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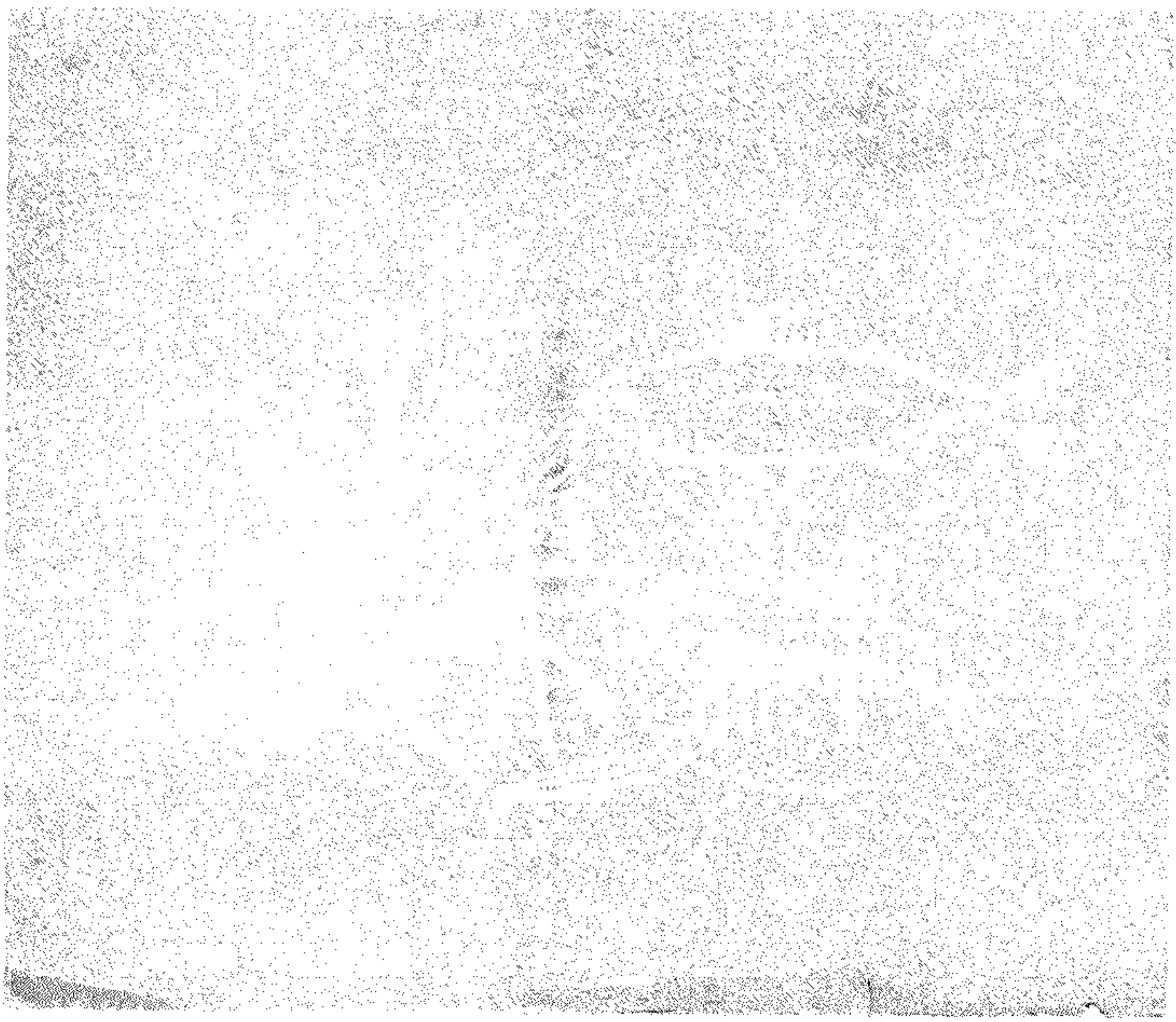

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PRIMARY PRODUCTION AND POTENTIAL FISHERY RESOURCES IN THE SEAS AROUND INDIA

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ABSTRACT

The paper deals with an account of the results of investigations on primary production using oxygen and C^{14} techniques in the Gulf of Mannar, Palk Bay and the west coast of India. These together with the data of *GALATHEA* and International Indian Ocean Expeditions have been used to estimate the productivity of the different regions.

It is found that the maximum production is towards the coast within 50 metres depth and gradually decreases seaward. The mean value over the shelf on the west coast is 1·19 $gC/m^2/day$ for < 50 metres, 0·43 $gC/m^2/day$ for 50–200 metres and 0·18 $gC/m^2/day$ for > 200 metres. Based on this the potential yield as the ratio of carbon production is 1·7 million tonnes.

On the east coast the average for the shelf is 0·63 $gC/m^2/day$ and 0·14 $gC/m^2/day$ outside the shelf, though very high rates of 2·0 $gC/m^2/day$ are usually found in the shallow near-shore regions of Gulf of Mannar and Palk Bay. The estimated yield from the east coast is over 0·6 million tonnes.

Hence the potential resources over the entire shelf region of the west and east coasts of India together would be of the order of 2½ to 3 times the present yield.

INTRODUCTION

As the size of the different populations of animals in the sea depends ultimately on the size of the primary production, these investigations provide at least partial answers to the questions that are asked in fishery research: where and when we can find the living resources, how large are these resources and what is the greatest sustained yield we can obtain ? While stressing the importance of the study of primary production in an integrated fishery research programme, Prasad (1963) has pointed out that due to the interaction of the factors influencing primary production and fish production it is necessary to study all their interrelations in their entirety. But due to the immensity of the problem it is not always possible to draw conclusions after a perfect understanding of all the trophic levels. Nevertheless, it is possible to achieve useful measures with less than perfect understanding. The following account of the primary production in the waters around India in relation to the fisheries potential is an attempt in this direction.

