as 0.244 mgm^{-3} and in column upto 100m as 16.8 mgm^{-2}. But again these values included pheopigments and therefore high. The average value calculated here is 7.749 mgm^{-2}. Bhattathiri (1984) reported low average of 2.33 mgm^{-2} in January 1980 but slightly higher value of 3.64 mgm^{-2} in February 1979. He also noticed higher chlorophyll a values at 1% light depth at few places.

The distribution of chlorophyll a at surface in three seasons is shown through isolines in Figs. 14, 15 and 16. The isolines are drawn by averaging the values for each one degree square. In pre-monsoon higher values are observed north of Panjim on west coast and in area off Calcutta along east coast. The values decrease towards south and also away from the coast on west coast. In monsoon, while negligible data is available for west coast, the east coast shows the decreasing values from shore to offshore. A patch of high concentration was noticed near Madras and south of Visakhapatnam. During post-monsoon no values are available for east coast. Along the west coast moderate values (0.1-0.2 mgm^{-3}) were found along most of the area.

The distribution of column chlorophyll a as seen in Fig.17, 18 and 19 reveals the same trend of distribution showing high values off Kerala, Goa and Gujarat coast. There are patches of high concentration (15 mgm^{-2}) even away from shore during pre- monsoon. During monsoon, on east coast the values higher than 15 mgm^{-2} were noticed, but most of the inshore areas had moderately high concentration of chlorophyll a. Along the west coast, from the available data, high concentration was seen south of Cochin which decreases northwest and away from shore. In post-

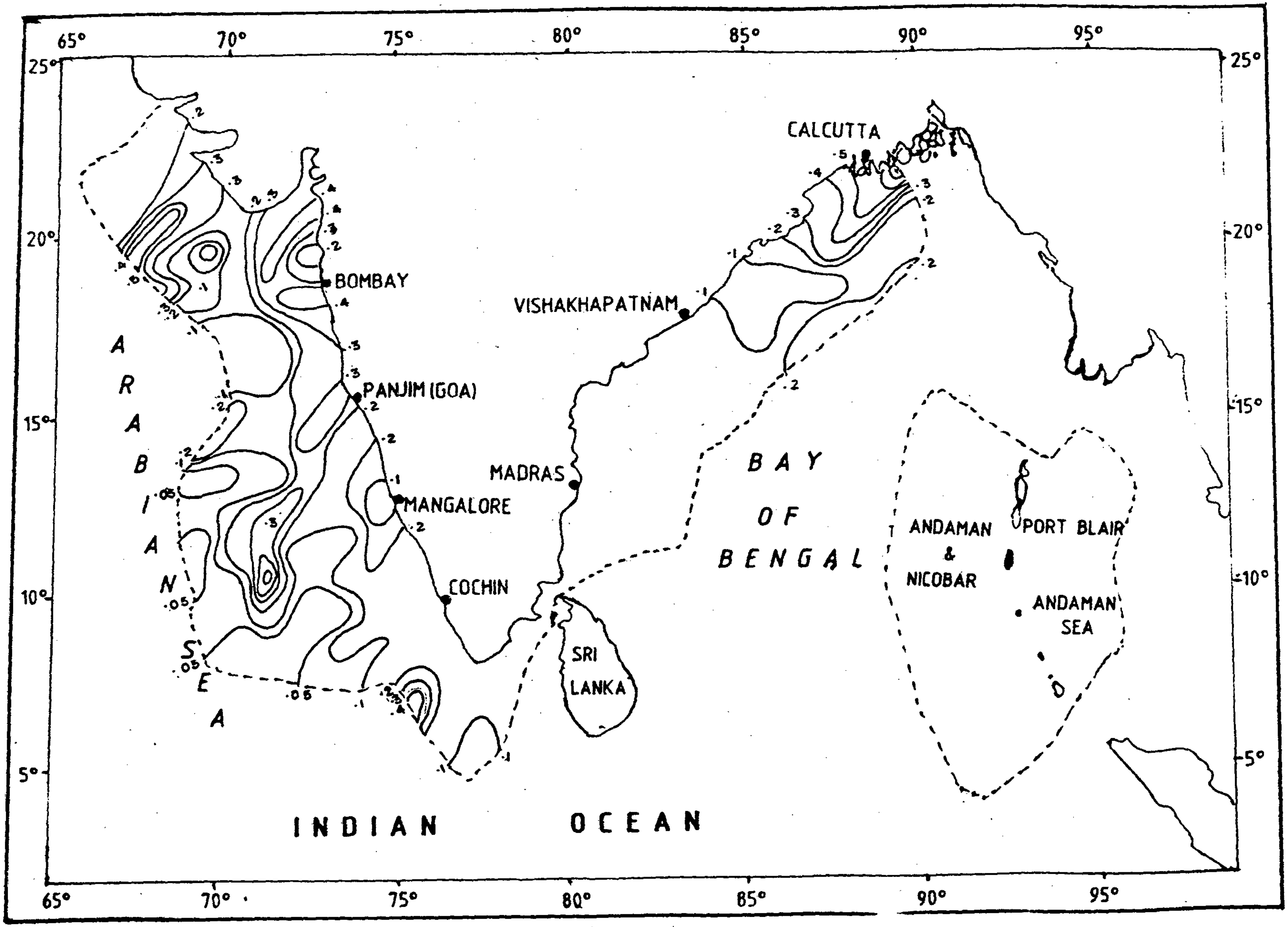

Fig. 14 . Distribution of chl. a (mg m^{-3}) at surface during pre-monsoon

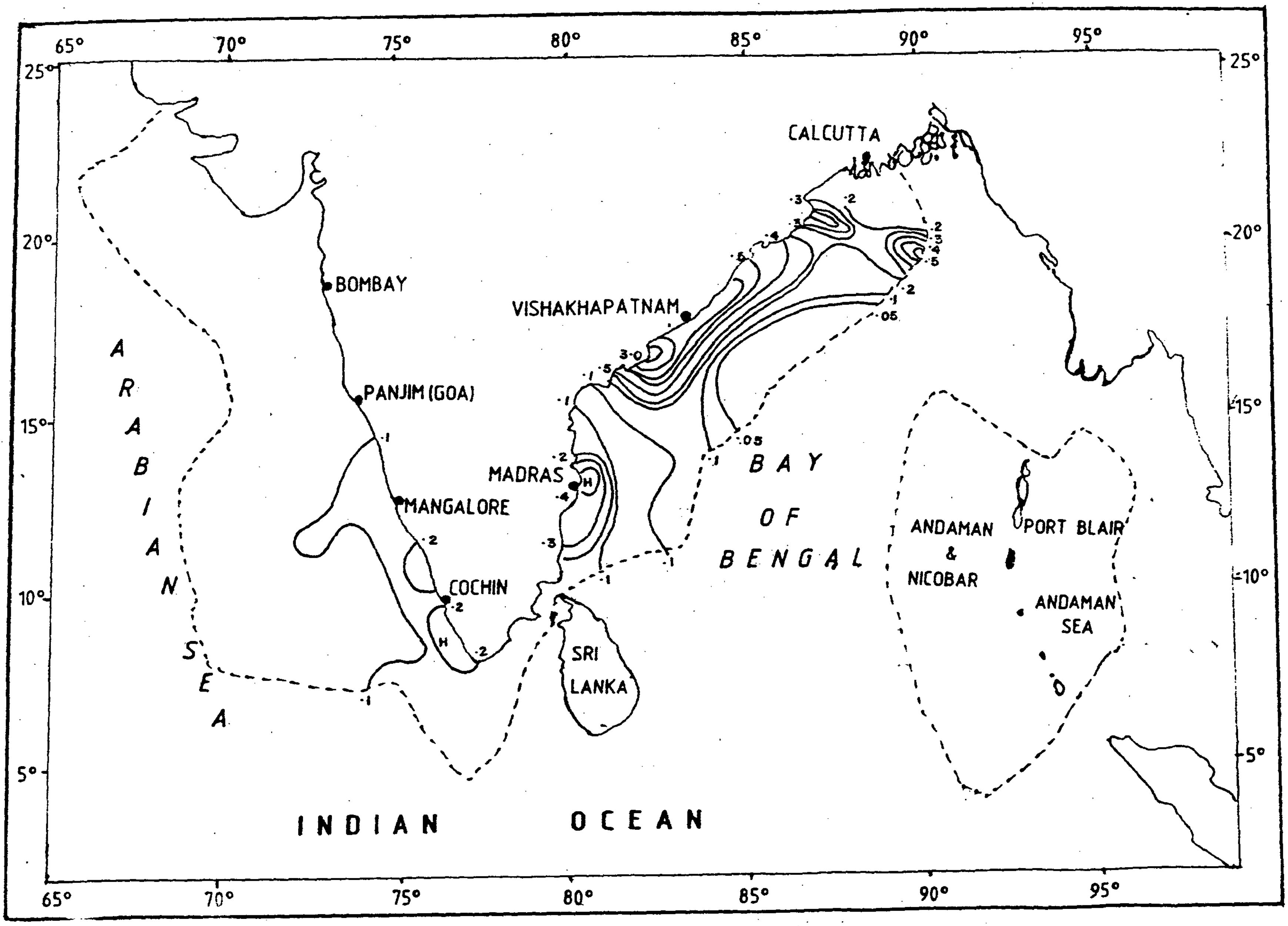

Fig. 15 Distribution of chl. a ($mg\,m^{-3}$) at surface during monsoon.

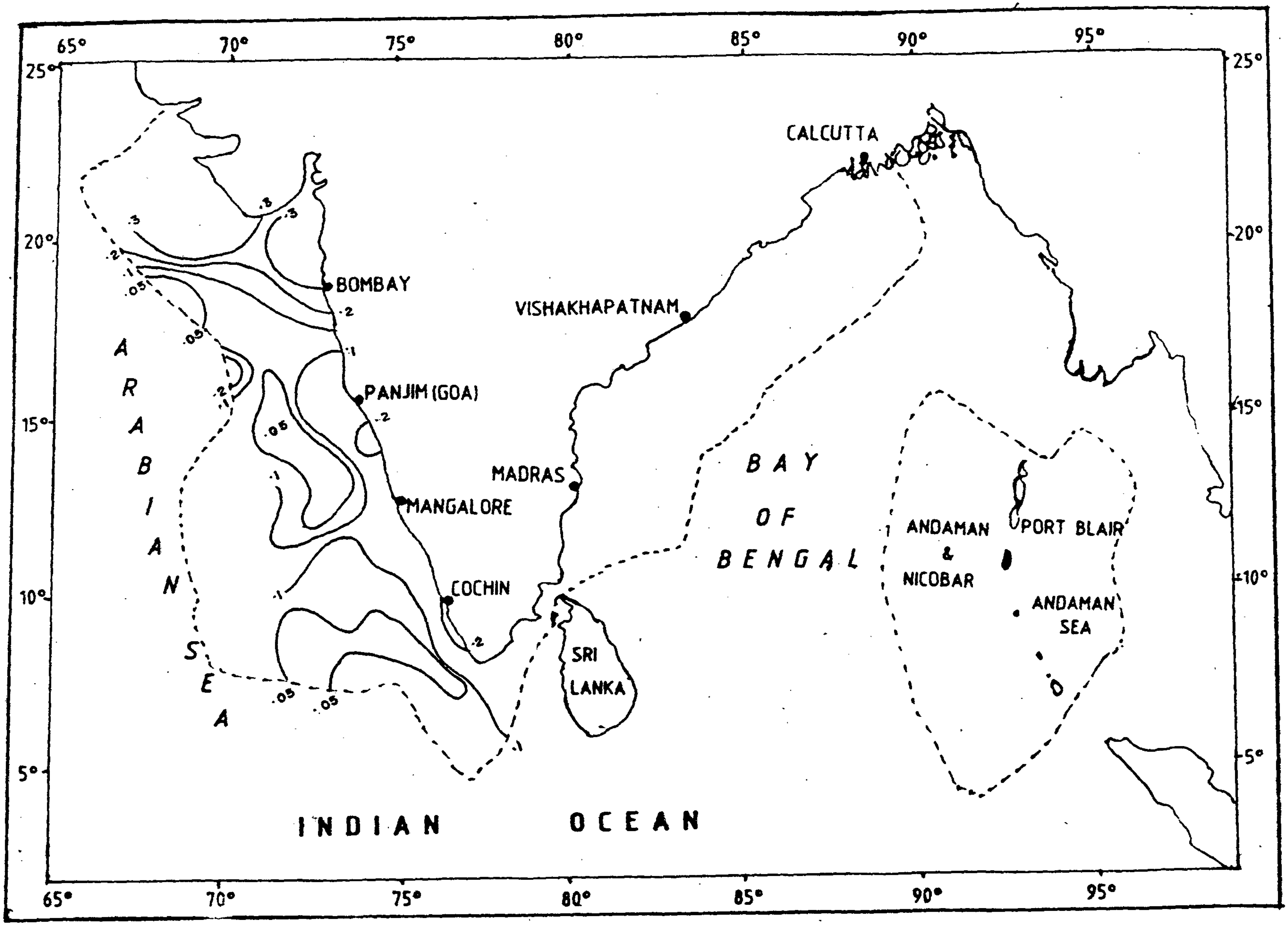

Fig. 16 Distribution of chl. a (mg m^{-3}) at surfae during post monsoon (Oct. - Jan.)

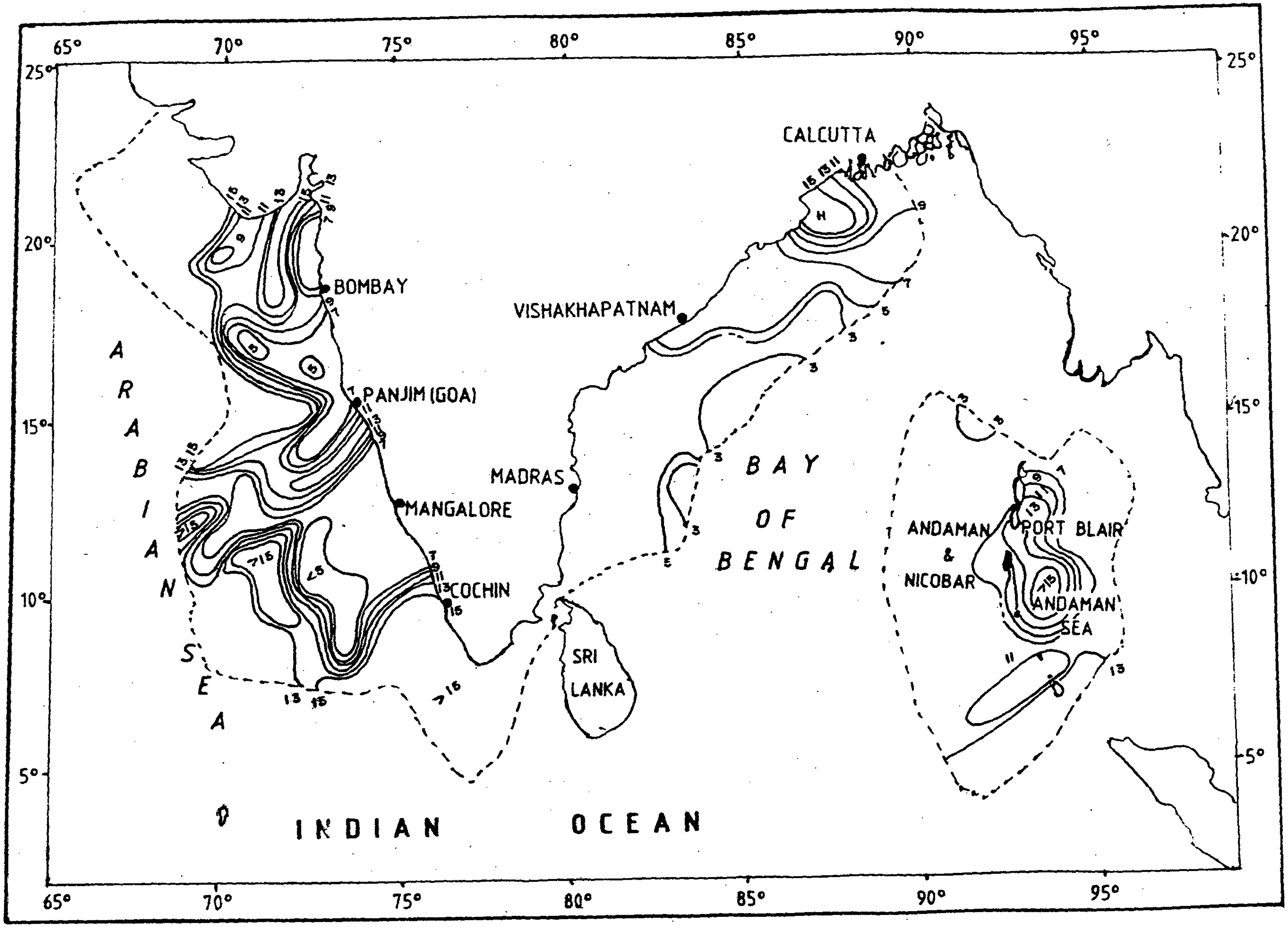

Fig.17 Distribution of chl. $\underline{a}$ ($mg\,m^{-2}$) in euphotic column during pre monsoon (Feb–May)

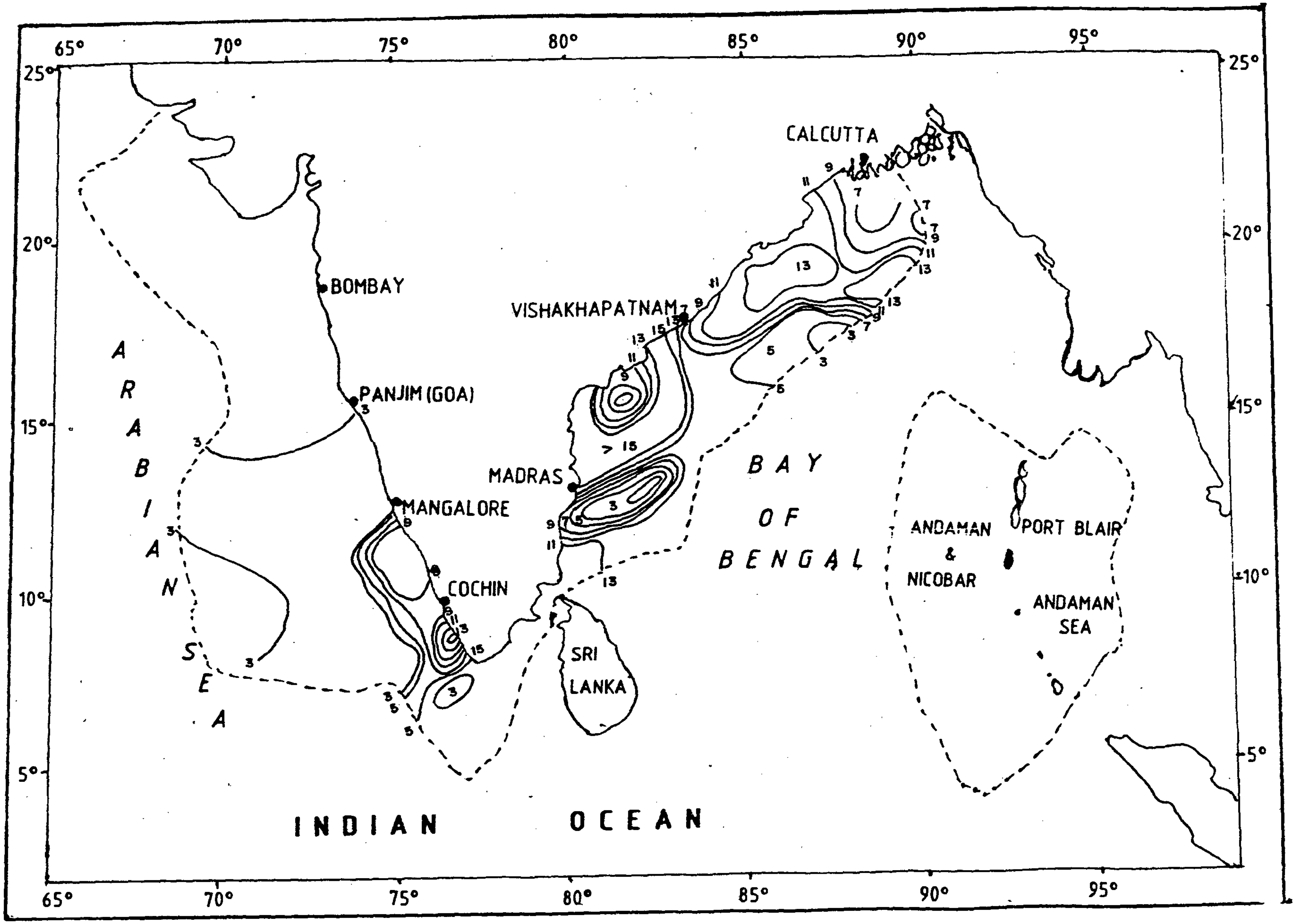

Fig.18 Distribution of chl. a (mg m^{-2}) in the euphotic column during monsoon (June-Sept.)

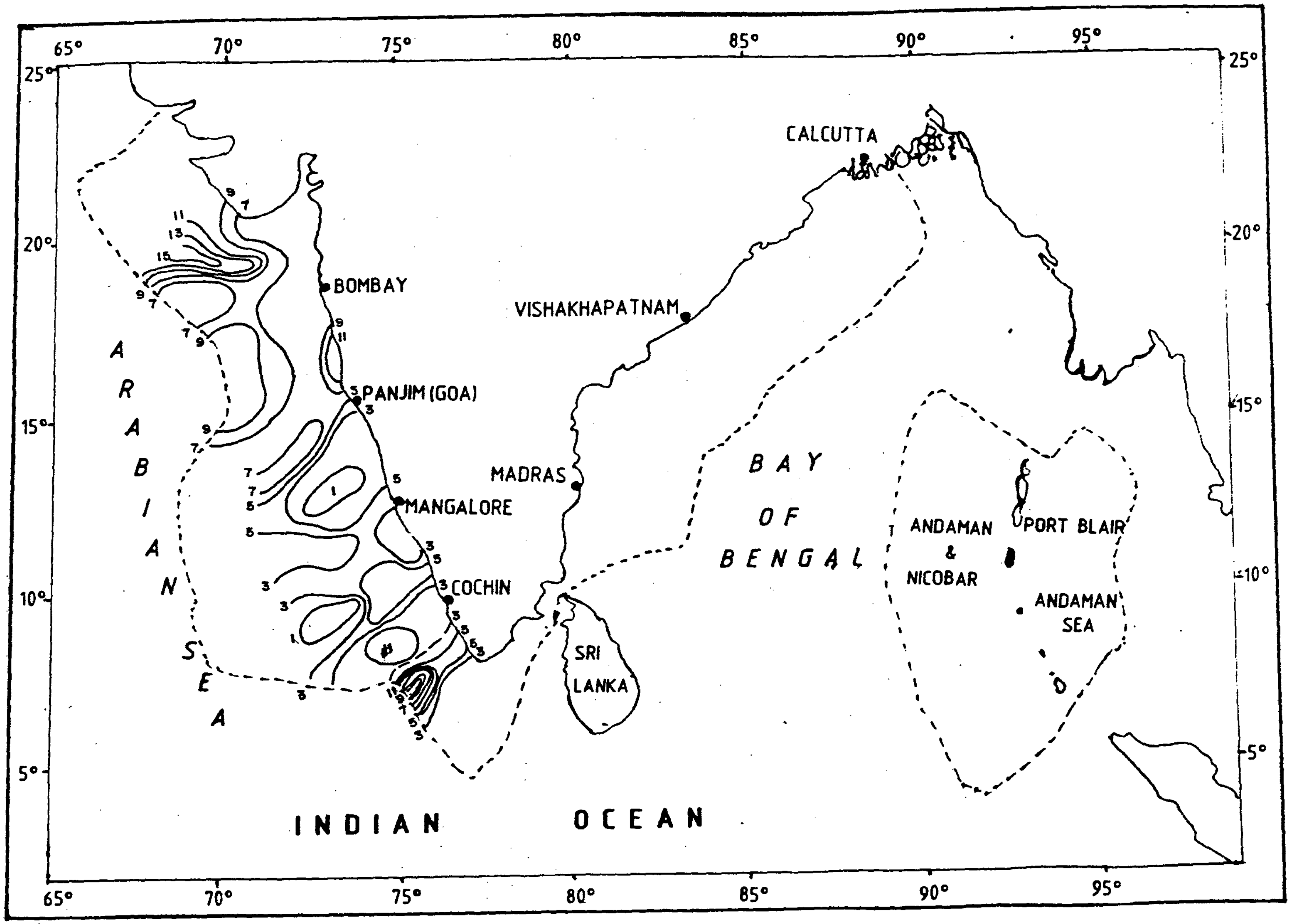

Fig.19 Distribution of chlorophyll a ($mg\ m^{-2}$) in the euphotic column during post-monsoon

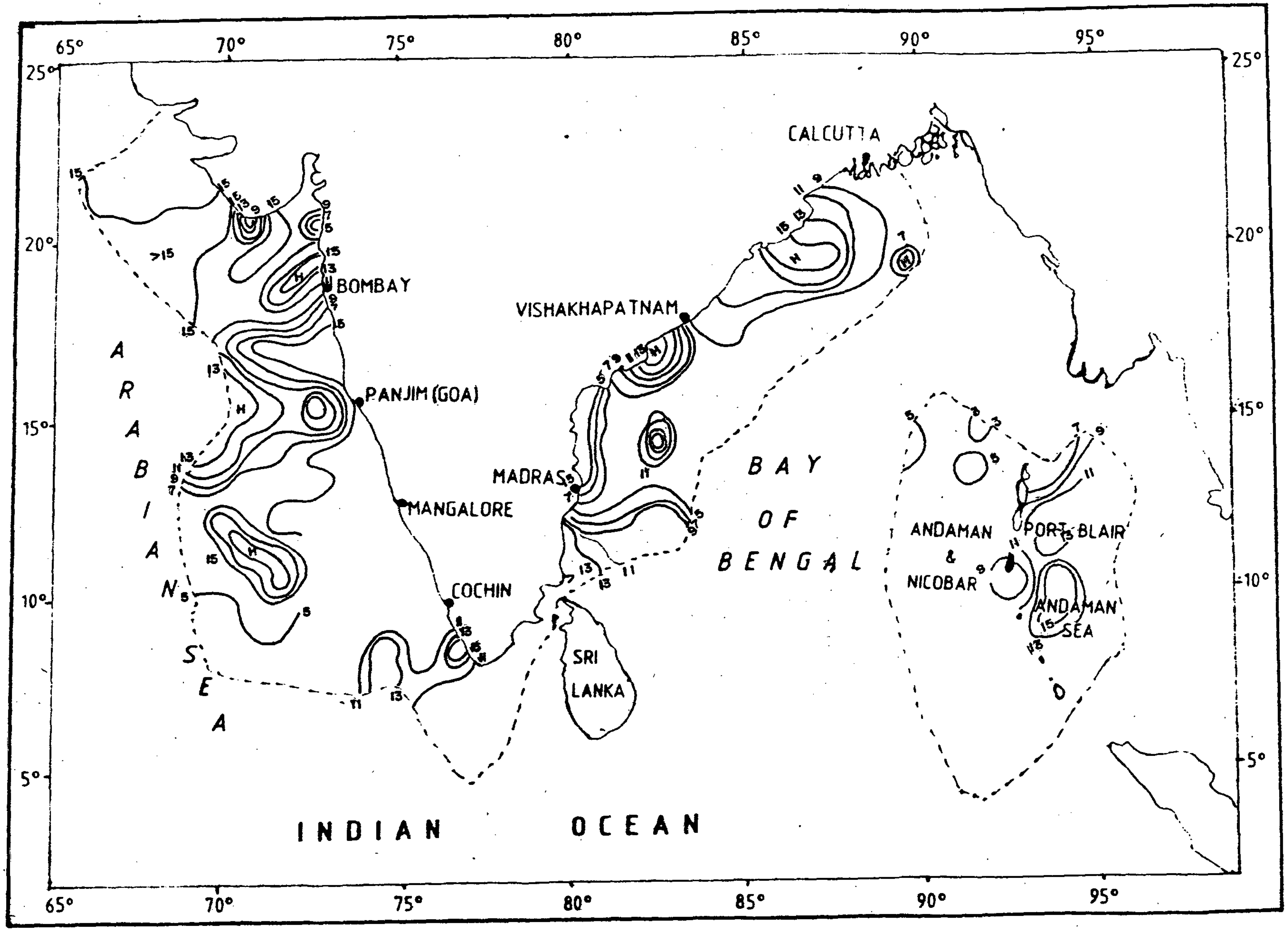

Fig.20 Distribution of chl. a (mgm^{-2}) in column waters. (Annual pattern)

monsoon the data was lacking along east coast while on west coast the column values were not very high but it generally increased away from the shore.

The annual pattern of distribution drawn by taking mean of all the values, is shown in Fig. 20. Higher values are noticed off Gujarat, Bombay and south of Cochin, Visakhapatnam and off Orissa. Near Lakshadweep Sea also there is a high concentration area having more than 15 mgm^{-2}.

4.2.2 *Primary production*

The production of the living matter is practically the beginning of the marine food chain. This takes place from inorganic matter through photosynthesis by phytoplankton and other chlorophyll bearing algae. The chemical reaction is presented by the equation -

$$6CO_2 + 6H_2 = C_6H_{12}O_6 + 3O_2$$

The living matter is produced at the primary level hence termed as primary production. This process is not as simple as it looks but is complex and dependent on many factors such as light, availability of nutrients, temperature, salinity, carbon dioxide and nature of phytoplankton. Carbon dioxide and water are available in the sea, the nutrients mainly PO_4-P and NO_3-N are essential for photosynthesis and has to be replenished. The reaction is also related to temperature and salinity of the water. The primary producers or the phytoplanton are the main food for the fishes and are therefore utilized for assessing the fishery potential of the area.

Many authors have measured primary production from the waters of world ocean. Notable among them are Steemann Nielson and Jensen (1957); Steemann Nielson (1963); Ryther (1963); Yentsch (1963), Strickland (1965), Koblentz - Mishke, *et al.* (1970); Cushing (1973); Platt & Subba Rao (1975). Among the Indian workers mention may be made of Qasim, Raghu Prasad, Radhakrishna, Dehadrai, Nair, Bhattathiri, Devassy, Bhargava and others. They have covered various ecosystems as estuaries, nearshore waters, Indian EEZ and the open deep sea.

The observations are made at a particular station at various depths in the euphotic zone. These levels are decided on the basis of light penetration and are generally 100% (i.e. surface) 60%, 30%, 10% and 1% light penetration and the column upto which the light penetrates is taken as euphotic zone. The samples are taken and incubated & suspended either *in situ* or simulated *in situ* conditions for a fixed number of hours or complete 24 hr. period. From these values, the column production is calculated.

Earlier, the oxygen evolved during photosynthesis was used to calculate the carbon fixed as an index of primary production - later, Steemann Nielson, during Galathea Expedition in 1952, developed a technique to measure directly the carbon fixed through the radio active carbon (C^{14}) method and till today it is in use as a standard method though modified from time to time.

However, there are many limiting factors for photosynthesis and production as stated earlier. Light is still most important for photosynthesis and its rate is very much dependent on light intensity. The photosynthesis is possible upto a certain depth called compensation depth where photosynthetic activity is equal to the respiration. The light penetration in the sea is reduced as we go down due to absorption and spreading. However, in tropical waters, for most of the year the sunshine is bright. The euphotic zone measures to a maximum of 100 meters in clear waters. This may be about a meter or even less in turbid waters of estuary. The penetration of light also depends on season, weather and area.

Many authors (Riley, 1946; Ryther, 1956; Talling, 1957; Steemann Nielson and Hansen, 1959; Smayda, 1963, 1969; Yentsch and Le 1966; Qasim *et al.*, 1972; Parsons and Takahasi, 1973; Raymont, 1980) have studied the effect of light on productivity in tropical waters under different environmental conditions and found complex relationships. The photosynthesis also differs with different phytoplankton. Recently Banse (1988) concluded that light limitation of photosynthesis at the lower depth where nutrient limitation is higher than that at the upper depth, if any, is excluded.

Besides light, other important factors responsible are nitrogen, phosphorus, silicon and organic compounds like amino acids and vitamins. Nitrogen is available in seawater in inorganic forms as nitrate, nitrites and ammonia. Ryther *et al.* (1966) have shown the favourable effect of high nutrients on primary production. Raymont (1980) has also found high production in nutrient rich waters and low production in nutrient - poor waters of Peru. Qasim et al. (1973) also studied the effect of nutrient on the growth kinetics and distribution of phytoplankters from tropical waters. Ryther and Dunstan (1971) considered nitrogen as the most important element for production.

Phosphorus occurs as dissolved phosphate in inorganic form and also in dissolved conditions as organic compounds. Both the forms are available for production process and there is a positive relation between production and nutrients.

After knowing some of the important information, let us have a look at the work and results in the EEZ of India. In the present study, the observations made during IIOE, by R.V. Gaveshani and ORV Sagar Kanya have been included and the measurement at surface and integrated values for the column have been given. A total number of 984 observations as detailed below have been included for seasonal and areawise study.

Sector	SurfaceColumn							
	Pr.M	M.	Pt.M.	Total	Pr.M.	M.	Pt.M	Total
West Coast	73	31	49	153	77	50	80	207
Lakshadweep Sea	19	9	13	41	21	12	44	77
East Coast	30	64	4	98	82	64	5	151
Andaman Sea	59	7	24	90	133	11	23	167
TOTAL	181	111	90	382	313	137	152	602

It is seen from this table that the coverage in various sectors in different seasons is good and enough to draw inferences, though the coverage along east coast in post monsoon is less.

The seasonwise surface primary production in the entire EEZ is as follows:

	Range (unit $mgCm^{-3}d^{-1}$)		
	Minimum	Maximum	Average
Pre-monsoon	0.01	64.9	12.778
Monsoon	0.80	497.20	43.069
Post monsoon	0.10	67.0	9.513

This shows that monsoon is having the highest average of primary production of all the seasons and the annual average for all the seasons comes to be 20.81 $mgCm^{-3}d^{-1}$. The high average in monsoon may be due to unusually high value of 497.20 $mgCm^{-3}d^{-1}$ during August of 1977.

Looking at the values in different sectors as given in Table 11, the east coast shows the highest average of 44.197 $mgCm^{-3}d^{-1}$ followed by west coast (18.488), Andaman Sea (6.346) and Lakshadweep Sea (4.865). On the west coast the pre-monsoon and monsoon values are very close but there is a decrease in post monsoon. In the pre-monsoon the minimum and maximum values are 1.20 and 264.90 $mgCm^{-3}d^{-1}$ (av. 22.535) while in monsoon the values range between 0.80 and 232.25 $mgCm^{-3}d^{-1}$. In the post monsoon the mimimum was 0.30 $mgCm^{-3}d^{-1}$ and the maximum was 57.17 $mgCm^{-3}d^{-1}$ only with an average of 10.416 $mgCm^{-3}d^{-1}$.

In Lakshadweep Sea the annual average is 4.865 $mgCm^{-3}d^{-1}$, while the averages in pre and post monsoon are almost identical of (5.269 & 5.25 respectively). The monsoon average drops to 3.458 $mgCm^{-3}d^{-1}$. The range of primary production in the Lakshadweep Seas in pre-monsoon, monsoon and post monsoon is calculated to be 0.79 to 16.0, 1.19 - 11.04 and 0.53 - 14.67 $mgCm^{-3}d^{-1}$ respectively.

Along the east coast, the surface production in pre-monsoon ranged between 0.90 and 169.70 with an average of 10.50 $mgCm^{-3}d^{-1}$. The monsoon figures are high ranging from 1.96 to 497 $mgCm^{-3}d^{-1}$ with an average of 63.02 $mgCm^{-3}d^{-1}$. The respective values in post monsoon varied from 0.10 to 1.20 $mgCm^{-3}d^{-1}$ with an average of 0.475 $mgCm^{-3}d^{-1}$ which are the minimum, the number of observation also being less.

Table 11 : Average and range of surface primary production
(sector and seasonwise) $mgCm^{-3}d^{-1}$

Sector Annual	Pre-monsoon (Feb - May)			Monsoon (June-Sept)			Post monsoon (Oct-Jan)			Average
	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	
West Coast excluding Lakshadweep Sea (Arabian Sea)	1.20	264.90	22.535	0.80	232.25	21.604	0.30	57.17	10.416	18.488
Lakshadweep Sea	0.79	16.0	5.269	1.19	11.04	3.458	0.53	14.67	5.250	4.865
East Coast (Bay of Bengal)	0.90	169.70	10.50	1.96	497.20	63.02	0.10	1.20	0.475	44.197
Andaman Sea	0.01	31.2	4.219	2.90	13.40	6.657	2.80	67.0	11.487	6.346

Data source : IIOE (1960-65), Sagar Kanya (1983-86) & R.V. Gaveshani (1976-87)

In the Andaman Sea, the surface primary production ranged between 0.01 and 31.2 $mgCm^{-3}d^{-1}$ (av. 4.219) in pre-monsoon, 2.90 - 13.40 (av. 6.657) $mgCm^{-3}d^{-1}$ in monsoon and 2.80 - 67.0 (av. 11.487) $mgCm^{-3}d^{-1}$ in post monsoon. This area has a maximum average in post monsoon and an annual average of 6.346 $mgCm^{-3}d^{-1}$ a little higher than Lakshadweep Sea but very much higher than west coast and east coast of India.

This is the trend at the surface which is generally more than other depths since maximum light is available inspite of inhibition. Towards the lower depths having less light intensity the rate of productivity decreases. But the integrated column productivity is always considered for estimating the fisheries potential.

The column production ($mgCm^{-2}d^{-1}$) in the entire EEZ in three seasons is summarised below:

	Minimum	Maximum	Average
Pre-monsoon	3.0	18560	72.317
Monsoon	30.0	4550	682.158
Post monsoon	6.0	13900	291.556

It is seen from the above table that the highest production is in monsoon and least in pre-monsoon. The yearly average for the entire EEZ is calculated to be 619.728 $mgCm^{-2}d^{-1}$.

From the column productivity (Table 12), it is seen that the east coast tops in average production (1081.065 $mgCm^{-2}d^{-1}$) followed by west coast (490.937) Andaman Sea (470.736) and Lakshadweep Sea (236.289). Seasonwise, the pre-monsoon value of 1391.457 $mgCm^{-2}d^{-1}$ was the maximum on the east coast. An analysis indicates that on west coast the values ranged between 30.0 and 1552.15 $mgCm^{-2}d^{-1}$ (av. 550.629) in pre-monsoon; 30.0 and 4550 (av. 720.935) in monsoon and 10 and 1390.0 (av. 289.736) in post monsoon. The maximum being in monsoon followed by pre-monsoon and minimum in post monsoon.

In the Lakshadweep Sea adjoining the EEZ of west coast, the pre-monsoon average was maximum (335.088 $mgCm^{-2}d^{-1}$) followed by monsoon and post monsoon having average values of 161.461 and 152.23 $mgCm^{-2}d^{-1}$ respectively. The ranges for the three seasons were found to be 112.0 to 648.0 in pre-monsoon; 40.0 to 1225.0 in monsoon and 21.80 to 263.9 $mgCm^{-2}d^{-1}$ in post monsoon.

Along the east coast, the column production varies from 70.0 to 18560 $mgCm^{-2}d^{-1}$ in pre-monsoon, 49.03 to 3608.23 in monsoon and from 6 to 46.0 $mgCm^{-2}d^{-1}$ in post monsoon. The respective averages being 1391.457, 765.897 and 24.8 $mgCm^{-2}d^{-1}$ in the three seasons. The east coast is mainly affected by north east monsoon with November and December as the peak months. Therefore, maximum production after the NE monsoon is justifiable.

In the Andaman Sea, the maximum production on an average is noticed during the period June to September (av. 586.727 $mgCm^{-2}d^{-1}$) followed by February to May (av. 465.598) and October to January (av. 440.684 $mgCm^{-2}d^{-1}$). The range of values is very large in pre-monsoon from 3 - 14930 $mgCm^{-2}d^{-1}$; in monsoon it is 70-1960 $mgCm^{-2}d^{-1}$ while in post monsoon it was noticed to be 196.1 to 1217.1 $mgCm^{-2}d^{-1}$ In the east coast and Andaman Sea, very high values were noticed during April/May 1964 during IIOE cruises.

Primary production has been measured by many authors in the Indian Ocean, Arabian Sea and the Bay of Bengal. Nair (1970) reported rate of production upto 50m in the waters from Karwar to Cape Comorin between 0.18 and 2.45 $gCm^{-2}d^{-1}$ and beyond 50m from the coast it ranged between 0.01 to 0.95 $gCm^{-2}d^{-1}$. These observations were made during July to December. In August - October of 1967, Radhakrishna (1969) measured primary production from Cochin to Quilon and found it to be between 0.38 - 1.11 $gCm^{-2}d^{-1}$. Silas (1977) worked out primary production for west coast of India within 50m and beyond. He calculated the average primary production within 50m as 1.24 and between 50 and 200m as 0.63 $gCm^{-2}d^{-1}$. These figures indicate that the primary production declines beyond 50m. In the west coast from Dabhol in north to Tuticorin in south, Qasim *et al.* (1978) found primary production to vary from 0.027 to 2.047 $gCm^{-2}d^{-1}$ in the month of March. In the northern Arabian Sea, the surface and column production during

December to May was 8.4 $mgCm^{-3}d^{-1}$ and 0.70 $gCm^{-2}d^{-1}$ as reported by Radhakrishna *et al.* (1978). In the north eastern Arabian Sea the column production in November was found to vary from 0.10 to 0.56 $gCm^{-2}d^{-1}$ (Radhakrishna et al., 1978). Kuzmenko (1973) measured primary production in the euphotic layer of Arabian Sea and found to vary from 0.1 to 3 $gCm^{-2}d^{-1}$. Further, Silas (1977) reported average production in shelf region to be 0.47 $gCm^{-2}d^{-1}$. Cushing (1973) measured production rates at various places and reported 1.16 $gCm^{-2}d^{-1}$ in Arabian upwelling area and 0.76 $gCm^{-2}d^{-1}$ in Arabian Sea during south west monsoon period. In the present study during the same period the production was found to be 720 $mgCm^{-2}d^{-1}$ as average. Qasim (1982) while reviewing the productivity studies from northern Arabian Sea reported as follows:

Surface ($mgm^{-3}d^{-1}$)

	Minimum	Maximum	Average
Pre-monsoon (Feb.- May)	0.2	280.7	18.9
S.W. monsoon (June-Sept.)	0.8	23.6	7.0
N.E. monsoon (Oct.- Jan.)	0.7	280.7	25.2

Column ($gCm^{-2}d^{-1}$)

	Minimum	Maximum	Average
Pre-monsoon	0.019	6.01	0.73
S.W. monsoon	0.1	2.22	0.92
N.E monsoon	0.013	5.79	0.92

This compares well with the present estimates where production rate in SW monsoon is maximum. The rate during pre- monsoon is higher in the present case. The estimates differ for surface values also. While Qasim (1982) has graded post monsoon, pre-monsoon and monsoon as highest, moderate and lowest, the present calculations show pre-monsoon as highest followed by monsoon and lowest in post monsoon. If we compare with the values of open ocean, it can be observed that they are lower than the shelf region. Kabanova (1968) reported 0.19 $gCm^{-2}d^{-1}$ during winter and between 0.5 and 1.0 $gCm^{-2}d^{-1}$ during summer, the average being 0.142 and 0.320 $gCm^{-2}d^{-1}$ respectively.

In the Bay of Bengal, the work on primary production is not very comprehensive. Steemann Nielson and Jensen, (1957) reported average primary production durin,, April & May 1951 to be 0.28 $gCm^{-2}d^{-1}$ while in 1963 the average was reported as 0.18 $gCm^{-2}d^{-1}$ during the same months (Anon. 1964). Radhakrishna's (1978) average figure was 0.17 $gCm^{-2}d^{-1}$ which was almost the same as that of Anon. (1964). The productivity in SW monsoon was measured in the year 1976, by Radhakrishna et al., 1978); Devassy *et al.*, 1983; Bhattathiri *et al.*,1980. Their values are summarised below:

	Surface production ($mgCm^{-3}d^{-1}$)			Column production ($gCm^{-2}d^{-1}$)		
	1976	1977	1978	1976	1977	1978
Minimum	2.71	2.0	2.0	49.03	0.14	0.12
Maximum	279.31	495.3	403.0	606.37	1.19	3.41
Average	40.5	25.6	69.4	0.64	0.28	0.98

However, the production off Madras and at the mouth of Cauvery River was 3 $gCm^{-2}d^{-1}$ which is slightly higher than at other places. In the present study the average value during SW monsoon period is 765.897 $mgCm^{-2}d^{-1}$ while the average for the entire year comes to 1081.065 $mgCm^{-2}d^{-1}$ for the column production. The average surface production is found to be 44.197 $mgm^{-3}d^{-1}$.

In the EEZ around Andaman, Bhattathiri (1984) reported column production in February 1979 and January 1980 to vary from 120 to 615 $mgCm^{-2}d^{-1}$ with an average of 273 in February 1979 but much higher during January 1980 with an average of 426 $mgCm^{-2}d^{-1}$ and values ranging from 196 to 1218 $mgCm^{-2}d^{-1}$. When compared to the pooled data, these values are quite low and the averages in all the seasons are high (Table 12) with an annual average of 470.74 $mgCm^{-2}d^{-1}$ showing that Andaman Sea is productive throughout the year.

