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A RESUME OF MARINE BIOLOGICAL AND OCEANOGRAPHIC RESEARCH BY THE CENTRAL MARINE FISHERIES RESEARCH INSTITUTE, COCHIN, INDIA

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ABSTRACT

An account of the past four decades of research carried out in Marine Biology and Oceanography by the Central Marine Fisheries Research Institute is presented. The need for integrating the environmental research with the resources for better understanding of the dynamics of the latter is emphasized. It is also suggested that suitable models for the assessment of the impact of environment on the commercial fisheries be developed, with a view for prediction and forecasting the fishery.

INTRODUCTION

INVESTIGATIONS on bioproductivity have occupied a prominent place in the research programme of the Central Marine Fisheries Research Institute (CMFRI), since its inception in 1947. Oceanographic investigations were initiated in 1957, when M. O. *Kristensen*, one of the fishing vessels of the erstwhile Indo-Norwegian Project (INP) was made available to the Institute. This vessel was replaced by R. V. *Kalava* of INP and regular research cruises were conducted along the west coast of India till 1961, when a modern research vessel R. V. *Varuna*, specially built in Norway for marine biological and oceanographic investigations was made available by the INP during 1962-1969. The acquiring of *Cadalmin* group of medium sized vessels, R.V. *Skipjack* and the addition of the Danish built and fully equipped research vessel FORV *Sagar Sampada* by the courtesy of the Department of Ocean Development, Government of India, had considerably increased the research activities of CMFRI. In addition, the Institute has taken part in the INTERNATIONAL INDIAN OCEAN EXPEDITION (IIOE), INDO-POLISH EXPEDITION AND THIRD INDIAN ANTARCTIC EXPEDITION.

The pioneer marine biological and oceanographic investigations carried out by the scientists of CMFRI have added a considerable amount of valuable information on primary and secondary productivity and on the environmental conditions of the seas around India. All the titles of Papers published by the staff of CMFRI till 1985 have been compiled by Rengarajan *et al.* (1986). The present paper deals with the salient features of the work done by CMFRI in the past, with suggestions for the future lines of research.

MARINE BIOLOGICAL RESEARCH

Primary production - phytoplankton

Though many scientists of CMFRI have worked on different aspects of Phytoplankton for several years, the investigations by Subrahmanyan (1958; 1959; 1960; 1967; 1968), Prasad and Nair (1960; 1963), Prasad (1967; 1969), Prasad *et al.* (1970), Chennubhotla (1972), Nair and Pillai (1972), Qasim (1972; 1973), Nair *et al.* (1973; 1978; 1985), Radhakrishna *et al.* (1978; 1982) and Silas *et al.* (1985) are particularly important from the production and distribution point of view.

Nair *et al.* (1973) have estimated the mean value of primary production over the shelf waters along the west coast of India as 1.19 g C/m^2/ day for areas less than 50 m, 0.43 g C/m^2/ day for 50–200 m and 0.18 g C/m^2/day for the areas beyond 200 m depth and of a potential

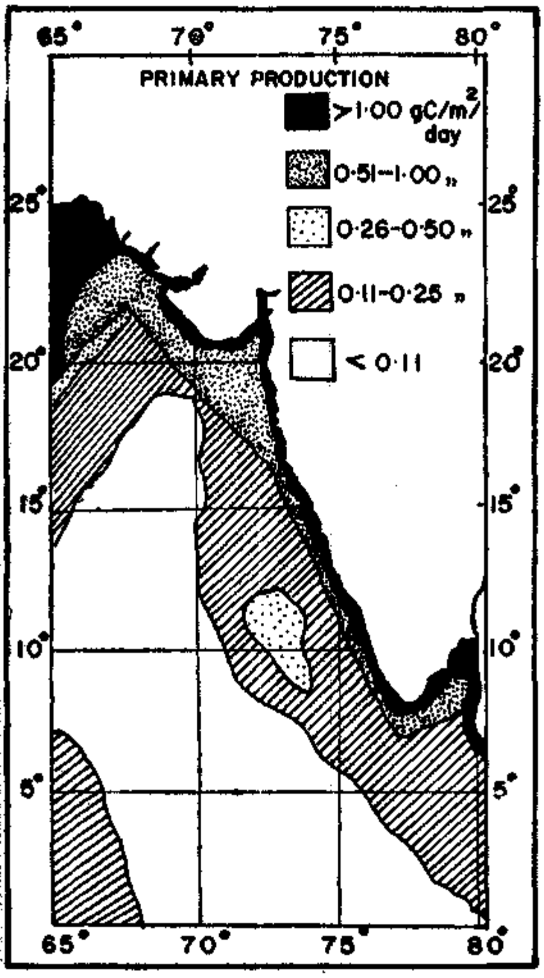

Fig. 1. Primary production in the Arabian Sea (after Nair *et al.*, 1973).

yield of 1.7 million tonnes of organic carbon (Fig. 1). The level of primary production is increasing from the open sea towards the coast and is maximum in the coastal waters. The estimated gross production within the 50 m depth contour is 434 g C/m^2/year. Assuming that 40% of this is being utilised for their metabolic activities in these tropical shelf waters, the net production would be 260 g C/m^2/year. Accordingly the gross production along the shelf within 50 m depth for an area of 114520 km^2 would be 5 x 10^7 tonnes of carbon, while the net production available to the ecosystem would be 3 x 10^7 tonnes of carbon.

Along the east coast the maximum production occurs during the southwest monsoon (June–August) followed by secondary peaks during the northeast monsoon period. The species diversity of phytoplankton has been found to be greater along the east coast than on the west coast (Subrahmanyan, 1967). According to Nair *et al.* (1973), the average productivity along the east coast is only 0.63 g C/m^2 /day for the shelf and 0.14 g C/m^2 /day in the offshore waters (Fig. 2). However, very high rate of organic production of 2.00–5.00 g C/m^2 /day have been recorded in the Gulf of Mannar and Palk Bay (Prasad and Nair, 1963; Prasad, 1969; Nair *et al.*, 1973).

Productivity experiments conducted around Lakshadweep have shown that the waters around Minicoy have the highest organic production of 50 mg C/m^3/day at the surface in shallow areas and upto 0.6 g C/m^2/day and 0.3 g C/m^2/day of column production in the shelf and deeper regions respectively in the vicinity of the island (Prasad, 1969). The latter value is a little more than the rate of production found in the tropical waters. Experiments have further proved that Minicoy reefs in Lakshadweep and the Manuali reef off Mandapam are autotrophic with annual net production of 2500 g C/m^2 and 3000 g C/m^2 respectively. The organic production at the reefs near Port Blair (Andaman Sea) is 1200 g C/m^2 /year which is found to be non-autotrophic ecosystem (Nair and Pillai, 1972).

Secondary production - zooplankton

The distribution and abundance of zooplankton from the inshore waters off west coast of India have been studied at selected zones-Gulf of Kutch (Ramamurthy and Dhawan, 1967); off Bombay (Pillai, 1971); North Karnataka coast (Ramamurthy, 1966); North Kerala coast (George, 1952); off Calicut (Mukundan, 1971); southwest coast of India (Silas, 1972); Alleppey mud bank (Mathew *et al.*, 1977); off Colachel (Suseelan *et al.*, 1985). Recently Girijavallabhan *et al.* (1983) have studied the trends in the zooplankton production along the inshore waters off Bombay, Karwar, Calicut and Vizhinjam. Quantitative studies from the east coast are chiefly confined to the Gulf of Mannar and Palk Bay by Prasad (1954); Subrahmanyan and Sen Gupta (1963; 1965); Ummerkutty (1965); Nair *et al.* (1973). The production trends at Tuticorin, Mandapam and Madras from the southeast coast have been published by Girijavallabhan *et al.* (1983) and from the Andaman Sea by Rangarajan and Marichamy (1972); and Marichamy (1983).

Zooplankton studies from the estuarine system are mostly confined to the Cochin Backwaters [George (1958); Srinivasan (1972); Pillai and Pillai (1974); Rengarajan (1975); Silas and Pillai (1977); Thompson and Easterson (1977); Rengarajan and David Raj (1984). Zooplankton of the Kakinada Bay have been studied by Narasimhan *et al.* (1984).

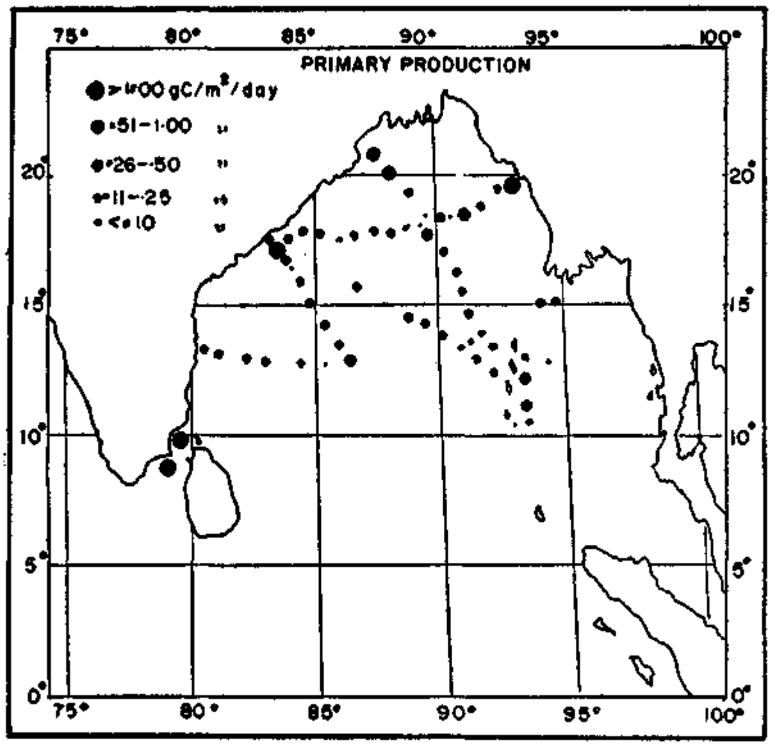

Fig. 2. Primary production in the Bay of Bengal (after Nair *et al.*, 1973).

From the oceanic waters, investigations by Silas (1972) on Zooplankton biomass and Deep Scattering Layer from the Lakshadweep region and the studies by Prasad (1969) on zooplankton production; Pillai (1974; 1980) on calanoid copepods; Thompson (1978) on cyclopoid copepods; James (1976) on ostracods; Srinivasan (1975) on chaetognaths; Rengarajan (1974, 1978, 1986) on siphonophores and Mathew (1983, 1986 a, b, c) on euphausiids are remarkable.

Zooplankton biomass varies quantitatively and qualitatively in space and time. Their concentration is high in the shelf waters than in the offshore regions as in the case of phytoplankton. Higher concentrations are recorded from the neritic waters particularly between Calicut and Quilon, Karwar and Cannanore and in the proximity of the Wadge Bank in the order of abundance (Fig. 3).

