Comparison of phytoplankton community structure in two tropical estuaries of East Coast of India

Chumki Chowdhury*
Department of Botany, Jangipur College, Jangipur, Murshidabad-742213, West Bengal, India

ABSTRACT
Dissolved nutrients concentrations in estuarine waters play important role in shaping phytoplankton community of two Indian river estuaries. The first study site was Saptamukhi river estuary which is a part of Hooghly-Matla estuarine system located in the Indian Sundarban and second study site was Mahanadi estuary located in Orissa coast (adjacent to industrial and coastal fishing zone). The Saptamukhi estuary received less anthropogenic waste compared to Mahanadi estuary and the main source of nutrient is autochtonous due to huge litter from surrounding mangrove forest. Mahanadi estuarine water received nutrients from industrial effluent and fishing waste. The Saptamukhi estuarine water had less dissolved inorganic phosphorus concentration but huge dissolved inorganic nitrogen concentration. High dissolved silicate concentration might encourage the diatom growth over other phytoplankton group here. In Mahanadi estuarine water, high amount of dissolved inorganic phosphate coming from the phosphate industries supported the growth of Cyanophyceae, Chlorophyceae and Dinophyceae. Chlorophyceae genus *Pediastrum* bloom observed in the post-monsoon during this study. In Saptamukhi Estuarine water, in spite of high phytoplankton population in post-monsoon season no individual species reached bloom condition during the study period. In both the estuarine water Gross Primary Productivity was high but the community respiration was higher. Monsoonal runoff from land considerably changed the community in both estuarine water. Dissolve inorganic nitrogen and dissolved inorganic phosphate ratio played major role for the community change of phytoplankton in two estuarine waters.

KEYWORDS: Phytoplankton; diatom; estuary; nutrients

INTRODUCTION
Phytoplankton, can be categorized as prokaryotic cyanobacteria and eukaroytic algal groups, is responsible for primary production, supporting food webs and play a central role in essential elements, nutrient, and oxygen cycling in estuaries. They respond to changes in different environmental conditions [1,2]. Eutrophication or change in transparency of water column [3,4] alter the structural characteristics of phytoplankton communities (i.e., diversity, richness, and dominant species groups) in estuaries and coastal waters. Changes in essential nutrients concentrations like nitrogen, phosphorus, silicate etc and the ratio of these nutrients have great impacts on controlling phytoplankton species diversity [5,6]. In tropical estuaries like Mandovi-Zuari, [7] and Cochin estuary [8] nitrogen limits primary productivity. High anthropogenic Phosphorus inputs may also shift ecosystem to N limited [9]. Study of phytoplankton community and controlling factors responsible for changes in community can give the researchers a clue about larger-scale, long-term changes in ecosystem function, including shifts in nutrient cycles, food webs, and fisheries [10]. Apart from elementary Carbon, Nitrogen and Phosphorous are two very important elements for algal growth. Phytoplankton growth flourishes when ratio of nutrients in the ambient water is C: N: P = 166:20:1 [11]. According to the modified Redfield ratio, the optimum dissolved nitrogen and dissolved phosphorus ratio is 20 for phytoplankton but alteration is quite common in this ratio throughout the world oceans and other aquatic bodies due to changes in atmospheric deposition, fertilizer use, waste waters discharge and reduced or increased rate of biologically controlled addition or removal of the nutrients [9]. In-spite of altered redfield ratio many of the phytoplankton species are adapted to that water and form a compact community [12]. But the species composition of community can shift greatly from place to place or time to time in a same place in response to that change [13, 14, 15, 16, 17, 18]. So dissolved inorganic nitrogen and dissolved inorganic phosphate ratio in the water is expected to play a crucial role in phytoplankton growth and community composition. Change in dissolved inorganic nitrogen concentration led to shift of phytoplankton community from one chain forming diatom species to another in the Harima-Nada,
eastern Seto Inland Sea, Japan [19]. In estuaries and coastal areas phytoplankton variability is the result of many integrated processes of land, water and lower atmospheric phenomenon. It is important to find out the key factors responsible behind the temporal and spatial changes of community. The controlling factors which play supportive role for phytoplankton growth can be different in estuaries than open ocean and again can be different in different estuaries depending on various physico-chemical and biological interactions. Fresh water runoff enriched with land-derived nitrogen and phosphorus can promote phytoplankton growth in large confined aquatic systems [20]. In coastal oceans upwelling can help in phytoplankton growth and nutrient enrichment and that nutrient may fuel bloom condition of phytoplankton in the estuaries [21]. The bloom condition may arise in the nutrient rich estuaries as a result of thermal stratification [22]. In Estuaries, presence of benthos at bottom sediment support strong benthic pelagic system. As a result of grazing, phytoplankton biomass sink at the bottom of the water body. Phytoplankton resting stages or spores present in sediments after sinking develop into vegetative cells that form seasonal blooms [23]. In a study by Prabhahar et al [24] in Palar river, Tamil Nadu, it was observed that phytoplankton community in 3 different study stations in a same river stretch was different. According to authors the diversity of coastal marine species may have been associated with the allochthonous phytoplankton species from the estuary. The Bay of Bengal and the associated river estuaries drain to coastal area of Bay of Bengal are characterized by dynamic environment [25].