During the last decade much data have been collected on the primary organic production of the seas around India. The Danish *GALATHEA* Expedition paved the way by the introduction of C^{14} in marine productivity studies (Steemann Nielsen, 1952). *GALATHEA*'s coverage included the equatorial part of the Indian Ocean and some parts of Bay of Bengal. Using oxygen and C^{14} techniques Prasad and Nair (1960, 1963) studied the inshore waters of Gulf of Mannar and Palk Bay. Since 1965 C^{14} has been regularly used to study the productivity of the west coast of India between Cape Comorin and Karwar and Laccadive sea during the cruises of *R.V. VARUNA*. During the International Indian Ocean Expedition primary production measurements were made in the Arabian Sea and Bay of Bengal, the reports of some of which have already appeared (Kabanova, 1964; Ryther *et al.*, 1966; Mitchell-Innes, 1967; Wooster *et al.*, 1967). Comparatively less data are available from the Bay of Bengal. However, it is possible to draw some general conclusions regarding the productivity of this region also from the *GALATHEA* Expedition reports (Steemann Nielsen and Jensen, 1957) and the reduced data in the cruise reports of *ANTON BRUUN* (*WHOI*, July 1964). These data have been pooled to compute the productivity of the comparatively highly fished inshore region within 50 metres depth, occasionally fished shelf region between 50 and 200 metres depth and the rarely fished deeper oceanic region outside the shelf. It has not been possible to obtain intensive data from the entire region nor an attempt has been made to follow the organic matter through the different trophic levels. Thus it is an attempt to bring together the available information on the primary production in the seas around India which are of immediate consequence and to assess how far the magnitude of the same can be applied in an estimation of the ratio of the present yield to that of potential yield and also the scope for further exploitation.

PATTERNS OF PRIMARY PRODUCTION

Theoretically regions of high productivity should be found where upwelling takes place. In localities associated with diverging surface currents also a relatively high productivity can be expected. On the other hand low productivity is to be expected in the central part of anticyclonic eddies where the surface water is slowly sinking.

The coastal areas in the tropics are generally rather productive except in the mouths of large rivers where the water is turbid due to silt bringing about poor light conditions for the plankton algae. The main cause for high production in shallow areas is the regeneration rate of nutrient salts due to high temperature accelerating all bacterial processes at the bottom. In shallow areas where light conditions are favourable photo-autotrophic plants and microbenthos also significantly contribute to the primary production which may be considerably higher than that due to the phytoplankton.

High primary production is possible in land plants with root systems penetrating deep in fertile soil. The land values for net production range from 18·4 g/m^2/day for the highest yields of sugarcane to 0·2 g/m^2/day for deserts—dry weight (Ryther, 1959). Phytoplankton on the other hand have to obtain their nutrients from water in which the concentrations are of a much less magnitude. Hence maximum theoretical values estimated as a function of total incoming solar radiation, which is about 25 g/m^2/day, is never attained in the sea. The highest values of primary production are between 5–6 gC/m^2/day for short periods. If production is considered on a volume basis as carbon fixation per cubic metre, values of 10–100 mgC/m^3/day are common for shallow coastal regions (Ryther, 1963) and may even reach 300 mgC/m^3/day (Prasad and Nair, 1963: Table II). For typical oceanic water the values rarely exceed 10 mgC/m^3/day. When calculated on an area basis the advantage of a higher unit volume production is partly offset by the depth of the euphotic zone which is less in turbid coastal areas and deep in the clearer oceanic regions.

Euphotic zone is reckoned as the depth to which 1% surface light penetrates. This depth can vary anything from less than a metre in highly turbid or plankton-rich waters to over 100 metres in clear unfertile oceanic waters (Steemann Nielsen and Jensen, 1957). It is usually observed that the organic production beneath a unit of surface area is inversely proportional to the depth of euphotic zone. Steemann Nielsen and Jensen (*op. cit.*) observed that in Walvis Bay, on the west coast of Africa, where the depth of the euphotic zone was 0·8 metres the organic production amounted to 3·8 gC/m^2/day whereas in the Sargasso Sea the production rate was only 0·03 gC/m^2/day where the depth of the euphotic zone was 120 metres.

INCIDENT RADIATION, TRANSPARENCY AND LIGHT PENETRATION

The intensity of the solar rardiation and transparency of the water are the two factors influencing the depth of the euphotic zone. Based on lux meter measuremens Qasim *et al.* (1968) have calculated the average radiation falling at Cochin as 250–550 g.cal/cm^2/day, the maximum radiation being in January–February and the minimum in June–July. Unlike in temperate countries the variation between the maximum and minimum amount of radiation is very l ttle here. This has a significant bearing on the primary production as the relative photosynthesis as a function of mean radiation has no signal seasonal variability. It has been pointed out by Steemann Nielsen and Jensen (*op. cit.*) that even if the incoming radiation is reduced by 50% the production per unit area would be about 80% to that of clear day. With a decrease in light intensity to one-third the photosynthetic rate per unit area is about two-third of that measured on a bright day. Only on extremely dark days when there is incessant rain the rate per unit area would be reduced to 25% when the light intensity at the surface would be only one-tenth of that on a bright day. Such days are few and far between and as such have no significant bearing on the overall seasonal production.

Of more significance than radiation, which is never a limiting factor in our waters, is the transparency of the water which is influenced by the concentration of phytoplankton and the presence of other particulate or dissolved substances which absorb light. For the production of matter only 0·02 to 2% of incident light energy in the visible part of the spectrum is being utilized or 0·1% on an average. The main reason for the low utilization of the light penetrating the sea surface is

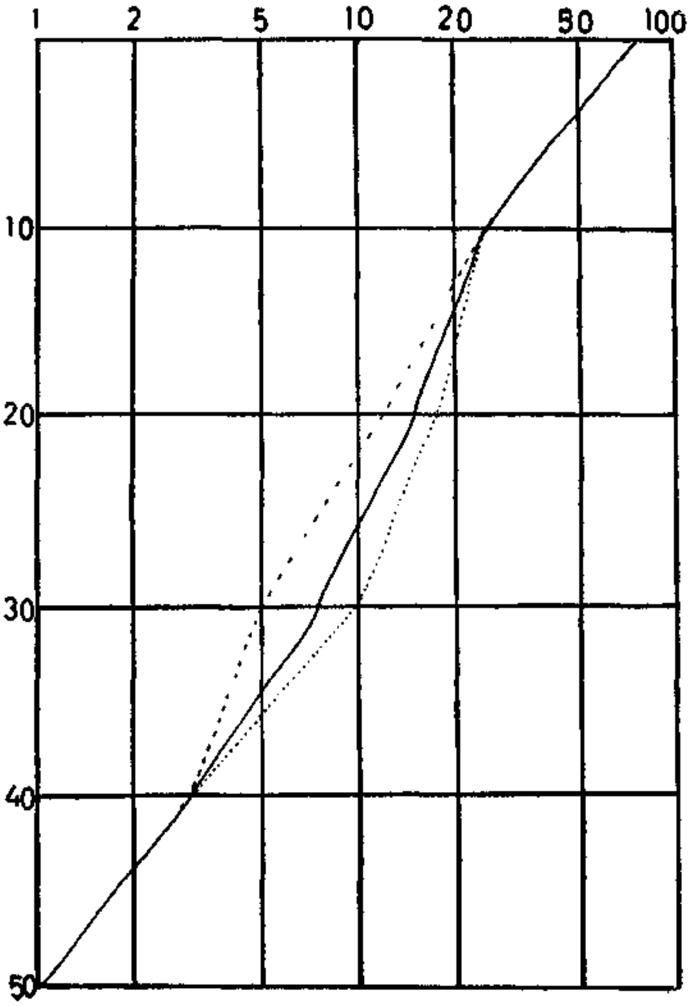

Fig. 1

due to the fact that the majority of it is absorbed by the water and particles of dead organic and inorganic material. A high utilization of the incident light is possible only if the plankton algae are concentrated in a shallow photosynthetic layer, when the light absorption by the water is reduced to the minimum.

