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Understanding the seasonal dynamics of primary productivity in relation to phytoplankton populations from the Bhagirathi – Hooghly estuary, eastern Indian coast.

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Phytoplankton productivity of Bhagirathi Hooghly estuary

Abstract:
A 2 – year study (July, 2009 – June, 2011) was carried out from the Bhagirathi – Hooghly estuary to understand the seasonal dynamics of primary productivity that encompassed a freshwater, an estuarine and marine sampling stations. The study revealed that gross primary productivity along this estuary was mainly regulated by phytoplankton populations. Phytoplankton density was highest in winter months and lowest during monsoon. Seasonally, winter months were most productive whereas the monsoon months were least, which was mainly due to dilution of phytoplankton cell density during periods of high seasonal precipitation. Influence of bacterial and other heterotrophic populations was significant on productivity, as evident from DO and BOD levels of the study area. This work establishes this coastal station to be eutrophic in nature that allowed proliferation of phytoplankton populations and subsequent productivity.

Keywords: primary productivity, phytoplankton, regression analysis, cell counts

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Introduction:

Phytoplankton are the most essential component of aquatic ecosystems of both lotic and lentic water bodies. Being the primary producer organisms, they act as the main food source for zooplanktons and other aquatic biota and control the primary productivity especially the gross primary productivity of the aquatic ecosystem. Phytoplankton contribute for more than 40% of the global carbon fixed (Reynolds, 1984). Half of the global photosynthetic carbon fixation occurs in the ocean of which 98% is accounted for the phytoplankton populations. The remaining 2% of marine primary productivity involves with the seaweeds and other photosynthetic organisms attached to the small illuminated fraction of the ocean floor (Falkowski, 2004). Productivity of any ecosystem depends upon both the flora and fauna of a particular ecosystem. But the main factor controlling the productivity of aquatic ecosystem is the phytoplankton population dynamics.

The Bhagirathi-Hooghly estuary is an important area of West Bengal both from an economical as well as from an ecological point of view. This estuary represents an ecosystem where the river Ganges is joined by different distributaries like Rupnarayan and Haldi Rivers as it approaches the Bay of Bengal. The productivity of the estuary is the main socio economic source of livelihood for the local human population of this area. The productivity of this ecosystem cascades in affecting the fish and other faunal population as well. Thus an understanding of the effects of phytoplankton on the productivity of this area is an important area of study. Unfortunately, only a few works have focused on working on the planktonic productivity of this area (Choudhury and Pal, 2010; Choudhury and Pal, 2011). Therefore, in the present study a thorough investigation was done to understand the interrelationship between the variation in primary productivity-both GPP and NPP to that of total phytoplankton population of eastern Indian coast.

The Bhagirathi – Hugli estuary, situated at the eastern coast of India is a deltaic offshoot of the River Ganges and lies approximately between 21 °31 '– 23 °20 'N and 87 °45 '– 88 °45 'E was considered as the study area in this work. It is a tropical coastal estuary and is associated with the Sunderbans Mangrove Biosphere Reserve. The estuary is funnel – shaped with the breadth and cross-sectional area at the mouth being 25 kms and 156250 m^2, which decreases to 6 kms and 36,799m^2 at the head end. Climatic condition is dominated by NE & SW monsoon where the annual rainfall varied between 188 cm to 245 cm, with 75 – 85 % of the total annual rainfall occurring in the monsoon months. The pronounced influence of south west monsoon winds resulted in heavy seasonal precipitation which may be as high as 500 mm in a month. This being a tropical coastline, showed a prolonged summer (April – May – June) with an average temperature of 35 ± 5°C and a long monsoon season (July – August – September) with an average temperature of 35 ± 2°C. Following monsoon, the months of October and November represented the post – monsoon period where the mean temperature was relatively lower as compared to the monsoon months with an average of 30 ± 5°C. Winter (December – January – February) is comparatively mild in this region of the world with the mean temperature of 12 ± 5°C. Thus, we selected three stations for our study which was mainly based on the salinity gradient of each sampling station (Diamond Harbour, Kakdweep, Junput and Digha). The sampling stations were designated as freshwater zone (Diamond Harbour), estuarine zone (Kakdweep) and marine zone (Junput and Digha).