The two study sites of the present investigation represent two different estuarine environments on the basis of natural input and anthropogenic stress. The Saptamukhi estuary has dense mangrove forest along its banks and numerous creeks from the forest ended in the river. The ecosystem is subdivided as forest sub-ecosystem and aquatic sub-ecosystem. Some of the land has been reclaimed for human settlement and agricultural purposes as patches inside the forest [26]. The river banks are periodically inundated and exposed with tide. In general, nutrients rich sediments are characteristic of this ecosystem and nutrient enrichment occurs from plant residues and Litter-fall which has significance impact in p input [27]. The Mahanadi estuary receives effluent from several industries, such as Paradeep Phosphates Ltd. (3264 m³.day⁻¹), Oswal Fertiliser Ltd., Paradeep (4085 m³.day⁻¹) and the East Coast Breweries and Distilleries Ltd., Paradeep (376 m³.day⁻¹) [28]. Both the study sites of the present investigation represent two different estuarine environments on the basis of natural input and anthropogenic stress. The Saptamukhi estuary is a part of the Hooghly-Matla estuarine ure 1a.[25], which is a part of the Hooghly-Matla estuarine system, on the northeast coast of the Bay of Bengal. This study site is under the influence of dense mangrove forest ecosystem. Tide in the study site 1 is semidiurnal and the tidal amplitude is meso-macro tidal in nature with a range of 2.5–7 m [26].

The study was conducted from 2015 to 2016. The first study site is located in the Indian Sundarbans (two stations: St. 1. 21°45.22 N and 86°41.29 E; St. 2. 21°45.23 N, 86°38.48 E, Figure 1a.[25]), which is a part of the Hooghly-Matla estuarine system, on the northeast coast of the Bay of Bengal. This study site is under the influence of dense mangrove forest ecosystem. Tide in the study site 1 is semidiurnal and the tidal amplitude is meso-macro tidal in nature with a range of 2.5–7 m [26].

The second study site (three stations: Stn.1, 20°17'38.1" N; 86°42'30.3" E, Sn.2, 20°18'29.5" N; 86°41'44.4" E and Stn.3, 20°20'22.9" N; 86°36'50.8" E) is located in the Mahanadi estuary, formed at the mouth of one of the 14 major rivers of India (Figure 1b [9]). The river originates from the Baster Hills and meets the Bay of Bengal near Paradeep. The tide in the estuary is predominantly semidiurnal. The vertical tide range at the mouth varies from 1.45 to 2.20 m. Climate in the region consists of the southwest monsoon (June–September), the northeast monsoon or post-monsoon (October–January), and the pre-monsoon (February–May); 70–80% of annual rainfall occurs during the summer monsoon (southwest monsoon), resulting in high river discharge, which then gradually diminishes during the non-monsoon months.

STUDY AREA

The study site is located in the Indian Sundarbans (two stations: St. 1. 21°45.22 N and 86°41.29 E; St. 2. 21°45.23 N, 86°38.48 E, Figure 1a.[25]), which is a part of the Hooghly-Matla estuarine system, on the northeast coast of the Bay of Bengal. This study site is under the influence of dense mangrove forest ecosystem. Tide in the study site 1 is semidiurnal and the tidal amplitude is meso-macro tidal in nature with a range of 2.5–7 m [26].

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MATERIALS AND METHODS

Water sampling was performed from February 2015 to January 2016 in every month covering three seasons, pre-monsoon (February to May), monsoon (June to September) and
Figure 1: (a) Map of study site 1 in Indian Sundarbans [25], (b) Map of study site 2 in Mahanadi, Paradeep port adjacent area [9]
rates were measured in situ using light and dark bottles following Gross primary production (GPP) and community respiration (R) on the Winkler's method [36]. Dissolved inorganic nitrogen present in water available to phytoplankton was as nitrate and ammonia. Nitrate, ammonia, phosphate and silicate in the water samples were measured following standard procedures [33] by using spectrophotometer (UV-VIS Spectrophotometer, 117; Systronics Limited, India, Ahmedabad, Gujrat). N:P molar ratio was derived from dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphate concentration.

