

Distribution of Chlorophyll *a* in the Indian Ocean

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Quantitative distribution of chlorophyll *a* (chl. *a*) in the Indian Ocean was studied from the data collected during the International Indian Ocean Expedition (IIOE). Average surface chlorophyll for the Indian Ocean was 0.158 mg/m³, whereas the average values for the Arabian Sea and Bay of Bengal were 0.244 and 0.224 mg/m³ respectively. Integrated values of chl. *a* for the water columns 0-50 and 0-100 m were plotted in 4 different ranges. For the entire Indian Ocean, the average value for 0-50 m was 8 mg/m² and for 0-100 m it was 16.8 mg/m². Relationship between primary production and chl. *a* was determined from the ratios between carbon assimilation and chl. *a*. About 86% of these ratios ranged between 1 and 10 and gave an average value of 3.7. Production rates were computed from chl. *a* for different regions of the Indian Ocean. Difference between observed and computed values was greater in coastal regions than in offshore waters, which may be due to land-mass effect.

ONE of the most widely accepted methods of expressing biomass of phytoplankton in the sea is the chlorophyll *a* (chl. *a*) concentration. In studies related to marine food chains or trophodynamics, an estimate of the standing crop of phytoplankton becomes a necessary prerequisite than that of carbon assimilation, for animals need food not photosynthesis, and chlorophyll indicates the total plant material available in the water at the primary stages of the food chain.

Very few reports are available on the distribution of chl. *a* in the Indian Ocean. Humphrey¹, and Humphrey and Kerr² have given the distribution of chl. *a* and *c* in the south-eastern Indian Ocean while Krey³ has reported the average values of chl. *a* in the Indian Ocean during the 2 seasons — June to September and December to March. Krey and Babenerd⁴ have published a series of maps on chl. *a* distribution, based on the data collected during the International Indian Ocean Expedition (IIOE). These data have been compiled by Babenerd and Krey⁵. Since no proper details are available on the overall distribution of chl. *a* in the Indian Ocean and its possible relation to primary production, it is considered worthwhile to attempt some of these aspects in this paper. In an earlier communication, biological productivity of the Indian Ocean at the primary, secondary and tertiary levels of the food chain has been described⁶.

Methods

Data on chl. *a* compiled by Babenerd and Krey⁵ were used in the present study. These data were collected by various ships participating in the IIOE and the details of methods used by various countries have been given in the compiled volume. The techniques used for the extraction and measurement of plant pigments in sea water have been reviewed and standardized by the SCOR-UNESCO Working Group 17 in 1964 for the IIOE work and the recommendations of the WG-17 published by UNESCO⁷.

In all, 2124 measurements of chl. *a* were used to illustrate its distribution at the surface, 1522

for its distribution at 0-50 m depth and 1139 between 0 and 100 m depth. Chl. *a* at the surface was expressed in mg/m³. For the column of water, chl. *a* was expressed in one square metre after integrating all the values from the sea surface to the required depth, e.g. 0-50 or 0-100 (for details see Babenerd and Krey⁵).

Results and Discussion

Distribution of chl. *a* at the surface of the Indian Ocean is shown in Fig. 1. The area covered was divided into 5° squares and all the data, irrespective of the seasons, were plotted on these squares and averaged for all the observations. For drawing the isolines, the values were grouped into 4 ranges. In the western Indian Ocean, the regions of maximum chlorophyll concentration are along the coastal waters of Saudi Arabia, Somalia and South Africa (Fig. 1). In the north-eastern Indian Ocean, maximum concentrations are found in the regions close to West Bengal, Bangladesh, Burma and in the Strait of Malacca. The coasts of Saudi Arabia and Somalia have been identified by several authors as the regions of intense upwelling during the south west monsoon. When this phenomenon occurs, nutrient-rich water is brought to the surface. This is followed by gradual warming up of the surface water and high phytoplankton productivity. Maximum primary production has been found to be largely confined to these regions⁸. High chlorophyll values, therefore, indicate the most fertile regions of the Indian Ocean.

