

## Seasonal Distribution of Phytoplankton Pigments in the Estuarine System of Goa

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Seasonal changes in the concentrations of chlorophylls and carotenoid were studied in the estuarine complex of Goa at 14 stations. Annual mean concentration of chl. *a* was 3.05, 4.42 and 4.12  $\text{mg/m}^3$  in Mandovi estuary, Cumbarjua canal and Zuari estuary respectively with a peak in May. Chl. *a* increased towards the mid reaches of Mandovi estuary. Chl. *b* ranged between 0 and 5.48  $\text{mg/m}^3$  while chl. *c* varied between 0 and 10  $\text{mg/m}^3$ . Annual mean of chl. *c* was 2.28, 2.69 and 3.03  $\text{mg/m}^3$  in Mandovi estuary, Cumbarjua Canal and Zuari estuary respectively. Carotenoid values were low and ranged between 0 and 3.6  $\text{m-SPU/m}^3$  with the peak in May in close relation to chl. *a*. Annual mean for Mandovi estuary, Cumbarjua canal and Zuari estuary was 1.10, 1.28 and 1.45  $\text{m-SPU/m}^3$  respectively. Ratios of chl. *c* to *a* and carotenoid to chl. *a* were mostly less than unity except on few occasions. It was noticed that Mandovi waters are significantly different from those of Cumbarjua canal and Zuari estuary while no such difference was noticed between that of Cumbarjua canal and Zuari estuary indicating that the latter influences the chlorophyll concentration in the canal.

MONG the estuaries in India, Cochin back-water on the west coast and Vellar estuary on the east coast have been studied fairly extensively. However, very little work has been done on other estuaries of India including the estuaries of Goa. The earlier work<sup>1-4</sup> includes chlorophyll distribution at one station each in Mandovi and Zuari estuaries and its diurnal variations. In the present communication, seasonal changes in surface phytoplankton pigments of the estuarine complex of Goa are presented in view of their importance in photosynthesis.

**Description of area** — Fig. 1 shows the location of the 2 estuaries and the connecting Cumbarjua canal in Goa. The mouths of the 2 estuaries are funnel-shaped and separated by a small 'Cabo' ridge. A fairly good account of the description is given by Parulekar and Dwivedi<sup>5</sup>.

Goa receives 80% of its annual rainfall (3000 mm) from June to August. But Mandovi gets fresh water throughout the year through its tributaries while Zuari receives most of its freshwater during the monsoon. In Cumbarjua canal, water enters through Zuari during the high tide and reaches as far as its mouth in Mandovi and at the low tide the flow is almost reversed<sup>6</sup>. The estuarine system receives domestic sewage and also wastes from the boat yards, etc. at different places. The depth in the complex ranges from 2.5 to 12 m.

### Materials and Methods

In this estuarine system 12 stations, almost equidistant from each other, were fixed within a distance of approximately 50 km (Fig. 1). There were 5 stations in Mandovi, 4 in Zuari and 3

in Cumbarjua canal. Stations 1 and 2 were operated along both the banks and hence were numbered A and B. Stations 5 and 9 were located in the mixed zone, i.e. at the openings of the canal on either side.

Samples were collected once in a fortnight for recording surface temperature, dissolved oxygen, salinity and pigments from June 1971 to May 1972. Salinity, oxygen and chlorophyll (chl.) were estimated by the usual methods as described by Strickland and Parsons'. Carotenoids were calculated from the formula given by Parsons and Strickland<sup>8</sup> wherein the optical density at 510 nm was omitted. The fortnightly values of chlorophyll and carotenoids were pooled for calculating the monthly mean values. No observations could be made during March.

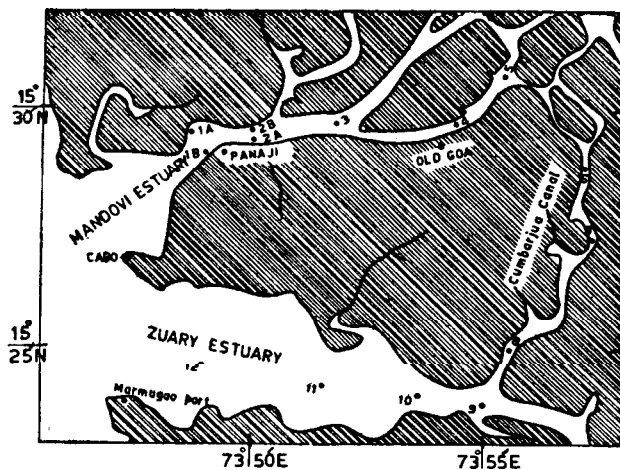


Fig. 1 — Estuarine system of Goa showing the location of 14 sampling stations

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Attenuation coefficient ( $k$ ) was calculated by the formula  $k = 1.5/D$  as given by Qasim *et al.*<sup>9</sup> where  $D$  is the Secchi disc reading in m. The whole year was divided into 3 seasons — monsoon (June to September), postmonsoon (October to January) and premonsoon (February to May).