The light penetration and depth of the euphotic zone has been studied on the west coast of India using a Tinsley Irradiance Meter. Extinction coefficients are determined by plotting the logarithms of percentage transmission against depth and also by using the formula given by Gall (1949). It has been found that the depth of the euphotic zone is found to vary from 50 to 60 metres on bright days in the region outside the shelf (Figs. 1 and 2). But on cloudy days and towards the coast the euphotic zone shrinks to 14–15 metres (Fig. 3). The average extinction coefficient varies from 0·07 in the oceanic water to 0·32 in the coastal water. The transmission ratio where the secchi disc disappears is normally found to be 17% and the relationship between extinction coefficient (k) and secchi disc depth (D) was:

$$k = 1{\cdot}8/\mathrm{D}.$$

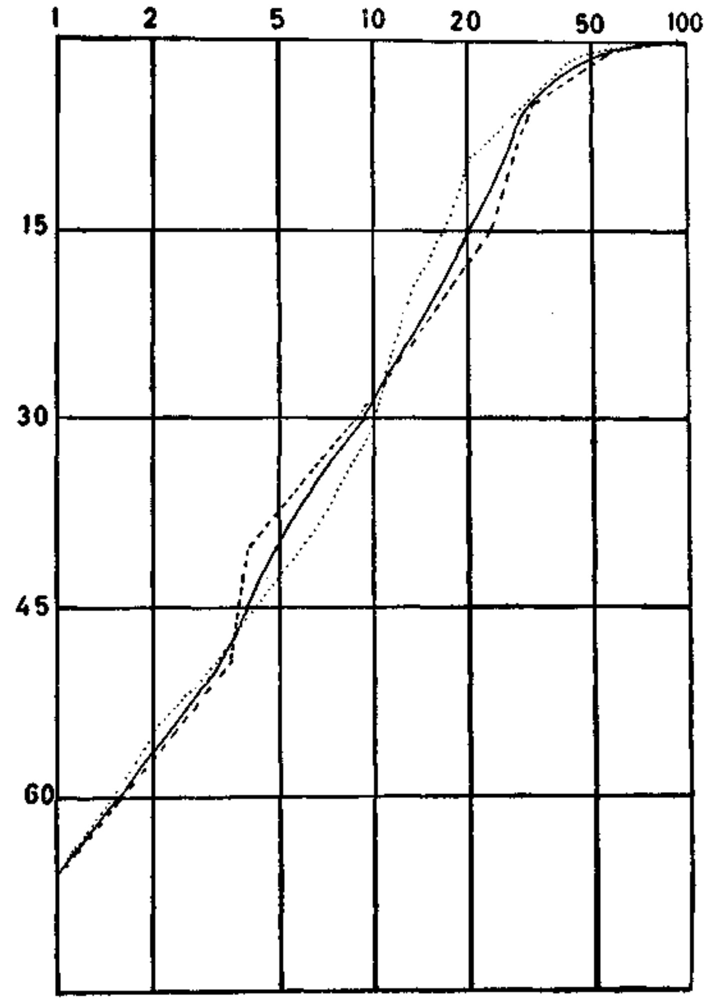

FIG. 2

It may be pointed out here that this ratio can vary from 1·9/D in very clear waters (Strickland' 1958) to 1·5/D in the turbid backwaters (Qasim *et al.*, 1968).

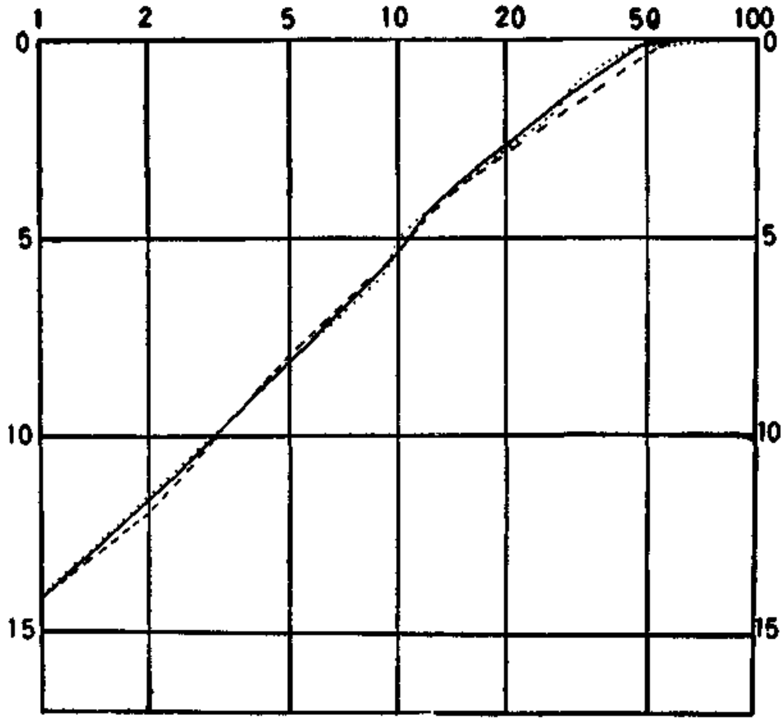

FIG. 3

The secchi disc visibility is around 5 metres in the near-shore waters and extends up to 30 metres in the Laccadive Sea. Roughly three times the secchi disc depth can be taken as the depth of the euphotic zone. So primary production of the waters at different 'light depths' estimated by *in situ* or simulated *in situ* techniques, the latter in sunlight with neutral mesh screen filters or in a constant light incubator. These values in mgC/m^3/day are integrated for obtaining column production and the values in gC/m^2/day are used for comparing the productivity of the different water masses and also for computing the overall productivity of the different zones to estimate the fisheries potential.

