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# Primary productivity in Mandovi-Zuari estuaries in Goa

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**Abstract**

Measurement on primary production, phytoplankton biomass, POC and PON were made for a period of ten months at a coastal station and for fourteen months at two estuarine stations in Goa (west coast of India). Irrespective of surface and bottom, chlorophyll *a* ranged from 0.07-2.68 mg/m$^3$ at the coastal station at off Cabo (Stn 1); 0.01-4.33 mg/m$^3$ at Mandovi (Stn 2) and 0.16 to 3.95 mg/m$^3$ at Zuari (Stn 3). PP varied from 0.5 - 54.69 mgC/m$^3$/hr at Stn 1, 0.19-67.69 mgC/m$^3$/hr at Stn 2 and 0.17-63.24 mgC/m$^3$/hr at Stn 3. Column productivity ranged from 18.98 to 795.52 mgC/m$^2$/hr (av: 206.21 mgC/m$^2$/hr) at Stn 1, 1.46 to145.98 mgC/m$^2$/hr (52.78) at Stn 2 and 6.71 to135.34 mgC/m$^2$/hr (av: 69.98) at Stn. 3.Column chlorophyll ranged from 4.35 to 36.23 mg/m$^2$ (av: 6.19 mg/m$^2$) at Stn 3. Phytoplankton biomass in terms of cell density was high in surface waters at Stn 1 and in bottom waters at Stn 2 and 3. Seasonwise surface PP was high during premonsoon at Stn 2 (av: 50.61 mgC/m$^3$/hr) and at Stn 3 (av: 46.72 mgC/m$^3$/hr) and post monsoon at Stn 1 (av : 18.68 mgC/m$^3$/hr). Estimated division rate of phytoplankton ranged from 0.12 to 10 (av: 1.8), 0.11 to 5.9 (av:0.9) and 0.15 to 0.63 (av:0.32) per day respectively for Stn 1, 2 and 3. Spatial and temporal difference in surface Chl *a* and PP between the three stations was found to be significant (P-0.01).

## Introduction

Estuaries are complex ecosystems and their constantly changing environment has proved to be an important area of study. The Mandovi-Zuari estuarine complex situated at lat. 15°25' - 15°30'N and long. 73°45' - 73°59'E is one of the unique tropical estuarine systems along the west coast of India. The influence of southwest monsoon results in dramatic changes in the overall function of these estuarine ecosystems. The primary producers (phytoplankton) are capable of taking up dissolved organic carbon and incorporating into particulate organic carbon that forms the energy source for organisms at higher trophic levels. Information on primary productivity and community structure of phytoplankton from these estuaries is limited (Bhattathiri *et al.*, 1976; Devassy 1983; Devassy and Goes, 1988, 1989). Qasim and Sen Gupta (1981) have studied some environmental characteristics of this ecosystem. The aim of the present investigation was to supplement information on primary productivity, chlorophyll *a* and related aspects in relation to other environmental parameters within this estuarine complex. An attempt has also been made to compare the observations with a coastal station along Goa coast.

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## Material and methods

Investigations were carried out for a period of ten months from St 1 (off Cabo) and fourteen months from St 2 (Mandovi) and St 3 (Zuari) during 1997-98 (Fig. 1). Water samples were collected from surface and bottom using 5 1 Niskin (PVC) sampler. Immediately after collection a known volume of water was fixed with Lugol's solution and preserved in neutralised formalin for enumeration of cell density and identification of major groups/species. For Chl *a*, known volume of water sample was filtered through a Whatman GF/F filterpaper (47 mm diam. 0.7 µm pore size) and pigments were extracted in 90% acetone. Fluorosence was measured on a Turner Fluorometer which was calibrated by chlrophyll *a* standards (Sigma). The values were expressed as mg $m^{-3}$. Primary productivity (PP) measurements were

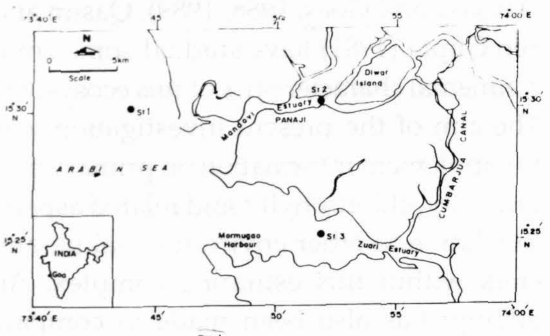


Fig.1 - *Map showing station locations*

made using the $^{14}C$ technique introduced by Steemann Nielson (1952). Immediately after collection the samples were passed through 200 µm nylon bolt net to minimise the possibility of grazing by zooplankton during incubation. The radioactive carbon in the form of sodium bicarbonate (5 µCu/ml) was added to duplicate samples in light and dark bottles. Appropriate neutral density filters were used for bottom samples. The bottles were incubated under natural light condition for 4-6 hrs duration on deck. Water in the incubation chamber was changed at frequent intervals to maintain the temperature. After incubation the contents were filtered onto a membrane filter (0.45µm) and subjected to acid fuming. The filters were analysed for $^{14}C$ uptake rate using liquid scintillation counter (Tri - CARB 2500 T R Packard). The values were expressed as mgC/$m^{-3}$/$hr^{-1}$. Particulate organic carbon (POC) and nitrogen (PON) content was determined by filtering known volume of water through a previously combusted GF/F filters (47mm diam.) and analysed on Perkin Elmer CHN analyser.