Another factor which may contribute to high chlorophyll values in fertile areas of the Indian Ocean is the Agulhas Current System, which flows off the east of South Africa. It is a weak western boundary current in the Indian Ocean. This current draws its water essentially from the South Equatorial Current⁹. High values of surface phosphate have been reported near the South African coast, which decrease progressively seaward^{8,9}. Chlorophyll *a* values appear to have a similar distribution in the region.

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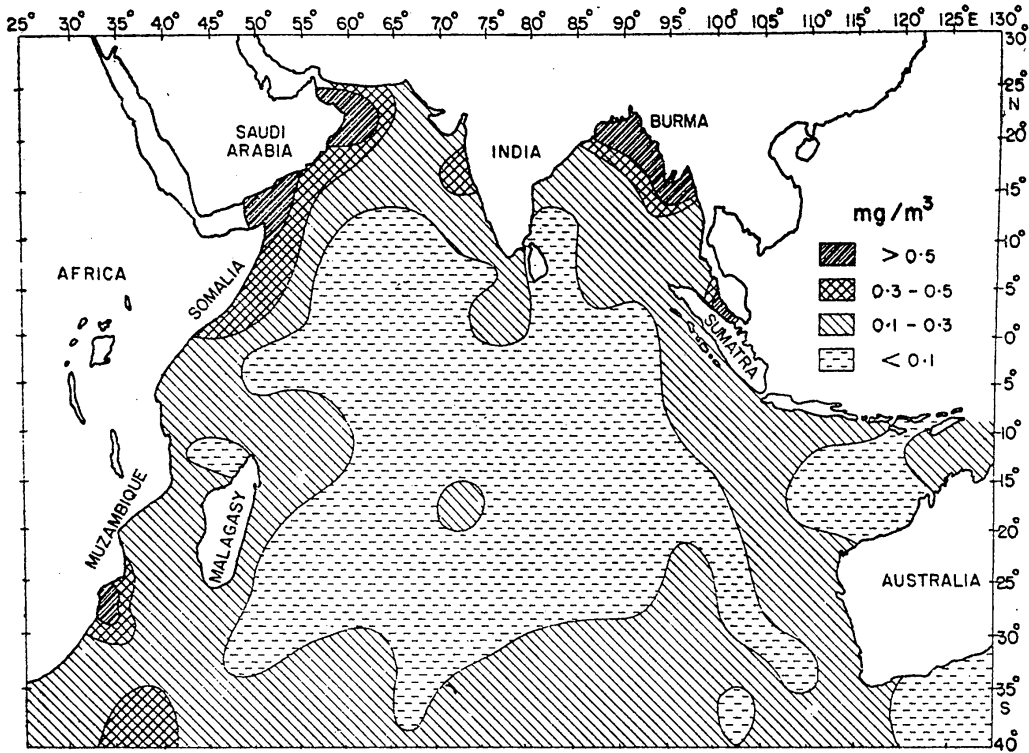


Fig. 1 — Chl. *a* at the surface of the Indian Ocean

The rest of the areas in the Indian Ocean, nearer to the land mass, and in between latitude 35° and 40°S, have chl. *a* ranging from 0.1 to 0.3 mg/m³. A very large area of low chl. *a* content (<0.1 mg/m³) gets demarcated in the central part of the Indian Ocean (Fig. 1). The average surface chlorophyll (1 m depth) for the Arabian Sea, with an area of about 6.8 × 10⁶ km², works out to be 0.244 mg/m³ or 1.66 × 10³ tonnes. For the Bay of Bengal, with an area of about 4.08 × 10⁶ km², the surface chlorophyll (within 1 m depth), would be 0.224 mg/m³ or 0.913 × 10³ tonnes. For the entire Indian Ocean, with an area of approximately 46.98 × 10⁶ km², the average surface chlorophyll would be 0.158 mg/m³ or 7.42 × 10³ tonnes.