**Results and Discussion**

**Chlorophyll a** — Monthly and stationwise variations of this pigment are shown in Figs. 2 and 3. A clear seasonal cycle was noticed with maximum chl. *a* concentration in the premonsoon followed by monsoon and postmonsoon. The peak was seen in May just before the monsoon. Earlier, maximum chl. *a* was reported<sup>2</sup> in May in both the estuaries.

Cumbarjua canal had the maximum concentration (11.86 mg/m<sup>3</sup>) of chl. *a* followed by Zuari and Mandovi estuaries. In Mandovi, chl. *a* increased towards the upper reaches. Between stations 1A, 1B and 2A and 2B, no significant difference in chl. *a* concentration was noticed except in September when at station 1A, it was low (0.56 mg/m<sup>3</sup>) while at station 1B it was relatively high (6.05 mg/m<sup>3</sup>). Similarly, in January chl. *a* was high at station 2A than at 2B. In Zuari estuary, chl. *a* was high at station 9, particularly during the monsoon.

Annual mean concentration of chl. *a* was 3.05 (±2.1), 4.42 (±3.23) and 4.12 (±2.65) mg/m<sup>3</sup> in Mandovi, Cumbarjua canal and Zuari respectively. Wide variations (10-12 times) were seen in Zuari during monsoon and postmonsoon. In Mandovi during premonsoon and in Cumbarjua during the monsoon, the fluctuations were of the order of 10 times. During the rest of the period fluctuations of the order of 3-6 times for the entire area were observed. A t-test between the mean chl. *a* values in different sections indicated that the variations were significant at a probability level of 0.05. Chl. *a* values were significantly different between Mandovi and Zuari and Mandovi and Cumbarjua canal which might be the result of different phytoplankton populations or perhaps due to the differences in the environmental conditions of the 2 estuaries. Differences between Zuari and Cumbarjua canal, on the other hand, were not significant. This indicated that Zuari influenced the Cumbarjua canal in chlorophyll distribution, probably because water flows into the canal from Zuari<sup>6</sup>.

Concentration of chl. *a* in this system compared well with those of Kille backwaters of Porto Novo where a maximum of 12.7 mg/m<sup>3</sup> was recorded by Bhatnagar<sup>10</sup>. Krishnamurthy<sup>11</sup> recorded chl. *a* concentration to be 21.5 mg/m<sup>3</sup> in Porto Novo waters, and recently as high as 39.8 mg/m<sup>3</sup> of chl. *a* was recorded<sup>12</sup> in Vellar estuary. In Cochin backwaters the concentration was found to be 5.7 mg/m<sup>3</sup> in November and 7.34 mg/m<sup>3</sup> in July.

**Chlorophyll b** — Chl. *b* concentration was low (<1 mg/m<sup>3</sup>; Table 1) and varied widely. In Mandovi, its concentration increased towards the mid-reaches except at station 1B where on one occasion it was unusually high (5.49 mg/m<sup>3</sup>).

In Cumbarjua canal the maximum was noticed in December and minimum in July and April, and the chl. *b* concentration was generally higher than in Mandovi estuary.

In Zuari, chl. *b* maximum was noticed in May. From July to November, the concentration was low (Table 1). Unlike in Mandovi chl. *b* concentration in Zuari increased towards the mouth region. In general, higher values of chl. *b* were observed in Zuari than in Mandovi and Cumbarjua canal.

When compared with chl. *a*, chl. *b* concentration was always very low except on some occasions when it reached a concentration of 5.49 mg/m<sup>3</sup>. Chl. *b* concentration was maximum in postmonsoon and minimum in monsoon. In Cochin backwater it ranged between 0 and 2.74 mg/m<sup>3</sup> during monsoon<sup>14</sup> while in Vellar estuary a concentration of 13.4 µg/litre was recorded in July by Krishnamurthy and Sundararaj<sup>12</sup>.