Diamond Harbour (22° 8.78′ N and 88°9.0′ E) is located at a distance of 56 kms from Kolkata, the state capital of West – Bengal, India (Fig. 1). Just upstream of this coastal station, river Rupnarayan merges with the Hugli River which is further joined by the Haldi River at a distance of 20 kms downstream. As this coastal station is located at the upstream region of the Bhagirathi – Hugli estuary, accordingly, salinity was relatively low (0 – 4.5 . psu) and reached as low as 0 psu in the monsoon months. Thus, this station was designated as the freshwater station (Fig. 1).

Our second sampling station Kakdweep (21° 53' 0" N, 88° 11' 0" E) is located at a distance of 36 kms from Diamond Harbour and was considered as an estuarine location (salinity: 4 – 17 psu). At this station, the mixing conditions were more prevalent between the freshwater of Bhagirathi – Hugli and marine waters of the Bay of Bengal, which resulted in the mesohaline conditions of this region (Fig. 1).

For our marine samples along a relatively high salinity gradient (26 – 36 psu), two coastal stations were chosen (Junput - 21° 43' N, 87° 49' E and Digha - 21°37′ N, 87°31′E) from the confluence of the Hugli River and Bay of Bengal and were together designated as the coastal marine region (Fig. 1).

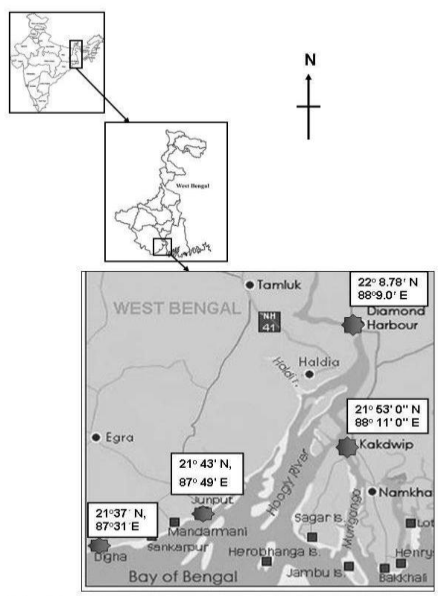


Fig. 1: Map of the study area along coastal West Bengal (lines and arrows not to scale)

Materials and Methods:

Phytoplankton samplings were carried out from each sampling spots at 15 days intervals for a period of two years (April, 2009 – June, 2011) using tow plankton net (Aquatic Instruments, USA) of mesh size 20µ. Thus, on each sampling occasion, 50 liters of sample water was passed through the phytoplankton net from each spot of the transect and the phytoplankton samples were subsequently pooled together in 75 mL PVC tubes and the collected samples were brought back to laboratory for further study. Identification of micro phytoplankton species was performed using appropriate monographs (Venkataraman 1939; Cupp 1943; Subrahmanyan 1946, 1958; Prescott 1982; Desikachary 1987). The samples obtained were preserved with 1% Lugol's solution and quantitative analysis was done from composite samples using cell counting methods using Sedgewick-Rafter cell counter.

Following Winkler's Iodometric Titration method (Winkler 1888) dissolved oxygen (DO) concentrations were measured from the following formula:

$$DO\ (mg.L^{-1}) = \frac{x \times 0.025 \times 8 \times 1{,}000}{V_2\,(V_1 - v) / V_1}$$

Where
V1 = total volume of sample taken (125 mL)
V2 = volume taken for titration (100 mL)
v = 2 mL (1 mLMnSO4 + 1 mL alkaline KI)
x = volume of sodium thiosulphate consumed in the titration (APHA 1975, 1998).

For the determination of biochemical oxygen demand (BOD) the water samples were kept under optimum conditions of light and temperature without fixation but with the addition of 1 mL each of K_2HPO_4, Na_2HPO_4, $7H_2O$, $MgSO_4$, anhydrous $CaCl_2$, and $FeCl_2$, $6H_2O$. After 5 days from the day of sampling, DO contents were subsequently measured following Winkler's Iodometric Titration Method (1888). BOD values were determined from the following formula:

$$BOD\ (mg.L^{-1}) = (DO_{0\ days} - DO_{5\ days})$$

Gross primary productivity (GPP), Net primary productivity and Community respiration rate (CRR) were determined following Winkler's light and dark bottle method (Winkler, 1888). Productivity values were determined from the following formulae:

$$GPP = \frac{[(O_2\ LB) - (O_2\ DB)]\ X\ 1000}{PQ\ X\ t}$$

$$NPP = \frac{(O_2\ LB) - (O_2\ IB)]\ X\ 1000}{PQ\ X\ t}$$

$$CRR = \frac{[(O_2\ IB) - (O_2\ DB)]\ X\ 1000}{t}$$

Where,
O_2 LB = DO content of the BOD bottle after incubation in sunlight for 3 hours
O_2 IB = DO content of the BOD bottle immediately after sampling
O_2 DB = DO content of the BOD bottle after incubation in dark for 3 hours
PQ = Photosynthetic Quotient (≡ 1.2)
t = time period of incubation (light/dark) (in hours)