Integrated values of chlorophyll between 0-50 m depth are shown in Fig. 2 in 4 different ranges. The overall picture remains almost similar to that shown in Fig. 1, except that the area in the northern Bay of Bengal, rich in chlorophyll (Fig. 1), falls within the lower range. This indicates that much of the chlorophyll in this region of the Bay of Bengal is largely confined to the surface. The average chlorophyll in the column 0-50 m of the Arabian Sea works out to be 13.81 mg/m² and for the Bay of Bengal 8.37 mg/m².

As has been shown elsewhere, photosynthetic production in the Bay of Bengal is largely confined to the surface⁶. Average chlorophyll in the Bay of Bengal at the surface being of a similar order of magnitude as that in the Arabian Sea and its significant reduction in the 0-50 m column of water of the Bay of Bengal further support the deduction made

earlier that much of the phytoplankton production in the Bay of Bengal is confined to the surface.

For the entire Indian Ocean, the average integrated value in the column 0-50 m would be about 8 mg/m². The total instantaneous chlorophyll content within the column (0-50 m) of the Arabian Sea would be 94 × 10³ tonnes; for the Bay of Bengal, the value would be 34 × 10³ tonnes and for the entire Indian Ocean the total chlorophyll content would be 376 × 10³ tonnes.

Fig. 3 shows the integrated values of chlorophyll distribution between 0-100 m. The overall picture of the distribution of chlorophyll within this depth-range remains unaltered except that the large central area gets broken into smaller units. Because of very little data available for the northern Bay of Bengal, the area has been left blank. A comparison of Figs. 1 to 3 would reveal, that although the general pattern of vertical distribution of chlorophyll up to 100 m follows more or less a similar pattern, maximum concentration of chlorophyll can occur at any depth between 0 and 100 m. The euphotic zone in the Indian Ocean, apart from the coastal areas, ranges from 80-100 m (ref. 6). The concentration of chlorophyll in the upper layers of euphotic zone is generally greater and decreases with depth. This is because of the maximum availability of optimum light for photosynthesis in relation to clarity of water. Vertical distribution of chlorophyll seems to be directly related to the depth of the mixed layer or to the extent of mixing of water. Humphrey¹ found that the greatest concentrations of chl. *a* and *c* occur at 75 m in the south-east