## Results

Monthly variations in Chl *a*, PP and cell density in surface and bottom waters at different stations are given in Fig. 2 and 3.

### *Chlorophyll a*

Surface chlorophyll values were high during post monsoon at all the three stations. Mean for the entire period of study is given in Table 1. Greater fluctuations in chlorophyll content were recorded in bottom waters at all the three stations. At both surface and bottom on an average low

**Table 1** - *Mean value of various parameters at Sts 1,2, and 3 (Depth range from 14 - 18 at St 1,2-4.5 m at St 2 and 2.5 to 4.5 m at St3)*

| Parameters | Depth | St.1 | St.2 | St.3 |
|---|---|---|---|---|
| Chl *a* (mg/$m^{-3}$) | S | 1.32 | 1.63 | 1.81 |
| | B | 1.08 | 1.09 | 1.12 |
| PP (mgC $m^{-3}$ $hr^{-1}$) | S | 14.21 | 28.24 | 32.33 |
| | B | 13.12 | 5.45 | 5.73 |
| Cell density(nos X$10^4$/1) | S | 0.84 | 0.63 | 0.68 |
| | B | 0.61 | 0.91 | 0.80 |
| C : Chl *a* ratio (mgC $hr^{-1}$/mg Chl | S | 16.19 | 25.64 | 24.93 |
| | B | 8.86 | 5.33 | 3.37 |
| Phaeopigments (mg $m^{-3}$) | S | 0.27 | 0.29 | 0.11 |
| | B | 0.09 | 0.14 | 0.32 |
| TSM (mg/l) | S | 51.14 | 40.39 | 48.55 |
| | B | 54.22 | 54.27 | 77.1 |
| POC (mg $m^{-3}$) | S | 734.9 | 1143.49 | 1235.2 |
| | B | 1095 | 1494.87 | 1920.52 |
| PON (mg $m^{-3}$) | S | 211.9 | 188.3 | 274.5 |
| | B | 159.9 | 287.43 | 311.68 |
| C : N ratio | S | 4.84 | 8.06 | 5.85 |
| | B | 6.8 | 6.64 | 5.99 |
| Temp°C | S | 29.78 | 29.24 | 29.29 |
| | B | 29.06 | 29.1 | 28.82 |
| Sal ‰ | S | 32.7 | 20.61 | 25.96 |
| | B | 34.67 | 22.58 | 27.68 |
| $NO_3$-N (μ mol/l) | S | 1.17 | 5.13 | 2.85 |
| | B | 1.8 | 5.64 | 3.54 |
| $NO_2$-N (μ mol/l) | S | 0.30 | 0.55 | 0.36 |
| | B | 0.48 | 0.75 | 1.07 |
| $PO_4$-P (μ mol/l) | S | 0.44 | 8.06 | 0.93 |
| | B | 1.72 | 1.36 | 1.55 |

values were observed during monsoon at St 2 and 3 and premonsoon at St 1. (Table 2). Column chlorophyll *a* ranged from 4.35 to 36.23 (av. 18.02) mg/$m^2$ at St. 1, 0.06-12.62 (av. 4.53) mg/$m^2$ at St 2 and 0.9 to 25.2 (av. 6.2) mg/$m^2$ at St. 3.

### *Phytoplankton cell density*

Difference in cell density was not recorded on an average basis between stations. Highest cell density of 2.19 x 104 and 3 x 104 cells/1 at St 1 was observed for surface and bottom during May 98 and Oct. 97 respectively. At St. 2 surface waters recorded highest cell density (1.98 x 104 cells/l) during April 98 and bottom waters (2.16 x 104 cells/l) during Nov. 97. Corresponding values at St 3 were 2.02 x 104 cells/l and 3.46 x $10^4$ cells/l during May

