Phytoplankton diversity in response to abiotic factors along Orissa coast, Bay of Bengal
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ABSTRACT

The qualitative and quantitative distribution of phytoplankton with regional variation in the coastal waters of Orissa coast were presented out of the pooled data of eight stations sampled during summer season of 2008-09 and 2009-10. Significant spatial variations in temperature, pH, salinity, dissolved oxygen, biochemical oxygen demand, nitrites, nitrates, ammonia, phosphate, silicate were monitored during the study. Total ninety five species of phytoplankton were recorded belonging to Bacillariophyceae, Dinophyceae, Cyanophyceae, Haptophyceae group. Phytoplankton density ranged from approximately 8460- 50720 nos. /l and showed complete dominance of diatom genera (Bacillariophyceae) in both the year in all stations. The concentration of chlorophyll-a ranged from 0.45 to 7.6 mg/m$^3$. Statistical analysis predicted that the phytoplankton population was positively related to the chlorophyll-a concentration and nutrients. The present study indicates that the phytoplankton population, diversity and species composition fluctuate significantly in relation to the various physico-chemical parameters.

Keywords: Phytoplankton, Physico-chemical parameters, species abundance, chlorophyll-a.

1. Introduction

Coastal regions are the most productive ecosystems in the world, exemplified by the fact that coastal habitats provide feeding and reproduction ground for approximately 90% of the world’s marine fish catch (Bashar et al., 2005). Phytoplankton is one of the initial biological component from which the energy is transferred to higher organisms through food chain (Rajesh et al., 2002; Ananthan et al 2004; Tiwari et al., 2006; Sridhar et al., 2006; Shashi et al., 2008; Saravanakumar, et al., 2008 ). Phytoplankton abundance and composition in an aquatic ecosystem are regulated by various abiotic or physicochemical factors such as pH, light, temperature, salinity, turbidity and nutrients (Buzzi, 1999; Lewis, 2000; Sin et al., 2002).

Besides, their importances as the primary producers in food webs and ensuing ecological balance, phytoplankton are useful indicators of water quality (Kitner & Poulíčková, 2003; Rey et al., 2004). Marine phytoplankton communities usually comprise several taxonomic groups and contribute to primary production and interaction between trophic levels (Roy et al., 2006). The phytoplankton population represents the biological wealth of a water body, constituting a vital link in the food chain (Boyd, 1982). The purpose of this study was to investigate the taxonomic composition of coastal phytoplankton assemblages of two
2. Materials and methods

2.1 Study Site

Orissa is situated on the east coast which extends from Bahuda estuary mouth on its south to Digha on its north and lies between 17.49’N-22.34’ N latitude and 81.27’E-87.29’E longitude.

The present study was carried out in eight coastal areas of Orissa such as Gopalpur, Rushikulya, Chilika, Puri, konark, Paradip, Mahanadi and Chandipur. The present investigation area lies between 19°18’ 11’’ N to 21°27’09’’ N latitude and 84°58’01’’ E to 87°02’47’’ E longitude. (Table 1 and Figure 1). The sampling cruise was undertaken through coastal research vessel Sagar Purvi/Paschimi during summer season of the year 2008-09 and 2009-10. The phytoplankton sample was collected from the surface with the help of Niskin
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water sampler. The sample were preserved with 4% formalin to disallow possible dissolution of diatom cell walls (Nwankwo, 1996) and stored in the laboratory prior to qualitative analysis.

Surface water sample were also collected for various physical and chemical analysis following standard procedures and methods as outlined in standard methods of seawater analysis (APHA, 2008). Surface water and air temperature as well as pH were measured in situ by using WTW kit. Salinity, dissolved oxygen, biochemical oxygen demand, nitrites, nitrates, ammonia, phosphate, silicate were measured by standard methods of seawater analysis.

### Table 1: Latitude and longitude of sampling stations

| Sampling Stations | Latitude  | Longitude |
|-------------------|-----------|-----------|
| Gopalpur          | 19°18’ 11” N | 84° 58’01” E |
| Rushikulya        | 19°22’ 20” N  | 85° 04’35” E |
| Chilika           | 19°39’37” N  | 85° 30’19” E |
| Puri              | 19°47’36” N  | 85° 49’23” E |
| Konark            | 19°51’54” N  | 86° 06’43” E |
| Paradip           | 20°15’30” N  | 86° 40’34” E |
| Mahanadi          | 20°17’34” N  | 86° 43’00” E |
| Chandipur         | 21°27’09” N  | 87° 02’47” E |

