

Particulate Organic Matter in the Coastal and Estuarine Waters of Goa and its Relationship with Phytoplankton Production

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In the coastal and estuarine waters of Goa, particulate organic carbon (POC) varied from 0.52 to 2.51 mg l⁻¹ and from 0.28 to 5.24 mg l⁻¹ and particulate phosphorus (PP) varied from 0.71 to 5.18 µg l⁻¹ and from 0.78 to 20.34 µg l⁻¹, respectively. The mean values of chlorophyll and primary productivity were 1.94 mg m⁻³ and 938.1 mg C m⁻² day⁻¹ in the coastal waters and 4.3 mg m⁻³ and 636.5 mg C m⁻² day⁻¹ in the estuarine waters, respectively.

POC/chl ratios were low in June and October even when POC values were quite high. The POC in surface waters was linearly correlated with the chlorophyll content. Also PP increased when chlorophyll and primary productivity remained high. The results suggest that the phytoplankton was sharply increasing and contributed to POC and PP content. The percentage of detritus calculated from the intercept values of chlorophyll on POC varied from 46 to 76% depending on season. Results indicate that the major portion of POC and PP during postmonsoon (October–January) is derived from phytoplankton production while the allochthonous matter predominate during monsoon (June–September).

Introduction

It is apparent that the particulate organic matter forms a potential source of food for marine animals (Menzel and Ryther 1970; Gordon 1970). Studies undertaken on the production and distribution of these materials in different water masses (Rao & Rao, 1975; Solorzano, 1977; Eppley *et al.*, 1977; Gordon, 1977; Copin-Montegut & Copin-Montegut, 1978; Tanoue & Handa, 1979) indicate wide fluctuations in particulate organic contents depending on the seasons and geographical location. However, very little is known about the seasonal changes of these materials along the west coast of India. An investigation was therefore conducted to estimate the particulate materials along with the chlorophyll and primary productivity in the coastal waters of Goa and the adjoining estuarine system.

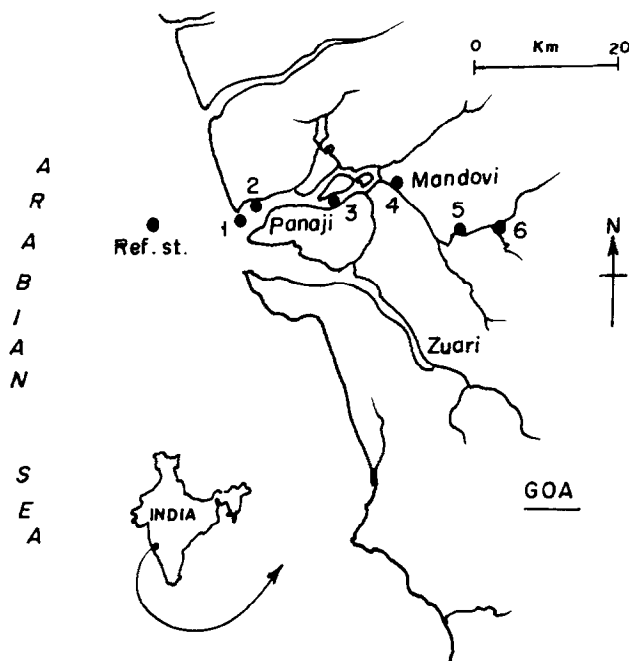


Figure 1. Map showing the location of the reference station and transect stations in the Mandovi River Estuary.

Materials and methods

The reference station ($15^{\circ}28'N$, $73^{\circ}39'E$) was fixed at a distance of about 10 km off the Goa coast, at an average depth of 30 m. The estuarine transect included a series of six stations from the mouth to the upper reaches in the freshwater zone, in the adjoining Mandovi river estuary (Figure 1). The depth of estuarine stations varied from 6 to 10 m except for station 6 which was about 1 m deep in the upper most part of freshwater region. Water samples were collected every month at all these stations using Van Dorn sampler.

