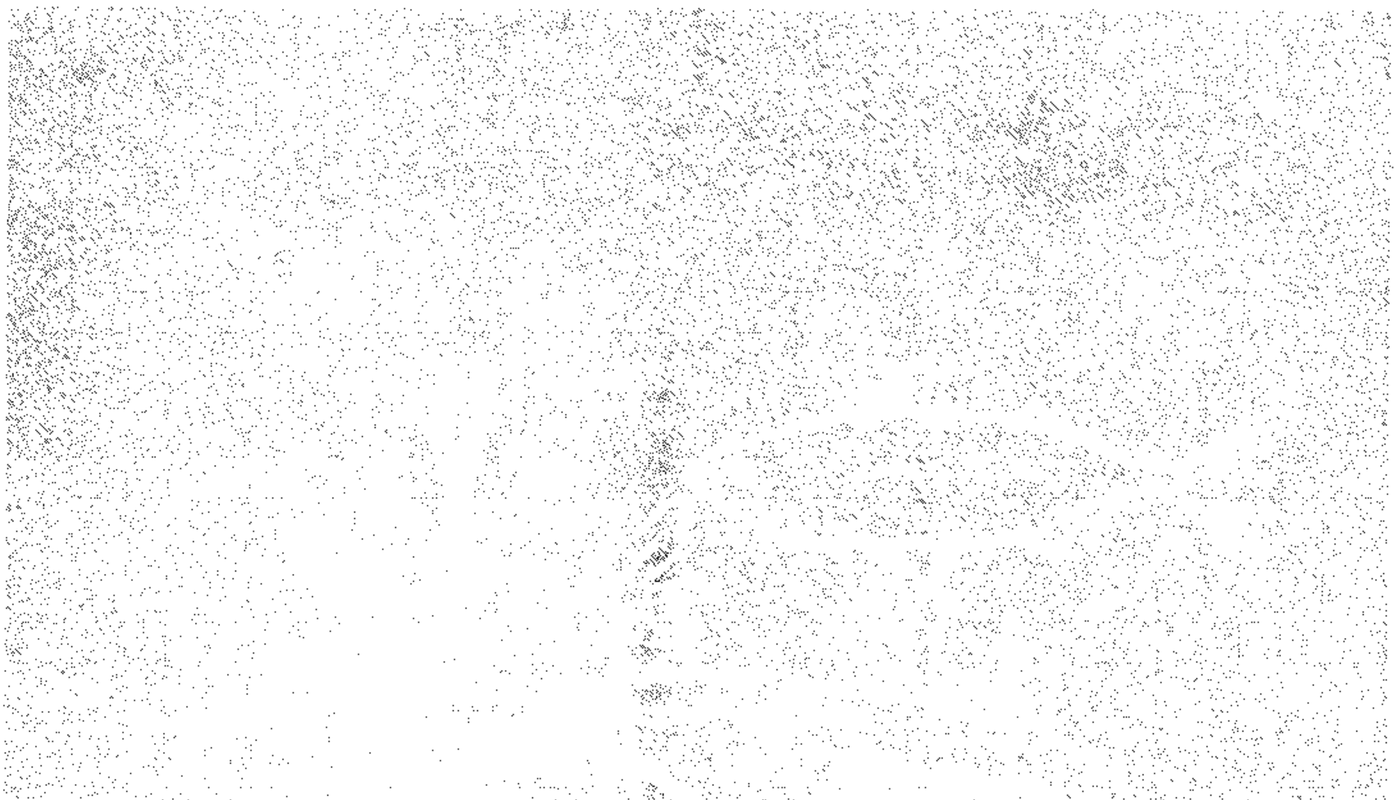
PROCEEDINGS OF THE SYMPOSIUM

ON

LIVING RESOURCES *of* THE SEAS AROUND INDIA



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HYDROGRAPHY AND PLANKTON AS INDICATORS OF MARINE RESOURCES

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ABSTRACT

Available data on the standing crop of phytoplankton and zooplankton are presented for the Indian region and hydrographical factors such as upwelling, divergence, convergence, currents, nutrients responsible for production of plankton, and distribution of plankton in time and space are dealt with. Role of south-west monsoon and the magnitude of the intense bloom of phytoplankton during this period are pointed out. The significance of the distribution of plankton to other organisms in the food chain including fish is indicated. Attempt is made to correlate the fisheries of the region with the above several factors and point out the potential resources and their location. The possibilities of using some of the factors as indicators of fishery resources are examined. Certain similarities in the hydrological features, production of plankton, its distribution and fisheries occurring here and elsewhere are reviewed.

It is also suggested that the high production of plankton which is also rich in oil—a product of the photosynthesis of the diatoms which form the bulk of the synthesizers of the organic matter-is responsible for the rather extensive oil deposits in the past geological ages in the northern Arabian Sea region which we are exploiting now; this is a continuing process. It is also pointed out that the general pattern of circulation of water during the period of heavy bloom of plankton, *viz.*, south-west monsoon in the Arabian Sea, is clockwise which is likely to lead to anticyclonic eddies on a large scale, particularly around Saurashtra coast which would have the effect of taking plankton to the bottom leading to gradual deposition of matter.

INTRODUCTION

THE rapid increase in the population of the world, particularly, since World War II, and shortage of food are forcing us to look for fresh resources; coupled with this, the inhabitants of vast areas, particularly in Asia, Africa and S. America bordering Indian, Atlantic and Pacific Oceans, suffer from an inadequacy of protein food. Naturally attention is being focussed on the seas for meeting this demand.

For exploitation of the resources of the sea, one must know what is available, where and how much and how to harvest it in a most economical manner.

Over 50 million tons of fish are landed all over the world from the sea. The catches are constituted by fishes mostly, crustaceans, molluscs and whales, all of which constitute the fisheries. All these and more present in the sea are sustained by the enormous organic production, the fixation of carbon by the minute floating plants occurring in the water—the phytoplankters, the chief constituent of which are the Diatoms. The products of photosynthesis comprise carbohydrates, oils, fats, proteins, vitamins, all that are needed by living organisms. These are consumed by small organisms and developing fishes which in their turn are eaten up by larger ones and so on at different trophic levels. Finally, man fishes the organisms needed at the different levels: the mollusca (oysters, clams, shellfish, etc.) which are filter feeders and only one link removed from the synthesizers; the herbivorous copepods are the major consumers of phytoplankton and they in their turns are devoured by the carnivorous plankters and both by fishes such as the oil sardine and mackeral caught in our waters. The antarctic whale, the largest of mammals, is a feeder of *Euphausia superba*, a crustacean which thrives on the diatoms directly. Fishes such as tunas are several levels removed from the synthesizers being feeders on other fishes, large crustacea, squids and so on.

The above brief illustration shows the dependance of all form of life in the waters on the phytoplankters, the prime synthesizers. Therefore, a fluctuation in the abundance of phytoplankters is sure to affect the different levels of our harvest.

The phytoplankters themselves are dependent on the nutrients in the water—phosphates, nitrates, silicates, trace elements and so on for their growth and multiplication, and, the content of nutrients again, is dependent on the vertical and horizontal movement of water and the mixing up of the water, to bring the nutrients to the euphotic zone. The movement of water masses is dependent on salinity and temperature gradients and meteorological factors such as wind force. Therefore, any change in any one of the these factors affects the fisheries ultimately and a study of the resources of the seas involves all the above factors.

The magnitude of the organic production has been assessed in several parts of the world using methods such as depletion of nutrients, oxygen released during photosynthesis, standing crop and in recent years by use of C^{14} (Subrahmanyan, 1959 *a*, p. 181; Steemann Nielsen, 1963). There have been fewer attempts to relate this to actual landings of fish. Perhaps the first of such an attempt was by Cooper (1933) for the North Sea region and next by Subrahmanyan (1959 *a*) for the west coast of India. Comparing a highly exploited area with the developing west coast of India, Subrahmanyan concluded that there is vast scope to exploit this region further from 3–10 times, one of the richest as regards organic production. Subsequent assessments based on the use of C^{14} have confirmed the conclusion of Subrahmanyan (Prasad and Nair, 1960, 1963).

One objective of marine resources studies is to arrive at a factor or factors which would give a clue to understanding the fluctuation of the harvests in advance at least an indication as to where fishing may profitably be conducted.

In the present account the data on the standing crop of phytoplankton, zooplankton and hydrography recorded from the Indian Ocean region are presented including some from the author's and his colleagues' work till now unpublished.

Observations on the Standing Crop of Plankton

Near-Shore Area

Data on the standing crop of phytoplankton is available for the nearshore region on the west coast of India for several years (Subrahmanyan, 1958, 1959 *a*, *b*; 1960 *a*, *b*; Subrahmanyan and Sharma 1960, 1965, also original data of author included here)*. For the east coast continuous data for a period of 2–3 years is available only for 2 centres, the south-east coast (Prasad, 1954) and Madras Coast (Subrahmanyan and Gupta, 1965) and for one year period on a few occasions for Waltair (Ganapati and Murthy, 1955; Ganapati and Subba Rao, 1958) and Madras (Ramamurthy, 1953 *b*).

The data collected for the standing crop on the west coast and east coast are presented in Tables I, II, III, and IV.

In Table I, columns 2 to 5 the data for standing crop are shown in terms of pigment units, number and dry weights.† The values are the monthly average standing crop in terms of pigment units for the period 1949–54 and 1955–62. In Table II, the quantity of nanoplankton alone is shown for the period 1956–57 to 1961–62.

It may be seen that the standing crop of phytoplankton is of high order throughout but during south-west monsoon period it attains the peak of developm nt. The considerable quantity of nano-

* For other accounts dealing with west coast plankton, please refer Subrahmanyan, 1959 *a*, 1960.

† The term "biomass" is avoided here as this has been used generally to indicate "displacement volumes" of plankton.

TABLE I

Monthly average data for standing crop of phytoplankton in terms of number and Harvey units and zooplankton in terms of number/L and dry weight mgm/m³ (mainly phytoplankton)

Month	Phytoplankton HU/m³ 1949–54	Phytoplankton total number of cells/L 1949–54	Zooplankton total number of cells/L 1949–54	Dry weight mgm/m⁻³ average 1952–55		Phytoplankton HU/m³ 1955–62
				B	C	
May ..	18,366	663,700	2,418	4,564	1,125	18,881
June ..	30,700	8,921,800	6,858	3,000	731	28,474
July ..	66,684	28,372,400	8,142	3,980	2,000	67,891
August ..	31,516	8,089,350	8,358	3,980	1,519	73,130
September ..	25,166	1,112,800	2,196	3,152	1,575	56,474
October ..	19,516	1,119,700	2,478	1,780	1,525	27,413
November ..	11,766	205,800	2,754	2,116	1,561	11,418
December ..	12,600	401,500	2,580	2,364	1,289	10,330
January ..	10,634	833,460	4,446	2,916	1,258	13,657
February ..	12,634	591,900	2,292	2,816	1,030	13,601
March ..	11,416	865,000	3,108	4,064	1,338	12,740
April ..	11,416	957,200	3,660	3,132	1,116	12,321

B and C—two locations.

TABLE II

Nanoplankton in HU/m³ West Coast

Month	1956–57	1957–58	1958–59	1959–60	1960–61	1961–62	1962–63
May ..	..	10,000	4,200	2,000	17,500	850	4,730
June ..	..	17,000	13,670	12,630	10,300	8,330	9,460
July ..	27,200	48,750	16,290	8,100	10,850	16,250	..
August ...	24,000	..*	56,430	20,810	24,800	6,880	...
September ..	75,000	..*	29,170	3,600	13,000	6,000	..
October ..	24,000	..*	1,000	9,950	3,230	3,830	..
November ..	7,750	..*	330	4,500	Nil	Nil	..
December ...	3,600	..*	3,000	4,150	1,130	Nil	..
January ..	10,000	..*	Nil	3,050	420	1,800	..
February ..	10,750	..*	10,000	5,680	Nil	750	..
March ..	9,750	..*	9,480	4,100	500	170	..
April ..	5,000	1,000	8,500	1,100	..	4,500	..

* Not recorded separately.

plankton may be noted which is of considerable importance to very young zooplankters and developing fish larvae (Subrahmanyan and Sharma, 1965).

The dry weight estimation include some zooplankters also though the major portion consists of phytoplankters. Dry weight data are given for two different stations separated by about 3 miles; the considerable variation reflects patchy distribution.

Zooplankters do not fluctuate very much, however, most of the organisms are small ones (small copepods, developing stages of the bottom fauna) during the south-west monsoon period while they are bigger during north-east monsoon. Moreover, they are obviously kept down due to the grazing on them by the pelagic fishes, the oil sardine and the mackeral, plankton feeders, whose fisheries commence in the period succeeding the stormy south-west monsoon months. Subrahmanyan (1959 *a*) has already pointed out the high fertility of the waters of the west coast comparable with some of the most fertile waters elsewhere (*l.c.* 1959 *a*, Tables IV–IX, 1959 *b* Table II and III). Recent work using C^{14} (Prasad and Nair, 1963) have confirmed the earlier observations of the author (*l.c.* 1959 *a*). The author (*l.c.* 1959 *b*) had also pointed out the high nutrient content of the waters of the west coast which, besides the factors already discussed, is now known to be mainly due to the presence of upwelled waters along the whole of the coast between Cape Comorin to Karwar (Banse, 1959, 1968; Ramamirtham and Jayaraman, 1960; Patil and Ramamirtham, 1963).

The fall in the standing crop during the north-east monsoon season is partly due to the grazing effect and probably also owing to lack of some essential nutrients acting as a limiting factor (Subrahmanyan, 1959 *b*).

The observations of Ramamurthy (1965) on the west coast, north of Calicut, point out to a similar picture already discussed above. It would appear that conditions all along the west coast of India during south-west monsoon season is similar, except for the slight lapse of time in the development of the flora which is to be expected.

In Table III the displacement volume of the standing crop for the east coast off Madras is presented. Column I: plankton almost exclusively phytoplankters; II: very few phytoplankters, mostly copepods; III and IV, mixture of phyto—and zooplankters, latter more, and V exclusively large zooplankters. The dry weight estimates for the respective collections are given in Table IV.

In Table V the standing crop is terms of HU for identical hauls on the west coast and east coast for the same period are shown. It may be seen that the magnitude of the crop on the east coast is of a lower order.

It may be mentioned here that the plankton samples from the east coast water contain quite some quantity of detritus which would go to increase the displacement volume and dry weight; this becomes evident when values are calculated on m^3 basis and compared. However, the relative magnitude of production is evident from pigment values.