Analysis of chlorophyll sample was done by spectrophotometric method according to Strickland & Parson [34]. Phytoplankton samples were collected by net collection and sedimentation process side by side. Net collection was performed by using plankton net made of bolting silk of pore size 20 µm fitted with flowmeter (Hydro Bios, 438110, Hydraulic Pitch = 0.3 m per revolution, range of counter = 99999 revolutions, impeller diameter = 75 mm, material = plastic, titanium). Then the total net collection was concentrated into 250 ml and 15ml of formalin (strength=4%) was added for preservation. For sedimentation process of collection, water samples were collected in 1L broad mouth sedimentation tank and preserved with 5 ml of acidified Lugol’s iodine (strength=5%) solution. Then water samples were collected in 1L sedimentation tank and were kept undisturbed on the bench top for 5 day [35]. After that, supernatant was siphoned out using a rubber tube and the final sample volume was made to 10ml. The concentrated samples of both net collection and sedimentation collection were analyzed for phytoplankton counts and identification by Sedgwick rafter counting chamber [25]. Measurement of cell size was performed by using calibrated Ocular and stage micrometer under bifocal microscope (Leica 13395H2X, Leica, Buffalo, NY, USA) at 400 X magnification. Randomly selected 30 cells of each species dimension was measured to the nearest ocular unit (1 ocular division = 0.01 mm) [25].

Calculation of % of relative abundance

\[(\text{R.A.}) = \frac{n}{N} \text{ [where, } n = \text{Total number of individual of species in all samples, } N = \text{Total number of individual of all species]}\]

Estimation of dissolved oxygen in estuarine water was based on the Winkler’s method [36].

Gross primary production (GPP) and community respiration (R) rates were measured in situ using light and dark bottles following dissolved oxygen method [33]. Water samples collected in BOD bottles and were fixed immediately with Winkler’s reagents for estimating initial dissolved oxygen concentration, and remaining bottles were fixed after incubation period. Changes of oxygen were converted to carbon assimilated/respired assuming a photosynthetic quotient of 1.2 and respiratory quotient of 1. GPP and community respiration R were calculated by using formulae 1 and 2

\[
\text{GPP (mg C m}^{-3} \text{ hr}^{-1}) = \frac{12 \times (\text{LB} - \text{DB}) \times 1000}{32 \times \text{PQ} \times t} \quad (1)
\]

\[
\text{And Respiration (mg C m}^{-3} \text{ hr}^{-1}) = \frac{12 \times (\text{IB} - \text{DB}) \times 1000}{32 \times \text{RQ} \times t} \quad (2)
\]

Where,

- \(\text{IB} = \) Dissolved oxygen in the initial bottle in mg L\(^{-1}\)
- \(\text{DB} = \) Dissolved oxygen in the dark bottle in mg L\(^{-1}\)
- \(\text{LB} = \) Dissolved oxygen in the light bottle in mg L\(^{-1}\)
- \(\text{PQ} = \) Photosynthetic quotient (1.2)
- \(\text{RQ} = \) Respiration quotient (1.0)
- \(t = \) Time of incubation in hours

Statistical analyses were done by using MINITAB statistical software (19.2.0).

**RESULT**

**Meteorology**

In Saptamukhi estuary, total rainfall occurred was 1800 mm (Indian Meteorological Department, http://www.imd.Gov.in.) during this study. Air temperature varied annually from 21°C to 35 °C. Highest air temperature was recorded during the month of May with a mean value of 34.7 ± 0.28 °C while the lowest temperature was recorded in the month of January with the average value of 22.4 ± 1.21 °C. The annual rainfall at Paradeep was 1919 mm (Indian Meteorological Department, http://www.imd.Gov.in.) of which about 83% occurred during the summer monsoon period (June–September). The average air temperature was 30.2 ± 2.39 °C in the pre-monsoon and 24.3 ± 4.2 °C in the post-monsoon. Temperature decreased progressively from May to January and showed lower values in January.