In the Lakshadweep Sea Bhattathiri and Devassy (1979) worked out the column production which ranges between 254-830 $mgCm^{-2}d^{-1}$ during March - April and

Table 12: Average and range of column primary production
(Area & Seasonwise) $mgCm^{-2}d^{-1}$

Sector	Pre-monsoon (Feb- May)			Monsoon (June-Sept)			Post monsoon (Oct - Jan)			Annual Average
	Min	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	
West Coast excluding Lakshadweep Sea	30.0	1552.15	550.629	30.00	4550.00	720.935	10.00	1390.0	289.736	490.937
Lakshadweep Sea	12.0	648.0	335.088	40.0	1225.00	161.461	21.80	263.9	152.23	236.289
East Coast	70.0	18560.0	1391.457	49.03	3608.23	765.897	6.00	46.0	24.8	1081.065
Andaman Sea	3.0	14930.0	465.598	70.0	1960.0	586.727	196.1	1217.1	440.684	470.736

Data source : IIOE (1960-65), R.V. Gaveshani (1976-87), Sagar Kanya (1983-85) gave an average of 372 $mgCm^{-2}d^{-1}$. This is inspite of absence of nitrate - nitrogen upto 75m depth. These values are lower than that of northern Arabian Sea (698 $mgCm^{-2}d^{-1}$) and higher than that of north eastern Arabian Sea (216 $mgCm^{-2}d^{-1}$). Bhattathiri (1984) in October 1976 found the values to range from 23-359 $mgCm^{-2}d^{-1}$ with an average of 134. Out of a total of 145 stations almost half of the stations had values less than 100 $mgCm^{-2}d^{-1}$. But in December he found higher values to range from 45-1167 $mgCm^{-2}d^{-1}$ with an average of 358 $mgCm^{-2}d^{-1}$. It is, however, seen that production was found to be less in areas very near to Island and coral reefs. In the present study the pre-monsoon (February-May) average was highest (335.09 $mgCm^{-2}d^{-1}$) and the overall annual average was also fairly high (236.29 $mgCm^{-2}d^{-1}$) indicating high productive areas.

The rates of primary production at surface are shown in Fig. 21, 22 and 23 in three seasons. The isolines indicate higher values i.e. 50 $mgCm^{-3}d^{-1}$ and above in north west portion of EEZ in pre-monsoon and also in waters off Visakhapatnam on east coast. A small patch of high production is also noticed on the western side of Lakshadweep. Pockets of high productivity rate were observed from Gujarat to Goa and also in Lakshadweep waters. In Andaman Sea the rate of primary production was lower and moderate. During monsoon, the isolines of available data show high concentration on the central east coast and moderate to high on other areas of east coast and on south-west coast. In post- monsoon while no data is available along east coast, along the west coast the production was moderate to high reaching upto 40 $mgCm^{-3}d^{-1}$ in nearshore waters off Bombay.

The rate of column production is shown in figs. 24-26. In pre-monsoon, the isolines on the west coast shows high rates (1050 $mgCm^{-2}d^{-1}$) off Gujarat coast. This decreases gradually towards south and offshore with a minimum of 150 $mgCm^{-2}d^{-1}$. Along east coast the data shows moderate rate between Calcutta and Visakhapatnam otherwise low at all other areas including Andaman Sea. Monsoon data show high rates off Cochin and Cape Comorin along west coast and off Calcutta on east coast. The scanty data along east coast show poor rates while hardly any data is available for north and central Arabian Sea. From Cochin to Mangalore the column productivity decreases. No data is however available for the Andaman Sea for monsoon period. In post monsoons, the eastern EEZ is completely devoid of

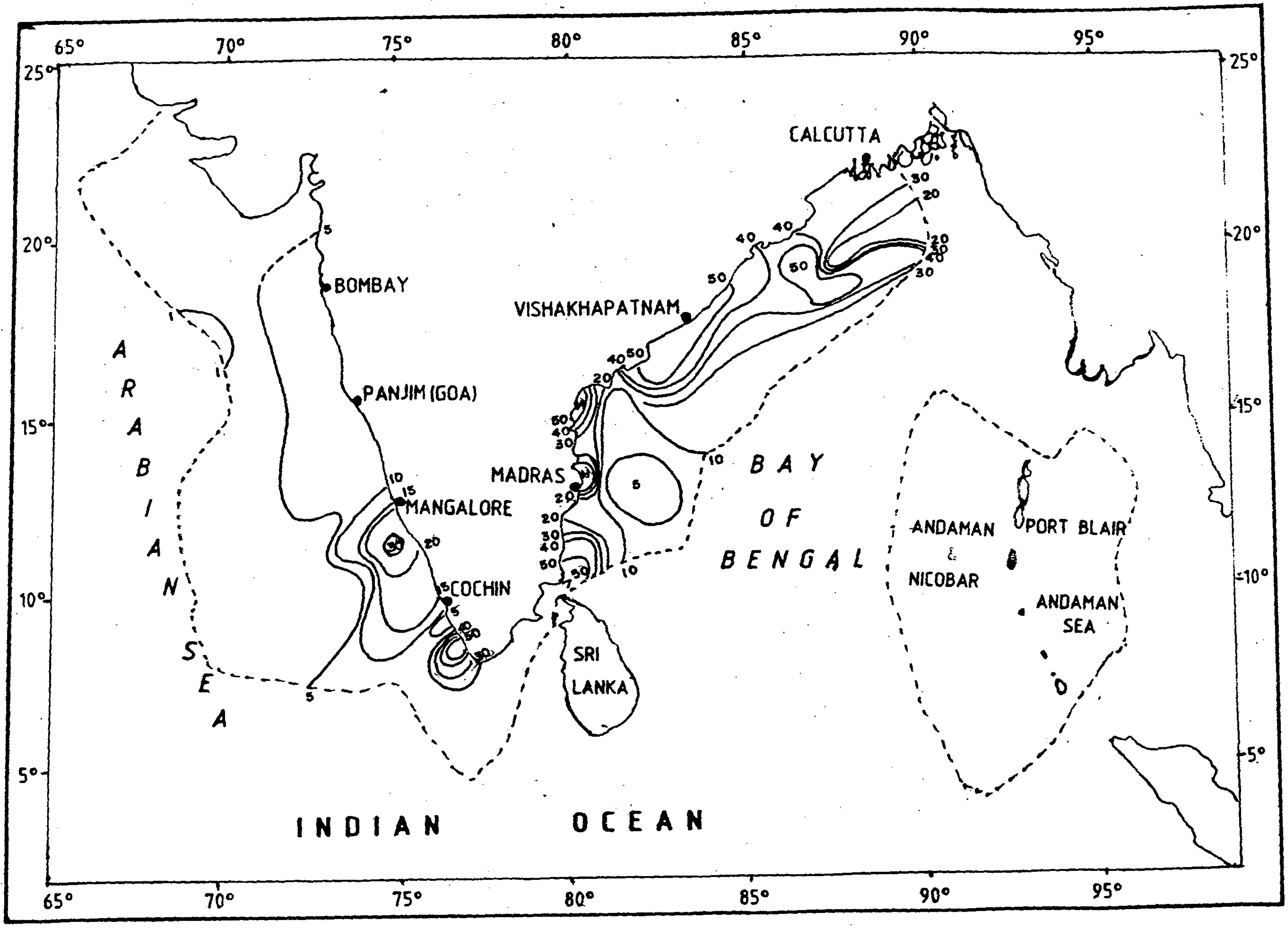

Fig.2? Rates of primary production (mgC m^{-3} d^{-1}) at surface during monsoon (June Sept)

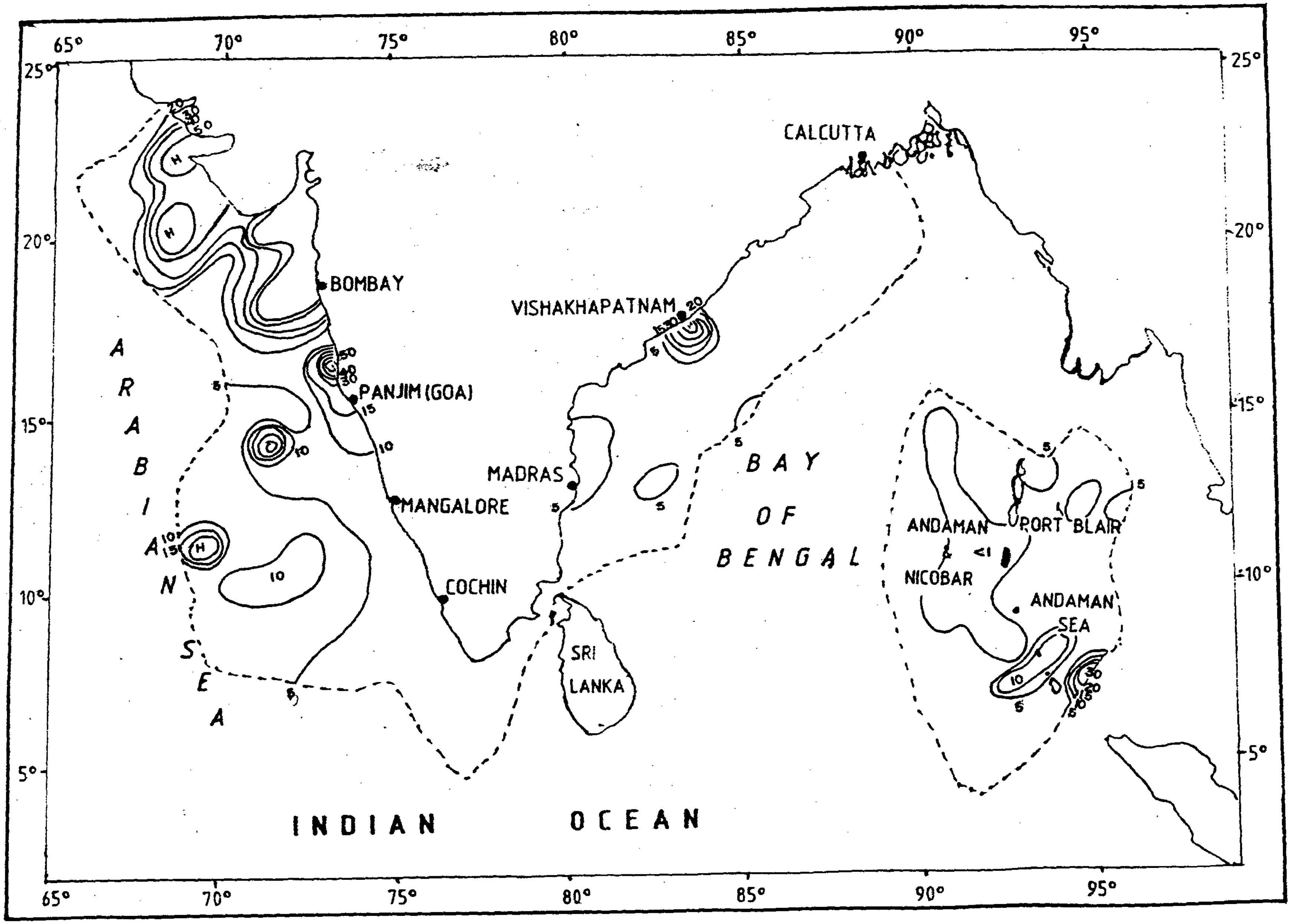

Fig. 21 Rates of primary production (mg C m^{-3} d^{-1}) at surface during pre monsoon (Feb - May)

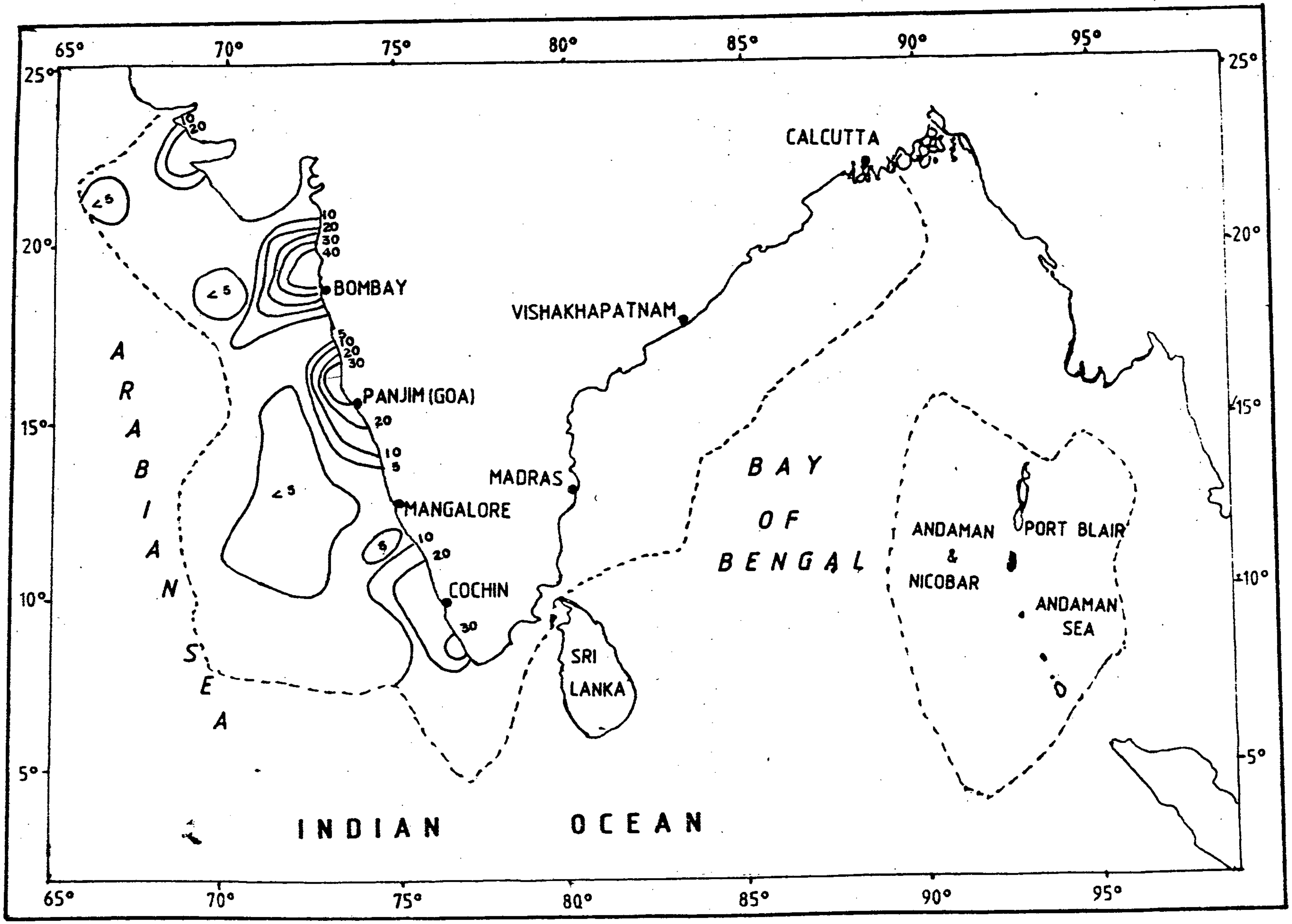

Fig.23 Rates of primary production ($mg\,C\,m^{-3}d^{-1}$) at surface during post-monsoon (Oct.-Jan.)

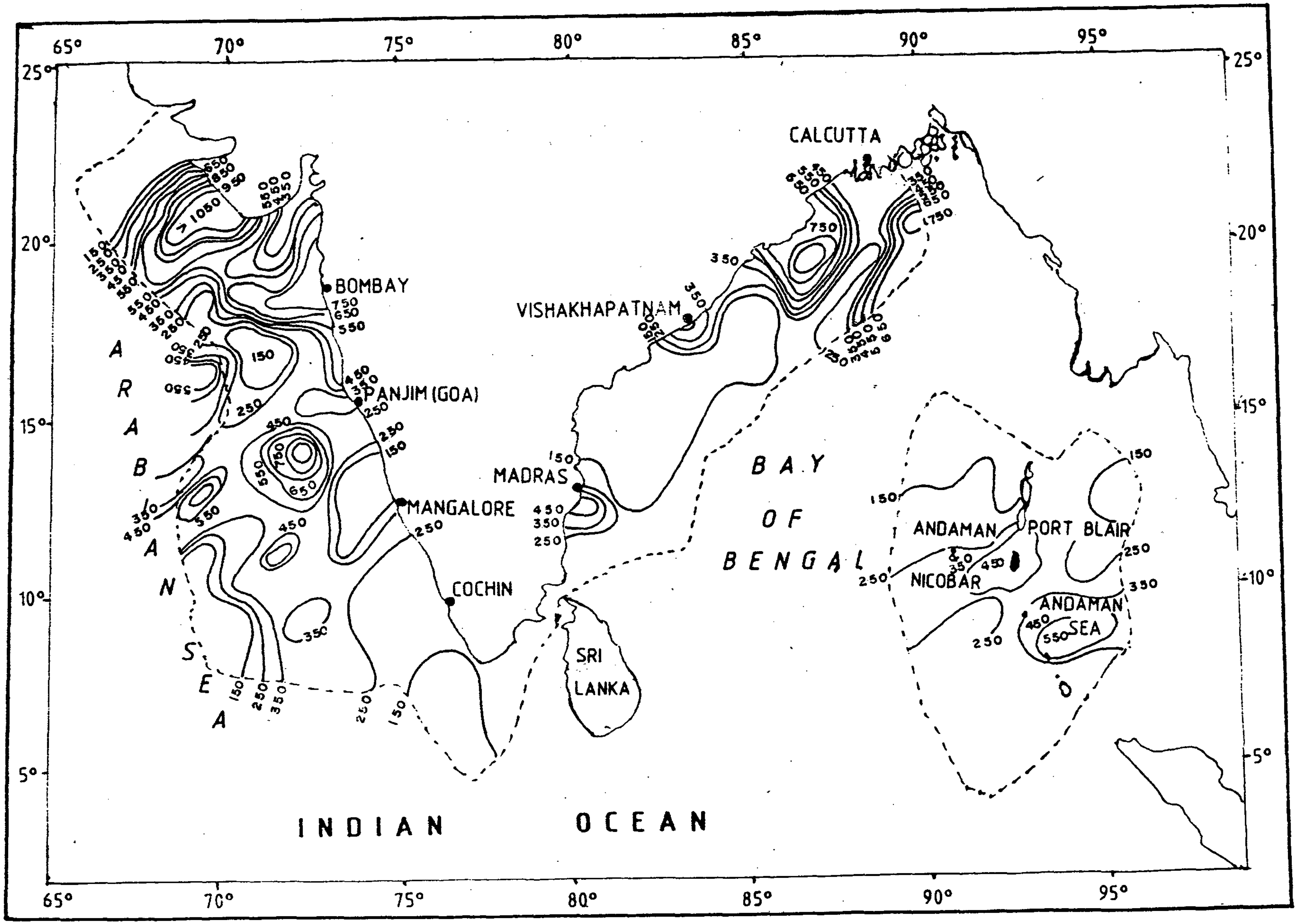

Fig.24 Rates of primary production (mg C m^{-2} d^{-1}) in euphotic column during pre monsoon

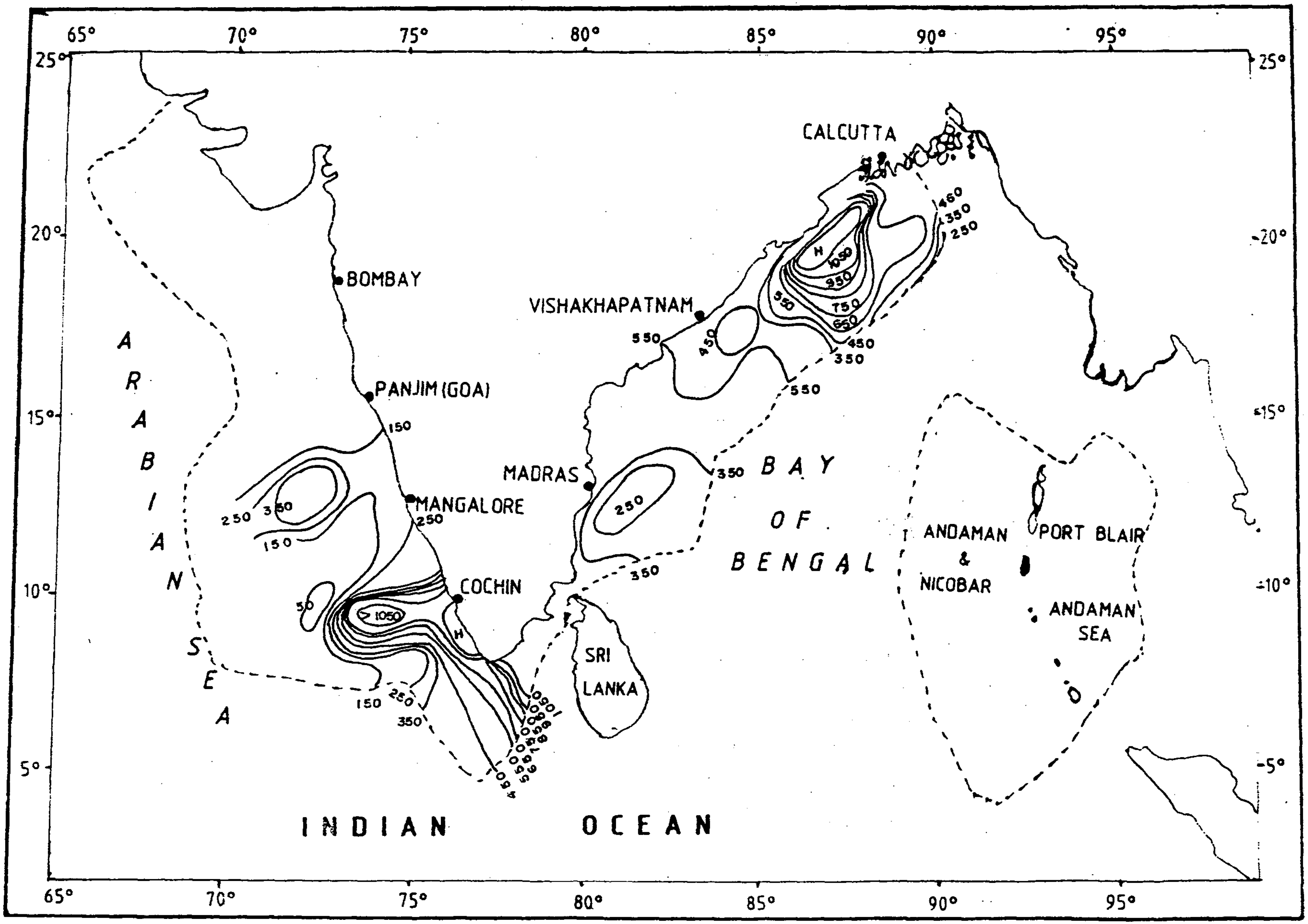

Fig.25 Rates of primary production $(mgC\ m^{-2}\ d^{-1})$ in euphotic column during monsoon (June-Sept)

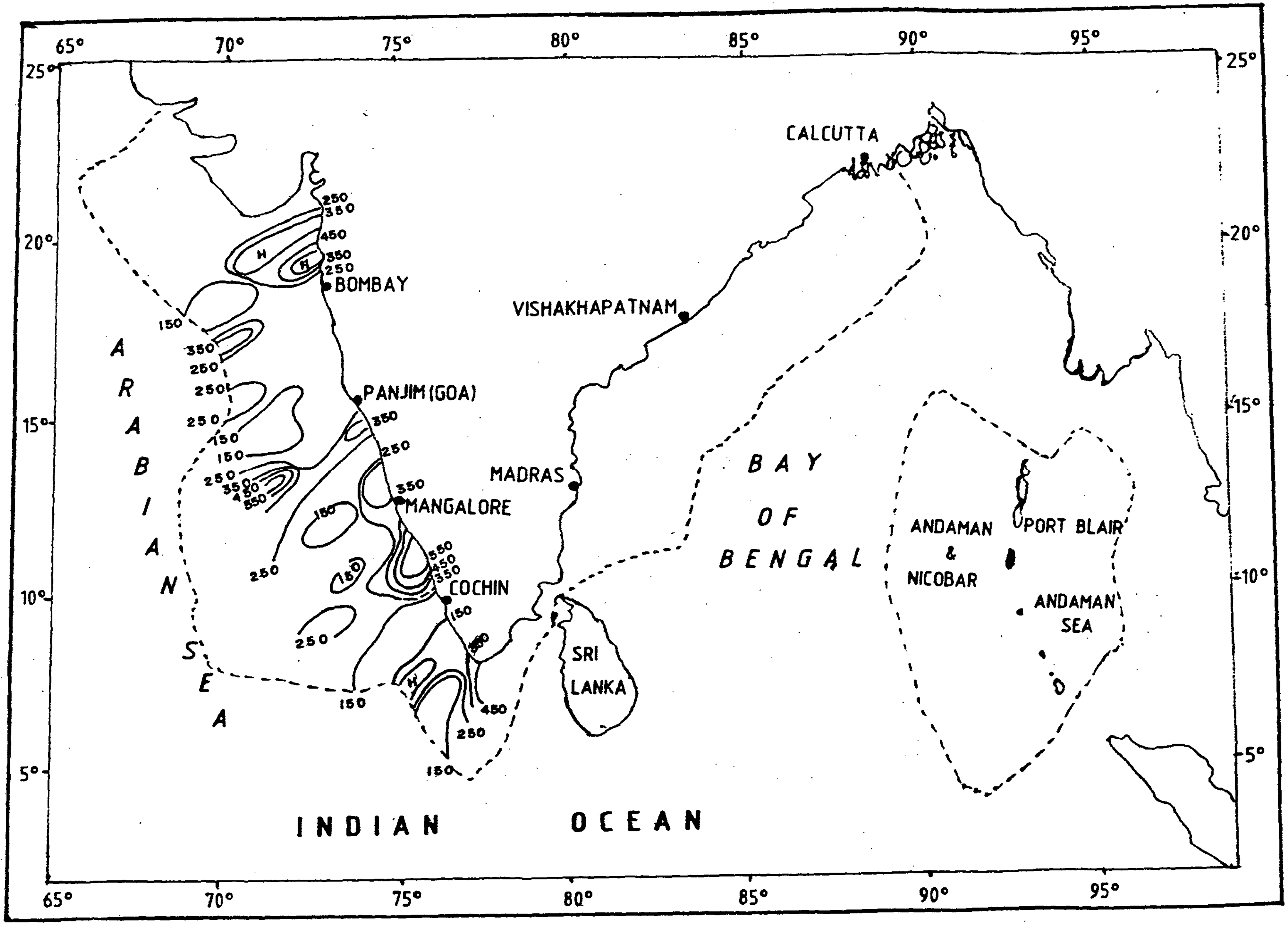

Fig.26 Rates of primary production (mg C m^{-2} d^{-1}) in euphotic zone during post monsoon.

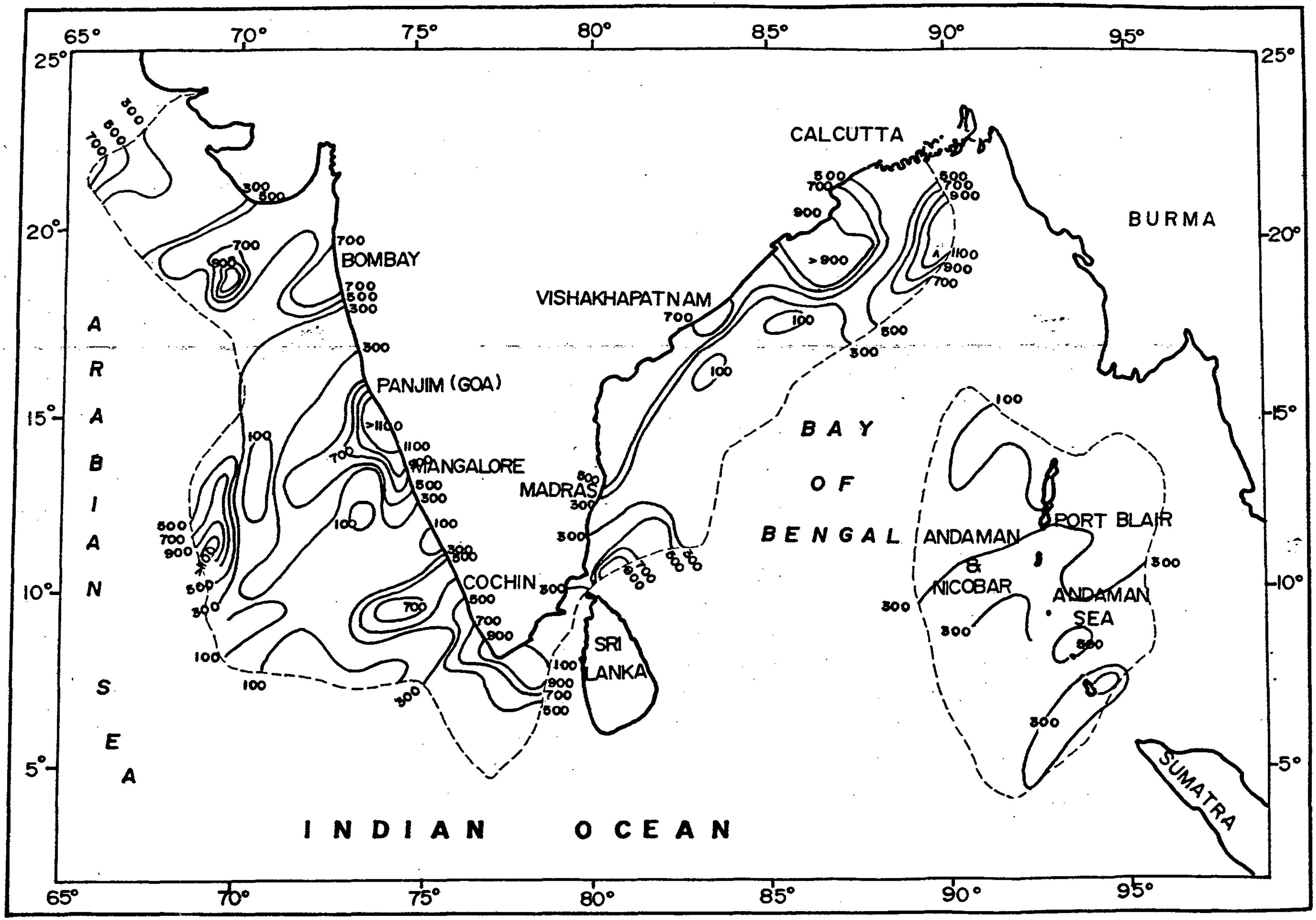

Fig. 27 Annual rates of Primary Production in column water ($mgC\,m^{-2}\,d^{-1}$)

data. Along the western EEZ the productivity rates are quite low but fish catches start increasing which may be due to the result of high primary production in monsoon. The other reason of low productivity rate may be due to the grazing of phytoplankton by zooplankton and fishes.

The average annual rate of primary production is depicted in Fig. 27. This shows high rates of production between Goa and Mangalore in the nearshore waters. This is followed by the rates in nearshore waters along Kerala and Bombay coast. As expected it decreases away from the shore. However, in the Lakshadweep waters there is a patch of high productivity rate of 1100 $mgCm^{-2}d^{-1}$. A medium rates of 700-900 $mgCm^{-2}d^{-1}$ is seen off Bombay and Gujarat.

Along east coast, the nearshore waters show a low rate of production (30-500 $mgCm^{-2}d^{-1}$) while off Orissa between Calcutta and Visakhapatnam high rates upto 1100 $mgCm^{-2}d^{-1}$ are noticed. The isolines along east coast show a fluctuating trend. The waters of the Andaman & Nicobar Seas indicate a low productivity rates ranging from 100-500 $mgCm^{-2}d^{-1}$.

4.2.3 *Secondary production:*

The second stage in the food chain is zooplankton which primarily feed on primary producers and is therefore termed as secondary producers and its production as secondary production.

Zooplankton forms the largest ecological group of animal organisms in the sea. By virtue of their abundance and intermediary role between phytoplankton and fish, they are considered as the chief index of utilization of aquatic biotope at the secondary trophic level. The zooplankton inhabit the oceans at almost all depths and occupy practically every type of ecological niche. They exhibit vertical migration and facilitate transportation of organic matter from surface layers to bottom and vice-versa. The zooplankton also help in the regeneration of nutrients.

In view of the important role played by zooplankton in overall economy of the sea, a detailed study on their standing stock during different seasons in the EEZ of India is made. This study received great impetus during International Indian Ocean Expedition (1960-65). The distribution of zooplankton biomass and zoogeography of common groups have been published (UNESCO collected reprints 1-8, 1965-72, IOBC Atlases and Handbooks 1-3, 1968-73 and Zeitschell, 1973). Subsequent investigations (Prasad, 1969; Nair *et al.*, 1977, 1978; Peter and Nair, 1978; Goswami, 1979, 1983; Achuthankutty *et al.*, 1980; Madhupratap, 1981 and others) provided a great deal of information on zooplankton production and distribution in different areas of EEZ of India. The earlier studies were confined mainly to the oceanic realms and the seasonal aspects were not covered. In this section, the zooplankton distribution in the Exclusive Economic Zone of India along west coast, Lakshadweep Sea, east coast and Andaman Sea is discussed. This is a seasonal analysis based on the data collected during IIOE and also by INS *Darshak*, R.V. *Gaveshani* and ORV *Sagar Kanya*, that are available at the Indian National Oceanographic Data Centre. In addition, the published results from individuals in time and space have been mentioned to characterize those areas. The number of sectorwise and seasonwise number of observations considered here are shown below :

No. of Observations

Sector	Pre-monsoon	Monsoon	Post monsoon
West Coast	297	125	356
Lakshadweep Sea	23	2	41
East Coast	51	204	11
Andaman & Nicobar Sea	93	-	31

The coverage is fairly good except during monsoon in Lakshadweep and Andaman Sea. The west coast has been covered well in all seasons.

The zooplankton samples were collected by vertical hauls from 200m to the surface using Indian Ocean Standard Net of the International Indian Ocean Expedition. In some cruises and during cruises of INS *Darshak*, R.V. *Gaveshani* and ORV *Sagar Kanya* a Heron-Tranter (HT) square net was used. In both cases flow meter was attached. Displacement volume for each haul was then taken and expressed in $ml m^{-3}$.

The ranges and seasonal averages of zooplankton biomass are shown in Table 13. Along the west coast, in the pre-monsoon the biomass ranged between 0.02 and 20 mlm^{-3} (av. 0.774 mlm^{-3}). This was the highest among the three seasons and followed by monsoon where it ranged from 0.05 to 7.67 mlm^{-3} with an average of 0.558 mlm^{-3}. The lowest average (0.455 mlm^{-3}) was observed during post-monsoon where the biomass varied from 0.01 to 13.3 mlm^{-3}. The column primary production was also lowest in the post-monsoon months. Nair and Peter (1980) reported the zooplankton biomass to range between 0.1 to 1.05 mlm^{-3} on the west coast between Dabhol and Tuticorin in March 1977 when primary production was also reported high by Qasim et al. (1978). Qasim (1982) estimated the average biomass from coastal waters of northern Arabian Sea as 62 mlm^{-2} for the water column of 200m which comes to about 0.31 mlm^{-3}. Along the south west coast of India, Menon and George (1977) based on four years work, observed the average biomass to vary from nil upto 1.1 mlm^{-3}. They noticed low values from January to April with a peak during July-September period. The biomass differ at various depths as evidenced by results of Goswami *et al.* (1977) who found it to increase upto 20m depth along central west coast of India. The biomass varied from 0.27 to 0.238 mlm^{-3} off Karwar and Vengurla with maximum values in February unlike along south west coast of India as mentioned above.

In Lakshadweep Sea, according to present analysis, the biomass varies from 0.01 to 0.31 mlm^{-3} (av. 0.151) during pre- monsoon, 0.08 to 0.13 (av. 0.105) in monsoon and 0.01 to 1.2 mlm^{-3} (av. 0.133) in post monsoon. The highest being in pre monsoon (February-May) followed by post monsoon and monsoon averages. In Lakshadweep Sea there are lagoons which differ from open sea. Goswami (1979) reported biomass values to vary from 0.023 to 0.188 mlm^{-3} in open sea while working in the lagoons. Goswami (1983) found lower biomass in lagoons than in open sea and attributed it to their consumption by coral reefs. Therefore, part of this food is consumed by reefs and reduces its availability for fishes.

Along the east coast, the areas are affected by north east monsoons (November-February). Here the highest average biomass (0.991 mlm^{-3}) was seen during October-January followed during February-May (av. 0.434) and lowest being in June-September months (0.237 mlm^{-3}). As compared to the values of west coast it is

Table 13: Range and Averages of Zooplankton Biomass (mlm^{-3}) in different seasons

Sector	Pre-monsoon (Feb.-May)			Monsoon (June-Sept.)			Post monsoon (Oct.-Jan.)		
	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.
West Coast	0.02	20.0	0.774	0.05	7.67	0.558	0.01	13.3	0.455
Lakshadweep Sea	0.01	0.31	0.151	0.08	0.13	0.105	0.01	1.20	0.133
East Coast	0.015	3.00	0.434	0.01	4.80	0.237	0.24	5.30	0.991
Andaman & Nicobar Sea	0.015	0.84	0.117	-	-	-	.06	0.37	0.173

more in October-January period (more than double) otherwise during other periods it is much less. The values range between 0.01 and 5.3 mlm^{-3} around the year. Nair *et al.* (1977) observed increase in biomass from north to south during south west monsoon period with a maximum biomass of 0.6 mlm^{-3} and higher values in nearshore waters. Similar conclusion was drawn by Achuthankutty *et al.* (1980) where they noticed the biomass to range between 0.01 and 0.11 mlm^{-3}. Exceptional high values from 0.4-4.80 mlm^{-3} were noticed at few stations in late south west monsoon months (August-September 1978). High biomass of 1.32 mlm^{-3} was noticed off Tuticorin by Santhakumari and Saraswathy (1981) in February which coincides with upwelling off the coast of Ceylon as reported by Kabanova (1968).

In Andaman and Nicobar Sea, the average biomass during pre- monsoon was found to be 0.117 mlm^{-3} with a range of 0.015 to 0.84 mlm^{-3} while no data is available for south west monsoon period, the range in post monsoon varied from 0.06 to 0.37 mlm^{-3} with a mean of 0.173 mlm^{-3} which is higher than pre-monsoon months though the maximum is less. This indicates that most of the values are higher. In the month of February 1979, Madhupratap *et al.* (1981) reported the zooplankton biomass to vary from 0.018 to 0.144 mlm^{-3}. The abundance was moderate with a patch of high biomass around Andaman Island. These authors also quoted the ranges of biomass obtained during *Anton Brunn* cruises in March (0.01-0.135 mlm^{-3}) and *Pioneer* cruises in April (0.038-1.24 mlm^{-3}) from Andaman Sea during International Indian Ocean Expedition.

From the data the annual average of zooplankton biomass was found to be highest along west coast (0.59 mlm^{-3}) followed along east coast (0.31 mlm^{-3}). The averages for Lakshadweep Sea and Andaman Sea are almost identical being 0.12 and 0.13 mlm^{-3} respectively.

The isopleths of the zooplankton distribution are shown in Fig. 28-30 in different seasons. During pre-monsoon, the biomass is always high near to the coast and decreases away from the shore. A value of 0.5 to 1 mlm^{-3} was observed along the entire nearshore waters of west coast. In the Lakshadweep waters the value of 0.05 mlm^{-3} was noticed. Along the east coast also, the values ranged between 0.1 to 0.05 mlm^{-3}. Biomass of 0.1 mlm^{-3} was only noticed in a small area near Visakhapatnam.

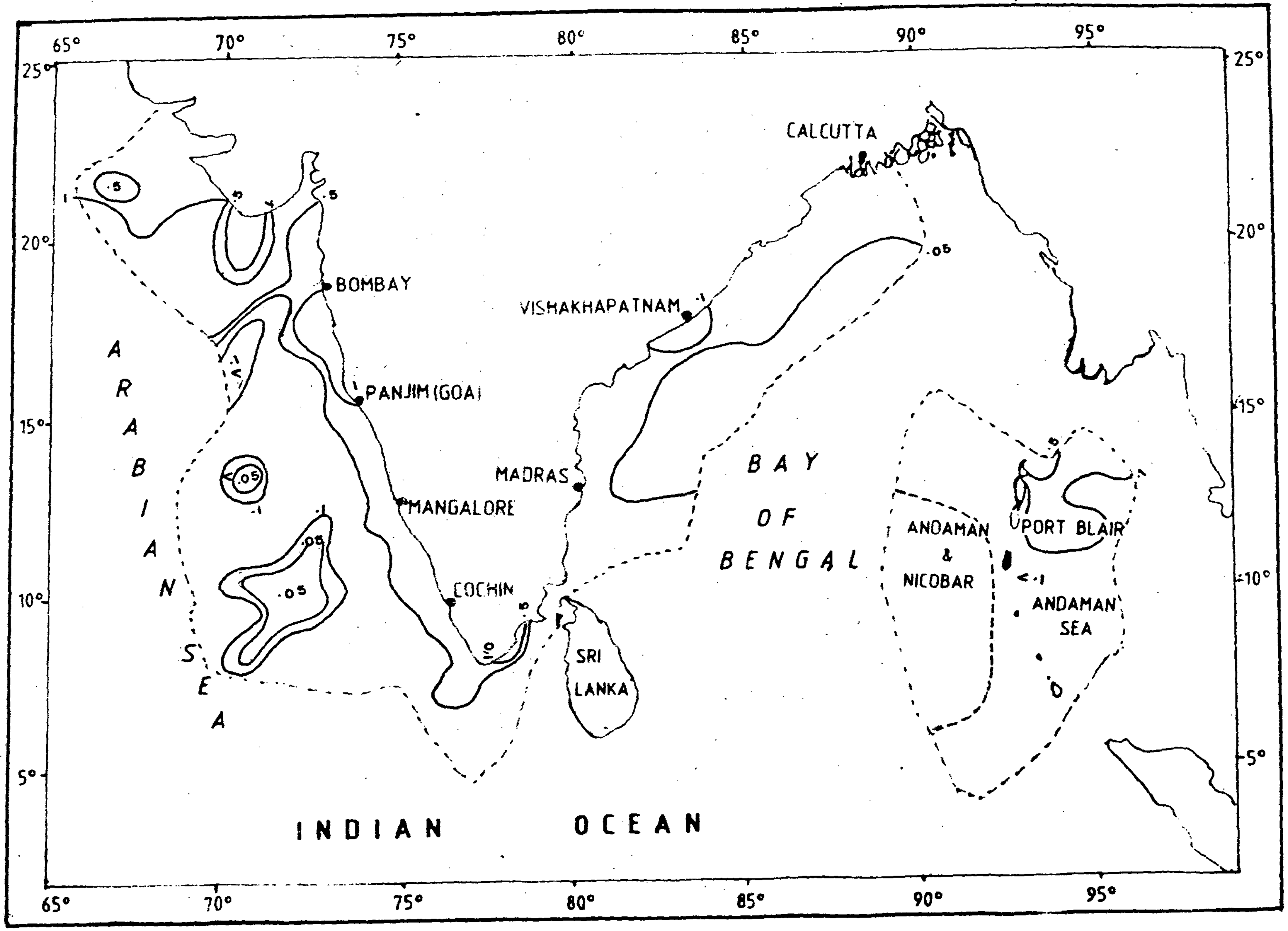

Fig. 28 Distribution of zooplankton biomass (ml m^{-3}) during pre-monsoon

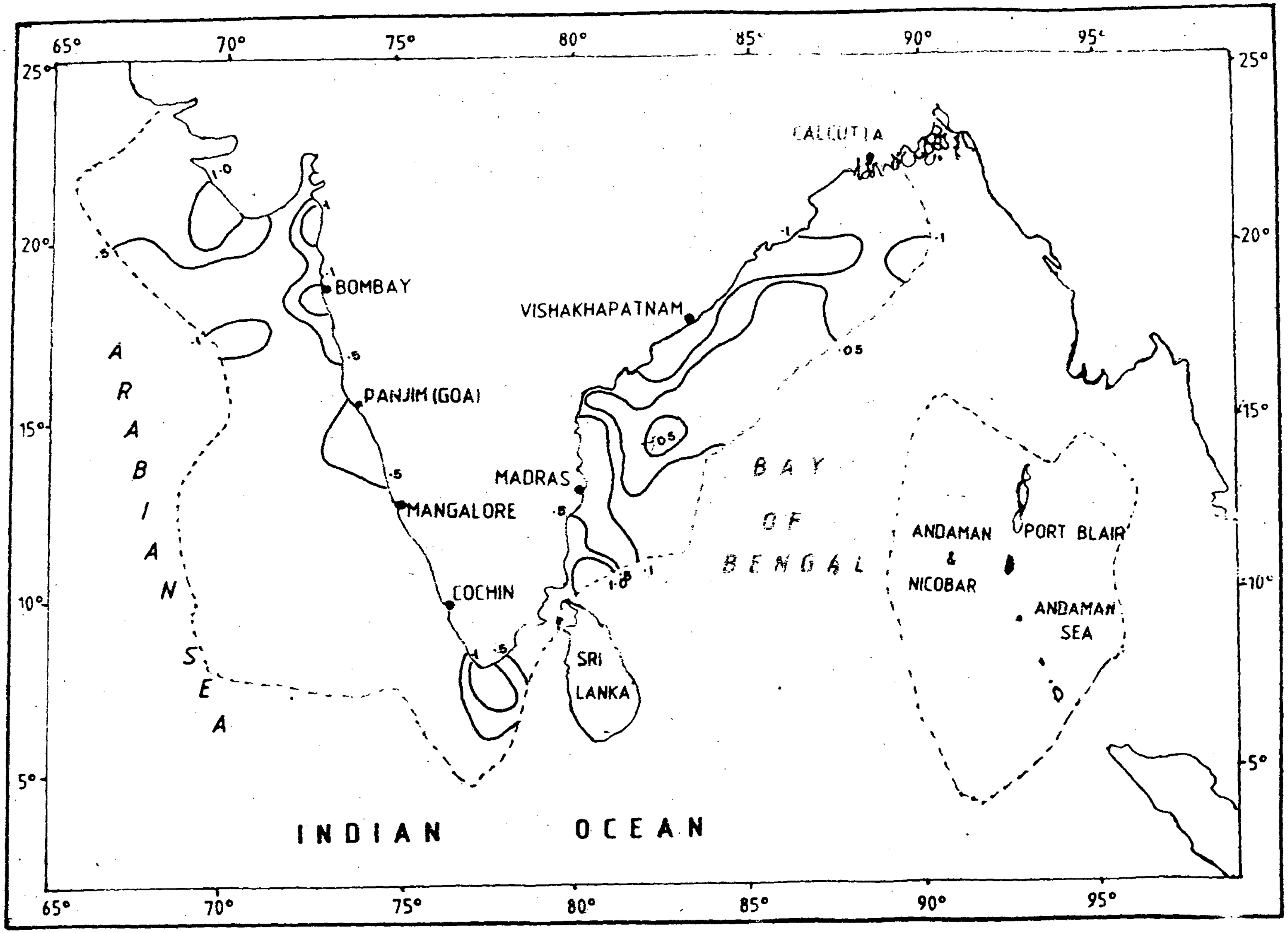

Fig.29 Distribution of zooplankton biomass ($ml\ m^{-3}$) during monsoon (June-Sept.)