Further on the east coast an evaluation of the standing crop in terms of pigment units during south-west monsoon and north-east monsoon indicates that the standing crop during the former season is about double that during the latter period. On the west coast the crop during south-west monsoon is about 3–4 times that during the north-east monsoon season.

For the region off Waltair, Ganapati and Subba Rao (1958) have given some data. The maximum standing crop of phytoplankters is recorded in March/April and in October/November a secondary peak occurs. Zooplankton number does not show any conspicuous peak. The

TABLE III

Displacement volume ml/haul of Plankton, East Coast off Madras

Month	1959–60					1960–61					1961–62				
	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
May ..	..	..	..	..	..	12·4	39·2	35·2	53·6	26·0	6·0	15·0	12·0	16·5	8·0
June ..	9·7	26·7	30·0	19·0	..	4·0	21·0	19·5	24·0	7·5	5·5	35·5	2·2	29·5	25·5
July ..	4·0	15·0	12·0	11·5	..	9·5	37·5	25·5	42·0	3·0	12·5	31·0	25·0	29·0	24·5
August ..	4·0	23·0	18·5	17·0	..	4·0	12·0	11·6	16·4	5·2	16·8	62·4	54·8	57·2	31·2
September	7·8	30·4	23·4	39·6	..	7·0	24·0	14·5	23·5	20·5	5·5	42·5	19.0	32·0	11·0
October ..	3·3	16·7	10·7	13·3	..	5·0	16·5	14·0	13·5	8·0	7·2	47·2	18·0	44·4	9·2
November	5·3	12·0	8·0	7·3	..	8·0	16·0	10·5	19·0	5·0	36·0	56·0	26·0	56·0	7·0
December	5·2	12·8	14·8	10·8	..	5·3	6·6	8·0	8·0	4·0	11·5	21·5	14·0	19·0	27·0
January ..	9·3	35·5	40·5	39·0	..	3·6	13·6	12·0	13·6	4·8	6·8	14·0	10·8	13·6	2·4
February	6·0	9·5	6·0	8·0	..	4·5	13·0	19·5	24·0	18·3	4·5	8·3	5·5	8·8	1·5
March ..	9·2	37·6	22·8	93·6	..	7·2	24·4	35·2	31·2	29·6	4·5	14·0	17·0	13·5	8·0
April ..	9·7	25·5	18·0	27·5	4·5	7·5	24·5	11·5	16·5	7·5	7·0	10·5	10·0	7·0	4·5

I. Half metre No. 21 Bolting silk net; II: ¾ m. No. 2 Bolting silk net, vertical haul 20–0 m; III: Organdi ¾ m net surfae haul, 10 minutes; vertical haul, 20–0 m; IV: Organdie ¾ m net, oblique haul 20–0 m; V: Mosquito netting ¾ m net surface haul 10 minutes.

TABLE IV

Standing Crop, mgm/haul, East Coast

Month	1959–60					1960–61					1961–62				
	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
May	..	..	..	..	..	335	1,047	1,027	1,697	769	379	639	572	768	412
June	420	601	939	996	..	207	807	797	1,006	490	374	1,574	1,008	1,180	1,026
July	363	538	537	600	..	292	1,097	726	1,380	184	548	715	611	576	329
August	319	1,085	905	815	..	268	517	690	845	326	437	1,669	1,313	1,663	418
September	449	1,128	783	1,240	..	315	617	169	632	252	455	1,442	921	1,118	474
October	216	1,627	1,168	470	..	275	652	572	595	674	347	1,226	676	114	397
November	174	289	247	328	..	254	430	314	553	109	965	1,303	830	1,380	268
December	202	380	332	358	..	193	244	270	313	98	435	744	480	590	199
January	267	597	516	537	..	191	368	309	391	173	405	678	625	721	314
February	413	491	384	529	..	298	443	159	506	278	270	422	371	485	255
March	467	1,268	878	1,315	..	371	673	669	838	406	597	825	911	867	639
April	499	934	677	1,225	221	463	783	486	695	306	494	726	829	646	567

I: No. 21 Bolting silk ½ m net Vertical haul 20–0 m; II: No. 2 Bolting silk ¾ m net. Vertical haul 20–0 m; III: Organdi ¾ m net surface haul 10 minutes; IV: Organdi ¾ m net Oblique haul, 0–20 m; V: Mosquito netting ¾ m surface haul, 10 minutes.

TABLE V

Standing crop of phytoplankton HU/haul 0–15 M: Comparison between West and East Coasts

Month	1959–60		1960–61		1961–62	
	West Coast	East Coast	West Coast	East Coast	West Coast	East Coast
May	3,600	2,625	25,150	4,875	3,400	951
June	2,450	10,440	11,220	625	4,830	2,644
July	7,200	234	20,500	2,779	26,200	5,845
August	12,390	314	4,400	980	21,630	5,865
September	3,480	2,539	8,250	1,378	5,900	2,546
October	15,030	825	4,200	925	4,400	2,976
November	2,700	750	9,050	1,701	2,270	4,136
December	1,900	981	2,230	1,248	4,600	1,457
January	2,430	384	1,520	849	2,920	1,191
February	3,350	1,230	1,430	666	1,750	567
March	3,380	1,617	1,770	1,688	2,130	570
April	750	3,098	..	2,485	8,500	1,324

TABLE VI

Plankton data for east coast of India off Waltair (after Ganapati and Rao, 1958)

	Max.	Month	Min.	Month
1. Phytoplankton cells/L ..	25,405	March	94	December
2. Zooplankton cells/L ..	414	March	16	December
3. Displacement Volume cc/m^3 ..	194	February	6·25	September
4. Pigment units HU/m^3	8,426	April	67	December
5. Biomass, dry weight mgm/m^3	1,230	February	123	January

data for 1956 (Ganapati and Subba Rao, 1958) are quoted in Table VI for comparison with the west coast data already given.

Apart from the difference in the productivity of the waters of the Bay of Bengal and Arabian Sea, one interesting point observed was that qualitatively almost as many species occur on both coasts; on the east coast no one species occurs to constitute the bulk of the standing crop, whereas on the west coast a few species contribute to the bulk of the crop (Subrahmanyan and Sharma, 1960). A similar picture is reflected in the fisheries also; a few species constitute the bulk of the catches on the west coast while no one species occurs in bulk on the east coast (Subrahmanyan and Sharma, 1960; Subrahmanyan and Gupta, 1963). In this respect east coast of India resembles the East African Coast where also the fish 'although numerous in variety, there are no large quantities of any particular (demersal) species of commercial importance' (Dibbs, 1964; Kerr, 1966).

Shelf and Offshore Regions

In Figs. 1 and 2 the distribution of the standing crop of phytoplankters in terms of number and displacement volume are shown averaged for each degree square for the south-west and north-east monsoon seasons, based on *R. V. Varuna* cruise material (courtesy: Sydney Samuel). The values are per vertical haul 75-0 m. The richness of the crop during the south-west monsoon season may be noted generally over the whole region and especially over the shelf. The crop is fairly rich on the south-west coast between 7-10°N, 74-76°E. The magnitude is, however, far less compared to the near shore region already described.

The standing crop of zooplankton over this same region according to the observation of Silas (unpublished personal communication) fluctuates from 100- over 700 ml/1000 m^3 over the shelf and decreases somewhat beyond. The richest area is between Quilon and Calicut, Cannannore to Karwar and Wadge Bank in the South. The peak occurred in June and another of almost same intensity in October, the values fluctuating from 221–761 ml/m^3 over the shelf. For the oceanic area high value of 144 ml/1000 m^3 was recorded in July and there was no conspicuous secondary peak of abundance.

International Indian Ocean Expedition Results

Phytoplankton

The results published so far indicate rich standing crop of phytoplankters in these areas.

Sukhanova (1962 *a, b*) found during north-east monsoon of 1959-60 that high concentration of phytoplankton obtained off Java and in the Western region. Regions rich in phytoplankters are those where upwelling took place; thus betweeen about 55°–65°E at the equator concentrations were as high as 40,000 cells/m^3 in the layer of 100 m; in the region of moderate upwelling the concentration was less (South of Equator up to 15° S between 55–65°E; 5°–15°S between 90° and 120°E). A region of fairly high concentration is recorded between 15°–19°N and 70°–75°E, off Bombay coast, and off the south-west coast of the Indian peninsula west of Ceylon. The author gives also some information on the species composition.

The observations of Zernova (1962) based on material collected during 33rd cruise of *R/V Vityaz* in October, 1960 to August, 1961, indicate maximum concentration of phytoplankters in the Andaman Sea, Aden Bay, Arabian Sea and south of Bay of Bengal (30°–70°N, 80°–90°E) and lowest in the equatorial region.

During south-west monsoon, in the north-eastern part of the Indian Ocean, Sukhanova (1964) found the region between Indonesia and Australia, near the Equator and the southern part of the Bay of Bengal very rich in phytoplankters, the quantity was 2-2·5 times that of the north-east monsoon. The region of Central Indian water was extremely poor, this zone was on 8–10°S during south-west monsoon, but displaced to 18°–20°S during north-east monsoon.

Zernova and Ivanov (1964) record for the transition period between the monsoons, October-December 1960, rich phytoplankton North of 12°N and South of 8°N. Between 8°N and 12·°N the waters were barren, so also off the Arabian peninsula. In the Bay of Bengal also phytoplankton was poor except south-west of Nicobars and the Andaman Sea.

In the eastern Indian Ocean, Wood (1966) found the horizontal distribution of phytoplankton related to land mass and upwelling; thus, the largest concentration occurred on the coasts of

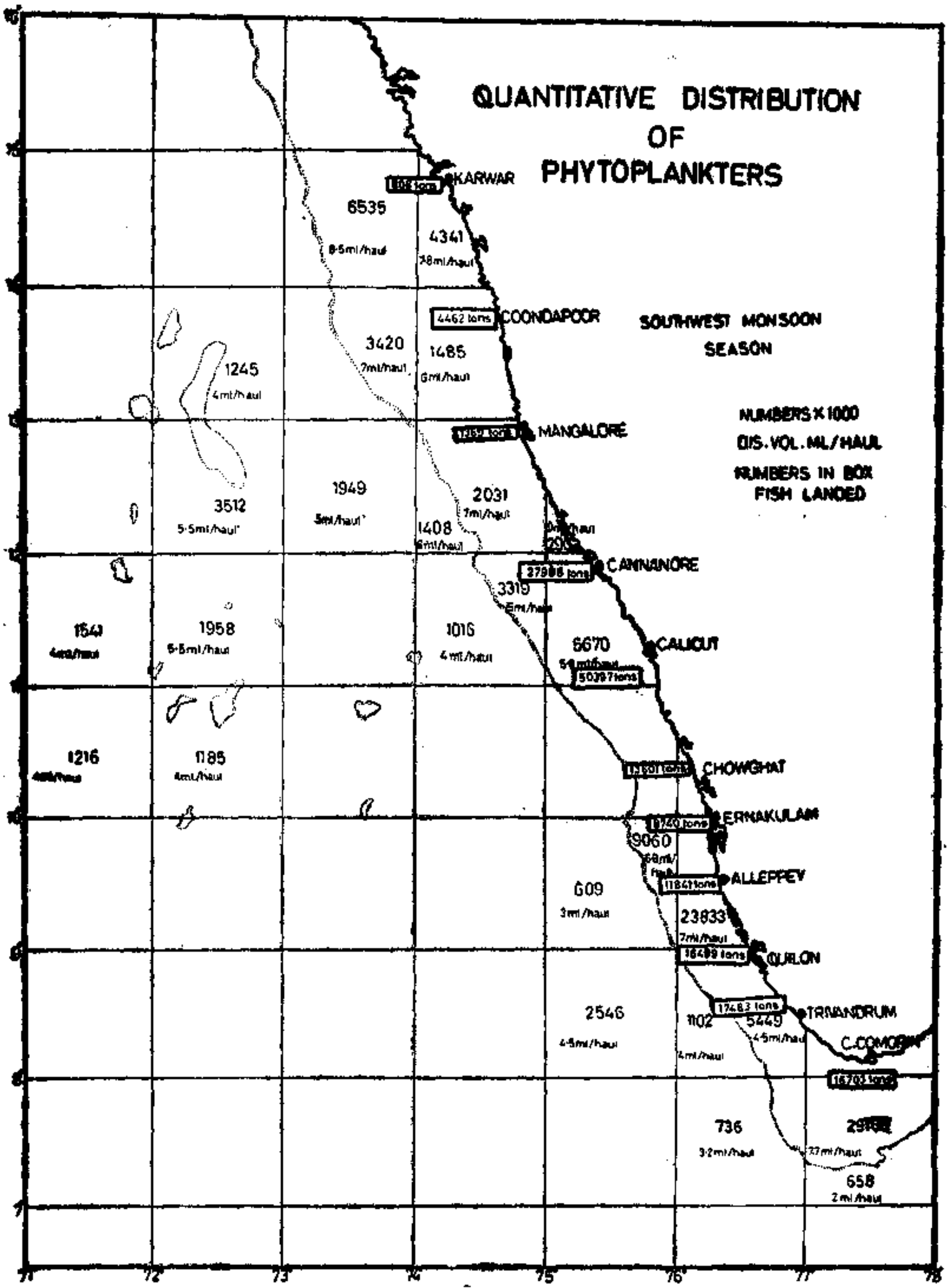

Fig. 1. West and South Coast of India. Quantitative distribution of phytoplankton during the south-west monsoon season and quantity of fish landed at different centres (Fish landings data from the Annual Reports of the CMFRI for 1966 and 1967).