Copepods are the highly dominating group in space and time. Decapod larvae are abundant along the southeast coast and fish eggs and larvae off Mandapam with their peak during March. Along the west coast, fish eggs and larvae show an increasing trend during summer months (Premonsoon season) when the coastal drifts are at a minimum (David Raj and Ramamirtham, 1981). In general, zooplankton biomass shows a decline during the peak S.W. and N.E. monsoon months with an increase in production immediately after the monsoon period. Due to oscillation of monsoon season, their density varies region-wise and year-wise, In surface waters, night collections have higher density of zooplankton than during day time indicating diurnal migration Estuaries and backwaters have the maximum crop during summer months.

Zooplankton biomass is relatively richer close to the coral reefs of Lakshadweep than in the open oceanic waters, but much lesser in density when compared to the shelf waters of the southwest coast of India. Silas (1972) has estimated the mean monthly standing crop based on 1541 samples collected during 1963–1967. This shows that the standing crop is 2.5 to over 21 times greater in the neritic waters along the southwest coast of India than in the Lakshadweep Sea (Table 1).

The results obtained from the surveys by M.T. MURENA from areas of depth between 55–360 m along the northwest coast of India during premonsoon, S.W. monsoon and postmonsoon seasons show many interesting features. The zooplankton biomass is chiefly constituted by copepods followed by chaetognaths, ostracods, appendicularians and lucifers in the order of abundnace, (Bapat *et al.*, 1982). Copepods show decreasing trend in their density as 93%, 79% and 72% during the premonsoon, postmonsoon and monsoon months respectively, followed by chaetognaths (11.6% - monsoon, 7.8% - postmonsoon, 2.0% - premonsoon), ostracods (3.0 % - post-monsoon, 2.4% - premonsoon, 1.46%-monsoon). appendicularians (3.3% – monsoon, 1.1% – postmonsoon, 0.25% – premonsoon) and lucifers (1.26% - monsoon, 0.77% - postmonsoon, 0.12% - premonsoon). Fish eggs and larvae are few in numbers (less than 0.25%) in all seasons.

Prasad (1969) has observed moderately high plankton production in the Andaman Sea. The biomass vary from 1.4 to 40 ml in the Andaman Sea (Marichamy, 1983). The plankton production is high at Port Blair during colder months and low during the period of high temperature and salinity (Rangarajan and Marichamy, 1972). Among the larval forms, gastropod larvae are abundant (nearly 75%) followed by decapod larvae, the latter being prominent in the coastal waters around Nicobar Islands. Fish eggs and larvae are comparatively more around Havelock.

Investigations on krill resources of the Antarctic waters (Mathew, 1986 a, b, c) indicate that while only three species of euphausiids

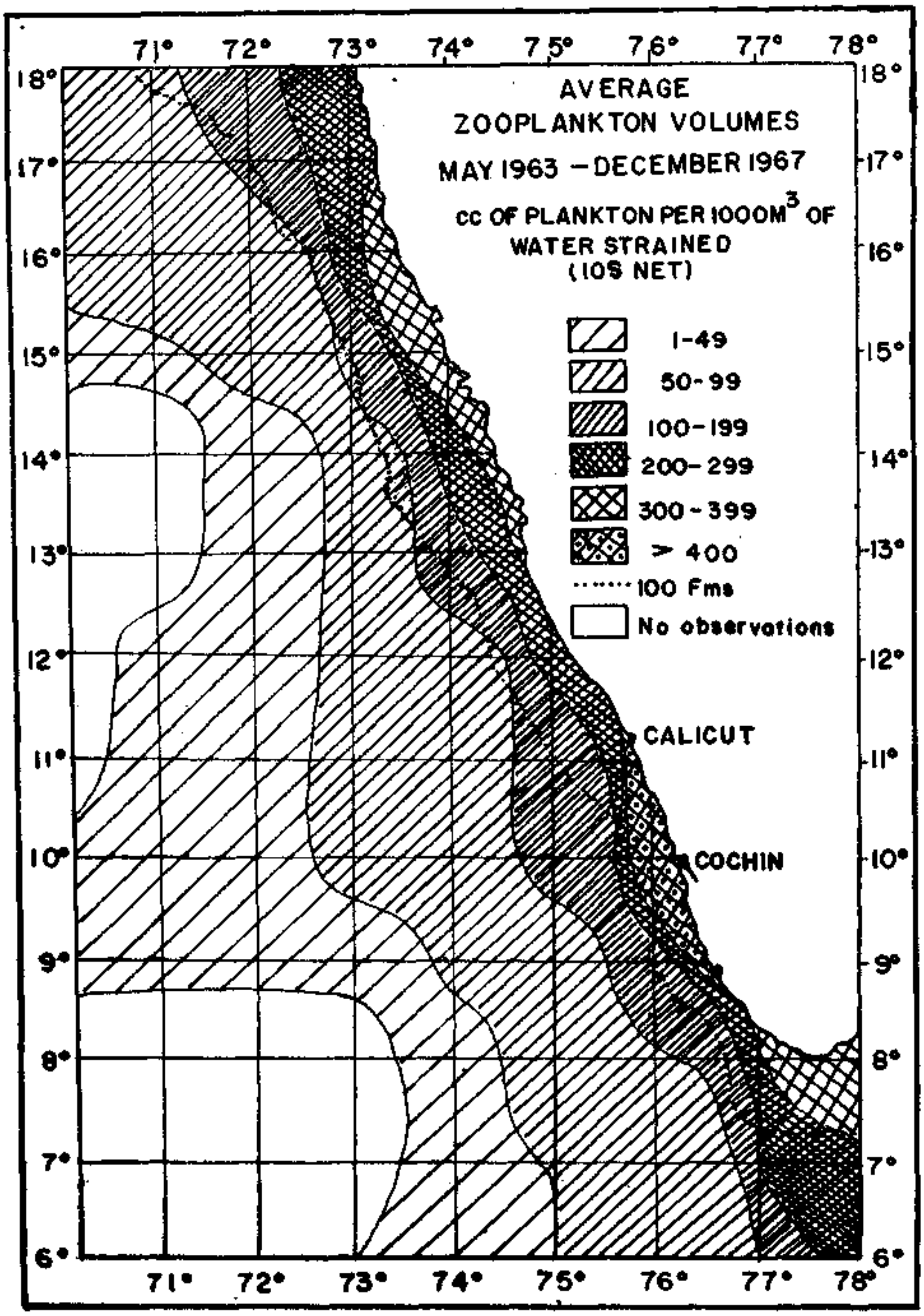

Fig. 3. Standing crop of zooplankton along the west coast of India and Lakshadweep (after Silas, 1972).

(including the krill *Euphausia superba* Dana) are present around the Antarctic circle, as many as eight species are found to occur between 20° S and the Antarctic circle. The density of zooplankton is more in the colder waters.

Plankton in relation to fisheries

Nair and Subrahmanyan (1955) and Subrahmanyan (1959: 1973) have attempted to correlate the magnitude of the intense bloom of phytoplankton and zooplankton with the fisheries along the west coast of India and to point out the potential resources and their locations. Nair *et al.* (1973) have estimated the possible yield of 1.2 x 10^6 tonnes of fish along the west coast based on the primary production. Along the east coast the estimated fish production is o.6 million tonnes only. Prasad (1967) has estimated very high rate of fish production in the Gulf of Mannar and Palk Bay regions and this has been found to be true by the exploratory fishing carried out subsequently.

It has been found that the plankton of the west coast contain more fat in them when compared to those of the east coast (Subrahmanyan and Sen Gupta, 1963). This is of significance for, this might explain the high fat content of the oil sardine and mackerel caught on the west coast. Thus, fishes form the best and economical mode of utilising this vast production of organic matter.

TABLE 1. *Estimated mean monthly standing crop of zooplankton along southwest coast of India and the Lakshadweep Sea for the period May* 1963 *to December* 1967 *(after Silas, 1972).*

Month	No. of samples	Area covered Latitude	Longitude	No. of 1° lat. square covered during the month	Mean displacement volume of zooplankton in cc/1000 m³ of water filtered: Shelf area (S.W. coast)	Oceanic area (Lakshadweep Sea)
January	50	7°–13°N	72°–76°E	15	231	52
February	62	7°–12°N	74°–76°E	10	253	38
March	74	7°–11°N	74°–77°E	13	385	35
April	182	7°–13°N	73°–77°E	18	462	35
May	285	7°–16°N	71°–76°E	21	351	33
June	155	7°–12°N	74°–77°E	15	761	36
July	100	7°– 9°N	75°–77°E	8	478	144
August	111	9°–14°N	73°–76°E	14	198	77
September	151	8°–16°N	71°–76°E	12	391	61
October	84	7°–12°N	72°–76°E	17	717	53
November	97	7°–16°N	70°–77°E	22	342	45
December	190	8°–16°N	70°–76°E	32	421	26

Occasionally, blooms of the blue green algae *Trichodesmium* have been recorded to cause discolouration along the coasts of India and in the Lakshadweep region (Qasim, 1970; Prabhu *et al.*, 1971; James, 1972; Qasim, 1972; Chellam and Alagarswami, 1981). Among the other Chrysophyceae, *Hornella marina* is also responsible for such discolouration called 'Red tide' or 'Red water'. The other genera which bring out this red water phenomena are *Gymnodinium, Noctiluca, Peridinium, Cochlodinium, Goniaulax* and *Haplodinium.* The failure of oil-sardine fishery due to *Trichodesmium* bloom has been indicated by Prabhu *et al.* (1971). The phenomenon of 'Red tide' and its effects have been dealt by Gopinathan and Pillai (1976).

Extensive mass mortality of fish, sometimes covering vast area of about 1000 km long and 200 km wide have been reported (Jones, 1962). The presence of very high concentration of nutrients along the coast with optimum solar energy indicates potentially very high productive and biologically unstable situation. The resulting mass phytoplankton bloom followed by the swarming of zooplankton and their subsequent death, decay and sinking deplete the oxygen in the subsurface waters. This accelerates the mass mortality of fishes and other aquatic animals rather than the other hydrographical factors.

Instance of mass mortality of fishes and prawns in the Muttukadu farm near Madras by the blooming of dinoflagellates (*Peridinium* and *Ceratium)* during April 1983 has been reported (Rajagopalan *et al.*, 1985).

Seaweeds: The macroscopic algae comprising chlorophyceae (green algae), phaeophycaeae (brown algae) and Rhodophyceae (red algae) are important as sources of agar and algin and they are often used directly as food, fodder and manure. An account of the important Indian seaweeds of commercial value and their potential resources in the Indian waters has been published by Umamaheswara Rao (1973). The flora of the coral reefs occurring in the Gulf of Mannar and Palk Bay areas around Mandapam are documented by Umamaheswara Rao (1972), with special reference to their distribution and relative abundance. The studies further indicate that the physical conditions like substratum and water level above the substratum influence the distribution of the flora.