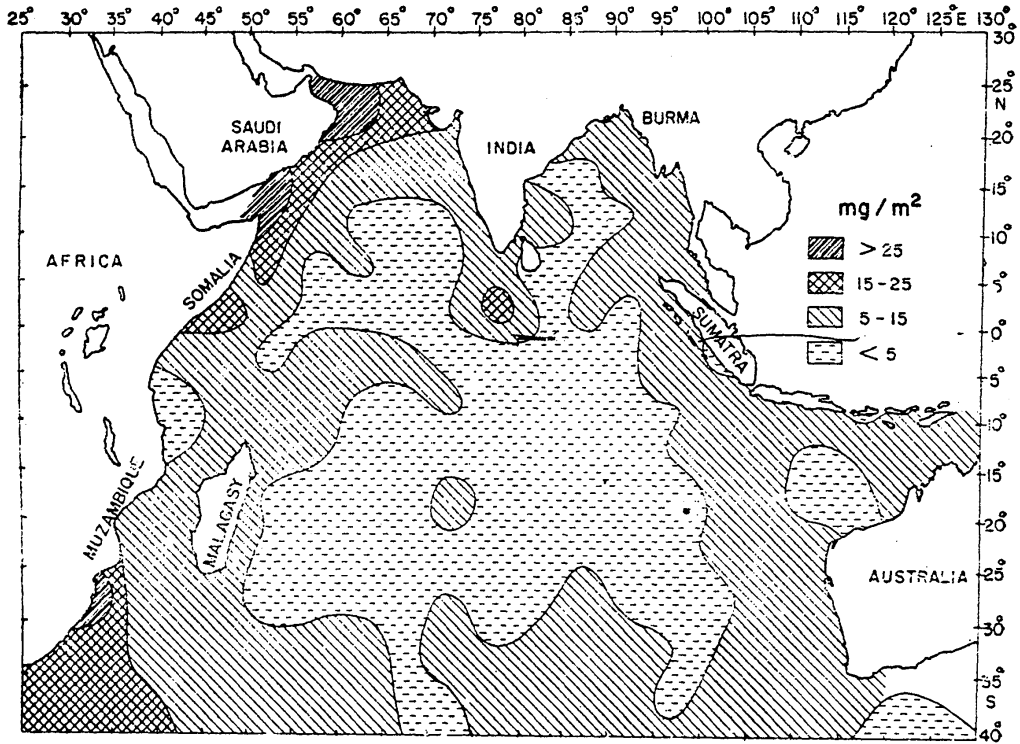


Fig. 2 — Integrated values of chl. *a* from 0-50 m depth of the Indian Ocean

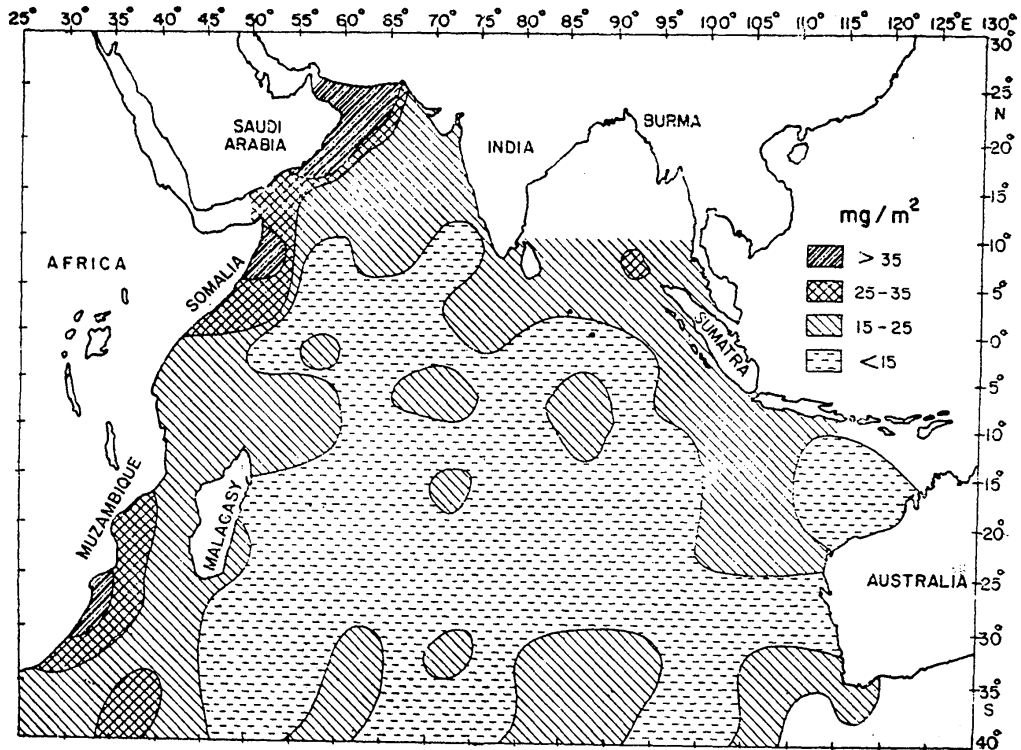


Fig. 3 — Integrated values of chl. *a* from 0-100 m depth of the Indian Ocean

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Indian Ocean. Subsequent studies of Humphrey and Kerr² in the Indian Ocean along 110°E showed that both chl. *a* and *c* vary significantly with depth and that within the water column 0-150 m, maximum concentration can occur at any depth.

The average integrated concentration of chl. *a* in the Arabian Sea from 0-100 m depth would be 22.6 mg/m², in the Bay of Bengal, within the limits of available data, the average value would be 19.5 mg/m² and in the entire Indian Ocean, the average concentration would be 16.8 mg/m². The total instantaneous chl. *a* concentration in the Arabian Sea, within 0-100 m water column would be 154 × 10³ tonnes, Bay of Bengal, 79 × 10³ tonnes and in the Indian Ocean about 790 × 10³ tonnes.