**Chlorophyll c** — Monthly mean values of chl. *c* are given in Table 1. Chl. *c* distribution was irregular with annual mean values of 2.28 mg/m<sup>3</sup> in Mandovi, 2.69 mg/m<sup>3</sup> in Cumbarjua canal and 3.03 mg/m<sup>3</sup> in Zuari. In Mandovi, the peak was noticed in January at most of the stations while in Cumbarjua canal and Zuari, the maximum concentration was obtained in February. Like chl. *a*, chl. *c* concentration also increased towards the upper reaches in Mandovi. In Cumbarjua canal, stations

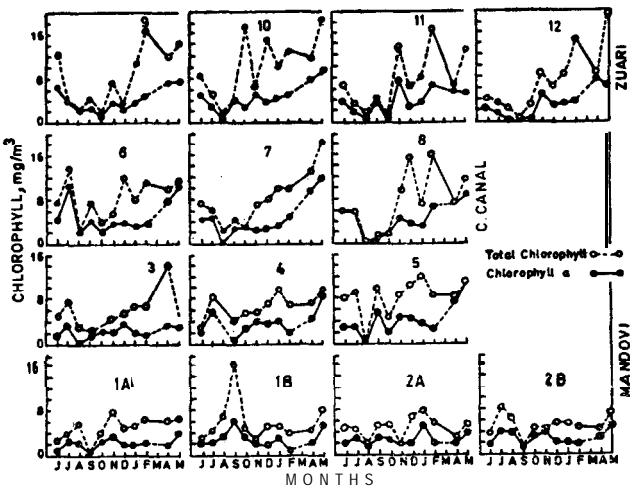


Fig. 2 — Monthly variations of chl. *a* and total chlorophyll at all the stations

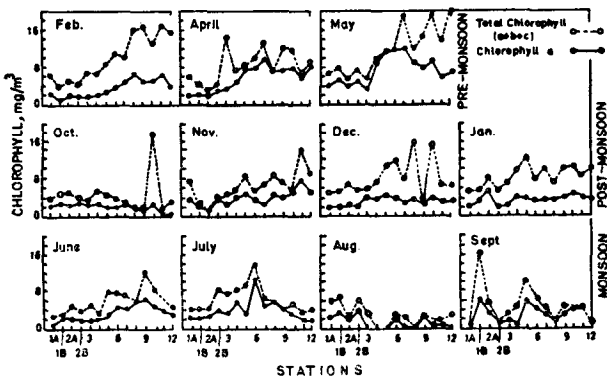


Fig. 3 — Stationwise variations of chl. *a* and total chlorophyll during different seasons