**Physico-chemical Parameters**

In the Saptamukhi estuarine water, water temperature ranged from 19.6 °C to 33.5 °C during the study period. Salinity of estuarine water decreased considerably during the monsoon when huge amount of freshwater flux into the estuary caused considerable dilution of seawater. Lowest salinity (20.3 ± 2.86 psu) was recorded during monsoon period while highest salinity (25.4 ± 1.40 psu) was recorded during pre-monsoon season when the upstream freshwater flux was minimum. In the Saptamukhi estuarine water, Dissolved oxygen concentration
Dissolved nitrogen concentration included Nitrate and Ammonia. Ammonia concentration ranged from 4.6 µM to 5.8 µM and Nitrate concentration ranged from 18.8 µM to 24.2 µM in the Saptamukhi estuarine water during the study period. Highest DIN concentration (26.3 ± 0.04 µM) was recorded during the monsoon. During the post monsoon, its concentration was gradually decreased to 22.9 ± 1.00 µM and in the pre-monsoon the concentration was further decreased to the lowest value of 19.3 ± 0.31 µM. Highest concentration of DIP was observed during the monsoon (1.00 ± 0.07 µM) which was decreased to 0.8 ± 0.03 µM during the post-monsoon. Lowest concentration (0.6 ± 0.01 µM) was recorded during the pre-monsoon. Due to the high river discharge during monsoon season, silicate concentration was higher with a range of value 40.5 to 47.0 µM from June to September. In the post monsoon and pre-monsoon season the concentrations were 33.8 ± 1.63 µM and 31.8 ± 6.60 µM respectively and during monsoon the concentration reached 47.3 ± 6.29 µM.

High transparency (78.6 ± 45.5 cm) was observed during the post-monsoon season when river discharge was minimum. During the monsoon, water showed maximum turbidity (24.7 ± 11.1 cm) due to high river discharge. During the pre-monsoon time, intermediate value of water column transparency was found to be 53.9 ± 24.5 cm.

Water temperature in the Mahanadi estuarine water varied from 22.3 to 31.5 °C during the study period. Highest surface water temperature was observed in the month of May having the temperature range 29.7 to 31.5 °C. Lowest water temperature was recorded during the month of January when the temperature varied from 22.3 to 23 °C. Dissolved oxygen concentration ranged from 4.98 ± 0.05 mg.L⁻¹ (Monsoon) to 6.53 ± 0.02 mg.L⁻¹ (Post monsoon) with the intermediate value of 5.44 ± 0.05 mg.L⁻¹ in pre-monsoon.

During the monsoon months the salinity decreased from highest value of 24.8 psu (non-monsoonal months) to very low value of 5.0 psu in this estuary. In the month of September, during heavy monsoonal precipitation time, only in the upstream station (st. 3) water, the lowest salinity of less than 1 psu was recorded. Comparatively high salinity was recorded during post-monsoon season (13.5 psu). Highest salinity was recorded during the non-discharge period (pre-monsoon) with a range of 18.0 to 24.8 psu. Dissolved oxygen concentration varied from 5.0 to 7.0 mg.L⁻¹ during study period. Lowest concentration (5.0 ± 0.02 mg.L⁻¹) was recorded in the monsoon months. Highest value was recorded in the post-monsoon months (6.7 ± 0.03 mg.L⁻¹). Comparatively lower values (5.4 ± 0.1 mg.L⁻¹) were observed during pre-monsoon months. DIN concentration was much lower in the estuarine water during post-monsoon (7.6 ± 1.25 µM, Nitrate = 4.12 ± 2.11 µM; Ammonia=3.5 ± 1.56 µM) and pre-monsoon season (6.2 ± 1.78 µM; Nitrate=3.5 ± 0.57 µM; Ammonia= 2.7 ± 1.0 µM) during this study. DIN concentration was generally higher during the monsoon period (30.8 ± 2.32 µM; Nitrate=26.7 ± 1.03 µM; Ammonia= 4.1 ± 0.82 µM). In this estuarine water the DIN concentration was high throughout the year except in the month of May (0.58 to 0.65 µM). In the monsoon period, the DIP concentration was much higher (3.48 ± 1.60 µM) than post monsoon (1.84 ± 0.68 µM) and pre monsoon (0.71 ± 0.66 µM) season. Dissolved silicate concentration was highest during monsoon (137.1 ± 69.6 µM) and become lower during post monsoon (112.5 ± 35.7 µM) reached the lowest value during pre-monsoon (59.4 ± 45.1 µM).

Secchi disc transparency of the water column gradually increased from 25 cm during the monsoon period to 99 cm in the post-monsoon period, and then to 133 cm during the pre-monsoon period.

**Primary Productivity and Respiration**

In Saptamukhi estuary, gross primary productivity in the photic zone of water column showed seasonal variation with a minimum of 27.1 ± 9.18 mmol C m⁻² d⁻¹ (monsoon), a maximum of 106.0 ± 16.98 mmol C m⁻² d⁻¹ (post monsoon) and intermediate of 75.7 ± 27.7 mmol C m⁻² d⁻¹ (pre-monsoon) respectively. Photic zone respiration was higher than the productivity (Pre-monsoon = 164.8 ± 60.63 mmol C m⁻² d⁻¹; Monsoon = 67.8 ± 21.5 mmol C m⁻² d⁻¹; Post-monsoon = 113.5 ± 20.10 mmol C m⁻² d⁻¹). Chlorophyll-a values varied with season with highest value of 11.4 ± 2.4 µg. L⁻¹ in post-monsoon season, lowest value of 3.1 ± 1.1 µg. L⁻¹ in monsoon season and medium value 4.9 ± 1.2 µg. L⁻¹ in pre-monsoon season.