2.2 Sampling and analysis

The samples for the analysis of nutrients and chlorophyll-a were preserved in ice box and brought to the laboratory and analyzed immediately. The water samples were filtered through GF/C filter paper and the filtrates were taken for the analysis of nutrients and the residue for chlorophyll-a analysis. The concentration of chlorophyll-a was estimated by the method of Strickland Parsons (1972). The nutrient contents (NO$_3^-$-N, NO$_2^-$-N, NH$_4^+$-N, SiO$_4^{4-}$-Si, and PO$_4^{3-}$-P) were determined in duplicate samples by UV-Visible spectrophotometer (Perkin-Elmer No. Lambda 35) as described in standard methods of seawater analysis (Grasshoff, Ehrhardt, & Kremling, 1999).

2.3 Phytoplankton Analysis

The phytoplankton species were identified with the help of biological microscope and counted in Sedgewick-Rafter counting chamber taking 1 ml of sample aliquot as per the phytoplankton identification protocol (Subramanyan, 1946; Desikachari, 1986).

3. Result and discussion

The hydrographical parameters of two years in each sampling stations were shown in the Table-2(A & B). Temperature is an important factor which regulates the biogeochemical activities in the aquatic environment. During the investigating period, the air and water temperature remains fairly constant with slight variation. Highest water temperature was recorded in Mahanadi shore i.e. 30.2°C. The air temperature varied from 21.0 to 35.7°C. In the foregoing study the water pH was alkalinity in nature which varied from 8.13 to 8.45. This stable pH may be attributed to the buffer properties of sea water (Nwankwo, 1994). The salinity is the main physical parameter that can be attributed to the plankton diversity.
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(Kouwenberg, 1993; Ramaiah & Nair, 1997; Chandromohan & Sreenivas, 1998; Balasubramanian & kannel, 2005). And in the current study, it ranged from 22.10 to 28.96 PSU and highest value was recorded in Gopalpur. The DO values varied between 6.14 and 9.14 mg/l while BOD ranged from 0.81 to 3.26 mg/l. The maximum value of BOD reached up to 3.20 mg/l in Paradip station in the year 2009-10 which may be due to high phytoplankton population density as shown in table-2. High level of BOD value could be attributed to the discharge of pollutants through washing, sewage contamination, agricultural wastes etc.

Nutrients are essential for survival, reproduction and growth of phytoplankton and in an aquatic environment it serves as bio-indicators. Along Orissa coast, Puri shore recorded the highest concentration of nitrite, nitrate and ammonia which might be due to direct drainage of industrial waste, fertilizer run off, municipality sewage and domestic sewage (Welch, 1992). The concentration of phosphate ranged from 0.13 to 54.37 µmol/l and highest was recorded in Mahanadi which may is attributed to the inputs of domestic and industrial effluents of fertilizer based industries. While the concentration of silica ranged from 3.96 to 85.20 µmol/l. The concentration of Nitrite (1.62 µmol/l) was found to be highest in Gopalpur in the year 2008-09. Dissolved phosphorous is probably the most important factor affecting the water quality, because it’s needed for phytoplankton growth (Boyd, 1982; Hossain, Begum, Hoque, Karim & Wahab, 2006). In the current study the highest concentration of phosphate was found in Mahanadi station which may be attributed to inputs of domestic and industrial effluents. The chlorophyll-a concentration ranged from 1.32 to 7.6 mg/m³ and 0.45 to 5.39 mg/m³ in the year 2008-09 and 2009-10, respectively. The high value of chlorophyll-a concentration in Puri and Mahanadi may be due to high phytoplankton population during the particular period.

Table 2 (a): Hydro chemical parameters in Puri, Paradip, Mahanadi and Gopalpur stations in both the year