Results:

On an average, among all the sampling stations, the total cell count was maximum at marine coastal zone (mean = 986 cells/mL) and minimum at the estuarine location (mean = 97 cells/mL) while the freshwater zone occupied an intermediate position (mean = 439 cells/mL) (Fig. 2). Seasonal variation with respect to cell count was well evident at all the sampling stations, where winter season was the most productive and monsoon was the least. Gradual decreases in cell count were recorded from the summer to monsoon period whereas gradual increases in cell count from the post – monsoon to the winter period was observed. At the freshwater region, total cell counts ranged from 65 cells/mL (August, 2010) to 1820 cells/mL (December, 2009). At the estuarine location, it ranged from 9 cells/mL (August, 2010) to 203 cells/mL (December, 2009). Likewise, cell count ranged from 345 cells/mL (April, 2010) to 3158 cells/mL (June, 2010) at the marine coastal region.

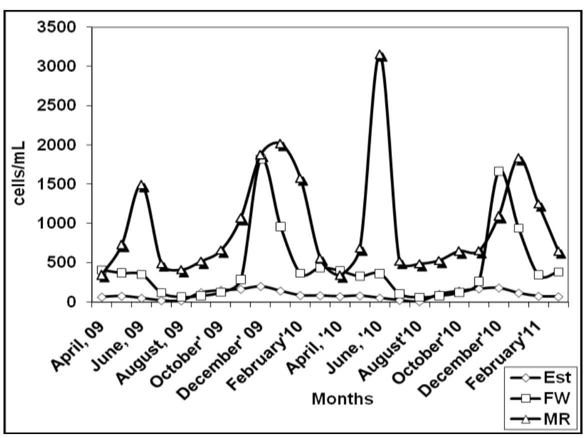
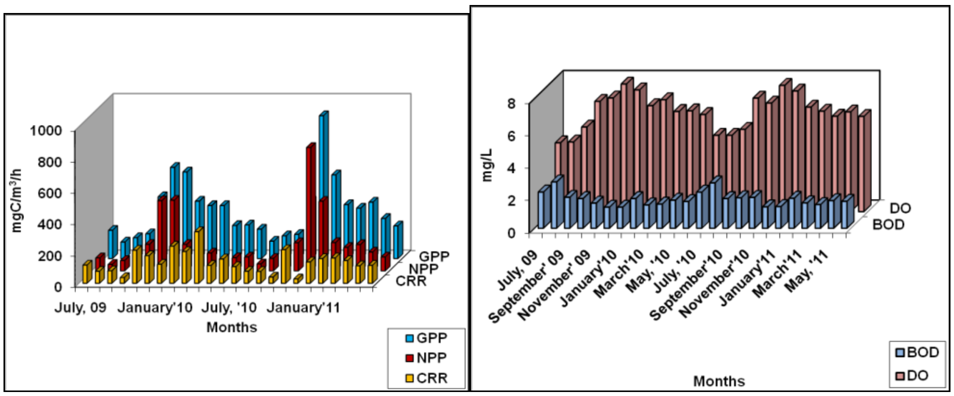


Fig.2. Monthly variations in total cell count (cells/mL) at the three sampling stations (FW – freshwater station, Est – estuarine station and MR – coastal marine region).

On an individual site basis, phytoplankton productivity was maximum at the coastal marine region and minimum at the estuarine region with the freshwater station occupying an intermediate position. CRR values also represented a similar pattern as was observed for primary productivity. Seasonally, winter months were most productive and monsoon periods were least productive. The average DO values being a reflection of the photosynthetic efficiency of phytoplankton population, showed a similar seasonal pattern as was observed for primary productivity also. In contrast, BOD values were minimum in winter and maximum in monsoon at all the sampling stations. The

CRR values also represented a similar pattern as was observed for primary productivity. Seasonally, winter months were most productive and monsoon periods were least productive.