Lakshadweep Islands have been surveyed during 1977–79 and estimates of standing crops are made. All islands except Bangaram support the growth of marine algae. Altogether 82 species of seaweeds are identified and the biomass estimates (wet) of the standing crop for all Lakshadweep islands covering an area of 1334 ha is found to be within 4,940–10,110 tonnes (George *et al.*, 1986). *Gelidiella acerosa* is one of the very common seaweed resources in the Lakshadweep. Regulated harvest of the seaweeds upto 50% level of the resource has been recommended.

The survey conducted during 1978 by Gopinathan and Panigrahy (1983) on the potential resources of seaweeds in the Andaman-Nicobar Islands has indicated the domination of alginophytes such as species of *Turbinaria, Sargassum* and *Padina* and the poor representation of agarophytes such as *Gracilaria* spp., *Gelidiella acerosa* and *Gelidium* spp. There appears to be only limited scope for the exploitation and utilisation of the naturally available seaweed resources in the islands. However, attempts can be made for culture of alginophytes since the seedling material of this group of algae is available in plenty during January – April, especially in the Andaman group of islands.

Mangroves: Mangrove invesitgations with special reference to their ecology in relation to fisheries have been carried out in the Gulf of Kutch, Cochin, Tuticorin, Killai, Kakinada and Andaman-Nicobar Islands. The extent of Mangrove areas on the mainland is about 2,56,000 ha and in the Andaman-Nicobar Islands it is about 1,00,000 ha (CMFRI, 1984 c).

Mangroves are lesser in extent along the west coast and they are vast, denser and fertile along the east coast (Selvaraj, MS) where the vast Sundarben mangrove forest, Godavari and Pitchavaram mangroves are present.

The mangroves of Kutch are of open scrubby type with low wooded *Avicennia marina* and *Rhizophora mucronata*. Seeds of mullets and prawns suitable for culture practices are present in the shallow waters at Dwaraka. The degree of sedimentation in the inshore waters of the Gulf seems to be most deleterious factor affecting the marine fauna (Pillai and Rajagopalan, 1979).

In the Cochin estuarine system, the mangrove areas of Vypeen and Perumbalam form good nursery grounds for *Penaeus indicus, Metapenaeus dobsoni* and *M. monoceros* (Rajagopalan *et al.*, 1986). The construction of barrages and bunds for irrigation has brought about imbalance in the mangrove ecosystems of Kerala. The common sources of pollution such as oil spillage, sewage, effluents from industries, and agriculture practices have been a threat to the mangrove ecosystem in Kerala.

Mangroves of Godavari delta are denser and dominated by *Avicennia marina*, *A. officinalis* and *Excoecaria agallocha*. *Rhizophora* spp. are absent. The considerable quantities of litter-fall from the mangroves and their degradation enrich the mangrove environment with detrital food on which the coastal fisheries are dependent. More than 80% of the bottom fauna are the juveniles of prawns (Selvaraj, MS).

The Pitchavaram mangroves with a net work of creeks and canals, dominated by *Rhizophora* spp. and *Avicennia* spp. provide shelters and food for juveniles of mullets, prawns and edible oysters.

The mangrove resources of Andaman-Nicobar Islands are well preserved (Gopinathan and Rajagopalan, 1983) and would provide ideal grounds for coastal aquaculture. Silas and Alagarswami (1983) have suggested that the mangrove areas in the upper reaches of the creeks of the Andaman-Nicobar Islands can be utilised for developing aquaculture farms without disturbing the mangroves on the sea front which protect the coastal zone against sea erosion.

Coral reefs: Coral reefs form one of the major tropical and subtropical communities of appreciable economic importance. The three major types of reefs present in the seas around India are the fringing, barrier and atoll. The fringing reefs are distributed in the Gulf of Kutch, Andaman-Nicobar Islands and Palk Bay, the barrier reef in the Gulf of Mannar and atolls in the Lakshadweep and Maldive regions.

342 species of Scleractinian corals of 76 genera have been so far recorded from the seas around India of which 253 species (49 genera) are hermatypic and the rest ahermatypic. The Palk Bay and the Gulf of Mannar are known to have 117 species (32 genera) (Pillai, 1972). The Maldivian coral fauna includes 166 species (66 genera), the Lakshadweep 73 species (28 genera) and the Andaman 68 species (31 genera) (Pillai, 1983; 1986).

The coral reef province of Andaman-Nicobar is widely separated from Sri Lanka and southeast Indian coral by nearly 1000 km. This significant gap in the coral growth of Indo-Pacific could be due to the great influx of fresh water, deposition of large quantities of terrigenous mud and acidic nature of the waters of the Ganges – Brahmaputra river system. This is also evident from the fact that the coastal waters of India is devoid of any coral reefs due to the large quantity of fresh water and mud brought out by the great rivers. The major limiting factor of coral growth and many filter feeders in the inshore waters is the high degree of silting. A detailed study on the rate of silting in Lakshadweep is to be taken up.

Better growth of corals are observed along the west coast of Andaman-Nicobar Islands than along their east coast. This may be due to the flow of the oceanic waters from the open Bay of Bengal to the west coast during the S.W. monsoon which brings in rich supply of plankton and nutrients to the coasts. The presence of large quantities of zooplankton, filter feeders and coral fishes often turns the ecosystem non-autotrophic in that the respiratory requirements of the organisms on the reef far exceed the total production (Nair and Pillai, 1972).

The corals are being quarried for industrial purposes. This affects directly as well as indirectly the general fishery of the area. The coral reef areas are well known for large number of fishes and other animals living associated with the ecosystem. The destruction of the coral beds, thus, is detrimental to many reef dwelling animals including fishes.

Sponges: Marine sponges are found in fair abundance in the Indian region and widely distributed in the shallow water areas of Gulf of Mannar, Palk Bay and Laccadives Archipelago. The Indian region between 60°E–100°E Long. with southern limit fixed at 10°S Lat. has a distribution of 481 species of sponges. These are Demospongiae - 427 species (88.8%), Hexactinellida - 44 species (9.1%) and Calcarea-10 species (2.1%) (Thomas, MS). Studies revealed that 35.4% of the Indian Demospongean species are common to the Australian region, 21.1% to the Pacific Ocean, 20.4% to Red Sea and 18.3% to the Atlantic Ocean. The other two groups also bear more or less similar pattern of distribution as the former.

The systematics and distribution of the sponge fauna of the Gulf of Mannar and Palk Bay have been studied in detail (Thomas, 1968, 1972, 1986). The boring sponges form a major group among the marine organisms causing considerable destruction to the coral reef system as well as to molluscs. The bores made by sponges weaken the entire reef making it more susceptible to the stress caused by waves.

Although the importance of ocean currents in relation to distribution of sponges is realised, it is not known whether the larvae of these groups can migrate long distances tolerating wide range environmental conditions. The duration of the larval life of sponges is not clearly understood.

Stomatopods: Of the 275 species of stomatopods recorded from different parts of the world, 115 species are known from the Indian Ocean. Systematic account of these with key for their identification as well as the resource estimate of the southwest coast of India have been published (Shanbhogue, 1973, 1982, 1986). With the initiation of large scale trawling operations along the southwest coast of India in recent years, the stomatopods are being caught in large quantities (10–20% of catch in a shrimp trawler) during November–April with their peak during December–February. The catch mainly constitutes *Oratosquilla nepa* (Latrielle) and the other important species are *Oratosquilla holoschista* (Kemp), *Oratosquilla woodmasoni* (Kemp) and *Harpiosquilla raphidea* (Fabricius). A moderate estimate of stomatopods caught by trawl nets along the southwest coast of India would be nearly 30 tonnes per day during December–February and is about 6 tonnes during November, March and April. In Bombay, the 'dol' nets land large quantities of stomatopods.

Polychaetes: Apart from the detailed studies on the biology and systematics of polychaetes (Tampi and Rangarajan, 1964), their role in the marine ecosystem has been stressed (Achari, 1971). The observations made on synchronised habits of polychaetes with the habits of other invertebrates from the Indian region have indicated the scope of the interactions of the species components in benthic animal community which has an ultimate bearing on the fisheries.

Echinoderms: The distribution of echinoderms along the southeast coast of India in the Gulf of Mannar and Palk Bay, Sri Lanka, Lakshadweep and Maldive regions and Andaman Islands has been studied (James, 1986). Curiously enough the distribution presents difference in the Gulf of Mannar –Palk Bay region and Sri Lanka inspite of the proximity of the regions. Thus, the genus *Actinopyga* is not recorded in the Indian region while five species of this genus are recored from Sri Lanka. This could be due to a barrier to currents which restricts the movements of echinoderms from Sri Lanka to the Indian region and also due to the vast coast line of Sri Lanka, compared to that of Gulf of Mannar.

59 species of Asteroidea, 55 of Ophiuroidea, 54 of Echinoidea and 73 of Holothuroidea are known from the Indian seas (James, 1986). Among the echinoderms, holothurians and sea urchins are economically important. Field keys for their identification have been published by James (1983).

Along the Indian coasts, holothurians occur in large numbers in the Gulf of Kutch and along the southeast coast. They are abundant in the Palk Bay than in Gulf of Mannar (James, 1973).

More than 40 species of the sea-cucumbers are known from the shallow waters of the Lakshadweep and Andaman-Nicobar region of which some are suitable for *beche-de-mer* industry. *Holothuria atra* seems to be the most abundant species around the Andaman and Nicobar Islands. The other species suitable for this are *H. scabra, Thelenota ananas, H. marmorata* and *Actinopyga mauritiana.* Among the sea urchins, *Tripneustes gratilla* appears suitable for farming as it grows to a large size on algal beds in shallow waters.

Oceanographic Research

Water mass characteristics

Three main types of water masses are noticed in the Arabian Sea (Jayaraman *et al.,* 1960; Rama Sastry, 1960; Patil *et al.* (1964). They are (i) Arabian Sea upper subsurface water mass, which participates mostly in the upwelling and sinking phenomena characterised by rather sharp salinity gradients of very small temperature range, and density (sigma-t) values between 21.00 and 23.00 from surface down to 75–100 m; (ii) Arabian Sea Lower subsurface water mass characterised by a steep temperature gradient with salinity range hardly exceeding 0.8%, sigma-t values between 23.00 and 25.00 and more clearly defined than the first one; and (iii) Indian Ocean Equatorial water mass below 200 m having small temperature and salinity gradients and appearing like isohaline waters at certain places. In addition to these the Antarctic Intermediate water mass characterised by higher oxygen content (3.5 ml/l) is seen at depths greater than 2000 m (Jayaraman *et al.,* 1959; Patil *et al.,* 1964; Ramamirtham, 1971).

Along the East coast of India between Point Calimere to Vizag in the continental shelf waters the most predominant water mass has the temperature range 27°–28°C and salinity range 33–34‰ (Rao *et al.,* 1966). Wherever inversion in temperature occurs, the range is slightly reduced to 26°–27°C with the same salinity range and latter mass predominates in the 20–50 meter column.