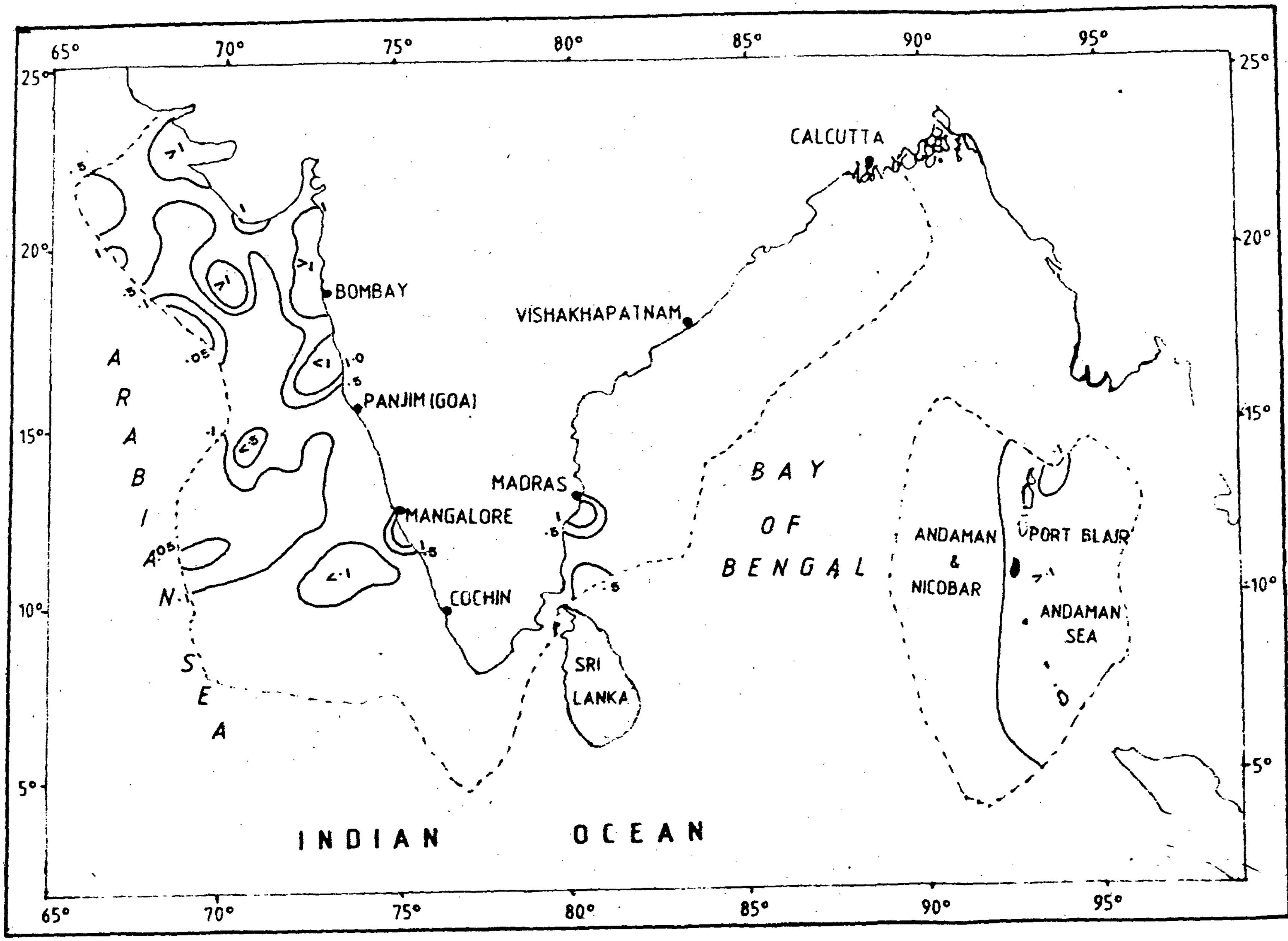

Fig.30 Distribution of zooplankton biomass(ml m^{-3}) during post-monsoon

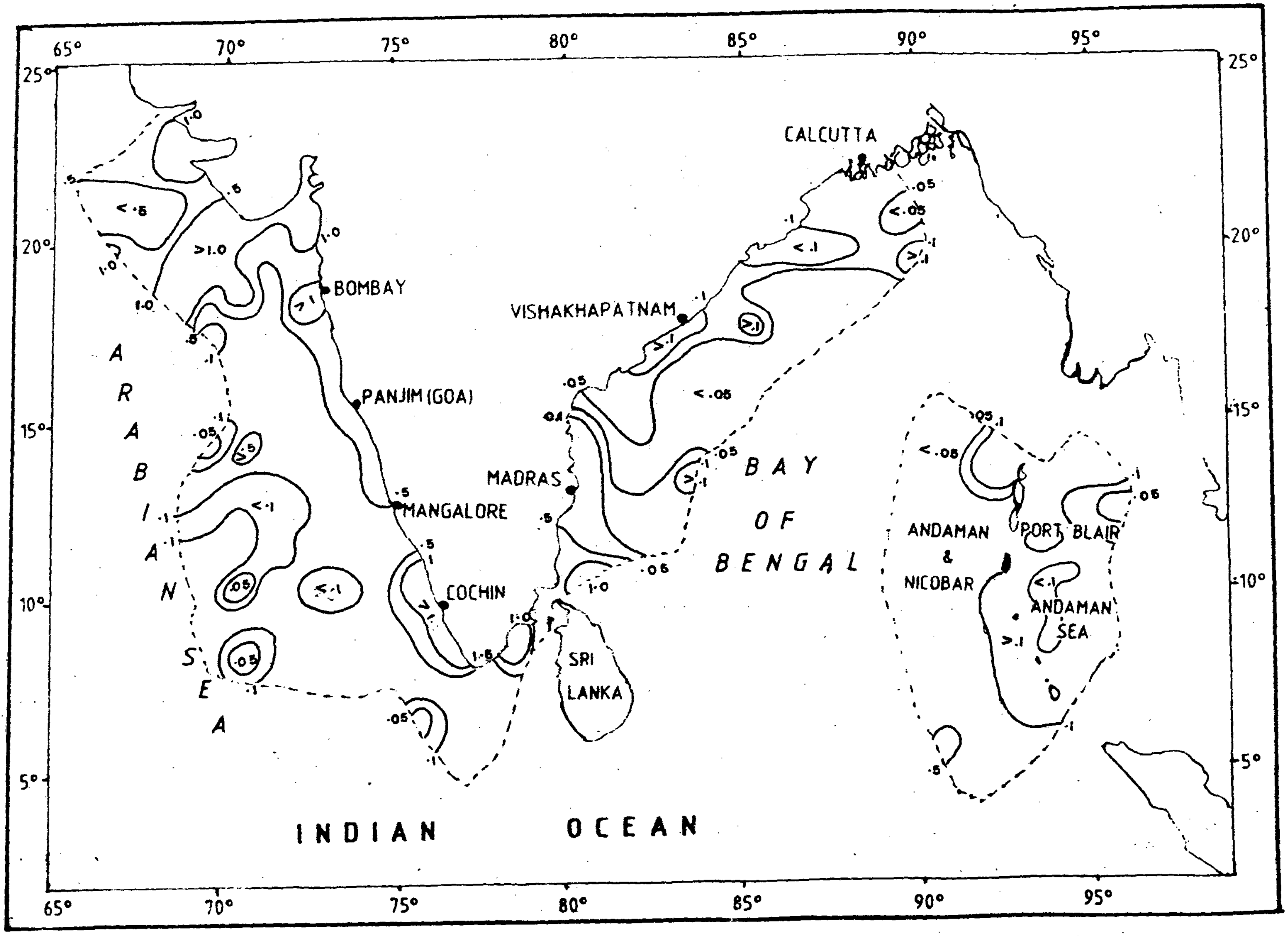

Fig.31 Distribution of zooplankton biomass(ml m^{-3}) - (Annual pattern)

With the limited studies in Andaman Sea, a small area was noticed with a value of 0.5 mlm^{-3}. During monsoon, along west coast the available data for its northern portion shows values ranging from 1 to 1.0 mlm^{-3}. The highest value was seen off Gujarat. Some data along the southern tip of mainland shows isolines of 0.1 and 5 mlm^{-3}. In the eastern EEZ the most of the area shows values of 1 mlm^{-3} but with a large area having low biomass of 0.05 mlm^{-3}. The post monsoon distribution shows high values between 0.5 and 1 mlm^{-3}. In the waters near to the coasts of Gujarat, Bombay, Goa and Mangalore it decreases away from coast. Along east coast the data is available for waters near Madras with values between 0.5 and 1 mlm^{-3}. In Andaman Sea also, data show the value of 0.1mlm^{-3}.

The annual distribution of zooplankton biomass is shown in Fig. 31 depicting the overall average based on round the year data. The isolines show the biomass to be more than one mlm^{-3} in the nearshore waters all along the west coast and gradually decreasing upto 0.05 mlm^{-3} at the edge of the EEZ boundary. The maximum value was noticed off Cape Comorin. In Lakshadweep waters the value is about 0.1 mlm^{-3}. Along the east coast, low values were noticed along the shore and increasing towards EEZ boundary at few locations contrary to that of west coast. There is a small patch having the biomass of 1 mlm^{-3}. In Andaman Sea the average values varied from 0.05 to 0.1 mlm^{-3} as indicated through isopleths.

4.2.4 *Benthic production*

The bottom living fauna forms an important link in the biological production in the sea. These are mostly responsible for the demersal fishery resources such as prawns, crabs and bottom dwelling fishes etc. Though all bottom living fauna is known as benthos, the term is referred here to fauna which is used mainly as food for higher animals. The benthos can mainly be divided into two groups viz. macro- and meiobenthos but in the present analysis it is discussed as one group.

The data available in the centre were collected during five cruises of INS *Darshak* and more than 55 cruises of R.V. *Gaveshani* of NIO. The samples had been collected by using different gears but the values are uniformly represented as per meter square. 1108 samples from 980 stations as shown below have been taken into consideration for benthic study and drawing the inferences :

Arabian Sea	.....	504
Bay of Bengal	.....	398
Andaman Sea	.....	75
Lakshadweep Sea	.....	5

Most of these represent shelf and slope regions for the sampling done till 1980. Subsequent to this hardly any data for the EEZ is available.

Parulekar *et al.* (1982) have studied the distribution and abundance in detail. As per their observations the benthic biomass varies from 0.01 to 601 gm^{-2}. Sectorwise they have given the following averages :

Arabian Sea	....	17.61 gm^{-2}
Andaman Sea	....	7.32 gm^{-2}
Bay of Bengal	....	5.32 gm^{-2}
Lakshadweep Sea	....	0.74 gm^{-2}

The northwest and southwest coast of India shows value higher than 500 gm^{-2}. It is found that shelf region upto 200m depth supports the highest standing crop ranging from 14.1 gm^{-2} in Arabian Sea to 1.8 gm^{-2} in Lakshadweep Sea. Beyond this, the crop decreases sometimes to more than 80% in Andaman Sea.

Qasim (1982), based on 143 samples in the EEZ of India, reported macro-benthos to range from 0.15 to 153.20 gm^{-2} with an average of 10.556 gm^{-2} in the depth range of 0 to 200 m. He also found the biomass to decrease with increasing depth and distinct latitudinal variation. This was in agreement with the earlier observations of Parulekar and Wagh (1975). On the other hand the meiobenthos was reported to increase with increasing depth (Qasim, 1982). The meiobenthic biomass ranged from 0.02 to 14.74 gm^{-2} (av. 12.64 gm^{-2}) in shelf region from 0 - 200 m depth.

Fig. 32 is based on data collected at 531 stations during the cruises of R.V. *Gaveshani* only. As seen from the figure the maximum density is seen north of Cochin and at the southern tip of India where the biomass ranged between 10 and 20 gm^{-2} on the west coast. The same density was noticed along part of Orissa and West Bengal on the east coast. For most of the area along west coast, east coast and Andaman Sea, the average biomass is found to be between 1 and 10 gm^{-2}. This also shows that the biomass decreases towards offshore.

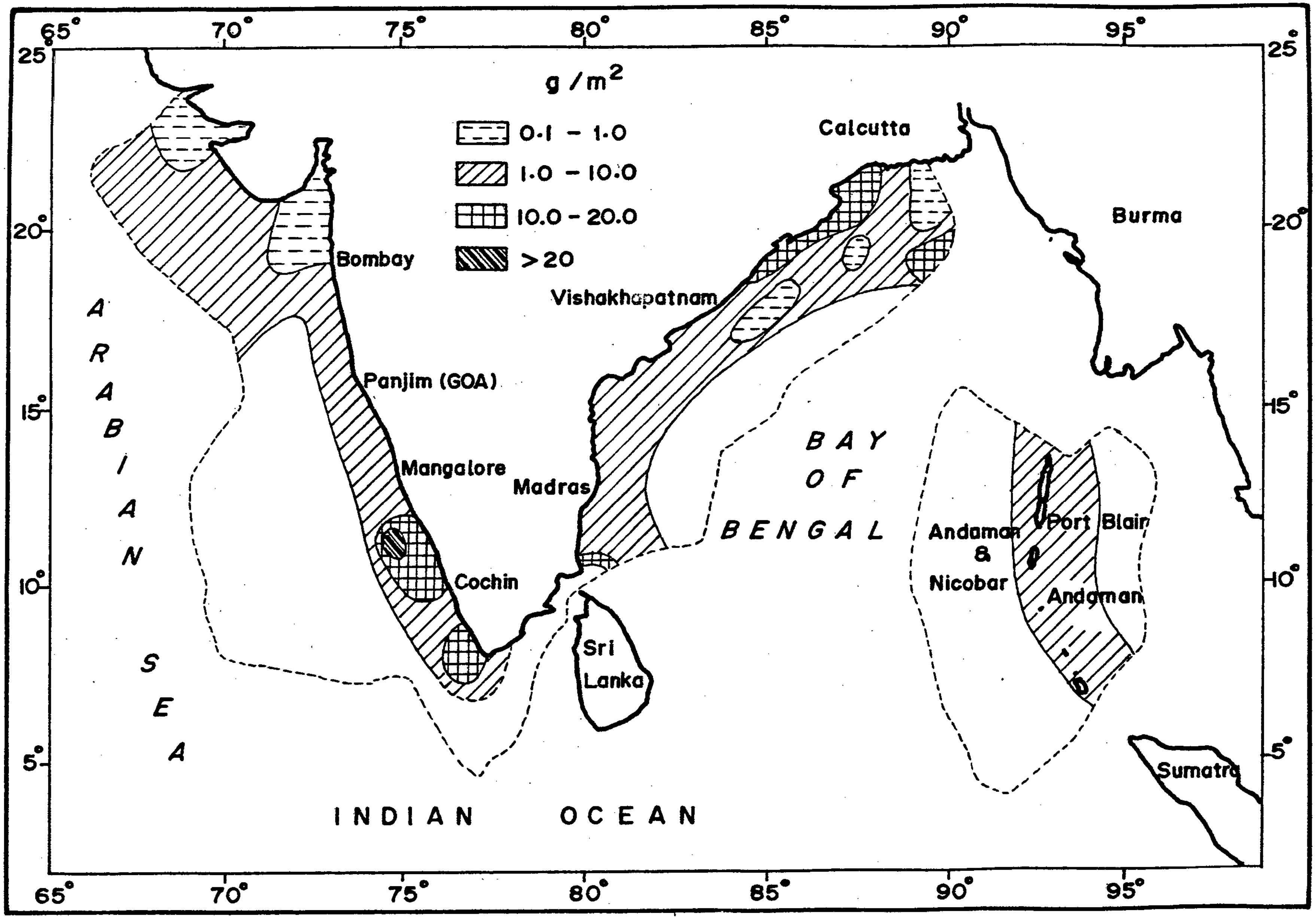

Fig. 32 Distribution of Benthic Biomass (g/m^2) (Source : EEZ Atlas, NIO, 1988)

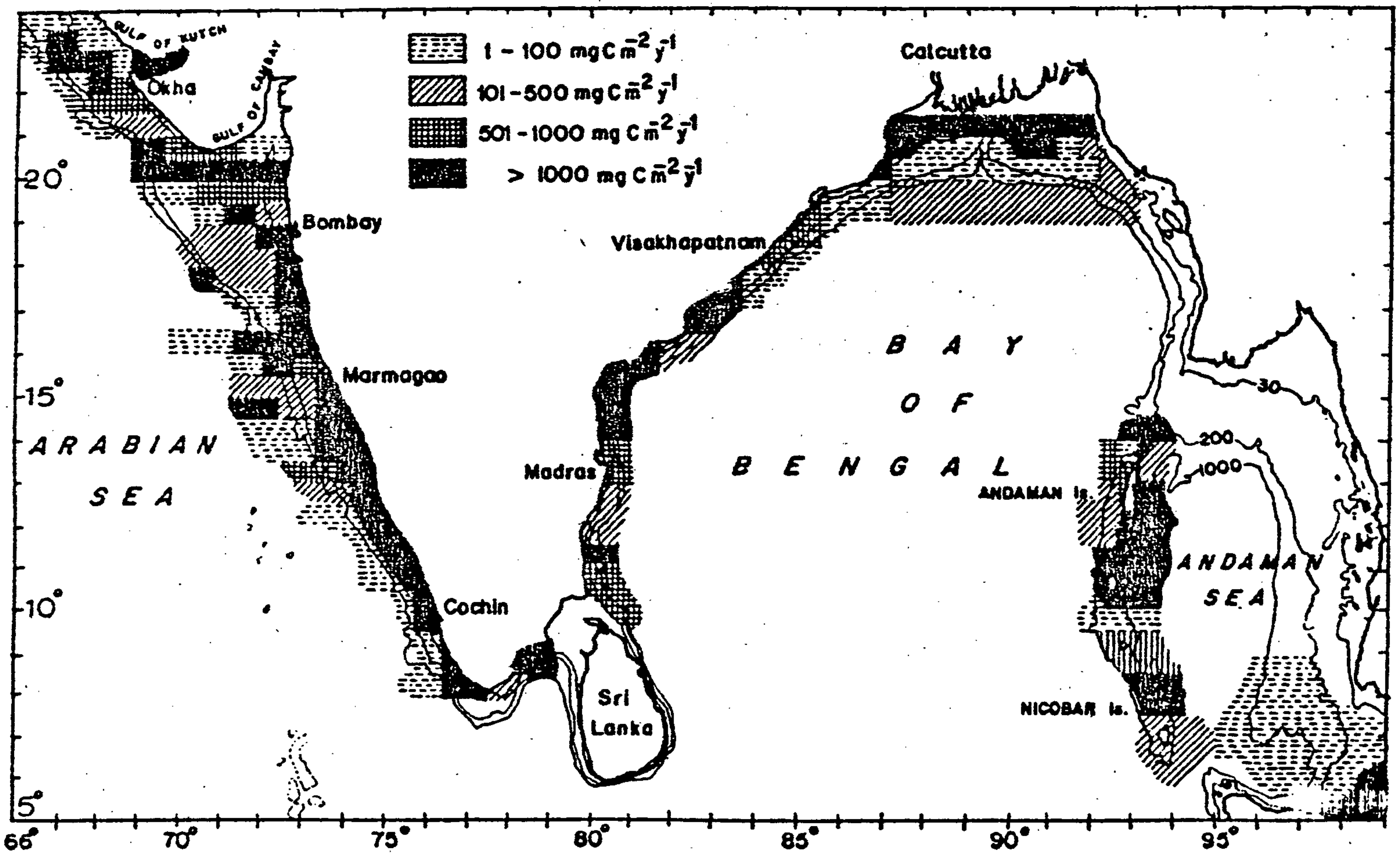

Fig. 33 Annual Benthic production in the Indian Seas (after Parulekar et. al, 1982)

The benthic production in terms of carbon is shown in Fig. 33. This shows that carbon production through benthos is uniformly moderate but with high production rates. Along most of the west coast and some isolated patches along east coast and Andaman Sea the production is more than 1000 $mgCm^{-2}y^{-1}$. The production at Lakshadweep Sea is low. However, as seen earlier the production decreases away from the shore with increasing depth. In the shelf region (0-200m) they reported the following values and ranges of benthic productivity ($gCm^{-2}y^{-1}$) :

Area	Range	Average
Arabian Sea	1.0-2.3	1.9
Lakshadweep Sea	0.7	0.7
Bay of Bengal	0.6-3.1	1.18
Andaman Sea	0.5-7.2	1.9

This reveals the richness of benthic production in the Arabian Sea and Andaman Sea. The minimum is in Lakshadweep Sea.

The data show high biomass value along southern part of the Arabian Sea. Elizarov (1968) correlated this abundance to an inflow of equatorial waters of low salinity causing a strongly expressed stratification of water masses, while the high benthic crop in the northern Bay of Bengal is attributed to the riverine inflow enriching the environment (Lonhurst, 1966). The high benthic crop in south Andaman Sea is in continuation of rich fauna of Malacca strait (Parulekar & Ansari, 1981). An overall evaluation shows that the Indian EEZ particularly upto 200m depth sustains rich benthic biomass and production.

5. CORRELATION AMONG PARAMETERS

5. CORRELATION AMONG PARAMETERS :

The interrelationship between primary production and other parameters and also among various parameters themselves has been worked out. This was carried out only for surface parameters as it was not possible to integrate the values for the entire column because of noncompatability of data. Also, only two regions viz. along west coast and east coast were taken for analysis as they are considered more important. The correlation coefficients thus obtained are given in the form of a matrix with corresponding percentage of significance (Table - 14).

From this table it can be seen that along west coast, the primary production exhibits positive correlation with chlorophyll a, zooplankton biomass and to a certain extent with nitrate concentration otherwise exhibit no significant relation with any other parameters. Among other parameters there is a positive relation between temperature, salinity, dissolved oxygen and phosphorus. The relations between other parameters are found to be insignificant.

Along east coast, a positive correlation at a significance level of 99% was noticed between primary production and chlorophyll a and also between primary production and zooplankton. Primary production also exhibited a significant relation with nitrate. The relationship among other parameters were found insignificant.

An attempt has also been made through multiple linear regression analysis to relate primary production as the dependentvariable to seven independent parameters viz. chlorophyll, zooplankton biomass, temperature, salinity, dissolved oxygen, inorganic phosphate and nitrate. The data comprise of several sets of observation on these parameters. From such data it is expected to derive the following equations (Davis, 1971).

$$Y = b_1X_1 + b_2X_2 + b_3X_3 + ...b_nX_n + C$$

where Y is the predicted value of the dependent variable (primary production at surface in this case) and b_1, b_2, b_3 etc. form a set of coefficients for the values of the independent variables. X_1, X_2, X_3 etc. C is the intercept constant (1).

Since the values of these partial regression coefficients depend on the units in which the original variables were measured; it is advantageous to normalize the

TABLE - 14 : Correlation matrices for primary productivity and related parameters at surface.

Along West Coast: (N=122)

	PP	CHL	ZP	T	S	O_2	PO_4	NO_3
PP								
CHL	.467a							
ZP	.044	.073						
T	.050	.191	.121					
S	.082	.202	.113	.857a				
O2	.035	.295	.084	.423a	.524a			
PO4	.081	.151	.091	.332a	.371a	.328a		
NO3	.187b	.190	.164	.110	.136	.206	.0995	1

Along East Coast: (N=64)

	PP	CHL	ZP	T	S	O_2	PO_4	NO_3
PP								
CHL	.318c							
ZP	.314c	.127						
T	.048	.012	-.110					
S	.031	.038	-.039	.796a				
O2	.028	.046	-.156	.617a	.516a			
PO4	.075	.288	-.093	.168	.225	.244		
NO3	.153	.149	-.070	-.382	- .339	- .019	.087	1

(Level of significance (%) a-99.9; b-94; c-99) measurements by expressing each one of the deviation from its mean by -

$$Z = \frac{X - X}{S}$$

where Z is measured in units of 1 standard deviation. Taking this into consideration the regression equation may then be written as -

$$Y = B_1Z_1 + B_2Z_2 + B_3Z_3 + \ldots\ldots\ldots B_nZ_n$$

the B coefficient provide a measure of the contribution of each independent variable to the predicted value of the dependent variable.

This method and equation is applied in the present data sets of the EEZ along west and east coast of India. The surface primary production is taken as dependent variable while others as mentioned above are taken as independent. it may be stated that column values could not be considered since it was practically difficult to integrate the column values of other parameters.

For the west coast the two equations can be written as :

$$PP = 0.0019 \times Chl. + 0.0712 \times ZP. + 0.0038 \times T + 0.0152 \times S -$$

$$0.0148 \times O_2 + 0.102 \times PO_4 + 0.00905 \times NO_3 - 0.2247$$

where mean values are used the equation can be written as -

$$PP = 0.398 \times Chl. + 0.143 \times ZP. + 0.0172 \times T + 0.0917 \times S -$$

$$0.0701 \times O_2 + 0.2006 \times PO_4 + 0.0021 \times NO_3$$

From these equations, the surface primary productivity values were computed which comes close to the average primary production of that area. It is also seen that on the west coast, phosphate concentration is found to affect the most. All these values were taken from various places at different times. Therefore, to check the validity, the equation was derived from the data of a single cruise along the west coast and it is noted that the computed values of primary production comes near to the average value only.

Similar exercise was done for eastern EEZ using the data collected in the EEZ along the east coast of India. The two equations (with observed value and other with normalized - deviation from its mean values) came out to be.

$$PP = 0.00103 \times Chl. + 0.1397 \times ZP. - 0.2813 \times T - 01154 \times S -$$

$$0.2445 \times O_2 - 0.3779 \times PO_4 - 0.9278 \times NO_3 + 30.07$$

Normalized equation :

$$PP = 0.07245 \times Chl. - 0.1321 \times ZP - 0.0292 \times T - 0.0779 \times S -$$

$$0.1725 \times O_2 - 0.2846 \times PO_4 - 0.0859 \times NO_3$$

Here also the phosphate and nitrates are found to be comparatively important factors affecting the primary production and substituting the values of independent parameters, the computed value of primary production comes close to the average value of primary production in that area.

The correlation between other parameters can also be worked out. Dalal & Bhargava (1986) worked out the relationship between surface and chlorophyll a and column primary production. Surface chlorophyll can easily be measured by remote sensing method. Hence this relationship was worked out and they derived the following equation :

$$Y = 0.549 \times 0.54 \ (r^2 = 0.64)$$

where X is chlorophyll and Y is the column primary production. This relationship was found to be statistically significant. The surface chlorophyll values can, therefore, be used for getting a fairly good estimate of column production which can be further used to estimate fishery potentials.

6. TERTIARY PRODUCTION AND FISHERY POTENTIALS

6. TERTIARY PRODUCTION AND FISHERY POTENTIALS

In the preceding chapters are given the distribution of various physical, chemical and biological parameters in the four regions separately. One of the main objectives of studying these is to characterize the waters collectively i.e. their interaction with each other and ultimately estimating the potential fishery resources of the sea.

Before arriving at the estimations of fish production, it is worthwhile to discuss the general physical conditions at sea and the inter-relationships between the various oceanographic parameters and their possible influence on the biological production.

The waters of the Indian Coast in the Exclusive Economic Zone are affected by monsoons, circulation patterns, upwelling, freshwater discharge etc. and therefore the biological production is also, directly or indirectly influenced by these factors. The seas on west and east coast of India having different characteristics, differ in nature and behaviour since they are influenced by different conditions like topography, light penetration, freshwater discharge including silt and sediments, intrusion of other waters, circulation, upwelling, monsoon etc. Towards north both the seas are landlocked. These features cause a symmetrical structure and circulation. The circulation itself changes with season and is a cause for upwelling. Also the intrusion of waters of Red Sea and Persian Gulf affects the intermediate waters of the west coast of India (Premchand et al., 1986 and Sarma *et al.*, 1986).

West Coast : During south-west monsoon period a branch of Somali current comes eastwards and causes a southerly current all along west coast of India. The eastward flow merges into clockwise gyre as confirmed by Sastry and D'Souza (1971) and Wyrtki (1971). The flow is cyclonic near Lakshadweep Islands. Though UNDP (1976) studies indicate that upwelling starts in the month of March but it appears to start with the onset of south west monsoon in May - June off the Kerala coast, intensifies in July-August and move northwards up to 15^{0}N as has been stated by many authors (Banse, 1959, 68,84; Ramamritham and Jayaraman, 1960 and Sankaranarayanan et al., 1978). However, Carruthers et al., 1959 reported upwelling north of Bombay (19^{0}N) during October and November with its possible effect surmised on lower latitude. Jayaraman and Seshappa (1957) presented evidence that upwelling in some form occurs upto as far as 18^{0}N on the basis of the study of phosphorus distribution. There are different views for causes of upwelling. *Banse* (1968) attributed upwelling to large scale upsloping on the shelf and to currents in the Arabian Sea, rejecting wind induced coastal upwelling which is also supported by *Wyrtki* (1973). The idea is similar to that put forth by Derbyshire (1967). Shetye *et al.* (1990a) suggested that during south west monsoon, the upwelling is wind generated. But with the onset of south west monsoon, a clockwise circulation sets in the Arabian Sea transporting surface waters towards south which requires replacement from below which lead to upwelling. It may be possible to state that in the absence of favourable winds, the upwelling might be due to the dynamical factors associated with southerly currents.

During the north-east monsoon, Banse (1968) indicated a change over from southward current to the northward flow in the months of October-November and due to the coolwinds from continents the nearshore surface waters cool down. Shetye (1990b) stated that the overall circulation and hydrography is characterized by down welling near the continental slope and northward flow near the surface. However the circulation and upwelling appear to influence the productivity of the area. Dehadrai & Bhargava (1972) while studying the chlorophyll distribution along central west coast of India found that chlorophyll distribution appears to be associated with the upwelling.

East Coast : In the Bay of Bengal there are reports of the presence of clockwise cells during south west monsoon period. Varadachari *et al.* (1968) reported that circulation is characterized by two anticyclone cells centered at 11^{0}N, 83^{0}E, 16^{0}N and 85^{0}E and extending south east from the region of Godavari and Krishna river mouths to 87^{0}E longitude. During this period Sewell (1932) found high salinity Arabian Sea waters into the Bay and sink gradually to subsurface. This is also indicated later by *La Fond* (1958). Upwelling is also reported during both the monsoon at different locations by *La Fond* (1954); Balaramurty, (1958) and *Poornachandra Rao* (1959). After the north east monsoon i.e. in March-April upwelling occurs in the Bay off Visakhapatnam. Colborn (1975) noticed that the surface mixed layer depth increases with onset of south west monsoon and reaches maximum (80-90m) during July - August).

During north-east monsoon Duing (1970) indicated a northerly coastal current along the east coast of India. Maslennikov (1973) reported cyclonic and anticyclonic cells in the Andaman Sea. Ramesh Babu and Sastry (1976) found that the flow consists of cells and the southward flow leaves the Andaman Sea near 10^{0}N. Channel. Wyrtki (1961) also found a drift current originating in Bay and flowing southward. Suryanarayana (1988) found that in western Bay of Bengal the fresh-water discharge influence the circulation characteristics of water in upper 50 m and below this the influence of the wind stress on circulation is evident.

These winds and current modify the productivity directly and indirectly. The upwelling brings nutrient rich but oxygen-poor and low temperature waters to the surface and is known to trigger the biological processes. It is estimated that 50% of the world fish catch comes from 0.1% of upwelling areas (Ryther, 1969). This is true for the west coast of India where maximum fish catches are obtained during or immediately after the upwelling time. The fact that about two thirds of the total annual production of sea fish in the country is obtained from the west coast obviously points to a higher productivity of the Arabian Sea when compared with that of the Bay of Bengal. But the exact reasons for this in terms of oceanographic conditions are yet to be elucidated. However, one of the reasons as conjectured by many observers is the possibility of nutrient laden deep waters coming to the surface through the influence of (a) bottom drifts striking against sub-marine ridges; (b) upwelling of waters associated with the prevailing current systems; (c) large scale turbulence caused by strong monsoon winds which pile the water against the west coast of India; and (d) coastal eddies resulting from the local wind effects. Many studies have shown, as stated earlier, that during upwelling, high values of phosphates, plankton and high organic production along west coast corroborate high fish catches on this coast. The upwelling, though, has been reported along east coast also but its impact on fisheries is not yet established.

The photosynthesis, the basis for biological production broadly depends upon :

1. The availability of sun light.

2. The availability of nutrients in euphotic zone.

While Arabian Sea and Bay of Bengal are almost located in the same geographical region with respect to equator, the sun light should be the same but it is seen that over Bay of Bengal there are more clouds and its waters are more turbid due to fresh water discharge and hence the penetration of light and the euphotic zone is reduced. Secondly the nutrient concentration is less in Bay of Bengal than Arabian Sea limiting the production. Therefore the observation that the Bay of Bengal is less productive than Arabian Sea is valid. However, from the present studies it is noticed that the rate of production on an annual basis is higher in Bay of Bengal. It is 727.38 $mgCm^{-2}d^{-1}$ in the Bay of Bengal while it is 520.43 $mgCm^{-2}d^{-1}$ in the Arabian Sea. Apparently the difference seems to be due to higher amount of seston in the Bay of Bengal. Similarly the production rate (497.67 $mgCm^{-2}d^{-1}$) in Andaman and Nicobar Sea is comparable to that in the Arabian Sea waters. But since the area of EEZ is Bay of Bengal and Andaman & Nicobar Sea is much less that of Arabian Sea, the ultimate production becomes less. However, around Lakshadweep Island, even the productivity rate is much lower being 216.26 $mgCm^{-2}d^{-1}$ than at any other area in Indian EEZ. The Table 15 shows the productivity rates in the different months in all the four areas. The months of February to May are most productive while October to January months are least productive in the eastern EEZ. Otherwise, the rates of primary production are very well comparable in all the months.

In this regard Ryther *et al.* (1967) have also explained, as below, the influence of river water upon the primary productivity through the effect of any of the following parameters :

A. Nutrient species : If the plant nutrients are in higher concentration in the river waters than in the sea, stimulation of plant growth occur. If such substances are present in lower levels in river as compared to ocean water; the mixed water will yield smaller plant population. Further, river borne suspended loads may remove nutrient species from the waters to which they are introduced and hence limit plant activity.

B. Light intensity : Particular species or coloured dissolved substances can diminish the light intensity and hence the depth of the euphotic zone.

C. Stability of photic zone : The formation of a low density surface layer increases the stability of water column. As a result, phytoplankton population can attain higher levels by a reduction of the probability that plants are carried below the critical depth for photosynthetic activity by turbulence.

These above factors have a great impact in the EEZ along east coast where a large amount of fresh water enters the sea and influences the productivity.

The analysis is made here in order to find out the potentials of living resources in the sea so that maximum benefit is taken with perhaps minimum of efforts and expenditure. However, it is very difficult to estimate the potential yield in the sea since so many factors and phenomena are operating at the same time and also sea is an ever changing environment. There are many pathways and loops for energy transfer and different authors have tried to calculate by different methods.

It may be noted that primary production measured by all these methods does not take into account the production by nanno and pico plankton and also by bacteria. Studies indicate that nannoplankton may be responsible upto 90% of primary production in neritic waters of Goa (Pant et al., 1976) while in estuaries of Goa it may be upto 85 percent (Bhargava *et al.*, 1977). The primary production is therefore marginally underestimated which may also result in underestimation of tertiary production. The best approach in these circumstances is to use as many methods as possible to infer the living resources and then to conclude which is logically more convincing and appropriate.

In this studies the primary and secondary production are utilized to arrive at the tertiary production in terms of standing stock from which potential yield is determined. The average of the two estimations can be regarded as the potential yield.

From Primary production : The average primary production in different sectors and in various seasons have been discussed and given in earlier chapter. This is food of fishes and also of zooplankton which in turn is again the food of carnivorous fishes. The values of primary and secondary production in terms of carbon has to be converted into live weight. This is also true in case of estimations by zooplankton.

Here, carbon values are multiplied by a factor of 10 to convert into live weight. This factor has been derived from data published by Omori (1969) and Childress & Nygaard (1973) and Childress (1977). The former two authors gave a range of 35-68% of carbon (Ashfree dry weight) while Childress (1977) estimated the water content in fishes and crustacean to be about 80% . From these values, the conversion factor ranges between 8 and 14, and hence a factor of 10 is taken which seems to be very reasonable. Qasim, (1977) has also used this conversion factor. From the value of primary productivity the tertiary production and fish yield have been estimated by the following four methods (Table 15).

Method A : Cushing (1975) considered 1% of the primary production as tertiary production in terms of carbon which is then converted into live weight by multiplying by a factor of 10. This method gives a production of 4.61, 6.14 and 2.49 x 10^6 tonnes in pre-monsoon, monsoon and post-monsoon respectively along west coast of India. The maximum production, however, is during monsoon. In Lakshadweep Sea, the maximum (0.93 x 10^6 tonnes) is during pre-monsoon followed by 0.45 x 10^6 tonnes in monsoon and 0.43 tonnes in post-monsoon. Along east coast the total annual estimate is 13.59 x 10^6 tonnes, of this 8.6 x 10^6 tonnes during February to May; 4.82 x 10^6 tonnes during June - September and the rest 0.16 x 10^6 tonnes during October - January months. Around Andaman Sea, again the production is estimated to be higher during south west monsoon months followed by pre and post monsoon. However, these figures seems to be too high and there is remote possibility of achieving this figure and therefore considered non-viable.

Method B : In this calculations,0.1% is taken as more realistic factor (Qasim, 1977) to calculate the carbon production at tertiary level and then converting in... live weight by using a factor of 10. This estimation gives along west coast a total of 1.32 x 10^6 tonnes of live weight in a year. When split up, it gives 0.46 x 10^6 tonnes in pre-monsoon; 0.61 x 10^6 tonnes during south west monsoon and 0.25 x 10^6 tonnes in post-monsoon. Around Lakshadweep, the respective figures are 0.09; 0.05 and 0.04 x 10^6 tonnes with an annual estimate of 0.18 x 10^6 tonnes. The east coast figures are slightly higher

TABLE - 15: ESTIMATES OF TERTIARY PRODUCTION & POTENTIAL YIELD

EEZ Region	Area in km x 10^6	Season	Av. Pr. production $mgCm^{-2}d^{-1}$	Carbon production	Method 'A'	Method 'B'	Method 'C'	Method 'D'	Average of B+C+D	Average Zooplankton Biomass mlm^{-3}	Carbon production	Tertiary production	Total potential average of 10 + 13	Total annual pelagic potential	Total demersal potential	Total annual potential	Average present catch
			From Primary Production	⟨------ tonnes x 10^6 ------⟩						From Secondary Production	⟨------ tonnes x 10^6 ------⟩						
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
West Coast (Arabian Sea)		Pre.mon	550.63	46.14	4.61	1.46	0.5[illegible]	0.64	0.56	0.77	1.67	0.42	0.49				
	0.698	Monsoon	720.94	61.42	6.14	1.61	0.7[illegible]	0.84	0.74	0.56	1.23	0.31	0.52	1.29	0.75	2.04	1.131
		Post.mon	289.74	24.89	2.49	1.25	0.3[illegible]	0.34	0.30	0.46	1.01	0.25	0.28				
Around Lakshadweep Islands		Pre.mon	335.09	9.25	0.93	1.09	0.1[illegible]	0.1[illegible]	0.11	0.15	0.11	0.03	0.07				
	0.023	Monsoon	161.46	4.53	0.45	1.05	0.0[illegible]	0.06	0.05	0.11	0.08	0.02	0.04	0.15	*	0.15*	.089
		Post.mon	152.23	4.31	0.43	1.04	0.0[illegible]	0.06	0.05	0.13	0.10	0.02	0.04				
East Coast (Bay of Bengal)		Pre.mon	1391.46	86.07	8.61	1.86	1.0[illegible]	1.13	1.04	0.43	0.69	0.17	0.61				
	0.516	Monsoon	765.90	48.17	4.82	1.48	0.6[illegible]	0.66	0.58	0.24	0.38	0.10	0.34	1.16	0.33	1.49	0.524
		Post.mon	24.80	1.57	0.16	1.02	0.0[illegible]	0.0[illegible]	0.02	0.99	1.62	0.41	0.21				
Around Andaman & Nicobar Islands		Pre-mon	465.60	31.65	3.17	1.32	0.4[illegible]	0.44	0.38	0.12	0.21	0.05	0.22				
	0.567	Monsoon	486.73	40.55	4.06	1.41	0.5[illegible]	0.56	0.48	-	-	-	0.48	0.92	*	0.92*	0.006
		Post.mon	440.68	30.71	3.07	1.31	0.3[illegible]	0.42	0.37	0.17	0.31	0.08	0.22				

* The figures for these two seas do not include the demersal resources which together comes to 0.12 million tonnes. The total, therefore, for column 17 comes to 4.72 x 10^6 tonnes.

showing a total annual estimate as 1.36×10^6 tonnes. The highest is during the months of February - May being 0.86×10^6 tonnes followed by monsoon (June to September) and very little (0.02×10^6 tonnes) during October - January months. In neighbouring area of Andaman, the annual estimate comes to be 1.04×10^6 tonnes with a breakup figure of 0.32, 0.41 and 0.31×10^6 tonnes in the three seasons respectively.

Method C : The tertiary production has been calculated by multiplying primary production by yield ratio which is 0.005 for the Indian Ocean (Nair, 1970 and Prasad *et al.*, 1970). This gives carbon production which is converted into live weight of which 25% can be taken as exploitable yield. By using this method the tertiary production calculated is given in Table 15. Since the basic rate of primary production is same, the trend, too, in different regions and in various seasons is the same. The tertiary production is maximum along east coast followed along west coast, Andaman Sea and Lakshadweep Sea. The annual potential figures being $1.656 \times 10,^6$ $0.225 \times 10,^6$ 1.698×10^6 and 1.280×10^6 tonnes along west coast, Lakshadweep, east coast and Andaman Sea respectively. The higher production is during June - September along west coast and during February - May along east coast. In Andaman Sea also the maximum production is found to be in the months of June to September while in Lakshadweep Sea it is during February to May.

MethodD:In this method the primary production is equally divided into two viz. first and second stages carnivores. 1% of first stage and 0.1% of second stage will give the total standing stock of which 25% is taken as sustainable yield. The method has been used by Qasim (1977). This calculation gives slightly higher tertiary production but still comparable. The annual and seasonal production calculated by this method is given in the Table 14. The trend is same and the calculated figures are 1.82×10^6; 0.248×10^6; 1.859×10^6 and 1.415×10^6 tonnes in the EEZ of west coast, Lakshadweep, east coast and Andaman Sea respectively.

From the perusal of the results by four different calculations, it is observed that the Method A gave an unusually high figure, even if we take 25% as the harvestable stock, it would give a very high estimate (9.7 million tonnes) of fishery potential in the entire EEZ which is very difficult to achieve and therefore has not been considered in estimating the fishery potential. As far as other three methods are concerned, the values seems to be comparable and feasible targets. Since different authors have used these various methods and we are taking a generalized picture, it would be quite reasonable if an average of all the three values are taken. The average values as calculated by three calculations (B+C+D) are given in the Table 15.

From Secondary production :

The tertiary production and the potential yield can also be calculated from secondary production as stated earlier. The basic value of zooplankton in mlm^{-3} has to be first converted into organic carbon to find the energy available through zooplankton. It is therefore necessary to know the organic carbon content of zooplankton. For Indian water, it is found that one ml of displacement volume of zooplankton has a dry weight of 75.4 mg and this contains 34.2 percent of organic carbon (Madhupratap *et al.*, 1981). From these studies, a factor of 0.025 is arrived to convert ml into a mg of organic carbon in Indian water while Cushing (1971) obtained a factor of 0.065 from cold waters. This also indicates that organic carbon in tropical zooplankton is less than half from those of temperate waters.

However, here the only factor available from Indian waters is taken for calculating the organic carbon. Ten percent of this production is considered as tertia., production which is then converted into live weight by multiplying by a factor of 10 as explained earlier. Now whole of live weight is not exploitable and for this, Moiseev (1971) has given a wide range of 5 to 50% as exploitable. For coastal waters, 25% can be taken as exploitable yield as also used by Qasim (1977). Based on these calculations, the tertiary production and the exploitable potential yield from secondary production is given in Table 15. A look at the table will show that the total yield from west coast is 0.98×10^6 tonnes a year. Out of this, a highest of 0.42×10^6 is available in pre-monsoon followed by 0.31×10^6 in monsoon and 0.25×10^6 in post-monsoon. In the EEZ around Lakshadweep Island, while the total estimated yield is 0.07×10^6 tonnes the seasonal estimate is given as 0.03, 0.02 and 0.02 million tonnes in pre-monsoon, monsoon and post-monsoon respectively. This is the minimum among the four regions. Along the east coast the maximum is during October - January (post south west monsoon) followed during February to May and minimum is during the months of June to September. The total yield is 0.67 million tonnes. In Andaman Sea, the data for the months of June to September are not available. In other months a higher value of 0.08 million tonnes is estimated during October to January (post south west monsoon) and 0.05 million tonnes during February to May i.e. south west monsoon.

Total Pelagic Resources :

In the foregoing account, the potential yield has been calculated from primary and secondary production and given in columns 10 and 13 of the Table 15. The two estimates differ and for a generalized picture, an average of the two is taken as the potential yield. This is given in column 14 of the same table.

This shows that along west coast the maximum of 0.52×10^6 tonnes is expected during south west monsoon, then an amount of 0.49×10^6 is in pre-monsoon and minimum during post monsoon. The total annual yield is calculated to be 1.29 million tonnes. The Indian marine catch along west coast is mostly during October to February/March i.e. in post-monsoon and few months of pre- monsoon. Therefore, it can be inferred that more than the present catch can be had during monsoon months also or otherwise from April to September. Unfortunately during these months due to weather conditions it is not possible to go for fishing and we lose the catch.

Around Lakshadweep Island the annual potential yield comes to be 0.15 million tonnes with a seasonal figure of 0.07, 0.04 and 0.04 million tonnes for pre-monsoon, monsoon and post-monsoon respectively. In this region the maximum is estimated during the months of February to May.

