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Seasonal variation of phytoplankton community in Gopalpur Creek: a tropical t idal backwater ecosystem, East Coast of India

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Present study consists of phytoplankton community of Gopalpur creek in pre-monsoon, monsoon and post-monsoon season There was a significant seasonal variation in water temperature (p < 0.01). Salinity and *p*H varied significantly (p < 0.05) among the stations. Chlorophyll ***a*** and phytoplankton density found to vary significantly (p < 0.01) among seasons rather than the stations. A total of 99 phytoplankton species were identified. Diatoms formed 77, dinoflagellates 14, green algae five, blue green algae two and cocolithophore one species. Phytoplankton species composition was found dissimilar in the three seasons. In pre-monsoon *Noctiluca scintillans*, *Thalassiothrix longissima*, *Odontella sinensis*, *Thalassionema nitzschioides*, *Coscinodiscus gigas*, *Rhizosolenia alata* formed the dominant species. In monsoon, *Rhizosolenia alata*, *Pleurosigma elongatum*, *Melosira sulcata*, *Amphora coastatum*, *Rhizosolenia setigera* dominated the phytoplankton population. In post-monsoon *Odontella sinensis*, *Rhizosolenia setigera*, *Coscinodiscus gigas*, *Thalassiothrix longissima*, *Noctiluca scintillans*, *Oscillatoria spp.* dominated. Univariate diversity indices showed maximum diversity during post-monsoon. Pielou's evenness (J') and Simpson's dominance have shown little variation among the seasons.

[Keywords: Phytoplankton, Seasonal, Gopalpur creek, East coast of India]

Introduction

Phytoplankton at the base of the marine food chains has evolved into a diverse group of photosynthetic organisms. These are the skeleton of food web dynamics, which control many ecological processes such as, carbon budget[1], modulation of sea surface temperature (SST) through absorption of solar radiation affecting global climate[2] etc. They are very efficient and easily detectable indicators of ecological alteration. Food chain trophic conditions can be estimated by assessing the phytoplankton abundance and chlorophyll concentrations[3-4]. Presence of certain species of phytoplankton can trigger the fishery or deplete also resulting toxicity. Patterns of phytoplankton and water quality are interdependent in nature[5]. Phytoplankton analyses can be utilized as indicators of water quality change in the system[6]. For the last few decades, there has been much interest to study different factors influencing the development of phytoplankton communities, primarily in relation to physico-chemical factors[7-9]. Phytoplankton composition is affected by different environmental factors such as pH, light and temperature[10].

Review of literature shows that some work on floristic composition of phytoplankton of south coast of Odisha with occurrence of blooms has been reported by several workers[11-17]. Thorough perusal of literature revealed a few published study, fully or partially related to the water quality of the study area[18-19]. Present study primarily focuses on the determination of the seasonal variation in phytoplankton community with its associated physicochemical parameters which was previously attempted by Choudhury and Panigrahy in January 1987 to December 1988 with the report of *Asterionella glacialis* bloom[14]. After a long interval of 21 years our study is directed to bridge the gap. As the study area is under the influence of anthropogenic pressure by means of receiving pollutants from Gopalpur Township and nearby hatcheries.

Materials and Methods

Gopalpur creek is a backwater biotope situated in the north-eastern side of Gopalpur NAC along southern Odisha (latitude 19º16'22"N - 19º15'39"N and longitude 84º54'0.6"E - 84º55'15"E)and connected to Bay of Bengal by means of a small channel (Fig. 1). The locations of five study sites (S-1 to S-5) are also shown in Fig .1. Average annual rainfall of the region is 1,210 mm[20] and has semidiurnal tidal pattern[21]. Regular influx and outflux of seawater makes this ecosystem fragile. In summer, due to formation of sand bar, the inlet is normally closed. Seawater enters to the creek by means of seepage through porous sandbar[18] and flushing during regular high tide. In monsoon, the creek receives freshwater from adjacent agriculture fields as runoff whereas in post-monsoon, by means of a small stream "*Nandia Nala*". This area is having immense importance due to its capture (marine fishes) and culture (shrimp) fishing activities[18]. Nearby presence of Gopalpur Port, introduction of pollutants by means of sewage discharge from Gopalpur Township, agricultural runoff, oil spills due to regular mechanized fishing boat movements and anthropogenic influence due to tourism activities of Gopalpur beach, one of the famous beaches of Odisha receive attention for the scientific study of this area.