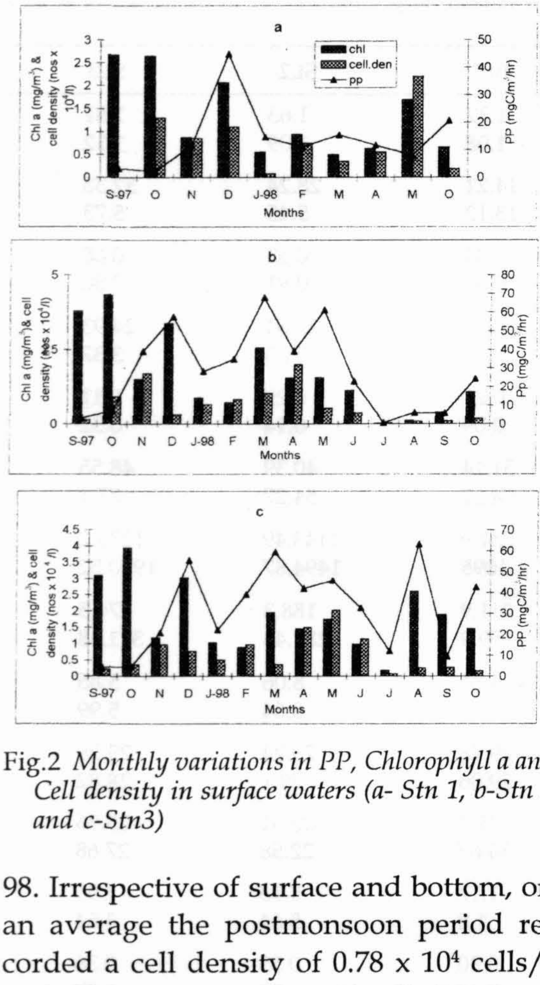


Fig.2 *Monthly variations in PP, Chlorophyll a and Cell density in surface waters (a- Stn 1, b-Stn 2 and c-Stn3)*

98. Irrespective of surface and bottom, on an average the postmonsoon period recorded a cell density of 0.78 x $10^4$ cells/l and premonsoon 0.68 x $10^4$ cells/l at St. 1. At St. 2 and 3 premonsoon period recorded a mean cell density of 1.28 and 1.09 x $10^4$ cells/l respectively. Corresponding cell density at St. 2 and 3 during postmonsoon and monsoon were 0.85 and 0.73 x $10^4$ and 0.28 and 0.37 x $10^4$ cells/l respectively.

***Phytoplankton species composition***

A total of 49 species belonging to different genera were recorded during the period of study. Of these, 36 species belonged to diatoms 7 to dinoflagellates and 6 species represented by silicoflagellotes and blue-green algae. Seasonal contribution (>5%) of dominant groups is given in Table 3. *Chaetoceros* sp. dominated at St 1 (35%) during premonsoon and *Coscinodiscus sp* (49%) during postmonsoon. At St 2, *Coscinodiscus* sp dominated during all the three seasons (Premonsoon - 47%, monsoon - 31% and post monsoon - 25%). *Rhizosolenia* sp, also formed a dominant group during postmonsoon at St.2. At St. 3, *Thalassionema sp.* dominated during premonsoon and monsoon and *Pleurosigma* during postmonsoon.

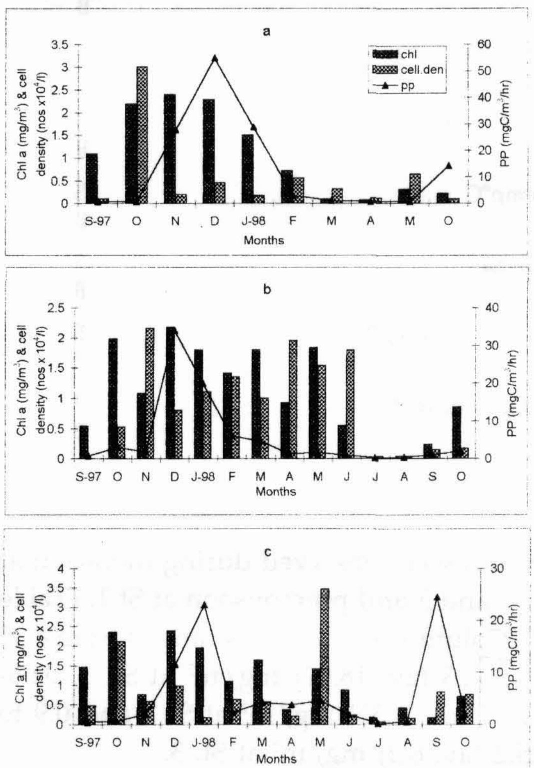


Fig.3 *Monthly variations in PP, Chlorophyll a and cell density in bottom waters (a- Stn 1, b-Stn 2 and c-Stn3)*