|                | Puri 2008-09 | Puri 2009-10 | Paradip 2008-09 | Paradip 2009-10 | Mahanadi 2008-09 | Mahanadi 2009-10 | Gopalpur 2008-09 | Gopalpur 2009-10 |
|----------------|--------------|--------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Air temp(°C)   | 26.4         | 31.35        | 25.0            | 30.30           | 26.8            | 30.60           | 26.6            | 32.90           |
| Water temp(°C) | 26.2         | 29.65        | 24.9            | 27.70           | 25.6            | 30.20           | 26.0            | 30.00           |
| pH             | 8.25         | 8.35         | 8.18            | 8.21            | 8.16            | 8.33            | 8.23            | 8.15            |
| Salinity(PSU)  | 27.46        | 25.96        | 25.36           | 27.77           | 22.25           | 24.32           | 28.05           | 28.96           |
| DO(mg/l)       | 6.73         | 7.29         | 7.06            | 7.32            | 7.03            | 7.35            | 7.09            | 6.58            |
| BOD(mg/l)      | 2.25         | 2.91         | 1.39            | 3.26            | 1.46            | 2.55            | 1.38            | 1.27            |
| NO2(µmol/l)    | 1.04         | 0.21         | 0.67            | 0.22            | 0.53            | 0.32            | 1.62            | 0.35            |
| NO3(µmol/l)    | 8.03         | 9.44         | 2.17            | 6.28            | 2.06            | 4.91            | 2.00            | 2.43            |
| NH4+(µmol/l)   | 18.85        | 4.02         | 0.73            | 0.64            | 2.12            | 1.05            | 0.45            | 0.53            |
| TN(µmol/l)     | 93.435       | 51.13        | 53.55           | 12.32           | 72.00           | 34.76           | 80.55           | 62.31           |
| PO4(µmol/l)    | 32.495       | 0.46         | 36.25           | 0.72            | 54.37           | 2.81            | 28.75           | 0.23            |
| TP(µmol/l)     | 70.935       | 1.58         | 73.75           | 1.19            | 87.50           | 4.31            | 32.50           | 0.78            |
| SiO4(µmol/l)   | 54.325       | 8.70         | 10.95           | 3.96            | 85.20           | 17.06           | 8.47            | 4.23            |
| Phytopop(nos./l)| 30000        | 50720       | 24607           | 49800           | 35572           | 13860           | 20429           | 15660           |
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| Parameters | Chilika | Rushikulya | Konark | Chandipur |
|------------|---------|------------|--------|-----------|
| Air temp(°C) | 31.2 | 35.70 | 29.6 | 31.50 | 31.3 | 32.20 | 21.0 | 26.40 |
| Water temperature (°C) | 27.4 | 29.70 | 26.6 | 29.40 | 26.7 | 29.60 | 21.5 | 27.10 |
| pH | 8.16 | 8.41 | 8.21 | 8.15 | 8.18 | 8.45 | 8.13 | 8.16 |
| Salinity(PSU) | 27.83 | 26.31 | 27.35 | 28.79 | 25.92 | 27.55 | 22.10 | 25.98 |
| DO(mg/l) | 7.14 | 6.90 | 6.35 | 6.55 | 6.14 | 7.32 | 6.84 | 7.90 |
| BOD(mg/l) | 1.03 | 1.36 | 0.81 | 0.36 | 1.34 | 0.91 | 2.30 | 2.78 |
| NO2(µmol/l) | 0.72 | 0.12 | 0.58 | 0.20 | 0.65 | 0.17 | 1.10 | 1.15 |
| NO3(µmol/l) | 3.40 | 7.17 | 3.13 | 1.15 | 1.62 | 5.12 | 2.44 | 4.91 |
| NH4+(µmol/l) | 0.42 | 0.51 | 0.52 | 0.35 | 0.39 | 0.27 | 1.24 | 1.33 |
| TN(µmol/l) | 46.55 | 28.52 | 84.53 | 12.32 | 57.15 | 26.48 | 50.03 | 53.83 |
| PO4(µmol/l) | 13.75 | 0.62 | 11.25 | 0.13 | 17.50 | 0.19 | 11.25 | 0.22 |
| TP(µmol/l) | 21.87 | 1.61 | 19.37 | 0.47 | 23.12 | 1.14 | 13.75 | 0.62 |
| SiO4(µmol/l) | 40.92 | 7.11 | 44.20 | 5.53 | 13.35 | 4.14 | 6.74 | 13.32 |
| Phytoplankton(nos/l) | 17607 | 15000 | 21671 | 8460 | 20571 | 15840 | 9857 | 16800 |
| Chl-a(mg/m3) | 2.98 | 5.39 | 3.19 | 1.87 | 7.6 | 0.56 | 1.96 | 0.53 |
| Zooplankton(org./m3) | 190 | 909 | 1205 | 2885 | 885 | 5685 | 789 | 481 |
| Zoobiomass(ml/m3) | 0.121 | 0.32 | 0.962 | 0.16 | 0.5 | 0.8 | 0.211 | 0.2 |

Table 2(b): Hydro chemical parameters in in Chilika, Rushikulya, Konark and Chandipur stations in both the year

3.1 Phytoplankton

A total of ninety five species of phytoplankton were identified and recorded from four different taxonomic groups- Bacillariophyceae, Dinophyceae, Cyanophyceae and Haptophyceae. In both the year the phytoplankton population was dominated by Bacillariophyceae followed by Dinophyceae. In the Bacillariophyceae group centrals type constitute about 58% and rest by Pennales. In the year 2008-09 only 5% of total phytoplankton population was constituted by Cyanophyceae and 2% by Haptophyceae, but in the year 2009-10 there was complete absence of Cyanophyceae and Haptophyceae group (Figure.2). During the year 2008-09, Puri recorded the highest number of species composition i.e. 22 followed by Paradip due to high nutrient concentration. In the year 2009-10 highest number of species was recorded in Paradip station followed by Mahanadi.