Sampling description

Water samples were collected from five selected stations (Fig. 1) within Gopalpur creek. Three field surveys were made during pre-monsoon (PRM), monsoon (MON) and post-monsoon (POM) of year 2010. Above seasons [PRM (Mar-Jun), MON (July-Oct), POM (Nov-Feb)] were classified according to the onset and termination of south west monsoon which is the climatic factor of the study area[18]. At each station, surface water samples were collected using a plastic bucket. Air and water temperature were measured using a mercury filled centigrade thermometer of t 0.1^{o}C accuracy. The *p*H of the water sample was recorded by a digital field *p*H meter (Model Eutech *p*H scan 2) with an accuracy of 0.1 unit. Water samples for estimation of salinity were collected in separate containers and taken to the laboratory for analysis. Samples for the analysis of dissolved oxygen (DO) were fixed with Winkler's A and B solution. Phytoplankton samples were collected by surface hauling and preserved with acid Lugol's iodine solution. All the sample collections were made during high tide.

Laboratory analysis

Salinity was estimated following the Knudsen's titrimetric method[22] and expressed in PSU. DO was analyzed by Winkler's titration method[23]. Phytoplankton samples, preserved with Lugol's iodine solution, were analyzed for phytoplankton cell density and taxonomic identification. 1 mL of the concentrated sample was placed in a Sedgwick Rafter cell and observed for identification and counting under a compound microscope. Standard literature such as Easter E. Cupp[24]**,** Newell & Newell[25] and Verlencar and Somshekar[26] were referred.

Data Analysis

The data was classified into three seasons: Pre-Monsoon (PRM), Monsoon (MON) and Post monsoon (POM). Analysis of variance (ANOVA) was applied to hydrographic and biological datasets obtained to see any significant variation among seasons as well as stations. Correlation analysis among all the parameters was performed to find out any possible relationship between them. Univariate measures [Shannon-Wiener diversity index (H'), Margalef's species richness (R) and Pielou's evenness (J'), Simpson dominance (D)] were

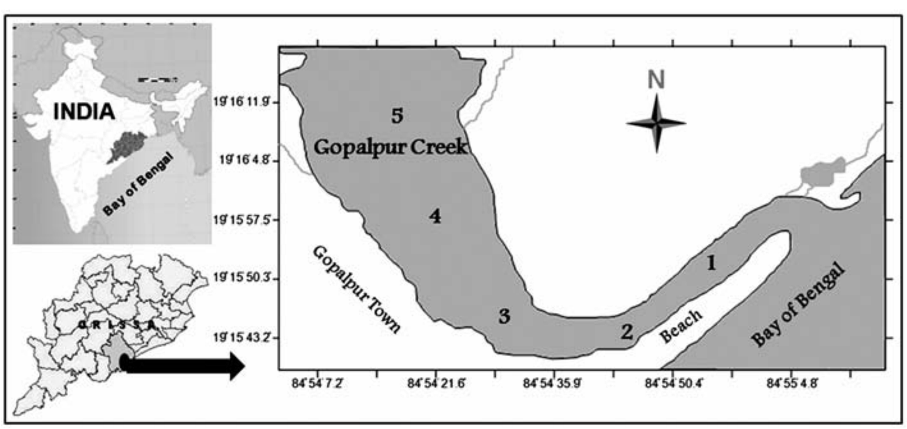

Fig. 1—Showing sampling locations (Numerical figures 1-5) in the study area map

determined using PRIMER (Plymouth Routines in Multivariate Ecological Research, Version 5).

Species Richness[27] [R] = (S - 1)/ln N

S = number of taxa

N = number of individuals.

Species Diversity: Shannon Diversity Index[28] [H']

H' = ∑ - (P_i * ln P_i)

I = 1

H = the Shannon diversity index

P_i = fraction of the entire population made up of species i

S = numbers of species encountered

∑ = sum from species 1 to species S

Species Evenness[29] [J']

J' = H/In S

H = Shannon – Wiener diversity index

S = total number of species in the sample

Species Dominance: Simpson's Dominance Index[30] [D]

D =∑ $(pi)^2$

D= Simpson's Dominance Index

P_i = fraction of the entire population made up of species i

Results

Hydrographic parameters

Hydrographical parameters such as air temperature (AT) (Fig 2a), water temperature (WT) (Fig 2b), salinity (Fig. 2f) and *p*H (Fig. 2e) showed temporal variation during the present study. Mean values of the hydrographical parameters are given in Table 1. AT and WT were found lower in monsoon season due to south-west monsoon and followed the trend PRM>POM>MON. This type of trend was also observed at Mandarmani creek, West Bengal[31]. Spatial variation in water temperature at the stations might be influenced by viable intensity of prevailing streams and the resulting mixing of sea water[32]. Transparency of the creek ranged from 0.52 to 2.5 m (avg 1.1 m) with higher transparency in post monsoon (Fig. 2c). Average salinity was found higher in pre-monsoon period (32.19 PSU) but minimum in monsoon season (28.48 PSU) (Table 1). This type of seasonal variation was also observed by many authors[31,33,34]. Recorded salinity values were in close approximation with the observations of Choudhury and Panigrahy[18]. Station wise salinity values were found to be lower towards inner creek and were gradually increasing towards the outer creek in all the three seasons (Fig. 2f). *p*H was also found lower in monsoon season due to freshwater influx as a result of south-west monsoon rain and was lower towards inner creek which first receives the land runoff water (Fig 2e). DO values ranged from 5.10 to 8.10 mg/L (Avg 6.65 mg/L) with higher values in MON (Fig. 2d).