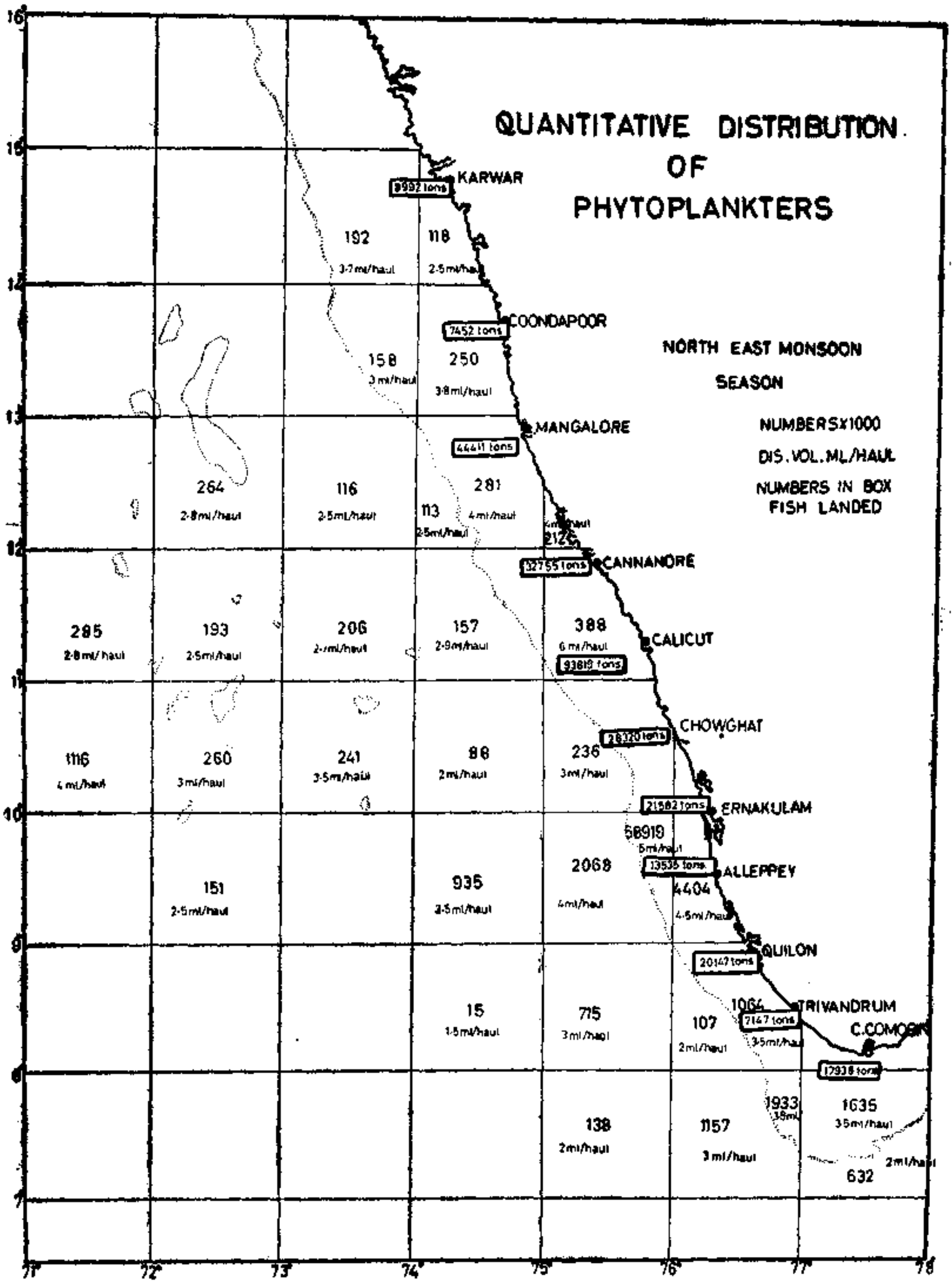

FIG. 2. West and South Coast of India. Quantitative distribution of phytoplankton during the north-east monsoon season and quantity of fish landed at different centres. (Fish landings data from the Annual Reports of the CMFRI for 1966 and 1967).

Indonesia, N.-W. Australia, and half-way between Sumatra and N.-W. Australia. The area between 25° to 35°S off the coast of Australia was barren. Only during blooms (*e.g., Trichodesmium* sp.) plankton was recorded at surface. Otherwise in tropical and sub-tropical waters concentration of plankton occurred at 75–100 m, normally below the thermocline and below level of 1% illumination.

Based on the IIOE results Wooster *et al.* (1967) give estimations of the standing crop of phytoplankters in terms of chlorophyll for the Arabian Sea region. During the south-west monsoon season large standing crop obtained along the western side of the Arabian Sea as also offshore waters, > 1·60 mg/m³. Between September through November values diminish along the coast of Arabia; however, high values obtain in the northern region. Between December and February chlorophyll values are low over most of the area.

Again, during March to May values are low over most of the region except the eastern margin of the Arabian Sea, and north-eastern region of the Gulf of Kutch where moderately high values were recorded, 0·40–1·60 mg/m³. The chlorophyll values in the south-east Indian Ocean were rather low (Humphery, 1966).

Zooplankton

Data for zooplankton is available mostly from the Plankton Atlas published by IOBC, Cochin, (Prasad, 1966, 1968 *a, b*); Ponomareva and Naumov. 1962 and Wooster *et al.*, (1967) for the Arabian Sea. During south-west monsoon season, between 0°–25°N between 45° and 80°E the standing crop is rich along the Somali coast, Arabian coast, Persian coast and south-west coast of India up to Mangalore. Between 60°–70°E and 5°–15°N the waters are poor in plankton content.

During north-east monsoon the crop is rich off Quilon to Calicut, the Somali coast and West of South Arabia as well as Equatorial region between 65°–70°E up to 5°N.

East of 80° long. the crop is not so rich as on the west. Except the middle of Bay of Bengal the crop is fairly rich north of 5°N during south-west monsoon. During the north-east monsoon the crop is noticeably rich in the region 80°–85°E, 0°–15°N and 10°–17°N, 85°–95°E.

During south-west monsoon season a rich crop is present south of Java and a few places elsewhere south of the Equator. During the north-east monsoon rich standing crop is noticed west and north-west of Australia also. Displacement volumes of plankton were of a high order between 5°N to 10°S between 90°–100°E (Daniel and Kumar, 1967).

The studies on vertical distribution of the biomass of zooplankton by Ponomareva and Naumov (1962) show that biomass is higher between 100–0 m than 200–100 m and 500–200 m. A portion of Somali coast, Gulf of Oman, Persian coast, regions off Madras and Waltair are indicated with standing crops varying from 500 to over 1000 mg/m³. Patches occur with crops varying from 500–100 mg/m³. Most of the areas of the Arabian Sea and Bay of Bengal and south up to the Equator are shown indicating crop of 100–300 mg/m³. Vinogradov (1962) also found bulk of the plankton in the upper 100 m.

Voronina (1962 *a, b*), Vinogradov and Voronina (1961) and Vinogradov (1962) have dealt with the species distribution as well as quantitative distribution of some species.

An examination of the data relating to primary production in this region (Prasad and Nair, 1962, 1963 1964; Kabanova, 1961, 1964; Ryther, 1963; Ryther *et al.*, 1965, 1966; Wooster *et al.*, 1967) also indicates that in almost whole of the area where standing crop is rich, organic production also is of a high order.

The areas rich in plankton crop both during the south-west monsoon and north-east monsoon season are shown in Fig. 3, in which data discussed above have been incorporated (no attempt is made to show the relative abundance in this figure; areas with very low standing crop are omitted).

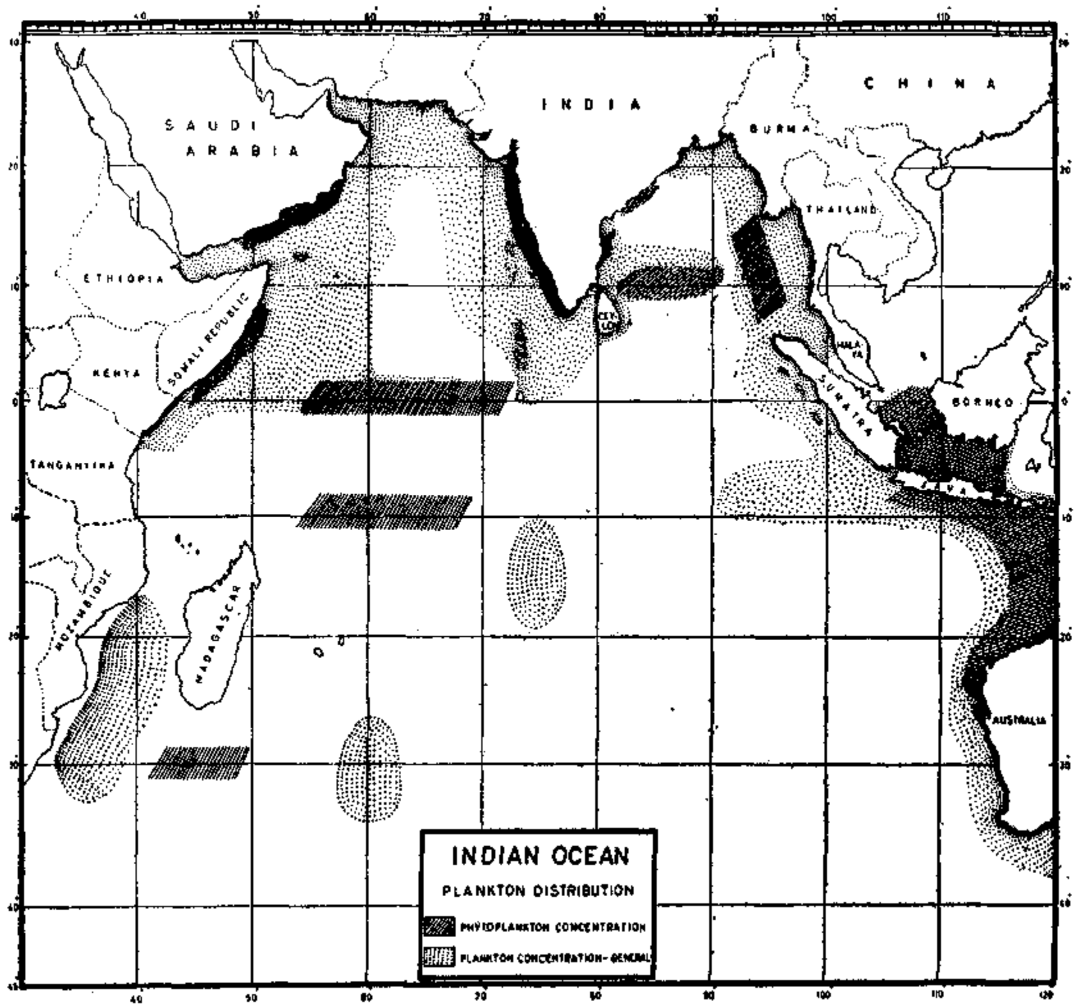

FIG. 3. Plankton distribution in the Indian Ocean and adjacent seas. Compiled by the author from published accounts. Regions of poor plankton not indicated. Part of the distribution shown in Fig. 4.

The above review shows that the standing crop of plankton is rich in certain regions and exhibits seasonal fluctuations, which is well pronounced and evident where investigations have been carried out for some years. Even the data collected by the expeditions show this seasonal fluctuations, as may be seen from the cited literature. The standing crop of phytoplankton is found to be of a high order during the south-west monsoon season, several times the magnitude of that during the north-east monsoon season. The zooplankton crop does not show such sharp oscillation for, their peak development succeeds that of the primary producers, the phytoplankters and are, probably being grazed down.

It is evident from the above that the monsoons play an important role in this region as pointed out by Subrahmanyan (1959 *a*, 1960).

Monsoons and Water Movements

Horizontal Transport

The Indian Ocean region is influenced by two systems of winds, the south-west (May to September) and north-east monsoons (November to March); October and April are transition months between the monsoons. It is well known that surface currents of the ocean are driven by the winds and vertical circulation near the coasts and at the Equator also is wind-induced to a considerable extent.

The wind force on the west coast during the south-west monsoon is strong and may reach upto Beaufort 10 (Indian Meteorological Dept. data for west coast of India). During north-east monsoon, it seldom exceeds Beaufort, 5·5. On the east coast also the wind force is higher during south-west monsoon than during the north-east monsoon season (Meteorological Dept.).

The pattern of circulation in the Arabian Sea and Bay of Bengal has been described in some detail by Subrahmanyan (1960 *a*). The salient feature to be noted is that from about February a clockwise circulation comes into being in the Arabian Sea and Bay of Bengal which strengthens during the south-west monsoon period; thereafter, after October (a transition month) the current reverses due to the north-east monsoon and an anticlockwise circulation obtains from November to about the beginning of February.

Further, it may be mentioned here, that the Cold Antarctic flow, according to Carpenter (1887; *vide* Sewell, 1925, pp. 47–48) extends up to 10°N and gradually surfaces. One arm of his flow extends to the Bay of Bengal, a second towards the Malay Archipelago and a third into the Arabian Sea. Upwelling of the waters of this current is very much hastened by the south-west monsoon winds. The influence of this bottom drift on the temperature and nutrient salt content of the Arabian Sea and other waters must be considerable. Recent investigations (IIOE) however, confirm Antarctic water coming to the surface only eastward from 90° E (Ivanov-Frantskevich, 1961). It is also known that there is an exchange of water between the Arabian Sea and Red Sea (Thompson, 1939). The foregoing review also show that there is an exchange of water between the Bay of Bengal and Arabian Sea (*also refer* Burns, 1966).

South of the Arabian Sea and Bay of Bengal, the pattern of circulation is as follows (mainly based on Jerlov, 1953, Defant, 1961; Knauss, 1963; Knauss and Taft, 1963, 1964; Ovchinikov, 1960, 1961; Ivanov-Frantskevich, 1961; Shomura *et al.*, 1967; Wyrtki, 1962).

The circulation pattern in the open parts of Indian Ocean is also subject to influences of the monsoon winds every five months. This definitely proves that winds have a decisive rôle in the generation and maintenance of the ocean currents.

The circulation in the Indian Ocean may be briefly summarized here. The conspicuous feature of the circulation in the S. Hemisphere is a major counterclockwise gyre between 8° S and 40° S, the northern boundary of this being the South Equatorial Current. This system of circulation persists throughout the year.

Circulation in the northern part is somewhat complex. During south-west monsoon (May-September) waters from the Pacific Ocean pass into the Indian Ocean through the Timor Sea and Torres strait. This together with the northern portion of the gyre constitutes the South Equatorial Current which flows westward. At the African Coast a major portion of the current gets deflected north and flows along the African Coast and is known as the Somali Current. A lesser portion gets deflected south by Madagascar to form the Agulhas Current. During this season the surface currents in the Arabian Sea and Bay of Bengal move in a clockwise direction. The easterly flowing Countercurrent is present throughout the year and during south-west monsoon, has its axis at the Equator.

During north-east monsoon the circulation is reversed in the Bay of Bengal and the Arabian Sea and a counterclockwise flow is established. In the oceanic region, in the southern part, the circulation remains same as during south-west monsoon. The core of the Equatorial Counter-current is shifted south to about 8° S. The easterly flowing monsoon current is absent during this season and surface flow is westerly and the westerly flowing north Equuatorial Current becomes established when the winds are from the north-east.