Relationship between chl. a and primary production — During the IIOE, many parallel measurements of chl. *a* and ¹⁴C uptake were made and hence it seems desirable to work out the relationship between the two. One of the easiest methods of determining this relationship is from carbon assimilation: chlorophyll ratios or assimilation numbers. Since primary production and chl. *a* for many stations were known, the assimilation numbers of 136, 5° squares were determined. These ratios, pertaining to the surface, varied from 0.125 to 90. Percentage frequencies of these ratios were plotted in Fig. 4. About 70% of the values were <6 and about 86% of the values were <10 (Fig. 4). The mean ratio of the values ranging from 1 and 10 was 3.704.

The widely used method available in the literature to calculate primary production from chlorophyll is that of Ryther and Yentsch¹⁰. The basic require-

ments of the method are data on solar radiation, attenuation coefficient of light and assimilation number. Since all the 3 types of data are available for the Indian Ocean, it was considered worthwhile to calculate primary production from chl. *a*. Data on solar radiation for each 5° square as averages of all seasons have been given by Mani *et al.*¹¹, and *k* can be determined from the depth of the euphotic zone given earlier⁶, using the expression $k = 4.6/d$ (ref. 12); where *k* is the attenuation coefficient and *d* is the depth of the euphotic zone. The mean assimilation number 3.704 noted above is in agreement with the working value given by Ryther and Yentsch¹⁰. Although this method has certain limitations, it can nevertheless give a close approximation of the production values.

Thus, the production rates from the chlorophyll data for the different 5° square were computed (136 in all, Fig. 5). Since the calculated values

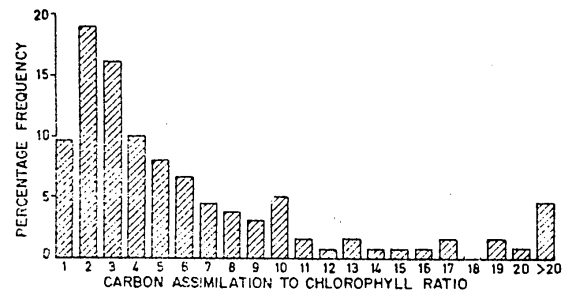


Fig. 4 — Percentage frequency distribution of carbon assimilation to Chl. *a* ratio (assimilation numbers)