Water movements and circulation

The main feature of the circulation in the southeastern Arabian Sea during November–January period is the northward movement of waters with northwest deflection around 13° and 15°N latitudes (Ramamirtham, 1968). This drift has a good velocity, the maximum being attained in the region between 16° and 17°N latitudes (Fig. 4).

In the Maldive region there is a large cyclonic gyre between 4° and 8°N latitude within the meridians 74° and 78°E, mainly in the subsurface layers during September–October (Ramamirtham, 1981). An anti-cyclonic gyre of lesser spacial extent and lesser intensity is also present along the 2°N latitude within the same meridians (Fig. 5). These are supposed to be associated with divergence and convergence phenomena occurring in the area.

Along the west coast of India from Ratnagiri to Kanyakumari during the southwest monsoon a strong southward drift (especially in the region Calicut–Karwar) is prominent in the upper layers (Ramamirtham and Rao, 1974). A northward counterflow exists around the lower boundary of the thermocline, the flow being comparatively weaker and discontinuous. Along the coast these southward drifts reverse, and a weak northward flow exists during winter in the northern regions. In the section of 14°N an anticyclonic eddy of nearly 160 km width is seen at the top of the thermocline revealing convergence phenomenon during winter. During winter in the open part of the Arabian Sea there are strong northward currents north of 13°N in the upper layers with strong intensity at 75 m (Prasad, 1969). One large divergence zone exists between 70°–72°E and 8°–11°N and one convergence zone with an axis roughly along 74°E longitude (Fig. 6). During winter along the Maharashtra coast, north of 17°N, the flow is mainly eastward which deflects towards south with increase in depth (Rao *et al.*, 1972). At 50 m depth a continous southward drift is noticed.

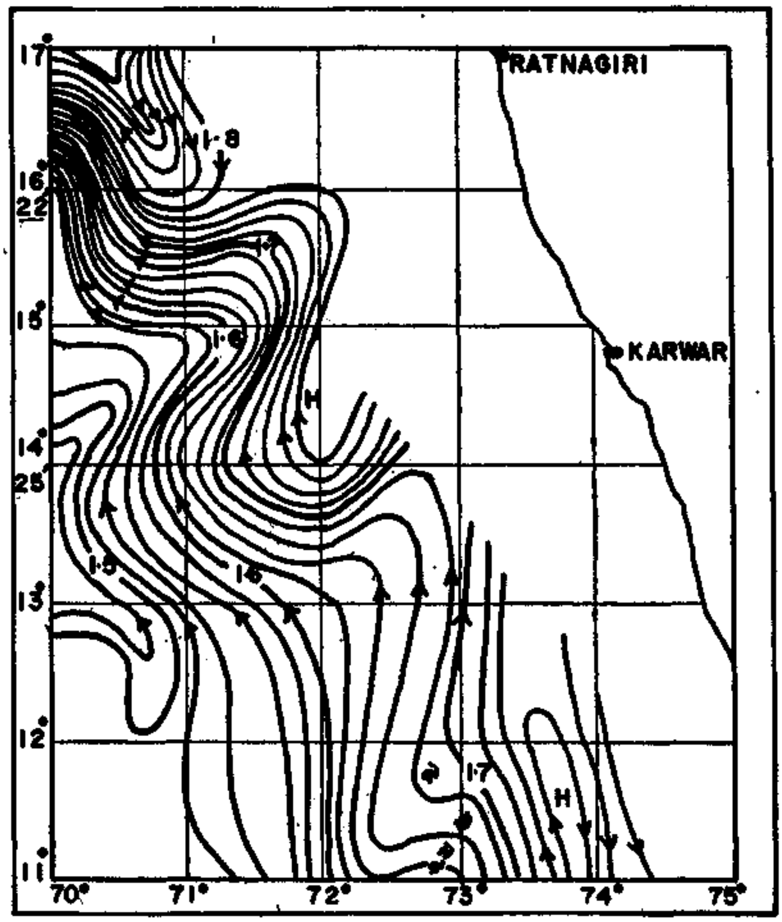

Fig. 4. Geopotential topography of the sea surface relative to the 1000 db surface. Also given velocity of currents in cm/sec (after Ramamirtham, 1968).

Around the Lakshadweep Islands during summer a fairly pronounced anticyclonic motion (eddies) is present around the islands in the upper 100 m and reverse of that below that level (Jayaraman *et al.* 1960). The circulatory water movements are present during winter also, but with lesser intensity (Patil *et al.*, 1964) and only in upper layers upto 200 m. Significant circulatory movements mostly cyclonic are found near Bitra Island while near Agatti and southeast of Kiltan Islands these are anticyclonic. Superimposed upon these general circulatory movements around the islands the northwesterly drift produced by the prevailing winds is noted in the upper 30 m towards west of Suheli par and further towards east due south of Agatti Island during winter. Towards the north of Agatti and Androth Islands an easterly drift in the upper layers is noticed (Patil *et al.*, 1964).

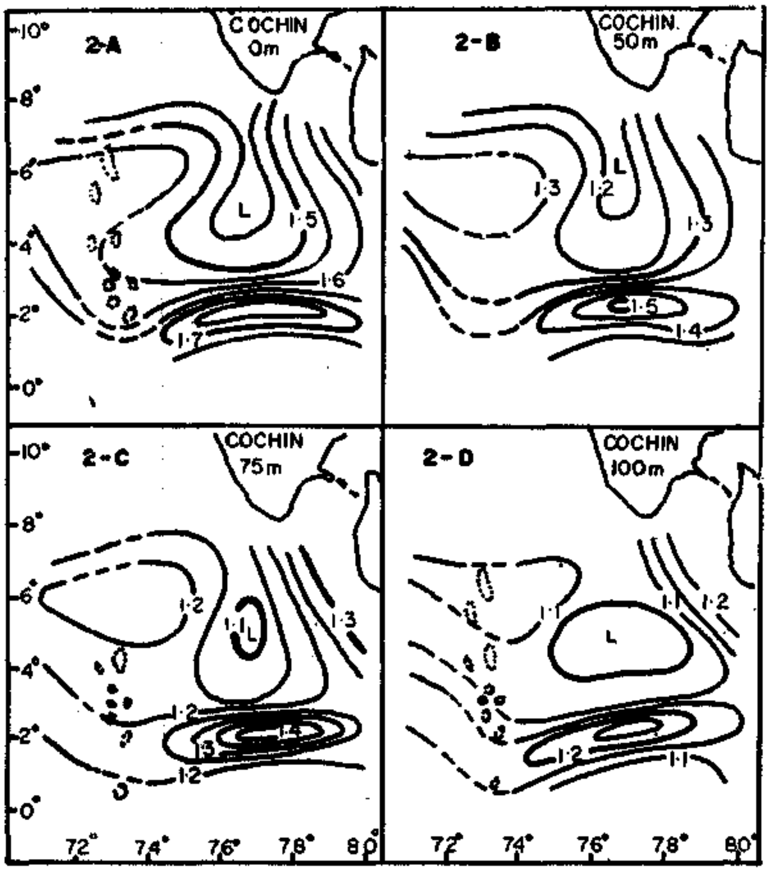

Fig. 5. Geopotential topography of different levels in the Maldive region (contour interval 0.05 dyn. metres) (after Ramamirtham, 1981).

In the region off Cochin, vertical turbulence has been found during the monsoon and early monsoon. It is also noted that the high stability values over the bottom during summer and winter seasons are sufficient enough to immobilize the bottom nutrients during these seasons (Ramamirtham and Jayaraman, 1961).

Between Goa and Veraval a weak eastward drift is noticed in the region off Bombay during winter (January), north of which there is intense surface cooling. During the middle dary off Bombay presenting higher values in the northern regions are noticed. Dissolved oxygen values are higher north of this boundary, with values 7 ml/l and more off Jamnagar. In

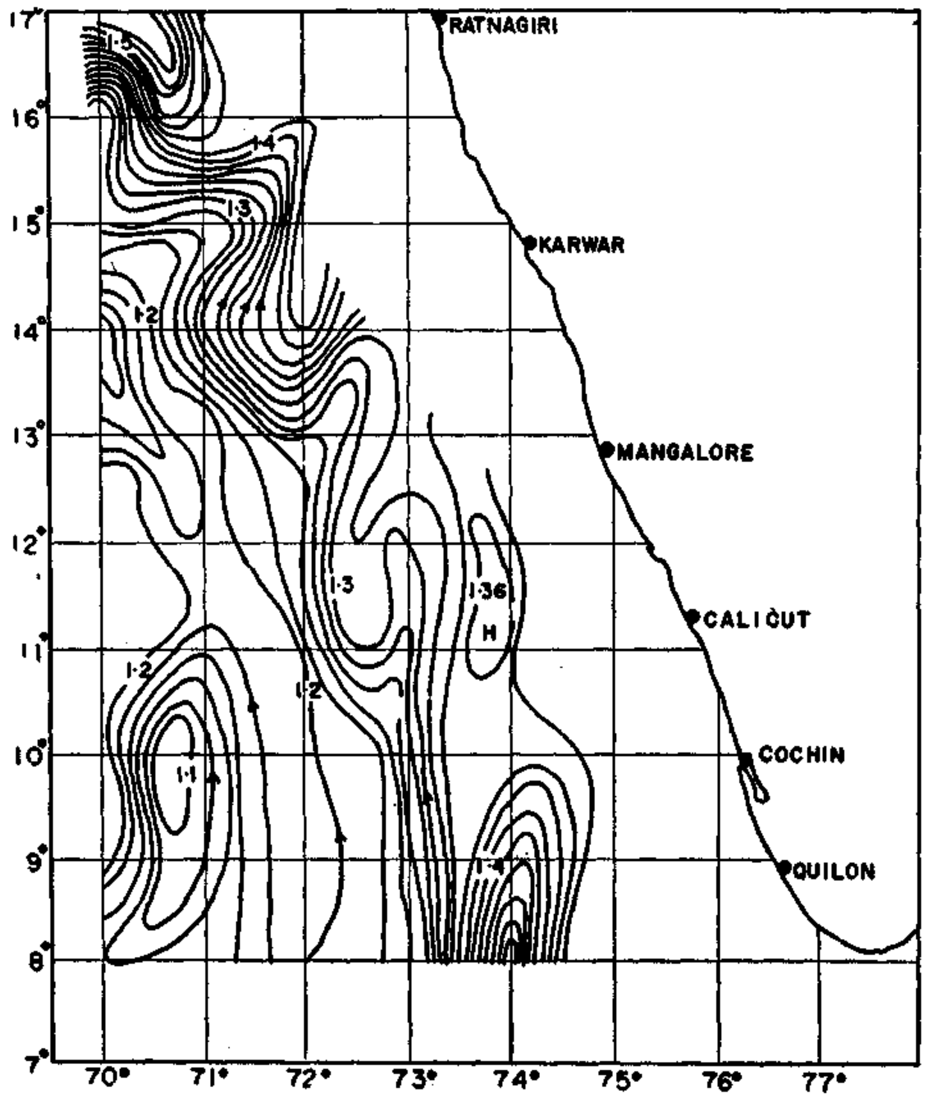

Fig. 6. Geopotential topography of the sea surface, 75 db surface relative to 1,000 db surface (after Prasad, 1969).

of June the area indicates a predominance of eddies, especially in the northern regions. Two distinct zones of salinity with zonal boun- September, a weak northeastward gradient in temperature is seen off Jamnagar and a south-eastward flow is indicated (Bapat *et al.*, 1982).