Vertical Transport

The circulation in the Indian Ocean described above apart from bringing about horizontal transport of the water, which is obvious, gives rise to vertical movement also, in which due to impact of two currents with water mass of different quality convergence or divergence, sinking of surface water or upwelling of deeper water, respectively, is brought about. Bottom current water may also surface if it confronts an obstacle in its path such as submerged land mass or ridges. These are of importance from the biological point of view.

Upwelling usually occurs in the narrow coastal belt on the western coasts of continents in the middle latitudes. Characteristic of this phenomenon are that cold nutrient rich water, often deficient in oxygen which is brought up to the surface influences weather on the one hand and life in the water on the other hand. The best regions where the phenomenon occurs are the California Coast, West Coast of Africa, and the West Coast of S. America (Sverdrup *et al.*, 1942; Defant, 1961; Hart and Currie, 1960; Gunther, 1936 *a, b*) Within the last two decades, the tropical Pacific near the Equatorial region also was found to show considerable upwelling (Cromwell, 1953; Knauss, 1963).

Several areas in the Indian Ocean region also exhibit this phenomenon.

Along the coast of Java and Sumbava upwelling occurs during the south-east-monsoon, from May to September, when part of the waters of the well-developed South Equatorial Current north of New Guinea flow through Halmahera and Banda Seas and form the Monsoon Current. During the north-west monsoon, November to March, the surface flow in Halmahera Sea is reversed and flows east, and the south Equatorial Current is shiffed to South. Sinking occurs at this time. The movements of water here is a good example for the opposite interaction and the deep circulation and water exchange between the Pacific and the Indian Oceans (Wyrtki, 1958, 1962; Rochford, 1962).

In the Equatorial region, during north-east monsoon upwelling occurs between 50°–110° E around latitude 3–10° S. North of the Equator upwelling occurs over scattered areas between 5°–6° N and 58°–70° E. (Ovchinikov, 1960, 1961; Ivanov, 1964). Upwelling of deep water has been recorded south of Mozambique Channel (Menache, 1961).

Observations of Carruthers *et al.* (1959) indicate possible upwelling off Bombay in the beginning of north-east monsoon. Rao and Jayaraman (1966) observed upwelling in November–December in the Minicoy region (*also refer* Prasad, 1966).

Strongest upwelling occurs off Somali Coast during the south-west monsoon and temperatures as low as 14° C has been recorded at the surface. The only other comparable region for such low temperatures as a result of upwelling within 10° off the Equator is the Peruvian Coast which is noted for the very pronounced upwelling.

In the same season, all along the west coast of India from Karwar southwards upwelled water is in evidence, the maximum intensity being north of Calicut (Banse, 1959, 1968; Ramamirtham and Jayaraman, 1960; Ramasastry and Myrland, 1960; Patil and Ramamirtham, 1963). According to these authors upwelling on the west coast of India occurs upto even September or October and sinking from November to February. According to Sharma (1966) upwelling in the coastal waters occurs from February to July/August and sinking from September to January, the topography of the thermocline exhibiting peculiarities during April and October, transition months between the two monsoons. According to this author the upward tilting of the thermocline reaches the surface almost by July indicating upwelling; in August the winds strengthen and are south-westerly to westerly; the surface flow which is easterly or south-easterly flows parallel to the coast owing to the boundary conditions and gives rise to a southerly component; this, together with the high river inflow of freshwater owing to precipitation, stratifies the surface layers and these are unfavourable for upwelling; hence, it is doubtful whether there is upwelling from the beginning of August onwards. It is becoming clear that conditions are a little complicated on this coast and would require further investigations.

As this phenomenon is intimately connected with biological factors, it would be worthwhile here examining this aspect from the biological point of view. It is well known that upwelling enriches the euphotic zone leading to a bloom of phytoplankters. This will not happen suddenly, for, the algae in the water have to grow and multiply and usually the bloom occurs after some lapse of time and away from the actual place of upwelled water, the locus of the bloom depending on its displacement by currents and direction of the latter.

On the west coast the bloom of phytoplankton during the south-west monsoon is noticed off Trivandrum Coast from January onwards reaching a peak in May; data are available for two years only (Menon, 1945). Further north, at Calicut and northwards the peak is attained in July/August. This would indicate a commencement of upwelling much earlier even when the current is northwards on the west coast; and south-west monsoon has not strengthened, and the uniformity of the bloom subsequently all over the west coast over the same period could also be due to the reversal of the current and its flow southwards in which, not improbably, the earlier upwelled water from Somali and Arabian Coasts also play a part with their content of plankton.

From September onwards the phytoplankton bloom wanes; this would indicate the cessation of upwelling from thereon. The biological observations lend support to the view of Sharma.

Upwelling has also been reported to occur in the Bay of Bengal all along the coast from Madras to the Hoogly River leading to the enrichment of the water (La Fond, 1954, 1957, 1958 *a*, *b*, *c*). Jayaraman (1965) has raised some doubts as to such an occurrence in the Bay of Bengal chiefly on the ground of the oxygen status of the water, *viz.*, that concentrations are not as low as is usual with upwelled water, *e.g.*, as on the west coast and no upwelling has been observed on the east coast of continents except the Somali Coast. It may be pointed out that one characteristic feature of upwelled water in the Arabian Sea is low oxygen content (Nejman, 1963; Vinogradov and Voronina, 1962; Banse, 1959, 1968).

The oxygen content will depend on the past history of the water; if it had been rich in organic matter, as it is on the west coast (Sewell, 1952), oxygen is used up in the oxidation of this organic matter. The lower layers in the Bay of Bengal are not rich in organic matter for, as is known, organic production in the Bay is of a lower order and this accounts for the higher content of oxygen in the upwelled water.

It is not necessary that oxygen values should be low in upwelled water (*e.g.*, California Coast, Wooster and Reid, 1965). Further, the wind direction during south-west monsoon is such that it displaces the water away from the coast enabling subsurface water to upwell almost similar to the occurrence as of the Somali Coast. Further, what happens here is just the reverse of the events on the west coast of continents in the southern hemisphere (*e.g.*, West Coasts of S. Africa and S. America) whicl is what is to be expected owing to Coriolis force. It may also be noted that the south-west and north-east monsoons are peculiar features of the Indian Ocean region. The intensity of the upwelling might vary depending on the velocity of wind and its sustained duration and a change in these may change the locus of upwelling. Observations of Ganapati and Subba Rao (1957) off Lawson's Bay confirm the findings of La Fond and his co-workers (*refer* literature). It may be added that Varadachari and Sharma (1967), in their study of circulation of the surface waters in the Northern Indian Ocean, indicate in their figures upwelling in the Bay of Bengal from January to June at different centres.

The study of the same authors (Varadachari and Sharma) cover all the months of the year, indicate a number of divergence and convergence points; this would show that there is upwelling in some part of the ocean or other resulting in subsurface water coming up and at a number of other points there is sinking of water. Even slight mixing of the layers by such hydrographical phenomena, particularly over shallow regions and continental shelf, would lead to a bloom of the algae as has been indicated by Subrahmanyan (1959 *a*, *b*).

Effects of Hydrographical Factors

Upwelling resulting in vertical mixing and the horizontal transport of water in currents are of biological interest. The unicellular microscopic plants, phytoplankters, ubiquitously distributed in the water in the upper layers, the euphotic zone, are responsible for all organic production, by their growth and multiplication. Their growth depends on nutrient salts. In the process of upwelling nutrient-laden waters surface and replenish the needs of the plants. The enrichment of bottom waters itself is the result of decomposition of organic matter which had sunk elsewhere and transported by bottom currents to other regions; meeting with submarine obstacles, the bottom water rises and in this the meteorological factors also play a role whereby when the surface waters are displaced by steady winds as during south-west monsoon, subsurace water comes up bringing about upwelling and mixing. It is believed that the waters which sink in the Antarctic and which contain enormous quantities of organic matter (result of the very huge production during southern summer) are transported north and encounter the Carlsberg Ridge in the Indian Ocean and upwell to the surface merging into the circulation of this region enriching the euphotic zone. The oxygen deficiency of this upwelled water is due to its consumption during oxidation of the rich organic dead matter in the water during its course. Attention has been drawn to the rich organic content of the bottom waters in this region (Sewell, 1952, also Vinogradov and Voronina, 1962 *a*). It may be mentioned that all analyses for the nutrient salts in the water on the west coast as well as east coast waters have shown a high concentration of phosphates, nitrates, nitrites, and silicates (Ganapati *et. al*., 1956, 1958; George, 1953; McGill, 1966; Seshappa, 1953; Ivanenko, 1964 *a*, *b*; Jayaraman and Seshappa, 1957; Rao, 1957; Rozanov, 1964; Rozanov and Bykova, 1964; Seshappa and Jayaraman, 1956; Subrahmanyan, 1959 *a*, *b*).

Upwelling brings about ideal conditions for the growth of phytoplankters, the primary synthesizers; the aquatic environment is conditioned so to say, like a culture medium for growth— a fall in temperature to optimum levels (from 31–32° C to 22–25° C), slight lowering of salinity (from 35–36% to 30–32%) and plentiful supply of essential nutrients (Subrahmanyan, 1959 *a*). Hence, a rich bloom of the phytoplankters ensues, particularly evidenced by the high rate of production and the standing crop as already pointed out earlier, its density varying with the fulfilment of the above conditions of growth (Subrahmanyan, 1959 *a*, *b*).

The Trophic Levels

The enormous pasturage thus produced goes to sustain a host of herbivores, mostly copepods, and omnivorous copepods, and a host of higher forms including some fishes, and these in turn nourish the carnivores and larger forms. Therefore, a relationship which commences as a direct one gradually becomes inverse with forms at a higher trophic level predominating in patches. (For more particulars on phyto-zooplankton relationship *please see* Subrahmanyan, 1959 *a*, pp. 164–171.) By this time the particular water mass concerned also would have reached farther off. This is clearly illustrated in Fig. 4 reproduced from Vinogradov and Voronina (1962 *b*) in which it may be seen that herbivores are found proximate to the zone of upwelling where phytoplankters are produced and the other groups mainly farther from this zone. In other words, the farther a given link in the food chain is from the phytoplankters, the farther it is down the Current from the divergence zone (Vinogradov and Voronina, 1965).

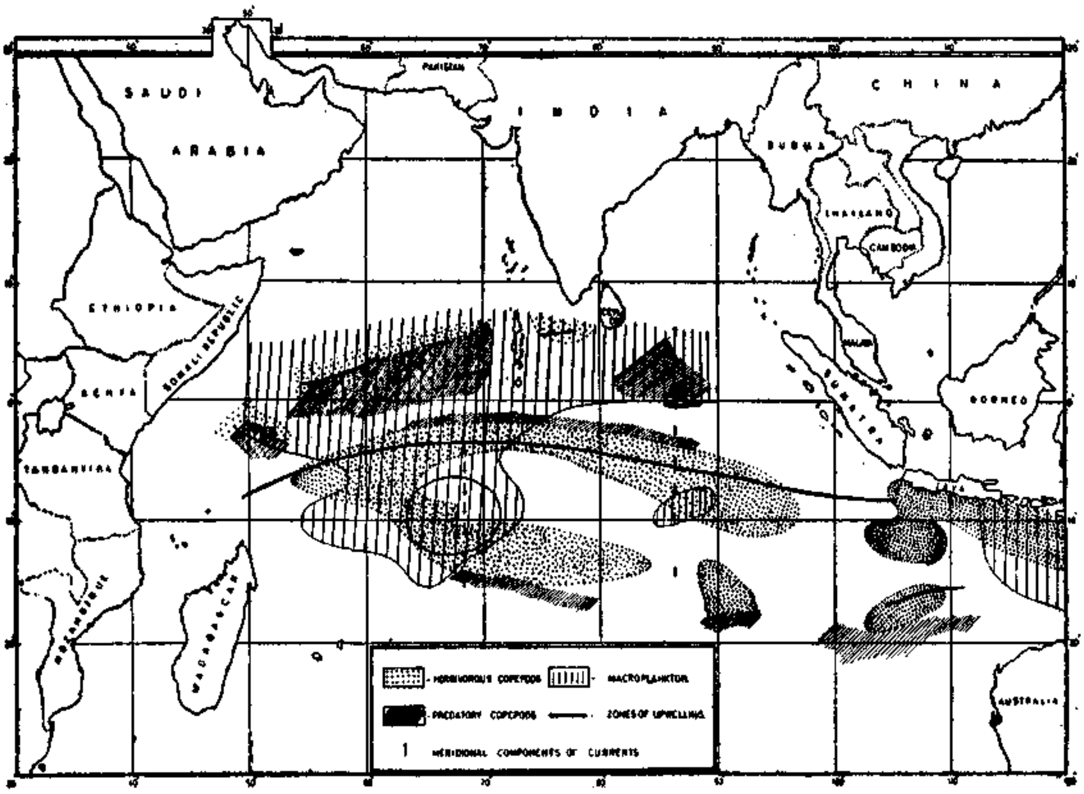

FIG. 4. Distribution of different groups of plankton in the Equatorial Indian Ocean (from Vinogradov and Voronina 1962 (*b*)

Preliminary studies on the distribution of plankton off the Indian West Coast area as a whole show that the herbivores generally are found nearer the shore and most of them are relatively smaller in size compared to the omnivores and carnivores. Table VII illustrates the above point as regards the copepods, which are the most important organisms in the food chain next to the synthesizers. The chaetognaths found mostly farther offshore are carnivors and feed on hydromedusae, crustaceans, other chaetognaths and young fishes (Alvarino, 1965). The tropical Euphausiids are omnivores feeding on phytoplankters (*Coscinodiscus, Planktoniella, Ceratium*), copepods, meroplankton, tintinnids and so on (Ponomareva *et al.*, 1962). The euphausiids form one of the main food items of tunas which abound in the offshore waters and high seas. The salps, found also mostly offshore, feeding generally on diatoms and small animal matter, are to be regarded as omnivores (Foxton, 1966). They graze down phytoplankton quickly and in their turn are eaten by several fishes.

Considerable quantities of plankton organisms, dead and otherwise rain down the water column and near and at the bottom on the shelf form food for a variety of organisms, prawns, crabs, lobsters and bottom living fishes (such as *Cyanoglossus* sp.). The matter not utilized is broken down by bacterial action; part of it comes back into circulation not soon after and some go to form deposits (*refer later below*).