Gross primary productivity in the photic zone of water column was highest in the post-monsoon season in the Mahanadi estuary. The seasonal variation was observed in the GPP values (Pre-monsoon = 108.01 ± 21.02 mmol C m⁻² d⁻¹; Monsoon = 52.46 ± 12.28 mmol C m⁻² d⁻¹; Post-monsoon = 184.07 ± 65.95 mmol C m⁻² d⁻¹). The Chlorophyll-a values followed the seasonal pattern like the Site 1. Highest value of 8.19 ± 2.9 µg. L⁻¹ was recorded during post-monsoon season and lowest value of 3.85 ± 0.74 µg. L⁻¹ was recorded in monsoon season with intermediate value of 5.1 ± 0.22 µg. L⁻¹ during pre-monsoon season.

**Comparison of Phytoplankton Community**

The composition and total population of phytoplankton for Saptamukhi and Mahanadi estuarine water are given in the Table 1 and Table 2 respectively. Phytoplankton community of Saptamukhi estuary was dominated by diatom with the presence of few dinoflagellate (dinophyceae) species. In this study, in Saptamukhi estuary, total number of microphytoplankton genera was found to be 39 with 7.39 -9.06% abundance of pennate (Gyrosigma acuminatum, Pyramimonas spp., Melosira granulata, Odontella mobilensis, Odontella sinensis, Denticella regia etc.). Out of the centric diatom, dominant species were found to be Asterionella formosa, Ditylum brightwellii, Melosira granulata.
the genus *Skeletonema* and *Chaetoceros*. Harrison et al [37] observed phytoplankton community comprising mostly of centric diatom in Indus River delta, while Dham et al. [38] recorded nano-plankton dominated diatom bloom in the Achara River estuary, India.

Abundance of phytoplankton was greater in the post-monsoon than the monsoon and the pre-monsoon seasons in Mahanadi estuary. The highest cell count (7.21x10^5 cells L^-1) was observed during the post-monsoon period when phytoplankton was dominated by two species of *Pediastrum*,