Along east coast, while the total annual yield is estimated to be 1.16 million tonnes, a maximum of 0.61 is during the months of February to May which is post north east monsoon. This is followed by south west monsoon months and minimum (0.21 m tonnes) during the months of October to January.

The EEZ around Andaman and Nicobar Islands, can sustain potential yield of 0.92 million tonnes a year. In the months of pre and post south west monsoon the yield is estimated at 0.22 m tonnes while during June to September it is shown as 0.48 m tonnes. This seems to be on higher side probably because of only few values of primary production which are quite high. Zooplankton data was not available.

Taking into consideration, the total potentials for the entire EEZ of India are estimated to be 1.29 + 0.15 + 1.16 + 0.92 = 3.52 million tonnes per year.

Demersal Resources :

Besides the pelagic resources, the benthic or the demersal fishery also provides a considerable catch in the form of prawns, crabs, mussels etc. Therefore, the benthos also forms an important pathway for energy transfer. Though the major source of food at bottom comes from primary and secondary production from pelagic areas, there are other energy pathways at the bottom itself such as sediments, debris, dead fauna, microbial cycle etc. It cannot be said with certainty how much is contributed by pelagic sources and how much by bottom environment. Therefore, it is preferred to include the demersal estimate in the total fish potential. For demersal estimates many authors have given the data, but the latest one is made by Parulekar *et al.* (1982), who has given an estimation of 1.2 million tonnes for the shelf area. This estimate is based on more than 1100 samples from the Arabian Sea, Bay of Bengal and Andaman Sea. This is the only figure available and seems to be reasonable too, therefore considered here.

The total fish potential from the entire EEZ of India, therefore, comes to 3.52 + 1.2 = 4.72 million tonnes. These estimates have been made on the data available for EEZ only. However, earlier authors have given estimates for the Indian Ocean and 46% of it comes from Indian waters (Qasim, 1985). The yield from Indian EEZ has been calculated from their estimates and compared with the present estimated yield in the following table : --

Source (Ref.)	Estimates for Indian Ocean	Estimates for Indian EEZ (46% of Col. 2)
	Figures in million tonnes	
1	2	3
Moiseev (1971)	7.8	3.59
Gulland (1971)	14.25	6.55
Prasad (1970)	11.00	5.06
Prasad *et al.* (1973)	10.00	4.60
Qasim (1977)	16.00	7.36
Nair & Gopinathan (1981)	-	5.5
Present works	-	4.72

The estimates made in this present work (4.72) compares very well with that calculated with figures reported by Prasad and Nair, 1973 (4.6 million tonnes). If the demersal catch is not included as one may object, the present estimate of 3.52 mt is almost similar to that given by Moiseev (1971). But inspite of adding the demersal catch, it is felt that the estimate is conservative but realistic and therefore such a target is achievable.

Present Indian Catch :

The Indian marine fish catch for the past ten years has been fluctuating from 1.427 to 1.779 million tonnes as shown below :

1977	-	1.448	1983	-	1.519
1978	-	1.489	1984	-	1.779
1979	-	1.491	1985	-	1.734
1980	-	1.554	1986	-	1.720
1981	-	1.444	1987	-	1.648
1982	-	1.427	1988	-	1.77

The average, therefore, comes to about 1.6 million tonnes a year, while the average for different areas is as follows :

West Coast	-	1.132	million	tonnes
East Coast	-	0.524	"	"
Andaman & Nicobar Island	-	0.009	"	"
Around Lakshadweep Island	-	0.006	"	"

From the above figures and those in Table 15 it can be inferred that -

1. Along west coast the average catch is 1.13 m tonnes while estimated potential is 2.04 m tonnes and therefore the catch can be increased by about a million tonnes. However, most of the catch comes during the months from October to February, there is scope to increase the catch during other months particularly during monsoon. But unfortunately, it is very difficult to go for fishing because of turbulent conditions at sea otherwise we may perhaps reach not only the estimated potential but cross it.

2. Around Lakshadweep Islands the average catch at present is only 6417 tonnes while estimated is 15,000 tonnes. The catch can therefore be increased by more than twice of the present catch.

3. In the EEZ along east coast the present average catch is 0.524 million tonnes and the potential comes to be 1.49 m tonnes. In this region, therefore, the catch can be tripled. There is tremendous scope when compared to the west coast of India.

4. Around Andaman and Nicobar Islands, the catch, at present, is about 6400 tonnes while the potentials are much higher i.e. 0.92×10^6 tonnes. This seems to be quite high because of higher primary production particularly in SW months and being no data available for secondary production. Even if we omit this value the potential comes to 0.22×10^6 tonnes and there is tremendous scope to increase the catch. Combining the observations for all the four regions, the estimated potential comes to 4.72×10^6 tonnes a year while the average Indian catch is about 1.6×10^6 tonnes. It shows that the catch can be increased by 2 to 3 times of the present one provided the fishing efforts are increased particularly along east coast. Perhaps some may not agree to include the benthic potential as explained earlier, even than the estimated potential is 3.52×10^6 tonnes and certainly the fish catch can be easily doubled.

7. SUMMARY AND CONCLUSIONS

7. SUMMARY/CONCLUSIONS

Based on the study and analysis of data the conclusions drawn are summarised below :

1. India along its coastline of 7517 kms has an Exclusive Economic Zone measuring about 2.01 million square kilometer.

2. No direct estimates based exclusively on EEZ data for the fishery potential for the EEZ of India have been made while the potentials for the Indian Ocean have been given varying from 7.8 to 16 million tonnes.

3. The entire EEZ has been divided into four regions viz. along west coast, east coast around Lakshadweep and Andaman Islands, the area of which are 0.698, 0.576, 0.23 and 0.566 million square kilometers respectively.

4. The study is based on the data collected during 220 cruises spread over more than 20 years in different seasons. The data were collected onboard ships like *Darshak, Gaveshani,* and *Sagar Kanya* and those participated in IIOE, from 1364 stations in the EEZ.

5. Study has been made and maps prepared to show the coverage of study and existing gaps. The area is divided into 249 one degree squares, out of which a total of fifteen squares have not been covered in any season: eleven in Andaman Sea, one along east coast and 3 on west coast. These should be covered and observations made.

6. The euphotic zone or the light penetrating depth varies from 14m in nearshore waters to 90m in clear waters of Lakshadweep. In offshore waters it generally varies between 40 and 60m.

7. Temperature along west coast varies between 21.7 and 39.2°C with minimum variation in monsoon and maximum temperature during April to May. In Lakshadweep waters the average temperature is slightly higher. Mixed layer depth was found between 50 and 60 m. Temperature increases away from the coast. Along east coast, the temperature varies between 20 to 30°C and it

decreases away from the coast. In Andaman Sea the maximum temperature further rises to $31^{0}C$ and the mixed layer depth lies at 75-80 m on western side. The isolines show temperatures to increase from north to south along west coast at surface.

8. The salinity at three depths are given. Generally, the salinity in all the seasons is higher along west coast than that on east coast. An unexpected low salinity of 21.7×10^{-3} was noticed in pre-monsoon along west coast. The average salinity values increases slightly with depth.

9. The O_2 concentration decreases with the depth at all the places. The lowest values were noticed during pre-monsoon. The maximum reached upto 8.5 mll^{-1} along west coast during monsoon months. the isolines show the O_2 concentration ranging between 4 and 5 mll^{-1} with few pockets of values higher than 5 mll^{-1}. There is a sharp decline at 100 m along west and east coasts.

10. The phosphate concentration shows an increasing trend with depth. High concentration exists off Bombay and Goa on west coast and off Calcutta and between Madras and Visakhapatnam along east coast. There is high concentration at 100 m depth in entire area of study. Andaman waters are poor in phosphate.

11. The nitrate values also increase from 0 to 100 m depth in almost all areas but they decrease away from coast. The highest value of 4.74 ug-atl^{-1} reached during pre-monsoon along west coast. The concentration at 100 m depth was unusually high particularly along west coast and in Andaman waters.

12. The chlorophyll a at surface in the entire EEZ ranged between 0.017 and 7.16 mgm^{-3}. The west coast showed higher values and averages than the east coast during all the seasons. Minimum values were found to be in Andaman and Lakshadweep Seas except few unusually high values in pre- monsoon in the later which increased the average to 0.438 mgm^{-3}.

13. The average chlorophyll a concentration in entire EEZ was 11.81 mgm^{-2}. It was high during pre-monsoon in west coast where the average was 18.075 mgm^{-2} with a range of 0.16 to 92.85 mgm^{-2}. The annual average was highest

(13.37 mgm^{-2}) along west coast followed by east coast (13.01 mgm^{-2}). The waters of two islands do not differ much in column chlorophyll.

14. The annual pattern indicates higher concentration of chlorophyll a off Gujarat, Bombay and Trivandrum on west coast and off Visakhapatnam and whole Orissa along east coast. There was a small patch of high concentration of about 15 mgm^{-2} near Lakshadweep Sea.

15. The surface primary production in the entire EEZ was highest (43.07 $mgCm^{-3}d^{-1}$) during monsoon followed by pre-monsoon and post monsoon (12.78 and 9.51 $mgCm^{-3}d^{-1}$) respectively. Areawise, it was highest along the east coast followed by west coast, Andaman Sea and Lakshadweep Sea.

16. The values of column primary production were also highest along the east coast (682.16 $mgCm^{-2}d^{-1}$) in monsoon followed by post-monsoon and pre-monsoon (291.56 and 72.32 $mgCm^{-3}d^{-1}$) respectively. The high production in monsoon results in higher fish catches in post-monsoon. If we look region wise, again the east coast tops with 1081.06 $mgCm^{-2}d^{-1}$ followed by west coast (490.94), Andaman Sea (470.74) and Lakshadweep Sea (236.29 $mgCm^{-2}d^{-1}$).

17. The rate of primary production is higher along the east coast than that of west coast except during post-monsoon months. But the area of EEZ is much less on east coast hence the potential estimates are less.

18. Seasonwise pre-monsoon was the best along the west coast and post-monsoon was the best along east coast. Overall picture shows biomass decreases towards outer boundary of EEZ along west coast.

19. The annual zooplankton biomass was found to be the highest (0.59 mlm^{-3}) along the west coast followed by the east coast (0.31 mlm^{-3}), Lakshadweep and Andaman Seas with an almost identical value (0.12 mlm^{-3}).

20. A correlation matrix among various parameters show that primary production has positive correlation only with chlorophyll *a*, zooplankton and nitrate concentration. Using multiregression analysis two equations are derived to

compute the primary production from seven other parameters. The computed values were found to be close to the average value of primary production.

21. The benthic studies show that shelf region upto 200 m depth supports highest standing crop ranging from 14.1 to 1.8 gmm^{-2}. The maximum density (10 20 gmm^{-2}) is seen north of Cochin and southern tip of mainland. This corroborates high fishery production (prawns) off Cochin. At other places it varies between 1 and 10 gmm^{-2}. The biomass also decreases towards offshore. The annual demersal yield is known to be 1.2 million tonnes. Out of this 0.75 m tonnes is estimated to be from the west coast and 0.33 m tonnes from the eastern EEZ.

22. The fishery potential from primary and secondary production has been estimated for each season in every region of the EEZ. The highest pelagic potential is calculated to be 0.52×10^6 tonnes during monsoon on the west coast while on the east coast it is during pre-monsoon months so also in Andaman and Nicobar Seas.

23. The total annual pelagic potential has been estimated as 1.29×10^6 and 1.16×10^6 tonnes along the west coast and the east coast respectively. Around Andaman Island the waters can sustain 0.92×10^6 tonnes while that of Lakshadweep Sea the least (0.15×10^6 tonnes).

24. The total annual estimated yield, taking into consideration the pelagic and the demersal resources, therefore, comes to 2.04; 0.15; 1.49 and 0.92 million tonnes along the west coast, Lakshadweep, east coast and Andaman Sea plus a combined total of 0.12 mt of demersal resources for areas of Lakshadweep and Andaman Seas not included in respective areas since separate figures are not available. This brings the estimate to a total of 4.72 million tonnes.

25. The present annual catch on an average is 1.6 million tonnes while the potential as estimated is 4.72 million tonnes per year. Therefore the marine catch from Indian EEZ could be stepped upto three times. The areawise figures are :

Area	Present catch	Estimated potential
	(million tonnes)	
West Coast	1.13	2.04
Lakshadweep Sea	0.009	0.15
East Coast	0.524	1.49
Andaman Sea	0.006	0.92
-	-	0.12*

* This is a combined total of demersal resources for areas of Lakshadweep and Andaman Seas.

It is observed that there is maximum scope for increasing the fish catch in the waters around Andaman and Lakshadweep Islands. Along the east coast it can be increased by almost three times while along the west coast it can be atleast doubled. This requires integrated approach efforts and infrastructure facilities.

26. The Indian catch particularly along west coast is seasonal and mostly restricted between October and March but other months too have shown a good potential therefore fishing efforts should be increased all the year round to augment the production.

27. More efforts are needed particularly along east coast and around Andaman Islands to increase the fish catch of these areas.

28. These are conservative estimates since the production through nanno-and pico-plankton is not included, and the actual production may therefore vary.

29. It is suggested that the relationship between surface chlorophyll a and column primary production should be further authenticated so as to estimate the column production from surface chlorophyll values to avoid long and tedious process of estimating column production by conventional methods.

30. It is also suggested that more direct estimates based on acoustic and experimental fishing surveys are also made for better prediction.

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ANNEXURE - I

List of papers published by the candidate

ANNEXURE - I

LIST OF PUBLICATIONS

Scientific Papers

1. 1971 Bhargava, R.M.S. The fecundity of *Heteropnuestes fossils* (Bloch). *J. Bombay Natural Hist. Soc.*, **73:** 583-588.

2. 1972 Dehadrai, P. V. and R.M.S. Bhargava. Seasonal organic Mandovi and Zuari estuaries, Goa. *Indian Jour. mar. Sci.*, **1:** 52-56.

3. 1972 Dehadrai, P. V. and R.M.S. Bhargava. Distribution of chlorophyll, carotenoids and phytoplankton in relation to certain environmental features along the central west coast of India. *Mar. Biol.*, **17:** 30-37.

4. 1972 Ramamurthy, V. D., R. A. Selvakumar and R.M.S. Bhargava. Studies on the blooms of *Trichodesmium erythraeum* (Ehr.) in the waters of central west coast of India. *Curr. Sci.*, **41:** 803-805.

5. 1973 Bhatt, V.S. and R.M.S. Bhargava. Studies on eggs and larvae of the Garfish *Tylosurus crocodilus* (Le sueur). *Indian Jour. mar. Sci.*, **2:** 127-132.

6. 1973 Bhargava, R.M.S., R.A. Selvakumar and S.Y.S. Singbal. Hydrobiology of surface waters along Panaji-Bombay Coast. *Indian Jour. mar. Sci.*, **2**: 103-107.

7. 1973 Bhargava, R.M.S. Diurnal variation in phytoplankton pigments of Mandovi estuary, Goa. *Indian Jour. mar. Sci.*, **2**: 27-31.

8. 1974 Dwivedi, S.N., R.M.S. Bhargava, A.H. Parulekar, R.A. Selvakumar, S.Y.S. Singbal and V.N. Sankaranarayanan. Ecology and environmental monitoring of Mandovi, Zuari and Cumbarjua canal complex during monsoon months. *Jour. Indian Fish. Assoc.*, **3 & 4:** 113-130.

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11. 1975 Dwivedi, S.N., R.M.S. Bhargava and A.G. Untawale. Marine living resources and ecosystems along the west coast of India. *Proc. 3rd International Ocean Development Conference*, Tokyo, Japan: 31-41.

12. 1976 Bhargava, R.M.S. and S.N. Dwivedi. Seasonal distribution of phytoplankton pigments in the estuarine system of Goa, *Indian Jour. mar. Sci.*, **5:** 87-90.

13. 1976 Pant, A., R.M.S. Bhargava and S.C. Goswami. Nanno-plankton, total phytoplankton and zooplankton standing stock measurements in Goa waters. *Indian Jour. mar. Sci.*, **5:** 103-106.

14. 1976 Bhattathiri, P. M. A., V. P. Devassy and R.M.S.Bhargava. Production at different trophic levels in the estuarine system of Goa. *Indian Jour. mar. Sci.*, 5: 83-86.

15. 1977 Bhargava, R. M. S., P.M.A. Bhattathiri and V.P. Devassy. Relative contribution of nannoplankton to the primary production to two estuaries of Goa. *Mahasagar - Bull. natn. Inst. Oceanogr.*, **10:** 61-66.

16. 1978 Radhakrishna, K., V.P. Devassy, P.M.A. Bhattathiri and R.M.S. Bhargava. Primary productivity in the north eastern Arabian Sea. *Indian. Jour. mar. Sci.*, 7: 137-139.

17. 1978 Bhargava, R.M.S., P.M.A. Bhattathiri, V.P. Devassy and K. Radhakrishna. Productivity studies in the south eastern Arabian Sea. *Indian Jour. mar. Sci.*, **7:** 267-270.

18. 1978 Radhakrishna, K., V.P. Devassy, R.M.S. Bhargava and P.M.A. Bhattathiri. Primary production in the northern Arabian Sea. *Indian Jour. mar. Sci.*, **7:** 271- 275.

19. 1978 Devassy, V.P. and R.M.S. Bhargava. Diel changes in phytoplankton population in Mandovi and Zuari estuaries of Goa. *Mahasagar - Bull. natn. Inst.Oceanogr.*, **11:** 195-199.

20. 1980 Abidi, S.A.H., V.S. Bhatt and R.M.S. Bhargava. Hydrographic conditions of Mafia Channel (Tanzania) along the East African Coast. *Jour. Ind. Fish. Assoc.:* 123-130.

21. 1981 Bhargava, R.M.S., Avinash Chandra and R.K. Sharma. Data and Information : Present and Future. Theme paper presented in the workshop on Ocean Futures held at Goa, March, 1981.

22. 1981 Bhargava, R.M.S. and J.S. Sarupria. Ocean Data Management - Theme paper presented in the workshop on Indian Ocean Data Management held at Goa from 17-19 October, 1981.

23. 1981 Bhargava, R.M.S. Oceanographic Data & Information. Its importance and management. *Science and Culture,* **49(1):** 5-8.

24. 1981 Bhargava, R. Ocean Future - *Indian Review of Management and Future*, 4(80) and **1(81):** VII-VIII.

25. 1986 Dalal, S.G. and R.M.S. Bhargava. Relationship between surface chlorophyll and primary production. *Mahasagar - Bull. natn. Inst. Oceanogr.*, **19(1):** 61-64.

26. 1988 Desai, B.N., R.M.S. Bhargava, J.S. Sarupria and T. Pankajakshan. Oceanographic coverage of Andaman and Nicobar Sea. In: *Island Development, Technology* Option_Eds. S.N. Dwivedi & Pradeep Chaturvedi. Pub. Indian Assoc. for the Advancement of Science, New Delhi.

27. 1989 Desai, B.N., R.M.S. Bhargava, J.S. Sarupria and G.V.Reddy. Present status of oceanographic studies and characteristics of the Exclusive Economic Zone of India. *Proc. EEZ Resources : Technology Assessment Conference*, Jan. 22-26, 1989, Honolulu, Hawaii, Pub. International Ocean Technology Congress.

28. 1990 Bhargava, R.M.S. and J.S. Sarupria. Data bases and management in Oceanography. In *Current Trends in Coastal Marine Sciences*. Eds. S. Ramachandran and S. Rajagopal. Ocean Data Centre, Anna University, Madras: 24-35.

29. 1990 Desai, B.N., R.M.S. Bhargava and J.S. Sarupria. Biological productivity and estimates of fishery potentials of the EEZ of India. In *Current Trends in Coastal Marine Sciences*. Eds. S. Ramachandran and S. Rajagopal. Pub. Ocean Data Centre, Anna University, Madras: 52-67.

30. 1990 Kunte, P.D. and R.M.S. Bhargava. Role of LAN in oceanographic information management - A case study of N.I.O. Presented at IX Convention & Conference of Society of Information Science held at Goa.

31. 1990 Sarupria, J.S. and R.M.S. Bhargava. New technological trends for the management of oceanographic data & information. Presented at Co-data Conference at Pune,5-7, Feb. 1990.

32. 1990 Desai, B.N., R.M.S. Bhargava and J.S. Sarupria. Estimates of fishery potentials of the EEZ of India. *Estuarine, Coastal and Shelf Science.* (In Press)

Data Products :

1. 1989 Sarupria, J.S., G.V. Reddy and R.M.S. Bhargava. Nansen Cast Data Report - R.V. Gaveshani (1976-85), INODC, NIO.

2. 1989 Ghosh, Aravind., T. Pankajakshan and R.M.S. Bhargava. Atlas of Mechanical Bathythermograph Data, INODC, NIO.

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4. 1989 Pankajakshan, T., K. Aravind Ghosh, J.S. Sarupria, G.V. Reddy and R.M.S. Bhargava. Bathythermograph Data Report, Vol. 2 - ORV Sagar Kanya (1983-86), INODC, Goa.

5. 1990 Reddy, G.V., J.S. Sarupria and R.M.S. Bhargava. Nansen Cast Data Report - R.V. Gaveshani (1981-85), Ref. 1308, INODC, NIO.

6. 1990 Reddy, G.V., J.S. Sarupria and R.M.S. Bhargava. Nansen Cast Data Report - ORV Sagar Kanya (1985-88), Ref. 1311, INODC, NIO.

Book Reviews :

1. 1974 Review on 'Proceedings of the symposium on Living Resources of the seas around India', CMFRI, Cochin, India, 1973. *Mahasagar - Bull. natn. Inst. Oceanogr.* **7:** 132-133.

2. 1980 'Coasts and Estuaries' by R. Barnes. *Mahasagar -Bull. natn. Inst. Oceanogr.,* **13:** 81-82.

3. 1980 Development in Deep-Sea Biology by N.B. Marshal. *Mahasagar - Bull. natn. Inst. Oceanogr.,* **13:** 385-86 (with Dr. S.Z. Qasim).

4. 1984 Marine Fisheries by D.V. Bal and K. Virabhadra Rao. *Mahasagar - Bull. natn. Inst. Oceanogr.,* **17:** 243-244.

ANNEXURE - II

Reprints of relevant papers of the candidate

Marine Biology 17, 30—37 (1972)

Distribution of Chlorophyll, Carotenoids and Phytoplankton in Relation to Certain Environmental Factors along the Central West Coast of India

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Abstract

Distribution of chlorophyll pigments, carotenoids and abundance of phytoplankton in relation to certain environmental factors of the nearshore waters off the central west coast of India (latitudes 15°30′ to 18°50′N) were studied monthly at 7 stations during 1970/1971. Changes in the hydrographical factors and the biological processes occurring in the region during different months appear to be influenced by the pattern of upwelling along the northern and southern parts of the west coast of India. The pigment concentration shows a marked decrease in October, but is followed by a slow but steady rise, which reaches its maximum in April/May. A slightly smaller maximum is noticed in December/January. The composition of various chlorophyll pigments and carotenoids indicated the physiological state of phytoplankton populations during different months in the region investigated. Abundance of specific phytoplanktonic elements, consisting mainly of diatoms, in space and time, characterises the waters of the central west coast of India, indicating a clear succession of species.

Introduction

Marine fish landings from the Arabian Sea along the west coast of India account for nearly 75% of the total sea food production of the country. Along this coastline, the strip between Quilon in the south and Ratnagiri in the north yields the bulk of the catch, which has been tentatively explained on the basis of the nutrient distribution pattern associated with the occurrence of seasonal upwelling (Panikkar and Jayaraman, 1966).

The upwelling is reported to be prevalent along the west coast of India between latitudes 7° and 16 °N during July to early October (Banse, 1959). On the other hand, in the region north of Bombay, the upwelling has been reported during October, November (Jayaraman and Gogate, 1957; Carruthers et al., 1959). Occurrence of this phenomenon along the west coast of India would have a profound influence on the biological processes in the area. Gradual movement of mackerel shoals pursuing food from the Malabar coast in the south to Ratnagiri in the north, varies exponentially with time from September onwards (Selvakumar, 1970); this indicates the dynamic nature of biological production along the central west coast.

Observations on seasonal distribution of chlorophyll pigments, carotenoids, and abundance of phytoplankton, in relation to certain environmental factors in these waters, help in understanding, to some extent, the trend of biological processes occurring in the region.

The present study forms part of the program sponsored by the National Institute of Oceanography, India on the central west coast of India in which, besides the authors, Dr. A. B. Wagh and Shri R. A. Selvakumar participated and undertook zooplankton studies. Detailed aspects of hydrography, distribution of zooplankton and their biomass will be published separately.

Material and Methods

During 1970/1971, monthly observations were conducted to study certain environmental factors, phytoplankton abundance, and chlorophyll distribution along the central west coast of India on board a passenger ship sailing between Panaji (Goa) and Bombay. Due to cessation of steamer services during the south-west monsoon, the cruises were possible only from September to May.

The sampling program included observations once a month at 7 coastal stations where the passenger ships had their regular stops (Fig. 1). The depth of the water at the sampling stations near all the ports touched by the ships varied between 4 and 6 m. Precautions against churning and other disturbances were taken, and sampling at all the stations was carried out during day time. The area and actual time of sampling at each station remained about the same throughout the period of observations.

In reporting the observations, 7 ports from south to north between Panaji and Bombay have been discussed in series, i.e., Vengurla, Malvan, Deogad, Vijaydurg, Harnai, Sriwardhan and Janjira, which are coastal areas; the observation points lie approximately within 1 km from the shore.

Surface water samples were collected by a heavy plastic bucket. Temperature was immediately noted. Dissolved oxygen was determined by Winkler's method on board ship, whereas salinity was determined in the laboratory.

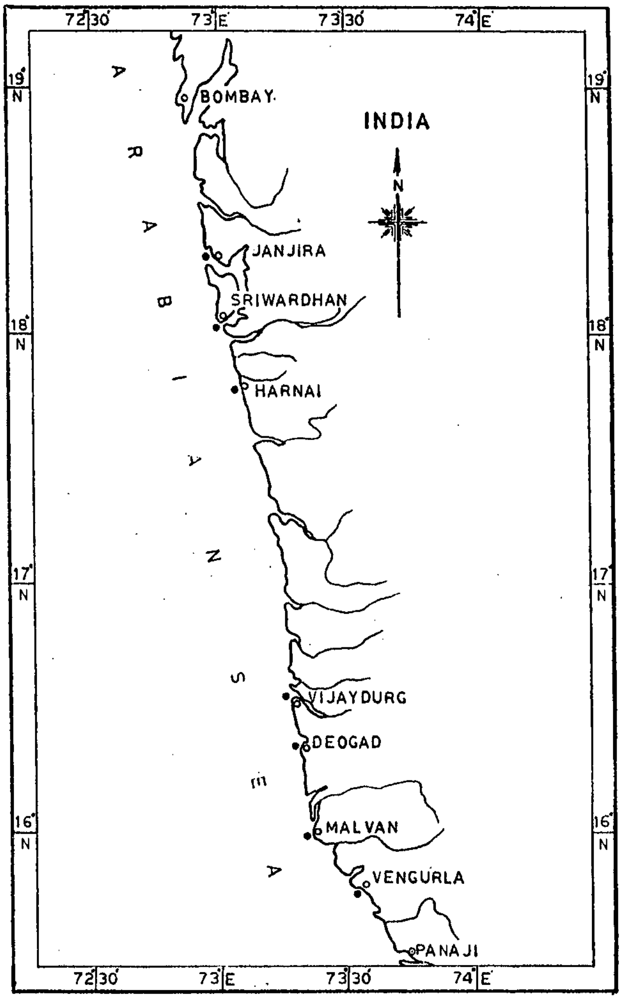

Fig. 1. Station positions along Goa-Bombay Coast, central west coast of India

For phytoplankton studies, a 1 l sample of surface water was collected, and the organisms were preserved by adding 10% formalin. The preserved samples were left undisturbed for about 1 week until fully settled. Later, the settled substrate was made up to 5 ml with water. For quantitative estimation of phytoplankton and their relative abundance, a subsample was taken and organisms were counted. These were computed to the total volume of the water sample taken.

Chlorophyll pigments and carotenoid contents of phytoplankton were determined after Richards with Thompson (1952) on a VSU-2 spectrophotometer, using the equations proposed by Strickland and Parsons (1965).

Results

Temperature

All along the section connecting the 7 stations from south to north, the temperature in September was low, ranging from 25° to 27 °C, and suddenly rose in October simultaneously at all stations, ranging then between 30.5° and 31.0 °C (Fig. 2). From November onwards, there was a gradual fall in temperature at all stations. The lowest values of 24.4° to 26.5 °C were recorded during December and January, after which the temperature rose steadily until it reached a maximum of 28.75° to 32.0 °C by April/May. However, the lowest temperature of the season, at Vengurla, was recorded in November.

Salinity

Surface salinity during September at all the stations was uniformly low (4.0 to 18.6‰) (Fig. 2). From October onwards, the salinity stabilized in the range of 32.3 to 36.85‰ at all stations.

Salinity values showed two distinct peaks, in December and April, respectively, with a significant drop observed during January/February.

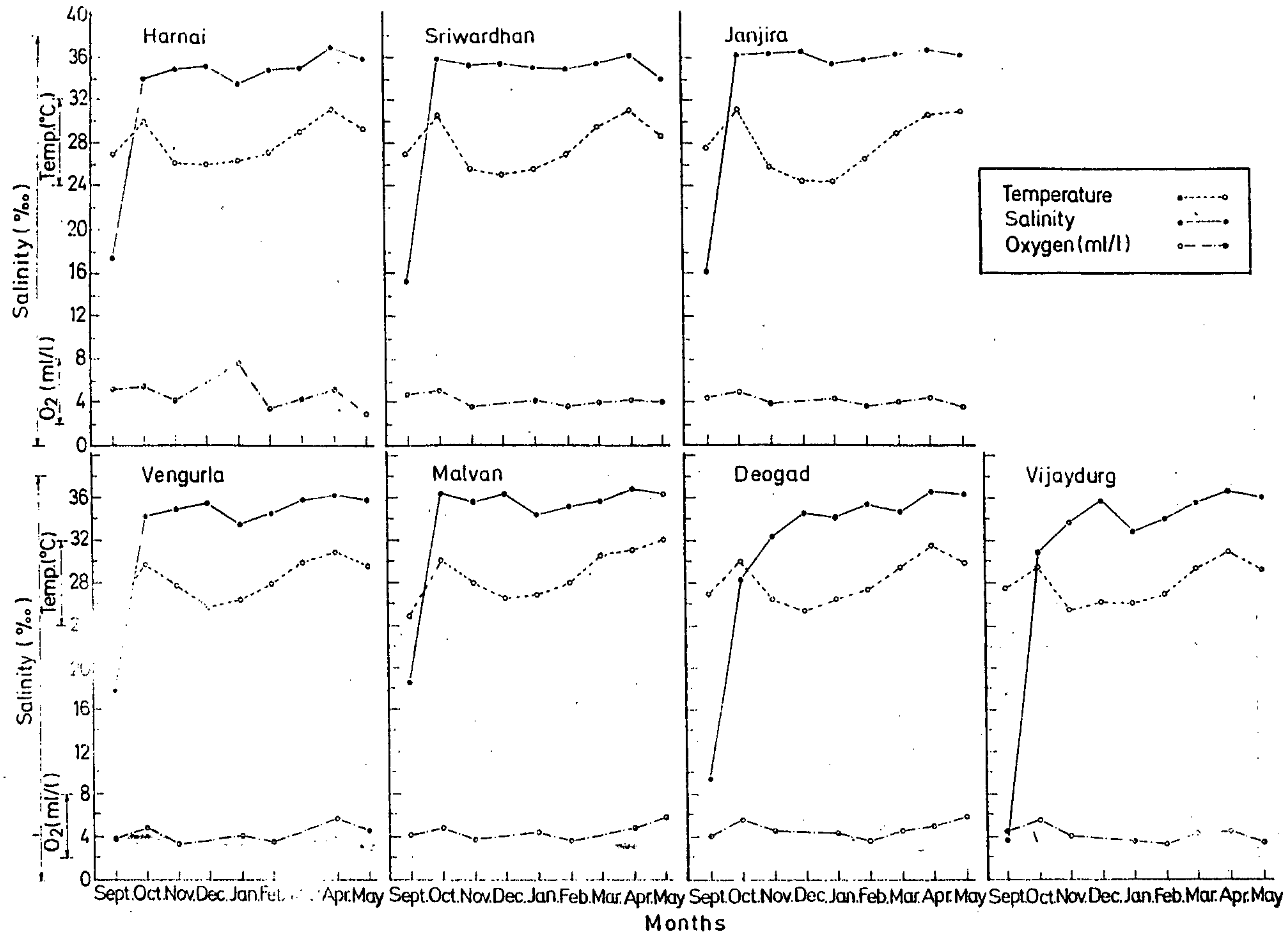

Fig. 2. Monthly changes in environmental factors at 7 stations along central west coast of India

Dissolved Oxygen

Oxygen values in September at all 7 stations ranged between 4.0 and 5.25 ml/l (Fig. 2). In October there was a uniform rise in oxygen concentration at all stations; average between 4.8 and 5.8 ml/l. Thereafter, through November to March, the fluctuations in the oxygen concentration were small until April/May, when the second peak was evident, with oxygen values as high as 6 ml/l.

Chorophyll Pigments

Monthly variations in chlorophyll *a*, *b*, *c*, and carotenoid concentration from surface water samples at the 7 stations are shown in Fig. 3.

The values of chlorophyll *a* at the 7 stations showed generally 3 peaks during the period of observations from September to May. Immediately after the monsoon, in September, the chlorophyll *a* concentration was high, ranging from 2.3 to 8.2 mg/m^3; this was followed by a sudden drop in October at all stations, particularly at Vengurla, Harnai, Sriwardhan and Janjira. From November, the steady rise in chlorophyll *a* values resulted in peak concentration at the majority of stations by November/December and, in some cases, by January (Harnai), when the values ranged from 2.4 to 18.8 mg/m^3. The highest values of this period were recorded at Vengurla, Deogad, Harnai, Sriwardhan and Janjira. At Malvan and Vijaydurg, the range of variations in chlorophyll *a* values was moderate (0.75 to 4.4 mg/m^3), except in May when, at Malvan, chlorophyll *a* rose to 9.5 mg/m^3.

A successive decrease in chlorophyll *a* at Vengurla, Malvan, Deogad and Vijaydurg occurred in January and February. At Harnai, Sriwardhan and Janjira, the decrease occurred during February/March; this decrease was considerable, and was followed by a gradual and steady rise in chlorophyll *a* values by April/May.

At Vengurla, Deogad, Harnai, Sriwardhan and Janjira, the pre-monsoon peak of chlorophyll *a* was secondary in magnitude; the values ranged from 2.7

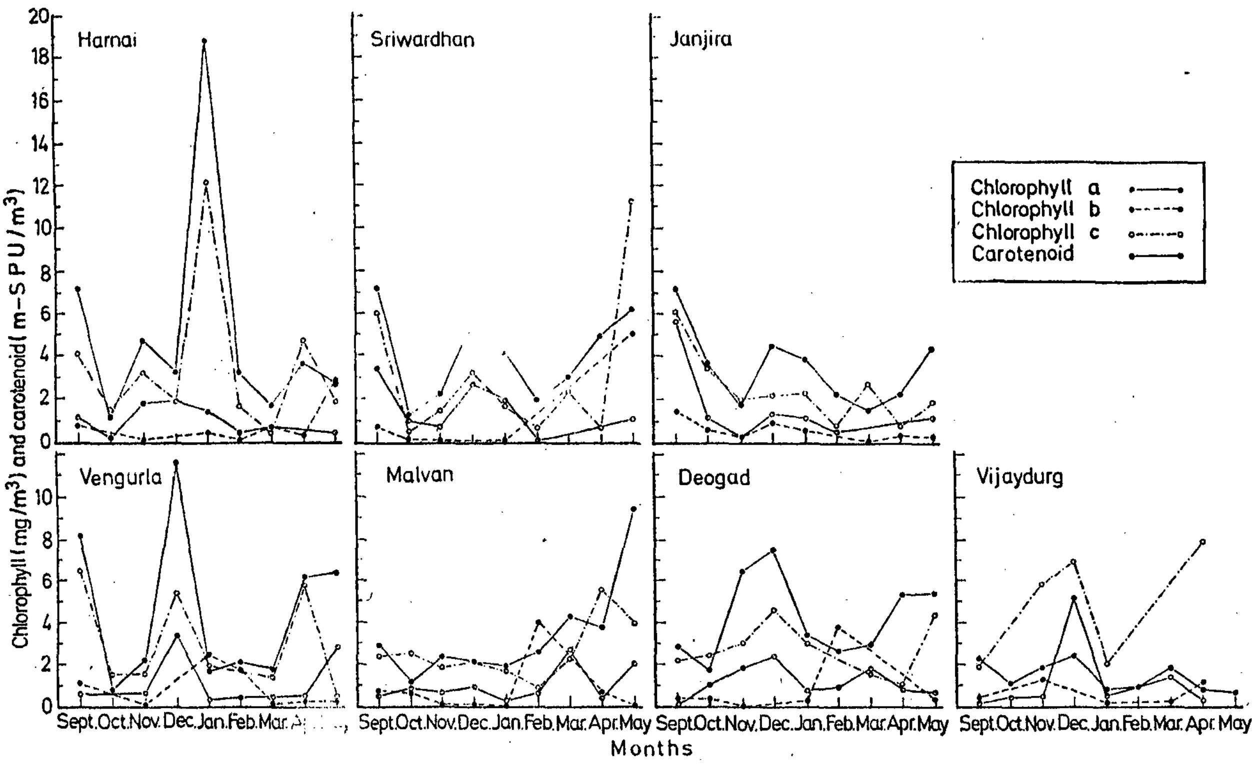

Fig. 3. Monthly variations in chlorophyll and carotenoid concentration at 7 stations along central west coast of India. (m-SPU/m³ = milli-specified plant pigment unit)

to 6.4 mg/m³, while at Malvan and Vijaydurg, the pre-monsoon period peak of chlorophyll *a* was highest, ranging between 7.9 and 9.5 mg/m³.

Corresponding monthly values of chlorophyll *c* were generally lower than chlorophyll *a* at all stations except Vijaydurg, where chlorophyll *c* formed the major constituent of the total plant pigments throughout the period of observations from September to May. At Vijaydurg, chlorophyll *c* showed two major peaks, one in December and the other in April, ranging from 2 to 8.0 mg/m³. Similarly, at most stations in October, chlorophyll *c* content attained slightly higher values than the corresponding chlorophyll *a* content. Again, during the pre-monsoon period, at Malvan, Harnai, Sriwardhan and Janjira, chlorophyll *c* exceeded chlorophyll *a* considerably.

Values of chlorophyll *b* were generally low at all stations, but occasional dominant peaks during various months were noticed (particularly during January and February at Vengurla; during February and March at Malvan and Deogad; and during March and April at Sriwardhan and Janjira), indicating an apparent succession in time from south to north along the central west coast.

Carotenoids (m-SPU/m³)[1] contents showed monthly variations in close relation to chlorophyll *a* and *c*, and indicated corresponding peak values at all the stations. However, again at Vijaydurg, the carotenoid value exceeded the value of chlorophyll *a* in December and was close to that of chlorophyll *c* (5.2 m-SPU/m³).

[1] milli-specified plant pigment unit.

Phytoplankton Abundance

Monthly variations in the counts of phytoplankton per litre were recorded at all 7 stations from September to May (Fig. 4).

Observations beginning from September showed high density of phytoplankton at all stations except Malvan, where the counts were generally low, but consistent, until February. At Vengurla, the occurrence of phytoplankton was consistently high until February/March, whereas at Deogad, the values fluctuated, with moderate peaks in November, January and April.

At the stations in the northern region of the coast, namely Vijaydurg, Harnai, Sriwardhan and Janjira, the phytoplankton density was high in September, with a marked decrease in October, followed by a significant rise in December/January.

It may thus be seen that, throughout the central west coast of India, there is a pre-monsoon peak of

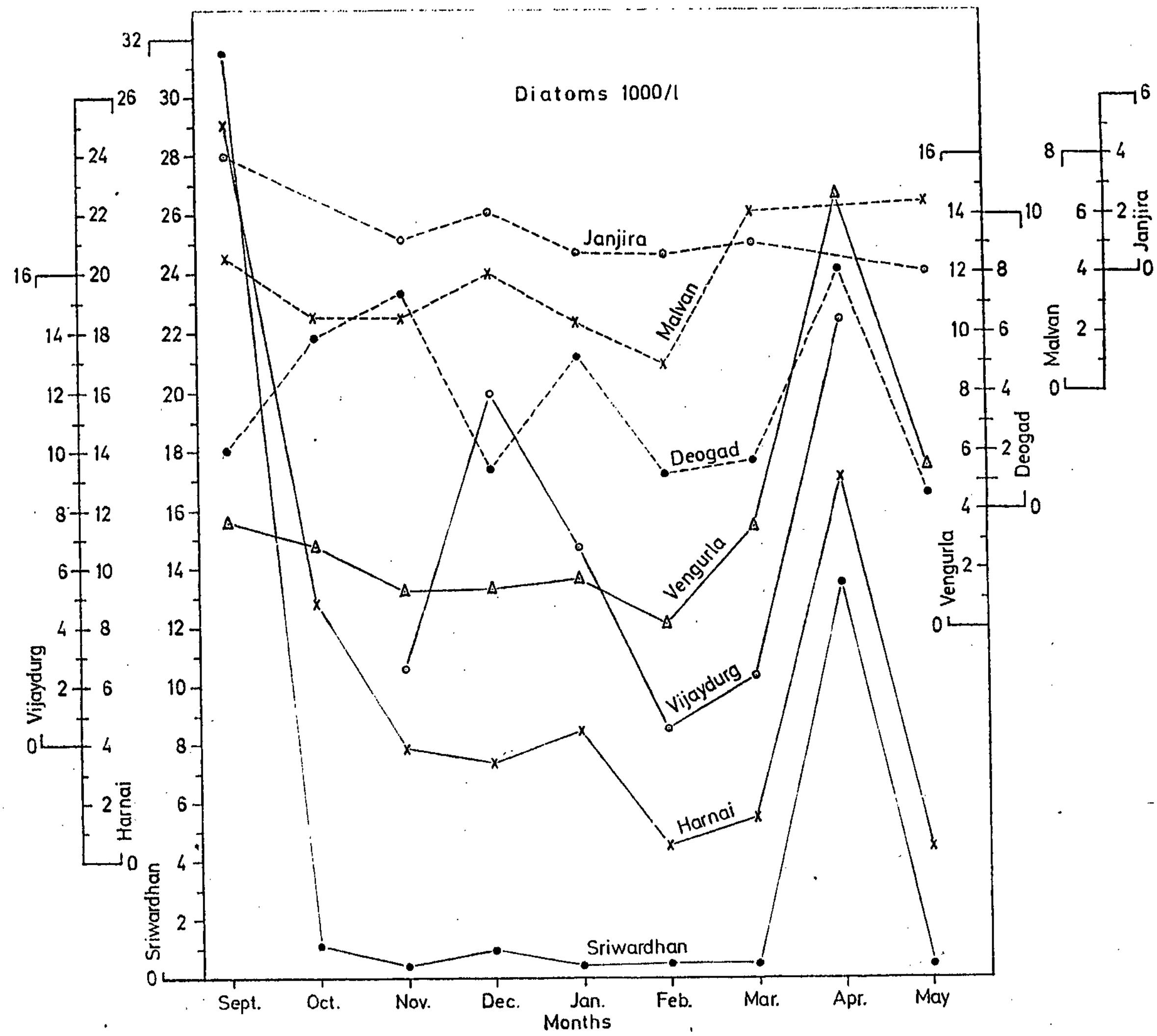

Fig. 4. Monthly variations in diatom counts at the 7 stations

phytoplankton bloom in the months of April and May.

Some differences in the phytoplankton distribution in the waters of this region were observed during September to May 1970/1971. In September, *Nitzschia* spp. and *Thallasiosira* spp. were dominant. The phytoplankton crop, mostly consisting of *Thallasiosira* spp., was meagre in October; in November, however, a sudden bloom of *Melosira* spp. characterised the coastal waters in the southern end, whereas *Thallasiothryx* spp. dominated in the northern region. The phytoplankton crop mainly consisted of *Thallasiothryx* spp. and *Nitzschia* spp. in December, although a variety of other diatoms were also noted. *Pleurosigma* spp. appeared in January in the southern region, whereas *Coscinodiscus* spp. dominated in the northern region of the central west coast.

In February, a sudden bloom of green algae occurred accompanied by diatoms, mostly *Aulacodiscus* spp.

During March/April/May, the southern region of this coast showed an abundance of *Thallasiothryx* spp., *Thallasiosira* spp., *Coscinodiscus* spp., *Asterionella* spp. and *Chaetoceros* spp., whereas in the northern part, *Chaetoceros* spp., *Eucampia* spp. and *Thallasiosira* spp. were present.

Discussion

The main environmental factors in the waters along the central west coast of India follow a seasonal cycle. The changes in the hydrographical parameters and the biological production in the region appear to be very much influenced by the pattern of upwelling occurring along the southern as well as the northern part of the west coast of India, as has been reported by several workers. Although it is still too early to make a definite statement, it appears that the waters along the central west coast of India constitute a zone of transition between two upwelling regions.

Occurrence of upwelling off Calicut along the south-west coast of India, up to 15 °N has been discussed by Banse (1959). Rao and Jayaraman (1970) recently reviewed the oxygen distribution in the Arabian Sea, and indicated Goa as the northernmost boundary of the upwelling influence, occurring during the south-west monsoon off the south-west coast of India. Earlier, on the basis of the study of the phosphorus cycle and the total phosphorus distribution in the surface water off the Indian coasts, Jayaraman and Seshappa (1957) presented evidence that upwelling in some form occurs up to as far as 18°N. Off Calicut, Banse (1959) and Ramasastry and Myrland (1959) reported that the effect of upwelling near the coast is felt mostly from July to September. On the other hand, in the region north of Bombay, the occurrence of upwelling during October and November has been reported and its possible effect on the lower latitudes also surmised (Carruthers et al., 1959).