The species recorded during the study period and their abundance in percentage was presented in table 3(a&b). Phytoplankton species composition and its abundance exhibited
temporal variation corresponding to changes in the hydrographical parameters. The phytoplankton count was mainly dominated by *Thalassiothrix longissima*, *Coscinodiscus eccentricus*, *Skeletonema costatum*, *Chaetoceros* sp., *Ceratium* sp., *Prorocentrum* sp., *Protoperidinium* sp. etc. About thirty two species of phytoplankton were found once in a particular station and year. A few pollution indicating species, viz. *Dinophysis* sp., *Nitzschia seriata*, *Prorocentrum micans*, *Phaeocystis* sp., *Oscillatoria* sp. were recorded.

Diatoms dominated the phytoplankton population during the study. This finding is also similar to earlier reported by many workers (Olaniyan, 1969; Onyema et al., 2003). The highest number of phytoplankton in the study was recorded in Mahanadi due to high load of the nutrients and influx of freshwater. In this study it is demonstrated that the phytoplankton species composition and diversity changes in relation to various physico-chemical parameters. High species diversity coincided with significantly higher relative diatom abundance. Bacillariophyceae have been reported by many authors to be dominants in the phytoplankton composition (Hadi et al., 1984; Polat et al., 2000). The study reflects that the variation in phytoplankton abundance, composition and diversity have been greatly affected by various abiotic factors.

![Figure 2: Total Phytoplankton in the year 2008-09 and 2009-10](image)

**Figure 2:** Total Phytoplankton in the year 2008-09 and 2009-10

**Table 3(a):** Relative Abundance of phytoplankton species (%) in Puri, Paradip, Mahanadi and Gopalpur stations during both the year

| Species              | Puri  | Paradip | Mahanadi | Gopalpur |
|----------------------|-------|---------|----------|----------|
|                      | 2008-09 | 2009-10 | 2008-09 | 2009-10 | 2008-09 | 2009-10 | 2008-09 | 2009-10 |
| Actinotychus sp.*    | ---    | ---    | ---     | 2.52    | ---    | ---    | ---    | ---    |
| Actinotychus undulatus | ---    | ---    | ---     | ---     | ---    | ---    | ---    | ---    |