Present study recorded higher chlorophyll ***a*** concentration both in PRM and POM than MON. Similar trend was also reported by several authors[35-37]. It ranged between 1.63 and 5.93 mg/m^3 (avg 4.27 mg/m^3), 0.54 and 1.11 mg/m^3 (avg 0.83 mg/m^3), 1.56 and 6.32 (avg 3.85 mg/m^3) in PRM, MON and POM respectively (Table 1). Station wise chlorophyll ***a*** concentration increased from outer creek to inner creek. Higher chlorophyll ***a*** values in inner area suggests there is good availability of nutrients for growth and proliferation of phytoplankton. Phytoplankton population also followed the same seasonal trend as chlorophyll ***a***. Similar trend in phytoplankton abundance was also reported in at Brahmani estuary by Palleyi ***et al.***[38].

Phytoplankton Community

Taxonomic identification revealed a total of 99 species of phytoplankton, of which 77 species are of diatoms, 14 species are of dinoflagellates, 5 species are of green algae, 2 species are of cyanobacteria (blue green algae) and 1 species of cocolithophore in the creek during the observation period (Table 2). According to the number of species under different groups a pattern of Diatom > Dinoflagellate > Green algae > Cyanobacteria > Cocolithophore was noticed. This type of trend in species number was also in conformity with several workers[12,39,33]. Further the seasonal variability of phytoplankton community is described as below.

During premonsoon, the phytoplankton population varied from 23232 to 82956 Nos./L (avg 56918 Nos./L). Dinoflagellates dominated the phytoplankton community followed by the diatoms (Table 3). The other groups found were green algae, cyanobacteria and cocolithophore. Stationwise dinoflagellate, diatom and phytoplankton population gradually increased towards the inner creek (Fig. 2h, 2i, 2j). The species viz. *Noctiluca scintillans* (5.7%), *Thalassiothrix longissima* (4.9%), *Odontella sinensis* (4.7%), *Thalassionema nitzschioides* (4.7%), *Coscinodiscus gigas*