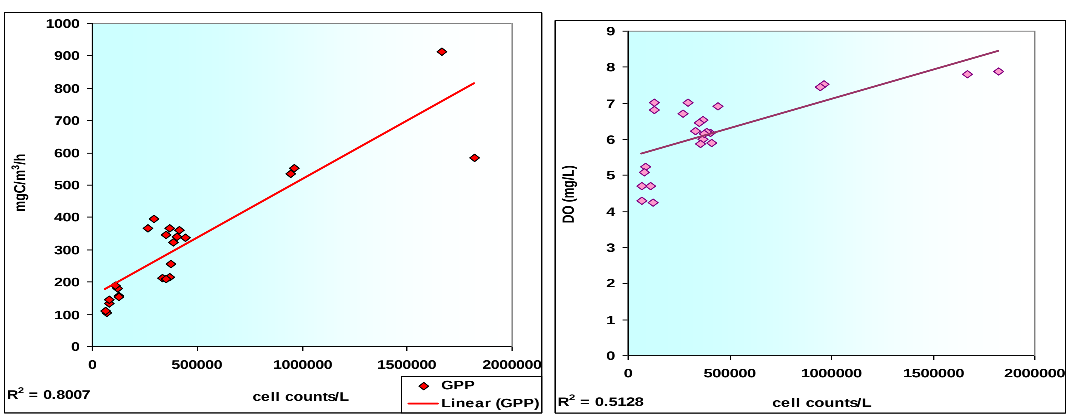
At the freshwater station, winter months were most productive with respect to carbon equivalents as was evident from GPP values. Typically, monsoon periods were least productive both in respect to phytoplankton productivity (GPP) as well as community productivity (NPP) with insignificant inter annual variations. As can be expected, CRR varied significantly as well, where maximum CRR was in winter (178.67 mgC/m^3/h) and minimum in monsoon (86.37 mgC/m^3/h) (Fig. 3a). Dissolved Oxygen (DO) was present in optimal quantity in the habitat waters that ranged from 4.25 mg/L (July 2009) to 7.882 mg/L (December 2009) (Fig. 3b). Seasonally, DO showed a similar trend with that of productivity and cell count that was maximum in winter (7.32 mg/L) and minimum in monsoon (4.59 mg/L).



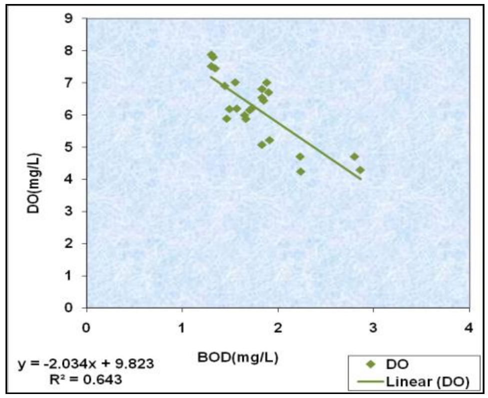
(a) (b)

Fig. 3: Monthly variation in (a) productivity (NPP, GPP and CRR) and (b) oxygen concentrations (DO and BOD) at the freshwater station (Diamond Harbour).

A highly positive significant correlation between GPP and cell count ($r^2 = 0.8$, $r = 0.9$, $p \leq 0.05$) was established (Fig. 4a). DO contents in the habitat waters had positive significant correlation with cell count ($r^2 = 0.51$, $r = 0.68$, $p \leq 0.05$, $n = 24$) (Fig. 4b) whereas BOD, which represented the heterotrophic oxygen requirements, showed an opposite pattern with maximum values in monsoon and minimum values in winter. Thus, a negative correlation was observed between DO and BOD ($r^2 = 0.64$, $r = 0.8$, $p \leq 0.05$, $n = 24$) (Fig. 4c).