For the measurement of particulate organic carbon (POC) and particulate phosphorus (PP), the water samples were obtained from the surface and near bottom at all stations while at the reference station an additional sample from mid-depth was also collected. About 1 to 3 l of seawater was filtered separately for POC and PP analysis using precombusted GF/C glass filter pads. To compute primary productivity for the entire water column the samples were obtained from three to five depths in the photic zone and measurements made using ^{14}C technique.

During monsoon (June to September) due to the formation of sand bar at the Aquada mouth, it was not possible to obtain samples at the reference station. The POC was estimated by the method of El Wakeel and Riley (1957) and PP determined by perchloric acid digestion method as recommended by Strickland and Parsons (1972). Chlorophyll was extracted in 90% acetone and measured by fluorescence. (Lorenzen, 1966).

Results and discussion

Particulate organic carbon at the reference station varied from 0.52 to 2.51 mg l^{-1} [Figure 2(a)]. In the estuarine region the POC shows large fluctuations, with values

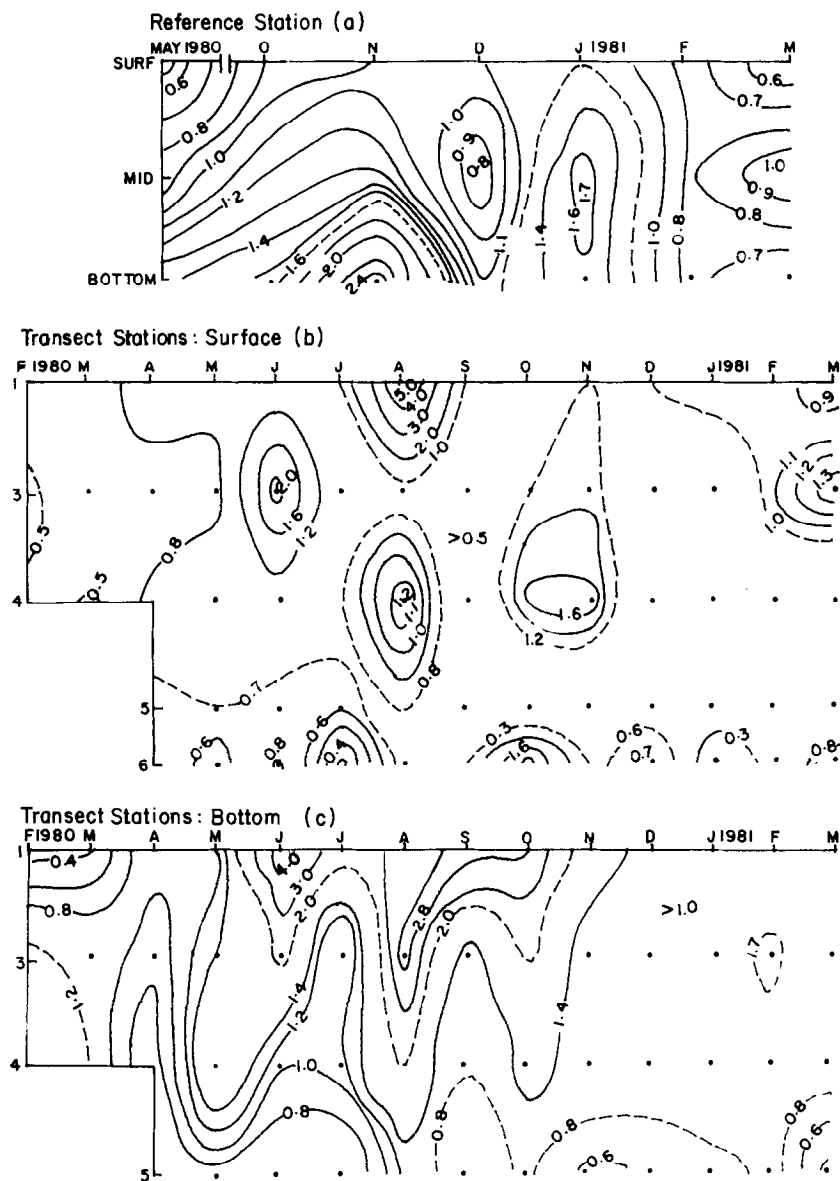


Figure 2. Distribution of particulate organic carbon in mg l^{-1} , at (a) the reference station in vertical profile and (b) and (c) at the transect stations in the Mandovi River Estuary, showing all stations by date. In (a), note that there is a break in the horizontal scale between May 1980 and October 1981.