| Table 1: Seasonal patterns of phytoplankton average number (No/l), in Saptamukhi estuarine water during study period |
|-----------------------------------------------|-----------------|-----------------|-----------------|
| **SAPTAMUKHI** | **Pre-Monsoon** | **Monsoon** | **Post-Monsoon** |
| Bacillariophyceae | **No/l** | **No/l** | **No/l** |
| *Thalassiosira eccentricus* | - | - | 435 |
| *Coscinodiscus gigas* | - | - | 152 |
| *Coscinodiscus excentricus var. lineatus* (Ehrenberg) Cleve | - | - | 1179 |
| *Azpeitia bidentata* | 454 | 278 | 814 |
| *Chaetoceros willei* Gran 1897 | - | - | 825 |
| *Chaetoceros bulbosus* (Ehrenberg) Heiden 1928 | 479 | 362 | 500 |
| *Chetoceros compressum* | - | 9 | 250 |
| *Chaetoceros pseudocurvisetus* Mangin 1910 | - | 49 | 150 |
| *Chaetoceros decipiens* Cleve | - | - | 100 |
| *Chaetoceros didymus* | - | - | 179 |
| *Cyclotella affinis* Grunow | 276 | 515 | 633 |
| *Ditylum brightwellii* Grunow | 447 | 607 | 212 |
| *Eucampia zodiacus* Ehrenberg | 413 | - | 352 |
| *Halosphaera minor* ostenfeldii | 447 | 347 | 373 |
| *Laudaria annulata* | 401 | 135 | 960 |
| *Leptocylindrus danicus* | 887 | - | - |
| *Aulacoseira granulate* (Ehrenberg) Simonsen | 1275 | 370 | 1776 |
| *Coscinodiscus biauritus* A. Schimdt | 187 | 19 | 745 |
| *Coscinodiscus sol* C. G. Wallich | 164 | 9 | 186 |
| *Triceratium annulatum* Wallich | 11 | - | 1315 |
| *Skeletonema costatum* (Greville) Cleve | 7458 | 3312 | 8924 |
| *Surirella ovata* Kützing | 2335 | 702 | 500 |
| *Thalassiosira decipiens* | 2793 | 775 | - |
| *Podosira subtilis* Ostenfeld | - | 659 | 437 |
| *Odentella mobilis* Grunow | - | - | 250 |
| *Odentella sinensis* | - | - | 250 |
| *Denticella regia* Schultz | 600 | 400 | 250 |
| *Paralia sulcata* (Ehrenberg) Cleve | 200 | - | 250 |
| *Asterionellopsis japonica* Cleve | 500 | 200 | 1533 |
| *Amphora constricta* (Ehrenberg) | 350 | 600 | 719 |
| *Amphipleura pellucida* Kützing | 279 | - | 629 |
| *Amphora hyalina f. parvula* Grunow | - | - | 373 |
| *Halamphora coffeaeformis* (C. Agardh) | - | - | 620 |
| *Bacillaria pacifica* (F. Muller) T. Marsson | 500 | 18 | 453 |
| *Belleroca heletta* Brightwell | 357 | - | 774 |
| *Cylinodioschisma closterium* | 328 | 360 | 586 |
| *Pseudo-nitzschia seriata* (Cleve) H. Peragallo | 301 | 303 | 795 |
| *Nitzschia harbighawii* Febiger ex Cleve & Möller | 87 | 11 | 31 |
| *Paribellus rhombicus* (W. Gregory) E. J. Cox | - | 473 | - |
| *Gyrosigma acuminatum* (Kützing) Rabenhorst | 34 | 90 | 39 |
| *Pinnularia viridis* (Nitzsch) Ehrenberg | 196 | - | - |
| *Proboscia alata* (Brightwell) Sundström | - | - | 72 |
| *Rhizosolenia hebetata* f. semispina (Hensen) Gran | 93 | - | 114 |
| *Guinardia delicatula* (Cleve) Hasle in Hasle & Syvertsen | 750 | 32 | 106 |
| *Rhizosolenia setigera* Brightwell | 185 | 66 | 238 |
| *Toxarium hennedyanum* (W. Gregory) Pelletan | 48 | 23 | 54 |
| *Thalassionema frauenfeldii* (Grunow) Tempère & Peragallo | 210 | 21 | 199 |
| *Thalassiothrix longissima* Cleve & Grunow | 137 | 13 | 179 |
| Dinophyceae | | | |
| *Tripos fusus* (Ehrenberg) F. Gómez | 196 | 60 | - |
| *Tripos furca* (Ehrenberg) F. Gómez | 171 | 85 | - |
| *Tripos muelleri* Bory | 30 | - | - |
| *Dinophysys caudata* W. S. Kent | 128 | 59 | 145 |
| *Protoperidinium pentagonum* (Gran) Balech | 112 | - | 88 |
| *Proserpinocentrum micans* Ehrenberg | - | - | 67 |
| **Total** | 23819 | 10962 | 29811 |
### Table 2: Seasonal patterns of phytoplankton average number (No/l) in the Mahanadi estuarine water during study period

<table>
<thead>
<tr>
<th>MAHANADI</th>
<th>Pre-Monsoon</th>
<th>Monsoon</th>
<th>Post-Monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacillariophyceae</td>
<td>No/l</td>
<td>No/l</td>
<td>No/l</td>
</tr>
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<td>Amphipora constricta</td>
<td>1050</td>
<td>-</td>
<td>600</td>
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<tr>
<td>Amphora hyalina f. parvula Grunow</td>
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<td>1333</td>
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<tr>
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<td>248</td>
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<td>600</td>
<td>30677</td>
</tr>
<tr>
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<td>-</td>
<td>849</td>
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<td>Bacteriastrum hyalinum</td>
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<tr>
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<td>-</td>
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<td>Ditylum brightwellii Grunow</td>
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<td>155</td>
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<td>71</td>
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<tr>
<td>Eucampia zodiactum Ehrenberg</td>
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<td>197</td>
<td>747</td>
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<td>365</td>
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<td>666</td>
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<td>Rhizosolenia hebetata f. semispina (Hensen) Gran</td>
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<td>831</td>
<td>544</td>
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(Contd...)
Trichodesmium erythraeum, two species of Dinophyceae genus Tripos and two Cyanophyceae genus Oscillatoria and Nostoc. Diatoms were most abundant in the post-monsoon period with an overall contribution of some species like Toxarium hennedyanum, Melosira granulata, Thalassiosira decipiens were significant. Contributions of different species of genus Coscinodiscus and Chaetoceros Were less. The abundance of phytoplankton was low (0.68x10^5 cells L^-1) during the monsoon period when the genus Trichodesmium erythraeum dominated (~ 45%) followed by different species of the genus Chaetoceros, Skeletonema costatum, Parlibellus rhombicus, and Pseudo-nitzschia seriata During the pre-monsoon, the lowest phytoplankton densities (0.52 x 10^5 cells L^-1) was recorded and composition was dominated by Pediastrum simplex and Pediastrum duplex followed by Gloeocapsa aeruginosa. The potentially toxic dinoflagellate, Alexandrium minutum was observed in low densities (0.02-0.19%). Overall, dinoflagellate and cyanophyceae population declined from 10.6 to 0.91% and from 49.0 to 18.8%, of the total abundance respectively during the pre-monsoon period, whereas Bacillariophyceae and Chlorophyceae increased from 29.6 to 44.4% and from 18.9 to 39.9%, of the total abundance, respectively, during this season. 57 species of Bacillariophyceae, 6 species of Dinophyceae, 8 species of Cyanophyceae and 9 species of Chlorophyceae were recorded. During the post-monsoon Pediastrum duplex was the dominant species of Chlorophyceae group. Dominance of bigger sized Bacillariophycean species was recorded in Mahanadi estuarine water.