TABLE VII

Certain families of pelagic copepoda (calanoids) their habitat and probable feeding behaviour

Family:	Calanidae	Epiplanktonic	Herbivores
,,	Megacalanidae	Oceanic	Herbivores
,,	Eucalanidae	Epiplanktonic, oceanic and coastal	Herbivores
,,	Paracalanidae	Coastal, Epiplanktonic	Herbivores
,,	Pseudocalanidae	Coastal Epiplanktonic	Herbivores
,,	Spinocalanidae	Oceanic	Herbivores
,,	Euchaetidae	Oceanic	Predators
,,	Scolecithricidae	Oceanic	Herbivores
,,	Centropagidae	Estuarrine, Epiplanktonic and Coastal	Omnivores
,,	Temoridae	Estuarine, Epiplanktonic and Coastal	Herbivores and Omnivores
,,	Pseudodiaptomidae	Estuarine, coastal	Herbivores and Omnivores
,,	Pontellidae	Epiplanktonic, Coastal and Oceanic	Predators.
,,	Tortanidae	Coastal	Predators
,,	Candaciidae	Epiplanktonic	Predators

* By courtesy Sri. P. Parameswaran Pillai.

MAGNITUDE OF THE ORGANIC PRODUCTION *Versus* FISH LANDING

Until very recently, it was the belief that the tropical waters are poor as regards plankton production and hence their fishery resources were also regarded as poor. The writer's investigations over several years conclusively proved that this view is not tenable at least as far as the west coast of India is concerned (Subrahmanyan, 1959 *a*, *b*) and subsequent investigations on the standing crop again confirmed this fact (Subrahmanyan and Sharma, 1965).

Recent investigations employing sophisticated techniques such as use of C^{14} have further confirmed the writer's earlier assessments and also that the fertile area is of wider extent (Prasad and Nair, 1960, 1963, 1964; Ryther, 1963; Ryther *et al.*, 1965, 1966; Wooster *et al.*, 1967).

The reason for the high production have also been sbstantiated in the phenomenon of upwelling noticed at several places during both the monsoons (*refer above*).

Attention has been drawn to the high standing crop over most of the region (*refer adove*).

These findings would lead one to expect a good fishery also along the coasts bordered by the Indian Ocean waters.

We have some accounts which give expression to the total organic production for various waters and for the hydrosphere as a whole (Riley, 1944, 1950; Clarke, 1946); however, as mentioned earlier Cooper (1933) appears to be the first person to evaluate the relationship between organic production and actual fish landed. The next account appears to be one from the CMFRI, and for the first time in a tropical environment. This was done in 1956 (Published: Subrahmanyan, 1959 *a, b*) based on data collected during 1949-54 on the west coast of India and comparing them with data from fairly all over the world. It was stated that the landings on the west coast which account for 80% of marine fish landed in India, constituted a very small percentage of the total plankton production and there was scope for increasing the harvests from 3 to 10 times the then level (Subrahmanyan, 1959 *a*) assuming the possibility of same level of exploitation as in the North Sea (Cooper. *l.c.*). Subsequent increased exploitation by more number of mechanised boats inclusive had only reduced the gap by 004% in 1962.

The above figures on percentage of exploitation have been substantially borne out by the assessments based on primary production using C^{14} by later workers (Prasad and Nair, 1962, 1963).

Schaefer (1965) has attempted calculation of the efficiency at different levels. Farther removed the organisms fished are from primary production in their food habits, lesser will be the harvest of this resource.

Indication of Resources

While much has been done to find correlations between plankton crop and fisheries and to identify indicator organisms in the temperate and arctic regions (for *literature refer* Subrahmanyan, 1959 *a, b*) practically little has been done in the tropical regions, particularly India, mostly due to paucity of investigations. Nair and Subrahmanyan (1955) and Subrahmanyan (1959 *a*) attempted some correlations for the Indian oil sardine, *Sardinella longiceps*, but much more remains to be done; the difficulty lies in that we do not have enough knowledge about the biology of the fishes contributing to our fisheries as well as quantitative studies on plankton. Nevertheless, on the basis of existing knowledge some indicators of the resources may be arrived at.

Upwelling as mentioned earlier brings to the upper layers nutrients laden water in which plants rapidly multiply leading to enormous production of organic matter. If the previous course of this water is known and its source, with knowledge of meteorological factors, particularly wind, areas of upwelling can be predicted as has been done for the West Coast of Africa (Orren, 1967). The upwelling regions mentioned earlier—Somali Coast, Arabian Coast, West Coast and East Coast of India, Equatorial and Java regions—appear to be well established.

Owing to the horizontal displacement of the water by currents, this water is carried away from the area of upwelling and plankton crop appears separated by time and space, former depending on the rate of growth of constituents and latter the displacement during the time. The time may be short in a tropical environment due to higher rate of metabolism and the space will depend on direction and velocity of the currents concerned.

During the south-west monsoon, the water mass in circulation in the Arabian Sea and to some extent in the Bay of Bengal is the upwelled water (*refer* pp. 210-211). Part of the upwelled water also flows towards the Indonesian Archipelago. The plankton standing crop is very rich. The Arabian Sea has been found to be the richest part of the Indian Ocean in plankton content (Subrahmanyan, 1959 *a, b*, 1960; Bogorov and Vinogradov, 1961). This goes to sustain the pelagic fisheries of the oil sardine, the Indian mackeral and several others, high seas fisheries and of the demersal fisheries on the shelf chiefly prawns, which feed on the matter raining down to the bottom.

As there is much in common in the habits of the fishes occurring here and elsewhere on which much work has been done, *e.g.*, the North Sea herring, the South African pilchard, Peruvian anchovy, Pacific tunas and the Antarctic whales, this knowledge could be used as a basis for interpreting the observations here. Perhaps the most important factor which leads to fish aggregation in a tropical environment is the availability of food and basic productivity controls the distribution of fish ultimately (*refer also*: Murphy and Shomura, 1958).

Relationship between plankton production and fisheries has been discussed by Subrahmanyam (1959 *a*, pp. 171–79) and it was summarised that movements of fishes could be related to the water movements and plankton bloom, and it is possible, as observed by Sette (1950, p. 295), that the fishes reach various areas along their route of migration at times, when, on the average feeding conditions are favourable; in other words, fish catches coincide with plankton concentration suggesting that fish tend to tarry in waters rich in plankton.

In the clockwise circulation of the plankton-rich water in the Arabian Sea and Bay of Bengal, a number of convergence zones and eddies occur; in these places, plankton tends to accumulate. Being feeders on the smaller plankters, phyto—and zoo-plankton, the oil sardine and the mackeral are to be sought for not far from the zone of upwelling where these plankters occur and accumulate in the eddies; they are to be located nearer the shore and on the shelf. Migratory fishes are known to stay in eddies and run quickly, between eddies (for food of the oil sardine and mackeral *refer* Nair and Subrahmanyan, 1955; Subrahmanyan, 1959 *a*; George, 1964; Rao, 1964; Rao, K. V. N. and Rao, K. P., 1957; Rao, K. V. N., 1964). The predators of these pelagic fishes, *e.g.*, cat-fishes, sharks, and so on may be found near these places.

In this context a reference to Figs. 1 and 2 and a comparison of the fish landed at the different centres may be made; it may be seen that catches are several times higher during the north-east monsoon months which is the result of the high production of plankton during the earlier south-west monsoon season. Almost all the landings are from nearshore by county crafts using gear locally popular; only less than 6% of the landings accrue from mechanised vessels.

Farther off, where one encounters the larger plankters omnivorous and carnivorous copepods, euphausiids, chaetognaths, micronekton and so on, their predators abound, the several species of tunas. (For more information on food of tunas please *refer* Kumaran, 1964; Raju, 1964; Thomas, 1964; Watanabbe, 1964). The tunas show a wide range of distribution from near the shore on the shelf to far off oceanic waters in the Arabian Sea and almost all over the Indian Ocean to almost 30° S (Fig. 5; Nakamura *et al.*, 1956; Mimura, 1958, 1967; Mimura and Nakamura, 1959; Miyamoto, 1967; Morrow, 1964; Jones, 1967 *a*, *b*, *c*; Silas, 1967; Silas and Rajagopalan, 1967; Shomura *et al.*, 1967; Blackburn, 1965). A reference to Fig. 4 reproduced from Vinogradov and Voronina (1962 *b*) would show that tuna grounds are located in the areas where larger zooplankters and micronekton abound. This has been the experience of investigators in the Equatorial Pacific where the tunas occurred far removed west (near Japan) by some hundreds of miles from the zone of upwelling at the Equator in the east (nearer to North America) and were caught by the Japanese not far from their Islands (Sette, 1955; Blackburn, 1965).

Fishing grounds of some important commercial fishes such as flying fish, skipjack and mackerals are located on topographically stationary eddies formed by islands or submarine banks.

Studies by Varadachari and Sharma (1967) indicate a number of convergence and divergence zones, the former more in number during the north-east monsoon season as is to be expected and they are situated where the standing crop of plankton also is rich and hence, latter tend to accumulate. The convergence zones are indicators of potential fishing grounds; those about the Equatorial zone, as is now known, are tuna long-line fishing zones. The convergence zone near Laccadives and the Andamans would account for the tuna fishery in these locations. The former region is also rich in the larvae and juveniles of tunas (Jones, 1958–65; Jones and Kumaran, 1964 *a*, *b*).

Spawning has also been reported in the Bay of Bengal (March to May), Timor Islands and Banda Sea (January to February) and the Indo-Australian Archipelago is regarded an important spawning ground (Ueyanagi, 1964).

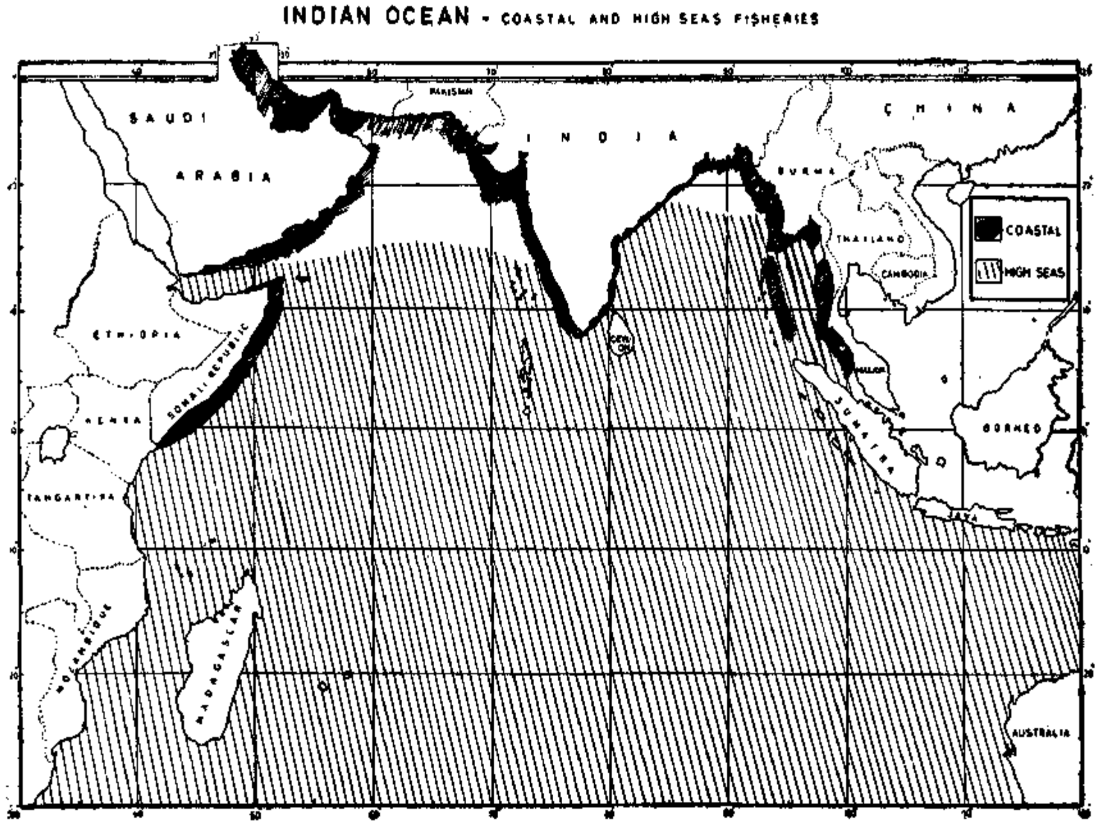

FIG. 5. Fishing areas in the Indian Ocean and adjacent seas. Compiled from various accounts.

Since the fifties, the Japanese have consistently exploited the tunas of the Indian Ocean in the Equatorial waters, south Bay of Bengal, Andaman Sea, and Laccadive Sea (Shomura *et al.*, 1967). Jones (*l.c.*) has drawn attention to these resources since long but there have been no Indian ventures to share in this abundance of the tunas yet.

Our knowledge of the bottom topography, and submarine ridges, banks, etc., is rather poor. These structures hinder the even flow of the currents, cause eddies which lead to sinking of plankton rapidly than otherwise. As most of the demersal fishes have a food chain with the sinking matter as the first link one might trawl usefully on the banks and the environment of submarine elevations. The resources (Mendis, 1965) of the Wadge Bank are to be attributed to such a cause.

Also the trawl fisheries off Gujarat and Maharashtra coasts (Jayaraman *et al.*, 1959; Kagwade, 1967; Rao, K.V. *et. al.*, 1966; Sudarsan, 1965; Pruter, 1964; Hida and Pereyra, 1966) could be attributed to production during south-west monsoon and the concentration and sinking of plankton in these regions during north-east monsoon season, A similar pattern of indications of fisheries discussed above has been found also by Longhurst (1966).

It has been suggested by some (Banse, 1959, 1968) that the demersal fisheries are considerable affected temporarily on the west coast due to O_2 deficiency in the upwelled water which spreads over the shelf. In the absence of the O_2 requirements of the organisms concerned, it is difficult to say how far the set-back to fisheries is due to O_2 deficiency, for, even concentrations as low as 0·1 ml/L have been found sufficient for plankton animals, more so at lower temperatures, (Nikitine, 1931; Nikitine and Malam, 1934; Schmidt, 1925; Jespersen, 1935; Sverdrup *et al.*, 1942). Adverse effect on the organisms is attributed more to presence of hydrogen sulphide which has been found in the intermediate layers as a result of the action on sinking organic matter by sulphur reducing bacteria, (Ivanenkov, and Rozanova, 1961; Sewell, 1952). It has also been noticed that different species react in different manner to fall in O_2 content (Vinogradov and Voronina, 1962 *a*).

Excessive bloom of plankton which often discolours the water has an adverse effect on other organisms in the water including fishes and such an occurrence will affect the marine resources. Several instances have been recorded (*refer* Subrahmanyan, 1954, 1959 *a*; Brongersma-Sanders, 1957; Foxton, 1965), however, they are not of such frequent occurrence in our waters.