ranging from 0.28 to 5.24 mg l^{-1} [Figure 2(b), (c)]. The maximum values were observed during monsoon especially in June and August with concentrations increasing towards the river mouth. Almost homologous conditions were found prevailing both at the reference and estuarine stations with POC peaks being noticed in October–November and January–February. In the upstream portion of the estuary, at stations 5 and 6 the POC content usually remains lower than those in the downstream stations.

Particulate phosphorus during post and premonsoon periods at the reference station

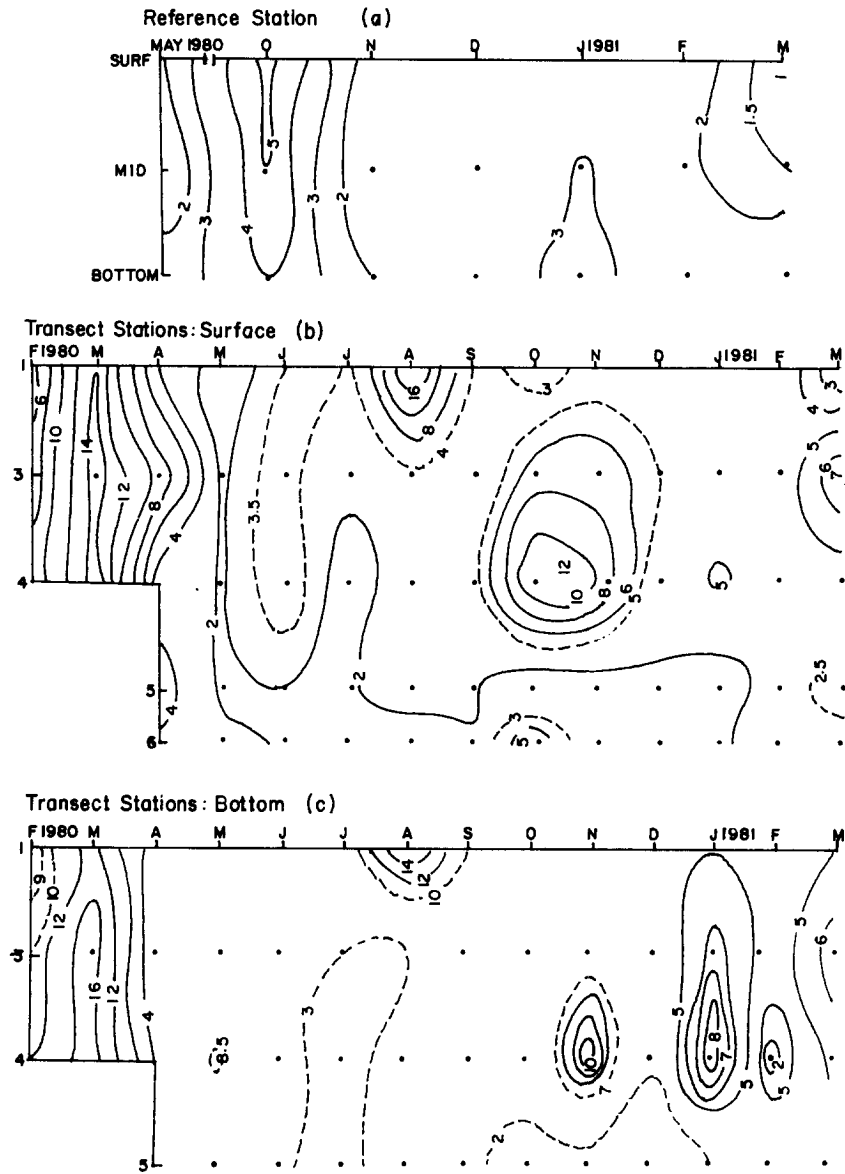


Figure 3. Distribution of particulate phosphorus in $\mu\text{g l}^{-1}$, at (a) the reference station in vertical profile and (b) and (c) at the transect stations in the Mandovi River Estuary, showing all stations by date. In (a), note that there is a break in the horizontal scale between May 1980 and October 1981.