Upwelling and sinking

In the region between Kanyakumari and Karwar upwelling is noticed with the onset of southwest monsoon with the temperature discontinuity layer at a shallower level of 20 m (Rao and Ramamirtham, 1976). During July and August, the surface mixed layer becomes more or less obliterated with temperature maximum dclining to 26.5°C and the oxygen deficit less in the region south of Quilon. It is also noticed that upwelling starts in the southern regions first and then extends northwards with the progress of southwest monsoon season. The nature of the coastline towards southeast helps this trend (Ramamirtham and Rao, 1974). The coastal southward drift, the prevailing winds and the subsequent divergence in the Arabian Sea are the causes of this upwelling.

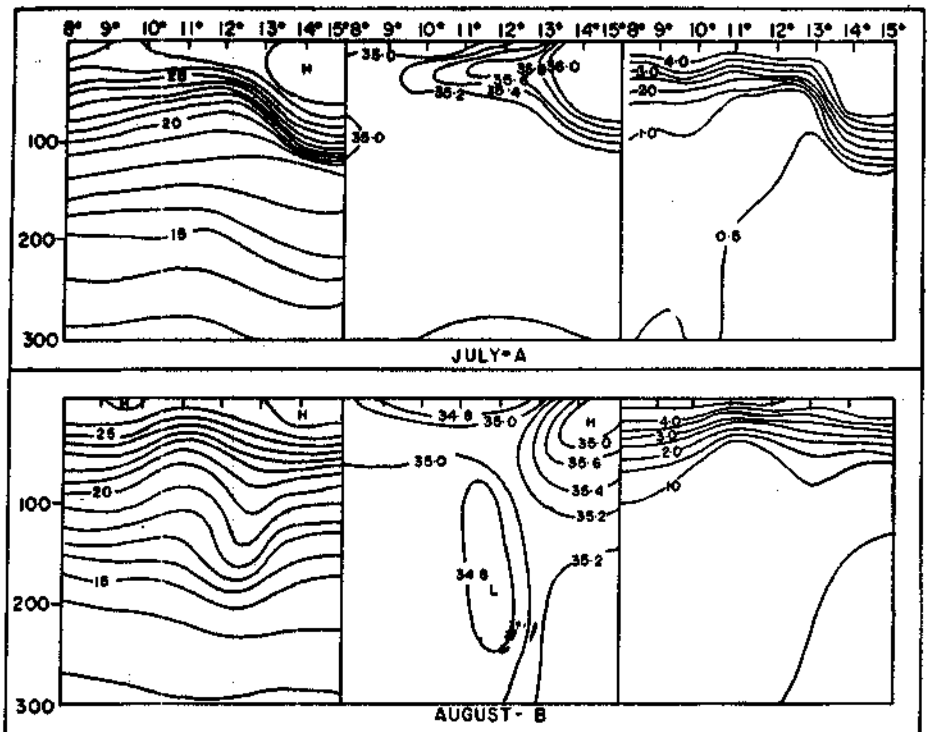

Fig. 7. Distribution of temperature, salinity and dissolved oxygen in the meridional section during July and August (after Rao and Ramamirtham, 1976).

layer migrating even upto the surface (Fig. 7) indicating the existence of the coastal upwelling. The maximum intensity of the upwelling is in the Calicut-Karwar region (Rama Sastry and Myrland, 1959; Rao and Ramamirtham 1976; Ramamirtham and Rao, 1974). This feature extends throughout the region from Kanyakumari to Karwar though the intensity is very

During November, December and January southward sinking of the offshore waters at the top of the thermocline over the shelf is noticed (Fig. 8). This sinking is more prominent off Mangalore and off Karwar the intensity being pronounced due to the anticyclonic eddy of nearly 160 kms indicating convergence. Off 16°N, the sinking of waters below an isothermal mixed layer of 60 m thickness is noticed over the continental shelf. The summer heating of surface layers occurs during April and May. The depth of the thermocline along the west coast does not exceed 150 m in any month of the year and it is deepest in the months of January-February and shallowest during the peak monsoon indicating upwelling upto August after which the thermocline tilts downward indicating sinking, the intensity of which is more during November and December (Sharma, 1968). Along the Maharashtra Coast the upwelling continues upto December off Bombay though with less intensity (Rao *et al.*, 1972). The presence of upwelling from 12°N to 16°N, is noticed during the month of October with low oxygen values in the near surface water in the inshore regions (Rao, MS). Along the Gujarat Coast (Rao *et al.*, 1984) during summer, sinking and spreading of high saline waters from Gulf of Eden and Persian Gulf over the region is also noticed. Upwelling has also been observed in the region from Pulicat to Krishnampatnam along the east coast during the month of July (Rao, per. comm.).

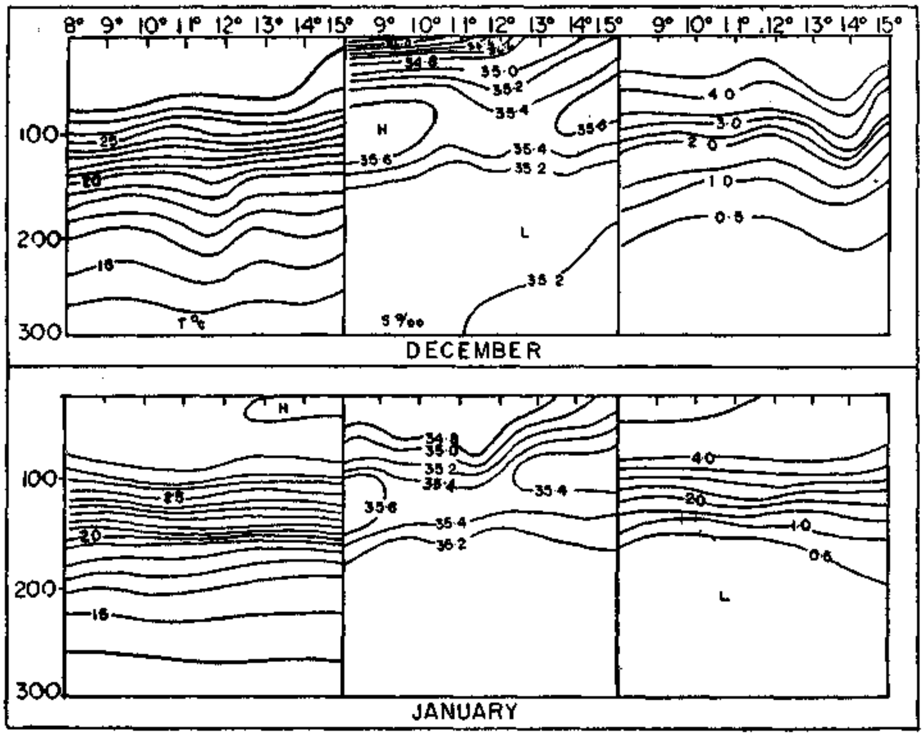

Fig. 8. Distribution of temperature, salinity and dissolved oxygen in meridional section during December and January (after Rao and Ramamirtham, 1976).

The Ekmann transport inferred from the wind-induced currents for the seas around India indicated the possibility of upwelling along the west coast of India, as well as in the southeastern and central area off the east coast of India during the summer transition and south-west monsoon periods. Conditions are favourable for upwelling at the head of the Bay of Bengal throughout the year except for the winter transition period (Murty, 1981).

Other oceanographic features

Along the southwest coast of India the higher pH values are associated with higher temperature and high oxygen content, and the pH discontinuity layer coincides with that of temperature and dissolved oxygen content. In the mixed layer above the thermocline the pH distribution is mostly uniform and it is lowest in the oxygen minimal column. These peculiarities in the distribution are mostly due to the photosynthesis by phytoplankton and the consequent assimilation of carbon dioxide (Rao and Madhavan, 1965).

In the Palk Bay during summer the Bay of Bengal waters entering through the Palk Strait have major influence on the hydrographic conditions in the Palk Bay (Murty and Varma, 1965). The Gulf of Mannar waters influence the Palk Bay only to a minor extent. When the winds blow over the Palk Bay from the north-east, they are strong at the Palk Strait and weak towards the southern end of the Bay. The dissolved oxygen reaches its saturation value over the entire Bay and sometimes exceeds its saturation limit by a small percentage. The waters adjacent to the coast have high temperature, low salinity and low density. The Bay of Bengal water extends its influence almost to the middle of the coast and hence separates the coastal water into two cells. Denser sea water is pocketed near the coast at the south-eastern region of the Bay. The south-western zone is the least disturbed area under the protective configuration of the coast and the non-disturbing atmosphere. The coastline of the western region is also similarly protective. But the waters in this region are disturbed by the strong north-easterly winds and by the associated circulation of the water through the strait.

Along the Maharashtra Coast during winter a northward gradient in temperature north of 17°N and eastward gradient south of it are noticed (Rao *et al.*, 1972). The thermocline is found at shallower depths in the northern regions. A steady increase in the salinity is observed northwards, the maximum being off Bombay. Dissolved oxygen at surface and 20 m depth are mostly uniform, but at 50 m depth where a continuous weak southward drift is noticed, eastward gradients in oxygen distribution is observed. Sharp decline in oxygen occur from the top of the theremocline and the oxygen minimum layer is prominently noticed. The total phosphorus content is less in the region off Bombay and between 15°N and 18°N latitudes. Higher values are found south and north of these latitudes. The distribution pattern of dissolved oxygen and total phosphorus show an inverse relationship. A westward gradient in phosphorus values is seen at 50 m depth.

Along Gujarat Coast during summer the waters are mostly isothermal within the continental shelf and the thermocline is present outside the continental shelf. Maximum salinity is observed in the region off Porbunder, where there is minimum temperature and maximum oxygen content. A southward increase in temperature is noticed with a southward decrease in salinity (Rao *et al.*, 1984).

A general increase in phosphate and silicate contents of the waters has been observed in the region from Kanyakumari to Cochin during the southwest monsoon period when upwelling is prevalent. An increasing trend in the nutrient content of the waters are observed from south to north in this region and Cochin region shows higher values than the region south of Quilon, which may be due to the higher intensity of upwelling off Cochin compared to the southern region. Uniformly higher reactive phosphate values have been noticed at the bottom over the shelf region. The vertical distribution of phosphate shows an increase in phosphate content with depth thus showing an inverse relationship with dissolved oxygen. The vertical distribution also shows an abrupt increase in the phosphate value within the thermocline layer (Rao, MS).