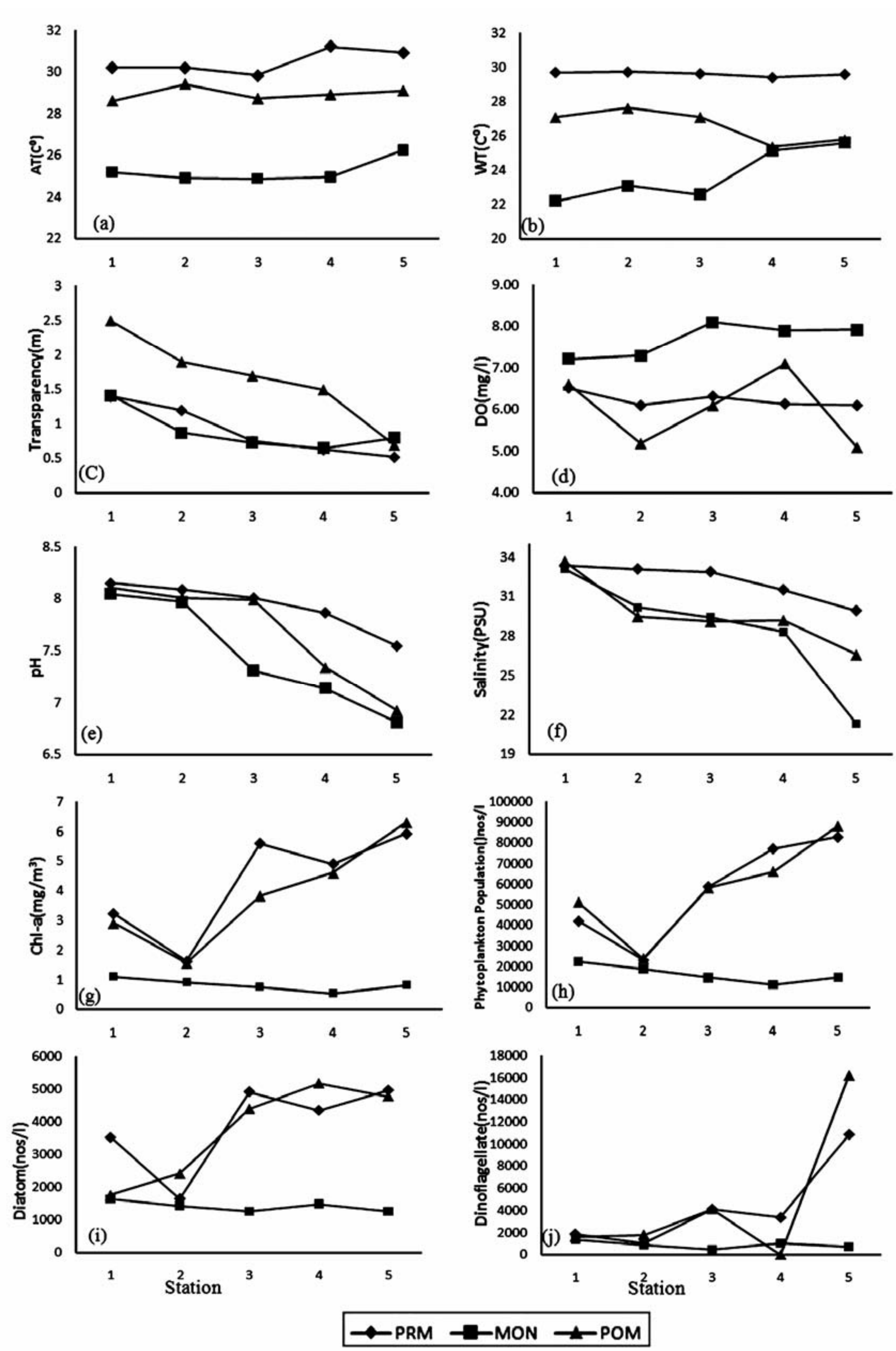

Fig. 2—Graphs of different hydrographic and biological parameters [a to j] (PRM: Pre-monsoon,MON: Monsoon, POM: Post-monsoon)

Table 1—Range and average (avg) of hydrographic and biological parameters

	PRM			MON			POM		
Parameters	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Air Temp(°C)	29.8	31.2	30.5	24.9	26.3	25.2	28.6	29.4	29.0
Water Temp (°C)	29.4	29.7	29.6	22.2	25.6	23.8	25.4	27.6	26.6
Transparency(m)	0.5	1.4	0.9	0.65	1.41	0.9	0.7	2.5	1.7
Salinity(PSU)	29.95	33.41	32.19	21.33	33.1	28.48	26.61	33.67	29.63
pH	7.55	8.15	7.93	6.81	8.05	7.46	6.93	8.11	7.68
DO (mg/L)	6.10	6.52	6.24	7.22	8.10	7.69	5.10	7.10	6.02
Chlorophyll-a (mg/m^3/Nos./L)	1.63	5.93	4.27	0.54	1.11	0.83	1.56	6.32	3.85
Phytoplankton (Nos./L)	23232	82956	56918	11230	22568	16410	23940	88290	57623

(4.2%), *Rhizosolenia alata* (4.0%), *Triceratium favus* (3.8%), *Coscinodiscus eccentricus* (3.7%) were found abundant (Table. 2). Similar type of phytoplankton species with the dominance of *Noctiluca scintillans* (Dinoflagellate) along south Odisha coast was reported by Mohanty *et al.*[17].

During monsoon, phytoplankton population ranged from 11230 to 22568 Nos./L (avg 16410 Nos./L). Diatoms dominated the community followed by cyanobacteria. (Table 3) Diatom, dinoflagellate and phytoplankton population had not shown any conspicuous variation among stations (Fig. 2). As compared to other seasons the population was low which can be probably attributed to the change in hydrographic parameters. Species viz. *Rhizosolenia alata* (5.0%), *Pleurosigma elongatum* (4.3%), *Melosira sulcata* (4.1%), *Amphora coastatum* (4.0%), *Rhizosolenia setigera* (3.6%), *Ditylum sol* (3.4%), *Surirella fluminensis* (3.3%) dominated the population.

During post monsoon, the phytoplankton population varied from 23940 to 88290 Nos./L (avg 57623 Nos./L). In this season increased abundance values in the creek might be due to the fact of improvement in salinity and nutrient structure[38]. In postmonsoon cyanobacteria dominated the phytoplankton community followed by diatoms (Table 3). As compared to other seasons, this season had shown high population density. This might be due to increased nutrient influx from rainwater and land runoff[12,39] Station wise diatom, dinoflagellate and phytoplankton population gradually increased towards the inner creek exhibited the similar trend of premonsoon. Species like *Odontella sinensis* (5.3%), *Rhizosolenia setigera* (5.1%), *Coscinodiscus gigas* (4.7%), *Thalassiothrix longissima* (4.5%), *Noctiluca scintillans* (4.2%), *Oscillatoria sp.* (3.8%), *Coscinodiscus eccentricus* (3.6%) were found abundant (Table 2).