varied from 0.71 to $5.18 \mu\text{g l}^{-1}$ [Figure 3(a)]. These are comparable to the PP values ranging from 0.93 to $4.65 \mu\text{g l}^{-1}$ reported by Rao and Rao (1975) from the coastal waters off Waltair (East coast of India). Like POC the concentration of PP attained a peak in October while low values were encountered during the rest of the period.

The PP in the estuarine transect (stations 1 to 4) showed short peaks at different periods. The annual values in this transect ranged from 0.78 to $20.34 \mu\text{g l}^{-1}$ [Figure 3 (b), (c)]. The maximum concentrations during post and premonsoon periods was 18.89

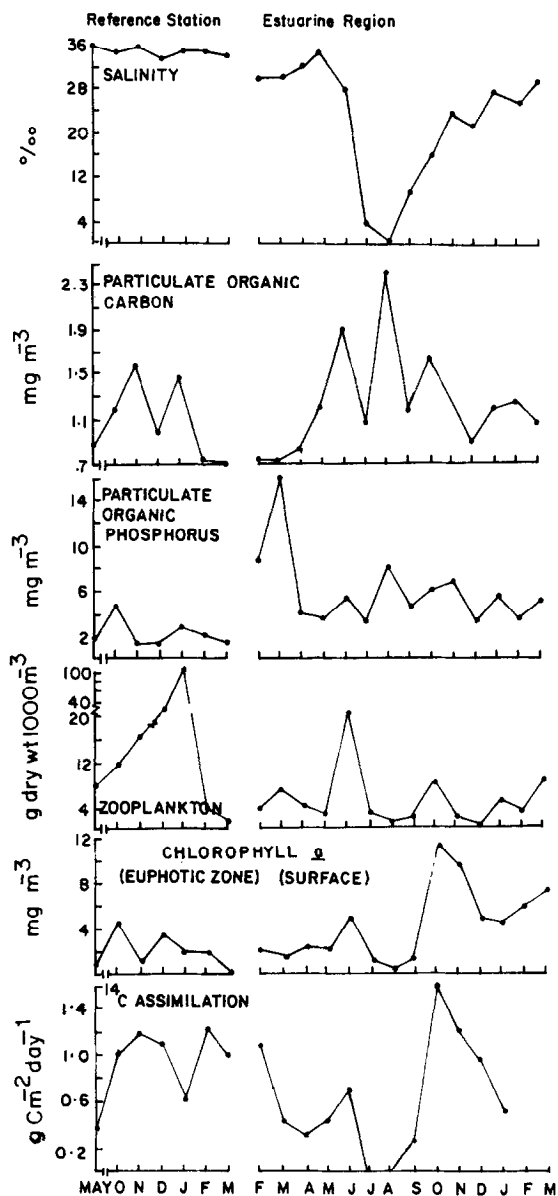


Figure 4. Monthly mean variation of different parameters in the coastal and estuarine (stations 1 to 4) waters.

$\mu\text{g l}^{-1}$ which is quite high, compared to the maximum value of $5.18 \mu\text{g l}^{-1}$ encountered at the reference station. PP values during monsoon increased towards the estuarine mouth. In the upstream portion of the estuary, stations 5 and 6, the values remain much lower than the downstream stations. The vertical distribution suggests that the surface concentrations usually remain lower than the depths below.