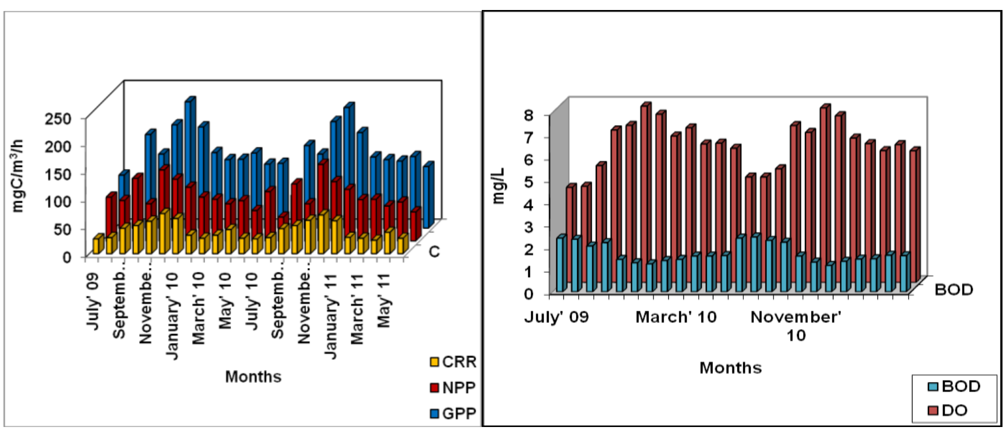
(a) (b)



(c)

Fig.4: Graphical representation of significant correlation between (a) cell count and GPP, (b) cell count and DO and (c) BOD and DO at the freshwater station.

Seasonally, maximum productivity with respect to carbon equivalents was recorded in winter when cell counts showed highest values as well (136 cells/mL). On the contrary, minimum productivity with respect to both carbon equivalents as well as total phytoplankton cell counts was recorded in the monsoon months (cells/mL) (Fig. 2). Phytoplankton productivity [Gross Primary productivity (GPP)] at the estuarine station was maximum in December, 2010 (227.77 mgC/m^3/h) when total phytoplankton cell count was maximum as well (203 cells/mL) and minimum in August, 2010 (58.95 mgC/m^3/h) (Fig. 5a). Community respiration rate (CRR) being a measure of catabolic loss of carbon equivalents due to respiration, was minimum in April, 2011 (24. 158 mgC/m^3/h) whereas it was maximum in December, 2010 (72.2 mgC/m^3/h) (Fig. 5a). Dissolved oxygen content is a reflection of the photosynthetic activity of the phytoplankton biomass. Accordingly DO values were higher in those months where plankton count was high, with a maximum of 7.88 mg/L in December, 2009 and minimum of 4.25 mg/L in July 2010 (Fig. 5b). BOD value ranged from 1.18 to 2.45 mg/L, with highest value in monsoon (August, 2010) and lowest in winter (January, 2011) when DO content was high (Fig. 5b).



(a) (b)

Fig 5: Monthly variation in (a) productivity (NPP, GPP and CRR) and (b) oxygen concentrations (DO and BOD) at the estuarine station (Kakdweep).

Results of 2 – d scatter plot shows highly significant positive correlation between total phytoplankton cell count and GPP as well (r^2 = 0.84, r = 0.92, p<0.05, n = 24) (Fig. 6a). Almost similar patterns were observed for Net Primary productivity (NPP), which was maximum in November, 2010 (137.78 mgC/m^3/h) and minimum in August, 2010 (42.72 mgC/m^3/h). An intermediate significant positive correlation was established between phytoplankton cell count and NPP (r^2 = 0.48, r = 0.7, p<0.05, n = 24) (Fig. 6b). From the correlation matrix plot it was observed that there was a positive correlation between cell count and dissolved oxygen content (r^2 = 0.66, r = 0.81, p<0.05, n = 24) (Fig. 6c) and negative correlation with BOD (r^2 = 0.61, r = -0.46, p<0.05, n = 24) (Fig. 6d).