During June along the coast from Kanyakumari to Pulicat, colder water prevails in the region south of Kanyakumari with the temperature about 25°C whereas the region from Point Calimere to Pulicat presented warmer waters with about 29°C in the upper layers. The region south of Kanyakumari shows higher dissolved oxygen and higher reactive phosphate, nitrite, nitrate and silicate contents in the waters, but their values were less along the east coast from Point Calimere to Pulicat. The pH values were, however, less off Kanyakumari than along the east coast (Rao, MS).

In the region off Cochin it is found that actual period of commencement of monsoon disturbances in the Arabian Sea could be assessed with an approximattion of less than 10 days. The monsoon characteristics and upwelling which are seen during June–July are found to disappear due to the failure of the southwest monsoon during middle of August. This starts again with the revival of monsoon by early September. This type of intermittent upwelling affects the fishery of the region adversely (Ramamirtham, per. comm.).

Mud banks

Mud banks are formed at some places along the southwest coast of India during the southwest monsoon period. The source of mud for the Alleppey mud bank is the subterranean mud and the Vembanad Lake system provides the mud for this mud bank (Rao *et al.*, 1980; Mathew *et al.*, 1981; Gopinathan *et al.*, 1984). "Mud cones" or "Mud volcanoes" erupt in the weakest areas of the shore and in the intertidal zone. The source of mud for the mud bank between Parapanangadi and Tanur is the aggregation of coastal mud. The mud banks at Chellanam–Manassery (Cochin bar mouth), Narakkal (Azhikode bar mouth), Vallappad–Nattika (Chetwai river mouth), Elathur (Korapuzha river mouth), Quilandy (Kuttiyadi river mouth), Muzhippilangadi (Dharmadam river mouth), Kottikulam, Ajanur-N-Bella, Adakathubail (Chandragiri river mouth), Kumbala (Kumbala river mouth), Uppala (Uppala river mouth), and at Ullal (Netravati river mouth) are formed by the sediments and organic debris discharged from rivers and estuaries. Mud bank at Vypeen (Cochin) is formed by the accumulation of mud resulting from dredging operations.

The formation of mud banks is by the mud brought in suspension at the beginning of the southwest monsoon by the prevailing environmental conditions such as force and direction of winds, currents, offshore movements of the surface waters and the resulting onshore movement of the bottom waters. The calmness associated with the mud banks is due to the colloidal system formed by the mud with the waters, a phenomenon known as 'thixotrophy', and to the Kinematic viscosity of the medium largely controls the dampening of the waves (Rao *et al.*, 1984).

Mud banks are maintained by the southwest monsoon with its westerly winds having more northerly components which causes the monsoon swells in the inshore region which along with the waves produce a constant thrust, thereby preventing the mud from spreading into the sea. The monsoon swell also provides a continuous source of energy to keep the mud in suspension. The mud sediments of the Alleppey mud bank contain more interstitial volatile oily matter as it comes up from the subterranean region as mud cones and this helps in the stabilisation of the thixotrophic colloidal solution by its lyophobic effect, thus imparting a longer lasting nature of calmness for mud bank at Alleppey. In the case of other mud banks the sediments are either those brought by the rivers or already existing coastal mud. Here, the volatile matter is less as the sediments are either washed down by rivers or removed by water movements. Hence, the mud banks formed in these cases are of a transient nature. Even in the case of Alleppey mud bank, when fresh subterranean mud is not brought by way of the 'mud cones', the mud bank formed by the already present mud is of short duration.

Mud banks formed on the southern side of the river/bar mouths remain only for a few days and then disappear. But the mud bank at Alleppey region exhibits a slow movement from one place to the other in course of time and this movement is mainly southward.

The dissipation of the Alleppey mud bank takes place when the onshore thrust from the sea and from the backwater becomes reduced due to the decline in the intensity of the monsoon. With this the heavy swells and waves which maintain the mud in suspension also declines in intensity and the southerly drifts start reversing along the coast. The continued effect of the decline in shoreward winds, waves, swells and setting in of the northerly and on shore components of currents help in the dissipation of loose mud in colloidal suspension and also in the settling down of mud (Rao *et al.*, 1984; Mathew *et al.*, 1984). This accounts for the occurrence of the mud banks along the coast during the southwest monsoon only.

The common belief that the mud bank and fishery are interdependent, has been found to be incorrect. It is observed that when the fishing is almost suspended all along the coast, the mud banks due to calmness in their environs provide ideal facilities for the fishermen to launch their canoes. Direct observations have confirmed that bulk of the fish catch landed at the mud bank area is from areas far away from the limits of the mud bank. After being launched, taking advantage of the calm water, the canoes go in all directions in search of fish shoals. However, there have been occasions when good catches were obtained from within as well as outside the mud bank areas. During this season a changing pattern of the fishery is seen (Regunathan *et al.*, 1984). It is significant to note that the mud bank formation has been found to decrease the intensity of erosion in the region.

During the mud bank (monsoon) season the temperature and salinity in the mud bank region are lowest compared to other seasons. The dissolved oxygen are lower during the monsoon season, lowest during the post-monsoon and highest during summer in the region of mud bank. The reactive phosphate, silicate, nitrate and nitrite contents of the waters are highest in the region during the monsoon. These cooler waters being rich in nutrient content, and low in salinity seem to favour primary production (Rao *et al.*, 1984). The primary production, surprisingly, is high only before, and not during or after the formation of the mud bank. This is due to the turbidity of water in the region during the mud bank season. Qualitatively a total of 58 species of phytoplankters were observed. Blooming of *Noctiluca millaris* was observed at the time of dissipation of the mud bank (Nair *et al.*, 1984).

Investigations were made on the diurnal variations in the distribution of plankton biomass in relation to currents and other ecological parameters in the mud bank region at Alleppey (Mathew *et al.*, 1977, 1984). The flow of waters is exclusively southerly in May and rotatory in August (Fig. 9, 10). While the salinity and temperature of the water are high in May, they are very low in August due to the discharge of fresh water through the Thottappally spill-way. The direct effect of fresh water influx on zooplankton is the absence of chaetognaths and appendicularians and the significant reduction in the number of copepods in August. Despite the fact that light is the most important factor which governs the diurnal variations of the zooplankton, the effect of current associated with the tidal variations upon the zooplankton is pronounced. In May, the direction of the current flow over a diurnal period is found to influence the distribution of zooplankters also showing a simultaneous increase or decrease with currents (Fig. 9, 10).

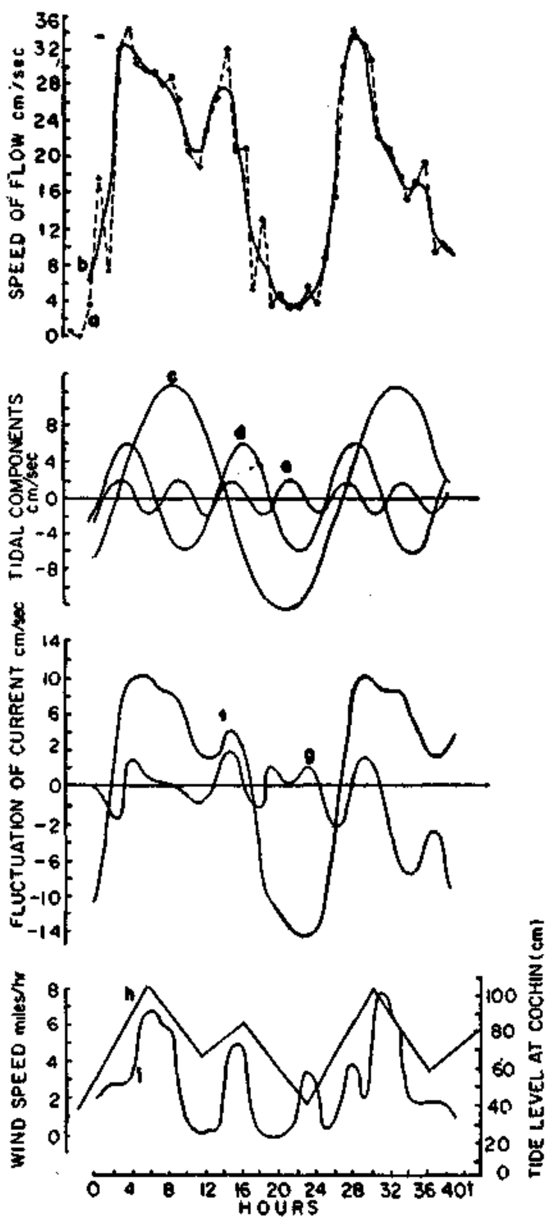

Fig. 9. Speed of current flow, tidal components, current fluctuation and wind speed during 42 hours, at Purakad mud bank, starting from 1200 hrs on 16th May. a: Absolute values of currents observed, b: observed currents after smoothening overlapping values, c: diurnal component of tidal flow (after Mathew *et al.*, 1984).

Hydrography of the Vembanad Estuary

During the monsoon, the Vaikom–Cochin region of the Vembanad estuarine system has been classified as a highly stratified or salt wedge type of estuary with a surface outflow, bottom inflow and with the associated entrainment (Ramamirtham *et al.*, 1986).

During the pre and post-monsoon periods the estuary presents two major types viz., partially mixed type and vertically homogenous type. The latter type is met with at the shallowest regions, Perumbalam and Pallipuram. There is the incursion of offshore upwelled subsurface waters into the estuary and the mixing process, such as, entrainment during monsoon. In the Cochin–Azhikode region the estuary opens at two places into the Arabian Sea. *viz.*, at Cochin and Azhikode. Both the inlets are affected by similar tidal cycles (high and low) simultaneously each producing two opposite flows respectively, which converge and diverge and resulting in a lull zone, almost free of the tidal effect around Kodakara, situated midway between Cochin and Azhikode. A significant feature is the presence of a patch or lens of extreme low salinity between Karthedam and Cherai region during monsoon and early postmonsoon brought about by the deflected waters of the Periyar, opening at the northern end of the estuary (Ramamirtham *et al.*, 1986).