Double seasonal oscillations of temperature, salinity and oxygen concentration of the surface water along the central west coast of India were noted. The period of sudden lowering of temperature and oxygen values and the simultaneous rise in the salinity of the waters in the region between 15°30′ and 18°30′N (Vengurla to Janjira) during November/December and January followed that of the phenomenon of upwelling (with similar influences) off the south-west coast of India and that observed off Bombay. However, the high oxygen concentration during April and May in the entire region could be due to photosynthetic activity of the abundant phytoplankton in the water.

Most of the work to date on biological production along the west coast of India concerns the south-west coast only. Recent studies on the waters of Goa (Dehadrai, 1970), and other reports covering the west coast from Calicut to Bombay (Bal and Pradhan, 1946; Gonzalves, 1947; George, 1953; Subrahmanyan and Sarma, 1960; Ramamurthy, 1965) indicate that the production potential in Goa waters (as well as that in the north of the region) is high, and there appears to be a northerly succession in the peak of production rates in space and time along the entire west coast of India from Cochin to Bombay after the south-west monsoon. Humphrey (1966) reviewed the distribution of chlorophyll *a* and *c* in the South East Indian Ocean, but no correlation of recorded chlorophyll distribution pattern with environmental factors exists for the Indian Ocean.

Marked lowering in the concentration of chlorophyll pigments during October at all the stations coincides with the similar abrupt lowering of temperature and oxygen values, and increased salinity during October. Thereafter, the rise in the chlorophyll pigments during November/December in the southern zone (Vengurla) and during December/January in the northern zone of the region (Janjira), and the phased maxima of the chlorophyll pigments in the southern and northern zones of the central west coast, appear to be associated with the upwelling phenomena emanating from off Calicut (Banse, 1959) and off Bombay (Carruthers et al., 1959), respectively.

Later, in April/May, the high values of chlorophyll pigments and peak abundance of phytoplankton almost throughout the central west coast could be regarded as a passive culmination of the process of slow but steady growth of the phytoplankton population initiated after cessation of the south-west monsoon.

Percentage composition of various chlorophyll pigments and carotenoids indicates, to some extent, the physiological state of phytoplankton populations in the waters of the central west coast during different months (Fig. 5).

The chlorophyll *a*: carotenoid ratio is known to be more constant than the chlorophyll concentration by itself, and a low ratio of chlorophyll *a* to carotenoid would certainly indicate a chlorotic, unhealthy phytoplankton population (Ketchum et al., 1958). However, wide variations in the ratio are observed under different conditions in the sea. Particularly phosphorus and nitrogen deficiencies have been shown to produce these variations (Yentsch, unpublished, *in*: Ketchum et al., 1958).

In September and October, the relative concentrations of chlorophyll *a* and carotenoid were fluctuating highly at different stations, but in November, the carotenoid content stabilized to low values until February, accompanied by a high concentration of chlorophyll *a* and *c*, indicating a healthy crop in the waters of the central west coast.

Again in March, the phytoplankton population appeared highly chlorotic and unhealthy, with a high carotenoid content in relation to chlorophyll *a*. It is possible that the high algal blooms of the January/February period may have caused considerable nutrient depletion in the environment. By April/May, however, the phytoplankton population appeared to revive, with an abundance of chlorophyll *a* and *c* and a small amount of carotenoid. The dominance of chlorophyll *c* in the plant pigments at different stations may be due to the abundance of diatoms and dinoflagellates.

Abundance of specific phytoplanktonic elements in space and time characterises the waters of the central west coast of India as observed at the 7 stations. Marked differences in the species composition of the phytoplankton crop, consisting mostly of diatoms in the waters of southern and northern regions of the central west coast of India, are significant. Moreover, the seasonal changes in the dominant groups of the phytoplankton indicate clear succession of species.

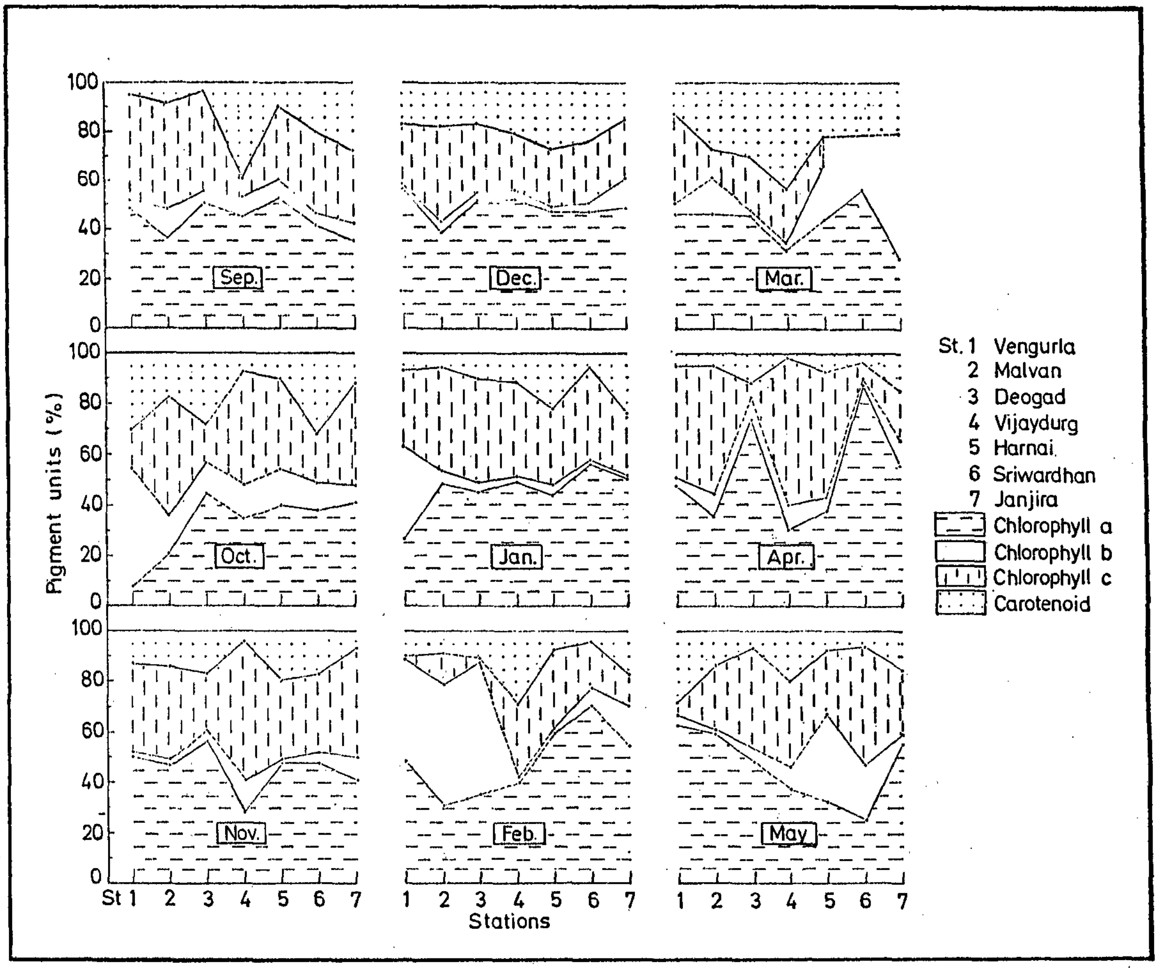

Fig. 5. Composition of chlorophyll pigments and carotenoids during different months at the 7 stations

However, it is interesting to note that the green algal bloom occurred only in February.

The biological processes in relation to certain environmental features occurring in the region appear to be broadly influenced by the upwelling phenomena which start at the southern and northern ends of the central west coast after the southwest monsoon. However, for a detailed understanding of the ecology of the region, observations on depth profiles of certain environmental factors and biological production processes in relation to fresh-water drainage from numerous rivulets and tidal creeks, as well as the overall larger influences of the south-west monsoon causing upwelling in the area are necessary.

Summary

1. Double seasonal oscillations of temperature, salinity and oxygen concentration of the surface waters are noted in the nearshore waters of the central west coast of India. The sudden lowering of temperature and oxygen concentration values and the simultaneous rise in salinity during November to January follows the phenomenon of upwelling.

2. The values of chlorophyll *a* are high at all 7 stations in September, followed by a drop in October, thereafter they show a steady rise, with a peak in November/December. However, the highest value of chlorophyll *a* (18.8 mg/m^3) was recorded in January at Harnai.

3. Values of chlorophyll *b* are generally low at all 7 stations.

4. Chlorophyll *c* values are generally lower than that of chlorophyll *a* except at Vijaydurg, but in October and again in the pre-monsoon period at a few stations, chlorophyll *c* values exceed the chlorophyll *a* values.

5. Carotenoid contents show monthly variations in close relation to chlorophyll *a* and *c*, but at Vijaydurg, the carotenoid values exceed the values of chlorophyll *a*

in December and are close to those of chlorophyll *c*.

6. The phytoplankton bloom occurs at most of the stations in April, except at Malvan and Janjira, where variations are small.

7. The distribution of chlorophyll in relation to temperature, salinity and oxygen values appears to be associated with the upwelling reported to emanate from off Calicut and off Bombay.

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MARINE LIVING RESOURCES AND ECOSYSTEMS ALONG THE WEST COAST OF INDIA

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ABSTRACT

The West coast of India with a wide continental shelf and a long coastline accounts for three fourth of marine fish landings of the country. The estuaries and backwaters receive nutrients from the hinterland, and are most productive area for food but they are also extensively used for disposal of domestic waste, sewage, industrial effluents, and oil wastes and thus face serious threat of pollution and present hazards for public health. In this presentation back-waters of Cochin and estuaries near Goa are discussed, where mangrove are very common. They add organic matter to the aquatic environment and modify the ecology. These areas have fringing mangroves and mangrove swamps. The fringing mangroves are common in estuaries and mangrove swamps are found in back-waters and low lying areas. The most abundant mangrove swamps are in Gulf of Kutch. These have a special ecosystem which is highly productive and the substratum is rich in organic matter. Around Bombay city a large low lying areas are full of dwraf mangroves and are being reclaimed for urban development at a very high cost. An urgent need has arisen for management of these ecosystems and enhancing food production.

Strong shoreward winds influence the coastal areas in different ways during the monsoon season. In some areas strong coastal upwelling is observed, and in others it may be weak or negligible. Coastal and oceanic islands also influence the environment around them. The combined effect of all these factors lead to creation of separate ecosystem and four major ecosystems can be identified along the West coast of India. They are i) Estuaries and backwaters including mangroves ii) Coastal zone upto 200 m, iii) Open Ocean and iv) Islands and atolls. These systems are adjacent to each other but have their typical physico-chemical characteristics. They differ from each other in food chain and production at different trophic level. Biologically their dominant fauna and flora is also different and each of them have smaller sub ecosystems of their own. Amongst these ecosystems except estuaries and a part of the coastal zone which are intensively utilised for fishing, other ecosystems at present are under exploited. There is, therefore, the need to study these ecosystems for harvesting the exploitable resources at an optimum level.

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INTRODUCTION

The West coast of India and the continental shelf along the Indian coastline are highly productive and accounts for three fourth marine fish landings of the country which is around 1.3 million tons. Along the Indian coastline various changes occur in different areas and these modify the biological processes. Study of these processes shows existance of atleast four major biological ecosystems. Each ecosystem has its special characteristics and their physical, chemical and biological components are different. The production and food chain in marine ecosystems is influenced principally by the geological formation of the area and the physical and chemical processes which occur. These jointly constitute the environment and govern the inter relationship amongst the organisms and their qualitative and quantitative production. Considerable work on these aspects has been done along the West Coast of India during and after the International Indian Ocean Expedition and sufficient information is available on ecological and biological processess which occur in this area. In this paper an attempt has been made to characterise the ecosystems which are found along the west coast of India.

The west coast presents different environments from south to north. These are the backwaters of Cochin, estuarine areas in Karnataka and Goa States where large but shallow rivers open into the Sea and the shallow region of the Gulf of Kutch with extensive Mangroves. In addition there are a large number of islands in the nearshore and offshore regions. Besides all these, this coast is periodically affected by upwelling in different areas. The available information enables us to deliniate four major ecosystems along this coast. These are (i) Estuaries and backwaters including mangroves, (ii) Coastal Zone upto 200 m (iii) open ocean and (iv) Islands and atolls,

1. ESTUARIES AND BACKWATERS

Estuaries and backwaters which form the transititional zone from freshwater to the sea, are very extensive and play an important role through food production, disposal of effluents and sewage, transport etc. The total area of these waters along west coast is about 30.5 lakh acres (Mitra, 1970) and the state-wise break up is given below: (1 lakh acre - 100,000 acres).

State	Backwaters	Estuaries	Total
	area in lakh acres		
Gujarat	9.2	10.0	19.2
Maharashtra	2.0	1.0	3.0
Karnataka	2.0	0.5	2.5
Kerala	5.0	1.0	6.0
Total	18.2	12.5	30.7

It is seen that the estuaries and backwaters are most extensive in Gujarat. This is followed by Kerala, Maharashtra and Karnataka States. In all these areas generally back waters are more important.

Cochin backwaters and the estuaries of Goa have been extensively studied which are discussed here as the representative areas for tropical backwaters and estuaries.

The hydrography of these waters is influenced by the tides and the seasional changes due to monsoon. Considerable changes occur due to heavy rains and results in lowering the temperature and salinity. The salinity changes during the year range from 0 to 35‰. In Mandovi estuary of Goa, salinity reaches zero in monsoon while in other summer months it is as high as 35‰. These result in strong differences in animal fauna during monsoon and non-monsoon seasons. In Cochin backwaters stratification occurs from June to September when surface and bottom waters are clearly differentiated, (Qasim, 1975, in press). The light penetration is reduced particularly during monsoon months. During the course of a year the euphotic zone varies from 2-6 m. The attenuation coefficient (k) ranges between 0.60 - 3.00 in Cochin backwaters (Qasim, et al, 1968) and 0.48 to 7.5 in Goa estuaries (Bhargava and Dwivedi, in press). No distinct stratification was noticed in Goa estuaries.

The gross and net organic production in Cochin backwaters ranged from 0.5 to 1.50 $gC/m^2/d$ and 0.35 to 0.88 $gC/m^2/d$ respectively (Qasim et al, 1969). C^{14} uptake in surface waters of Mandovi estuary ranges from 134-550 mg $C/m^3/d$ and during high tide 44-122 $mg/C/m^3/d$ during low tide.

In Zuari estuary which is more marine in nature, the C^{14} uptake during high tide varies from 580 to 1950 $mg/C/m^3/d$ and from 22 to 82 $mg/C/m^3/d$ during low tide. In both these estuaries variations occur due to tide and production is higher during high tide.

Recently Bhattathiri et al (In press) have estimated the column production and chlorophyll a values during monsoon season from June to September as follows.

Estuary	Organic production ($mgC/m^2/d$)	Chlorophyll a (mg/m^2)
Mandovi	59.04 - 549.38	1.60 - 12.70
Zuari	108.24 - 502.45	1.90-16.70
C.Canal	176.28 - 439.71	2.40 - 12.60

It is seen that the highest values occur in Cumbarjua canal which connects the two estuaries at a distance of about 12 kms from the sea.

The phytoplankton counts in Cochin backwaters were maximum in November and minimum in September and ranged from 22,200 to 299,700 cells/litre (Devassy and Bhattathiri, 1974) with diversity index ranging from 1.59 to 4.50. In Goa estuaries the phytoplankton counts from surface waters during June to September are available which ranged from 3,600 to 430,00 cells/litre.

The secondary production is also high in these waters. The average zooplankton biomass in ml per m^3 in Cochin backwater ranged from 0.09 in July to 0.35 in March (Pillay et al, 1973). The zooplankton biomass in Goa estuaries from a single station was 175 $g/1000\ m^3$ in Zuari and 82 $g/1000m^3$ in Mandovi

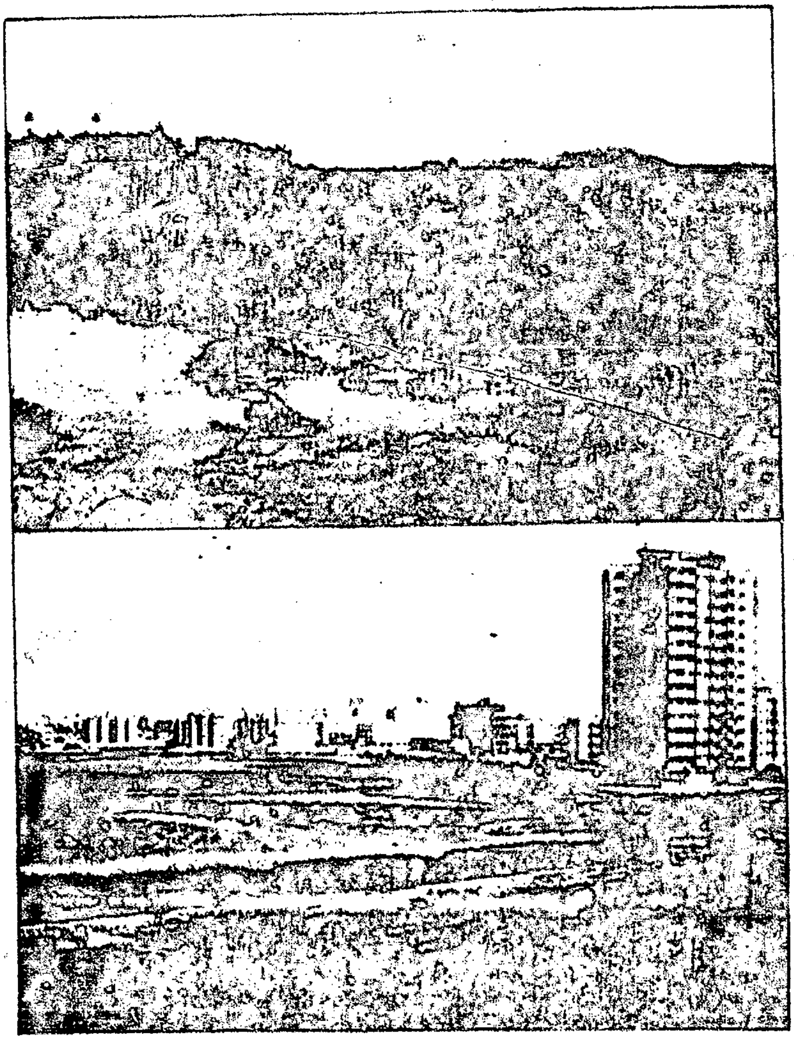

Plate I. Dwarf mangroves around Bombay city. Above - Large mangrove swamp between Andheri and Versova area; below, a part of the same area under reclaimation for urban development.

(Goswami et al, 1975). The average zooplankton biomass expressed as wet weight per 1000 m^2 was found to be 439 gm in Cochin backwater, 61 gm in Mandovi estuary and 149 gm in Zuari estuary. In all these three areas the copepods were the most dominant.

MANGROVES

The mangroves are the tropical ecosystems found in the brackish waters and the estuaries where wave action is negligible and substratum is soft and muddy. They have specialised root systems which help in building up the land mass and harbour variety of benthic life. Along the west coast of India, the fringe mangroves and mangrove swamps are abundant. The southern coast of the Gulf of Kutch is very rich in mangroves, while northern part is devoid of any mangroves. Gulf of Cambay has mangroves in sheltered areas and around islands. Bombay is surrounded by dwarf mangroves (Navalkar, 1940, 42, 48). Navalkar and Bharucha (1948, 49) have studied the various ecological and physiological parameters of this region. At present these mangroves around Bombay city are of no economic value and are being reclaimed at a very heavy cost for urban development & (Plate 1).

South of Bombay from Ratnagiri to Mangalore, along the central west coast, almost all the estuaries have mangroves. Further south in Kerala, Cochin has extensive backwaters with fringing mangroves.

Untawale et al (1973) and Dwivedi et al (1975) have studied favourable and unfavourable environmental parameters for growth of mangroves. In mangrove swamps bacteria break down dead foliage and as a result of biodegradation, the nutrients are regenerated and phosphates and nitrates occur in high concentration. The primary and secondary producers also feed on the organic matter enriched with nutrients. These mangrove swamps act as the nursery grounds for nearshore and estuarine organisms including prawns, shrimps and various fishes like Chanos, Mugil, Anabas and mud skippers. These areas are also subjected to strong variations in the environmental parameters, therefore animal fauna varies from season to season. The most common plants are Rhizophora mucronata, Avicennia officinalis, Sonnertia apetala, Acanthus ilicifolius, Aegiceros cornniculata. These are specially abundant along the central west coast of India. Untawale et al (unpublished) studied the phytoplankton counts, the range was from 50-6000 cells/litre with maximum concentration in May and June while minimum concentration occurs in August and September. The average values of C^{14} uptake in these swamps was 37.8 mg $C/m^3/d$ (Pant, personal communication).

Based on the available data from Cochin backwaters and Goa estuaries the values are 9.75 mg $C/m^3/h$ for organic production and 216 gm/1000m^3 for Zooplankton. Thus the estuaries and backwaters along with the mangroves is a highly productive ecosystem and also has a high potential for yield at third trophic level. These areas can be utilized for culture of molluscs, prawns and fishes. However, the present practices of indiscriminate exploitation of the young ones adversely affect production and perhaps this may be the reasons for low yield at the third trophic level inspite of high production at primary and secondary trophic levels. Therefore, these areas should be given high priority for aquaculture.

The greatest danger to these highly productive areas is from the disposal of domestic sewage and industrial effluents and in recent years the situation has become worse. In order to protect and harness these areas for production, the wastes should be treated before discharge and their disposal should be regulated.

2. COASTAL ZONE UPTO 200 m:

Along the west coast of India fishing is extensively undertaken by non-mechanised boats who follow the traditional fishing methods. There are about 1.06 million fisherman who do not generally go beyond 8-10 kms from the coast. This zones accounts for more than 80% of India's fish landings and has been studied most intensively. Based on these data, the whole coastal zone can be divided in three distinct areas.

i) South-west coast where upwelling is prevalent.
ii) Central west-coast where upwelling is negligible and
iii) Bombay Saurashtra coast with a large continental shelf and mild upwelling.

The organic production along the South West Coast has been measured from Karwar to Cape Comorin (Nair et al, 1970). The rate of production upto 50 m depth ranged between 0.18 - 2.45 $gmC/m^2/day$ with an average value of about 1.19 $gmC/m^2/d$. However, at the Wadge bank during upwelling months the production is much higher. In the zone starting from 50 m depth to 200 m. the production rates decreases to an average of 0.43 $gmC/m^2/d$ on the nearshore waters of Central west coast. Between Goa and Bombay the chlorphylla values ranged from 2.4 to 18.8 mg/m^3 (Dehadrai and Bhargava, 1972). Higher concentration was seen in November-January and slight upwelling was surmised.

The secondary production through zooplankton has been assessed by many research workers. Based on the data of IIOE, plankton atlases have been published which summarise the total zooplankton biomass. The Zooplankton biomass off Cochin during April-October is of the order of 30 g/m^2 but gradually decreases to 10 gm/m^2 towards offshore areas, (Dwivedi, 1973). Off Saurashtra coast a concentration of 1800 $ml/1000m^3$ of zooplankton biomass has recently been recorded, and indicates high potential for pelagic fishery.

The fish yield from these areas is high and mechanised fishing is generally practised upto 100 m depth zone. This is indicated by the trawl catches from three different areas. The figures are 226.0 kg/h off Cochin; 115.35 kg/h off Karwar and 220.5 kg/h off north Bombay and Saurashtra (Dwivedi 1973). These zones also differ in the fish fauna and each of them are dominated by different groups of commercially important fishes. The fishing off South coast is dominated by crustaceans and sardines, the Central zone by mackerals and Lactarius while the northern zone by pomfrets, thread fins, Bombay duck and Pseudosciaena Sp.

These areas are still under utilised and the fish production can be further increased. An additional production of 2.27 million metric tons has been estimated from complete Indian continental shelf upto 200 m depth zone. The major share of the yield will come from pelagic resources of the west coast alone. Therefore, this zones has three distinct sub-ecosystems which differ in rates of production and support different combinations of commercially important fishery. Though these ecosystems are adjoining and the physical limits of these systems overlap but each of them when examined as larger systems show distinct biological characteristics at primary, secondary and terriary trophic levels. These differences are also supported by the physical and chemical characteristics. It is necessary to investigate and develop different approach for the optimum utilization of each of these sub-ecosystem. In these areas pollution problem is not serious, however, recently some studies of fishes caught around Bombay Harbour showed the mercury content higher than the permissible limit (Halkar and Tejam, 1974).

In this area Bombay is largest city which has problems of disposal of sewage and industrial effluents, and as a result some bays and creeks have become polluted (Dwivedi and Desai, in press). A detailed study of trawl catches conducted over a five year period abroad R/V Harpodon also show a gradual decrease in fish yield from 1968 to 1973 (Abraham et al, per.comm.). It thus appears that these areas are used for various purposes which are not compatiable for each other and require very careful management policies.

3. OPEN OCEAN

The area beyond 200 m zone is considered here as open ocean. This ecosystem at present is poorly exploited by Indian fishing Industry. The most important is Tuna fishery of the Indian Ocean which is exploited principally by Non-Indian Ocean countries. In comparison to estuaries and coastal zone this area is less productive and the average organic production is only 0.18 $gC/m^2/d$ while the chlorophyll concentration off Alleppy ranged between 7.6 - 30.35 mg/m^2. Off Cochin it ranged between 2 - 210 mg/m^2. The secondary production in terms of zooplankton biomass has been very well studied during International Indian Ocean Expedition. Indian Ocean Biological Centre, Cochin has published a series of zooplankton atlases on the Zoo-geography of zooplankton in Arabian Seas. Based on this data the estimated average zooplankton biomass is 19 $ml/200\ m^3$ for the Arabian Sea and 14 $ml/200\ m^3$ for whole of Indian Ocean (Saktivel, personal communication).

The known resources of the open ocean are tuna and Myctophid like fishes. The Indian Ocean central water area and subtrophical convergence area (75°E) formed good ground for albacore tuna (Uda and Nakamura, 1973). Panikkar and Jayaraman (1966) pointed out rich fishery for oil sardine and mackerel in upwelling areas of Arabian Sea while Uda and Nakamura (1973) also confirmed upwelling areas a favourable grounds for tuna fishing in the equatorial zone.

This ecosystem may have lesser rates of production but turnover of energy between trophic levels is high. Apart from the fast turnover, large area and a deep euphotic coloumn make this zone important as a source for food potential. The present data suggests over fishing of some tuna species and now it is necessary to concentrate on smaller tunas and tuna like species. Further extensive investigations are also necessary to deliniate area of seasonal upwelling where fishing efforts can be concentrated.

4. ISLANDS AND ATOLLS

There are several nearshore and offshore islands in the Arabian Sea along the west coast of India. These areas have not received enough attention from scientific angle. However, they can be classified into 3 major groups ;

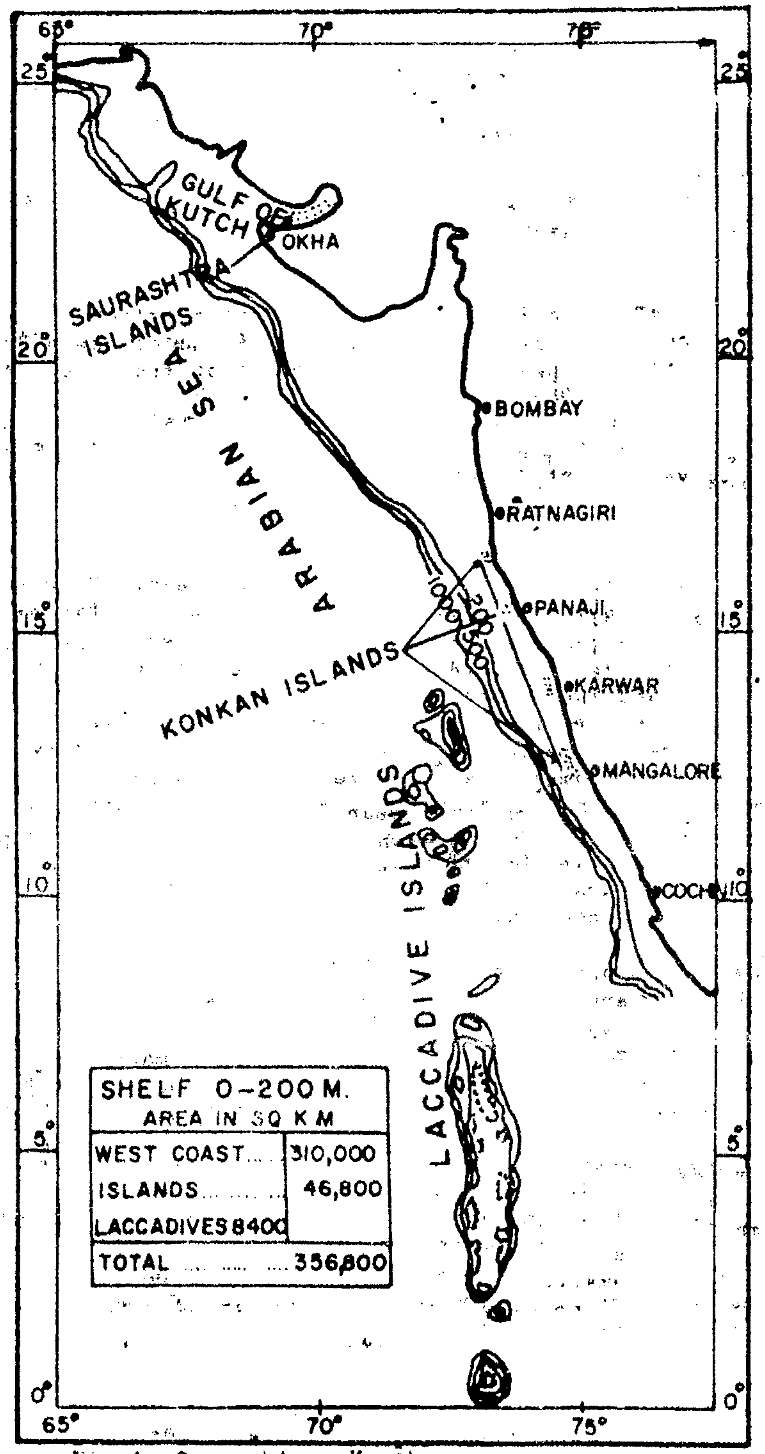

Fig 1.- Saurashtra, Konkan and Laccadive group of islands along the west coast of India.

(i) Saurashtra group (ii) Konkan group and (iii) Laccadive and Minicoy group (Panikkar, et al, 1972) (Fig 1). The Saurashtra group consists of 35 islands in the Gulf of Kutch, and in the Gulf of Cambay. Konkan group: This group also consists of nearly 36 nearshore islands along Central west coast from Bombay to Malpe. Laccadive and Minicoy group: From its name 'Lakshdwipa' it appears that there were one hundred thousand islands in this region. Today there are approximately 40 islands and several islets. This group of islands is 400 kms away from the mainland. The three groups of islands described above are of two types, the continental islands and oceanic islands.

The Continental islands are Saurashtra and Konkan group and the Oceanic islands are the Laccadive and Minicoy islands. Later are mainly coral atolls in open ocean.

From the preliminary studies of these islands Panikkar et al.(1973) Parulekar (1973), have observed that sea surrounding the islands is more productive. Some of the islands like Laccadives and Minicoy, Karwar group, and others have a rich fishing ground in their vicinity. Important ecosystems develop around the islands which produce a variety of living resources. In this concentration the mangroves around the islands in Gulf of Kutch and tuna fishery around Laccadives are very significant and require special attention.

Very little data is available for these islands. Minicoy group of island have been studied by some authors, Qasim et al.(1972), Qasim and Bhattathiri (1971), and Goswami (1973). Qasim and Bhattathiri (1971) studied primary production of grass bed on Kavaratti atoll of the Laccadive Archipelago. These atolls largely consists of turtle grass (*Thalassia hemprichii*) and manatee grass (*Cymodicea isoetifolia*) with substratum of Sand coral rocks and debris. The gross production was estimated to be 11.97 $gC/m^2/d$ and the net production was 5.81 $gC/m^2/d$. In the Kavaratti Lagoon Qasim et al.(1972) recorded gross productions as 4715 gC/m^2/year, the highest value recorded in such waters except in Hawaiian coral reefs where Gordan and Kelly (1962) reported as 7300 gC/m^2/year. The lagoon waters have higher values of temperature, salinity and oxygen as compared to the surrounding sea water (Goswami, 1973). The zooplankton biomass was 253 ml/1000 m^3. Tranter and George (1969) estimated that zooplankton provide 0.32 gc/m^2 of energy. These ecosystems are highly productive and the sea grass after decay serves as the food for certain animals.

Also around Laccadives, Minicoy and Maldives rich tuna fisheries exist. Thus these islands appear to influence the production around them and modify the food web and distinct ecosystems are created.

The above data supports the presence of four major ecosystems along the west coast of India. Each of these systems have typical food web and differ in their physico-chemical parameters and production at various trophic levels is also different. These eco-systems are incontinuity with each other and each of them have sub-systems of their own. Therefore for optimum development of food resources, each echo-system should be studied in detail to enable us to plan and formulate marine food resources development and conservation programmes which are suited to each eco-system.

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Nannoplankton, Total Phytoplankton & Zooplankton Standing Stock Measurements in Goa Waters

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Nannoplankton appears to be an important part of the phytoplankton standing stock in these estuarine and neritic waters and may be responsible for up to 90% of primary production in the region studied. Zooplankton species distributions indicate a mixing of estuarine and neritic waters. The influence of the Mandovi-Zuari estuary is felt as far south as Bogmalo. Results showing apparent respiration dominated community production at one station (Bogmalo) are discussed as a function of zooplankton and phytoplankton standing stock values.

NANNOPLANKTON is known to form an important part of phytoplankton standing stock in nearshore[1,2] and offshore[3,4] waters. Although some work has been done off Goa regarding phytoplankton standing stock and chlorophyll estimations[5,6] no attempt has been made to quantify the relationship between nannoplankton and net phytoplankton in this area.

To relate productivity from the primary to secondary trophic levels, it is useful to have an estimate of community production. One method of estimating such production is to determine oxygen differences over a 24 hr period. The method has been used by Odum and Hoskin[7] in shallow waters and Sugiura[8] in oceanic regions.

The present investigation is a preliminary attempt to relate standing stock and productivity estimates of both nanno and net phytoplankton to zooplankton estimates and community production in the estuarine and neritic waters of Goa. For the purposes of this study, nannoplankton is defined as photosynthesizing organisms which will pass through a 60 μm mesh net.

Materials and Methods

Two stations were chosen for investigation. One at the mouth of the Mandovi river (Verem, Fig. 1) where conditions are estuarine and the other in the nearshore region off Bogmalo. Depth at Bogmalo varied between 10 and 15 m depending on the drift of the boat. Depth of the euphotic zones at both the stations was 4 and 4·5 m respectively. Diurnal studies were carried out at both the stations.

Surface water was sampled every 3 hr for the determination of ^{14}C assimilation, chlorophyll, phytoplankton abundance, oxygen, salinity, nitrate, phosphate and temperature. For the estimations, a 10 l sample was divided into 2 portions. One portion was subsampled *per se* for chlorophyll, phytoplankton and ^{14}C assimilation and the other was filtered through a 60 μm net prior to similar subsampling. Chlorophyll, nutrients, oxygen, salinity and ^{14}C assimilation were estimated following the methods of Strickland and Parsons[9]. To measure ^{14}C fixation, samples inoculated with ^{14}C-labelled sodium bicarbonate were incubated in a deck incubator for 6 hr. Radioactivity fixed by the phytoplankton was determined using a thin-window GM counter with an efficiency of 2·45%.

Phytoplankton standing stock estimates were made on 500 ml filtered and unfiltered water samples fixed with 0·5 ml Lugol's iodine and settled for 48 hr. From a final volume of 20 ml, 1 ml subsample was taken for counting in a Sedgewick-Rafter counting chamber. Duplicate counts were made for each sample which gave a standard deviation of ± 15%.

Zooplankton samples were taken with a 300 μm net fitted with a Rigosha TSK flowmeter. A 3-5 min horizontal haul was taken for each sample.

To estimate standing stock from the above data, caloric values for 2 species of algae were estimated. Unialgal cultures of *Chlorella* sp. and *Tetraselmis gracilis*, grown at a light intensity of 12000 lux at

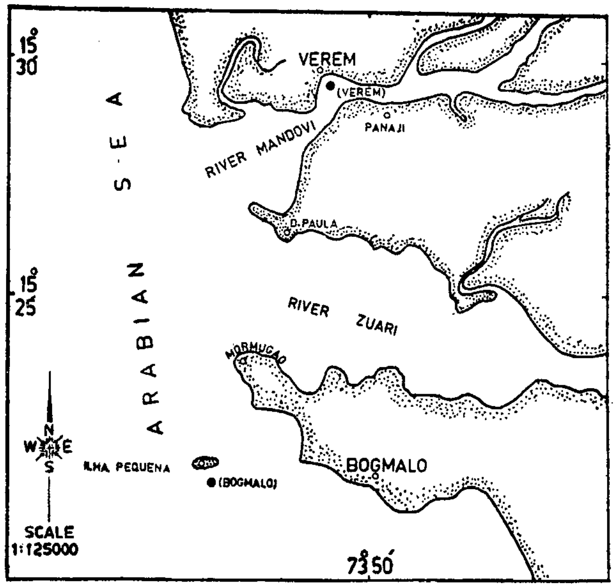

Fig. 1 — Location of the 2 stations

room temperature in Erdschreiber medium, were used for caloric determinations by the Kazinkin and Tarkovskaya method[10]. Average caloric value for both species was 2300 ± 10% cal/g dry weight for cells in the exponential phase of growth. Using the Platt and Irwin's[11] factor of 11·4 calories/mg C for phytoplankton, the carbon content per cell was calculated as $61{\cdot}97\times10^{-8}$ mg C/cell from the culture.

Results

Table 1 shows nutrient, salinity and temperature data for the two stations. Plankton counts are presented in Fig. 2.

The null hypothesis that there is no significant difference in abundance of nanno and total phytoplankton is tested by analysis of variance on the 2 groups for cell count and chlorophyll data. Results indicate that there is no significant difference between nanno and total phytoplankton abundance and the 2 groups of data are, therefore, discussed as samples from one population where nannoplankton are dominant organisms.

Tetraselmis gracilis and *Chlorella* sp. are the dominant members of the phytoplankton population both at Verem and Bogmalo. *Euglena* sp. and *Synechocystis* sp. are recorded at Verem. Diatoms, (*Nitzschia seriata, Fragillaria oceanica, Navicula* sp., *Chaetoceros* sp. and *Coscinodiscus* sp.) constitute about 3-5% of the population at Bogmalo and about 10-15% of the population at Verem. Except *Coscinodiscus* sp., representatives of these species are found in both filtered and unfiltered samples.

^{14}C assimilation values (Fig. 3) tested by analysis of variance show no significant differences in assimilation by nanno and total phytoplankton.

TABLE 1 — DIURNAL CHANGES IN TEMPERATURE, SALINITY AND NUTRIENTS FOR VEREM AND BOGMALO

Date	Time (hrs)	Temp. (°C)	Sal. (‰)	PO_4-P (µg-at/litre)	NO_3-N (µg-at/litre)
		VEREM (MANDOVI ESTUARY)			
30.9.73	1000	29·0	32·16	1·225	0·162
	1300	30·0	33·68	0·875	0·108
	1600	30·2	26·89	0·875	0·288
	1900	30·0	14·42	0·613	0·288
	2200	29·0	18·42	0·355	0·108
1.10.73	0100	29·0	32·25	0·613	0·82
	0400	28·5	31·36	1·05	0·648
	0700	28·0	22·57	0·787	0·738
	1000	29·0	—	0·525	0·108
		OFF BOGMALO (NEAR SHORE WATERS)			
26.9.73	1100	29·0	33·4	2·04	0·212
	1400	29·0	34·13	1·7	0·69
	1700	29·0	34·13	1·7	0·431
	2000	28·0	33·86	1·36	0·862
	2300	28·0	30·21	2·72	0·172
27.9.73	0200	28·0	28·08	1·27	0·603
	0500	28·1	32·79	1·27	0·862
	0800	28·5	31·27	1·02	0·603
	1100	29·0	32·7	1·19	0·431

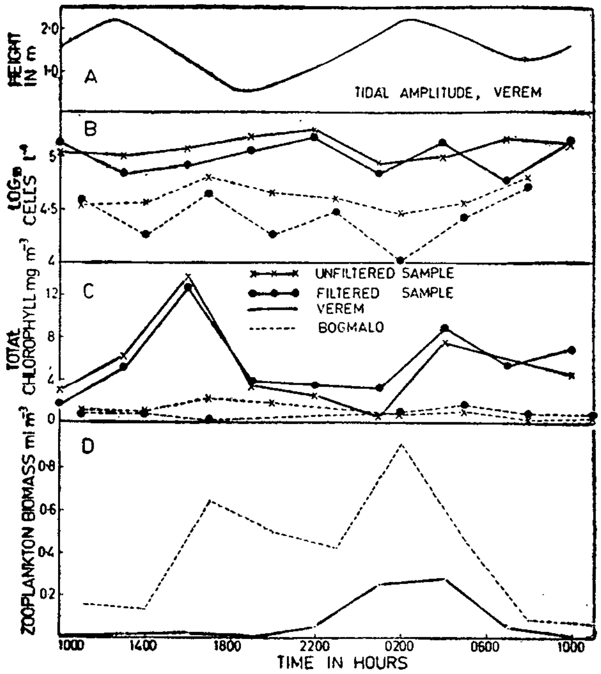

Fig. 2 — Diurnal variations of different parameters at the 2 stations

There appears to be no consistent variation with time of day for cell counts or chlorophyll at either Verem or Bogmalo. The peaks in chlorophyll values at Verem (1600 and 0400 hrs, Fig. 2C) are not reflected in the cell counts and appear to be more closely related to tidal cycles rather than the time of day with maxima appearing just before the low tide. Zooplankton data, on the other hand, show a correlation of biomass with the time of day (Fig. 2D). At Verem, for example, tidal fluctuation appears to have little effect on the standing stock values. Copepods are dominant in all samples (Table 2).

Oxygen measurements taken over the 24 hr cycle have been used to calculate community production (corrected for diffusion) at Bogmalo by the method of Odum and Hoskin[7] (Fig. 4). Due to the constant and rapid flow of water at Verem, the diffusion constant is both erratic and high and it is, therefore, not possible to estimate community production in this way at this station.

Discussion

Fig. 2 indicates that nannoplankton is responsible for most of the primary production in both nearshore and estuarine waters in this region. These results are in general agreement with seasonal studies from the Cochin backwaters[12,13] and reports from other tropical and temperate regions[3,14].

Higher values of total chlorophyll (Fig. 2C) appear to be associated with the ebb tide at Verem, as earlier reported[6]. The peaks in chlorophyll at this estuarine station are not substantiated by either cell count determinations (Fig. 2B) or productivity estimates (Fig. 3, 1600 hrs). It is possible that the resuspension of bottom deposits such as dead algal

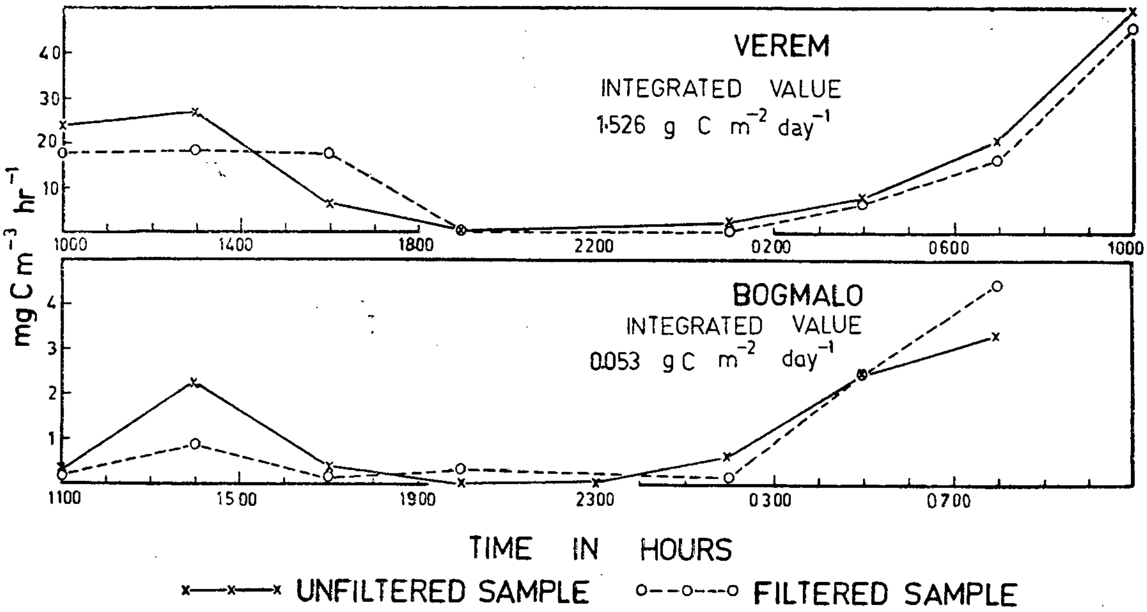

Fig. 3 — ^{14}C assimilation rates at Bogmalo and Verem [Values of production are integrated over the 24 hr cycle]

TABLE 2 — DIURNAL CHANGES IN PERCENTAGE OF DOMINANT COPEPOD SPECIES AT THE 2 STATIONS

Verem					Off Bogmalo									
Date	Time	*Centropages tenuiremis*	*Pseudodiaptomus aurivilli*	*Oithona rigida*	Date	Time	*Centropages tenuiremis*	*Pseudodiaptomus aurivilli*	*Oithona rigida*	*Euterpina acutifrons*	*Temora turbinata*	*Pseudodiaptomus meritoni*	*Acrocalanus gracilis*
30.9.73	1300	2·75	1·83	0·9	26.9.73	1100	89·4	0·16	2·4	2·3	—	—	—
	1600	0·11	11·72	0·29		1400	52·7	0·89	7·52	15·58	—	—	—
	1900	—	0·28	—		1700	10·54	3·83	10·15	—	29·51	11·3	—
	2200	—	58·84	0·17		2000	54·96	5·69	—	7·97	21·94	—	—
1.10.73	0100	—	65·18	4·65		2300	54·8	1·36	28·26	—	—	—	—
	0400	—	5·78	—	27.9.73	0200	78·62	1·22	—	—	—	—	—
	0700	2·25	7·72	0·64		0500	71·95	—	—	—	—	—	—
	1000	2·98	13·46	23·18		0800	40·46	6·82	—	—	—	—	20·04
	—	—	—	—		1100	80·15	—	11·03	—	—	—	—

material due to the reversal of current direction at this time results in high chlorophyll values. Goedheer[15] for example, has reported that chlorophyllide, a chlorophyll derivative, may sometimes be estimated as an equivalent amount of chlorophyll *a* in spectrophotometric observations. Total biomass values of zooplankton (Fig. 2D) show a correlation with time of day, apparently being less affected by tidal influences.