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| Phytoplankton Species | Concentration 1 | Concentration 2 | Concentration 3 | Concentration 4 | Concentration 5 | Concentration 6 | Concentration 7 | Concentration 8 |
|----------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Amphora lineolata    | 2.55           | ---            | 5.00           | ---            | ---            | 2.27           | ---            | ---            |
| Asterionella japonica| 3.66           | 4.11           | ---            | ---            | ---            | ---            | ---            | ---            |
| Auliscus reticulatus*| ---            | ---            | ---            | ---            | ---            | ---            | ---            | ---            |
| Bacillaria paradoxa  | 2.50           | ---            | ---            | ---            | ---            | ---            | ---            | ---            |
| Bacteriastrum hyalinum*| ---        | 2.74           | ---            | ---            | ---            | ---            | ---            | ---            |
| Bacteriastrum varians| ---            | ---            | ---            | 3.15           | ---            | ---            | ---            | ---            |
| Bidulphia heteroceros| ---            | ---            | ---            | 2.01           | ---            | ---            | ---            | ---            |
| Bidulphia mobiliensis| ---            | 2.59           | 6.62           | ---            | 3.21           | ---            | 4.60           | ---            |
| Bidulphia sinensis  | ---            | ---            | 6.67           | ---            | ---            | ---            | ---            | ---            |
| Caloneis elongata    | 6.189          | ---            | ---            | ---            | ---            | 9.09           | ---            | ---            |
| Campylodiscus iengarii*| 10.00       | ---            | ---            | ---            | ---            | ---            | ---            | ---            |
| Campylodiscus sp.    | ---            | ---            | ---            | 7.55           | ---            | ---            | ---            | ---            |
| Ceratium furca       | ---            | ---            | ---            | ---            | ---            | 5.75           | ---            | ---            |
| Ceratium sp.         | 2.50           | ---            | ---            | 1.58           | ---            | ---            | ---            | ---            |
| Chaetoceros capense* | ---            | ---            | ---            | 4.10           | ---            | ---            | ---            | ---            |
| Chaetoceros constrictus*| ---         | ---            | ---            | 1.58           | ---            | ---            | ---            | ---            |
| Chaetoceros carvisetus*| ---         | ---            | ---            | ---            | ---            | 2.41           | ---            | ---            |
| Chaetoceros lorentzianus| ---          | ---            | 5.00           | ---            | 7.63           | ---            | ---            | ---            |
| Chaetoceros peruvianus| ---           | 4.4186         | ---            | 1.26           | ---            | 0.40           | ---            | ---            |
| Chaetoceros socialis*| ---            | ---            | ---            | ---            | 6.43           | ---            | ---            | ---            |
| Chaetoceros sp.      | ---            | 6.93           | ---            | 5.68           | ---            | 7.23           | ---            | ---            |
| Coscinodiscus eccentricus**| ---         | 8.91           | ---            | 10.73          | 9.43           | 3.61           | ---            | 12.64          |
| Coscinodiscus gigas  | 7.32           | ---            | 8.33           | ---            | 7.55           | 5.4            | ---            | ---            |
| Cyclotella striata   | ---            | ---            | ---            | 4.02           | ---            | ---            | ---            | ---            |
| Dinophysis caudata   | ---            | 1.37           | ---            | ---            | 0.40           | ---            | ---            | ---            |
| Diploneis weissflogii| ---            | 4.11           | ---            | 1.89           | ---            | 0.40           | ---            | ---            |
| Ditylum brightwelli  | ---            | ---            | ---            | 1.26           | ---            | 2.81           | ---            | ---            |
| Ditylum sol          | ---            | ---            | 5.00           | ---            | 1.89           | 0.80           | ---            | ---            |
| Eucampia sp.*        | ---            | ---            | 3.33           | ---            | ---            | ---            | ---            | ---            |
| Eucampia zoodiacus   | ---            | 2.74           | ---            | 3.15           | ---            | 5.22           | ---            | ---            |
| Fragillaria sp.*     | ---            | ---            | ---            | 0.95           | ---            | ---            | ---            | ---            |
| Gonialux minima      | ---            | ---            | ---            | ---            | ---            | ---            | ---            | ---            |
| Gonialux birostris*  | 4.88           | ---            | ---            | ---            | ---            | ---            | ---            | ---            |
| Gramatophora undulate*| 3.66          | ---            | ---            | ---            | ---            | ---            | ---            | ---            |
| Guinardia striata*   | ---            | ---            | 0.95           | ---            | ---            | ---            | ---            | ---            |
| Gyrosigma balticum   | ---            | ---            | ---            | ---            | 2.99           | ---            | 2.30           | ---            |
| Gyrosigma sp.*       | ---            | ---            | 1.58           | ---            | ---            | ---            | ---            | ---            |
| Lauderia annulata    | ---            | ---            | 0.63           | ---            | ---            | ---            | ---            | ---            |
| Leptocylindrus minimus| ---            | ---            | 6.62           | ---            | 3.61           | ---            | ---            | ---            |
| Licmophora abbreviate*| ---            | ---            | ---            | ---            | ---            | ---            | ---            | ---            |
| Licmophora sp.*      | ---            | ---            | ---            | 0.40           | ---            | ---            | ---            | ---            |
| Mediopyxis helysia   | ---            | ---            | 6.31           | ---            | 2.01           | ---            | ---            | ---            |
| Phytoplankton species                  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---------------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|
| Melosira sulcata                      | 4.11 |       | 1.26 |       | 0.40 |       |       |       |     |     |     |     |     |     |
| Navicula longa                        | 2.74 |       | 2.84 |       |       |       |       |     |     |     |     |     |     |     |
| Navicula sp.                          |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Nitzschia closterium*                 | 4.88 |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Nitzschia longissima                  |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Nitzschia sigma                       |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Nitzschia seriata                     | 6.1585 |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Noctiluca miliaris                    |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Noctiluca sp.*                        | 7.50 |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Oscillatoria sp.                      |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Phaeocystis sp.*                      |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Pinnularia alpina                     |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Pleurosigma directum                  |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Pleurosigma elongatum                 |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Pleurosigma sp.                       |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Pseudonitzschia pungens*              |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Pseudonitzschia sp.*                  |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Pyrocystis pseudonoctiluca*           |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Rhabdonema mirficum*                  |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Rhabdosphaera sp.*                    | 1.22 |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Raphoneis discoide*                   |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Rhizosolenia alata                    | 11.738 | 6.85 |       |       | 9.43 | 2.29 | 4.55 |     |     |     |     |     |     |     |
| Rhizosolenia castracanei              | 5.5793 |       |       |       | 3.77 | 4.55 |       |     |     |     |     |     |     |     |
| Rhizosolenia cochlea*                 | 1.22 |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Rhizosolenia crassipina               | 2.44 | 5.94 |       |       | 2.3 |       |       |     |     |     |     |     |     |     |
| Rhizosolenia cylindrus                | 9.2683 |       |       |       |       | 22.73 |       |     |     |     |     |     |     |     |
| Rhizosolenia imbricata                | 3.66 | 0.63 |       |       |       |       |       |     |     |     |     |     |     |     |
| Rhizosolenia setigera                 | 4.88 | 11.67 | 1.58 | 18.87 |       | 2.27 |       |     |     |     |     |     |     |     |
| Rhizosolenia stolterforthii           |       |       |       |       | 2.01 |       |       |     |     |     |     |     |     |     |
| Rhizosolenia styliformis              | 2.44 |       | 2.84 |       | 3.21 |       |       |     |     |     |     |     |     |     |
| Skeletonema costatum**                | 2.74 | 8.33 | 1.26 | 9.43 | 13.25 |       |       |     |     |     |     |     |     |     |
| Stephanopyxis turris*                 |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Surirella eximia                      | 2.74 | 3.33 | 2.21 | 7.55 |       |       |       |     |     |     |     |     |     |     |
| Surirella fluminensis*                |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Synedra formosa                       |       |       |       |       |       | 3.77 |       |       |     |     |     |     |     |     |
| Thalassionema nitzschioides           | 4.42 |       | 2.21 |       | 4.82 |       |       |     |     |     |     |     |     |     |
| Thalassiosera sp.                     |       |       |       |       |       |       |       |     |     |     |     |     |     |     |
| Thalassiosera subtilis                | 8.54 | 3.15 | 3.77 | 0.80 |       |       |     |     |     |     |     |     |     |     |
| Thalassiothrix                        | 24.116 | 33.745 | 15.00 | 1.89 | 1.61 | 43.18 | 42.53 |     |     |     |     |     |     |     |
Table 3(b): Relative Abundance of phytoplankton species (%) in Chilika, Rushikulya, Konark and Chandipur stations during both the year