**Table 2** *Seasonal variations in PP (mgC/m³/hr), Chl and Phaeopigments (mg/m³) at stations 1,2&3*

| Stations | PP | Chlorophyll | Phaeopigments |
|---|---|---|---|
| | | Premonsoon | |
| IS | 11.41 | 0.93 | 0.01 |
| B | 1.21 | 0.30 | 0.15 |
| 2S | 50.61 | 1.58 | 0.20 |
| B | 3.30 | 1.50 | 0.12 |
| 3S | 46.75 | 1.50 | 0.00 |
| B | 3.62 | 1.12 | 0.24 |
| | | Post Monsoon | |
| 1S | 18.68 | 1.35 | 0.34 |
| B | 25.15 | 1.71 | 0.04 |
| 2S | 31.06 | 2.22 | 0.29 |
| B | 12.04 | 1.58 | 0.12 |
| 3S | 29.03 | 2.13 | 0.22 |
| B | 7.72 | 1.63 | 0.56 |
| | | Monsoon | |
| 2S | 7.52 | 1.08 | 0.37 |
| B | 0.57 | 0.27 | 0.16 |
| 3S | 24.30 | 1.70 | 0.09 |
| B | 5.73 | 0.62 | 0.14 |

## *Primary productivity*

Average PP values for surface and bottom waters at different stations are given in Table 1. A major peak in PP value has been recorded in surface waters at all the three stations during December with corresponding increase in chlorophyll content. At St. 2 surface waters recorded a second peak in March and a third one in May. Similarly at St. 3 second peak was in March and third one in August. PP values were generally high during premonsoon in bottom waters at all the stations. Seasonwise PP was high during postmonsoon at St. 1 and premon-soon at St. 2 and 3 (Table 2). Integrated PP values fluctuated from 0.19 - 7.96 (av. 2.01) gC/m²/day at St. 1, 0.02 to 1.46 (av. 0.53) gC/m²/day at St. 2 and 0.07-1.35 (0.7) gC/m²/day at St. 3. The annual net primary production works out to be 632.9 gC/m² at St. 1, 224.9 g/m² at St. 2, and 299.67 gC/m² at S. 3.

Scatter diagram of chl *a*, phytoplankton cell numbers and primary production versus salinity at different stations are given in Fig 4. It shows that phytoplankton population was high at a salinity range of 26-

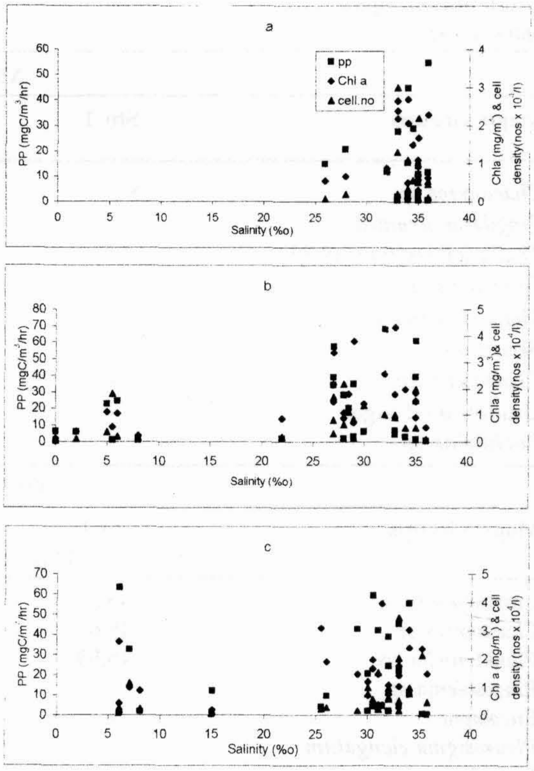


Fig.4 *Correlation of Salinity with PP, Chl a and cell density (a-Stn 1, b-Stn 2 and c-Stn 3)*

36‰ at St. 1 and 3 and 22-36‰ at St. 2.

The turnover time scales of phytoplankton carbon in the study area are derived from the column primary production rate and the standing stock of phytoplankton carbon. Phytoplankton carbon was estimated from Chl *a* using the conversion factor 1 mg chlorophyll = 50 mg carbon (Tranter, 1973). The turnover time scales averaged 3.12 at St.1, 3.29 at St. 2 and 3.31 at St.3. The division rate of phytoplankton