The influence of the Vembanad estuary over the region shoreward at the 30 m depth off Cochin results in the formation of a low salinity plume and an associated plume front near the region of the fareway buoy especially during the south west monsoon. During this period, the salinity characteristics of the region from

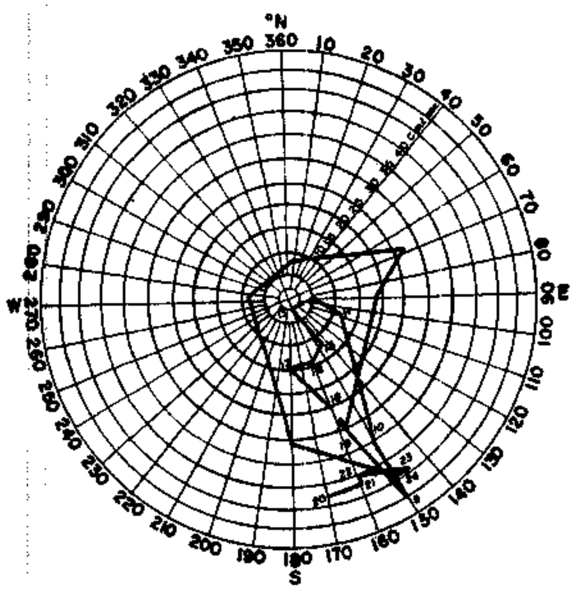

Fig. 10. Hourly observation of currents over a total period of 24 hr in August at Purakkad Mud Bank region (after Mathew *et al.*, 1984).

the confluence to about 10 m depth greatly resemble those of an estuary, though this region lies outside the geographical boundaries which often define an estuary. At least during the monsoon and postmonsoon the nearshore waters in the region off Cochin are similar to those of the Salt-Wedge type of estuary. A feature observed in this region is the intermittent nature of upwelling caused by the discontinuity of the southwest monsoon (Ramamirtham *et al.*, MS).

Biological Oceanography

Oceanography in relation to phytoplankton

Upwelling along the southwest coast of India during the southwest monsoon has considerable influence on the coastal productivity. Along the west coast, maximum production of phytoplankton takes place during the southwest monsoon months of May–September after which there is a decline in the crop. Later during northeast monsoon of December–February another peak production takes place with lesser magnitude. The magnitude of the south west monsoon bloom on the west coast waters is of a very high order surpassing those known from some of the most fertile waters of the world. Investigations on salinity, temperature and nutrients have shown that the optimum conditions are obtained during both the southwest and northeast monsoon months; the salinity of water falls from 35‰ or more to 30–31‰, temperature registers a fall from 31–32°C to 23–25°C; and nutrients such as phosphate, nitrate and silicate become abundant due to upwelling and river discharges. These are the important factors for a high production of phytoplankton (Subrahmanyan, 1967).

Higher concentrations of nutrients have been observed in the open part of the Arabian Sea at or near the base of the photic zone, especially at regions of deep water ascent (upwelling areas) with high production rate being recorded in the euphotic zone (Prasad, 1967). Record of higher concentration of nutrients does not seem to act as limiting factor in the tropical Indian waters. On the other hand, it is the rate of replenishment of the nutrients in the euphotic zone that determines the productivity.

The seas around the Lakshadweep and the reef lagoons are of great ecological significance as they influence the fauna and flora associated with the coral reefs and the oceanic resources to a great extent. The waters have been found to be highly productive at the primary and secondary levels (Prasad, 1969). In the Lakshadweep Sea, comparatively low salinity and temperature have been recorded during dry months indicating the presence of the sub-antarctic bottom drift and this also may favour the primary and secondary production and thereby the tuna fishery resources.

Along the east coast, though these aspects have not been investigated in detail as for the west coast, the maximum production occurs during the southwest monsoon months followed by one or two peaks of production of a lesser magnitude during the northeast monsoon months. But, species diversity of phytoplankton has been found to be greater along the east coast than on the west coast (Subrahmanyan, 1967).

Oceanography in relation to zooplankton

The productive value of upwelling is found to be reflected in the abundance of the total zooplankton biomass. Temporal and spatial lag of occurrence of zooplankton with respect to upwelling is noticed. Upwelling and plankton production are earlier in the southern regions of the coastline along the west coast than in the northern ones (Murty, MS). Periodic variations of zooplankton biomass have indicated semi-annual and quarter-annual cycles in addition to the annual cycle of variations. The pelagic fish landings in general show an exponential relation with the plankton in each season.

Correlation of oceanographic features with zooplankton biomass and abundance of fish eggs and larvae (David Raj and Ramamirtham, 1981) shows that the continental shelf region along the southwest coast is markedly richer than the offshore regions as far as plankton biomass is concerned. The peak of plankton biomass is observed during peak monsoon and post-monsoon periods, that is, during and after upwelling phenomenon, while the abundance of fish eggs and larvae shows a different trend with peak during premonsoon months.

Fisheries Oceanography

Seasonal variations in oceanography in relation to mackerel and sardine fisheries

Correlation of the ten year average distribution of temperature, salinity and sigma-t (density) of the waters along the west coast of India with the corresponding ten year average of mackerel and oilsardine fishery data, one degree squarewise and monthwise (Rao *et al.*, 1973), revealed a noticeable regional and seasonal variations in the abundance of oil sardine and mackerel along the coast. The abundance of mackerel is more in the northern region (north of 13° N) than in the southern region. The higher salinity values in the northern region appear to be more favourable to mackerel than oil sardines. Their abundance is significantly low during the monsoon. The oilsardine fishery appears to dominate in the region between Alleppey and Malpe and mackerel fishery from Calicut to Malvan. December is the peak season for oil sardine fishery (Fig. 11) and October for mackerel. The abundance of sardine during December may be related to the convergence (sinking) phenomenon along the coast. The upwelling occurring along the west coast during the southwest monsoon enriches the waters to a great extent leading to a high organic production and a good pelagic fishery after the monsoon.

The intensity of monsoon plays a role in the long term fluctuations of the Indian oilsardine fishery, the higher intensity being favourable for the fishery. There is a critical intensity of monsoon tuning in favour of the pelagic fishery (Murty and Edelman, 1971).

Oceanography in relation to other fisheries

During upwelling, there is the incursion of offshore sub-surface colder waters with lower oxygen content and rich in nutrients to the surface layers over the continental shelf which

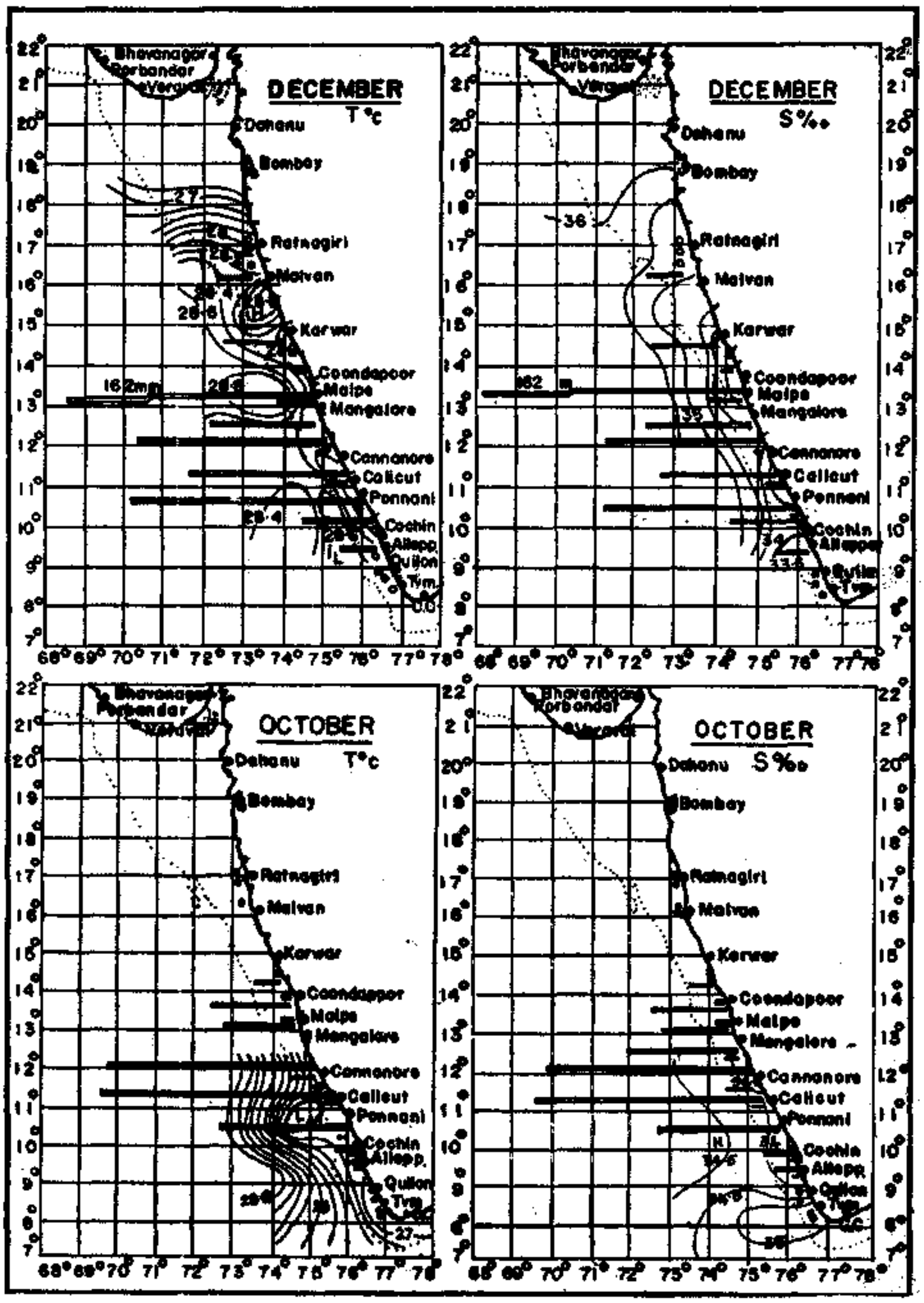

Fig. 11. Abundance of Oil Sardine and mackerel in relation to the surface oceanographic conditions during the months of December and October (after Rao *et al.,* 1973)
(▬ Mackerel and ▭ Oil sardine).

promotes the primary production in the area. Sometimes the intensity of upwelling is so high that a decrease of nearly 7°C occurs at the upper layers than the proceeding summer. During this period, both pelagic and demersal fishes, will try to escape the oxygen poor colder waters brought up by upwelling and either migrate to the offshore surface layers, or towards the shore to within 2-3 m depth where saturation of oxygen takes place due to vertical mixing by wind and wave action. Thus the fishes are found to move away from the normal fishing zones. Investigations in the trawling grounds of the west coast of India between 8° and 15° N indicated strong upwelling during monsoon. The oxygen content of the upwelled water is further reduced by the increased oxygen consumption on the shelf which causes the demersal fishes to disappear from a rather broad belt parallel to the coast (Banse, 1959). In addition to the drastic decrease of temperature and depletion of oxygen, the intensely rough nature of the sea also make fishes to avoid such areas.

Within the sea the nutrient contents generally increase depthwise. The upwelled water being thus nutrient rich, fertilises the coastal waters and promotes primary production which in turn forms the food stock for the fishes. As the upwelling subsides, the standing crop of phytoplankton and zooplankton attracts the fishes and the fishery starts. The sinking (convergence) of the offshore waters over the continental shelf also favours the concentration of zooplankton and an accompanied concentration of fish and during this period we find the maximum fishery. Several fish species concentrate in the centre of eddies and spawning takes place in these regions in some cases. Large eddies keep the fish eggs and larvae concentrated at the particular locality. Thus the eddies around Lakshadweep contribute to rich fishery.