Oil Deposits—Remarks on Possible Origin

The enormous production of organic matter has been referred to already. Not all of it is used up, only a fraction appears to be consumed. Workers (Sewell, 1952; Ivanenkov and Rozanov, 1961) have drawn attention to the enormous quantities of organic matter in the deposits in the Arabian Sea where decomposition at times leads to evolution of hydrogen sulphide with deleterious effects. These deposits are rather rich in the northern regions and it would appear that the circulation pattern with eddies and convergences also lead to sinking of much matter.

Subrahmanyan and Gupta (1963) in their investigation, on the lipid content of plankton observed that the east coast plankton is relatively poorer in lipid content compared with plankton of the west coast (Venkataraman and Chari, 1953).

It is well known that rich deposits of organic matter, particularly micro-organisms in a former epoch are responsible for the present day source of oil. It is possible that the oil deposits in and along the Arabian and Persian coasts had such an origin when those areas were also submerged; and the Saurashtra region also is likely to yield good results. Geological studies indicate that the sea bed in the Gulf of Oman to be Middle Eocene and further north, similar beds were found to be petroliferous (Sewell, 1952; *also refer*: Bordovsky, 1964, 1966). It is probable that the bed in the rest of the northern region also is similarly petroliferous. Considerable sinking occurs in this northern region during north east monsoon which might account for the enormous organic matter deposits in the northern region. The process appears to continuing one and present production of plankters might be a living source which die and form deposits of future resources.

General Remarks

According to Shomura *et al.* (1967) the yield of marine resources in the Indian Ocean could be increased four to six fold to bring it to a level comparable to that of the Atlantic and Pacific Oceans, if productivity is similar in the three Oceans. The maximum yields for the Atlantic and Pacific Oceans have not yet been attained. This potential assessment given, hence, is only a minimal level.

From what is already known of organic production in the three Oceans and what has been presented here, organic production is not any the less in the Indian Ocean region. The high fertility of the waters of the Arabian Sea, the Laccadive region, the Equatorial region and the Andaman waters should be quite obvious from the data presented. The possibility of a three to ten fold increased exploitable resources pointed out over a decade ago by the writer (Subrahmanyan, 1959) is not far off the mark. This is the picture in a "well exploited—inshore area of the Indian Ocean region by a developing nation"; the western and northern region of the Arabian Sea, parts of the Bay of Bengal and in the bordering developing countries where rich organic production and standing crop are indicated (Fig. 3), exploitation is much less. An indication of the potential resources of these near east countries is given by Mietle (1967). It may be mentioned here as of interest that beyond the very narrow belt fished by the country crafts, the mechanised vessels introduced also confine themselves to a few select places for fishing and vast areas remain untouched and mechanised fishing even now accounts for, on an average, only less than 6% of the total landings (CMFRI data).

There were sceptics when the above possibility of increasing the resources was indicated by the writer over a decade ago; not long after, however, the observations were confirmed by subsequent work on organic production (Prasad and Nair, *l.c.*).

It might be of interest to notice here the report of a phenomenal mortality of fishes in the Arabian Sea (Jones, 1964) encountered by the Russian ship IRKUTSK in 1957; it was reported that the dead fish estimated amounted to over 20 million tons—nearly equalling world's then annual catch. Though this is not a regular feature and of this magnitude, if this could be the figure for dead fish what must be the resources of this area, may well be imagined. Even discounting all this, the following statement by the Russian scientists (Bogorov and Rass, 1961; quoted by Jones, 1967 *c*) is very significant and revealing. "There is evidence of significant fishing resources in open parts of the Indian Ocean, first of all in waters of the Aradian Sea...The route from the Soviet Black Sea ports (Kherson, Odena, Kerch) to the Arabian Sea is no larger than 4–4·5 thousand miles and the possibilities of developing *our* fishes here are undoubtedly of practical interest." The *our* refers to 'Soviet Russia'. It is now well known that vessels not only from Japan and Russia but also Korea fish in the Indian Ocean waters. There is no reason why India should not take a share of the resources available at her doors.

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REFERENCES

ALVARINO, A. 1965. Chaetognaths. *Oceanogr. Mar. Biol. Ann. Rev.*, 3: 115–194.

ALVERSON, F. G. 1963. The food of Yellowfin and Skipjack tunas in the eastern tropical Pacific Ocean. *Inter. Amer. Trop. Tuna Comm. Bull.*, 7 (5): 293-396.

BANSE, K. 1959. On upwelling and bottom trawling off the south-west coast of India. *J. Mar. Biol. Ass. India*, 1 (1): 33–49.

———. 1968. Hydrography of the Arabian Sea shelf of India and Pakistan and effects on demersal fishes. *Deep-Sea Res.*, 15: 45–79.

BERNER, JR, L. 1959. The food of the larvae of the northern anchovy *Engraulis mordax*. *Inter. Amer. Trop. Tuna Comm. Bull.*, 4 (1): 1–22.

BLACKBURN, M. 1965. Oceanography and the Ecology of Tunas. *Oceanogr. Mar. Biol. Ann. Rev.*, **3**: 299-322.

BOGOROV, V. G. AND T. S. RASS 1961. On the productivity and prospect of fishing in waters of the Indian Ocean. *Okeanologia*, (1), 107-109.

—— AND M. E. VINOGRADOV 1961. Some features of plankton biomass distribution in the surface water of the Indian Ocean during the winter of 1959-60. *USSR Acad. Sci. Okeanol. Issled.*, (4): 66-71.

BORDOVSKY, O. K. 1964. On the characteristics of the organic matter in the sediments of the Pacific and Indian Oceans. *Environment and Process of Petroleum Formation*, Moscow. Nauka 1964, 100-129 (In Russian).

————. 1966. Chemical composition of organic matter in bottom sediments of seas and oceans. *2nd Internatl. Oceanogr. Congr. Moscow*, Abs.: 56-57.

BROADHEAD, G. G. AND I. BARRET 1964. Some factors affecting the distribution and apparent abundance of yellow-fin and skipjack tuna in the eastern Pacific Ocean. *Inter-Amer. Trop. Tuna Comm. Bull.*, **8** (8): 417-473.

BRONGERSMA-SANDERS, M. 1957. Mass mortality in the Sea. *Geol. Soc. Amer. Mem.*, 67, 1: 941-1010.

BROWN S. G. 1962. The movements of fin and blue whales within the Antarctic Zone. *Discovery Rep.*, **33**: 1-54,

BURNS, R. E. 1966. Source and circulation of the Basin water in the Andaman Sea. *2nd Internatl. Oceanogr. Congr. Moscow*, 1966. Abs: 740.

CARPENTER, A. 1887. The mean temperature of the Deep waters of the Bay of Bengal. Nat. Hist. Notes from H.M's Ind. Mar. Sur. Steamer *Investigator* No. 8. *J. Asiat. Soc. Bengal*, **56** (2).

CARRUTHERS J. N. *et al.* 1959. Shorewards upslope of the layer of minimum oxygen off Bombay, its influence on marine biology especially fisheries. *Nature, Lond.*, **183** (4668): 1084-1087.

CLARKE, G. L. 1946. Dynamics of production in a marine area. *Ecol. Monogr.*, **14** (4): 322-335.

COOPER, L.H. N. 1933. Chemical constituents of biological importance in the English Channel, November 1930 to January, 1932. Part II. Hydrogen ion concentration, excess base, carbohydrates and oxygen. *J. Mar. biol. Ass. U.K.*, **18**: 729-753.

CROMWELL, T. 1953. Circulation in a meridional plane in the Central Equatorial Pacific. *J. Mar. Res.*, **12**: 196-213.

CUSHING, D. H. 1955. Production and a pelagic fishery. *Fish. Invest. Lond.*, **18** (7): 1-104.

DAVIES, D. H. 1956. The South African Pilchard (*Sardinops ocellata*), Migration, 1950-55. *Invest. Rept. S. Afr.*, (24): 1-52.

————. 1957. The biology of the South African Pilchard. *Ibid.*, (32): 1-11.

DEFANT, A. 1961. *Physical Oceanography*, 1, i-xvi + 1-729. Pergamon Press: New York.

DIBBS, J. L. 1964. Report to the Government of Tanganyika: economic survey of marine and inland fisheries. *FAO/ETAP Rept.*, No. 1828. Rome.

FOXTON, P. 1965. A mass fish mortality on the Somali Coast. *Deep-Sea Res.*, **12**: 17-19.

————. 1966. The distribution and life-history of *Salpa thompsonii* Foxton with observations on a related species, *Salpa gerlachei* Foxton. *Discovery Rep.*, **34**: 1-116.

GANAPATI, P. N. AND V. S. R. MURTHY 1955. Preliminary observations on the hydrography and inshore plankton in the Bay of Bengal off Vishakhapatnam Coast. *Indian J. Fish.*, **2**: 84-95.

————. 1956. Phytoplankton production in relation to depth and distance in the Bay of Bengal off the Waltair Coast. *Proc. VIII Pacif. Sci. Congr. Quezon City*, **3** A: 1145-1155.

—— AND D. V. SUBBA RAO 1957. On upwelling and productivity of the waters off Lawson's Bay, Waltair. *Curr. Sci.*, **26**: 347-348.

————. 1958. Quantitative study of plankton off Lawson's Bay, Waltair. *Proc. Indian Acad. Sci.*, **B 48**: 189-209.

GEORGE, P. C. 1953 *a*. The marine plankton of the coastal waters of Calicut with observations on the hydrological conditions. *J. zool. Soc. India*, **5** (1): 76-107.

———— 1964. Our current knowledge on the food and feeding habits of the Indian Mackeral *Rastrelliger canagurta* (C). *Proc. Symp. Scombroid Fishes*, Part II, *Marine Biol. Ass. India*, 569-573.

*GUNTHER, E. R. 1936 *a*. Variations in behaviour of the Peru Coastal current with an historical discussion. *J. Roy. Geogr. Soc.*, **88**: 37-65.

————. 1936 *b*. A report on Oceanographic Investigations in the Peru Coastal Current. *Discovery Rep.*, **13**: 109-276.

HARDY, A. C. AND E. R. GUNTHER 1935 *a*. The plankton of the South Georgia whaling grounds and adjacent waters. 1926-27. Part I. Introduction, Hydrology and Method. *Discovery Rep.*, **11**; 1-38.

———. 1935 *b*. The plankton of the South Georgia whaling grounds and adjacent waters, 1926-27. *Ibid.*, **11**: 1-456.

HART, T. J. AND R. I. CURRIE 1960. The Benguela Current. *Discovery Rep.*, **31**: 123-298.

HELA, I. AND LAEVASTSU, T. 1961. *Fisheries Hydrography*. Fishing News (Books) Ltd., London.

HERALD, E. S. 1949. Pipefishes and sea horses as food for tuna. *Calif. Fish. Game.*, **35** (4): 329.

HIDA, T. S. AND J. E. KING 1955. Vertical distribution of zooplankton in central equatorial Pacific, July-August. *Spec. Sci. Rep. U.S. Fish Wildl.* Ser., 1952. No. 144.

——— AND W. T. PEREYRA 1966. Results of bottom trawling in Indian Seas by R/V Anton Bruun in 1965. *IPFC Proc.*, 11th Session, Kuala Lumpur, 1964. Sect. II: 156-171.

HUMPHREY, G. F. 1966. The concentration of Chlorophylls *a* and *c* in the South-East Indian Ocean. *Aust. J. mar. freshw. Res.*, **17**: 135-145.

IVANEKKOV, V. N. 1964 *a*. Distribution of P, CO_2, pH, alkalinity/chlorinity in the northern Indian Ocean. (In Russ. Eng. summ.) In: Studies of the Indian Ocean (Third voyage of the *Vityaz.*)). *Trudy Inst. Okeanol. Akad. Nauk SSSR*, **64**: 115-127.

———. 1964 *b*. (Changes of pH, Alkalinity, P and O_2 caused by the inner surface of Nansen bottles). (In Russ. Eng. summ.). In: Studies of the Indian Ocean (Third voyage of *Vityaz*). *Ibid.*, **64**: 80-84.

——— AND A. G. ROZANOV 1961. (The hydrogen sulphide contamination of the intermediate water layers of the Arabian Sea and the Bay of Bengal) (In Russian). *Okeanologiya Akad. Nauk, SSSR*, **1** (3): 443-449.

IVANOV, J. A. 1964. (Hydrological researches of the northern Indian Ocean) (In Russian Eng. summ.). In Studies of the Indian Ocean (third voyage of the *Vityaz*). *Trudy Inst. Okenol. Akad. Nauk SSSR*. **64**: 22-42.

IVANOV-FRANTSKEICH, G. N. 1961. (Some peculiarities of hydrography and water masses of the Indian Ocean,. (In Russ. Eng. Abst.). *Okeanolog. Issled., Mezhd. Komitet Proved. Mezhd. Goefiz. Goda, Parezidiume Akad, Nauk. SSSR*, (4): 7-18.

JAYARAMAN, R. 1965. Upwelling on the east coast of India. *Curr. Sci.*, **34** (4): 121-122.

——— AND G. SESHAPPA 1957. Phosphorus cycle in the sea with particular reference to tropical inshore waters. *Proc. Indian Acad. Sci.*, **B 46** (2): 110-125.

JAYARAMAN. R. *et al.* 1959. Observations on the trawl fisheries of the Bombay and Saurashtra waters, 1949-50 to 1954-55. *Indian J. Fish.*, **6** (1): 58-144.

JERLOV, N. G. 1953. The Equatorial Currents in the Indian Ocean. *Reports of the Swedish Deep-Sea Exped.* 1947-48. *Physics and Chemistry*, **3** (2): 113-125.

JESPERSEN, P. 1935. Quantitative investigations on the distribution of macroplankton in the different oceanic regions *Dana Rep.*, No. 7.

JONES, S. 1958-65. Notes on eggs, larvae and juveniles of fishes from Indian waters. 1. *Indian J. Fish.*, 1958, **5** (2). 357-61. 2. *Ibid.*, 1959, **6** (1): 204-210. 3 & 4. *Ibid.*, 1959, **6** (2): 360-373. 5. *Ibid.*, 1960, **7** (1): 101-106 6 & 7. *Ibid.*, 1960, **7** (2): 337-347. 8, 9 & 10. *Ibid.*, 1961, **8** (1): 107-120. 11. *Ibid.*, 1961, **8** (2): 413-421.