| Species                  | Chilika       | Rushikulya   | Konark       | Chandipur    |
|--------------------------|---------------|--------------|--------------|--------------|
| 2008-09                  | 2009-10       | 2008-09      | 2009-10      | 2008-09      | 2009-10 |
| Actinotychus sp.*        | ---           | ---          | ---          | ---          | ---      | ---      |
| Actinotychus undulatus   | 10.34         | ---          | ---          | ---          | ---      | 13.04    |
| Amphora lineolata        | ---           | ---          | ---          | ---          | ---      | ---      |
| Asterionella japonica    | ---           | 8.00         | 10.81        | 3.03         | 5.56     | ---      |
| Auliscus reticulates*    | ---           | ---          | ---          | 5.56         | ---      | ---      |
| Bacillaria paradoxa      | ---           | ---          | 5.41         | ---          | ---      | 4.04     |
| Bacteriastrum hyalinum*  | ---           | ---          | ---          | ---          | ---      | ---      |
| Bacteriastrum varians    | ---           | ---          | 2.13         | ---          | ---      | ---      |
| Biddulphia heteroceros  | 13.79         | ---          | ---          | 5.56         | ---      | ---      |
| Biddulphia mobiliensis   | ---           | 4.00         | ---          | 5.05         | ---      | ---      |
| Biddulphia sinensis      | ---           | ---          | ---          | ---          | ---      | 9.52     |
| Caloneis elongata        | ---           | ---          | ---          | ---          | ---      | ---      |
| Campylococcus iyengari*  | ---           | ---          | ---          | ---          | ---      | ---      |
| Campylococcus sp.         | ---           | ---          | 5.41         | 3.03         | ---      | ---      |
| Ceratium furca           | ---           | ---          | ---          | ---          | 23.91    | ---      |
| Ceratium sp.             | ---           | ---          | ---          | ---          | ---      | ---      |
| Chaetoceros capense*     | ---           | ---          | ---          | ---          | ---      | ---      |
| Chaetoceros constrictus* | ---           | ---          | ---          | ---          | ---      | ---      |
| Chaetoceros curvisetus*   | ---           | ---          | ---          | ---          | ---      | ---      |
| Chaetoceros              | ---           | ---          | ---          | 2.02         | ---      | ---      |