To know about any difference in the phytoplankton diversity and dominance in different seasons, univariate diversity indices are applied (Table 4). Diversity indices have shown the variation in different seasons. Marglef's species richness (R) was found higher in monsoon (4.630) than other two seasons with low population density. This result is in accordance with Madhav and Kondalarao[40]. Pielou's evenness (J') and Simpson's dominance (D) have shown little variation among the seasons. It indicates sharing of all the species in the ecosystem almost equal in the three seasons. Shannon Weiner Diversity index (H') was found higher in post monsoon (3.792). This result is supported by the observations of Bosak *et al.* [41]. at Lim Bay.

Discussion

Hydrographical parameters like water temperature, salinity and DO have shown significant seasonal variation in Gopalpur creek. Lowest water temperature was recorded in monsoon season which might be due to influx of freshwater and cloudy condition. Transparency of the water decreased much in monsoon season due to inflow of turbid rain water. But the variation in transparency among seasons and stations were found not to be significant. *p*H did not show any significant variation among season than among stations. Smaller seasonal variation shown by *p*H in coastal ecosystem was due to precipitation, reduction in salinity and temperature, decomposition of organic matter[42].

We evaluated Pearson correlation coefficient matrix of water quality variables like different hydrographical parameters, chlorophyll-phytoplankton abundance and abundant phytoplankton groups (Table 5). This helped to understand the strength of relationships between the variables and which variables covary with other variables[43].

Table 2—Phytoplankton species composition (Nos./L) and their percentage (in bracket) during PRM, MON and POM (*Contd.*)

No.	Species	PRM	MON	POM
	Diatom			
1	*Actinotychus undulatus* (J.W. Bailey) Ralfs,1861	-	480 (0.8)	-
2	*Actinotychus sp.* Ehrenberg, 1843	-	-	1890 (1.1)
3	*Amphisolenia bidentata* Schroder,1900	1440 (0.8)	-	1440 (0.9)
4	*Amphora coastatum*	-	2470 (4.0)	-
5	*Amphora lineolata* Ehrenberg, 1838	722 (0.4)	-	-
6	*Asterionellopsis glacialis* (Castracane) Round, 1990	2565 (1.4)	-	2205 (1.3)
7	*Bacillaria paradoxa* J.F.Gmelin in Linnaeus, 1791	1924 (1.0)	1946 (3.1)	3690 (2.2)
8	*Bacteriastrum delicatulum* Cleve, 1897	2880 (1.5)	-	2880 (1.7)
9	*Bacteriastrum varians* Lauder, 1864	-	-	1441 (0.9)
10	*Biddulphia mobiliensis*(J.W.Bailey) Grunow, 1882	-	572 (0.9)	1892 (1.1)
11	*Caloneis elongata* (Grunow) Boyer	-	464 (0.8)	-
12	*Caloneis madraspatensis*	-	340 (0.6)	-
13	*Campylodiscus sp.* .Ehrenberg ex Kutzing, 1844	-	910 (1.5)	-
14	*Chaetoceros constrictus* Gran ,1897	-	-	1080 (0.6)
15	*Chaetoceros lorenzianus* Grunow, 1863	3690 (1.9)	1298 (2.1)	-
16	*Chaetoceros peruvianus* Brightwell, 1856	5670 (3.0)	1393 (2.3)	4590 (2.7)
17	*Chaetoceros sp.* Ehrenberg, 1844	3960 (2.1)	-	1980 (1.2)
18	*Coscinodiscus centralis* Ehrenberg, 1844	-	467 (0.8)	-
19	*Coscinodiscus eccentricus* Ehrenberg, 1841	6990 (3.7)	1272 (2.1)	5990 (3.6)
20	*Coscinodiscus gigas* Ehrenberg, 1841	7920 (4.2)	1611 (2.6)	7920 (4.7)
21	*Coscinodiscus sp.* Ehrenberg, 1839	-	-	3420 (2.0)
22	*Cyclotella meneghiniana* F.T. Kutzing, 1844	1280 (0.7)	-	-
23	*Cyclotella sp.* (Kutzing) Brebisson, 1838	-	-	900 (0.5)
24	*Cyclotella striata* (Kutzing) Grunow in Cleve & Grunow, 1880	2610 (1.4)	1092 (1.8)	-
25	*Diploneis smithii* (Brebisson in W. Smith) P.T. Cleve, 1894	-	419 (0.7)	-
26	*Diploneis weissflogii (A. Schmidt)* Cleve, 1894	1280 (0.7)	-	-
27	*Ditylum brightwelli* (T.West) Grunow, 1885	1122 (0.6)	-	810 (0.5)
28	*Ditylum sol* (A.Schmidt) Cleve, 1900	-	2080 (3.4)	-
29	*Eucampia sp.* Ehrenberg, 1839	2610 (1.4)	-	2610 (1.6)
30	*Fragilaria oceanica* Cleve, 1873	1012 (0.5)	-	-
31	*Grammatophora marina* (Lyngbye) Kutzing, 1844	-	910 (1.5)	-
32	*Guinardia striata* (Stolterfoth) Hasle, 1997	3420 (1.8)	-	2160 (1.3)
33	*Gyrosigma balticum* (Ehrenberg) Rabenhorst, 1853	1776 (0.9)	1048 (1.7)	3330 (2.0)
34	*Gyrosigma sp.* Hassall, 1845	-	-	330 (0.2)
35	*Hemidiscus hardmanianus* Greville, 1865	1980 (1.0)	-	2250 (1.3)
36	*Lauderia annulata* Cleve, 1873	2610 (1.4)	-	330 (0.2)
37	*Leptocylindrus danicus* Cleve, 1889	-	650 (1.1)	3060 (1.8)
38	*Leptocylindrus minimus* Gran, 1915	-	-	1530 (0.9)
39	*Licmophora abbreviata* C.A. Agardh, 1831	-	550 (0.9)	-
40	*Mediopyxis helysia* Medlin & Kühn, 2006	-	-	900 (0.5)
41	*Mediopyxis sp.* L. Medlin & Kuhn, 2006	-	267 (0.4)	-
42	*Melosira sulcata* (Ehrenberg) Kutzing, 1844	-	2553 (4.1)	1800 (1.1)
43	*Navicula longa* Greg.,1857	4950 (2.6)	-	3356 (2.0)
44	*Nitzschia closterium* (Ehrenberg) W. Smith, 1853	-	1816 (2.9)	-
45	*Nitzschia longissima* (Brebisson in Kutzing) Ralfs in Pritchard, 1861	1890 (1.0)	-	2170 (1.3)