———. 1964. The phenomenal fish mortality in the Arabian Sea in 1957—A speculation on the possible identity of the species concerned. *Proc. Symp. Scombroid Fishes.* Part II, *Mar. Biol. Ass. India*, 713-718.

———. 1967 *a*. Tuna resources of the Indian Ocean. *Sea Food Trade J.*, **2** (1): 109-113.

———. 1967 *b*. The Scombroid fishery of India—present and future. *Proc. Symp. Scombroid Fish.*, MBAI, Pt. III: 994-1000.

———. 1967 *c*. Conservation of the tuna and billfish resources of the Indian Ocean. *Ibid.*, Pt. III, 1184-1189.

———. 1967 *d*. The crustacean fishery resources of India. *Proc. Symp. Crustacea. Ernakulam*, 1965; *MBAI, Symp. Ser.* 2, Pt. IV, 1328-1340.

——— AND M. KUMARAN, 1964 *a*. Eggs, larvae and juveniles of Indian scombroid fishes. *Symp. Scombroid Fishes*, MBAI, Part I, 343-378.

———. 1964 *b*. Distribution of larval Bill-fishes (Xiphidae and Istiophoridae) in the Indo-Pacific with special reference to the collections made by the Danish Dana Expedition. *Ibid.*, Part I, *Mar. Biol. Ass. India*. 481-498.

KABANOVA, YU G. 1961. (Primary production and nutrients in the Indian Ocean). (In Russ. Eng. Abs.). *Okeanol. Issled. Mezhd. Komitet Proved. Mezhd. Goefiz. Goda, Prezidiume, Akad Nauk*, SSSR., (4): 72–75. *Deep-Sea Res.*, **10** (1–2) 1963: 107.

———. 1964. (Primary production and nutrient salts content in the Indian Ocean waters in October-April 1960–61). *Trud. Inst. Okeanol Akad. Nauk SSSR*, **64**: 85–93.

KAGWADE, P. V. 1967. Prawn catches by mechanised vessels in the trawling grounds of Bombay and Saurashtra. *Proc. Symp. Crustacea, Ernakulam*, 1965, *MBAI, Symp. Ser.* 2, Pt. IV: 1348–1381.

KERR A. A. 1966. The fisheries of East Africa and their development prospects. A preliminary survey. *FAO Fisheries Circular*, No. 103.

KING, J. E. AND J. DEMOND 1953. Zooplankton abundance in the Central Pacific. *Fish. Bull., U.S.*, **54** (82): 111–144.

——— AND T. S. HIDA. 1954. Variations in zooplankton abundance in Hawaiian water, 1950–52. *Spec. Sci. Rep. U.S. Fish. Wildl. Serv.*, **118**: 1–66.

——— AND IKEHARA, I. I. 1957. Comparative study of food of big eye and yellowfin tuna in the Central Pacific. *Fish. Bull., U.S.*, **57** (108).

——— AND R. T. B. IVERSEN, 1962. Midwater trawling for forage organisms in the Central Pacific 1951–56. *Ibid.*, **210**: 271–321.

KNAUSS, J. A. 1963. Equatorial Current Systems. In: *The Sea* 2: 235–252. Interscience Publishers, New York.

——— AND B. A. TAFT, 1963. Measurements of Currents along the Equator in the Indian Ocean. *Nature, Lond.*, **198** (4878): 376–377.

——— AND B. A. TAFT 1964. Equatorial Undercurrent of the Indian Ocean. *Science*, **143** (3604): 354–356.

KUMARAN, M. 1964 *a*. Studies on the food of *Euthynnus affinis affinis* (Cantor), *Auxis thazard* (Lacéypède), *Auxis thynnoides* Bleeker and *Sarder orientalis* (Tenninck and Schlegel). *Proc. Symp. Scomb. Fish. MBAI.*, Pt. II: 599–606.

———. 1964 *b*. Observations on the food of juveniles of *Scomberomorus commerson* (Lacépède) and *S. guttatus* (Bloch and Schneider) from Vizhingam, West Coast of India. *Ibid.*, 586–590.

LA FOND, E. C. 1954. On upwelling and sinking off the East Coast of India. *Andhra Univ. Memo. Oceanogr.*, **1**: 117–121.

———. 1957. Oceanographic studies in the Bay of Bengal. *Proc. Indian Acad. Sci.*, **B 46**: 1–46.

———. 1958. On the circulation of the surface layers of the East Coast of India. *Andhra Univ. Memo. Oceanogr. Sci.*, **2**: 1–11.

———. 1958 *b*. Seasonal cycle of sea surface temperatures and salinities along the East Coast of India. *Ibid.*, **62**: 12–21.

———. 1958 *c*. Upwelling in the Bay of Bengal. *Proc. 9th Pacific Sci. Congr.*, **16**: 80.

LAWS, R. M. 1961. Reproduction, growth and age of southern fin whales. *Discovery Rep.*, **31**: 327–486.

LONGHURST, A. R. 1966. Biological basis of tropical fisheries. *2nd Internatl. Oceanogr. Congr. Moscow. Abs.*: 230–231.

MACKINTOSH, N. A. 1934. Distribution of the Macroplankton in the Atlantic Sector of the Antarctic. *Discovery Rep.*, **9**: 65–160.

MARR, J. W. S. 1962. The natural history and geography of the Antarctic krill (*Euphausia superba* Dana). *Ibid.*, **32**: 33–464.

MARUKAWA, H. 1939. Fisheries of the South Sea Islands: natural food of skipjack and tunas. *Nanyo Suisan*, **5** (7): 12–14.

McGILL, D. A. 1966. Chemical and biological observations in the western Indian Ocean during the south-west monsoon, 1963. *2nd Internatl. Oceanogr. Congr. Moscow. Abs.*, 248–249.

McHUGH, J. L. 1952. The food of albacore (*Germo alalunga*) off California and Baja California. *Bull. Scripps Inst. Oceanogr. Tech.*, **6** (4): 161–172.

MENACHE, M. 1961. (Discovery of an upwelling of deep water to the south of the Mozambique Channel). (In French). *Memo. Inst. Sci., Madagascar*, **7** (4): 167–173.

MENDIS, A. S. 1965. Resources of the Wadge and Pedro Banks. *Bull. Fish. Res. Stn. Ceylon*, **18** (2): 47–52.

MENON, M. A. S. 1945. Observations on the seasonal distribution of the plankton of the Trivandrum Coast. *Proc. Indian Acad. Sci.*, **B 22** (2): 31–62.

MERRIMAN, D. 1955. El Nino brings rain to Peru. *Amer. Sci.*, **43** (1): 63–77.

MIETLE, P. L. 1967. The fisheries of the Near East Region. *FAO Fish Circular*, No. 112.

MIMURA, K. 1958. Study of the fishing condition of yellowfin in Indian Ocean, especially on the annual difference of the hook-rate and size composition *Nankai. Reg. Fish. Lab. Rep.*, **7**: 59–71.

———. 1967. Present status of the tuna longline fishery in the Indian Ocean (1959). *Proc. Symp. Scomb. Fish. MBAI*, Pt. III: 1139–1145.

MIMURA, K. AND H. NAKMAURA 1959. The tuna long-line fishing ground in the Indian Ocean and its adjacent waters. *Nankai Reg. Fish. Re. Lab.*

MIYAMOTO, H. 1967. Summary of studies on tuna resources carried out at Nankai Fisheries Research Laboratory, Japan. *Proc. Symp. Scomb. Fish. MBAI*, Pt. III: 1158–1159.

MORROW, J. E. 1964. Marlins, sail fish and spear fish of the Indian Ocean. *Ibid.*, Pt. I: 429–442.

MURPHY, G. I. AND R. S. SHOMURA, 1953. Longline fishing for deep swimming tunas in the Central Pacific, 1950–51, *Spec. Sci. Rep. U.S. Fish. Wildl. Serv.*, **98**: 1–47.

———. 1958. Variations in yellowfin abundance in the central Equatorial Pacific. *Proc. 9th Pacific Sci. Congr.*, **16**: 108–113.

NAIR, R. V. AND R. SUBRAHMANYAN, 1955. The diatom, *Fragilaria oceanica* Cleve, an indicator of abundance of the oil sardine, *Sardinella longiceps*. *Curr. Sci.*, **24** (2): 41–92.

NAKAMURA, H. 1935. On the food habits of yellowfin tuna, *Neothunnus macropterus* (Schlegel) from the Celebes Sea. *Trans. Nat. His. Soc. Formosa*, **26** (148): 1–8.

——— *et al.* 1956. Longline tuna fishing grounds in the Indian Ocean. *I.P.F.C. 6th Session*: 220–238.

NEJMAN, V. G. 1963. (Water circulation in north-east Indian Ocean during the summer monsoon). (In Russian, Eng. Summ.). *Okeanologia*, **3** (3): 418–423.

NEWMAN, G. G., 1967. Abalone Research in South Africa. *Fish. Bull., S. Africa*, **4**: 28–34.

NIKITINE, W. N. 1931. Die unters Planktongrenze und deren Verteilung in Schwarzen Meer. *Int. Rev. Gesamtent Hydrobiol. Hydrogr.*, **25** (1–2).

NIKITINE AND E. MALAM, 1934. L'influence de l'oxygéne, des iones d'hydrogéne et de l'acide carbonique sur la distribution vertical du plankton de la mer noire. *Ann. Inst. Oceanogr. Monaco.*, **14** (3).

ORREN, M. J. 1967. Indian Ocean cruises by *R.S. Africana II*. *Fish. Bull., S. Africa*, **4**: 18–20.

OVCHINIKOV, J. M. 1960. (Water circulation in the north Indian Ocean during the winter monsoon). *Rept. 31st cruise of Vityaz.*

———. 1961. (Circulation of waters in the northern Indian Ocean during the winter monsoon) (In Russian, Eng. Abs.). *Okeanolog. Issledov., Mezhd. Komitet Proved. Mezhd. Goefiz. Goda. Prezidiume Akad. Nauk SSSR* (4): 18–24.

PAARISH, B. B. AND A. SAVILLE, 1965. The biology of the north-east Atlantic herring populations. *Oceanogr. Mar. Biol., Ann. Rev.*, **3**: 323–373.

PATIL, M. R. AND C. P. RAMAMIRTHAM, 1963. Hydrography of the Laccadive offshore waters—A study of winter conditions. *J. mar. biol. Ass., India*, **5** (2): 159–169.

PONOMAREVA, L. A. AND A. G. NAUMOV, 1962. (Distribution of zooplankton biomass in the Arabian Sea and Bay of Bengal during the period of monsoon change). *Dokl. Akad. Nauk. SSSR*, **142** (2): 449–452.

——— AND V. V. ZERNOVA. 1962. (The feeding of some Euphausiids in the Indian Ocean). *Trudy Inst. Okeanolog. Akad. Nauk SSSR*, **58**: 163–166.

PRADHAN, L. B. 1956. Mackeral fishery of Karwar. *Indian J. Fish.*, **3** (1): 141–182.

PRASAD, R. R. 1954. The characteristics of marine plankton at an inshore station in the gulf of Mannar near Mandapam. *Indian J. Fish.*, **1** (1 & 2): 1–36.

———. 1966. Recent advances in the study of production in the Indian Ocean. *2nd Internatl Oceanogr. Congr., Moscow. Abs.*: 293.

———. 1968 *a*. Maps on the total zooplankton biomass in the Arabian Sea and the Bay of Bengal. *I.O.B.C. Plankton Atlas*, **1** (1).

PRASAD, P., R 1968 *b*. Maps on the total zooplankton biomass in the Indian Ocean. *I.O.B.C. Plankton Atlas*, 1 (2) .

PRASAD, R. R. AND P. V. R., NAIR, A preliminary account of primary production and its relation to fisheries of the inshore waters of Gulf of the Mannar, *Indian J. Fish.*, 5 (1): 165–68.

———, 1960. A comparison of values of organic production obtained from oxygen and C^{14} methods. *Proc. Indian Acad. Sci.*, B 56 (5): 296-300.

———. 1963. Studies on organic production—1. Gulf of Mannar. *J, Mar. biol. Ass. India,* 5 (1): 1–26.

———. 1964. Preliminary observations on the productivity of certain tuna waters off the west coast of India. *Proc. Symp. Scomb. Fishes., MBAI.*, Pt II: 794–798.

PRUTER, A. T. 1964. Trawling results of the *R/V Anton Bruun* in the Bay of Bengal and Arabian Sea. *Comm. Fish. Rev. Suppl.*, 27–34.

RADHAKRISHNAN, N. 1958. Observations on mackeral fishery at Karwar for the seasons 1954–55 and 1955–56. *Indian J. Fish.*, 5 (1): 258–269.

RAJU, G. 1964. Observations on the food and feeding habits of the oceanic skipjack, *Katsuwonus pelamis* (Lumaen) of the Laccadive Sea during the years 1958–59. *Proc. Symp. Scomb. Fishes. M.B.A.I.* Pt. II: 607–625.

RAMAMIRTHAM C. P. AND R. JAYARAMAN 1960. Hydrographical features of the continental shelf waters off Cochin during the years 1958–59. *J. Mar. biol. Ass. India*, 2 (2): 199–207.

RAMAMURTHY, S. 1953. Hydrobiological studies in the Madras coastal waters, *J. Mad. Univ.*, B 23 (2): 148–136.

———. 1965. Studies on the plankton of the North Kanara Coast in relation to the pelagic fishery. *J. Mar. biol. Ass. India*, 7 (1): 127–149.

RAMASASTRY A. A. AND P. MYRLAND, 1959. Distribution of temperature, salinity and density in the Arabian Sea along the South Malabar coast (South India) during the post monsoon season. *Indian J. Fish.*, 6 (2): 223–255.

RAO, K. S. 1964. Observations on the food and feeding habits of *Scomberomorus guttatus* (Bloch & Schneider) and juveniles of *S. lineolatus* and *S. commerson* from the Waltair Coast. *Symp. Scombroid Fishes.* Part II, 591–598.

RAO, S. V. S. 1957. Preliminary observations on the total phosphorus content of the inshore waters of the Malabar coast off Calicut. *Proc. Indian Acad. Sci.*, B 45 (2): 77–85.

RAO, K. V. N. 1964. Observations on the bionomics of the Indian mackerel *Rastrelliger canagurta* (C) caught in the Lawson's Bay, near Waltair, Andhra Coast. *Symp. Scombroid Fishes.* Part II, 574–585.

RAO, K. V. *et al.* 1966. Relative abundance of trawl fishes in the Bombay-Saurashtra waters. *J. Mar. biol. Ass., India*, 8 (1): 205–212.