TABLE 1 — DISTRIBUTION OF CHL. *b*, CHL. *c* AND CAROTENOIDS

Month*	Stations													
	1A	1B	2A	2B	3	4	5	6	7	8	9	10	11	12
	CHL. <i>b</i> (mg/m <sup>3</sup> )													
1971		0.03	0.00											
June	0.35		0.05	0.12	0.47	0.13	0.21	0.71	0.75	0.01	2.28	0.27	0.25	1.66
July	0.00												0.25	0.13
Aug.	0.43	0.03	0.01	0.09	0.02 0.02	0.10	0.00	0.11	0.45	0.00	0.01	0.04	0.11	0.74
Sept.	0.04	5.49	1.1	0.24	1.14	0.61	2.35	0.85	1.18	0.00	0.7	0.29	0.46	0.52
Oct.	0.64	0.6	0.06	0.89	0.61	1.13	0.88	0.74	0.29	0.41	0.78	3.65	0.75	0.46
Nov.	0.57	0.47		0.2	0.45	0.89	1.41	0.65	0.59	0.81	0.56	0.58	0.00	0.00
Dec.	0.69	0.92	0.77	0.93	0.87	0.62	0.15	2.05	0.54	2.05	0.22	1.5	0.41	1.56
1972														
Jan.	0.39	0.07	0.00	0.47	0.53	0.47	1.38	0.56	1.4	0.02	1.41	0.58	0.42	1.03
Feb.	0.64	0.43	0.72	0.09	1.01	0.73	1.15	1.28	0.16	1.13	0.89	0.67	0.00	1.5
April	0.73	0.00	0.4	0.00	1.21	0.00	0.51	0.05	0.00	0.29	0.01	0.37	0.00	0.00
May	0.88	0.12	0.00	0.82	0.14	0.00	0.34	0.42	1.19	1.64	2.07	2.55	1.63	1.83
	CHL. <i>c</i> (mg/m <sup>3</sup> )													
1971														
June	1.31	0.74	2.8	1.81	2.84	0.7	3.77	2.2	1.96	0.00	3.53	3.18	2.8	0.00
July	2.7	1.73	1.38	3.77	3.84	2.2	5.03	2.86	1.43	0.1	0.00	1.6	1.05	1.91
Aug.	0.00	4.88	1.14	0.23	0.00	0.25	0.00	2.2	1.07	0.06	1.11	0.22 1.12	0.9	1.56
Sept.													0.00	0.00
Oct.	0.93	1.17	1.49	0.27	0.51	1.68	1.85	0.86	0.06	0.00	0.08	5.55	0.14	1.08
Nov.	3.52	0.22	0.00	0.27	1.82	0.74	2.29	1.02	3.76	3.36	2.86	0.78	6.27	3.85
Dec.	2.79	2.2	3.75	2.49	1.29	2.85	5.79	5.84	4.56	9.98	0.79	9.82	1.62	1.94
1972														
Jan.	2.92	2.51	2.64	3.02	4.00	5.4	7.29	3.91	5.40	3.95	5.45	5.17	4.14	2.65
Feb.	3.21	2.61	2.76	2.72	4.06	4.06	4.81	6.23	5.13	8.23	5.72	7.13	5.3	4.95
April	3.3	1.2	0.68	1.41	9.66	2.61	0.18	1.95	3.4	9.00	4.56	3.55	0.95	1.09
May	1.44	2.52	1.54	1.69	2.13	2.02	0.00	0.01	5.32	1.87	5.33	7.33	5.4	10.6
	CAROTENOID (m-SPU/m <sup>3</sup> )													
1971														
June	0.72	1.46	1.5	1.28	1.14	0.7	1.17	1.82	1.89	1.2	2.5	1.87	1.38	0.64
July	1.25	0.93	1.38	2.23	1.6	0.00	1.64	1.11	0.00	0.00	0.00	1.87	0.62	0.54
Aug.	1.92	1.52	0.77		2.27	0.77	1.69	3.48	0.00	1.53	3.58	2.3	2.89	0.37
Sept.	1.3												0.45	0.37
Oct.	0.31	21 047	0.33 1.75	0.36	3.04	1.08	1.18	0.44	0.88	0.41	0.48	0.24 1.06	0.61	0.48
Nov.	0.4	0.29	0.46	1.06	0.89	1.69	0.34	0.18	0.79	0.55	0.24	144	146	0.88
Dec.	0.45	0.58	0.55	0.41	1.03	0.75	1.03	1.93	0.39	0.31	1.26	0.57	1.14	0.84
1972														
Jan.	0.4	1.1	1.05	0.78	0.62	0.83	0.62	0.8	1.39	0.44	0.68	1.91	2.56	0.83
Feb.	1.08	0.26	0.98	0.68	0.74	0.64	0.46	0.22	1.86	2.72	2.45	2.83	2.92	2.21
April	1.18	0.96	0.77	0.96	1.7	1.5	1.81	1.79	2.48	1.87	2.64	2.51	2.1	2.32
May	1.53	1.96	1.53	0.81	1.68	2.68	3.55	3.41	2.48	2.28	1.30	1.96	1.23	0.87

\*No data for March 1972.

6 and 7 showed high values throughout the year but at station 8 high values were seen from November to February and also in May. During the other months it was almost negligible. In Zuari, low concentration was observed in the monsoon while in post and premonsoon periods, the water was rich in chl. *c*. High values of chl. *c* in Zuari and Cumbarjua canal may be due to high suspended sediments including dead chlorophyll and degraded products having more chl. *c* than chl. *a* as pointed out by Humphrey<sup>15</sup>. High values of chl. *c* (18.66 mg/m<sup>3</sup>) were noticed<sup>14</sup> in Cochin backwaters during monsoon. Krishnamurthy<sup>11</sup> reported chl. *c* values ranging between 2.70 and 26.5 µg/litre in Vellar estuary.

Ratios of chl. *c* to chl. *a* were fluctuating as also noted by Qasim and Reddy<sup>14</sup> in Cochin backwaters and Yentsch and Scagel<sup>16</sup> in waters of East Sound, Washington. This ratio indicates the physiological state of phytoplankton population and for a healthy

crop it is less than unity. In this estuarine system this ratio was generally less than one except during the postmonsoon months.