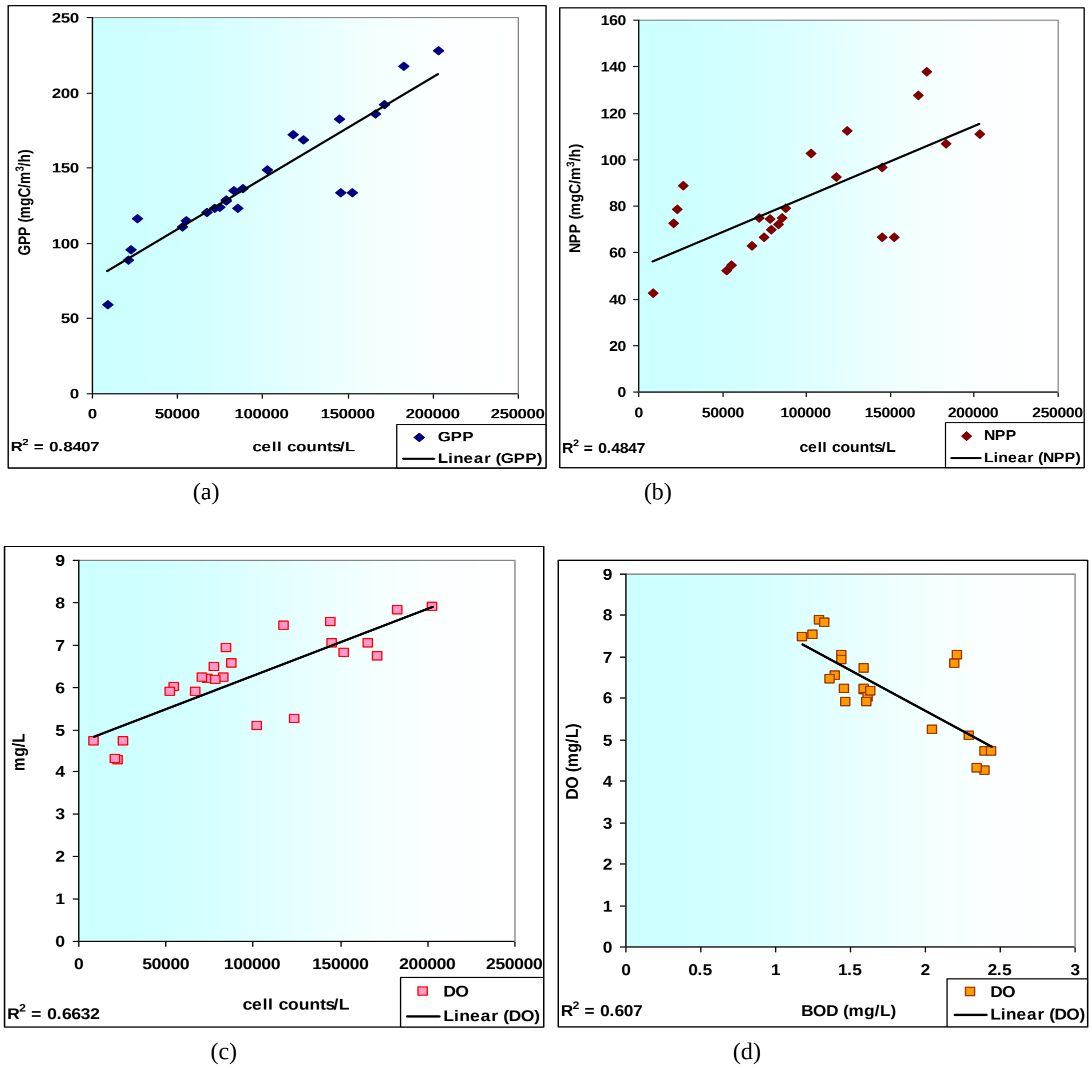
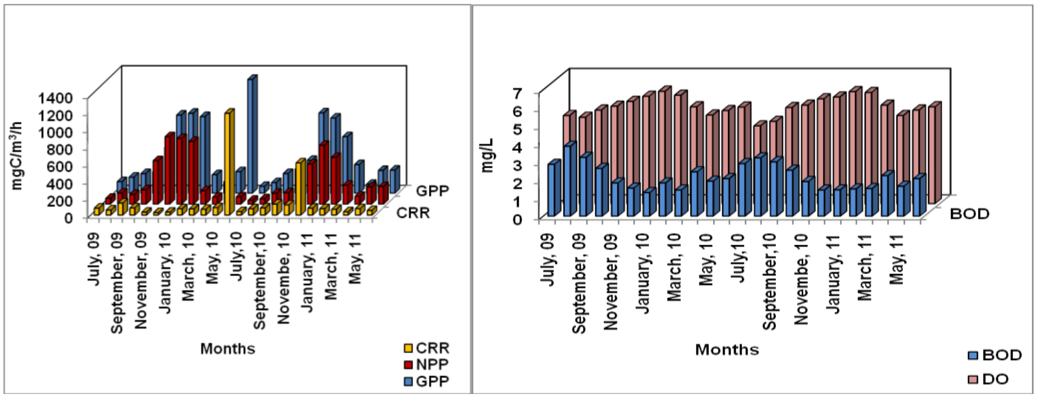


Fig. 6: Graphical representation of significant correlation between (a) cell count and GPP, (b) cell count and DO and (c) BOD and DO at the estuarine station (Kakdweep).