PRODUCTIVITY OF THE ARABIAN SEA

As mentioned before data are available only for the zone south of Karwar and north of Cape Comorin. Extrapolating it for the entire west coast of India and estimating from the Indian Ocean Expedition data for the rest of the Arabian Sea a fairly comprehensive picture of the productivity of the Arabian Sea can be made. However, from the resources point of view only the west coast of India has been considered.

Table I gives the organic production rates for some stations within the 50 metre depth, Table II for stations outside and Table III the regionwise productivity of the various zones on the west coast.

It may be pointed out here that it is not quite proper to divide the sea according to State boundaries or according to depth zones. But for the computation of the yield based on fishery survey data some zonal system has to be followed and hence the data have been summarised as in Table III.

TABLE I

(Values for daily primary production expressed as grams carbon fixed beneath a squre metre of sea surface with station positions, depths and dates (within 50 metres depth)

Date	Position		Depth in metres	Production $gC/m^2/day$
	Latitude N	Longitude E		
5–6–1965	8° 00′	77° 20′	38	2·09
15–12–1965	13° 26′	75° 10′	40	0·95
16·12–1965	Karwar Bay		7	1·39
3– 2–1966	9° 40′	76° 00′	40	0·18
6– 9–1966	9° 00′	76° 28′	25	1·24
7– 8–1967	14° 08′	74° 18′	30	0·61
6– 9–1967	9° 52′	76° 10′	18	2·37
7– 9–1967	9° 20′	76° 51′	50	1·18
7– 9–1967	8° 42′	76° 35′	35	1·26
9– 9–1967	7° 45′	77° 19′	50	0·48
9– 9–1967	7° 45′	78° 00′	47	1·43
20– 7–1968	8° 53′	76° 21′	50	1·12
21– 7–1968	10° 29′	75° 51′	37	0·89
22– 7–1968	11° 19′	75° 36′	28	1·34
24– 7–1968	12° 08′	74° 58′	37	2·45

It is found that the level of organic production is high towards the coast, becomes less towards the edge of the continent shelf and least outside the shelf. Values over 2·0 $gC/m^2/day$ are obtained within 50 metres depth. Over the Wadge Bank at a station 38 metres deep the production rate during the upwelling season was 2·09 $gC/m^2/day$. Just below the surface the rate per unit volume was 12 $mgC/m^3/hour$ suggesting a constant replenishment of nutrients. By using artificial light of 30 klux rates as high as 52 $mgC/m^3/hour$ have also been obtained with surface water during the upwelling period for a similar station south of Mangalore. The highest value recorded for the west coast was also from the Wadge Bank area for a station of 90 metres depth, the column production being 4·55 $gC/m^2/day$ in September. Values of over 1·0 $gC/m^2/day$ is commonly met with and production rates of lesser magnitude is more a rarity.

As seen from Table III the average for all the observations within 50 metres depth comes to 1·19 $gC/m^2/day$. This will amount to an annual gross production of 434 $gC/m^2/year$. Assuming that 40% of this is being utilised for respiration the net production would amount to 260 $gC/m^2/year$. Though this rate is fairly high, it is not unusual for tropical shelf areas (*see* Table IV). Based on this, the gross organic production on the shelf within 50 metres depth for an area of 1,14,520 sq. km., where there is active fishing, would amount to 50,000,000 tonnes of carbon.

TABLE II

Values for daily primary production expressed as grams carbon fixed beneath a square metre of sea surface with station positions, depths and dates (outside 50 metres depth)

Date	Position		Depth (m)	Production gC/m²/day
	Latitude N	Longitude E		
4- 6-1965	7° 30′	76° 00′	1,500	0·33
6- 6-1965	8° 50′	75° 20′	1,200	0·03
7- 6-1965	9° 30′	75° 10′	2,000	0·13
12-10-1965	9° 50′	75° 26′	2,000	0·11
13-10-1965	9° 20′	75° 39′	400	0·16
14-10-1965	8° 44′	75° 38′	350	0·05
15-10-1965	7° 53′	77° 04′	550	0·53
16-10-1965	8° 15′	75° 47′	1,200	0·06
11-11-1965	7° 56′	76° 55′	70	0·07
11-11-1965	7° 52′	76° 38′	900	0·22
12-11-1965	8° 32′	76° 00′	200	0·13
12-11-1965	8° 32′	76° 21′	300	0·01
13-11-1965	8° 43′	75° 26′	800	0·13
15-11-1965	..	..	200	0·50
24-11-1965	11° 26′	74° 51′	82	0·11
25-11-1965	12° 20′	74° 40′	58	0·05
25-11-1965	12° 40′	74° 15′	86	0·27
27-11-1965	13° 30′	73° 00′	1,600	0·21
27-11-1965	13° 30′	73° 30′	180	0·10
28-11-1965	12° 20′	74° 21′	180	0·14
29-11-1965	11° 15′	74° 34′	1,200	0·04
14-12-1965	11° 10′	75° 10′	60	0·57
19-12-1965	12° 30′	74° 16′	180	0·04
6- 1-1966	14° 09′	73° 20′	160	0·25
7- 1-1966	13° 35′	72° 55′	1,900	0·35
7- 1-1966	13° 06′	73° 33′	1,800	0·28
8- 1-1966	12° 27′	74° 20′	120	0·25
21- 4-1966	11° 15′	74° 49′	260	0·45
22- 4-1966	11° 40′	76° 08′	1,400	0·05
5- 2-1966	7° 50′	77° 11′	300	0·13
7- 2-1966	9° 30′	75° 35′	1,000	0·07
8- 2-1966	9° 55′	75° 09′	2,000	0·39
26- 5-1966	12° 50′	74° 05′	180	0·13
7- 6-1966	8° 12′	76° 44′	80	0·57
8- 6-1966	8° 46′	76° 10′	150	0·38
25- 6-1966	13° 30′	73° 34′	120	0·29
26- 6-1966	11° 56′	74° 11′	1,700	0·22
7- 8-1966	8° 00′	77° 11′	60	4·55
7- 9-1966	8° 00′	76° 58′	90	4·55
8-11-1966	16° 30′	73° 40′	110	0·11
8-11-1966	16° 29′	71° 42′	300	0·12
6-12-1966	11° 15′	74° 55′	120	0·09
9- 3-1967	9° 21′	75° 52′	188	0·05
18- 4-1967	10° 27′	72° 41′	1,600	0·12
20- 4-1967	10° 43′	74° 26′	2,160	0·21
8- 6-1967	10° 28′	72° 42′	1,900	0·06
9- 6-1967	11° 23′	72° 46′	1,900	0·04
6- 8-1967	12° 44′	74° 28′	56	0·18
31- 8-1967	11° 16′	73° 50′	2,100	0·05
8- 9-1967	8° 17′	75° 44′	1,400	0·40
9- 9-1967	7° 45′	76° 43′	183	0·42
10- 9-1967	7° 27′	77° 40′	117	0·95
10- 9-1967	7° 32′	76° 41′	850	0·95