Rare species occurring in a particular stations and year --- *
| Species                  | Abundance 1 | Abundance 2 | Abundance 3 | Abundance 4 | Abundance 5 | Abundance 6 |
|-------------------------|-------------|-------------|-------------|-------------|-------------|-------------|
| *Lorenzianus*            |             |             |             |             |             |             |
| *Chaetoceros peruvianus* |             |             |             |             |             |             |
| *Chaetoceros socialis*   |             |             |             |             |             |             |
| *Chaetoceros sp.*        |             |             |             |             |             |             |
| *Coscinodiscus eccentricus*** |         | 13.33       | 8.51        | 8.33        | 11.11       | 11.96       | 16.67       |
| *Coscinodiscus gigas*    | 10.34       |             |             |             |             |             |             |
| *Cyclotella striata*     |             |             | 2.13        |             |             |             |             |
| *Dinophysis caudata*     |             |             |             |             |             |             |             |
| *Diploneis weissflogii*  |             |             |             |             |             |             |             |
| *Ditylum brightwelli*    |             |             | 5.41        |             |             |             |             |
| *Ditylum sol*            |             |             |             |             |             |             |             |
| *Eucampia sp.*           |             |             |             |             |             |             |             |
| *Eucampia goodiacus*     |             |             | 2.13        |             |             |             |             |
| *Fragillaria sp.*        |             |             |             |             |             |             |             |
| *Goniaulax minima*       | 6.90        |             |             |             |             |             |             |
| *Goniaulax birostris*    |             |             |             |             |             |             |             |
| *Gramatophora undulate*  |             |             |             |             |             |             |             |
| *Guinardia striata*      |             |             |             |             |             |             |             |
| *Gyrosigma balticum*     |             |             |             | 5.56        |             |             |             |
| *Gyrosigma sp.*          |             |             |             |             |             |             |             |
| *Lauderia annulata*      |             |             |             |             | 1.01        |             |             |
| *Leptocylindrus minimus* |             |             |             |             |             |             |             |
| *Licmophora abbreviate*  |             |             |             |             |             |             |             |
| *Licmophora sp.*         |             |             |             |             |             |             |             |
| *Mediopyxis helysia*     |             |             |             |             |             |             |             |
| *Melosira sulcata*       |             |             | 2.13        |             |             |             |             |
| *Navicula longa*         |             |             |             |             |             |             |             |
| *Navicula sp.*           |             |             |             |             |             |             |             |
| *Nitzschia closteriam*   |             |             |             |             |             |             |             |
| *Nitzschia longissima*   |             |             |             |             |             |             |             |
| *Nitzschia sigma*        |             |             |             |             |             |             |             |
| *Nitzschia seriata*      |             |             |             |             |             |             |             |
| *Noctiluca miliaris*     |             |             |             |             |             |             |             |
| *Noctiluca sp.*          |             |             |             |             |             |             |             |
| *Oscillatoria sp.*       |             |             |             |             |             |             |             |
| Phytoplankton species | Abiotic Factors | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|-----------------------|----------------|---|---|---|---|---|---|---|---|---|---|---|---|
| Phaeocystis sp.*      | ---            | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Pinnularia alpina     | ---            | --- | 2.70 | --- | --- | --- | --- | --- | --- | --- | --- | --- | 2.38 |
| Pleurosigma directum  | ---            | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Pleurosigma elongatum  | ---            | --- | 8.11 | --- | 8.33 | --- | --- | --- | --- | --- | --- | --- | --- |
| Pleurosoma sp.         | ---            | 5.33 | --- | --- | --- | --- | --- | 6.06 | --- | --- | 11.90 | --- | --- |
| Prorocentrum micans   | ---            | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Prorocentrum sp.*     | ---            | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Protoperidinium sp.   | ---            | 6.67 | --- | --- | --- | --- | --- | 2.02 | --- | --- | --- | --- | --- |
| Protoperidium stenii  | ---            | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Pseudonitzschia pargens* | ---        | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Pseudonitzschia sp.*  | ---            | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Pyrocystis pseudonockiuca* | ---        | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rhabdonema mirificum* | ---            | --- | --- | --- | --- | --- | --- | 9.78 | --- | --- | --- | --- | --- |
| Rhabdiosphaera sp.*   | ---            | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rhaphoneis discoides* | ---            | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rhizosolenia alata    | ---            | 2.67 | 10.81 | 6.38 | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rhizosolenia castracanei | ---       | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rhizosolenia cochlea* | ---            | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rhizosolenia crassipina | ---         | --- | --- | 16.67 | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rhizosolenia cylindrus | ---            | --- | 8.11 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rhizosolenia imbricata | ---            | --- | --- | --- | --- | --- | --- | --- | --- | 8.08 | 6.52 | --- | --- |
| Rhizosolenia setigera  | 24.14          | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rhizosolenia stollerforthiia | ---      | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rhizosolenia styliformis | ---         | --- | --- | --- | --- | --- | --- | 3.03 | --- | --- | --- | --- | --- |
| Skeletonema costatum** | 17.24          | 4.00 | --- | 10.64 | 8.33 | --- | --- | --- | --- | --- | --- | --- | --- |
| Stephanopyxis turris* | 6.90           | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Surirella eximia      | ---            | --- | --- | --- | --- | --- | --- | 2.78 | --- | --- | --- | --- | --- |
| Surirella fluminensis* | ---            | --- | --- | --- | --- | --- | --- | --- | --- | --- | 7.14 | --- | --- |
| Synedra formosa       | ---            | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Thalassionema nitzschioides | ---        | 5.33 | --- | 4.26 | --- | 6.06 | --- | --- | 8.33 | --- | --- | --- | --- |
| Thalassiosera sp.     | ---            | 10.67 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
3.2 Statistical Analysis