Zooplankton data (Table 2) show the presence of similar species in both Verem and Bogmalo. There appears to be some mixing of neritic and estuarine waters in this region, the influence of the Mandovi-Zuari Estuary being felt as far south as Bogmalo. Euryhaline species such as *Pseudodiaptomus aurivilli* endemic to estuarine waters are found in fairly high concentrations at both Bogmalo and Verem, whereas *Euterpina acutifrons* which may be here regarded as an indicator of higher salinity waters is found only at Bogmalo.

Data on community production at Bogmalo (Fig. 4) where values have been corrected for diffusion, show an apparent excess of respiration over photosynthetic oxygen production over most of the period of the investigation. The diffusion constant (k) for the period for the euphotic zone is 11·25 g O m^{-2} hr^{-1}. These values are higher than those reported

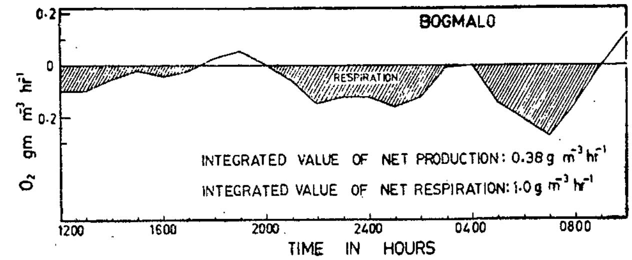

Fig. 4 — Community production calculated from the oxygen differences over 24 hr cycle at Bogmalo

by Odum and Hoskin[7] for shallow water regions and may possibly be due to wind and wave action in the area.

^{14}C production values integrated over the experimental period at Bogmalo is 0·053 g C m^{-2} day^{-1} (Fig. 3) which is considerably lower than the average for the Arabian Sea reported by Ryther and Menzel[16]. Similarly phytoplankton cell counts (Fig. 2B) are low whereas, zooplankton biomass is relatively high.

In order to compare the standing stock of phytoplankton and zooplankton, biomass values have been computed as mg C per litre. For zooplankton 1 ml displacement volume has been regarded as containing 65 mg C as estimated by Cushing[17]. The experimentally determined caloric values for *Tetraselmis* and *Chlorella* in exponential stages of growth in culture yield, an average of $61·97 \times 10^{-8}$ mg C per cell. In conjunction with the cell count data, this factor has been used to calculate values of cell carbon per litre at both Bogmalo and Verem (Fig. 5).

Two main assumptions are implicit in this analysis. The first is that in a natural population all phytoplankton elements have a similar carbon content. The data of Ketchum and Redfield[18] and Richman[19] show that negligible differences exist between caloric values of chlorophycean flagellated and non-flagellated organisms in culture. Parsons *et al.*[20] have found that marine phytoplankters grown under similar conditions of light, temperature and nutrients have very similar organic compositions. It seems reasonable, therefore, to infer that phytoplankton sampled at any one time of day from the same water mass is likely to have a similar history and, therefore, a similar organic carbon content.

The second assumption is that cells in the natural environment have the same carbon content as those in culture. No calibrated method exists, as yet, for discriminating between the contribution of organic carbon by viable algal cells and detrital matter in samples from the environment. No attempt has been made in the present investigation to estimate caloric values of natural phytoplankton populations.

The inverted biomass histogram at Bogmalo (Fig. 5) provides an explanation for the respiration dominated community production shown in Fig. 4, and suggests that the energy budget of the zooplankton trophic level at Bogmalo is likely to be supplemented by detrital and bacterial components of this ecosystem at this time of the year. In this connection it is interesting to note that the biomass of the benthic communities of the area also show an inverted pyramidal structure[21].

At Verem, on the other hand, phytoplankton standing stock in terms of mg C is at least 10 times higher than the zooplankton standing stock except during the period of maximum vertical migration. However, unless zooplankton is grazing at maximum efficiency on phytoplankton it is doubtful whether phytoplankton alone can supply the total energy requirement of the zooplankton trophic level even at Verem at this time of year.

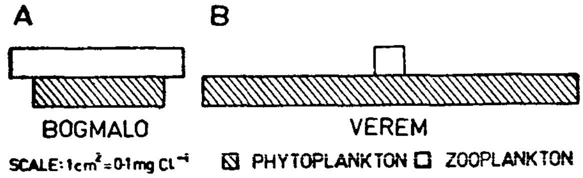

Fig. 5 — Phytoplankton and zooplankton standing stock data expressed as mgC l^{-1} at Bogmalo and Verem

Ryther and Menzel[16] have reported that living phytoplankton in the Arabian Sea represents no more than 10-20% of total organic matter except under conditions of a phytoplankton bloom and have pointed out the implications of this as regards food available for zooplankton. The data presented here, based on 2 diurnal studies, suggest that detrital matter may similarly play an important role in the community structure of the 2 areas sampled in the Goa waters. Further studies are in progress to test this hypothesis.

Acknowledgement

The authors thank Dr. S. Vijayaraghavan for help in estimating caloric values and Shri P. M. A. Bhattathiri for helpful discussions. They are grateful to Dr S. Z. Qasim for going through the manuscript and to Dr S. N. Dwivedi for encouragement.

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RELATIVE CONTRIBUTION OF NANNOPLANKTON TO THE PRIMARY PRODUCTION OF TWO ESTUARIES OF GOA

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ABSTRACT

The contribution of nannoplankton to the chlorophyll and primary production of the estuarine system of Goa has been described. The chlorophyll *a* concentration of nannoplankton ranged from 32.8 to 100% of the whole chlorophyll. The average organic production of nannoplankton is 271 in Cumbarjua Canal, 215 in Zuari and 209 (mgC $m^{-2}d^{-1}$) in Mandovi estuary. Average nannoplankton production consisted not less than 84.8% of the total primary production in any of the sectors of the system. The nutrient concentration was not found to be a limiting factor.

INTRODUCTION

Numerous investigations from neritic and oceanic waters of temperate and tropical regions have shown that nannoplankton contributes 80 to 100% of the total primary production Teixeira, 1963, (Anderson, 1965, Malone, 1971). Similar information was lacking from the seas around India until Qasim, Sumitra - Vijayaraghavan, Joseph and Balachandran (1974) studied the contribution of nannoplankters, to the organic carbon production in Cochin Backwater. These authors found that 45 to 96% of the production is due to nannoplankters and rest to microplankters. Sumitra Vijayaraghavan, Joseph and Balachandran (1974) reported that 36 to 94% of the photosynthetic carbon fixation from inshore regions of Cochin is due to nannoplankters. In order to obtain similar information from other areas the work was carried out in the waters around Goa. This paper presents information on the contribution of nannoplankters to the production and pigments of the Mandovi-Zuari estuarine system.

MATERIAL AND METHODS

Water sampling was done at fortnightly intervals from four depths representing 100%, 60%, 30% and 1% illumination levels. The observations were carried out at 5 stations during June-September (monsoon period) 1972. Stations 1 and 2 were in Mandovi, 3 in Cumbarjua and 4 and 5 in Zuari (Fig. 1). Production was measured by ^{14}C method. After incubation from midday to sunset the sample was passed through a 64 μm net before filtering on to a membrane filter paper. The radioactivity was estimated in a G.M. Counter. For estimating chlorophyll 0.5 l water screened through a 64 μm net was filtered on to a membrane filter. The chlorophyll was estimated by the method described by Strickland and Parsons (1968). Both ^{14}C uptake and chlorophyll concentrations were measured for the unscreened samples as well. Fortnightly values were pooled and averaged monthwise. Hereafter the nannoplankters will be denoted as filtered in comparison to the whole plankton as unfiltered

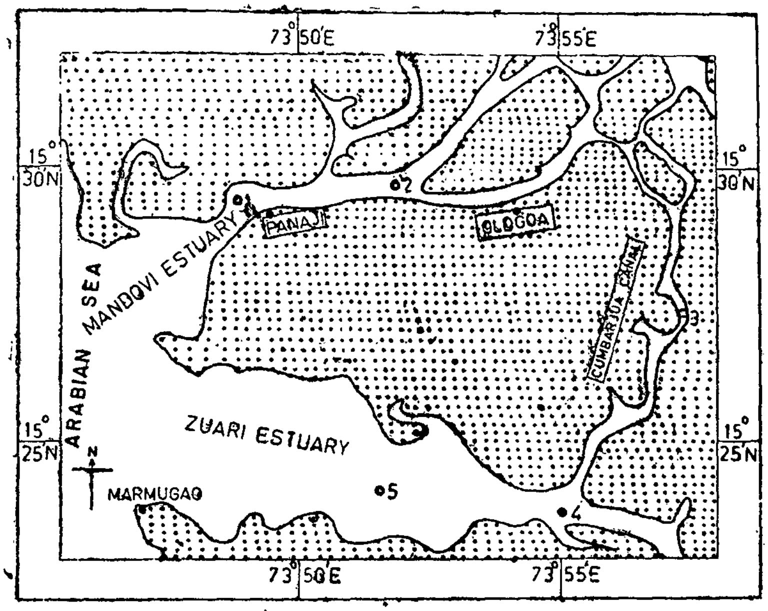

Fig. 1. Location of the 5 sampling stations in the estuarine system.

RESULTS

(a) Vertical distribution

The depthwise primary production and chlorophyll *a* concentration of the filtered and unfiltered samples are shown in Fig. 2. The nannoplankton production showed its maximum (1122 mgC $m^{-3}d^{-1}$) in Zuari during August and minimum (9.5) in Mandovi during July. In general production was at the minimum during July. The maximum production of chlorophyll was noticed at the surface (see Fig. 2)

(b) Column production and chlorophyll

The average column production of filtered samples is given in Table I. It is seen from the table that production at the estuarine mouths (stations 1 and 5) is generally less than that in mid-reaches (stations 2 and 4). The maximum production is in Cumbarjua Canal. The nannoplankton contributed 39 to 100% of the production in Mandovi, 72 to 100% in Cumbarjua and 70 to 100% in Zuari (see Fig. 3)

The chlorophyll *a* concentration ranged

Table I: The primary production (mgC $m^{-2}d^{-1}$) due to nannoplankton in the Mandovi–Zuari estuarine system

Stations	MONTHS				
	June	July	August	September	Average
1	261.30	26.66	137.83	220.58	161.59
2	693.28	32.26	90.27	213.10	257.23
3	348.40	127.19	424.32	184.94	271.21
4	129.19	63.15	644.28	197.62	258.56
5	90.60	150.13	272.48	175.57	172.24

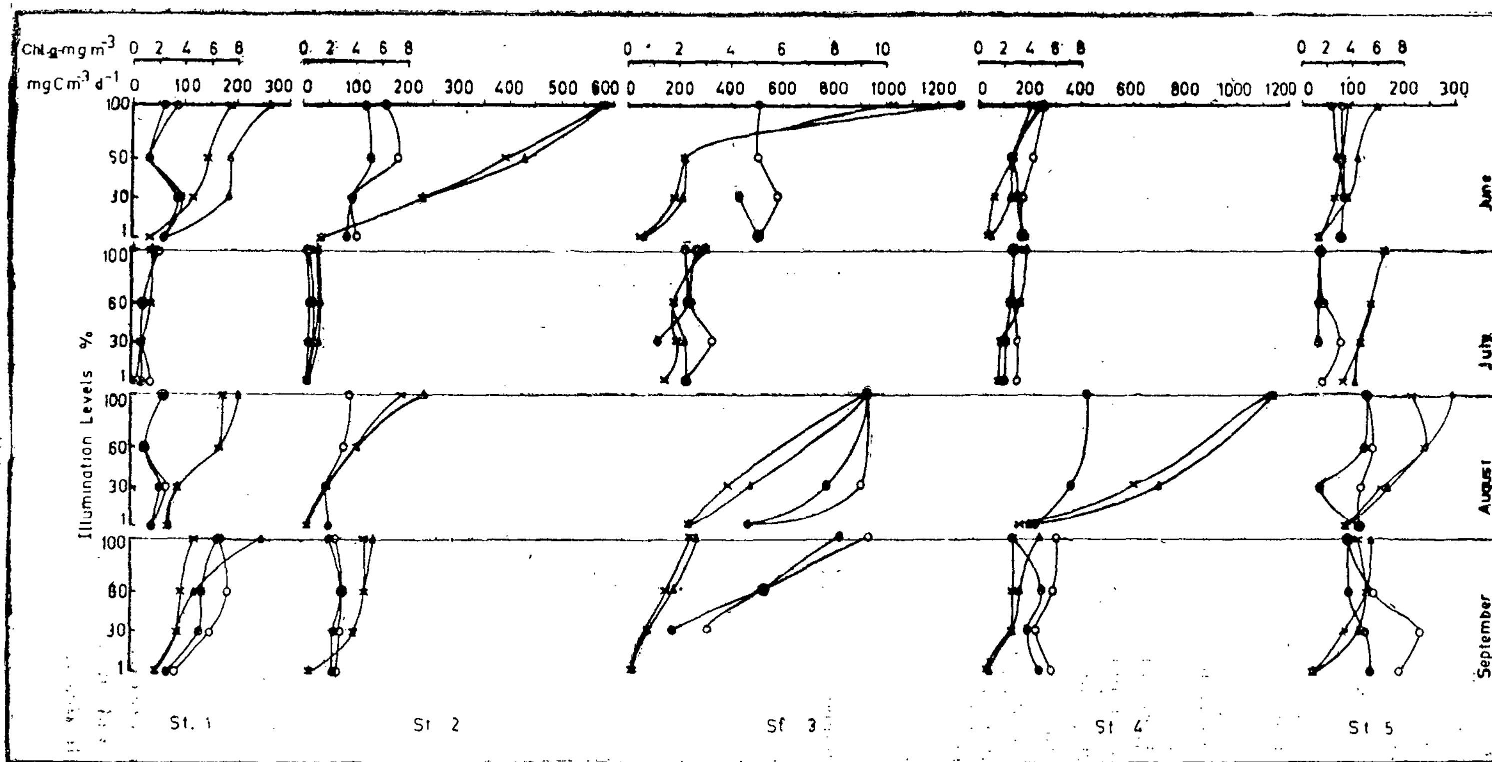

Fig. 2. Organic production and chlorophyll *a* concentration at 5 stations at different illumination levels during the four months : Production : Unfiltered (–▲–) and filtered (–×–) samples ; Chl. *a* : Unfiltered (–O–) and filtered (–●–) samples.

from 0·96 to 10·57 in Mandovi, 1·28 to 9·05 in Cumbarjua and 1·64 to 11·21 mg m^{-2} in Zuari. The minimum concentration was in July. Filtered samples contributed 81 to 97%, 45 to 91% and 87 to 100% of the chlorophyll from unfiltered samples from Mandovi, Cumbarjua and Zuari respectively.

DISCUSSION

The organic carbon production of the estuarine system is found to be mostly contributed by phytoplankters of small size (<64 μm). Since the average production (mgC $m^{-2}d^{-1}$) of nannoplankters during monsoon is 209 in Mandovi, 271 in Cumbarjua and 215 in Zuari as compared to the total production of 247, 316 and 249 respectively (Bhattathiri, Devassy and Bhargava, 1976), the nannoplankton production was not far from the total production. Similarly the chlorophyll concentration of the filtered samples show that nannoplankton contributes most of that from unfiltered samples. In this estuarine system it has been found that at the surface the contribution of nannoplankton to the total production vary from 49·3 to 100%. Most of the values are above 80%. Qasim, Sumitra - Vijayaraghavan, Joseph and Balachandran (1974) reported that in the Cochin Backwater the corresponding percentage ranged from 45–96. These indicate that in both the estuarine systems the contribution of nannoplankters is in the

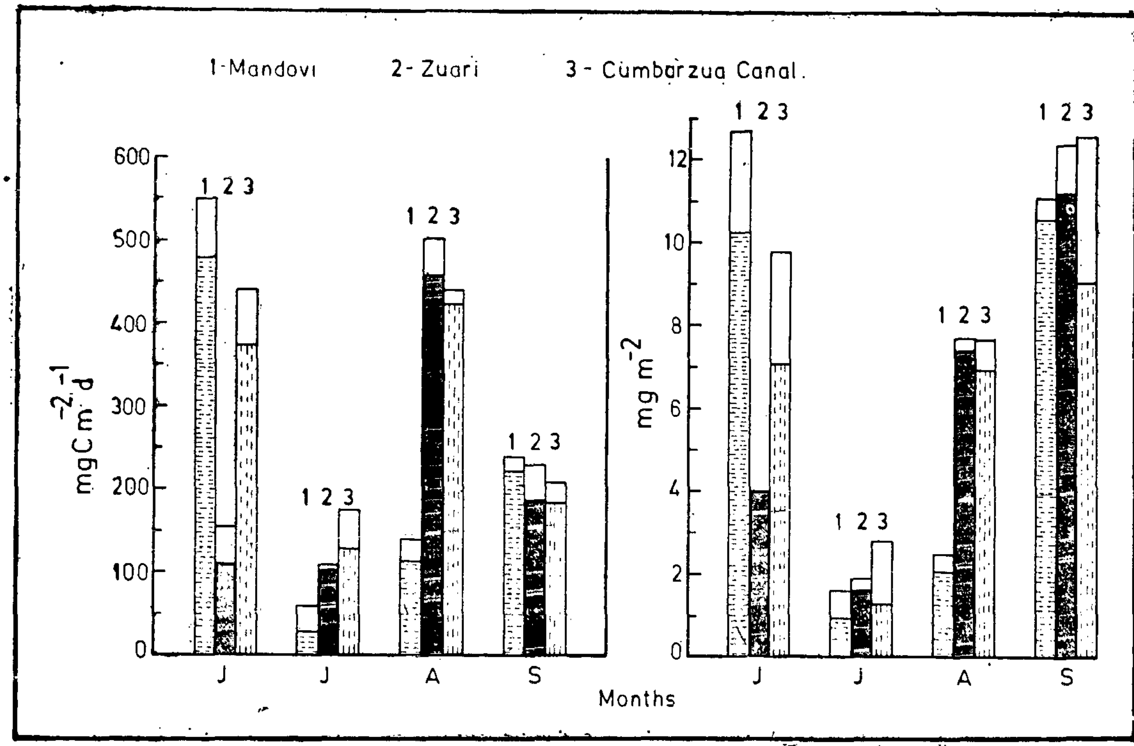

Fig. 3. Histogram showing the integrated values of organic production and chlorophyll *a* (unfiltered and filtered) in the three sectors of the estuarine system. The shaded portion indicates the contribution of filtered samples (nannoplankton).

same range. Pant, Bhargava and Goswami (1976) put the share of nannoplankton to total production as 90% in the estuarine and neritic waters of Goa. This conclusion was arrived at from the diel studies. The contribution of filtered samples to chlorophyll from unfiltered sample was found to be between 42 to 100% with most of the values above 70. From Cochin Backwater it has been shown that chlorophyll from nannoplankton varies from 55 to 86% of the total. In both these estuaries if the production and the corresponding chlorophyll from nannoplankton are compared it is found to be different; this is because of the variations in the production capacity with the size of the plankton (phytoplankters).

The nannoplankton production showed very little correlation with either PO_4–P or NO_3–N. A scatter diagram showed that production did not depend on the instantaneous concentration of the nutrients and did not increase as found by Malone (1971). Despite the low nitrate concentrations on certain occasions the ratio of nanno to total production was high, which is because of the fact that half-saturation constant for nitrate uptake is low for small cell-sized phytoplankters (Eppley, Rogers and McCarthy, 1969). The different factors controlling the dominance or absence of different sized phytoplankters have been discussed by Semina (1972), and Parsons and Takahashi (1973). Thus it has been pointed out that the mean cell size depends upon the velocity of water movement upwards. The author states that the cells are smaller if water velocities are higher regardless of its direction. Hydrodynamic factors also play an important role in controlling the cell size. But Parsons and Takahashi (1973) state that many factors other than mentioned by Semina have also to be considered. According to these authors the factors possibly contributing to the selectivity of size of the phytoplankters in an environment would be (i) the rate of nitrate or ammonium input to the cell, (ii) the extinction coefficient of the water, (iii) the mixed layer depth, (iv) the light intensity, (v) the sinking rate of phytoplankton and (vi) the upwelling velocity of the water.

During the present studies it has been found that the nitrate concentration from different location is always much more than 0.2 μg at/l (Bhattathiri, Devassy & Bhargava, 1976). Hence most of the time the nitrogen concentration is such as to promote the growth of larger phytoplankton, but this is not observed from the present values of production and chlorophyll. Further, the entire euphotic zone is well mixed and the attenuation coefficient is high as also the radiation values. Though most of the environmental factors are suitable for the growth of larger phytoplankton (see Parsons and Takahasi, 1973) it is noticed that in this estuarine system net plankton contributes very little to the production as well as to the chlorophyll concentration. Hence, there still may be some other factors which are decisive in the size of standing stock of phytoplankton and their contribution towards production and chlorophyll concentration.

As mentioned earlier nannoplankters are the major contributors for production and chlorophyll *a*. It is significant from the fact that the low area to volume ratio and smaller size of the nannoplankton enable them to utilize the nutrients and light in shallow turbid waters (Munk and Riley, 1952). However, it may be pointed that on the basis of food chain dynamics the efficiency of energy transfer to higher level will be less probably due to longer food chain which may affect the ecological efficiency in the estuarine system (Ryther, 1969). But it becomes easier for the organisms particulary larvae and filter feeders to consume these smaller cells which are distributed throughout the water column

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Seasonal Distribution of Phytoplankton Pigments in the Estuarine System of Goa

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Seasonal changes in the concentrations of chlorophylls and carotenoid were studied in the estuarine complex of Goa at 14 stations. Annual mean concentration of chl. *a* was 3·05, 4·42 and 4·12 mg/m³ in Mandovi estuary, Cumbarjua canal and Zuari estuary respectively with a peak in May. Chl. *a* increased towards the mid reaches of Mandovi estuary. Chl. *b* ranged between 0 and 5·48 mg/m³ while chl. *c* varied between 0 and 10 mg/m³. Annual mean of chl. *c* was 2·28, 2·69 and 3·03 mg/m³ in Mandovi estuary, Cumbarjua Canal and Zuari estuary respectively. Carotenoid values were low and ranged between 0 and 3·6 m-SPU/m³ with the peak in May in close relation to chl. *a*. Annual mean for Mandovi estuary, Cumbarjua canal and Zuari estuary was 1·10, 1·28 and 1·45 m-SPU/m³ respectively. Ratios of chl. *c* to *a* and carotenoid to chl. *a* were mostly less than unity except on few occasions. It was noticed that Mandovi waters are significantly different from those of Cumbarjua canal and Zuari estuary while no such difference was noticed between that of Cumbarjua canal and Zuari estuary indicating that the latter influences the chlorophyll concentration in the canal.

AMONG the estuaries in India, Cochin backwater on the west coast and Vellar estuary on the east coast have been studied fairly extensively. However, very little work has been done on other estuaries of India including the estuaries of Goa. The earlier work[1-4] includes chlorophyll distribution at one station each in Mandovi and Zuari estuaries and its diurnal variations. In the present communication, seasonal changes in surface phytoplankton pigments of the estuarine complex of Goa are presented in view of their importance in photosynthesis.

Description of area — Fig. 1 shows the location of the 2 estuaries and the connecting Cumbarjua canal in Goa. The mouths of the 2 estuaries are funnel-shaped and separated by a small 'Cabo' ridge. A fairly good account of the description is given by Parulekar and Dwivedi[5].

Goa receives 80% of its annual rainfall (3000 mm) from June to August. But Mandovi gets fresh water throughout the year through its tributaries while Zuari receives most of its freshwater during the monsoon. In Cumbarjua canal, water enters through Zuari during the high tide and reaches as far as its mouth in Mandovi and at the low tide the flow is almost reversed[6]. The estuarine system receives domestic sewage and also wastes from the boat yards, etc. at different places. The depth in the complex ranges from 2·5 to 12 m.

Materials and Methods

In this estuarine system 12 stations, almost equidistant from each other, were fixed within a distance of approximately 50 km (Fig. 1). There were 5 stations in Mandovi, 4 in Zuari and 3 in Cumbarjua canal. Stations 1 and 2 were operated along both the banks and hence were numbered A and B. Stations 5 and 9 were located in the mixed zone, i.e. at the openings of the canal on either side.

Samples were collected once in a fortnight for recording surface temperature, dissolved oxygen, salinity and pigments from June 1971 to May 1972. Salinity, oxygen and chlorophyll (chl.) were estimated by the usual methods as described by Strickland and Parsons[7]. Carotenoids were calculated from the formula given by Parsons and Strickland[8] wherein the optical density at 510 nm was omitted. The fortnightly values of chlorophyll and carotenoids were pooled for calculating the monthly mean values. No observations could be made during March.

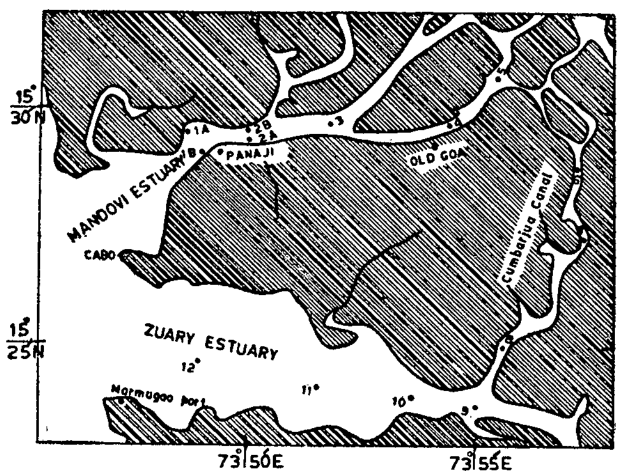

Fig. 1 — Estuarine system of Goa showing the location of 14 sampling stations

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Attenuation coefficient (k) was calculated by the formula $k = 1{\cdot}5/D$ as given by Qasim *et al.*[9] where D is the Secchi disc reading in m. The whole year was divided into 3 seasons — monsoon (June to September), postmonsoon (October to January) and premonsoon (February to May).

Results and Discussion

Chlorophyll a — Monthly and stationwise variations of this pigment are shown in Figs. 2 and 3. A clear seasonal cycle was noticed with maximum chl. *a* concentration in the premonsoon followed by monsoon and postmonsoon. The peak was seen in May just before the monsoon. Earlier, maximum chl. *a* was reported[2] in May in both the estuaries.

Cumbarjua canal had the maximum concentration (11·86 mg/m^3) of chl. *a* followed by Zuari and Mandovi estuaries. In Mandovi, chl. *a* increased towards the upper reaches. Between stations 1A, 1B and 2A and 2B, no significant difference in chl. *a* concentration was noticed except in September when at station 1A, it was low (0·56 mg/m^3) while at station 1B it was relatively high (6·05 mg/m^3). Similarly, in January chl. *a* was high at station 2A than at 2B. In Zuari estuary, chl. *a* was high at station 9, particularly during the monsoon.

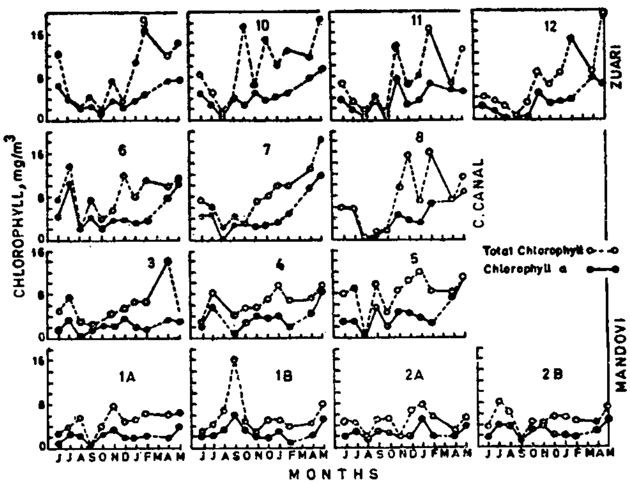

Fig. 2 — Monthly variations of chl. *a* and total chlorophyll at all the stations

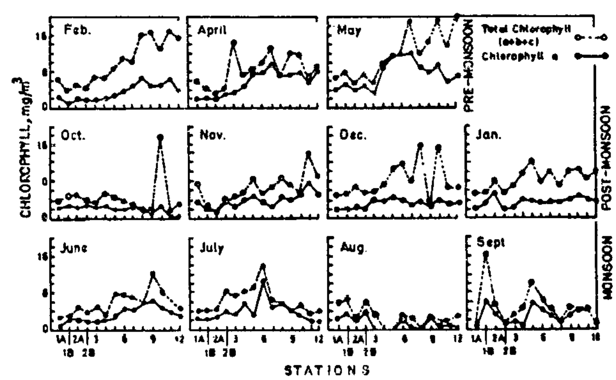

Fig. 3 — Stationwise variations of chl. *a* and total chlorophyll during different seasons

Annual mean concentration of chl. *a* was 3·05 (±2·1), 4·42 (±3·23) and 4·12 (±2·65) mg/m^3 in Mandovi, Cumbarjua canal and Zuari respectively. Wide variations (10-12 times) were seen in Zuari during monsoon and postmonsoon. In Mandovi during premonsoon and in Cumbarjua during the monsoon, the fluctuations were of the order of 10 times. During the rest of the period fluctuations of the order of 3-6 times for the entire area were observed. A t-test between the mean chl. *a* values in different sections indicated that the variations were significant at a probability level of 0·05. Chl. *a* values were significantly different between Mandovi and Zuari and Mandovi and Cumbarjua canal which might be the result of different phytoplankton populations or perhaps due to the differences in the environmental conditions of the 2 estuaries. Differences between Zuari and Cumbarjua canal, on the other hand, were not significant. This indicated that Zuari influenced the Cumbarjua canal in chlorophyll distribution, probably because water flows into the canal from Zuari[6].

Concentration of chl. *a* in this system compared well with those of Kille backwaters of Porto Novo where a maximum of 12·7 mg/m^3 was recorded by Bhatnagar[10]. Krishnamurthy[11] recorded chl. *a* concentration to be 21·5 mg/m^3 in Porto Novo waters, and recently as high as 39·8 mg/m^3 of chl. *a* was recorded[12] in Vellar estuary. In Cochin backwaters[13] the concentration was found to be 5·7 mg/m^3 in November and 7·34 mg/m^3 in July.

Chlorophyll b — Chl. *b* concentration was low (<1 mg/m^3; Table 1) and varied widely. In Mandovi, its concentration increased towards the mid-reaches except at station 1B where on one occasion it was unusually high (5·49 mg/m^3).

In Cumbarjua canal the maximum was noticed in December and minimum in July and April, and the chl. *b* concentration was generally higher than in Mandovi estuary.

In Zuari, chl. *b* maximum was noticed in May. From July to November, the concentration was low (Table 1). Unlike in Mandovi chl. *b* concentration in Zuari increased towards the mouth region. In general, higher values of chl. *b* were observed in Zuari than in Mandovi and Cumbarjua canal.

When compared with chl. *a*, chl. *b* concentration was always very low except on some occasions when it reached a concentration of 5·49 mg/m^3. Chl. *b* concentration was maximum in postmonsoon and minimum in monsoon. In Cochin backwater it ranged between 0 and 2·74 mg/m^3 during monsoon[14] while in Vellar estuary a concentration of 13·4 µg/litre was recorded in July by Krishnamurthy and Sundararaj[13].

Chlorophyll c — Monthly mean values of chl. *c* are given in Table 1. Chl. *c* distribution was irregular with annual mean values of 2·28 mg/m^3 in Mandovi, 2·69 mg/m^3 in Cumbarjua canal and 3·03 mg/m^3 in Zuari. In Mandovi, the peak was noticed in January at most of the stations while in Cumbarjua canal and Zuari, the maximum concentration was obtained in February. Like chl. *a*, chl. *c* concentration also increased towards the upper reaches in Mandovi. In Cumbarjua canal, stations

TABLE 1 — DISTRIBUTION OF CHL. *b*, CHL. *c* AND CAROTENOIDS

Month*	Stations													
	1A	1B	2A	2B	3	4	5	6	7	8	9	10	11	12
							CHL. *b* (mg/m³)							
1971														
June	0·35	0·03	0·00	0·12	0·47	0·13	0·21	0·71	0·75	0·01	2·28	0·27	0·25	1·66
July	0·00	0·33	0·05	0·49	0·23	0·11	0·96	0·09	0·00	0·00	0·00	0·4	0·25	0·13
Aug.	0·43	0·62	0·01	0·09	0·02	0·00	0·00	0·11	0·45	0·00	0·1	0·04	0·11	0·74
Sept.	0·04	5·49	0·92	0·24	1·14	0·61	2·35	0·85	1·18	0·00	0·7	0·29	0·46	0·52
Oct.	0·64	0·6	1·1	0·89	0·61	1·13	0·88	0·74	0·29	0·41	0·78	3·65	0·75	0·46
Nov.	0·57	0·47	0·06	0·2	0·45	0·89	1·41	0·65	0·59	0·81	0·56	0·58	0·00	0·00
Dec.	0·69	0·92	0·77	0·93	0·87	0·62	0·15	2·05	0·54	2·05	0·22	1·5	0·41	1·56
1972														
Jan.	0·39	0·07	0·00	0·47	0·53	0·47	1·38	0·56	1·4	0·02	1·41	0·58	0·42	1·03
Feb.	0·64	0·43	0·72	0·09	1·01	0·73	1·15	1·28	0·16	1·13	0·89	0·67	0·00	1·5
April	0·73	0·00	0·4	0·00	1·21	0·00	0·51	0·05	0·00	0·29	0·01	0·37	0·00	0·00
May	0·88	0·12	0·00	0·82	0·14	0·00	0·34	0·42	1·19	1·64	2·07	2·55	1·63	1·83
							CHL. *c* (mg/m³)							
1971														
June	1·31	0·74	2·8	1·81	2·84	0·7	3·77	2·2	1·96	0·00	3·53	3·18	2·8	0·00
July	1·63	1·73	1·38	3·77	3·84	2·2	5·03	2·86	1·43	0·1	0·00	1·6	1·05	1·91
Aug.	2·7	2·82	0·52	2·33	2·57	0·00	0·00	1·07	1·53	0·06	0·13	1·12	0·9	1·56
Sept.	0·00	4·88	1·14	0·00	0·00	2·95	1·77	2·52	0·36	0·00	1·11	0·22	0·00	0·00
Oct.	0·93	1·17	1·49	0·27	0·51	1·68	1·85	0·86	0·06	0·00	0·08	5·55	0·14	1·08
Nov.	3·52	0·22	0·00	0·27	1·82	0·74	2·29	1·02	3·76	3·36	2·86	0·78	6·27	3·85
Dec.	2·79	2·2	3·75	2·49	1·29	2·85	5·79	5·84	4·56	9·98	0·79	9·82	1·62	1·94
1972														
Jan.	2·92	2·51	2·64	3·02	4·00	5·4	7·29	3·91	5·40	3·95	5·45	5·17	4·14	2·65
Feb.	3·21	2·61	2·76	2·72	4·06	4·06	4·81	6·23	5·13	8·23	5·72	7·13	5·3	4·95
April	3·3	1·2	0·68	1·41	9·66	2·61	0·18	1·95	3·4	9·00	4·56	3·55	0·95	1·09
May	1·44	2·52	1·54	1·69	2·13	2·02	0·00	0·01	5·32	1·87	5·33	7·33	5·4	10·6
							CAROTENOID (m-SPU/m³)							
1971														
June	0·72	1·46	1·5	1·28	1·14	0·7	1·17	1·82	1·89	1·2	2·5	1·87	1·38	0·64
July	1·25	0·93	1·38	1·54	0·9	1·71	1·64	1·11	0·00	0·00	0·00	0·00	0·62	0·54
Aug.	1·92	1·52	0·77	2·23	1·6	0·00	0·77	1·69	3·48	0·00	1·53	3·58	2·3	2·89
Sept.	1·3	2·1	1·75	0·72	3·04	2·27	1·18	1·44	0·09	0·54	1·53	0·24	0·45	0·37
Oct.	0·31	0·47	0·33	0·36	0·69	1·08	0·53	0·44	0·88	0·41	0·48	1·76	0·61	0·48
Nov.	0·4	0·29	0·46	1·06	0·89	1·69	0·34	0·18	0·79	0·55	0·24	1·44	1·46	0·88
Dec.	0·45	0·58	0·55	0·41	1·03	0·75	1·03	1·93	0·39	0·31	1·26	0·57	1·14	0·84
1972														
Jan.	0·4	1·1	1·05	0·78	0·62	0·83	0·62	0·8	1·39	0·44	0·68	1·91	2·56	0·83
Feb.	1·08	0·26	0·98	0·68	0·74	0·64	0·46	0·22	1·86	2·72	2·45	2·83	2·92	2·21
April	1·18	0·96	0·77	0·96	1·7	1·5	1·81	1·79	2·48	1·87	2·64	2·51	2·1	2·32
May	1·53	1·96	1·53	0·81	1·68	2·68	3·55	3·41	2·48	2·28	1·30	1·96	1·23	0·87

*No data for March 1972.

6 and 7 showed high values throughout the year but at station 8 high values were seen from November to February and also in May. During the other months it was almost negligible. In Zuari, low concentration was observed in the monsoon while in post and premonsoon periods, the water was rich in chl. *c*. High values of chl. *c* in Zuari and Cumbarjua canal may be due to high suspended sediments including dead chlorophyll and degraded products having more chl. *c* than chl. *a* as pointed out by Humphrey[15]. High values of chl. *c* (18·66 mg/m³) were noticed[14] in Cochin backwaters during monsoon. Krishnamurthy[11] reported chl. *c* values ranging between 2·70 and 26·5 μg/litre in Vellar estuary.

Ratios of chl. *c* to chl. *a* were fluctuating as also noted by Qasim and Reddy[14] in Cochin backwaters and Yentsch and Scagel[16] in waters of East Sound, Washington. This ratio indicates the physiological state of phytoplankton population and for a healthy crop it is less than unity. In this estuarine system this ratio was generally less than one except during the postmonsoon months.

Distribution of total chlorophyll ($a+b+c$) was similar to chl. *a*, being maximum in May and minimum in August at most of the stations (Figs. 2 and 3). Variation in the estuarine system as a whole was large (0-20 mg/m³). Annual mean values for Mandovi, Cumbarjua canal and Zuari sector were 6·01 (±4·02); 7·86 (±5·08) and 8·12 (±5·54) mg/m³ respectively showing that Zuari had more chlorophyll concentration while Mandovi the least. The *t*-test at 0·05 *P* level on the data of total chlorophyll has again confirmed the significant variations between Mandovi and Cumbarjua canal and Mandovi and Zuari estuaries. No significant variations were noticed between the Canal and Zuari chlorophyll concentration. This, therefore, also indicated the different ecological conditions in this estuarine system.

Plant carotenoids — Monthly variations of carotenoid (0-3·6 m-SPU/m^3) are given in Table 1. Peak concentration was noticed in May when there were maximum chl. *a* and *c* in the water. In August and September too, the values were high. Minimum values were noticed in postmonsoon months. Annual mean values for Mandovi, Cumbarjua canal and Zuari was found to be 1·1, 1·28 and 1·45 m-SPU/m^3 respectively. This showed the highest concentration in Zuari and lowest in Mandovi as in the case of total chlorophyll. Further, stations 3 and 4 in Mandovi, station 7 in Cumbarjua canal and station 12 in Zuari, showed maximum annual mean. The carotenoid values in this estuarine system was relatively less when compared to other Indian waters. It ranged between 5 and 8 m-SPU/m^3 in Cochin backwaters[14] and 0 to 5·25 m-SPU/m^3 in Porto Novo waters[11].

Ratio of carotenoid to chl. *a* was mostly less than 1 except in August and September when it was high (3 to 10·54) at certain stations. This high ratio may be due to the stirred up sediments and degradation product of chl. *a* which increases the carotenoid value as suggested by Qasim and Reddy[14] who also reported high ratio between 1·98 and 3·05 in Cochin backwaters during monsoon months. Krishnamurthy and Sundararaj[12] found this ratio to be less than 1 in Porto Novo backwaters. In the Goa waters, this ratio remained less than 1 for the most part of the year indicating active physiological state of phytoplankton.

Chlorophyll and environment — The water temperature ranged between 24·0° and 31·8°C and dissolved oxygen content varied between 1·93 and 7·3 ml/litre. Temperature is known to affect only indirectly through metabolism while oxygen is the direct result of photosynthesis.But no correlation with chlorophyll was noticed in this case.

Salinity, however, is an important parameter in an estuarine environment. Its variations were large depending on the season, being highest (36·77‰) in premonsoon and lowest (0·12‰) in mosoon. Salinity was always higher in Zuari and least in Cumbarjua canal. In Cumbarjua canal where salinity was low, the chlorophyll concentration was more but when chl. *a* was plotted against salinity no correlation was seen for the entire estuarine system.

Other important factors are light penetration and turbidity. As calculated by Secchi disc readings the attenuation coefficient (k) was high throughout the year as shown below :

Season	k (range)		
	Mandovi	Zuari	Cumbarjua canal
Premonsoon	5·55-0·49	7·50-0·74	4·17-0·67
Monsoon	4·69-1·43	8·82-1·12	5·17-1·94
Postmonsoon	3·75-0·48	3·75-0·65	4·69-0·81

High turbidity in this system is caused by suspended material and affected the chlorophyll estimations. Since the dead chlorophyll and its degraded products present in suspended matter are simultaneously estimated, increased chlorophyll concentrations were estimated. This might be one of the reasons for higher values of chlorophyll in Cumbarjua canal and Zuari estuary.

Chlorophyll distribution showed differences in space and time in the estuarine complex of Goa. The distribution was irregular with fluctuating pigment ratios but the values were comparable with those of other estuaries and backwaters of India. The difference in chlorophyll concentration from one part of the estuarine complex to the other makes it an interesting study. Since this study was confined to surface waters only, a detailed investigation of plant pigment from the entire water column is warranted.

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Primary Productivity in the North-Eastern Arabian Sea

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Primary productivity, chlorophyll *a* and related data from 23 stations in the NE Arabian sea are presented. Productivity in the waters of shelf region averages 474·56 mgC m^{-2} d^{-1}, and is almost thrice the offshore average of 164·39. Correlation between chlorophyll *a* and primary production is highly significant. Assimilation number in the shelf region averages 96 and 22 offshore; the variation is attributed to the distribution of nannoplankton. Relationship of light intensity, POC and nutrients with productivity are briefly discussed.

PRIMARY productivity measurements from the coastal waters of India are still meagre. Although a good deal of information is available from the Indian Ocean[1,2] in general there are still large lacunae, especially of the Indian coast. The present study has been made to collect further information in this direction.

Primary productivity, chlorophyll *a*, pheophytin and particulate organic carbon (POC) were measured at 23 stations in the NE Arabian Sea. The data were collected in 3 cruises of *RV Gaveshani* (2nd cruise — February 1977; 3rd cruise — March 1977 and 12th cruise — November 1977). The station locations are given in Fig. 1.

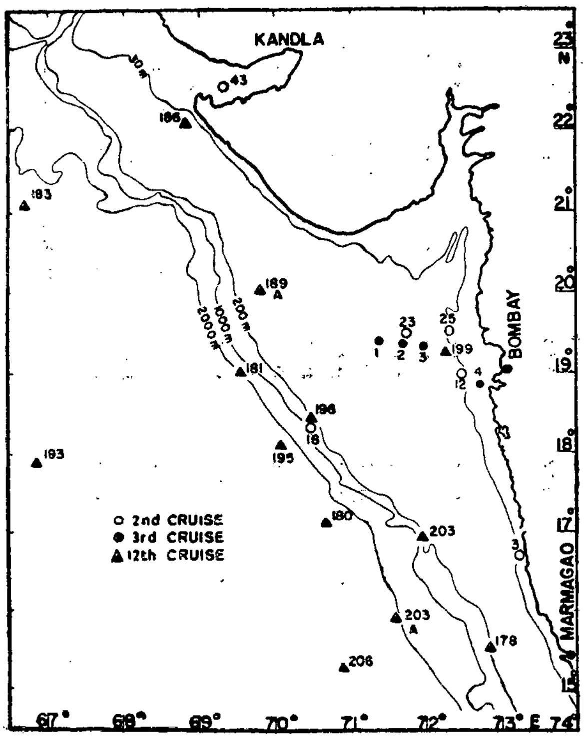

Fig. 1 — Station locations

Samples were collected from the optical depths of 100, 60, 30, 16 and 1% light penetration. Primary production was measured by incubating the samples for 24 hr under simulated *in situ* conditions. Chl. *a* was measured with Turner Designs fluorometer and pheophytin correction applied. POC was determined by wet acid digestion and colorimetry.

South of Ratnagiri, off Wagapur Point (station 3; cruise 2nd), primary productivity in the inshore waters at the surface was 88·5 mgC m^{-3} day^{-1} and in the column, 445·35 mgC m^{-2} day^{-1} (Table 1). Chl. *a* and pheophytin were not detectable at the surface. Nutrient concentrations were low.

Off Bombay, during February-March, production was generally high (av. 46·14 mgC m^{-3} day^{-1} at the surface 636·51 mgC m^{-2} day^{-1} in the column). Correspondingly, chl. *a* averaged 0·27 mg m^{-3} at the surface and 5·04 mg m^{-2} in the column and pheophytin 0·54 and 5·77 respectively. POC was low (237·7 mg m^{-3} and 8·15 gm^{-2} at the surface and column respectively). Nutrient values were high (e.g. PO_4-P, surface: 0·9 and IMC: 1·14 µg-at l^{-1}). In view of the proximity to the shore and concomitant high concentrations of nutrients, production off Bombay, on the average, was high notwithstanding the wide variations encountered. High productivity was recorded very close to Bombay at stations 12 (February) and 199 (November) — 98·97 and 57·18 mgC m^{-3} day^{-1} at surface and 1552·15 and 556·23 mgC m^{-2} day^{-1} in the column respectively. Chl. *a* values were also correspondingly high (Table 1).