TABLE III

Summary of primary production values for the different zones in gC/m²/day

States	up to 50 m			50 to 200 m			> 200 m		
	No. of Stns.	Total	Average	No. of Stns.	Total	Average	No. of Stns.	Total	Average
Madras (West Coast) ..	3	4·00	1·33	4 (1	1·49 4·55	0·37 4·55)	6	1·08	0·18
Kerala ..	10	12·17	1·22	13	3·20	0·25	22	3·80	0·17
Mysore ..	6	6·50	1·08	4	0·77	0·19	3	0·84	0·28
Maharashtra ..	..	..	..	2	0·23	0·12	..	..	..
	19	22·67	1·19	24	5·69	0·43	31	5·72	0·18

The net production available to the environment would be 30,000,000 tonnes of carbon. So the maximum yield as compared to intensely exploited waters would be 1,200,000 tonnes of fish (0·4% of organic production in terms of carbon). As the present yield from the west coast is 6,76,000 tonnes of fish this seems to be only a little over one-half of a potentially exploitable yield even if we confine our efforts to the area within the 50 metres line.

TABLE IV

Annual primary productivity (gross) in certain marine environments as grams carbon per square metre of sea surface

Locality	Production gC/m²/year	Reference
Barents Sea ..	170–330	Kreps and Verjbinskaya, 1932
English Channel ..	60–98	Cooper, 1933
Georges Bank ..	309	Riley, Stommel and Bumpus, 1949
North Sea ..	57–82	Steele, 1956
Long Island Sound ..	470	Riley, 1956
Off Hawaii (open ocean) ..	21	Doty and Oguri, 1956
Off Hawaii (inshore) ..	123	do.
Turtle grass bed (Florida) ..	4,650	Odum, 1956
Hawaiian coral reef ..	2,900	Kohn and Helfrich, 1957
Shelf waters off New York:		
Shallow coastal region ..	160	Ryther and Yentsch, 1958
Continental slope ..	100	
North Central Sargasso Sea ..	78	do.
Gulf of Mannar (inshore within 10 m depth) ..	745	Prasad and Nair, 1963
Temperate oceans ..	100–150	Strickland, 1965
Equator ..	110–146	do.
Barren tropical oceans ..	50	do.
West Coast of India (within 50 m depth) ..	434*	Present paper
East coast (Continental shelf) ..	230	do.

* In a recent paper Qasim *et al.* (1968), *Proc. Indian Acad. Sci.*, 69 (2) B, 51–94, have given 281 gC/m²/year as the gross production for Cochin backwaters.

Converting the present yield of fish into its carbon equivalent it would amount to 67,600 tonnes of carbon. This would be just over 0·2%. This approach also seems to indicate that the present yield is only about one-half of a possible exploitable yield. Hence it seems certain that by increasing the effort the present yield could be doubled within the 50 metre line itself. As this is only a theoretical estimate it has to be considered in the light of dynamics of fish populations for stock conservation to maintain the total yield at the highest practicable level by protecting the young fish and regulating fishing effort.

Extending the fishing limit to the edge of the continental shelf, nearly 169,000 sq. km. of additional area would be available where the organic production is of the order of 0·43 gC/m^2/day which is moderately high. The annual gross production of carbon would amount to 157 gC/m^2/year and the net production 94 gC/m^2/year. For the shelf region outside the 50 metre line the total annual net production would be about 16,000,000 tonnes, and as the waters are deeper and the fish population is more diffuse the percentage yield in terms of carbon may be taken as 0·3%. Hence the additional quantity of fish that could be harvested is 500,000 tonnes. Thus by exploiting the whole shelf region the total yield could possibly be raised to 1·7 million tonnes (*cf.* Subrahmanyan, 1959).

Outside the shelf the level of organic production falls to $<$0·2 gC/m^2/day (*see* Table III). But a this rate persists throughout the year an annual net production of about 50 gC/m^2 can be expected. Higher rates of production are found in the shallow waters in the coastal regions of Laccadive and Minicoy Islands (Prasad and Nair, 1962). The Arabian Sea when considered on the whole is a region of great contrast as was observed during the International Indian Ocean Expedition (Ryther *et al.*, 1966). High productivity was observed in the northern and western Arabian Sea (Fig. 4). Exceptionally high values were found off the coast of Saudi Arabia and West Pakistan. Twenty-three measurements made in that region by Ryther *et al.* (*l.c.*) show values in excess of 1·0 gC/m^2/day with a maximum of 6·4 gC/m^2/day. These authors remark that the Somali coast, though has been assigned only moderately high rates of production due to lack of measurements, higher levels of production are expected along the coast and perhaps some distance offshore at least during the south-west monsoon when there is strong coastal upwelling. A large area of low productivity with rates of $<$ 0·26 gC/m^2/day was observed by them between 60° and 70° E. long. But where there is deep water ascent the values of primary production increase and the daily rate is between 50 and 120 mgC/m/day (Kabanova, 1961).

The reason for the very high productivity in certain regions of Arabian Sea lies in the presence of unusually high levels of inorganic nutrients at shallow depths often within or close proximity to the euphotic zone. When these nutrients are brought to the surface high levels of primary production could be sustained. The monsoon shift provides the required energy for the vertical mixing which brings appreciable quantities of nutrients to the surface layers. Rao (personal communication) has observed high concentrations of phosphates (3·73 μg. at./l) during May–June in the eastern Arabian Sea between 0–200 metres. In the western Arabian Sea also high concentrations of phosphate ($\geq$ 2·0 μg. at./l) have been observed at depths of 100–500 metres (Ryther *et al.*, *l.c.*). The rich water from the intermediate depths when brought up to the surface support a heavy growth of plankton organisms which spread seaward with the surface currents. The migration of these organisms or the animals that feed on them can thus sustain large stocks of pelagic fishes in the open ocean where the apparent organic production is of a lower order. Hence large shoals of pelagic fishes could sustain in the open parts of the Arabian Sea in view of the high productivity in certain regions. But a quantitative assessment is not possible because of the patchiness of the distribution in organic production.