RAO, K. V. N. AND K. P. RAO, 1957. Differences in the food of the young and adult mackerel *Rastrelliger kanagurta* (C). *Nature*, 180: 711–712.

RAO, L. V. G. AND R. JAYARAMAN, 1966. Upwelling in the Minicoy region of the Arabian Sea. *Curr. Sci.*, 35 (15): 378–380.

REINTJES, J. W. 1952. Food and feeding habits of the yellowfin tuna, *Neothunnus macropterus*, in relation to its distribution in the Central Pacific region. (Unpublished Thesis. Honolulu).

———, AND J. E. KING 1953. Food of yellowfin tuna in the Central Pacific. *Fish. Bull. U.S.*, 54 (81): 91–110.

RILEY, G. A. 1944. The carbon metabolism and the photosynthetic efficiency of the earth as a whole. *Amer. Sci., Spring Issue*, 32 (2).

———. 1950. Food from the Sea. *The Scientific American*, October 1950.

ROCKFORD, D. J. 1962. Hydrology of the Indian Ocean. II. The surface waters of the South-east Indian Ocean and Arafura Sea in the spring and summer. *Austr. J Mar. Freshw. Res.*, 13 (3): 226–251.

ROZANOV, A. G. 1964. (The distribution of phosphates and silicates in water of the Northern Indian Ocean). (In Russian, Eng Summ). In: *Studies of the Indian Ocean (Third voyage of the* Vityaz). *Trudy Inst. Okeanol. Akad. Nauk SSSR*, 64: 102–114.

——— AND V. S. BYKOVA, 1964. (The distribution of nitrates and nitrites in water of the Northern Indian Ocean). (In Russ. Eng. Summ). In: *Studies of the Indian Ocean (Third voyage of the* Vityaz). *Ibid.*, 64: 94–101.

RYTHER, J. F. 1963. Geographic variations in productivity. In *The Sea*, 2: 347–380. Interscience Publishers, New York.

RYTHER, J. F. AND D. W. MENZEL, 1965. On the production, composition and distribution of organic matter in the western Arabian Sea. *Deep-Sea Res.*, **12** (2): 199–209.

——— *et al.* 1966. Primary organic production in relation to the chemistry and hydrography of the western Indian Ocean. *Limnol, Oceanogr.*, (3): 371–380.

SAVAGE, R. E. 1931. The relation between the feeding of the herring off the east coast of England and the plankton of the surrounding waters, *Fish, Invest, Lond.*, *Ser.* II. **12** (3).

———. 1937. The food of the North Sea Herring, 1930–34. *Ibid.*, *Ser.* II, **15** (5).

SCHAEFER. M. B. 1965. The potential harvest of the Sea. *Trans. Amer. Fish. Soc.*, **94** (2): 123–128.

———. 1967. Some new trends in investigation of tunas in the Pacific Ocean. *Proc. Symp. Scomb. Fishes, MBAI.*, Pt. III, 1160–1172.

SCHMIDT, J. 1925. On the contents of oxygen in the Ocean both sides of Panama. *Science*, **61** (1588).

SESHAPPA, G. 1953. Phosphate content of Mudbanks along the Malabar Coast. *Nature*, **171**: 526.

—— AND R. JAYARAMAN, 1956. Observations on the composition of the bottom muds in relation to the phosphate cycle in the inshore waters of the Malabar Coast. *Proc. Indian Acad. Sci.*, **B 43** (6): 288–301.

SETTE, O. 1950. Biology of the Atlantic mackeral (*Scomber scombrus*) of North America, *Fish. Bull., U.S.*, No. 49.

———. 1955. Consideration of midocean fish production as related to oceanic circulatory systems. *J. Mar. Res.*, **14**: 398–414.

SEWELL, R. B. S. 1925. Geographic and Oceanographic research in Indian waters. Part I. Introduction. The Geography of the Andaman Sea Basin. *Mem. Asiat. Soc. Beng.*, **9** (1): 1–26.

———. 1929. Geographic and Oceanographic research in Indian waters. Part V. Temperature and salinity of the surface waters of the Bay of Bengal and Andaman Sea, with references to the Laccadive Sea. *Ibid.*, **9** (5): 207–355.

———. 1952. Deep-sea Oceanographic exploration in Indian waters. *J. Bomb. Nat. Hist. Soc.*, **50** (4): 705–717.

SHARMA, G. S. 1966. Thermocline as an indicator of upwelling. *J. Mar. biol. Ass. India*, **8** (1): 8–19.

SHIMADA, B. M. 1958. Geographical distribution of the annual catches of yellowfin and skipjack tuna from the eastern tropical Pacific Ocean from vessel logbook records, 1952–55. *Inter-Amer. Trop. Tuna Comm., Bull.*, **2** (7): 287–363.

—— AND M. B. SCHAEFER, 1956. A study of changes in fishing effort, abundance and yield for yellowfin and skipjack tuna in the eastern tropical Pacific Ocean. *Ibid.*, **1** (7): 351–469.

SHOMURA, R. S. *et al.* 1967. The present status of fisheries and assessment of potential resources of the Indian Ocean and adjacent seas. *FAO Fisheries Rep.* No. 54.

SILAS E. G. 1967. Tuna fishery of the Tinnevelly coast, Gulf of Mannar. *Proc. Symp. Scomb. Fishes, MBAI.*, Pt. III, 1083–1118.

—— AND RAJAGOPALAN, M. S. 1967. On the sailfish and marlins of the Tuticorin Coast. *Ibid.*, 1119–1131.

STANDER G. H. 1967 *a*. Trends in the pilchard fishery 1950–65. *Fish. Bull. S. Africa*, **4**: 35–39.

———. 1967 *b*. The Benguela Current off South-West Africa. *Ibid.*, **4**: 1–8.

STEEMANN NIELSEN, E. 1963. Productivity, definition and measurement. In *The Sea. Ed.* M. N. Hill, **2**: 129–164, New York.

SUBRAHMANYAN, R. 1958. Ecological studies on the marine phytoplankton on the west coast of India. *Mem. Indian Bot. Soc.*, 1: 145–151.

———. 1959 *a*. Studies on the phytoplankton of the West Coast of India. Pt. I. Quantitative and qualitative fluctuation of the total phytoplankton crop, the zooplankton crop and their interrelationship, with remarks on the magnitude of the standing crop and production of matter and their relationship to fish landings. *Proc. Indian Acad. Sci.*, **B 50** (3): 113–187.

———. 1959 *b*. Studies on the phytoplankton of the West Coast of India. Part II. Physical and chemical flactors influencing the production of phytoplankton with remarks on the possible limiting factors, cycle of nutrients in the water and relationship of phosphate content to fish landings. *Ibid.*, **B 50**: 189–252.

———. 1960 *a*. Observations on the effect of he monsoons in the production of phytoplankton. *J. Indian bot. Soc.*, **39** (1): 78–89.

SUBRAHMANYAN, R. 1960 *b*. Phytoplankton of the waters of the west coast of India and its bearing on fisheries. In: *Proc. Symp. Algol.*, 1959, *ICAR*, pp. 292–301.

—— AND R. S. GUPTA, 1963. Studies on the plankton of the east coast of India. I. Seasonal variation in the fat content of the plankton and its relationship to phytoplankters and fisheries. *Proc. Indian Acad. Sci.*, **B 57** (1): (1) 1–14.

————. 1965. Studies on the plankton of the east coast of India. II. Seasonal cycle of plankton and factors affecting marine plankton production with special reference to iron content of water. *Ibid.*, **B 61**: 12–24.

—— AND A. H. SHARMA. 1960. Studies on the phytoplankton of the west coast of India. Part III. Seasonal variation of the phytoplankters and environmental factors. *Indian J. Fish.*, 7: 307–336.

————. 1965. Studies on the phytoplankton of the west coast of India. Part IV. Magnitude of the standing crop for 1955–62 with observtaions on nanoplankton and its significance to fisheries. *J. Mar. biol. Ass. India*, 7 (2): 406–419.

SUDA, A. 1953. Juvenile skipjack from the stomach contents of tunas and marlins. *Bull. Jap. Soc. Sci. Fish.*, 19 (4: 319–340.

—— AND SCHAEFER, M. B. 1965. General review of the Japanese tuna long-line fishery in the eastern tropical Pacific Ocean 1956–62. *Inter-Amer. Trop. Tuna Comm. Bull.*, 9 (6): 305–462.

SUDARSAN, D. 1965. Observations on the plankton and trawler catches off Bombay. *J. Mar. biol. Ass., India*, **6** (2): 222–225.

SUKHANOVA, I. N. 1962 *a*. (On tropical phytoplankton of the Indian Ocean). *Doklady Akad. Nauk., SSSR*, **142** (5), 1162–1164.

————. 1962 *b*. (On the specific composition and distribution of the phytoplankton in the Northern Indian Ocean). *Trudy Inst. Okeanol. Akad. Nauk, SSSR.*, **58**: 27–39.

————. 1964. (The phytoplankton of the north-eastern part of the Indian Ocean in the season of the south-west monsoon). *Ibid.*, **65**: 24–31.

SVERDRUP, H. U. *et al.* 1942. *The Oceans*. Prentice-Hall, Inc. Englewood Cliffs, N. J., 1087 pp.

SWALLOW, J. C. 1964. Equatorial Undercurrent in the western Indian Ocean. *Nature, Lond.*, **204** (4957): 436–437.

————. 1965. The Somali Current. Some observations made aboard *R.R.S. Discovery* during August, 1964. *Mar. Obs.*, 125–130.

—— AND J. G. BRUCE, 1966. Current measurements off the Somali Coast during the south-west monsoon of 1964' *Deep-Sea Res.*, **13**: 861–888.

TEMPLEMAN, W. 1966. Marine resources of New Foundland. *Bull.* 154, *Fish. Res. Bd., Canada*.

THOMAS, P. T. 1964. Food of *Katsuwomus pelamis* (Linnaeus) and *Neothunnus macropterus* (Tenninck & Schlegel) from Minicoy waters during the season 1960–61. *Proc. Symp. Scomb. Fish., MBAI*, Pt. II, 626–630.

THOMPSON, E. F. 1939. Chemical and Physical investigations. The exchange of water between the Red Sea and the Gulf of Aden over the "sill". *Sci. Rep. John Murray Expd.*, 1933–34, **2**: 105–119.

TSURUTA, B. 1963. Distribution of plankton and its characteristics in the oceanic fishing grounds with special reference to their relation to fishery. *J. Shimonoseki Univ. Fish.*, 12 (1): 13–214.

———— *et al.* 1957. (Oceanographical and planktological studies of Tuna-fishing ground in the Eastern part of the Indian Ocean). *Ibid.*, 7 (1): 1–20.

UEYANAGI, S. 1964. Description and distribution of larvae of five *Istiophorid* species in the Indo-Pacific. *Proc. Symp. Scomb. Fish., MBAI*, Pt. I: 499–528.

VARADACHARI, V. V. R. AND G. S. SHARMA, 1967. Circulation of the waters in the north Indian Ocean. *J. Indicn Geophy. Uni.*, **4** (2): 61–73.

VENKATARAMAN, R. AND S. T. CHARI, 1953. Studies on the mackerel fat variations: Correlation of plankton with that of fish. *Proc. Indian Acad. Sci.*, **B 37**: 224–227.

VINOGRADOV, M. E. 1962. (On the quantitative distribution of deep water plankton in the northern part of the Indian Ocean). *Okeanologia*, 2 (4): 577–592.

—— AND N. M. VORONINA 1961. (Distribution of some widespread species of copepods in the Indian Ocean). *Dokl, Acad. Nauk, SSSR*, **140** (1): 219–222.

VINOGRADOV, M. E. 1962 *a*. Influence of the oxygen deficit on the distribution of plankton in the Arabian Sea. *Okeanologia*, 1961, **1** (4): 670–678; *Transl. Deep-Sea Res.*, **9**: 523–530.

———. 1962 *b*. The distribution of different groups of plankton in accordance with their trophic levels in the Indian Equatorial Current area. *Rapp. Proc.-Verb. Cons. Internat. Explor. Mer.*, **453**: 200–204.

———. 1965. Some peculiarities of plankton distribution in the Pacific and Indian Equatorial areas. (In Russ Eng. abst.). *Okeanol. Issled. Rezult. Issled. Programme Mezhd. Geofiz. Goda Mezhd. Geofiz. Komitet Presidiume, Akad. Nauk SSSR*, No. 13: 128–136.

VORONINA, N. M. 1962 *a*. On the surface plankton of the Indian Ocean. *Trud. Inst. Okeanol. Akad. Nauk. SSSR*, **58**: 67–79.

———. 1962 *b*. Distribution of macroplankton in the northern Indian Ocean. *Okeanol.*, **2** (1): 119–125.

WALFORD, L. A. 1958. *Living Resources of the Sea.* The Ronald Press Co., New York.

WATANABE, H. 1964. Frigate mackerals (Genus *Auxis)* from the stomach contents of tunas and marlins. *Proc. Symp. Scomb. Fish., MBAI.*, Pt. II, 631–642.

WOOD, E. J. F. 1966. Phytoplankton studies in the eastern Indian Ocean. *2nd Internatl. Oceanogr. Congr., Moscow. Abs.*, 396–397.

WOOSTER, W. S. AND J. L. REID 1965. Eastern boundary currents. In *The Sea*, **2**: 253–280. Interscience Publishers, New York.

——— *et al.* 1967. Atlas of the Arabian Sea for Fishery Oceanography. *Univ. Cal., Inst. Mar. Res., IMR*, 67–12.

WYRTKI, K. 1958. The water exchange between the Pacific and the Indian Oceans in relation to upwelling processes. *Proc. 9th Pacific Sci. Congr.*, **16**: 61–66.

———. 1962. The upwelling in the region between Java and Australia during the South-East monsoon. *Austr. J. Mar. Freshw. Res.*, **13** (3): 217–225.

YABUTA, Y. 1953. On the stomach contents of the tuna and marlin from the adjacent seas of Bomin Islands. *Contrib. Nankai Reg. Fish. Lab.*, **1**, Contrib. 15: 6 pp.

ZERNOVA, V. V. 1962. (Quantitative distribution of the phytoplankton in the Northern Indian Ocean). In: P. I. Usachev, Editor. Biologicheskie issledovaniya morya (plankton). Biological marine studies (plankton). *Izd. Akad. Nauk, SSSR*, **58**: 45–53.

——— AND A. IVANOV 1964. (On the distribution of phytoplankton as depending from hydrological conditions in the northern part of the Indian Ocean). *Trud. Inst. Okeanol. Akad. Nauk, SSSR.*, **64**: 257–264.