Distribution of total chlorophyll ( $a+b+c$ ) was similar to chl. *a*, being maximum in May and minimum in August at most of the stations (Figs. 2 and 3). Variation in the estuarine system as a whole was large (0-20 mg/m<sup>3</sup>). Annual mean values for Mandovi, Cumbarjua canal and Zuari sector were 6.01 (± 4.02); 7.86 (± 5.08) and 8.12 (± 5.54) mg/m<sup>3</sup> respectively showing that Zuari had more chlorophyll concentration while Mandovi the least. The t-test at 0.05 *P* level on the data of total chlorophyll has again confirmed the significant variations between Mandovi and Cumbarjua canal and Mandovi and Zuari estuaries. No significant variations were noticed between the Canal and Zuari chlorophyll concentration. This, therefore, also indicated the different ecological conditions in this estuarine system.

**Plant carotenoids** - Monthly variations of carotenoid (0.3-6 m-SPU/m<sup>3</sup>) are given in Table 1. Peak concentration was noticed in May when there were maximum chl. a and c in the water. In August and September too, the values were high. Minimum values were noticed in postmonsoon months. Annual mean values for Mandovi, Cumbarjua canal and Zuari was found to be 1.1, 1.28 and 1.45 m-SPU/m<sup>3</sup> respectively. This showed the highest concentration in Zuari and lowest in Mandovi as in the case of total chlorophyll. Further, stations 3 and 4 in Mandovi, station 7 in Cumbarjua canal and station 12 in Zuari, showed maximum annual mean. The carotenoid values in this estuarine system was relatively less when compared to other Indian waters. It ranged between 5 and 8 m-SPU/m<sup>3</sup> in Cochin backwaters<sup>14</sup> and 0 to 5.25 m-SPU/m<sup>3</sup> in Porto Novo waters<sup>11</sup>.

Ratio of carotenoid to chl. a was mostly less than 1 except in August and September when it was high (3 to 10.54) at certain stations. This high ratio may be due to the stirred up sediments and degradation product of chl. a which increases the carotenoid value as suggested by Qasim and Reddy<sup>14</sup> who also reported high ratio between 1.98 and 3.05 in Cochin backwaters during monsoon months. Krishnamurthy and Sundararaj<sup>12</sup> found this ratio to be less than 1 in Porto Novo backwaters.. In the Goa waters, this ratio remained less than 1 for the most part of the year indicating active physiological state of phytoplankton.

**Chlorophyll and environment** — The water temperature ranged between 24.0° and 31.8°C and dissolved oxygen content varied between 1.93 and 7.3 ml/litre. Temperature is known to affect only indirectly through metabolism while oxygen is the direct result of photosynthesis. But no correlation with chlorophyll was noticed in this case.

Salinity, however, is an important parameter in an estuarine environment. Its variations were large depending on the season, being highest (36.77‰) in premonsoon and lowest (0.12‰) in monsoon. Salinity was always higher in Zuari and least in Cumbarjua canal. In Cumbarjua canal where salinity was low, the chlorophyll concentration was more but when chl. a was plotted against salinity no correlation was seen for the entire estuarine system.

Other important factors are light penetration and turbidity. As calculated by Secchi disc readings the attenuation coefficient (*k*) was high throughout the year as shown below :

Season	<i>k</i> (range)		
	Mandovi	Zuari	Cumbarjua canal
Premonsoon	5.55-0.49	7.50-0.74	4.17-0.67
Monsoon	4.69-1.43	8.82-1.12	5.17-1.94
Postmonsoon	3.75-0.48	3.75-0.65	4.69-0.81

High turbidity in this system is caused by suspended material and affected the chlorophyll estimations. Since the dead chlorophyll and its degraded products present in suspended matter are simultaneously estimated, increased chlorophyll concentrations were estimated. This might be one of the reasons for higher values of chlorophyll in Cumbarjua canal and Zuari estuary.

Chlorophyll distribution showed differences in space and time in the estuarine complex of Goa. The distribution was irregular with fluctuating pigment ratios but the values were comparable with those of other estuaries and backwaters of India. The difference in chlorophyll concentration from one part of the estuarine complex to the other makes it an interesting study. Since this study was confined to surface waters only, a detailed investigation of plant pigment from the entire water column is warranted.

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