Large mass mortalities of fish reported in the Arabian Sea (*cf.* Jones, 1962) is now considered an adverse effect of high productivity. As a result of the death and decay of a large quantity of organic matter the subsurface water becomes further enriched and depleted of oxygen. The levels of oxygen and nutrients which are inversely related depend on the speed of circulation and when the circulation is slow the subsurface waters tend to become anoxic. When these waters are

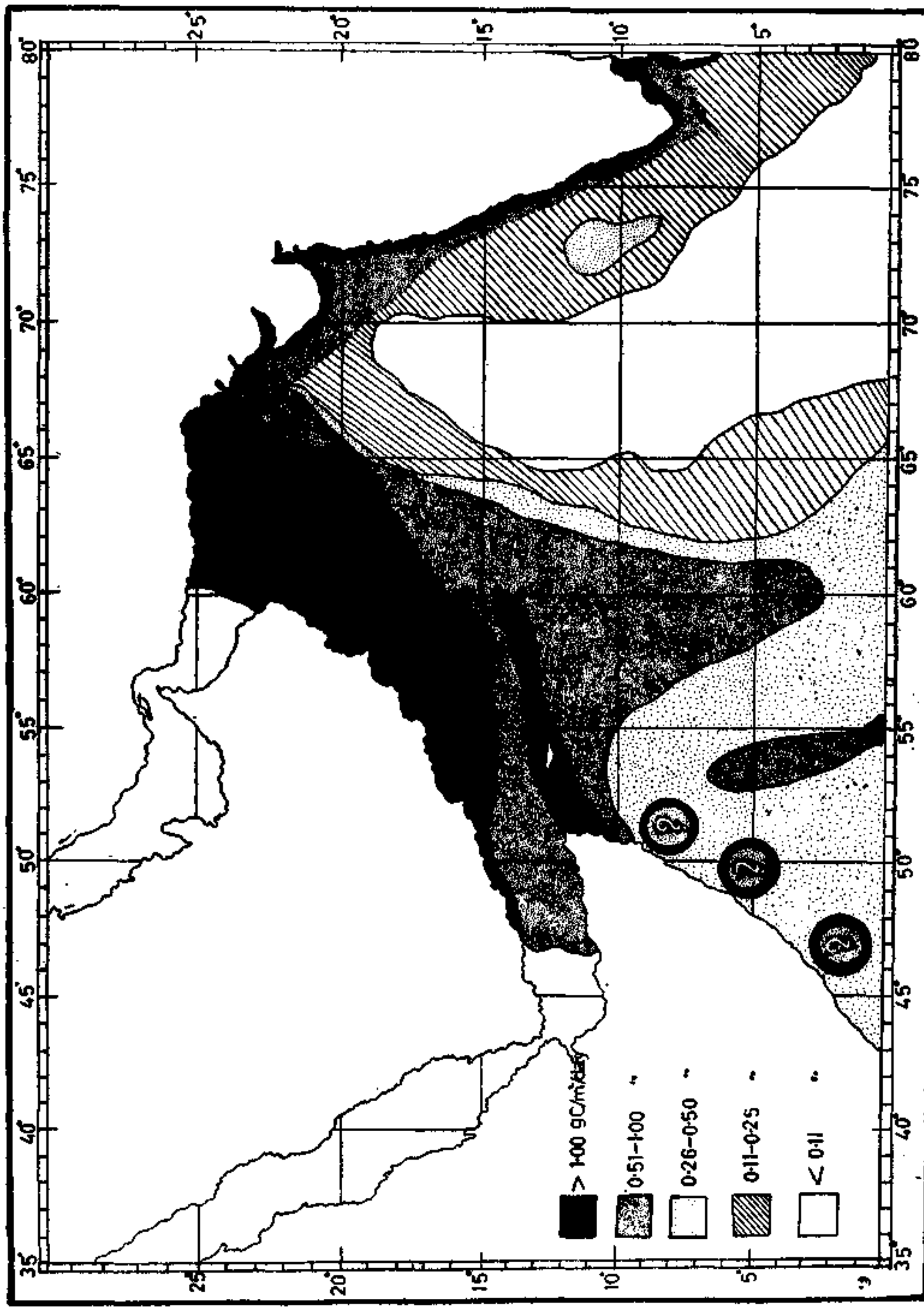

Fig. 4

transported to the surface mass mortalities occur. As pointed outby Prasad (1967) the shifting of the oxygen minimum layer will have a beneficial effect too by helping to drive large shoals of pelagic fishes shoreward.

PRODUCTIVITY OF THE EAST COAST

As mentioned before systematic data are available only for the inshore waters of the Gulf of Mannar and Palk Bay. By the use of C^{14} technique it was found that in the surface waters of tne Gulf of Mannar towards the coast organic production rates range between 250 and 300 mgC/m^3/day. For six near-shore stations the average production obtained by oxygen technique was 204 mgC/m^3/day. For the entire euphotic zone of 10–15 metres near the shore the gross production would thus amount to 2–3 gC/m^2/day and the annual gross production would be of the order of 700–1000 gC/m^2. Such high productivity is characteristic of shallow tropical areas where there is constant replenishment of nutrients by bacterial regeneration aided by high temperature. Off Tuticorin within 50 metre depth the surface waters possessed a rate of 237 mgC/m^3/day and at 10 metres 253 mgC/m^3/day. The column production for this area amounted to a very high value of 5 gC/m^2/day. Using oxygen technique at another station in Tuticorin, Prasad and Nair (1960) observed a column production of 3·4 gC/m^2/day. Hence we can come to the conclusion that this rate of production in the inshore regions of Gulf of Mannar is not an unusual or stray occurrence but a constant phenomenon typical of a tropical shallow area of high productivity.

The level of production in the Palk Bay is of a still higher order (C.M.F.R.I., unpublished data). Several inshore stations investigated in the Palk Bay with C^{14} were found to have very high

TABLE V

Values for daily primary production expressed as grams corbon fixed beneath a square metre of sea surface with station positions, depths and dates (Bay of Bengal)

Date	Latitude N	Longitude E	Depth (m)	Production gC/m^2/day
23-4-1961	14° 20′	82° 00′	3,240	0·12
24-4-1961	17° 10′	84° 30′	2,860	0·25
4-5-1961	13° 58′	91° 03′	3,000	0·24
2-5-1961	19° 53′	89° 05′	1,400	0·16
5-5-1961	10° 32′	90° 59′	850	0·31
26-4-1961	20° 37′	87° 33′	62	0·60
27-3-1963	11° 49′	92° 53′	87	0·01
28-3-1963	11° 23′	93° 31′	80	0·36
1-4-1963	15° 08′	94° 54′	29	0·25
1-4-1963	15° 08′	94° 04′	53	0·25
5-4-1963	19° 41′	93° 08′	38	2·16
5-4-1963	19° 32′	92° 52′	55	0·24
22-4-1963	20° 35′	87° 51′	80	0·83
28-4-1963	17° 41′	83° 19′	65	1·53
28-4-1963	17° 35′	83° 25′	67	0·11