In the Gulf of Kutch proper only 1 station was occupied (No. 43). The waters were very turbid and the euphotic zone was only 1·5 cm although depth to the bottom was 29 m. Nutrient concentrations were high throughout the water column (surface to bottom) due to the influence of the Indus river discharge on the north. But production was low: 66·05 mgC m^{-3} day^{-1} near the surface, 40·62 at 1·5 m and 80 mgC m^{-2} day^{-1} integrated for the euphotic zone. Obviously, light was a limiting factor because of the high turbidity which in turn was due to the constant churning up of bottom sediments caused by the prevailing tidal bores on the one hand and the Indus river land runoff on the other.

In the north-eastern Arabian Sea, productivity in the shelf region was much higher than offshore. In the present study, the average value of 14 stations on the shelf for the surface was 40·69 mg as compared to 4·9 mg offshore (9 stations). Similarly, column productivity was 474·56 being 3 times higher than the offshore value of 164·39 mgC m^{-2} day^{-1}.

Chl. *a* concentration varied from 0 to 1·5 mg m^{-3} at the surface. Higher concentrations, however, were encountered at lower depths. There was a very positive correlation significant at 0·001 level between chl. *a* and primary productivity at various light penetration depths as well as over the euphotic column (integrated). Correlation between light intensity and primary productivity was positive (significant at 0·02 level) but there was no correlation between light intensity and chl. *a* concentration at different depths. Mean values of primary production

TABLE 1 — PRODUCTIVITY AND NUTRIENT DATA AT VARIOUS STATIONS

Station No.	Surface: Primary productivity mgC m^{-3} day^{-1}	Surface: Chlorophyll *a* mg m^{-3}	Surface: Pheophytin mg m^{-3}	Surface: POC mg m^{-3}	Surface: PO_4-P µg at l^{-1}	Surface: NO_3-N µg at l^{-1}	Surface: NO_2-N µg at l^{-1}	Surface: NH_4-N µg at l^{-1}	Column: Primary productivity mgC m^{-2} day^{-1}	Column: Chlorophyll *a* mg m^{-2}	Column: Pheophytin mg m^{-2}	Column: POC gC m^{-2}	Column: PO_4-P* µg at l^{-1}	Column: NO_3-N* µg at l^{-1}	Column: NO_2-N* µg at l^{-1}	Column: NH_4-N* µg at l^{-1}
2ND CRUISE																
3	88·52	—	—	—	0·19	0·09	—	0·56	445·35	6·87	8·33	—	0·22	0·22	—	1·26
12	98·97	0·56	1·91	—	0·65	2·72	0·17	1·45	1552·15	12	13·61	—	0·71	2·69	0·19	0·7
18	4·36	—	—	—	0·21	1·19	ND	0·92	387·08	15·52	8·97	—	0·76	2·51	ND	0·88
23	38·06	0·42	0·91	—	—	—	—	—	579·1	1·83	7·11	—	—	—	—	—
25	62·35	—	—	—	1·9	2·96	0·48	2·28	873·65	—	—	—	2·25	3·22	0·71	2·95
43	66·05	0·21	0·69	—	1·28	2·4	0·56	2·17	80	0·52	1·73	—	1·44	3·12	0·66	1·99
3RD CRUISE																
1	6·71	0·07	0·03	233·1	0·42	1·59	0·07	4·6	202·79	4·34	3·22	13·65	0·73	2·5	0·24	3·12
2	6·29	0·08	0·03	143	0·31	0·79	0·03	1·83	326·77	5·18	4·91	8·25	0·71	3·2	0·09	1·93
3	41·08	0·2	0·24	274·6	0·72	2·51	3·44	2·21	637·99	5·54	5·49	8·12	1	3·02	1·11	2·26
4	69·51	0·29	0·12	299·9	1·42	6·01	0·47	3·58	283·15	1·36	0·55	2·07	1·44	6·11	0·54	3·4
12TH CRUISE																
178	3·58	0·06	0·04	725	0·29	ND	ND	0·38	210·17	6·23	8·63	70·97	0·81	ND	ND	ND
180	4·16	0·02	0·04	221	0·13	0·76	0·22	1·5	128·51	8·45	3·42	32·67	0·7	0·15	0·19	0·61
181	2·88	0·07	0·05	504	0·21	0	0·4	0·38	118·91	6·37	9·34	30·71	0·77	1·5	0·49	0·41
183	3·96	0·09	0·01	536	0·36	0	0·49	8	111·76	4	5·11	20·1	0·92	0·16	0·29	0·5
186	16·11	0·17	0·1	882	0·47	0	0	9·06	312·07	10·92	7·96	18·47	0·5	0·36	ND	9·68
189 A	8·67	0·09	0·03	32	0·13	0	0·03	10·27	177·4	6·86	4·34	25·9	0·5	0	0·11	6
193	6·01	0·04	0·03	315	0·27	3·49	0·28	14·19	182·83	5·33	5·57	30·34	0·97	3·03	0·2	14·5
195	4·5	0·05	0·03	252	0·21	0	0·3	5·13	120	5·09	6·4	28·1	0·33	6·08	0·37	8·87
196	5·37	0·12	0·06	126	0·27	0	0·3	13·29	99·58	8·93	2·49	16·3	0·59	1·17	0	11·44
199	57·18	1·5	0·3	252	0·33	1·53	NO	4·68	556·23	28·8	2·1	13·5	0·64	0·65	ND	4·98
203	5·74	0·08	0·03	189	0·12	1·4	0·12	9·06	230·08	4·25	5·54	9·7	0·96	3·32	0·29	6·54
203 A	8·02	0·04	0·06	284	0·12	0·85	0·06	12	257·64	12·87	8·15	21·87	0·42	4	0·12	4·97
206	7·68	0·08	0·02	504	0·11	ND	0·06	4	297·89	21·07	8·66	34·85	0·43	ND	ND	—

*Integral mean concentration values; — = no data; ND = not detectable.

and chl. *a* for all stations at different light penetration depths are as follows:

Light penetration (%) depth	Primary productivity mg/m³	Chl. *a* mg/m³
100	26·77	0·212
60	12·29	0·282
30	11·54	0·241
16	9·29	0·261
1	5·47	0·193

The assimilation number (AN — primary productivity per unit chl. *a*) in the column averaged 96 in the shelf region varying from 24 at the deepest station to 208 at the shallowest station. Offshore, the AN averaged 22 varying from 11 to 34. This would indicate that the shelf productivity was due not only to chl. *a* but also to other accessory pigments. Earlier observations in the nearshore waters of Arabian Sea[3,4] showed that nannoplankton, composed mainly of flagellates that contain accessory pigments like other chlorophylls, xanthophylls, carotenoids, etc., accounted for 40-100% of the primary production. Our preliminary observations, on the other hand, show that the contribution of nannoplankton in the offshore waters is relatively less. This, to a certain extent, accounts for the low AN in the deeper waters. It is further observed that liberation of extracellular carbon per unit chl. *a* is much less in the shelf region as compared to offshore. This also would account for the observed lower values of carbon particulate fixation per unit chl. *a* offshore, where carbon assimilated during photosynthesis is simultaneously lost in extracellular liberation.

Correlation between light intensity and primary productivity was significant at 2·5% level (correlation coeff. 0·21 for n 107). However, the correlation between light intensity and chl. *a* distribution was not significant implying a patchy distribution of chlorophyll in the euphotic zone.

The pheophytin distribution followed the same trend as chl. *a*.

POC values (Table 1) did not show significant correlation with chl. *a* or productivity, either at the surface or in the column. Its distribution did not show any clear trend in the shelf or offshore. Similarly, nutrient concentrations (PO_4-P, NO_3-N, NO_2-N and NH_4-N) also had no significant relationship with productivity or chl. *a*, indicating that nutrients are not a limiting factor for production during this study. They varied widely within stations and between stations (Table 1).

From the present data, the average primary productivity for the shelf region of Maharashtra and Gujarat is calculated as 474·56 mgC m^{-2} d^{-1}. This value is considerably higher than Kuzmenko's[5] range of <100 mg. Likewise, the present average of 1054·19 mgC m^{-2} d^{-1} found off Bombay is higher than Kuzmenko's range of 500 mg[5]. His range for waters off Gulf of Kutch is very high (>1000 mg) and for a station at the entrance of the Gulf he reported 2·23 gC m^{-2} d^{-1} (ref. 5). The station in the present study was well inside the Gulf with a productivity of 80 mgC m^{-2} d^{-1}.

Silas[6] reported the average primary productivity for the west coast within 50 m depth as 1·24 and between 50 and 200 m depth as 0·63 gC m^{-2} d^{-1}. These values are very high in comparison to the present values. In this connection, the statement by Krey and Babenerd[1], "the experimental techniques, especially the measurements of primary production by ^{14}C experiments and in particular, the incubation techniques, analytical methods and laboratory equipment employed differ so widely that data standardization is virtually impossible" is significant. Photosynthetic efficiency of phytoplankton depends on the time of sampling (whether day or night), season, hydrographic features, water mass characteristics and location of the station and unless the methodology is standardized, it is not always meaningful to compare the data of different authors. "Variability in time and heterogeneity in space which are naturally inherent in oceanic biological parameters"[1] make comparison of data rather troublesome.

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Productivity Studies in the Southeastern Arabian Sea

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Primary productivity, chlorophyll *a*, pheophytin, particulate organic carbon (POC), inorganic phosphate, ammonia, nitrate and zooplankton from 14 stations in October 1976 and 14 stations in December 1976 in the southeastern Arabian Sea were estimated. In the euphotic zone, daily primary productivity averaged 134 mgC/m²/day in October and 357·9 mgC/m²/day in December and chl. *a* averaged 6·44 mg/m² and 10·6 mg/m² respectively. Concentration of nutrients, likewise, were higher in December than in October, but POC was higher in October. Highly significant correlations between primary productivity and chl. *a* and between chl. *a* and nitrate and chl. *a* and ammonia were observed.

STUDIES on primary production and phytoplankton in Indian seas were relatively meagre compared to those on zooplankton. During the International Indian Ocean Expedition also, primary productivity studies did not receive adequate attention in the Indian waters. In the southeastern Arabian Sea, Anton Brunn[1] occupied 5 stations in her II cruise and Meteor[2] another 5 stations. Radhakrishna[3] investigated productivity and related factors at 13 stations on the southwest coast of India.

Nair[4] tabulated data on column productivity from 31 stations in this area. However, seasonal coverage of this area was still meagre. Besides, the factors affecting primary production were also not well covered. Hence, primary production together with related parameters like chlorophyll *a*, pheophytin, particulate organic carbon (POC), macronutrients and zooplankton were studied during the 10th and 13th cruises of *RV Gaveshani* and these results are reported here.

Materials and Methods

Samples were collected from 5 light penetration depths (100, 60, 30, 16 and 1%) at 14 stations during October 1976 and 14 stations during December 1976. Of these, only 3 stations occupied during the latter period were located in the continental shelf. The area covered was between 7°, 15°30′N and 71°E and the west coast (Fig. 1). Light penetration depths were determined by a 'Kahlsico' submarine photometer and by Secchi disc when the photometer could not be operated. Primary productivity was measured by ^{14}C method; samples were incubated for 24 hr under simulated *in situ* conditions employing appropriate neutral density filters. Dark assimilation was corrected for Chlorophyll *a* (chl. *a*) and pheophytin were estimated by fluorometry and POC by wet oxidation and sepectrophotometry. Inorganic phosphate, ammonia, nitrite and nitrate were estimated by standard methods[5]. Zooplankton samples were collected with IOS net from 150 m depth to surface and from near the bottom at shallow stations; biomass was determined by displacement method.

Results and Discussion

Studies were conducted at 28 stations and the results are given here separately for the shelf

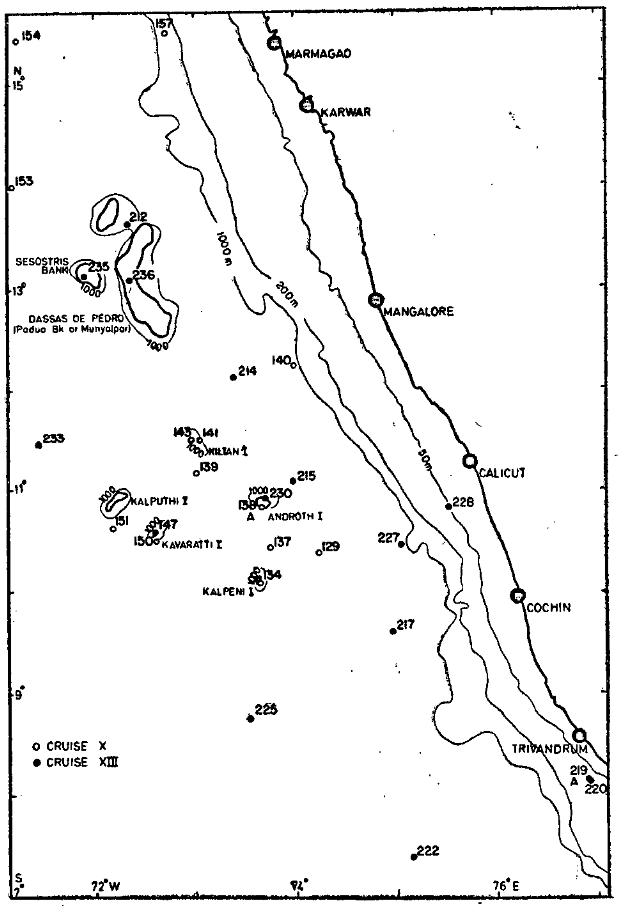

Fig. 1 — Station locations

region and beyond. Stations in the shelf region were highly productive. Thus at station 228 south of Calicut, primary productivity was quite high: 42·23 mgC/m^3/day at the surface and 1166·65 mgC/m^2/day in the column. Chl. *a* also was high. At the other 2 shelf stations (219A and 220 — south of Trivandrum), the average productivity and chl. *a* were high in the column: 607·12 mgC/m^2/day and 15·39 mg/m^2 respectively.

At 25 stations situated beyond the continental shelf daily productivity at the surface varied from 0·33-28·32 mgC/m^3/day (av. 5·37) and in the column from 21·8-676·07 mgC/m^2/day (av. 180·3). In comparison with the north Arabian Sea[6,7], the ranges encountered were less. Chl. *a* values were less variable: surface — 0·023 to 0·165 mg/m^3 (av. 0·09); column — 0·89 to 16·90 mg/m^2 (av. 7·69). Values of pheophytin, POC, PO_4-P, NO_3-N, NH_4-N and zooplankton are given in Table 1.

In the Laccadive sea region (71°30'-74°30'E and 10°15'-11°30'N) the average column productivity (at 10 stations) in October was 143·4 mgC/m^2/day while in December it was slightly higher (179 mgC/m^2/day from 4 stations). At station 222 the surface and column productivity were high during December (28·32 mgC/m^3/day and 676·07 mgC/m^2/day) as also the chl. *a* (0·165 mg/m^3 and 16·90 mg/m^2) and the nutrient concentrations. High productivity could probably be attributed to a dense patch of phytoplankton there, as corroborated by the high chl. *a* concentration at 16% and 1% light penetration depths.

It would be worthwhile here to summarize the work done so far in this region and compare with the present results. Average productivity values in the offshore waters of S.E. Arabian Sea are as follows:

Period	Av. productivity mgC/m^2/day	Period	Av. productivity mgC/m^2/day
May (5 stations)[1]	76·0	Oct. (5 stations)[4]	182·6
Feb. (5 stations)[2]	171·6	Oct. (14 stations)*	134·0
Aug.-Dec. (17 stations)[3]	806·6	Dec. (14 stations)*	357·9
Eight months (31 stations)[4]	210·6		

*Present work.

From the hydrographic point of view the month of October when upwelling ceases could be expected to be relatively infertile. During this period, the Arabian Sea upper subsurface water mass (up to 100 m) occupies the surface waters especially on the continental shelf[8]. In the present studies, σ ranged from 23 to 24 in the upper layers and the oxygen concentration dropped suddenly to approximately 0·5 ml/litre below 75 m. In conformity with above the productivity was low as also the concentration of chl. *a*, pheopigments and nutrients. On the other hand, during December σ_t was low (≈22) and the low oxygen layer shifted further downwards with the average oxygen concentration of >1ml/litre at 100 m. The nutrient concentration was also comparatively high. This is due to the fact that the surface water mass (up to 100 m) originates in the Bay of Bengal and flows southward along the east coast of India, rounds Ceylon

Table 1 — Variations in Primary Productivity and Related Parameters at All Stations

(Averages in parentheses)

Month	Primary productivity	Chlorophyll *a*	Pheophytin	POC	PO_4-P	NO_3-N	NH_4-N	
				Surface				
	mgC/m^3/day	mg/m^3	mg/m^3	g/m^3	μg-at/litre	μg-at/litre	μg-at/litre	
October	0·33-14·67 (5·43)	0·023-0·156 (0·082)	0·029-0·053 (0·043)	0·079-0·709 (0·222)	0·04-1·04 (0·49)	0·08-2·65 (0·9)	0·78-3·34 (2·18)	
December	0·67-42·23 (10·07)	0·043-0·578 (0·166)	0·007-0·32 (0·075)	0·05-2·46 (0·111)	0-0·88 (0·42)	0·09-10·34 (3·31)	1·53-9·18 (5·63)	
Pooled av.	7·75	0·121	0·059	0·164	0·45	2·15	3·97	
				Column				
	mgC/m^2/day	mg/m^2	mg/m^2	g/m^2	IMC	IMC	IMC	Zooplankton biomass ml/m^3
October	22-350 (134)	0·89-12·09 (6·44)	0·26-10·89 (4·63)	2·05-35·8 (18·26)	0·04-1·13 (0·68)	0·38-7·89 (2·82)	1·85-4·51 (2·74)	0·01-0·19 (0·048)
December	45-1167 (357·9)	3·84-18·86 (10·6)	1·35-11·49 (7·36)	1·97-14·75 (7·2)	0·25-1·57 (0·83)	0·52-8·05 (3·27)	3·09-10·31 (5·44)	0·034-0·453 (0·174)
Pooled av.	225	8·52	6·06	12·53	0·76	3·04	4·09	0·119

IMC = Integral mean concentration.

and then moves northward along the west coast of India and also enters the Laccadive region[9]. The nutrient concentration in this water mass is high due to the heavy river discharge and the NE monsoon in the Bay of Bengal resulting in the high production.

To find out the interrelationship between primary productivity and other parameters and among the various parameters themselves, multilinear regression analyses were carried out. Data for all the stations were pooled. The correlation coefficients thus derived are given in the form of a matrix with corresponding levels of significance (Table 2).

Correlation between primary productivity and chl. *a* was highly significant (0·1% level) both at the surface and in the column. To test whether such a correlation was present at different light penetration depths, further analyses were carried out. Light penetration depths and the corresponding correlation coefficients (r) with their levels of significance within parentheses are as follows:

60% : $r = 0{\cdot}79$ (0·1%)
30% : $r = 0{\cdot}39$ (2%)
16% : $r = 0{\cdot}75$ (0·1%)
1% : $r = 0{\cdot}59$ (1%)

When the data of light penetration depths were pooled the correlation was highly significant (at 0·01% level), the r value being 0·59 for n 131. In the present study the production was maximum at the surface. However, Radhakrishna[3] reported maximum production at subsurface levels in the SW Arabian Sea during August-December. In the northern Arabian Sea also maximum production during January-May was at subsurface[7]. When the average values of productivity for all stations at the 5 different light penetration depths are considered together with chl. *a* (Fig. 2), it is seen that productivity gradually decreased from surface to the 30% depth while chl. *a* remained constant. At the lower limits of the euphotic zone, viz. 16% and 1% light penetration depths, productivity showed an increase over that of 30% depth, notwithstanding the limiting light factor. This is obviously due to chl. *a* maxima observed at these depths (Fig. 2). Saijo[10] also observed chl. *a* maxima and concomitant high rate of photosynthesis at subsurface levels nearer to the lower limit of the euphotic zone and attributed them to the "growth of shade-adapted phytoplankton in the deeper layer and the deterioration of pigments by light in the upper layer".

Distribution of pheophytin closely followed that of chl. *a* (Table 2). Average pheophytin concentration (mg/m^3) increased with depth: surface, 0·048; 60%, 0·048; 30%, 0·067; 16%, 0·109; and 1%, 0·148. Distribution and concentration of pheophytin will give an idea of the amout of pigment which is not photosynthetically active. Its amount can vary depending on the grazing pressure of zooplankton. Variation in the column pheophytin during October and December was not much although the minimal value in October was much less as compared to that in December.

Concentration of POC varied widely at the surface and in the column (Table 1). It was minimum at the surface and showed an increasing trend

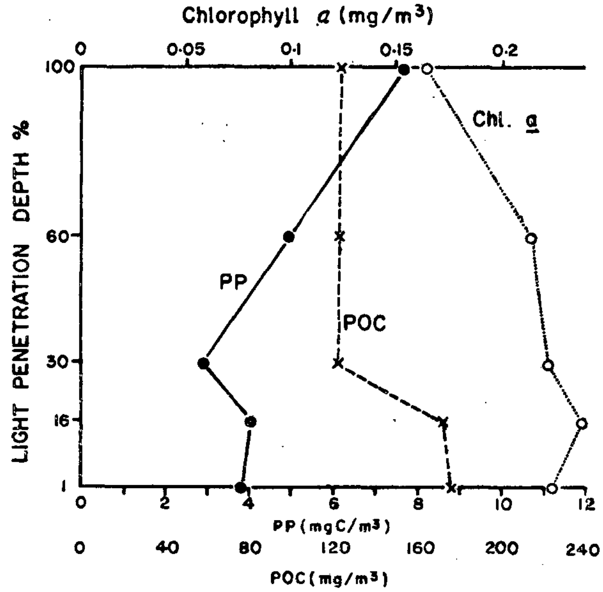

Fig. 2 — Distribution of primary productivity (PP), Particulate organic carbon (POC) and chl. *a* (Chl. *a*) at the 5 light penetration depths

TABLE 2 — CORRELATION MATRICES FOR PRIMARY PRODUCTIVITY AND RELATED PARAMETERS AT SURFACE AND IN COLUMN

	Surface						Column					
	Primary productivity	Chlorophyll *a*	Pheophytin	POC	Phosphate	Nitrate	Primary productivity	Chlorophyll *a*	Pheophytin	POC	Phosphate	Nitrate
Chlorophyll *a*	0·79[a]						0·65[a]					
Pheophytin	0·31[d]	0·43[b]					0·44[b]	0·46[b]				
POC	0·02	0·046	−0·17				−0·16	0·014	−0·043			
Phosphate	0·004	0·068	0·36[c]	0·07			0·25	0·46[b]	0·31	0·094		
Nitrate	0·59[a]	0·62[a]	0·058	−0·17	−0·28		0·12	0·36[c]	−0·29	0·35[c]	0·69[a]	
Ammonia	0·21	0·38[c]	0·048	−0·02	−0·07	0·31[d]	0·074	0·38[c]	−0·40[c]	−0·31[d]	0·098	0·20

Level of significance (%): a, 0·1; b, 2; c, 5 and d, 10.

through the lower light penetration depths (Fig. 2). It did not exhibit any positive relationship either with primary productivity or chl. *a* or pheophytin (Table 2). The studies of the column chlorophyll and POC values revealed that the living phytoplankton constituted a lower percentage of particulate carbon in October as compared to that in December assuming that carbon to chlorophyll ratio is the same in both periods. Ryther and Menzel[11] mention that living matter constitutes 10-20% of total particulate matter in the western Arabian Sea. Most of the particulate matter is refractory and hence may have little role in the biochemical cycle of organic matter[12]. In the present case it was found that during October though productivity was lower than that of December, POC within euphotic zone was twice as high as in December. The differences in the concentration are probably due to the different water masses existing at that time.

Variations and average values of macronutrients, viz. PO_4-P, NO_3-N and NH_4-N, at the surface and in the column are given in Table 1. Nitrite was below the level of detection at most of the stations in the euphotic column. The interrelationships of productivity and chl. *a* with these nutrients in the form of matrix of correlation coefficients are given in Table 2. At the surface PO_4-P did not show significant correlation with productivity or chl. *a*. In the column it showed no correlation with productivity but with chl. *a*, correlation significant at 1% level is seen. Nitrate showed highly significant correlation (at 0·1% level) at the surface with both productivity and chl. *a* while in the column, showed only with chl. *a* (at 5% level). Ammonia had no correlation with productivity either at the surface or in the column, while with chl. *a* the correlation was significant (at 5% level) both at surface and column.

Distribution of zooplankton biomass was similar to that of primary productivity. During October the average zooplankton biomass was 0·048 ml/m³ while during December it was 0·174 ml/m³. For both the months put together the average was 0·119 ml/m³. There was positive correlation between these 2 variables, significant at 0·001 level ($r = 0{\cdot}62$, $n = 25$).

Productivity studies through the year with wider coverage is needed to obtain information on the general level of productivity and their seasonal variations in the offshore region of the southeastern Arabian Sea.

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Primary Production in the Northern Arabian Sea

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Primary productivity was measured at 56 day stations in the northern Arabian Sea during the Oceanovex Expedition of *INS Darshak* (December 1973-May 1974). Daily primary productivity averaged 8·4 mgC m^{-3} at the surface and 698·39 mgC m^{-2} in the euphotic column. Column productivity in the shelf region (875·96 mgC m^{-2}) was higher than in the offshore region (607·2 mgC m^{-2}). Primary productivity by the simulated *in situ* method was greater than the *in situ* method by a factor of 2. Integral mean concentration (for the euphotic column) of inorganic phosphate and nitrate for the entire region averaged 1·01 and 2·18 µg-at l^{-1} respectively. Zooplankton biomass averaged 0·22 ml m^{-3}. Correlation between primary productivity and zooplankton biomass was positive, although not significant while the correlation between primary productivity and nutrients was negative.

MEASUREMENT of primary production is essential for the estimation of level of fish production and potential of exploitable fisheries. Production at the higher trophic levels depends ultimately on photosynthetic primary production. During the International Indian Ocean Expedition data on primary productivity collected from the northern Arabian Sea[1] covered only 26 stations (above 20°N), most of them being oceanic. Kuz'menko[2] has measured primary production at 56 stations in this area during August-November 1969. During December 1973 to May 1974, primary productivity has been measured in the northern and northeastern Arabian Sea as a part of the Oceanovex Expedition of *INS Darshak*. The results of these studies are discussed in the present paper.

Materials and Methods

Primary productivity was measured at 56 day stations (19 shelf and 37 offshore) during December 1973-May 1974. Samples were taken from 5 light penetration depths (100, 50, 25, 10 and 1%). Light attenuation and the euphotic zone were determined by a Kahlsico submarine photometer and by Secchi disc when the photometer could not be operated due to inclement weather. Samples were incubated for 24 hr under simulated *in situ* conditions, using appropriate neutral density filters. At 6 selected stations, *in situ* measurements were also taken for comparison. Nutrient concentrations were estimated by standard methods. Zooplankton was collected by IOS net from bottom to surface at shallow stations and 200 m to surface at deep stations. The biomass is expressed as displacement volume per m^3.

Results and Discussion

The euphotic zone varied from 20 to 60 m and averaged 36 m on the shelf and 42 m offshore. Varkey and Kesavadas[3] working in the same area and period reported euphotic depth range of 20-60 m, with a general average of 40 m. They recorded wider variations, 1 min the Gulf of Cambay and 68 m off Dabhol. For November-April, the IIOE values averaged 50 m for the Indo-Pak shelf region and over 90 m in the central Arabian Sea[1]. The narrow range between the shelf and offshore observed in the present study was also reflected in the productivity values. One of the reasons for the shallow euphotic zone in the offshore waters and the high production may be the rich phytoplankton biomass[2].

At 53 out of the 56 stations investigated, productivity was maximum at subsurface levels (5-20 m) compared to the surface. This would imply that the incident radiation at the surface was in excess of optimum intensity and caused photoinhibition at the surface layers. This is in contrast to the observations in the Bay of Bengal[4] where maximum photosynthesis was mostly at the surface. Radhakrishna[5] attributed the maximum photosynthesis at the surface in the Bay of Bengal to the heavy cloud cover prevailing there which attenuates the excess light intensity that would otherwise reach the sea surface and might result in photoinhibition at that level. It is likely that photoinhibition of phytoplankton in surface waters results in lower rates of carbon assimilation.

To test whether the situation was caused by the neutral density filters employed, *in situ* experiments, simultaneous with simulated *in situ* method were conducted at 6 selected stations for 3-4 hr during March 1974. The results are given in Fig. 1 together with column productivity, by the 2 methods. In all instances, except the *in situ* rate at one station, productivity was maximum at subsurface levels. Again at 5 out of the 6 stations, productivity as measured by simulated *in situ* method was more than by the *in situ* method. This is because of the neutral density filters used in the simulated *in situ* experiments which absorb all wave length of the visible spectrum. In nature, on the other hand, besides attenuation in the total intensity, the spectral quality of light is influenced by depth of water and amount of particulate and dissolved matter present therein. Consequently, in simulated *in situ* experiments, the total intensity of light reaching the particular depth is approximated by the neutral density filter and not its spectral distribution and hence the variation in the 2 sets of results. These experiments revealed further that measurement by the simulated *in situ* method overestimated the *in situ* productivity by a factor of 2.

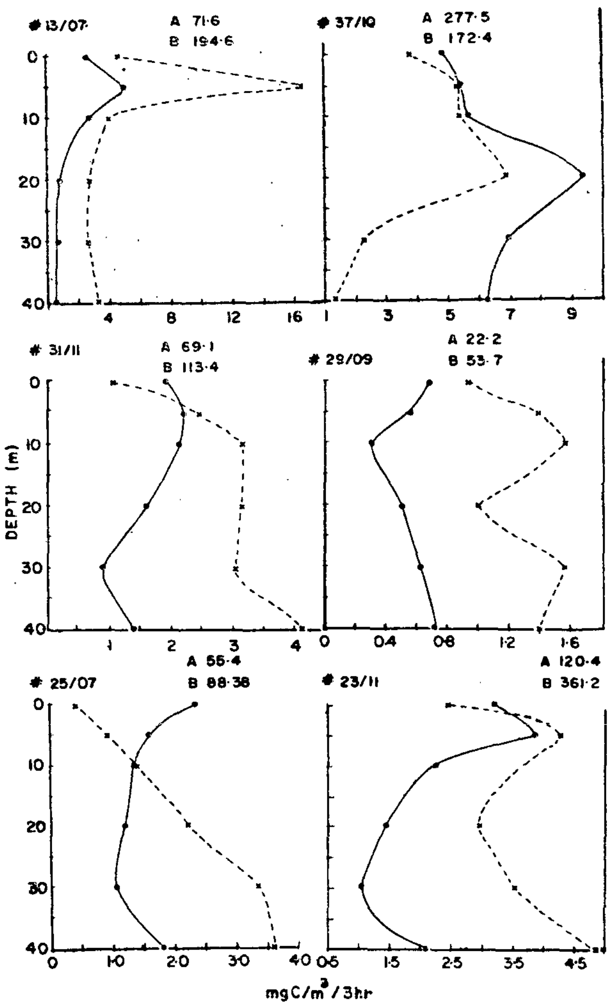


Fig. 1 — Primary productivity at selected stations by *in situ* method (●—●) and simulated *in situ* method (×---×) [Column productivity (mgC m^{-2} day^{-1}) by *in situ* (A) and simulated *in situ* (B) methods]

Primary productivity at the surface in the northern Arabian Sea varied widely ranging from 0·18 to 65·11 mgC m^{-3} day^{-1} and averaged 8·4 mgC (Table 1). Exceptionally high value of 280·7 mgC m^{-3}d^{-1} recorded near Bombay was not considered for averaging. High values were encountered quite close to the shore along the Kutch and Saurashtra coasts, e.g. 42·31 mgC on the Kori Great Bank, 33·84 mgC near Dwaraka Point and 65·11 mgC off Porbunder. Surface productivity varied from 1·12 to 65·11 mgC day^{-1} (av. 12·47; value of 280·7 not considered) in the shelf region and from 0·18 to 17·88 mgC day^{-1} offshore (av. 6·42). The use of means could be misleading in a region like this where production varied more than a 100 fold. Since the measurements are subject to diurnal, microdistributional and experimental sources of variability individual results are not discussed. Instead, the distribution of productivity both at the surface (Fig. 2) and in the column (Fig. 3) in the form of isolines with suitable intervals is given together with station positions. From Fig. 2, it is seen that with reference to surface productivity, the shelf waters of Pakistan and northwest India are quite fertile.

Column productivity for the entire area ranged from 109·06 to 2665·53 mgC m^{-2} day^{-1} (av. 698·39), the shelf and offshore averages being 875·96 and 607·2 mgC. Although the shelf waters are generally rich, pockets of high productivity occurred well offshore in as much as low productivity was encountered at individual inshore stations. The distribution of column production in the northern Arabian Sea for August-November given by Kuz'menko[3] broadly agrees with the present observation, in spite of methodological variations. For the Gulf of Cambay, Kuz'menko's value was 0·109 gC m^{-2}d^{-1} and the present value was 0·382 gC indicating that this area is rather poor.

Ryther and Menzel[6] gave the mean productivity for the Arabian Sea as 1·8 gC m^{-2}d^{-1}. This appears to be rather high, in comparison to the present average of 0·7 gC m^{-2}d^{-1}. The explanation for this disparity could be that Ryther and Menzel[6] considered the western shelf of the Arabian Sea where they encountered regions of very high productivity while in the present study, relatively poorer eastern shelf is considered.

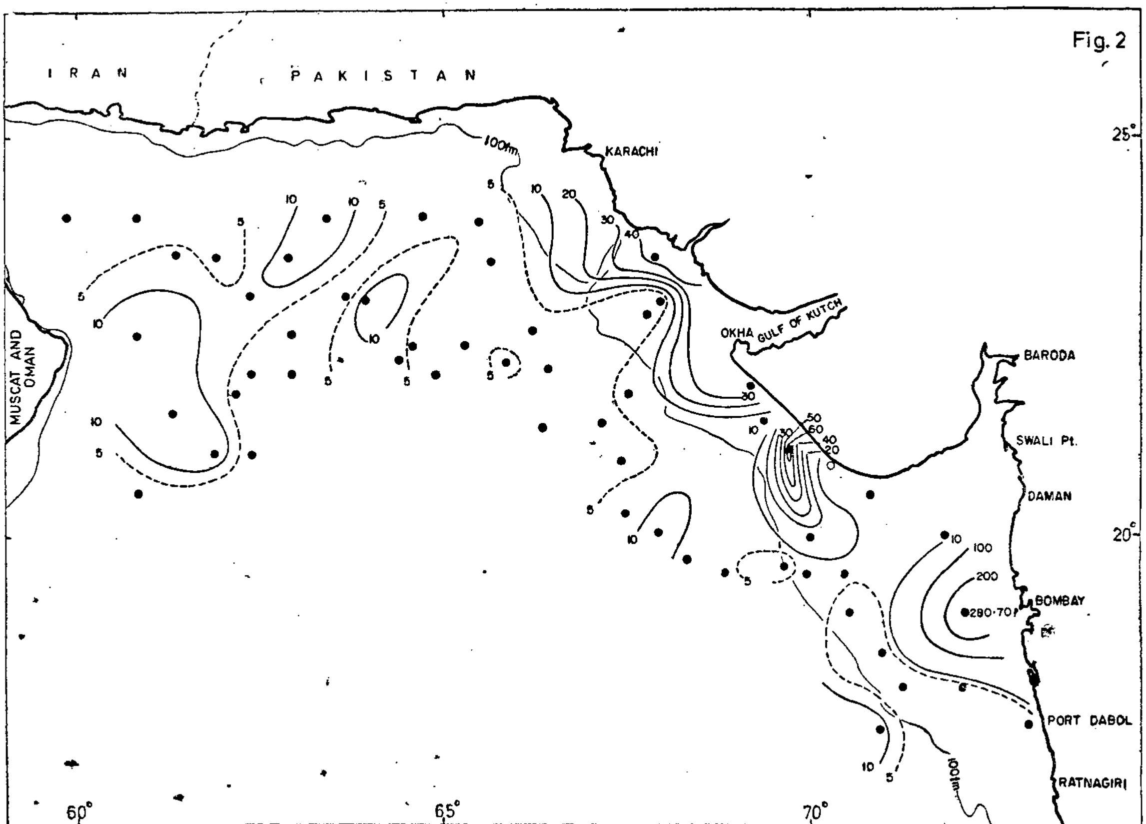
The Arabian Sea is a region of great contrast containing some of the richest and some of the most infertile waters. Ryther *et al.*[7] reported

TABLE 1 — PRIMARY PRODUCTIVITY AND NUTRIENTS IN THE NORTHERN ARABIAN SEA

(Average values with range in parenthesis are given)

Area	Surface			Column		
	Pri. prod. mgCm^{-3}d^{-1}	PO_4-P µg-at l^{-1}	NO_3-N µg-at l^{-1}	Pri. prod. mgCm^{-2}d^{-1}	PO_4-P IMC µg-at l^{-1}	NO_3-N IMC µg-at l^{-1}
Shelf	12·47	0·84	1·64	875·96	0·87	2·06
19 stations	(1·12-65·11)*	(0-2·18)	(0-12·44)	(109·06-2665·53)	(0·1-2·07)	(0·09-15·1)
Offshore	6·42	1·02	2·43	607·2	1·08	2·25
37 stations	(0·18-17·88)	(0·2-1·92)	(0-6·95)	(160·95-1590·07)	(0·27-1·88)	(0·15-4·93)
Entire area	8·40	0·96	2·16	698·39	1·01	2·18

*Value 280·7 not considered.



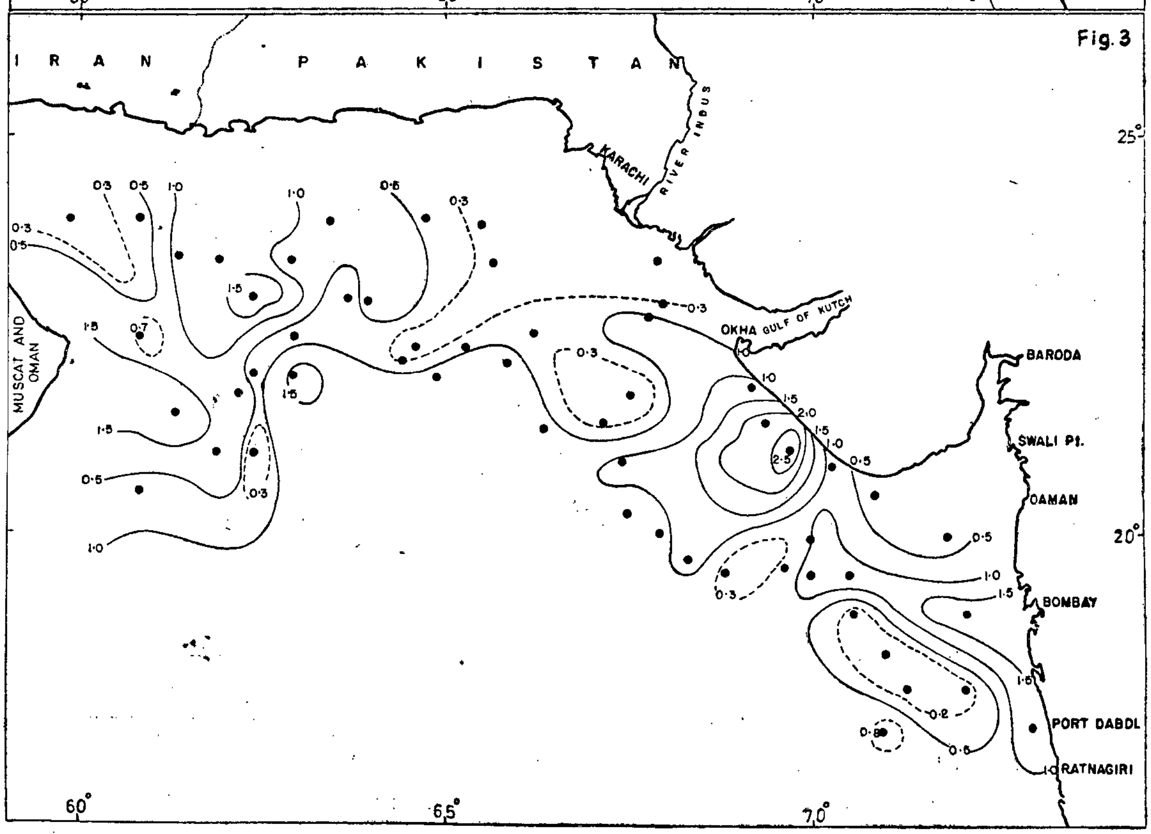


Fig. 2 — Distribution of primary productivity at surface in mgC $m^{-3}d^{-1}$ with station positions (●)

Fig. 3 — Distribution of primary productivity in the euphotic column in gC $m^{-2}d^{-1}$ with station positions (●)

variations from 0 to 6·58 gC $m^{-2}d^{-1}$. Kabanova's[8] ranges were less variable : 0·1-1·0 gC. Kuz'menko[2] encountered in the northern Arabian Sea the minimum value of 0·021 and the maximum of 2·676 gC $m^{-2}d^{-1}$. Radhakrishna *et al.*[9] for the northeastern Arabian Sea reported a variation of 0·08-1·6g. The present range was 0·1 to 2·7 gC $m^{-2}d^{-1}$.

The distribution of inorganic phosphate and nitrate in this area was interesting. Average concentrations of these nutrients in the shelf waters at the surface and in the euphotic column (integral mean concentrations-IMC) were less than offshore (Table 1). However, unusually high concentration of nitrate (surface 12·14, IMC 15·4 μg-at l^{-1}) was encountered at the shallow station — 4511 where the phosphate was also high: 1·74 and 2·07 μg-at l^{-1} respectively. Relationship between these nutrients and primary productivity was not positive. While primary productivity was generally high in the shelf region, nutrient concentration was low; offshore, productivity was lower whereas nutrient concentration was higher. Statistical analyses were carried out separately for the shelf, offshore and entire area both for surface and column but no significant correlations emerged. Productivity and nutrient data at a few selected stations are given in Table 2 to emphasize the lack of interrelationship.

Primary productivity being a rate measurement need not necessarily have a positive correlation with instantaneous nutrient concentration. On the other hand, turnover rates, *in situ* regeneration, vertical mixing etc. which affect the instantaneous concentration are probably more relevant than the instantaneous concentration itself. Phytoplankton biomass may be dependent more upon the nutrients as dissolved organic compounds rather than inorganic salts[10].

Sengupta[11] working on the same *INS Darshak* material reported total disappearance of nitrate from the surface waters during the later period (March-May) and citing Kabanova[8] attributed the deficiency of nutrients, particularly nitrogen compounds as causing lower values of photosynthetic productivity in the northern Arabian Sea. Kabanova[8] considered the northern Arabian Sea as highly productive notwithstanding the lower values of primary production in winter relative to the high summer values and did not attribute the low values to nitrogen deficiency. In our study, during March-May, nitrates could not be detected at the surface only in 5 out of a total 22 stations. At station 5709, when nitrate was below the level of detection at the surface, productivity was 14·05 mgC $m^{-3}d^{-1}$ and when the nitrate IMC was 0·39 μg-at l^{-1}, column productivity was 803·31 mgC $m^{-2}d^{-1}$ — quite high for offshore waters. Similarly, at station 2909, when the surface nitrate was as high as 6·90 μg-at l^{-1}, the surface productivity was low: 2·79 mgC m^{-3}. From these data and Table 2, it is clear that photosynthetic production is not controlled by inorganic nitrate as claimed by Sengupta[11]. Furthermore, although there is an absolute requirement for inorganic phosphate in the light reactions of photosynthesis at the sites of photophosphorylation, nitrogen has no such role in either the light or dark reactions of photosynthesis. Consequently, the assertion that inorganic nitrogen can affect photosynthetic production which is a rate measurement is untenable. The effect of inorganic or organic nitrogen may be related to the concentration of phytoplankton pigments or cell biomass but they cannot influence the effect of the phytoplankton (primary productivity). The nitrate uptake by phytoplankton is controlled by the ammonium concentration and the total amino acid pool within the cell through the feeder back control of nitrate permease system and/or nitrate reductase enzyme system[12]. Further, the ammonium control of nitrate uptake is a function of the past history of exposure to ammonium, the degree of nitrogen deficiency, the biological properties of the organism and its size, besides the diffusion transport of the nutrient[13].

Zooplankton biomass was nearly double in the shelf region than offshore; it averaged 0·33 ml m^{-3} (range: 0·03-0·8) for the 16 shelf stations and 0·17 ml m^{-3} (range: 0·03-0·42) for the 36 offshore stations. For the entire area the average biomass was 0·22 ml m^{-3}. Correlation between column productivity and zooplankton biomass was positive, although not highly significant ($r = 0{\cdot}2$ for n 52). The distribution of zooplankton biomass for the same expedition given by Paulinose and Aravindakshan[14] agrees very well with the distribution of column primary productivity (Fig. 3) in the present work.

Besides the geographical variations, temporal variations in productivity are also wide in the Arabian Sea. For example, Radhakrishna *et al.*[9] reported a high average value of 1001·6 mgC m^{-2} for the waters off Bombay during February and a low average value of 362·68 mgC m^{-2} during March

TABLE 2 — PRIMARY PRODUCTIVITY AND NUTRIENTS AT SELECTED STATIONS

Station	Surface			Column		
	Pri. prod. mgC m^{-3} d^{-1}	PO_4-P μg-at l^{-1}	NO_3-N μg-at l^{-1}	Pri. prod. mgC m^{-2} d^{-1}	PO_4-P IMC μg-at l^{-1}	NO_3-N IMC μg-at l^{-1}
4505	7·13	1·74	12·14	0·38	2·07	15·7
0101	0·18	1·33	2·88	0·17	1·38	3·39
3308	3·95	1·54	1·93	0·15	1·66	1·9
5103	280·7	0·58	0·68	1·58	0·56	0·82
4102	65·11	0·57	0·18	2·67	0·6	0·54
3902	8	0·57	1·07	2·25	0·6	0·62

of the same year. They further recorded low productivity (215·62 mgC m^{-2}) during November in the region between Mormugao and Dwaraka.