(*Contd.*)

Table 2—Phytoplankton species composition (Nos./L) and their percentage (in bracket) during PRM, MON and POM (*Contd*.)

No.	Species	PRM	MON	POM
46	*Nitzschia penduriformis* W. Gregory, 1857	-	-	3690 (2.2)
47	*Nitzschia seriata* P.T. Cleve, 1883	842 (0.4)	-	-
48	*Nitzschia sigma* (Kützing) W. Smith, 1853	2430 (1.3)	-	720 (0.4)
49	*Nitzschia striata* P.T. Cleve, 1883	5490 (2.9)	-	5490 (3.3)
50	*Odontella sinensis (Greville)* Grunow, 1884	8820 (4.7)	-	8820 (5.3)
51	*Odontella sp.* C. Agardh, 1832	3240 (1.7)	-	2250 (1.3)
52	*Paralia sulcata* (Ehrenberg) Cleve, 1873	-	1592 (2.6)	-
53	*Pinnularia alpina* W. Smith, 1853	-	456 (0.7)	-
54	*Planktoniella sol* (C.G.Wallich) Schütt 1892	1901 (1.0)	-	3960 (2.4)
55	*Pleurosigma directum* Grunow & Cleve, 1880	-	-	1151 (0.7)
56	*Pleurosigma elongatum* W. Smith, 1852	-	2680 (4.3)	-
57	*Pleurosigma sp.* W.Smith, 1852	1530 (0.8)	-	1530 (0.9)
58	*Pseudonitzschia pungens* (Grunow ex Cleve) G.R.Hasle, 1993	-	-	1080 (0.6)
59	*Rhabdonema mirficum* W. Smith 1856	-	-	2430 (1.4)
60	*Rhaphoneis amphiceros* Ehrenberg, 1844	2430 (1.3)	-	4905 (2.9)
61	*Rhizosolenia alata* Brightwell, 1858	7650 (4.0)	3113 (5.0)	3540 (2.1)
62	*Rhizosolenia castracanei* H.Peragallo 1888	3614 (1.9)	-	-
63	*Rhizosolenia crassipina*	4324 (2.3)	-	-
64	*Rhizosolenia robusta* G.Norman ex Ralfs, 1861	-	1393 (2.3)	-
65	*Rhizosolenia setigera* Brightwell, 1858	-	2234 (3.6)	8550 (5.1)
66	*Rhizosolenia stylifromis* Brightwell	5791 (3.1)	-	-
67	*Skeletonema costatum* (Greville) Cleve ,1873	3420 (1.8)	862 (1.4)	4417 (2.6)
68	*Stephanopyxis turris* (Arnott in Greville) Ralfs in Pritchard, 1861	3892 (2.1)	-	-
69	*Surirella eximia* Greville,	3240 (1.7)	929 (1.5)	3240 (1.9)
70	*Surirella fluminensis* Grunow, 1862	1890 (1.0)	2046 (3.3)	-
71	*Synedra formosa* Hantzsch, 1863	-	964 (1.6)	-
72	*Thalassionema nitzschioides Grunow ex Mereschkowsky, 1902*	8930 (4.7)	720 (1.2)	3645 (2.2)
73	*Thalassiosira subtilis* (Ostenfeld) Gran ,1900	3960 (2.1)	-	4257 (2.5)
74	*Thalassiothrix longissima* Cleve & Grunow, 1880	9225 (4.9)	2822 (4.6)	7504 (4.5)
75	*Trachyneis aspera* (Ehrenberg) Cleve, 1894	-	900 (1.5)	-
76	*Triceratium favus* Ehrenberg,1839	7245 (3.8)	-	-
77	*Tropidoneis antarctica (Grunow) Cleve, 1894*	-	1120 (1.8)	-
	Dinoflagellate			
78	*Ceratium densus*	-	680 (1.1)	-
79	*Ceratium extensum* (Gourret) Cleve, 1900	-	228 (0.4)	-
80	*Ceratium furca* (Ehrenberg) Claparède & Lachmann, 1859	2790 (1.5)	-	-
81	*Ceratium sp.* Schrank,1793	-	-	1710 (1.0)
82	*Dinophysis caudata* Saville-Kent, 1881	1814 (1.0)	1120 (1.8)	1665 (1.0)
83	*Noctiluca miliaris* Suriray ex Lamarck, 1816	-	780 (1.3)	-
84	*Noctiluca scintillans* (Macartney) Kofoid & Swezy, 1921	10866 (5.7)	1857 (3.0)	7020 (4.2)
85	*Prorocentrum gracile* Schutt, 1895	1890 (1.0)	-	-
86	*Prorocentrum maximum* (Gourret) Schiller 1937	-	960 (1.6)	1710 (1.0)
87	*Prorocentrum micans* Ehrenberg, 1834	3970 (2.1)	464 (0.8)	1890 (1.1)
88	*Prorocentrum rostratum* Stein, 1883	-	290 (0.5)	-
89	*Protoperidinium* sp. Bergh, 1882	5670 (3.0)	568 (0.9)	3240 (1.9)
90	*Pyrocystis fusiformis* (Wyville-Thomson ex Haeckel) Blackman 1902	-	900 (1.5)	-
91	*Pyrophacus steinii* (Schiller) Wall & Dale, 1971	-	1008 (1.6)	-