**Table 3** *Seasonal contribution (>5%) of major species. Total number of cells* is given in parenthesis*

| Pre-monsoon | | | |
|---|---|---|---|
| Major Groups | Stn 1 (5.42 x 104/1) | Stn 2 (10.17 x $10^4$/1) | Stn 3 (9.7x$10^4$/1) |
| *Chaetoceros sp* | 35.4 | - | 14.18 |
| *Coscinodiscus sp* | 16.5 | - | 14.84 |
| *Leptocylindrus danicua* | 15.02 | - | - |
| *Pleurosigma elongatum* | 8.3 | 10.34 | - |
| *Nitzschia sp* | 5.0 | 12.23 | 5.9 |
| *Thalassionema sp* | - | 6.29 | 15.5 |
| Unidentified algae | - | - | 9.5 |
| *Navicula sp* | - | - | 6.5 |
| **Monsoon** | | | |
| Major Groups | Stn 1 | Stn 2 (2.56 x $10^4$/l) | Stn 3 (2.98x$10^4$/1) |
| *Chaetoceros sp* | NS | 30.59 | 12.74 |
| *Fragilaria oceanica* | - | 13.1 | - |
| *Thallasiothrix frauenfelifiie* | - | 11.95 | 7.09 |
| *Gyrosigma sp* | - | 9.42 | - |
| *Thalassionerna sp* | - | 7.49 | 20.4 |
| *Skeletonema costatum* | - | 6.88 | 7.54 |
| *Chaetoceros sp* | - | - | 7.43 |
| Unidentified algae | - | - | 6.17 |
| *Biddulphia sp* | - | - | 5.01 |
| **Post-monsoon** | | | |
| Major Groups | Stn 1 (5.42 x 104/1) | Stn 2 (10.17 x $10^4$/1) | Stn 3 (9.7x$10^4$/1) |
| *Coscinodiscus sp* | 49.3 | 25.4 | 12.79 |
| *Chaetoceros sp* | 16.6 | 17.32 | 19.28 |
| *Planktoniella sol* | 15.53 | - | 5.91 |
| *Rhizosolenia sp* | - | 24.96 | 5.78 |
| *Eucampia* | - | 5.15 | - |
| *Pleurosigma elongatum* | - | - | 23.71 |
| *Surirella* | - | - | 5.13 |
| *Nitzschia sp* | - | - | 5.48 |

*Surface & bottom together NS-no sampling during monsoon at stn 1 ranged from 0.12-10 (av. 1.83 div/day) at St. 1; 0.11-5.9 (av: 0. 91/day) at St. 2 and 0.15-0.63 (av : 0.32 div/day) at St. 3.

### *Particulate organic carbon and nitrogen*

Information on particulate organic carbon (POC) is helpful in estimating the biogenic carbon available for the organisms at the higher trophic levels. Average for surface and bottom waters at different stations is given in Table 1. Monthly variations are given in Figs. 5 and 6. Particulate organic carbon and nitrogen content were generally high in bottom waters at all the three stations. In surface waters highest

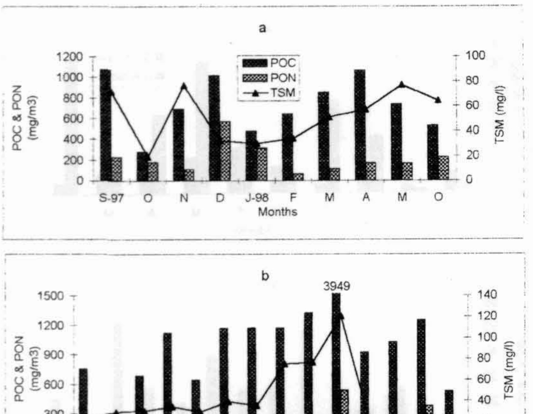


Fig.5 *Monthly variations in POC, PON and TSM in surface waters (a- Stn 1, b-Stn 2 and c-Stn3)*

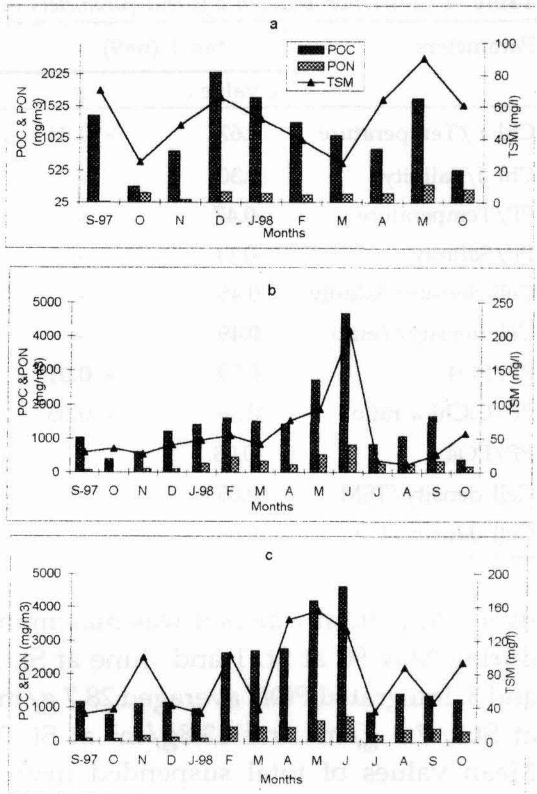


Fig.6 *Monthly variations in POC, PON and TSM in bottom waters (a- Stn 1, b-Stn 2 and c-Stn3)*

value (1071.5 mg/m$^3$) recorded in Sept. at St. 1 and in June (3949 and 2234 mg/m$^3$ ) at St. 2 and 3. Integrated POC was 144 g/m$^2$ at S. 1; 60.73 g/m$^2$ at St. 2 and 84.01 g/m$^2$ at St. 3. Percentage contribution of phytoplankton carbon to POC amounted to 6.3 at St. 1, 5.2 at St. 2 and 3. Bacterial carbon contributed 3.1% at St.1, 1.18% at St. 2 and 1.25% at St. 3.