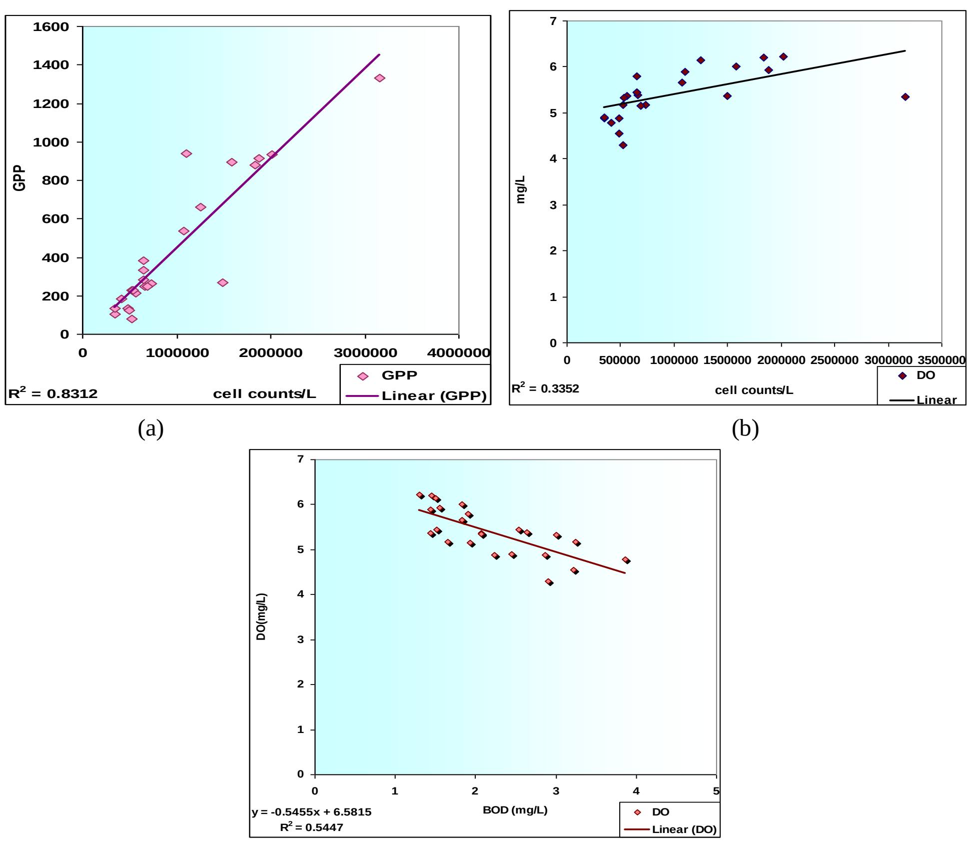
At the coastal marine region, maximum productivity [GPP] was recorded in June, 2010 (1330 mgC/m^3/h) and minimum productivity was recorded in July, 2010 (77.78 mgC/m^3/h) (Fig.7a). Maximum NPP value was recorded in December 2009 (788.88 mgC/m^3/h) when GPP (913.34 mgC/m^3/h) was also relatively high whereas it was minimum in July, 2010 (44.44 mgC/m3/h). An abruptly maximum CRR value was recorded in June, 2010 (1191.67 mgC/m^3/h) when GPP was high as well although NPP was much low (83.33 mgC/m^3/h) (Fig. 7a). On a seasonal basis, highest productivity was recorded in winter, followed by summer with the lowest productivity in monsoon. Regarding productivity, there was inter annual variation where productivity in post – monsoon period was higher than summer in 2009, unlike in 2010. Gross productivity in 2010 – 2011 (440.863 mgC/m^3/h) was higher as compared to 2009 – 2010 (383.361 mgC/m^3/h). Net primary productivity showed similar pattern as was with GPP with highest values in winter, intermediate values in summer and post – monsoon with lowest in monsoon. On the contrary, CRR values were relatively higher in monsoon as compared to the summer and post – monsoon periods. DO values were relatively low, with a maximum of 6.22 mg/L in January 2010 and minimum of 4.3 mg/L in July 2010 (Fig. 7b). DO content was maximum in winter and minimum in monsoon. BOD value ranged from 1 to 4 mg/l, with highest value in monsoon (August, 2009) and lowest in winter (January, 2010) when DO content was high.



(a) (b)

Fig. 7: Monthly variation in (a) productivity (NPP, GPP and CRR) and (b) oxygen concentrations (DO and BOD) at the coastal marine region (Digha and Junput).