(*Contd*.)

Table 2—Phytoplankton species composition (Nos./L) and their percentage (in bracket) during PRM, MON and POM (*Contd.*)

No.	Species	PRM	MON	POM
	Green algae			
92	*Chlamydomonas marina* Cohn	-	-	1710 (1.0)
93	*Chlorella marina* Butcher, 1952	1530 (0.8)	926 (1.5)	-
94	*Chlorella salina* Kufferath, 1919	2222 (1.2)	900 (1.5)	2220 (1.3)
95	*Oocystis* sp Nägeli ex A.Braun, 1855	1924 (1.0)	432 (0.7)	990 (0.6)
96	*Pediastrum* sp. Meyen, 1829	-	1254 (2.0)	-
	Cyanobacteria			
97	*Oscillatoria* sp. Vaucher ex Gomont, 1892	-	520 (0.8)	6390 (3.8)
98	*Trichodesmium erythraeum* Ehrenberg, 1830	1032 (0.5)	1404 (2.3)	-
	Cocolithophore			
99	*Phaeocystis* sp. . Lagerheim, 1893	1710 (0.9)	1050 (1.7)	2070 (1.2)

Table 3—Season wise and station wise variation of phytoplankton groups

Season	Station	Diatom	Dinoflagellate	Green algae	Cyanobacteria	Cocolithophore
PRM	1	3519	1890	1530	-	-
	2	1650	1018	1384	1032	-
	3	4914	4140	0	-	1710
	4	4344	3380	1778	-	-
	5	4964	10866	2565	-	-
	Average	3671	4500	1892	1032	342
MON	1	1648	1393	-	-	-
	2	1437	872	1254	520	-
	3	1271	493	432	-	-
	4	1495	1050	1050	-	1050
	5	1262	730	652	1404	-
	Average	1290	864	878	962	210
POM	1	1771	1620	720	-	-
	2	2419	1800	990	-	-
	3	4394	4140	1710	-	-
	4	5179	-	2880	6390	-
	5	4783	16200	3060	-	2070
	Average	3047	2873	1640	6390	2070