The south-eastern Arabian Sea also is an area of wide temporal and spatial fluctuations from the point of view of productivity. Bhargava *et al.*[15] while reviewing the productivity data of this region mentioned average values ranging from 76 to 806·6 mg C m^{-2} in different months. Silas[16] reported the productivity on the shelf between 50 and 200 m along the west coast of India as 470 mgC m^{-2} and for the offshore waters as 180 mgC m^{-2}. But in the present study high values of 875·96 mgC m^{-2} in the shelf and 607·2 mgC m^{-2} in the offshore waters are encountered. This would clearly indicate that the average production in the northern Arabian Sea is much higher than the average for the entire west coast implying that the northern region is by and large more fertile than the southern region, notwithstanding the high values (1240 mgC m^{-2})[16] encountered very close to the coast and the intense upwelling in the south.

In conclusion, it could be stated that (1) the level of primary production in the northern Arabian Sea is generally high; that the waters off Bombay are very fertile with column productivity of >1000 mgC m^{-2} day^{-1} followed by waters off Saurashtra where productivity is >500 mgC m^{-2} day^{-1}; (2) the maximum productivity occurs at subsurface levels implying photoinhibition at the surface; (3) the simulated *in situ* method over estimates production; (4) there is no direct relationship between production and concentration of inorganic nutrients; and (5) this is a region of great contrast containing both very rich and very infertile pockets.

Nearshore areas where fishing effort is presently concentrated are not yet adequately surveyed. The productivity potential of the Gulf of Kutch and the Gulf of Cambay is virtually unknown. Hence the need to survey these coastal areas is immediate.

More intensive studies on primary productivity with reference to seasonal variations are necessary to estimate the annual level of primary production in this area.

Acknowledgement

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RELATIONSHIP BETWEEN CHLOROPHYLL *A* AND COLUMN PRIMARY PRODUCTION

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ABSTRACT

Relationship between surface chlorophyll *a* and column primary production has been established to help in estimating the latter more quickly and accurately. The equation derived is Primary Production, $y = 0.54 \ \mathrm{Ln\ Chl\ a} - 0.6$. The relationship was found to be statistically significant.

Key-words : Chlorophyll *a*, Primary Production.

The last two decades have observed a tremendous increase in the rate of data collection in the oceanic and coastal areas. The data collections at sea are not only tedious but very expensive too. Hence various techniques are now being used to make the data collection more economical. These includes remote sensing of sea surface parameters, drifting and moored buoys, telemetry, etc.

Surface chlorophyll is one such parameter which can be estimated by remote sensing via satellite. Chlorophyll is an index of primary production which in turn is used for estimating the living resources in the sea. The primary production is generally measured by ^{14}C technique (Steemann Nielsen, 1952) and by measurement of oxygen evolved during the photosynthesis. The details of these methods have been described by Vollenweider (1974). While O_2 method has become obsolete, the ^{14}C technique is also said to give a low value as observed by Sheldon and Sutcliffe (1978), Gieskes, Kraay and Baars (1979), Schulenberger and Reid (1981) and Jenkins (1982).

If the surface chlorophyll upto a depth of 10m can be measured by any technique, it can be theoretically considered for estimating primary production. Relationship between chlorphyll *a* and photosynthesis at given light intensity and depth has been described by several authors (Qasim, Wellershaus, Bhattathiri and Abidi, 1969; Ryther and Yentsch, 1957 and Aruga and Monsi, 1963). In this note an attempt has been made to find out relationship between concentration of surface chl-a and primary production with a view to facilitate the estimation of the latter more easily.

The data from 60 stations collected by R V *Anton Brunn* during International Indian Ocean Expedition (Cruise 1 to 3) between latitude 19 —

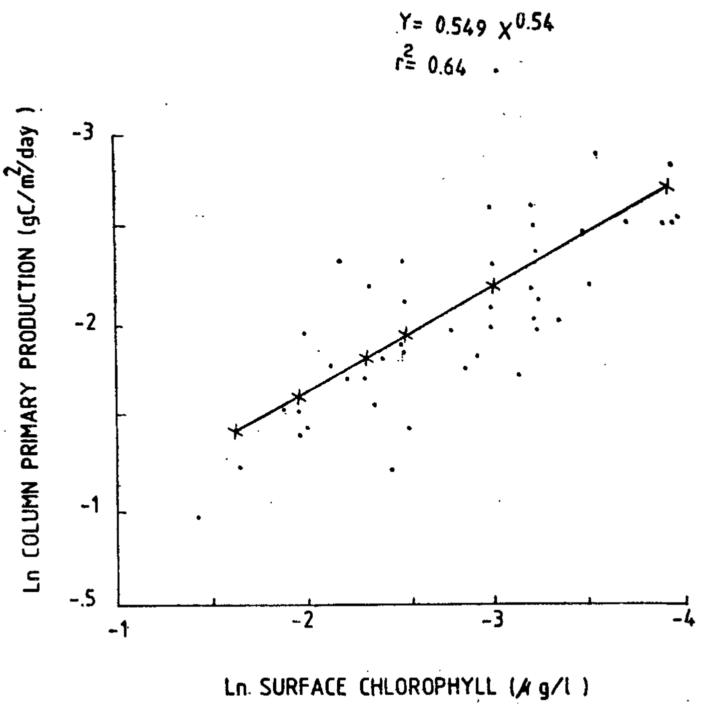

Fig. 1. Relationship between chlorophyll a and column primary production

24°N and Longitude 60 — 71°E have been used. The column primary production integrated from the values at different optical depths and the average concentration of chlorophyll a (from the 0 — 20 m depth) have been used to establish the relationship between the two parameters.

Since the maximum concentration of chlorophyll is not always at the surface but generally a little below it, an averaged value of surface and at 10 meter depth was taken and termed as 'surface chlorophyll'. The values of surface chlorophyll and the primary productivity used in this note ranged from 0.01 to 0.36 μg/l and from 0.008 to 0.32 gC/m²/day respectively.

The relation between the two variables can be evaluated by examining the reduction in the sum of square of the dependent variable produced by the regression function. The sum of squares divided into two components — one associated with linear regression, and the other with the extent of deviation of the data from the straight line. The reduction in the total sum of squares due to linear regression is then computed and is defined as the ratio of the total variability (r^2) to the total sum of squares.

Raw data showed a non-linear relationship on linear scale and called for the transformation. Secondly an increasing values of chlorophyll (x) demanded a transformation of logarithmic type. The transformation made the error additive and the data linear (Fig. 1). The criteria used to judge the fit of regression to the data points was coefficient of determination. The coefficient measures the fraction of the total sum of squares that can be attributed to the regression. The regression equation is $y = 0.549 \times 0.54$, ($r^2 = 0.64$) As the r^2 was increasing to higher order solution, the linear regression was considered adequate. The relationship was also found to be statistically significant.

Thus from this preliminary study, it is concluded that the surface chlorophyll values can be utilized for getting fairly a good estimate of column production. However, a more detailed work is warranted to support this finding.

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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, Lakshadeep 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 seasonly, 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 Lakshadeep 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/m^3/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 Lakshadeep 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.3) 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 ocuupied 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	
	DK	20	DK	-	DK	8	2671
	IIOE	236	IIOE	278	IIOE	367	
	SK	38	Sk	326	Sk	83	
Salinity	RVG	352	RVG	426	RVG	489	
	IIOE	307	IIOE	262	IIOE	359	2524
	SK	38	SK	218	SK	73	
Oxygen	RVG	362	RVG	320	RVG	355	
	IIOE	269	IIOE	219	IIOE	216	1997
	SK	62	SK	128	SK	66	
NO_3- N	RVG	334	RVG	238	RVG	260	
	DK	43	DK	-	DK	21	1202
	IIOE	59	IIOE	14	IIOE	-	
	SK	98	SK	115	SK	20	
PO_4- P	RVG	305	RVG	317	RVG	313	
	IIOE	149	IIOE	60	IIOE	40	1459
	SK	97	SK	112	SK	66	
Primary production	RVG	146	RVG	126	RVG	152	
	DK	14	DK	-	DK	2	686
	IIOE	104	IIOE	16	IIOE	11	
	SK	62	SK	29	SK	24	
Zooplankton	RVG	245	RVG	238	RVG	237	
	IIOE	60			IIOE	2	958
	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 discontinous 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 Autosal (Model 8400). Samples for the various chemical analyses were collected and analysed on board as per the standard procedures mentioned by Sen Gupta, Fondekar, 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 smothed 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, 1978). 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 x 10^{-3} on the Arabian Sea whereas in the Bay of Bengal it varied from 34-35 x 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°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 (Wyrtki 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 dicharge 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 µg-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 µg-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 µg-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 μg-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 μg-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 Orisa 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 mgC/m^3/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 x 10^6 tonnes carbon/yr in the Arabian Sea and out of this 50% is from northerrn 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 mgC/m^3/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 tmeperature as compared to the west coast.

Column production varied from 10 to 100 mgC/m^2/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/m^2. 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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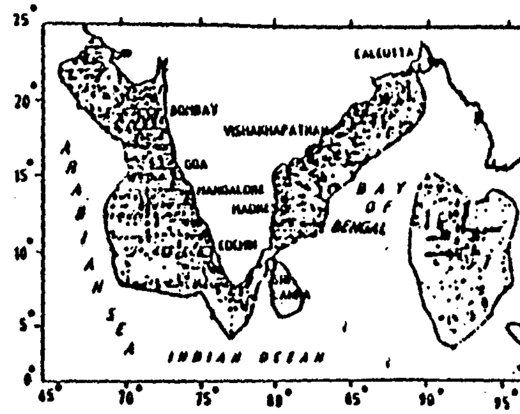
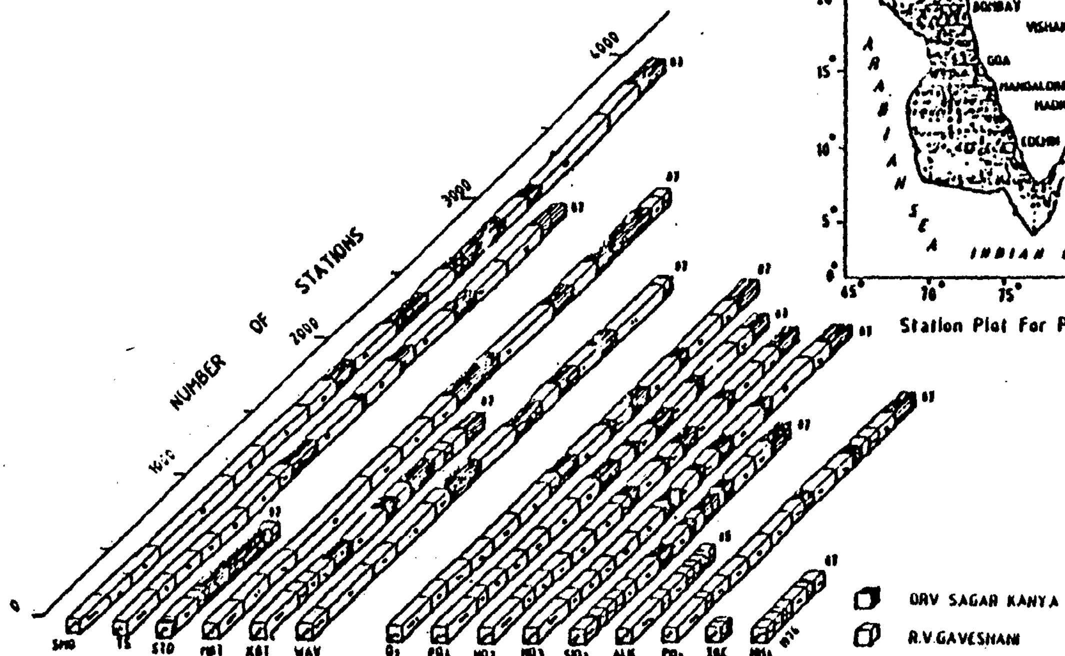


Station Plot For Phs./Chemi./Bio. data



STATION COVERAGE BY R.V.GAVESHANI (1976-87) AND ORV SAGAR KANYA (1983-87)

FIG. 1

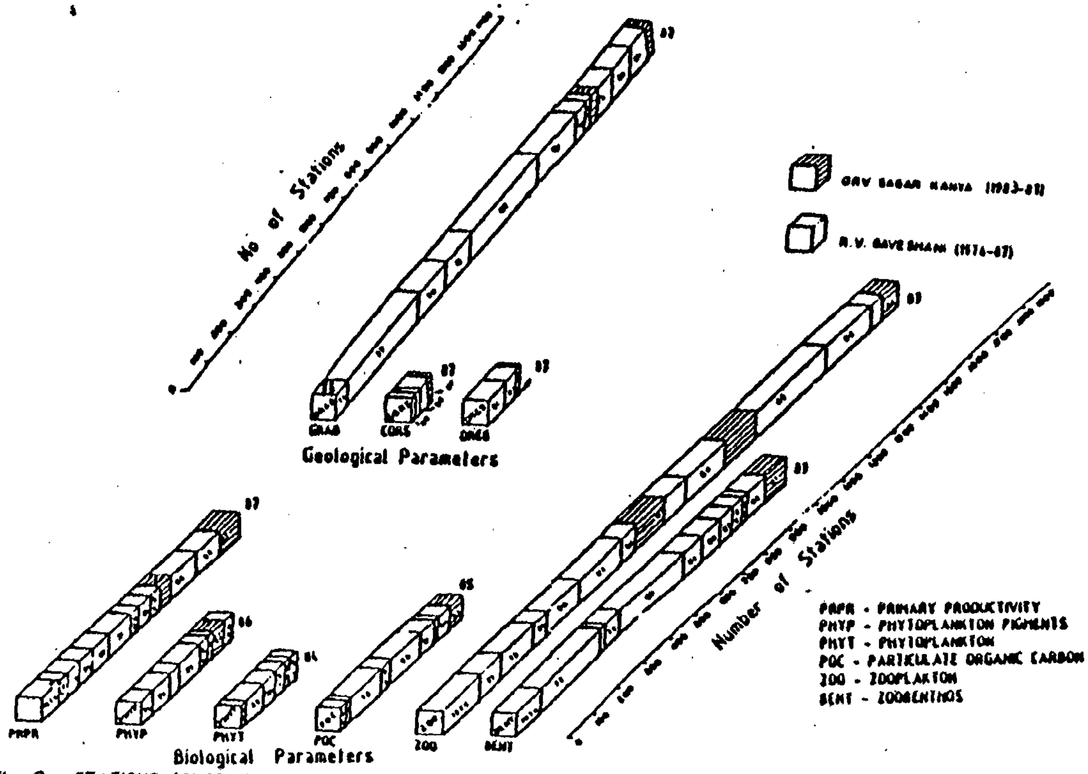
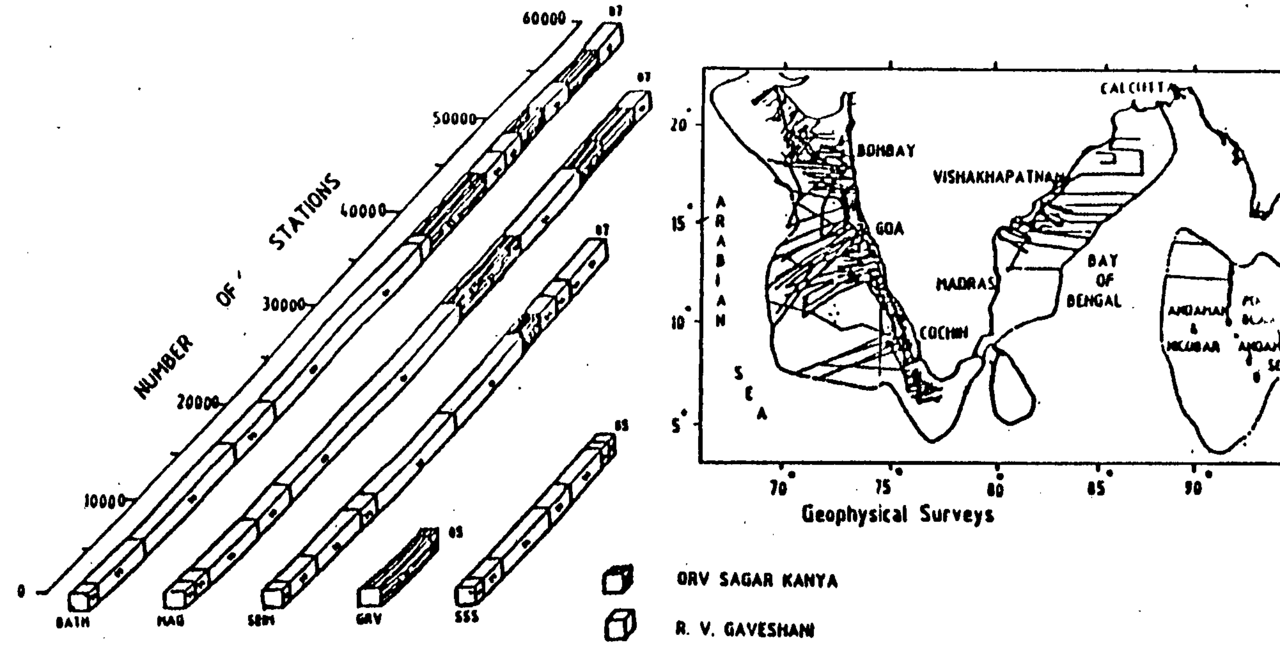


Fig. 2 STATIONS COVERAGE R.V.GAVESHANI (1974-87) AND O.R.V.SAGAR KANYA (1983-87) FOR BIOLOGICAL AND GEOLOGICAL PARAMETERS



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

Fig. 3

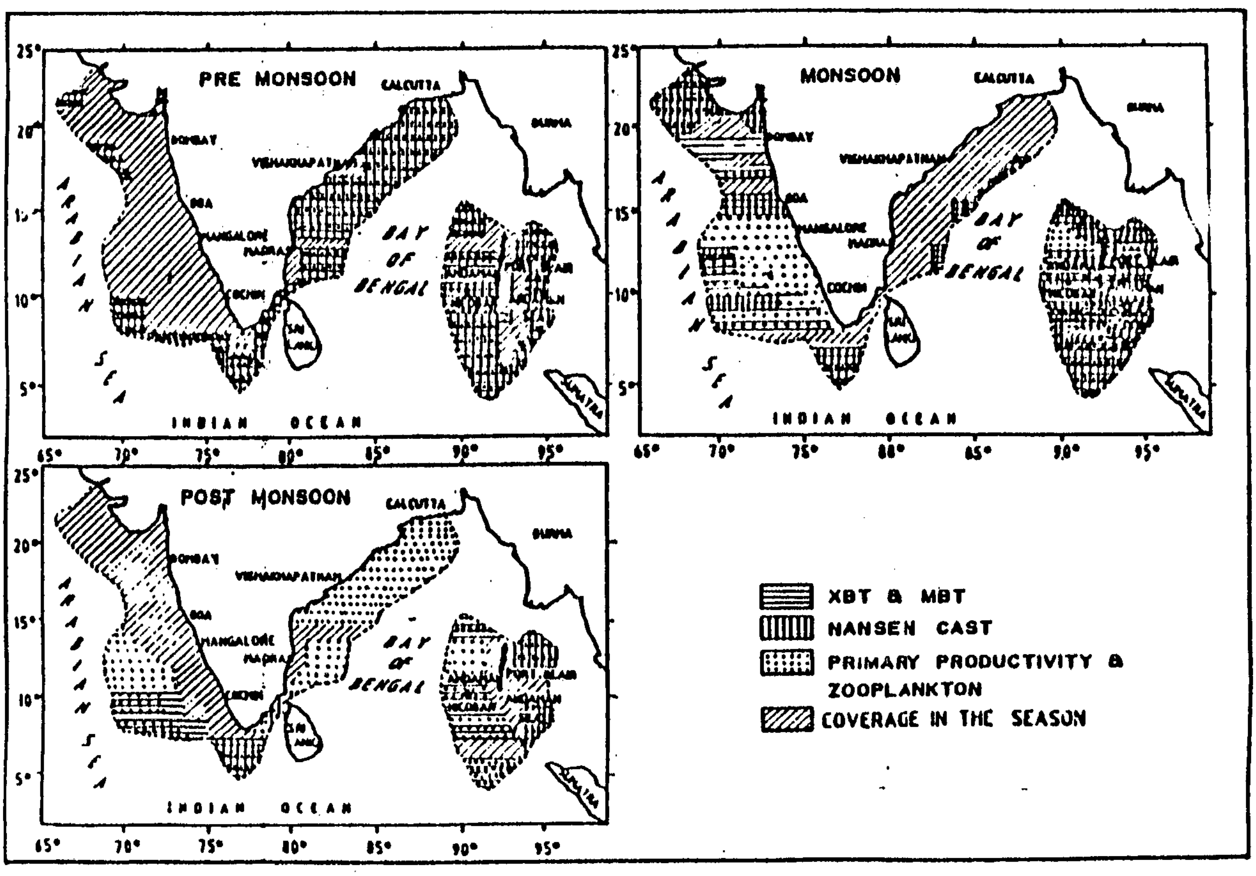


Fig. 4 PARAMETERWISE & SEASONAL DATA GAPS IN EEZ OF INDIA

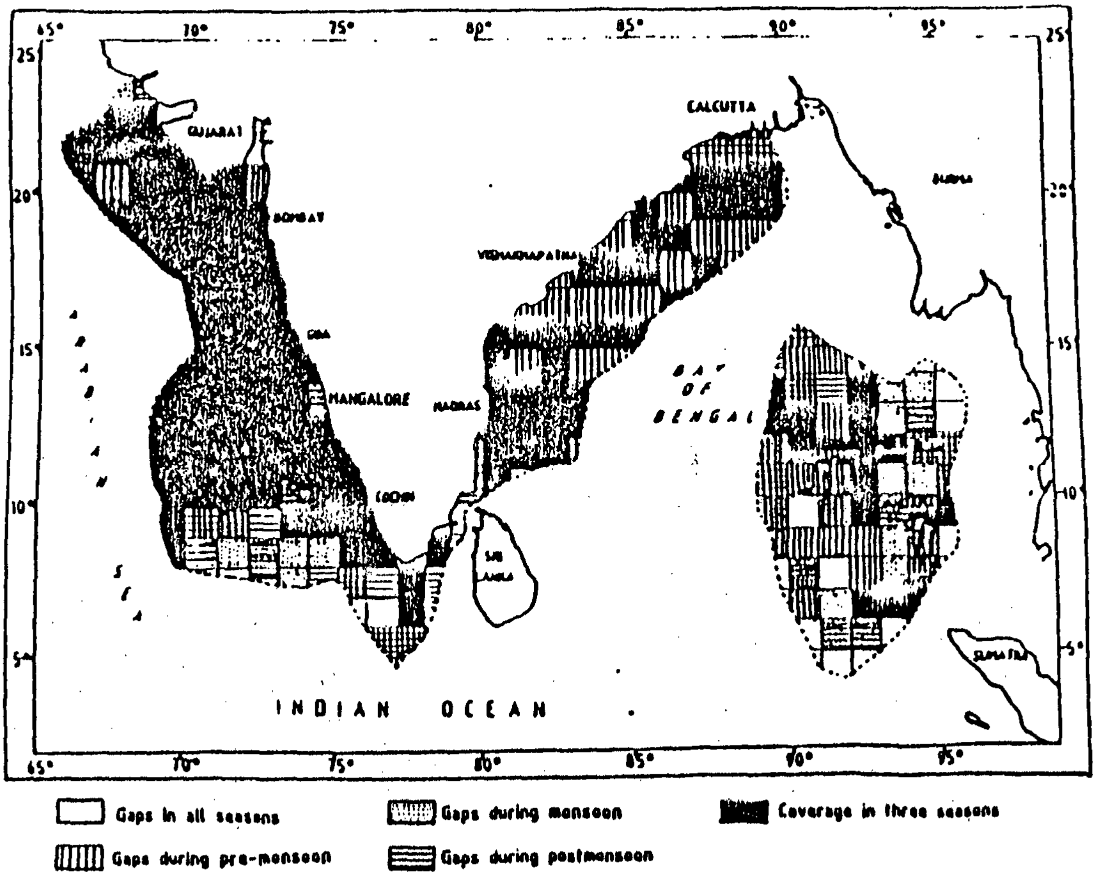


Fig. 5 Distribution of Seasonal coverage in one degree grid of EEZ

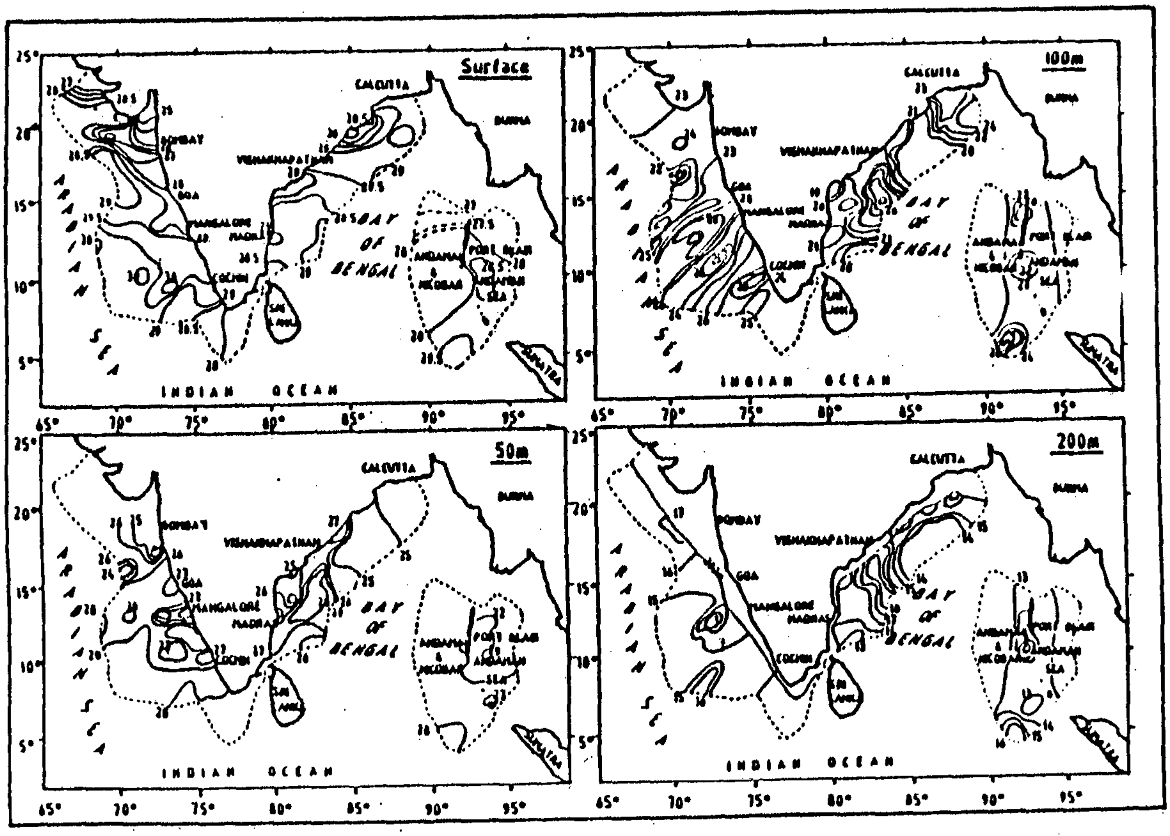


Fig. 6 Distribution of Temperature (°C) at four different depths

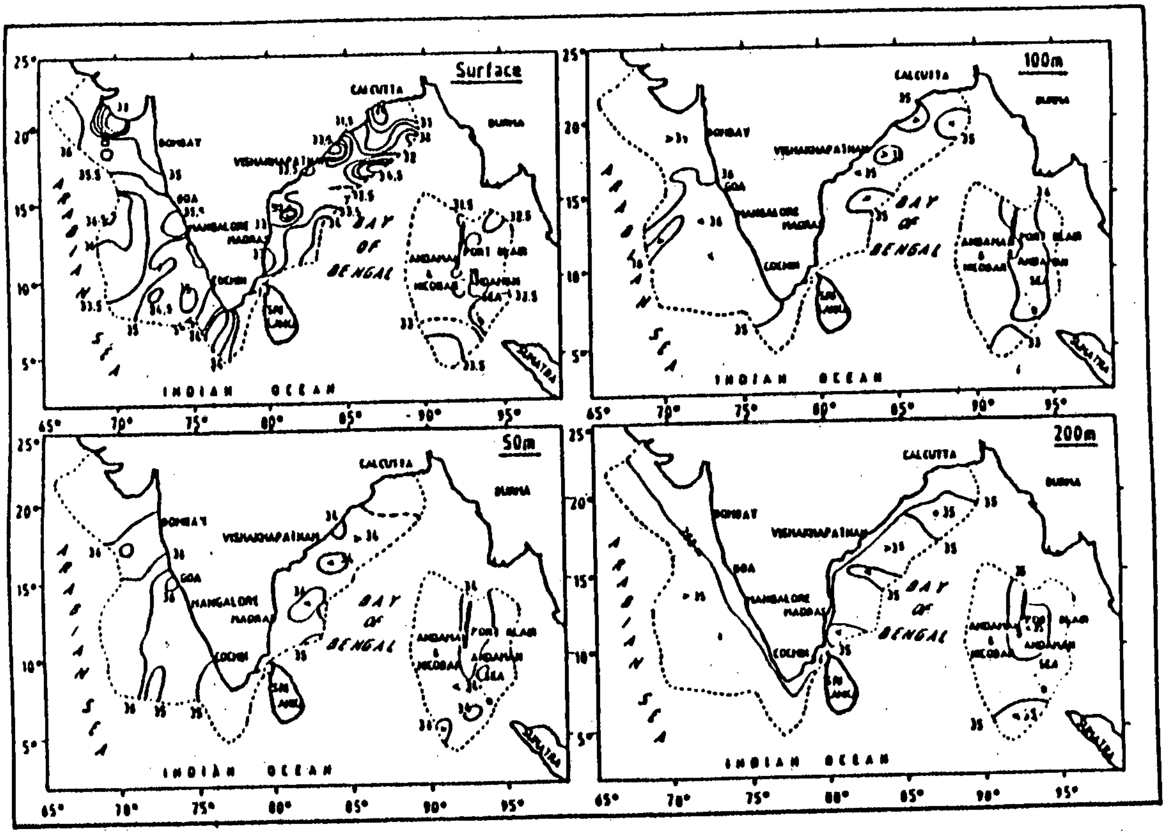


Fig. 7 Distribution of Salinity (x 10^{-3}) at four different depths

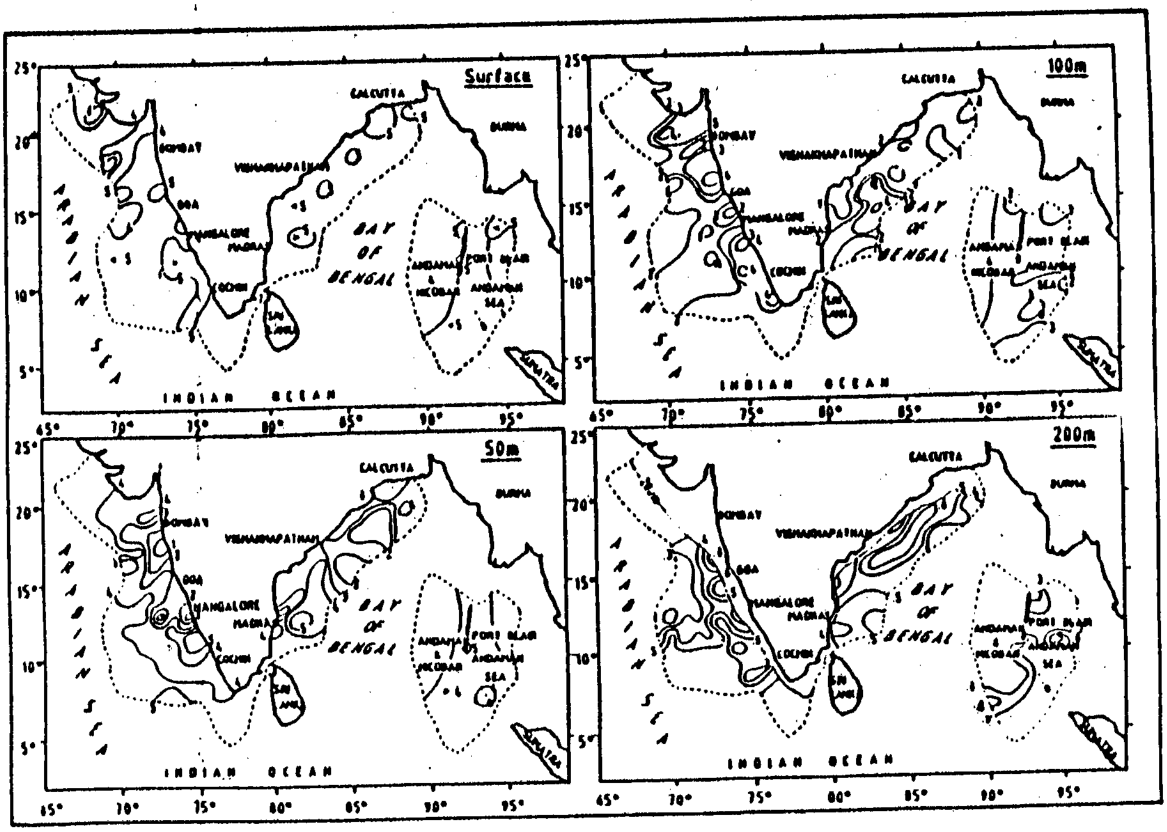


Fig. 8 Distribution of Dissolved oxygen (ml l^{-1}) at four different depths

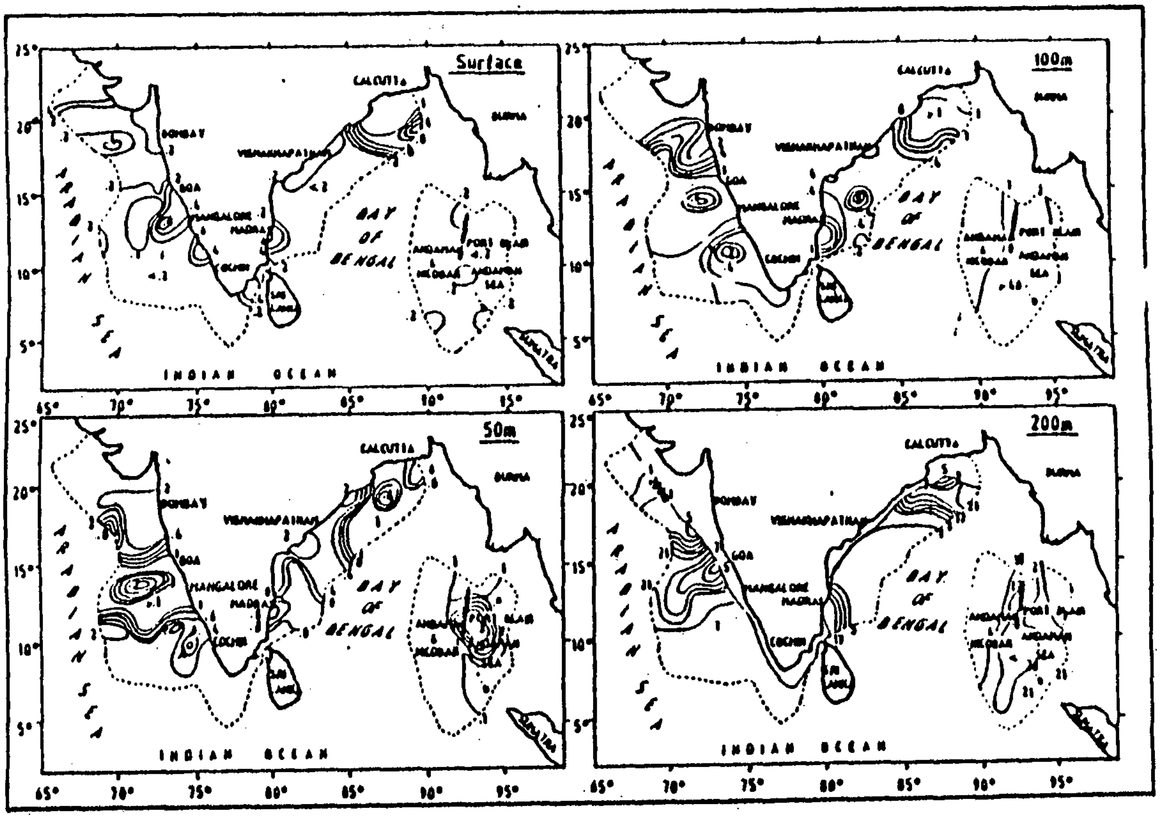


Fig. 9 Distribution of Nitrate-Nitrogen (µg-at l^{-1}) at four different depths

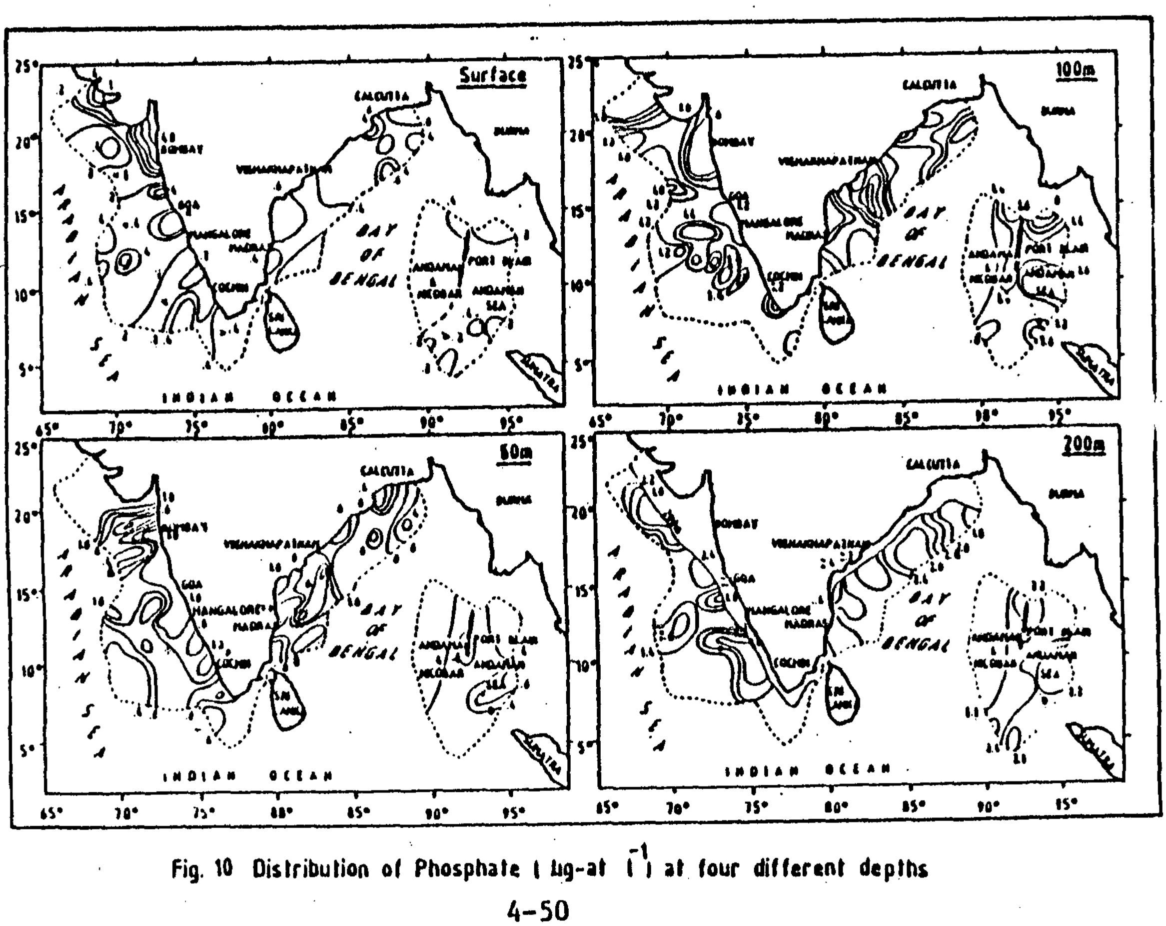


Fig. 10 Distribution of Phosphate (µg-at l^{-1}) at four different depths

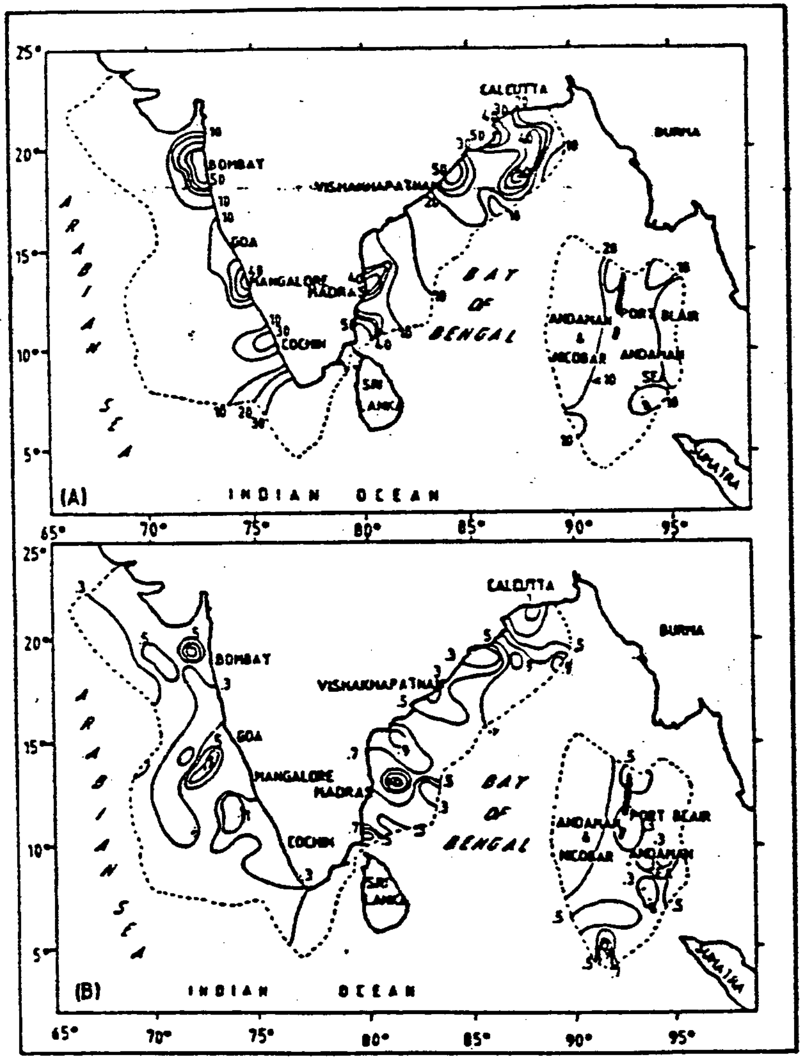


Fig. 11 Rates of primary production (^{14}C uptake) at the Surface (A) mg C/m^{3}/Day and column (B) g C/m^{2}/Day

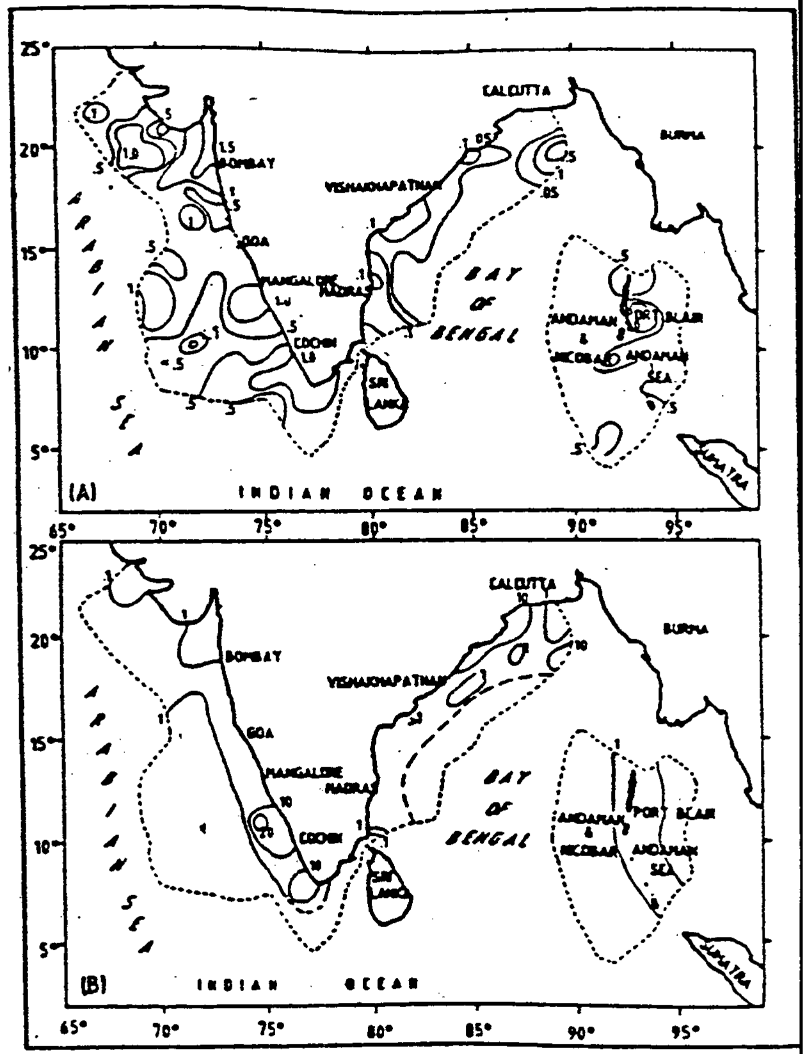


Fig. 12 A. Distribution of Zooplankton biomass (ml m^{-3})
B. Distribution of Benthic biomass (gm^{-2})