Particulate organic nitrogen (PON) content was maximum in Dec. (569 mg/m$^3$) in surface waters at St. 1 and the corresponding values at St. 2 and 3 were in June (536 mg/m$^3$) and Sept. (944.6/mg/m$^3$) respec-

**Table -4** *Correlation between different parameters in surface waters at the three stations*

| Parameters | Stn 1 (n=9) | | Stn 2 (n=13) | | Stn 3 (n=13) | |
|---|---|---|---|---|---|---|
| | r value | *p* | r value | *p* | r value | p |
| Chl *a* /Temperature | 0.67 | - 0.01 | 0.55 | - 0.05 | 0.26 | - |
| Chl *a*/Salinity | 0.30 | - | 0.64 | - 0.01 | 0.17 | - |
| PP/Temperature | -0.47 | - | 0.69 | - 0.01 | 0.19 | - |
| PP/Salinity | -0.11 | - | 0.60 | - 0.05 | -0.05 | - |
| Cell density/Salinity | 0.45 | - | 0.63 | - 0.01 | 0.24 | - |
| Cell density/Temp | 0.49 | - | 0.38 | - | 0.31 | - |
| PP/PO4 | 0.79 | - 0.01 | -0.03 | - | -0.43 | - |
| PP/C:Chl *a* ratio | 0.56 | - 0.05 | 0.25 | - | 0.27 | - |
| PP/PO4 | -0.08 | - | 0.54 | - 0.05 | 0.33 | - |
| Cell density/TSM | 0.05 | - | 0.28 | - | 0.83 | - 0.001 |
| Cell density/$PO_4$ | 0.04 | - | 0.13 | - 0.05 | 0.45 | - |

tively. In bottom waters it was maximum during May 98 at St. 1 and June at St. 2 and 3. Integrated PON averaged 28.7 g/m$^2$ at St.1, 7.6 g/m$^2$ and 13.8g/m$^2$ at St. 3. Mean values of total suspended matter (TSM) in surface and bottom waters for all the three stations are given in Table 1.

Monthly variation in C : N and C : Chl ratio is given in Fig. 7 and 8. On an average C : N ratio was 4.84; 8.06 and 5.85 in surface waters respectively at St. 1, 2 and 3. The corresponding values for bottom waters were 6.8; 6.64 and 5.99 (Table 1). However, extremely high value of 43.1 and 120 in bottom waters at St. 1 and 2 were not considered for averaging.

C : Chl *a* ratio in surface waters was always higher than that of bottom waters (Table 1). The specific productivity in surface waters on an average was 16.19 at St. 1, 25.64 at St. 2 and 24.93 at St. 3. In bottom waters without considering the extremely

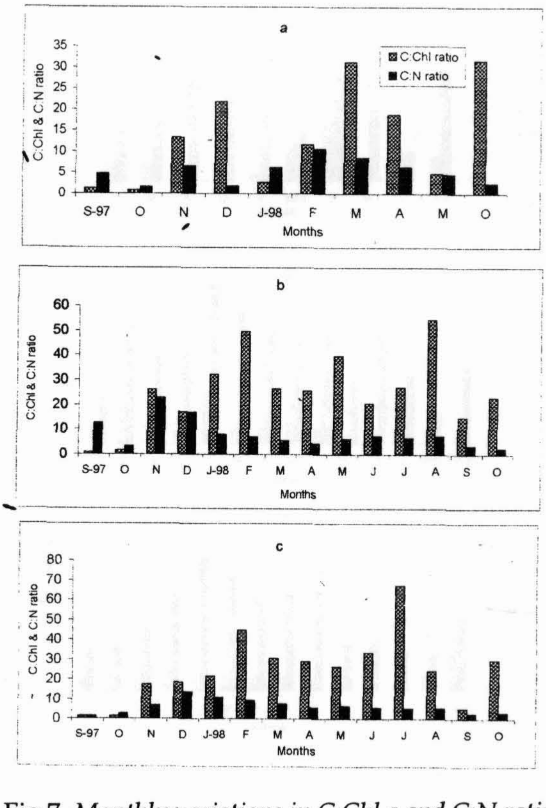


Fig.7 *Monthly variations in C:Chl a and C:N ratio in surface waters (a- Stn 1, b-Stn 2 and c-Stn 3)*