The variation of chlorophyll, primary productivity and some related parameters in the estuarine and coastal waters is shown in Figure 4. The mean values of chlorophyll and primary productivity in the euphotic zone during post and premonsoon periods at the reference station were 1.94 mg m^{-3} and $938.1 \text{ mg C m}^{-2} \text{ day}^{-1}$, respectively. The

Table 1. POC/chl ratio obtained from mean values of euphotic column at reference station and surface concentrations at the estuarine region

	Reference station	Estuarine region
Feb	—	338.8
Mar	—	425.1
Apr	—	366.8
May	791.2	520.9
Jun	—	386.0
Jul	—	842.2
Aug	—	4470.3
Sep	—	805.4
Oct	199.8	146.3
Nov	931.5	137.3
Dec	260.4	185.1
Jan	713.1	257.0
Feb	333.6	212.6
Mar	2863.0	147.8

annual mean of surface chlorophyll and the primary productivity of the euphotic column in the estuarine region were 4.3 mg m^{-3} and $636.5 \text{ mg C m}^{-2} \text{ day}^{-1}$ respectively. The increase in the chlorophyll and primary productivity values in October followed the POC maximum in November at the reference station. In the estuarine region also, the rise in the chlorophyll, a measure of phytoplankton concentration and primary productivity in June and October coincided with the peak in POC and PP content. Also POC/chl ratios (Table 1), decreased in June and October. These results suggest that the phytoplankton was sharply growing and contributed to the POC and PP content. Qasim *et al.*, (1969) after observing the relation between the seston and chlorophyll came to the conclusion that phytoplankton formed a considerable portion of particulate matter in Cochin Backwaters.

Two short peaks of PP were observed in March 1980 and January 1981, when both chlorophyll and phytoplankton production remained moderately low and unlike monsoon, the estuarine conditions during this period were quite stable. However, these periods were found to coincide with the zooplankton maxima, which seems to be the possible source for the rise in PP content (Ketchum, 1962). On the other hand the POC and PP attained high value in August when chlorophyll, primary production and zooplankton biomass remained low in the estuary. POC/chl ratio during this period remained high but decreased during postmonsoon when the production cycle was restored. This probably suggests that besides the living plankton, the concentrations of POC and PP can be affected by a sizeable portion of non living detritus in these waters.

To estimate each of the living and non-living fractions in total POC, the regression analysis was attempted, in which the slope and the intercept of the regression line could give the POC/chl ratio and the POC associated with detritus, respectively. A linear relationship was observed when surface values of POC and chlorophyll at three estuarine stations (1, 3 and 4) were treated, collectively irrespective of the seasons. From Table 2, it can be seen that the mean ratio of POC/chl (w/w) for combined values was 47.2. This value agrees well with the C:chl ratio of 35:1 reported by Menzel (unpublished, as cited by Ryther & Menzel 1965) for healthy growing phytoplankton cultures and that of 50:1 obtained by Menzel and Ryther (1964) from the regression of chlorophyll on POC in the Western North Atlantic. The present observations when split on the seasonal basis gave

Table 2. Regression analysis of particulate matter *vs* chlorophyll, units used are $\mu\text{g l}^{-1}$

Period	Regression equation	<i>r</i>	<i>N</i>	Confidence limit	% detritus
<i>POC vs chl</i>					
Ref. station					
Pre- and Post Monsoon	POC = 744.8 + (68.5) chl	0.43	7		86.39
Transect station 1, 3 and 4					
Annual values	POC = 705.0 + (47.2) chl	0.43	41	99%	77.37
Premonsoon	POC = 623.7 + (59.4) chl	0.44	17	90%	76
Monsoon	POC = 720.7 + (107.9) chl	0.47	11		75.89
Postmonsoon	POC = 479.9 + (74.2) chl	0.65	12	98%	46
<i>PP vs chl</i>					
Transect Stations 1, 3 and 4					
Postmonsoon	POP = 1.1 + (0.6) chl	0.64	12	98%	
Monsoon	POP = 2.5 + (0.3) chl	0.55	11	90%	