The one way ANOVA study of physico-chemical parameters (Table 3) and phytoplankton population showed the variation of N:P ratio and numerical abundance of phytoplankton for both Saptamukhi estuary data and Mahanadi estuary. For the analysis, alpha value was 0.05 and critical F- value was 4.11.
DISCUSSION

The water and air temperature did not differ much in the two study sites and follow the same seasonal pattern. Lower salinity perhaps triggered the Chlorophycean growth in the Mahanadi estuarine water. In a study by Park et al [39], they investigated the growth of chlorophyte Scenedesmus quadricauda in the experiments designed to have the salinity level 0, 3, 6, 12 psu with manipulated N:P ratio of 2, 5, 10, 20 at constant N and P concentrations alternately. The experimental set up with highest salinity ended up with inhibited growth of the alga. The major finding of the study was the tolerance of salt stress of Scenedesmus at highest N:P ratio with highest N by synthesizing intracellular proline. In present investigation, monsoon period was significantly different than other times of the year in terms of nutrients enrichment and turbidity in both the two study sites which brought subsequent changes in other physicochemical characters of estuarine waters. In a study by Biswas et al [26] in 3 distributaries of river Ganges, highest water column transparency was recorded during post-monsoon and out of 10 bloom forming diatom species of those estuarine waters, 7 species bloomed during post-monsoon season. In a study by Naik et al [32] in Mahanadi estuary, inspite of high transparency, high Chlorophyll a concentration was reported during the summer of the year 2006-2007. Monsoon rainfall caused high turbidity in the estuarine water and reduced water column transparency. Low transparency limited the light penetration of water column and resulted in reduced gross primary productivity in the water by limiting photosynthesis [40]. Increased nutrient load might fuel the bacterial activity in the water and respiration in water column was increased during monsoon. Instead of being a stratified estuary, Mahanadi estuarine water showed a good oxygen saturation of 78% to 89% throughout the year [9]. Oxygen concentration in both the estuarine waters were above the hypoxia (DO < 3mgL⁻¹, Schmid et al, [41]). High turbidity probably helped the small celled chain forming species Skeletonema costatum to flourish in Saptamukhi estuarine water in monsoon. Skeletonema costatum was the 95% of total contributor of phytoplankton cell in the October when the river water nutrients were highest in concentration and turbidity was very high due to upwelling in estuary in Matang Mangrove Forest Reserve (MMFR), Malaysia [42]. In a study by Chu et al [43] it was found that, Skeletonema costatum population increased steadily while the total phytoplankton population decreased in a highly turbid estuary of South East Asia. They found the Skeletonema costatum population was strongly positively correlated with DIN:DIP, turbidity and DSi:DIN ration than with the nutrients like Nitrate, Phosphate or Silicate separately. Moreover, Skeletonema costatum population was negatively correlated with salinity. In Saptamukhi estuarine water, more or less consistent dissolved Silicate concentration throughout the year might have not contributed to the monsoonal increase of Skeletonema costatum population. Almost 7 fold increase in dissolved nitrate concentration in Mahanadi estuarine water during monsoon might have fuelled the Pediastrum growth. Chu et al [43] found strong positive correlation of Pediastrum sp with dissolved nitrate concentration. Stepwise multiple regression with Pediastrum sp population with DIN, DIP, dissolved silicate, salinity, water column transparency and DO, DIN was found to be the main factor for variability in the present study. Higher dissolved phosphorus concentration might be the result of factory run-off coming from the Paradeep fertilizer factories [32]. Fluctuation in N:P ratio may change the species dominance in a mixed phytoplankton community. According to Christopher et al [44] decadal variation from 8.2 to 45.0 after phytoplankton growth and competition among the different species in the community. The line diagram depict the present study result of variation of phytoplankton abundance and N:P molar ratio in two study sites (Figure 2).