Remote sensing in fisheries

The remote sensing studies in fisheries were initiated in 1981 under the Joint Experiment Programme by the Space Application Centre (ISRO), Fishery Survey of India (Ministry of Agriculture) and Central Marine Fisheries Research Institute (ICAR). The studies conducted showed that the mean monthly fish catch rate was directly proportional to the mean quantity of Chlorophyll (Nair *et al.*, 1985). This suggests that mapping of Chlorophyll distribution either from airborne sensors optimised for ocean colour sensing or satellite scanners combined with 'sea truth' measurements will facilitate in better understanding of resource potential and also management of fishery resources (Silas *et al.*, 1985; Jadhav *et al.*, 1985). In a recent study off Cochin during October-December 1981, it was observed that a chlorophyll value of 6.4 mg/m^3 during October followed by a sharp fall during November (1.7 mg/m^3) and December (1.4 mg/m^3) when compared data with the available fish catch rate in the study area for the period 1977-1981, showed that the mean monthly fish catch rate for October, November and December was directly proportional to the mean quantity of Chlorophyll (Silas *et al.*, 1985). It has also been indicated that the chlorophyll values for water columns approximating to 15 mg/m^3 can sustain an yield of over 250 kg/ha/year of fish inclusive of both demersal and pelagic resources. An algorithm for estimating diffuse attenuation coefficient k from the ratio of inherent upwelling radiances at 443 nm and 550 nm has been developed. Since the coefficient k covaries with the chlorophyll pigment concentration present in ocean water it can be utilised for measuring the chlorophyll concentration. Further the values of k has been found useful in understanding the optical properties of the ocean water types (Beena Kumari *et al.*, 1985). Studies on the Landsat MSS data off Cochin Coast revealed a high correlation between the Chlorophyll concentration and gray values of Landsat MSS band 4 and 5. The particulate matter had a very poor correlation with the MSS gray values. It has also shown clearly that high concentrations of the pigment can be mapped to fairly satisfactory levels in the near shore waters using the Landsat MSS bands 4 and 5. Density slicing of band 4 was found useful in mapping pigment levels in nearshore waters.

Remote sensing studies using Ocean Colour Radiometer (OCR) and a photographic camera showed that fish schools could be directly spotted on three types of Kodak films (Kodak 2448, 2443 & 2402), but only in October and the schools were largely confined to nearshore waters. It was found that the indirect method of mapping the spatial distribution of chlorophyll concentration is more useful in estimating the fish potential. The upwelling radiance data from OCR can be suitably used in understanding the atmospheric effects and in developing the pigment algorithm (Narain *et al.*, 1985).

General Remarks

The organic productivity and all the estimates based on it indicate that the potential sea harvest could be increased by about three times of its present yield in our coastal waters. It is found that the waters near the islands and the coasts are more productive than the open sea. Considering the conventional resources and their scope for further expansion of the harvestable stock and nonconventional resources like tuna, horsemackerel, flyingfish, deep water prawns and crabs, cephalopods and other molluscan resources, an yield of 5 million tonnes from the Exclusive Economic Zone (EEZ) of India is a very reasonable estimate.

Along the east coast, the maximum production occurs during the southwest monsoon months followed by secondary peaks during the northeast monsoon. Species diversity of phytoplankton has also been found to be greater along the east coast than on west coast It has been noticed that the effect of southwest monsoon and its resultant features are more along the west coast. The pH concentration is higher in the Arabian Sea than the Bay of Bengal which indicates that the water along the east coast are comparatively acidic in nature, which may be due to the acidic nature of the waters of Ganges-Brahmaputra river system. The low productivity along the east coast may be due to the above nature of the monsoon effect coupled with the lower pH.

The role of upwelling phenomenon in the production of plankton and fisheries has been noticed well. The upwelling during the southwest monsoon along the west coast is followed by the higher concentration of zooplankters obtained during the post-monsoon (September–October) along the west coast and along the south east coast during February. There is generally an increase in the zooplankton biomass side by side with the increase of phytoplankton and most often these plant organisms are grazed upon. As a result, there would be increase in zooplankton biomass with simultaneous decline in phytoplankton as observed immediately after the peak southwest and northeast monsoon along the southwest coast (September–October) and southeast coast (February). The areas and period of abundance of zooplankton are closely related to the spawning ground and season of fishes and these areas correspond to convergence zones. This is followed by the appearance of fish eggs and larvae as shown by the increasing trend of these during the summer along the southwest coast of India. With the onset of southwest monsoon, these juveniles could make use of the primary and secondary production that follow this monsoon and the subsequent upwelling processes. It has been observed that certain deep water fishes are available in shallower areas of the sea particularly during the post-southwest monsoon. The process of upwelling which result in large scale changes of the oceanographic properties both at the surface as well as the subsurface layers of the sea could be one of the important causes for the same.

Thus the various factors like currents, upwelling and sinking, nutrient enrichment of surface layers, primary production, zooplankton production, spawning periodicity and development of fisheries are closely related in the marine ecosystem.

The surveys indicate that the seaweed and coral resources are being over exploited for industrial purposes especially along the southeast coast of India. There appears to be only limited scope for the exploitation and utilisation of naturally available seaweed resources in the Andaman-Nicobar and Lakshadweep Islands. The annual rate of removal of coral stones especially in the southeast coast of India, at the present level of exploitation, seems to warrent a detailed survey of the exploitable coral resources and the enforcement of a scheme for rational exploitation of the coral stones. Such man-made disturbances affect directly as well as indirectly the general fishery of the area. The coral reef areas are well known for large number of fishes and other organisms living associated with the ecosystem. The destruction of the coral beds thus is detrimental to many reef dwelling organisms including fishes. A rational exploitation is of prime importace for conservation of these resources in the shallow water zones. As such it appears that the rate of growth of corals of our area is not sufficient to replenish the loss due to death and removal. Utilisation of deeper dead substratum causing lesser degree of destruction to living colonies would assure a more prolonged supply to the industries; but new mechanical technologies may have to be adopted to implement this intio practice.

While the mangroves along the coasts of main land are under destruction by human interferences, those of Andaman-Nicobar islands are comparatively well preserved. The surveys indicate that the mangrove areas in the upper reaches of the creeks of the Andaman-Nicobar islands can be utilised for developing aquaculture farms without disturbing the mangroves on the seafront which protect the coastal zone against sea erosion.

The role of ocean currents in relation to the distribution of sponges is not clearly understood. The larval development and the factors such as the tolerance of larvae to changes in pressure, temperature etc. have to be studied in detail to arrive at definite conclusion.

Inspite of the high magnitude of stomatopod landings along the entire coastline of India, they are neglected very much. The possibilities of better utilisation of these crustaceans have to be examined properly. There is considerable scope for development of this potential resource and utilisation as human food, poultry feed or manure resources.

Our knowledge on the echinoderm resources in the Indian Seas is comparatively less. The availability of holothurians in the Lakshadweep provides a possibility of the *beche-de-mer* industry. The Andaman-Nicobar Islands provide one of the most suitable habitats for sea cucumbers and sea urchins due to the presence of sheltered bays and lagoons.

The role of polychaetes in the marine ecosystem requires more attention, with special reference to their interaction with the benthic communities which has an ultimate bearing on the fisheries.

Surveys along the coasts of India, Andaman-Nicobar and Lakshadweep Islands by CMFRI (1983; 1984 a, b) indicate that a cautious approach to the rational exploitation and conservation of turtle and saltwater crocodile resources is needed. Development of Biospheres, National Parks and other conservatory measures is another field which invites more attention.

The above findings, most of them well established, are mainly from the strenuous and continued efforts of the scientists and staff of CMFRI for the past four decades in the marine biological and oceanographic research in relation fisheries. Their efforts are still on to strengthen the findings and in persuit of new knowledge from the mysterious oceans, ultimately to augment the protein rich food from the sea for the ever increasing population. It would be definitely possible from the three dimensional sea to support the agricultural production which is obtained only from the few centimeters depth on the earth's surface.

Future Research

Although these investigations have brought to light much information and knowledge of be seas around India, much more remains to be done. The information on the seasonal changes taking place in the environment in the regions, north of Karwar up to Gujarat coast along the west coast of India, Lakshadweep, east coast of India and Andaman sea is not complete. The changes taking place in these environments should be studied more intensively and regularly from the oceanographic and marine biological angles and should be correlated with the marine resources.

Coastal environmental monitoring

The coastal environment is affected by the local conditions such as pollution due to drainage from land (pesticides used in agriculture), sewage etc. In addition there is oil pollution in the regions near harbours. In order to augment the present level of fish production, a regular environmental monitoring of these coastal zones is essential. The knowledge of the marine biological and oceanographic changes taking place in time provides guidelines for the fishery management and conservation.

The threat of pollution from the extensive uses of the waters for navigation and transport as well as from mechanised boats used for fishing, exploration and exploitation of oil and other minerals, have increased recently. The oil-well fire at the Bombay high, the blow out of an oil well in Gujarat and the oil tanker accidents like those near Kiltan Island in Lakshadweep and off Gujarat Coasts indicate that India is also getting increasingly exposed to the dangers of oil pollution. The pollution from sewage, industries and the drainage of pesticides from agricultural areas is also increasing day by day. Thus, one of the major emerging problems in environmental management is to control or reduce the marine pollution, with reference to coastal fisheries, which still contribute major portion of our fish catch and almost 90% of the Indian fishermen depend on the coastal waters for their livelihood.

A better knowledge of the offshore and oceanic environment is also equally essential for rational exploitation and management, particularly for those fish stocks that are migratory in habits. Further, the offshore, demersal and pelagic resources supplement the catches of conventional fishery. Oceanic fishes that move in and out of the Exclusive Economic Zone of one country to another also needs careful study and monitoring for a rational exploitation and sound management. The environmental changes taking place in the conventional fishing, feeding and breeding grounds also provide a clue to better management of these resources.

The benthic fauna of the traditional trawling grounds are also subject to change due to trawling activity and this would effect the stock and the fishery of the area. A thorough study of the composition of the benthic fauna through a period of time is needed for the management of conventional resources

Environment - Resource integration studies

The environmental features need integration with each of the commercial and capture fishery resources, so as to predict and forecast the variations in fishery resources. This will also indicate the conditions favourable for a particular fishery as well as those which have adverse effects on the fishery. Locations and time of occurrence of fishery resource also can be predicted so that there is no wastage of man power and energy.

Modelling

Changes in the environment, both in the marine biological and oceanographic features, have a great impact on the fish stocks and other biological populations. It is essential, therefore, that suitable models for assessment of the impact of environmental parameters on commerical fisheries be developed. These models can be tested and verified for their validity and reproduceability through the seasons and years and finally used for prediction and forecasting of fish biomass.

The marine biological and environmental studies in future should be concerned with rational exploitation, management and conservation of the marine resources. The Institute has quite recently put its major thrust of research studies on these and similar areas which deserve major attention so that our marine resources, their availability and potential are better understood for their rational exploitation and conservation.

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