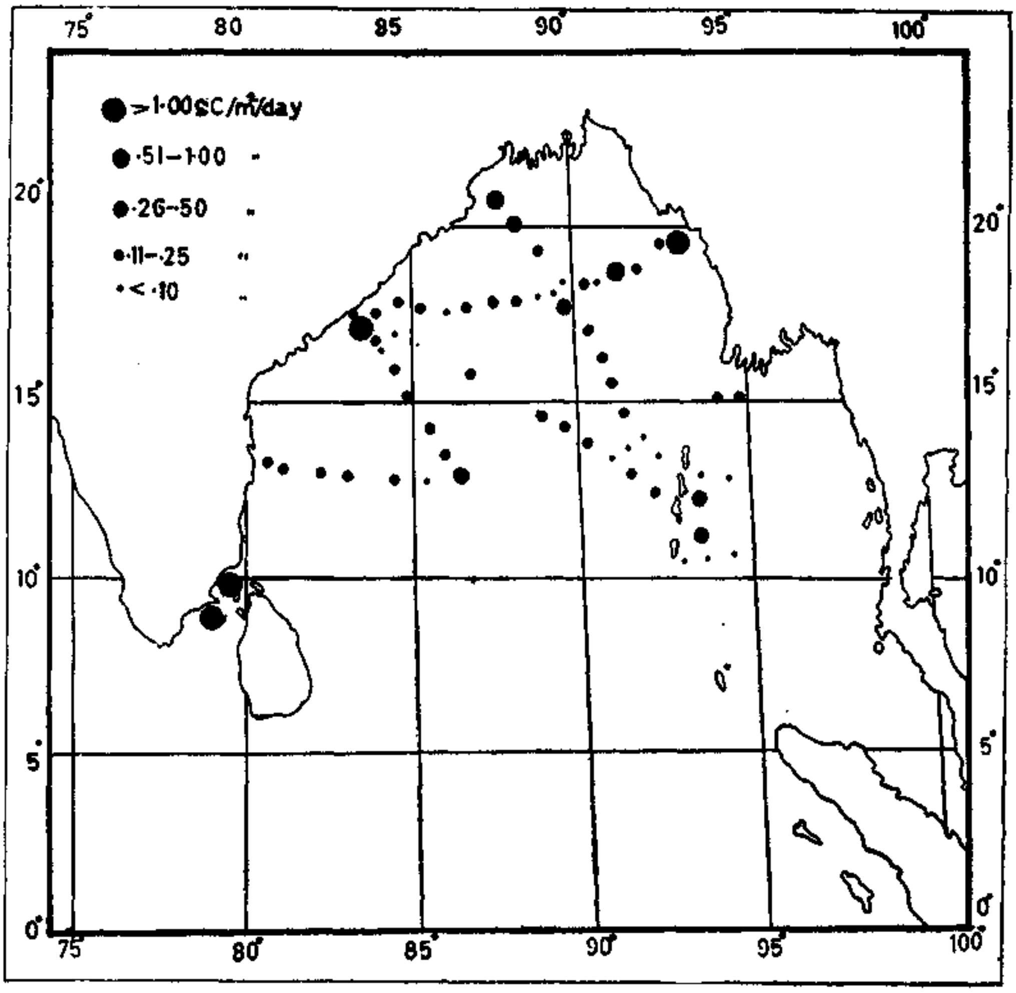

FIG. 5

values. In June–July the surface waters possessed values ranging from 435 mgC/m^3/day to 2,340 mgC/m^3/day. Values fell sharply within 5 metres but there were appreciable rates of production even in 10 metres. The column production thus amounted to 0·3 gC/m^2/day in March to 6·0 gC/m^2/day during June–July.

For the rest of the east coast the data from *Galathea* Expedition and IIOE data only are available which, however, do not cover all the seasons (Fig. 5). According to Steemann Nielsen and Jensen (1957) extensive investigations during different seasons are necessary in order to give a true picture of the productivity of the Bay of Bengal as the monsoon shift has considerable influence on the productivity there.

Though Bay of Bengal is a proper part of the Indian Ocean the salinity is relatively low through the supply of freshwater. The subsurface water rich in nutrients was found in the northern regions by the *GALATHEA* Expedition. The depth of the euphotic zone was 45–66 metres at the western region and 84–99 metres in the eastern region indicating low productivity. The lower transparency in the western part is presumably due to the organic and inorganic material conveyed by the rivers which decrease the rate of photosynthesis per surface area.

The production rate was on the average 0·19 gC/m^2/day in the deeper part while the shelf stations were all characterised by a high rate of production (average 0·63 gC/m^2/day—Table V).

Due to lack of adequate data it is not possible to divide the shelf regions as on the west coast and compute the productivity. The average value for the entire shelf is 0·63 gC/m^2/day which is moderately high but is only about one-half of the productivity of the west coast within 50 metre depth but slightly more than the average value for the region outside. However, in view of the extremely high values obtained for the inshore regions in Palk Bay and Gulf of Mannar this value will be only minimal. So taking this average value of 0·63 gC/m^2/day the net organic production on the east coast would be over 15,000,000 tonnes of corbon and the maximum exploitable yield would amount to a little over 6 lakh tonnes. As the present yield is 2,14,600 tonnes the resources on the east coast would be about three times the present yield. As indicated earlier, studies conducted in the near-shore waters of Gulf of Mannar and Palk Bay suggest that these waters are one of the most highly productive regions and as the fishing effort and the present level of exploitation is not much, the possibility of expansion is still higher in some of these shallow areas (Prasad and Nair, 1963).

Thus considering the east and west coasts together the potential resources over the entire shelf region would be about 2·3 million tonnes excluding the oceanic areas where additional resources could be located. Hence the possibility of increasing the present yield by 2½ to 3 times is a modest estimate as the values of primary production around the seas of India indicate.

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SUMMARY

The paper deals with an account of the results of investigations on primary production conducted in the Indian waters and includes a short review of the factors governing production, patterns of primary production in the different regions, the magnitude of carbon production and the potential fishery resources as a ratio of carbon production.

Data collected using oxygen and C^{14} techniques from Gulf of Mannar, Palk Bay and the west coast of India together with those of *GALATHEA* and International Indian Ocean Expedition have been used to compute the productivity of the different regions.