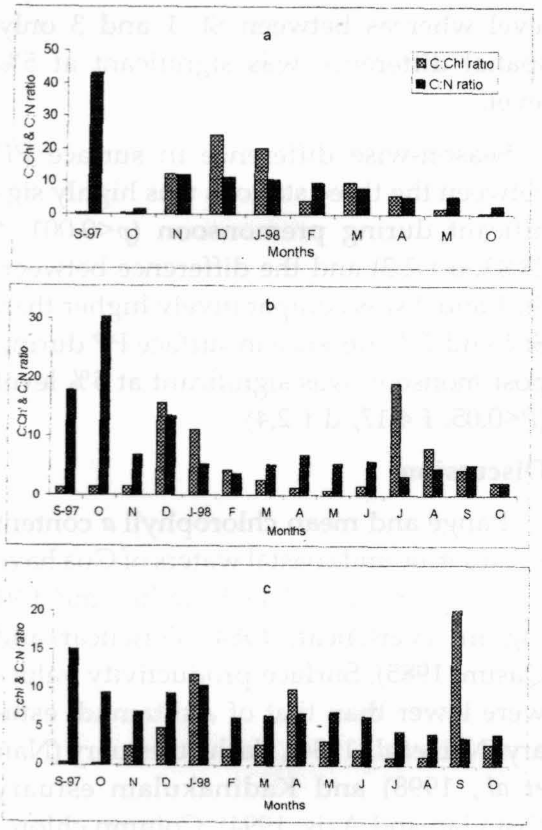


Fig.8 *Monthly variations in C:Chl a and C:N ratio in bottom waters. (a- Stn 1, b-Stn 2 and c-Stn 3)*

high value (at St. 1 and 3) it was 8.86 at St.1, 5.33 at St. 2 and 3.37 at St. 3.

**Statistical analysis**

Regression analysis has been carried out to find out the relationship between various parameters and the results are given in Table 4 and 5. In surface waters Chl *a* indicated a linear relationship with temperature at all the three stations. Correlation of PP with temperature and salinity and that of salinity with chlorophyll was significant at 1% level at St. 2. PP also showed a good relationship with temperature at St. 2. At St 1 PP was found linearly correlated with PON.

As far as bottom waters are concerned the relationship between PP and Chl *a* was positive at all the three stations, and it was significant at 5% level ($p = 0.05$, $r = 0.5$) at St. 2. Temperature and salinity indicated a linear relationship with chlorophyll *a* at 1% level at St. 2. Cell density was positively correlated with salinity at St. 2 and 3.

**Table -5** *Correlation between different parameters in bottom waters at the three stations*

| Parameters | Stn 1 (n=7) | | Stn 2 (n=12) | | Stn 3 (n=13) | |
|---|---|---|---|---|---|---|
| | r value | *p* | r value | *p* | r value | p |
| Chl *a* /Temperature | -0.04 | - | 0.69 | □ 0.01 | 0.32 | - |
| Chl *a*/salinity | -0.19 | - | 0.75 | □ 0.01 | 0.50 | - |
| PP/Temperature | -0.13 | - | 0.21 | - | -0.34 | - |
| PP/Salinity | 0.48 | - | 0.19 | - | 0.31 | - |
| Cell density/Salinity | -0.76 | - 0.01 | 0.38 | - | 0.36 | - |
| Cell density/Temp | 0.11 | - | 0.43 | - | 0.31 | - |
| PP/PO4 | 0.09 | - | -0.23 | - | -0.14 | - |
| PP/C:Chl a ratio | 0.89 | - 0.001 | 0.49 | - | 0.71 | - 0.01 |
| PP/PO4 | -0.33 | - | -0.23 | - | -0.29 | - |
| Cell density/TSM | -0.48 | - | 0.54 | - 0.05 | 0.30 | - |
| Cell density/$PO_4$ | -0.27 | - | 0.57 | - 0.05 | 0.31 | - |

When regression analysis has been carried out by combining both surface and bottom values a negative correlation was observed between chlorophyll and nutrients at all the three stations, whereas, it was positively correlated with salinity and temperature. However, this relationship was significant at 1% level at St. 2 (p. > 0.01 r = 0.57 and 0.6 n = 25). Cell density was linearly correlated at 1 and 5% level with total suspended matter respectively at St. 2 and 3.

PP and chlorophyll *a* values from all the three stations were subjected to Anova (two way without replication) to find out whether the spatial and temporal difference is significant or not. Spatial and temporal difference in surface chlorophyll was highly significant (P - 0.001, f 9.84, d f 2, 13 and f 7.86, d f 13,26) whereas the difference in bottom chlorophyll was significant only at 5% level ($p < 0.05$, f 4.18, d f 2, 13 and f 4.83, d f 13,26)

Spatial and temporal difference in surface PP between the three stations was highly significant. ($P<0.001$, f 15.67, d f 2, 13 and f 5.22, d f 13, 26 respectively). However, level of significance was more between St. 1 and 2 as compared to St. 1 and 3 or St. 2 and 3. Between St. 2 and 3 temporal differences in PP were observed at 1% level ($p<0.01$, f 4.5, d f 13, 13). In bottom waters spatial difference in PP between the three stations were significant only at 1% level ($p<0.01$, f 6.06, d f 2,13) and temporal difference was at 0.1% level ($p<0.001$, f 5.57, d f 13,26). Between St. 1 and 2 the difference was significant at 0.1% level whereas between St. 1 and 3 only spatial difference was significant at 5% level.