the POC:chl ratio varying from 59.4 to 107.9 (Table 2). Steele and Baird (1962) reported that the POC/chl ratio varied from 23 to 250 in the North Sea, the increase in ratio being attributed to the lack of nutrients limiting the phytoplankton growth. However, in the present analysis the rise in POC/chl ratio during the monsoon seems to be related to turbidity rather than nutrients, whereby subsurface illumination is reduced substantially resulting in the inactivation of chlorophyll to phaeophytin (Qasim *et al*, 1969).

The percentage of detritus in the POC, as observed from the intercept value was found to be 77.3% for annual values in the estuarine region. This is fairly high as may be expected for the estuarine environment. The detrital values obtained for three different periods varied from 40% to 76%, the lower value pertaining to postmonsoon when phytoplankton production was maximum. Because of less number of values at the reference station, statistically valid correlation could not be obtained. However, from the distribution profiles of chlorophyll *a*, POC and POC/chl ratio, it appears that the percentage of detritus is much more in coastal waters compared to estuarine region. This suggests that coastal waters act as a sink for a continuous detrital load from the estuarine region. Nevertheless, the results obtained in the regression analysis in the present study are comparable to those in the coastal waters of Bering Sea and northern coast of Taiwan, reported by Tanoue and Handa (1979) and Tsu Chang *et al*, (1981). These authors have pointed out that the POC/chl ratio in those regions varied from 17 to 250 and the average concentration of detritus from 24 to 98% depending upon the season and the location of study area; the high values being associated with the areas subjected to land drainage.

In another attempt to estimate the ratio of the living carbon in total POC, Holm Hansen (1969), reported the values varying from 67% to 73% and 55% to 73%, pertaining to living matter on the basis of biomass measured by ATP and chlorophyll *a*, respectively. In the present analysis, the POC associated with phytoplankton was found to vary from 24% to 54% depending upon the environmental conditions in these waters. Thus it can be inferred that the major portion of POC during the productive period of postmonsoon is derived from phytoplankton, while in monsoon allochthonous materials originating from surface runoff, predominate.

The correlation coefficient for the annual surface PP and chlorophyll was low. However, monsoon and postmonsoon values when treated separately gave statistically valid

correlation. The mean PP/chl ratio was found to be 0.27 and 0.57, with a PP intercept of 2.52 and 1.12 for monsoon and postmonsoon periods, respectively (Table 2) Menzel and Ryther (1964) observed that the regression line of PP on chlorophyll *a*, passed through origin, although seasonal changes in slope were noticed. Based on these observations and the evidences from the culture experiments they concluded that the chlorophyll and the organic phosphorus compounds are quickly decomposed, mineralised and denatured following the death of phytoplankton leaving a detrital residue containing mainly carbon and nitrogen. Their studies were mainly in the open ocean where water mass is almost stable and detritus primarily included the dead materials of plants and more particularly of animal origin (Parsons & Strickland 1960). In environments like estuaries, where the water mass is constantly renewed, the formation and decomposition of phytoplankton is relatively rapid leading to the accumulation of detritus. Besides due to the tidal movements the suspended sediments also remain high. Thus the PP intercept observed in the present analysis obviously represents the organic phosphorus associated with the suspended sediments and/or detritus (Holm-Hansen *et al.*, 1969). The increase in the intercept value in monsoon is probably due to the increased amount of suspended load during that period.

POC and PP values when subjected to regression analysis showed wide scatter without any relation between the two components. Ryther and Menzel (1964) also observed large scatter in their results of regression analysis of carbon and phosphorus, which was attributed to the detrital component, in which phosphorus was supposed to have mineralised more rapidly than carbon. The present analysis similarly supports the contention that the detrital component largely exceeds the living fraction in the estuarine and coastal waters of Goa.

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