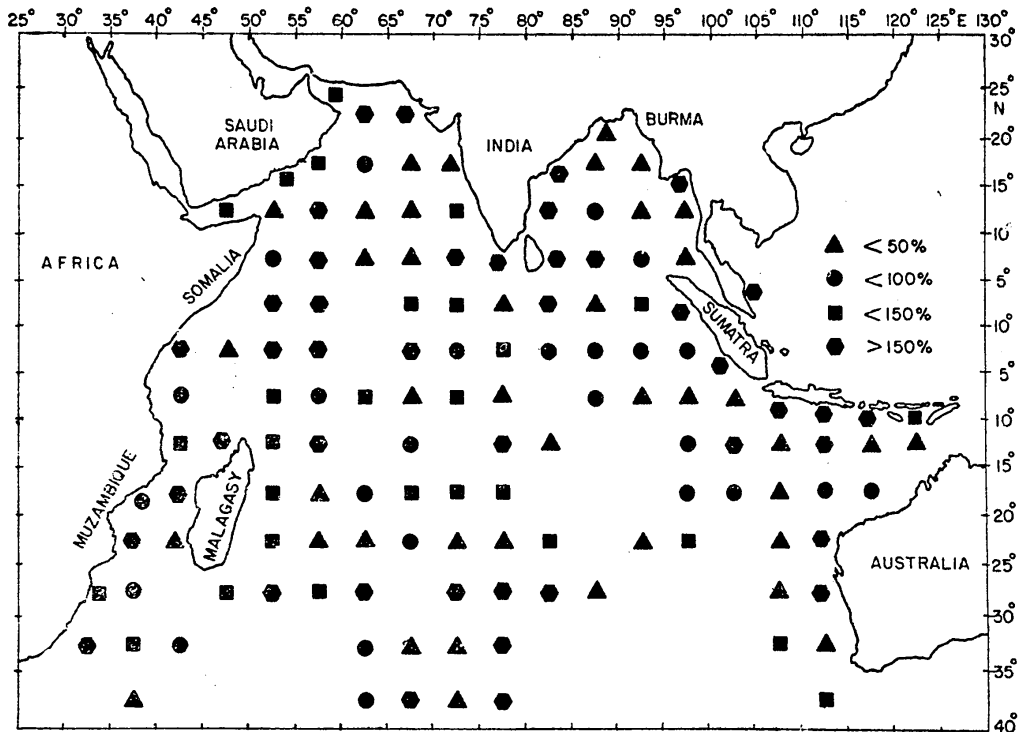


Fig. 5 — Range in difference between observed and computed values of primary production [Observed values refer to ¹⁴C uptake and computed values are from chl. *a*]

TABLE 1 — MEAN OBSERVED VALUES OF PRIMARY PRODUCTION IN DIFFERENT LATITUDES DETERMINED FROM ¹⁴C UPTAKE WITHIN 1m DEPTH (SURFACE) AND MEAN COMPUTED VALUES FOR THE SAME LATITUDES FROM CHL. *a*

Latitude	Coastal		Offshore	
	Observed gC/m ² /day	Computed gC/m ² /day	Observed gC/m ² /day	Computed gC/m ² /day
25-20°N	0.024	0.013	—	—
20-15°N	0.058	0.011	0.007	0.005
15-10°N	0.007	0.016	0.005	0.002
10- 5°N	0.024	0.004	0.005	0.002
5- 0°	0.046	0.008	0.007	0.002
0-5°S	0.009	0.004	0.005	0.002
5-10°S	0.018	0.003	0.005	0.003
10-15°S	0.007	0.002	0.006	0.002
15-20°S	0.013	0.005	0.002	0.002
20-25°S	0.019	0.004	0.001	0.001
25-30°S	0.029	0.009	0.003	0.003
30-35°S	0.015	0.004	0.004	0.002
35-40°S	—	—	0.005	0.003

from surface chlorophyll were in g C/m²/day, the production values were converted from g C/m²/hr into g C/m²/day using a factor of 10 daylight hours and 1 m depth. The average daylight hour between lat. 40°S and 25°N would be more than 10 hr, but it was assumed that the light which penetrates into the sea and which is available for photosynthesis at depths will be approximately 10 hr. All the production rates from ¹⁴C uptake were taken as observed values. The difference between observed values and those computed from chl. *a* for each 5° square was determined. All the differences were grouped into 4 ranges and these are shown in Fig. 5. Most of the areas where the difference is >100%, lie close to land mass. In other words, the large variation between observed and computed values may be because of land-mass effect. This effect may contribute towards large quantities of detrital chlorophyll which is inactive and does not take part in photosynthesis. The dead chlorophyll would probably lead to significant differences between observed and computed values. A similar situation has been reported earlier from a tropical estuary (Cochin backwaters)¹³.

To test the land mass effect, the observed and computed values of the coastal waters were separated from those of the offshore waters. The averages of the 2 sets of values for the various latitudes are given in Table 1.

It is evident from the table that in the nearshore areas, the variation is much larger than in the offshore areas. In the offshore areas, the difference is greater in the northern latitudes than in the southern latitudes. The difference between the 2 was tested statistically. Mean difference between observed and computed values in all the 5° squares under study was 4.65 (SD = 10.44). In the nearshore 5° squares, the mean difference was 12.58 (SD = 15.98) and in the offshore 5° square, the difference was 1.64 (SD = 4.47). These values further indicate that the difference is largely due to land-mass effect. No proper explanation, however, could be found of the large differences occurring in several observed and computed values of offshore waters. Possibly the difference could arise due to cumulative effect of analytical errors.

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