Shallow, intertidal estuaries or estuaries having high fresh water flow tend to have strong vertical mixing or short flushing time, though localised bloom can appear in deeper areas with lack of proper vertical mixing [45]. High vertical mixing and short flushing time might be less compared to phytoplankton doubling time or turnover time in estuaries. So in shallow and strong vertically mixed estuaries, effect of high N:P ratio could be overshadowed by short flushing time. That can lead to low phytoplankton population and can resist bloom formation. In some of the estuaries in East Coast of India, removal of phosphate through adsorption along with sedimentation of suspended particle could alter N:P ratios and leave an impact of that on diatom population [29]. In Saptamukhi estuary, during the non-monsoonal months, sediment deposition in the river bed may result in phosphate adsorption and reduction in N:P ratio as dissolved inorganic nitrogen concentration did not change much throughout the year. The phosphate may become limiting for phytoplankton growth which resulted into opposite trend with N:P ratio in Saptamukhi estuarine water. On the other hand, effluents received from the phosphate industries help to maintain high phosphate concentration throughout the year in Mahanadi estuarine water. But dissolved nitrogen concentration reduced drastically from monsoon to post-monsoon and GPP decreased gradually in pre-monsoon may indicate the nitrogen limitation [44, 46], as high transparency in water column ensured the light availability for photosynthesis. In a mesocosm experiment in Lake Donghu [47] lower TN:TP ratio was the result of Phytoplankton (Mirocytis sp) bloom and at the depletion of bloom the ratio became double of previous value. In a study, low TN:TP (Total nitrogen concentration was 5380 mg.L⁻¹ and total phosphate concentration was 490 mg.L⁻¹) ratio was negatively correlated with phytoplankton biomass and the investigators concluded that nitrogen and phosphorus ration in shallow eutrophic water bodies not always indicate properly the enhancement of limitation of growth of phytoplankton population [12].

In Saptamukhi estuarine water, the phytoplankton community was mostly dominated by Bacillariophyceae probably as a result of dissolved nitrogen availability and a stable N:P ratio near to modified redfield ratio. Investigation of elemental composition of some Bacillariophyceae species (Thalassiosira
sp., *Pseudo-nitzschia* sp etc) revealed that N:P ratio was very close to redfield ratio in a study by Garcia et al [48]. They also observed changes in cellular N:P ratio of Bacillariophyceae changed with temperature but the value ranged between 15 to 30. Lowering of the salinity in monsoon season in Mahanadi estuarine water might cause the presence of fresh-water phytoplankton species which were mostly found in upstream station throughout the year. Among the different study stations, in Ria-Marine Bay system, spain, Chlorophycean species bloom was recorded in the fresh water influenced stations [49]. During peak time of phytoplankton growth i.e. post-monsoon season the Mahanadi estuary showed four-fold greater phytoplankton stock than in the Saptamukhi estuary. Silicate concentration was sufficient in both the estuarine water and supported Bacillariophyceae growth. Previous study found Bacillariophyceae was dominating among phytoplankton when silicate concentration was more than 2 µM[50].

The difference in the N: P ratio in the two estuaries could play vital role in the composition of phytoplankton population in water column. Changes in nutrient supply are often accompanied by alterations in nutrient ratios [51] and as the relative availability of nutrients plays a major role in structuring phytoplankton communities[52], alterations in nutrient ratios can change phytoplankton biomass and species composition especially if there is an increase in N and P availability, but not Si [53]. Availability of nitrogen and phosphorus in the water column played major role for the composition of phytoplankton community. As per the ANOVA result, variation in N:P ratio and phytoplankton abundance for both the estuaries were significant.

**CONCLUSION**

Difference in N:P ratio might control the composition of phytoplankton community in tropical estuaries though the

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**Table 3: One way ANOVA result of related parameters and phytoplankton numerical abundance in two study sites**

<table>
<thead>
<tr>
<th>SL No</th>
<th>Parameters</th>
<th>Saptamukhi</th>
<th>Mahanadi</th>
<th>N</th>
</tr>
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<tr>
<td></td>
<td></td>
<td>F</td>
<td>P</td>
<td>F</td>
</tr>
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<td>0.591</td>
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<td>Transparency</td>
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<td>3</td>
<td>Temperature</td>
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<td>0.767</td>
<td>0.8</td>
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<tr>
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<td>0.578</td>
<td>0.67</td>
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<tr>
<td>5</td>
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<td>6</td>
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<td>7</td>
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<tr>
<td>8</td>
<td>Phytoplankton</td>
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<td>8.22</td>
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</table>

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**Figure 2:** Monthly distribution of average number of Phytoplankton (No/l) and N:P Molar ratio in (a) Saptmukhi estuarine water (b) Mahanadi estuarine water.
abundance and occurrence of bloom were the compound result of many other factors which were not considered in this study.

ACKNOWLEDGEMENT

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