As was found for the other two stations, a highly significant positive correlation was established between GPP and cell counts ($r^2 = 0.83$, $r = 0.91$, $p \leq 0.05$, $n = 24$) (Fig. 8a). From the regression plot it was found that there was a positive correlation between cell count and dissolved oxygen content ($r^2 = 0.34$, $r = 0.58$, $p \leq 0.05$, $n = 24$) (Fig. 8b). Similarly, a significant negative correlation was established between DO and BOD ($r^2 = 0.54$, $r = 0.74$, $p \leq 0.05$, $n = 24$) (Fig. 8c).



(a) (b)

(c)

Fig.8: Graphical representation of significant correlation between (a) cell count and GPP, (b) cell count and DO, (c) BOD and DO at the coastal marine region.

Discussion:

Results showed that both productivity and cell counts were maximum at the coastal marine region and minimum at the estuarine region. Highly significant correlations between phytoplankton cell counts and GPP clearly established that GPP was actually the total photosynthetically fixed carbon by the phytoplankton population. Seasonally, as can be expected from cell count data, productivity was maximum in winter and minimum during the monsoon period along West Bengal coast. Planktonic photosynthetic productivity is one of the major contributors to the overall productivity of open aquatic ecosystems. NPP is a measure of available photosynthetically fixed carbon after eliminating the catabolic loss of organic matter due to respiration (CRR).

Accordingly, a drop in NPP and rise in CRR clearly shows that carbon utilization was comparatively high in comparison to carbon assimilation. Such an observation can be attributed to the fact that a rise in nutrient rich freshwater influx in the habitat waters under warm conditions led to an increase in the heterotrophic population which accounted for the enhanced carbon utilizations. A similar result was also obtained from the Mandovi River estuary (Verlencar and Qasim, 1985) having highest productivity in the post-monsoon season with intermediate values in the pre-monsoon period and the lowest productivity in monsoon. A drop in primary productivity in the monsoon months and a rise of the same in the post-monsoon period was also reported from Lake Tana in Ethiopia (Wondie et al., 2007).

Variations in DO contents showed a similar pattern of variation as was observed for cell counts and productivity in both freshwater and estuarine stations. Thus, DO levels at the freshwater station were comparatively higher than at the estuarine station. Although the freshwater and estuarine stations represented optimum DO levels, DO levels at the marine coastal region represented an under saturated condition although cell counts were maximum among all the three stations. During the monsoon months, heavy seasonal precipitation promotes an enhanced freshwater inflow with high suspended matter content, resulting in a very turbid water column at the marine region. This turbid nature of the water column may result in a decrease in the photic zone. Thus, although the incident irradiance was high, the average irradiance in the water column was relatively low which may have accounted for the drop in DO levels in the habitat waters at the marine coastal region with low photosynthetic activity. Another significant observation was the rise in BOD levels in the monsoon months and a drop in the same during the winter periods. The purpose of DO in these habitat waters primarily lies in the cellular respiration of biotic components and decomposition of inorganic and organic components in the habitat which is mainly achieved by bacterial population. Thus, rises in levels of BOD indicate that the supply of DO in the habitat is less than the optimal level required for bacterial decomposition. Accordingly, an increase in BOD level indicates that the rate of decomposition of organic components in the water column is low which in turn will result in an increase in the population of detritus heterotrophic population. The significant negative correlations between DO and BOD levels at all the sampling stations further establish the high heterotrophic growth during the monsoon months which resulted in the decreased DO levels. This will subsequently result in decrease of the autotrophic components that often become the feed source for these heterotrophic populations. Hence, often in these periods of high BOD and low DO levels, there is a reduction in productivity as was found in our study from the Bhagirathi Hooghly estuary. As seasonal precipitation decreases in post monsoon and winter, the influx of high SPM containing runoffs from other sources reduces as well that may result in an increase in the photic zone of the water column. Moreover, the dilution of plankton population decreases as well that cascades in enhancing the autotrophic components in the water column. This result in an increase of DO and decrease in BOD levels that influences productivity positively. Thus, it can be concluded that productivity along coastal West Bengal was primarily regulated by phytoplankton population with marine region being most productive. Here DO contents tended to be low due to high BOD contents which indicate the eutrophic condition of the habitat. Finally, the study area represented a eutrophic habitat that promoted phytoplankton growth which is central to the overall functioning of this estuarine ecosystem.

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