Correlation Coefficient matrix is calculated among 16 Physico-chemical and biological variables (Table-4). The Phytoplankton population has showed a very strong positive correlation with the concentration of chlorophyll-a. The correlation between phytoplankton population and other parameters except water temperature, total suspended solid, nitrite and total nitrogen determined in this study were positive. The correlation matrix shows a negative relationship of phytoplankton population with that of total suspended solid. The correlation matrix showed that the phytoplankton population had a significant positive correlation with chlorophyll-a concentration at \( p \leq 0.01 \), while it had a negative correlation with nitrite-nitrogen and total nitrogen-nitrogen at \( p \leq 0.05 \). The chlorophyll-a concentration had a significant positive correlation with ammonia-nitrogen and total phosphorus at \( p \leq 0.01 \) and \( p \leq 0.05 \), respectively.

Table 4: Correlation coefficient matrix between physico-chemical characteristics in different stations during both the year

|       | P  | Chl-a | Z   | S   | DO | BO | NO₂ | NO₃ | NH₄* | TN | PO₄ | T   | P   | SiO₄ |
|-------|----|-------|-----|-----|----|----|-----|-----|------|----|-----|-----|-----|------|
| P     | 1  |       |     |     |    |    |     |     |      |    |     |     |     |      |
| Chl-a | 0.63* | 1    |     |     |    |    |     |     |      |    |     |     |     |      |
| Z     | 0.35 | 0.06 | 1   |     |    |    |     |     |      |    |     |     |     |      |
| S     | 0.03 | 0.09 | 0.15 | 1   |    |    |     |     |      |    |     |     |     |      |
| DO    | 0.15 | 0.05 | 0.23 | -   | 0.27 | 1 |     |     |      |    |     |     |     |      |
| BO D  | 0.39 | 0.34 | 0.09 | -   | 0.2 | 0.5 | 1   |     |      |    |     |     |     |      |
| NO₂   | - | 0.18 | 0.21 | -   | 0.27 | 0.1 | 0.2 | 0.73 | 1   |     |     |     |     |      |
| NO₃   | 0.29 | 0.27 | -   | 0.1 | 0.3 | 0.4 | -   | 1   |     |     |     |     |     |      |
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|      | 0.01 | 2    | 3    | 7*   | 0.3  | 3    |
|------|------|------|------|------|------|------|
| NH4  | 0.24 | 0.70 | -0.30| 0.0  | -0.0 | 0.2  |
|      |      |      |      |      |      |      |
| TN   | -0.03| 0.31 | -0.53| -0.1 | -0.2 | -0.1 |
|      |      |      |      |      |      |      |
| PO4  | 0.18 | 0.41 | -0.33| -0.1 | -0.2 | 0.2  |
|      |      |      |      |      |      |      |
| TP   | 0.24 | 0.51 | -0.33| -0.2 | -0.1 | 0.2  |
|      |      |      |      |      |      |      |
| SiO4 | 0.10 | 0.40 | -0.26| -0.4 | -0.0 | 0.1  |
|      |      |      |      |      |      |      |

P-Phytoplankton population, Z- Zooplankton population, S- Salinity

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