Season-wise difference in surface PP between the three stations was highly significant during premonsoon ($p<0.001$, f 28.83, d f 2,3) and the difference between St. 1 and 3 was comparatively higher than St.1 and 2. Difference in surface PP during post monsoon was significant at 5% level ($P<0.05$, f 4.17, d f 2,4).

## Discussion

Range and mean chlorophyll *a* content in estuarine and coastal waters of Goa have been reported as 0.3-11.3 mg/m$^3$ and 1.94 mg/m$^3$ (Verlencar, 1984, Verlencar and Qasim, 1985). Surface productivity values were lower than that of Ashtamudi estuary (Nair *et al.*, 1984), Vashisti estuary (Nair *et al.*, 1998) and Kadinakulam estuary (Nandan and Azis, 1994). Column chlorophyll and primary productivity values recorded in the present study agree well with the earlier reported values (Devassy and Goes, 1989). Observation of high surface Chl *a* during post monsoon in the present study agrees with the earlier observation (Goes, 1983). A threefold increase in total suspended matter in the Mandovi-Zuari estuarine system has been observed in the present study as compared to earlier observation (De Souza *et al.*, 1981). POC content recorded in the present study agrees well with the earlier reports (Verlencar and Qasim, 1985). Availability of nutrients has been recognised as one of the major factors controlling primary production. Obvious difference was not observed in nutrient level (mean) between the earlier and present observation. Nair *et al.* (1983) and Nair and Thampi (1980) reported higher productivity in bottom waters at Ashtamudi estuary and in tropical higher productivity in bottom waters at Ashtamudi estuary and in tropical areas. In the present study high productivity has been recorded in bottom waters during postmonsoon at St. 1 as compared to surface waters. Although photosynthesis is light dependent, there is a limit at which photosynthesis become light saturated and in bright light the surface water seems to receive illumination above the saturation level for most of the phytoplankton thus inhibiting the photosynthesis. In such a situation maximum photosysthesis occurs beneath the surface layers depending upon the light intensity. This can be one of the reasons for greater productivity in bottom waters at St. 1 especially during postmonsoon.

Nair *et al.,* (1983) reported maximum production in surface waters during premonsoon and monsoon because of turbidity of waters and during postmonsoon in bottom waters due to greater penetration of light. The same trend has been observed in the present study with high values (mean) in surface waters at all the three stations during premonsoon and monsoon periods and in bottom waters during post monsoon. The specific productivity recorded in the present study appears to be comparatively higher than the specific productivity range (0.5-15.29) and mean (4.7) reported earlier (Gonzalez - Podriguez, 1994).

Nitrate generally shows a negative correlation with salinity (Phillips, 1972) has been noticed at the two estuarine stations in the present study. Nair *et al.,* (1998) reported a negative correlation of chlorophyll with salinity. Chlorophyll and cell density showed positive correlation with temperature and salinity at all the three stations and this relationship was greater at St. 2 as compared to St. 1 and 3. In the present investigation, PP was linearly correlated with $PO_4$ at 5% level in surface waters at St. 2, however when surface and bottom values were combined PP and Chl were found negatively correlated with nutrients except at St. 2 whereas PP showed a linear relationship with $PO_4$. An increase in potential productivity at higher temperature and decrease in productivity with seasonal decrease in temperature along an Australian estuarine gradient and the difficulty to separate the role of temperature in regulating productivity from the simultaneous influence of nutrient concentration and light has been reported (O'Donohue and Dennison, 1997). PP was negatively correlated with temperature and salinity at St. 1. Whereas this relationship was positive with temperature at St. 2 and 3 and negative with salinity at St. 1. Influence of temperature and salinity on PP and phytoplankton growth has been reported earlier (Purushothaman and Bhatnagar, 1976, Nair *et al.,* 1998). Mallin (1994) reported the underlying influence of salinity on productivity in estuaries on the east coast of United States. Gessner and Schramm (1971) reported the importance of salinity as an ecological factor in controlling the abundance of phytoplankton organisms in estuaries. Though the availability of nutrients has been recognised as one of the major factors controlling primary production, the present observation supports the marked influence of salinity on phytoplankton growth and photosynthesis at the estuarine stations. However, factors influencing the productivity are many, a more detailed investigation along with application of multiple regression analysis is suggested to get a clear picture on the productivity of this complex estuarine system.

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