It is found that the maximum production is towards the coast within 50 metre depth and gradually decreases seawards. The mean value within 50 metres is 1·19 gC/m^2/day. This would amount to an annual gross production of 434 gC/m^2 and net production of 260 gC/m^2 on the west coast. For the shelf area within 50 metres the total annual net production is 30,000,000 of tonnes carbon and so the maximum available yield as compared to intensely exploited waters would be twice that of the present yield. Extending the effort beyond 50 metres to the edge of the shelf, where the rate of primary production is 0·43 gC/m^2/day and the annual net production about 94 gC/m^2 an additional yield of 5,00,000 tonnes could be taken. Thus the possible exploitable yield from the west coast for the entire shelf is of the order of 1·7 million tonnes.

The values for the east coast are comparatively lower excepting in the shallow regions of Palk Bay and Gulf of Mannar where some of the most productive grounds are found. In general, for the east coast the mean value within the shelf is 0·63 $gC/m^2/day$ which would amount to an annual net production of 15,000,000 tonnes and the maximum possible yield is a little over 0·6 million tonnes.

Thus for the east and west coasts together the available resources over the entire shelf region would be of the order of 2·3 million tonnes.

REFERENCES

ANON 1964. Final cruise report of *ANTON BRUUN* Cruise I, 1 (of 2). Woods Hole Oceanographic Institution.

COOPER, L. H. N. 1933. Chemical constituents of biological importance in the English Channel. *J. Mar. biol. Assoc. U.K.*, **18**: 677-714.

DOTY, M. S. AND M. OGURI 1956. Island Mass Effect. *J. Cons. Int. Explor. Mer.*, **22**: 33-37.

GALL, M. H. W. 1949. Measurements to determine extinction coefficients and temperature gradients in the North Sea and English Channel. *J. Mar. biol. Assoc. U.K.*, **28**: 757-780.

JONES, S. 1962. The phenomenal fish mortality in the Arabian Sea in 1957—A speculation on the possible identity of the species concerned. *Proc. Symposium on Scombroid Fishes, Mar. Biol. Ass. India*, **Pt. II**: pp. 713-718.

KABANOVA, Y. G. 1961. Primary production and nutrients in the Indian Ocean. *Acad. des Sci. de l'URSS Comite de l'Annee Geophysique Internationale*, X section of the IGY program (Oceanology), No. 4, Moscow: pp. 72-75.

————. 1964. Primary production and nutrient salts contents in the Indian Ocean waters in October-April 1960-61. *Trud. Inst. Okeanol.*, **64**: 85-93.

KOHN, A. J. AND P. HELFRICH 1957. Primary organic productivity of a Hawaiian coral reef. *Limnol. Oceanogr.* **2**: 241-251.

KREPS, E. AND N. VERJBINSKAYA 1930. Seasonal changes in the phosphate and nitrate content and in hydrogen ion concentration in the Barents Sea. *J. Cons. Int. Explor. Mer.*, **5**: 329-346.

MENZEL, D. W. AND J. H. RYTHER 1961. Annual variation in primary production of the Sargasso Sea off Bermuda. *Deep-Sea Res.*, **7**: 282-288.

MITCHELL-INNES, B. A. 1967. Primary production studies in the south-west Indian Ocean 1961-1963. *S. African Assoc. Mar. Biol. Res., Investigational Rep.*, **14**: 1-20.

ODUM, H. T. 1956. Primary productivity in flowing waters. *Limnol. Oceanogr.*, **1**: 102-117.

PRASAD, R. R. 1963. Study of primary production and its importance in an integrated fisheries research programme. *Fish. Tech.*, **1**: 1-4.

————. 1966. Some aspects of productivity and fisheries of the west coast of India. *Seafood Trade J.*, **1**: 11-15.

——— AND P. V. RAMACHANDRAN NAIR 1960. A preliminary account of primary production and its relation to fisheries of the inshore waters of the Gulf of Mannar. *Indian J. Fish.*, **7**: 165-168.

————. 1963. Studies on organic production. I. Gulf of Mannar. *J. Mar. biol. Asso. India*, **15**: 1-26.

QASIM, S. Z., P. M. A. BHATTATHIRI AND S. A. H. ABIDI 1968. Solar radiation and its penetration in a tropical estuary. *J. exper. mar. Biol. Ecol.*, **2** (1): 87-103.

RILEY, G. A. 1956. Oceanography of Long Island Sound.—IX. *Bull. Bingham Oceanogr. Coll.*, **5**: 324-344.

———, H. STOMMEL AND D. F. BUMPUS 1949. Quantitative ecology of the plankton of the western North Atlantic. *Ibid.*, **12** (3), 1-169.

RYTHER, J. H. 1959. Potential productivity of the sea. *Science*, **130**: 602-608.

————. 1963. *Geographical Variations in Productivity.* In *The Sea*, Ed. M. N. Hill, Interscience Publ., London. pp. 347-380.

——— AND C. S. YENTSCH 1958. Primary production of continental shelf waters off New York. *Limnol. Oceanogr.*, **3**: 327-334.

———, J. R. HALL, A. K. PEASE, A. BAKUN AND M. M. JONES 1966. Primrary production in relation to the chemistry and hydrography of western Indian ocean. *Ibid.*, **11**: 371-380.

STEELE, J. H. 1956. Plant production on the Fladen Ground. *J. Mar. biol. Assoc. U.K.*, **35**: 1-33.

STEEMANN NIELSEN, E. 1952. The use of radio-active carbon (C^{14}) for measuring organic production in the sea. *J. Cons. Int. Explor. Mer.*, **18**: 117-140.

———. 1954. On organic production in the Oceans. *Ibid.*, **49**: 309-328.

—— AND E. A. JENSEN 1957. Primary oceanic poduction. *Galathea Repts.*, Copenhagen, **1**: pp. 49-136.

STRICKLAND, J. D. H. 1958. Solar radiation penetrating the ocean. *J. Fish. Res. Bd. Canada*, **15** (3): 453-493.

———. 1965. Production of organic matter in the primary stages of the marine food chain. *Chemical Oceanography*, Vol. 1, Ed. J. P. Riley and G. Skirrow, Academic Press, pp. 477-610.

SUBRAHMANYAN, R. 1959. Studies on the phytoplankton of the west coast of India. *Proc. Indian Acad. Sci.*, **50**: 113-252.

WOOSTER, W. S., M. B. SCHAEFER AND M. K. ROBINSON 1967. *Atlas of the Arabian Sea for Fishery Oceanogrphy*, Institute of Marine Resources, University of California, pp. 67-12.