Results indicate a strong significant positive correlation between salinity and *p*H. Coastal water pH found to vary with salinity[44]. It can also be noted that the backwater *p*H is subjective to tidal salinity. Dissolved oxygen showed a significant negative correlation with air temperature as well as with water temperature. This result validates the fact that as the water temperature goes up, the concentration of dissolved oxygen goes down[45]. Dissolved oxygen also was found performing negatively with *p*H. This is being in accordance with the finding of Ingole and Parulekar[46]. Chlorophyll ***a*** exhibited a negative correlation with DO. Similar type of observation had been reported by Pip[47]. Chlorophyll a along with different dominant groups of phytoplankton exhibited positive relationship with air and water temperature. So it can be safely concluded that increase in solar irradiance triggers the primary production[48]. A very strong and positive significance (r=0.972) was exhibited of the relationship by phytoplankton abundance and chlorophyll ***a*** i.e. estimate of phytoplankton biomass[49]. Diatoms, dinoflagellates and green algae performed a significant positive correlation with chlorophyll ***a*** as well as with total phytoplankton abundance. From strong significant positive values obtained from correlation matrix the well pronounced dominant species were diatom followed by dinoflagellates. Similar type of results were also reported by Naik *et al.*[39] at Mahanadi estuary and Turkoglu *et al.*[50] at Dardanelles (Turkish Strait System) advocating the importance of positive correlation of Chlorophyll *a* with phytoplankton abundance than with different groups. Dinoflagellates performed negative correlation with DO, *p*H and salinity. Diatom performed positive correlation with salinity and negative correlation with DO and *p*H. The positive correlation of diatom with salinity signifies salinity as a major controlling factor of this group in brackish and marine waters[51].

Water temperature, salinity and DO have shown significant variation ($p < 0.01$) among seasons while *p*H has shown significant variation ($p < 0.01$) among stations (Table 6). Significant variation of many hydrographic parameters in tropical countries like India is highly influenced by monsoonal rainfall, tidal characteristics, evaporation and water current[52]. Variation of *p*H is attributed to distance of stations from the inlet and dilution of saline water by freshwater influx[42]. Chlorophyll *a* and phytoplankton density have shown significant variation ($p < 0.01$) among seasons while the variation among stations was not significant during the study period. Significant variation among seasons is due to prevalence of different hydrographic environment in different seasons[53].

Regression analysis between chlorophyll *a* and phytoplankton density has shown a very good linear trend (R^2=0.95) in the creek (Fig. 3). Similar linear relationship was also documented by many researchers[33,37].

As far as species number is concerned, dinoflagellate dominance in Indian coastal water was previously reported by Madhav and Kondalarao[40] during their extensive field survey along the east coast. This type of dominance of dinoflagellates (in premonsoon) over diatoms is a little deviation against a lot of reports on diatom dominance in world oceans[14,38,1]. This deviation in community structure in premonsoon compared to other two seasons might be due to low turbulence and high nutrient environments which favor dinoflagellate dominance[54,55].

Diatoms can tolerate a wide range of fluctuation in salinity and temperature[56]. So in the present study within the unstable physicochemical and nutrient environment during south west monsoon again this fact is proved with lower values of other groups[39]. As compared to other seasons the population was low in southwest monsoon which is probably due to the change in hydrographic parameters due to influx of freshwater through precipitation and wide stratification as result of rainfall, increased turbidity, decrease in *p*H and temperature[35,38]. During post monsoon, the increased abundance values in the ecosystem might be due to the fact of improvement in salinity and nutrient structure[38]. In postmonsson cyanobacteria dominated the phytoplankton community

Table 4—Univariate diversity indices during Pre-monsoon (PRM), Monsoon (MON) and Post-monsoon (POM).

Univariate Diversity indices	PRM	MON	POM
Total species (S)	53	52	55
Marglef's species richness (R)	4.279	4.630	4.492
Shannon Wiener Diversity index (H')	3.760	3.781	3.792
Pielou's evenness (J')	0.946	0.956	0.946
Simpson's dominance (D)	0.972	0.973	0.973

Table 5—Pearson correlation coefficient matrix of hydrological and biological parameters

	Transparency	AT	WT	Salinity	*p*H	DO	Chl-a	Diatom	Dinoflagellate	Green algae	Phyto abundance
Transparency	1										
AT	.113	1									
WT	.376	.865**	1								
Salinity	.641**	.686**	.932**	1							
pH	.572*	.343	.693**	.808**	1						
DO	-.219	-.772**	-.753**	-.610**	-.339	1					
Chl- *a*	-.152	.745**	.500*	.317	-.018	-.628**	1				
Diatom	-.143	.706**	.473*	.279	-.016	-.567*	.942**	1			
Dinoflagellate	-.339	.395	.180	-.018	-.304	-.615**	.721**	.582*	1		
Green algae	-.144	.473*	.225	.012	-.303	-.446*	.608**	.636**	.582*	1	
Phyto abundance	-.084	.720**	.459*	.291	-.030	-.622**	.972**	.902**	.723**	.682**	1

**. Correlation is significant at the 0.01 level.
*. Correlation is significant at the 0.05 level.

Table 6—One way ANOVA results of hydrographic and biological parameters

	Among seasons		Among Stations	
Parameters	F	Sig.	F	Sig.
WT	31.171	.000	.400	.805
Transparency	4.399	.037	2.098	.156
Salinity	9.190	.004	1.461	.285
*p*H	1.441	.275	6.364	.008
DO	12.993	.001	.348	.840
Chlorophyll a	8.106	.006	.842	.529
Phytoplankton density	7.080	.009	.885	.507

Significant values ($p < 0.01$) are given in bold.

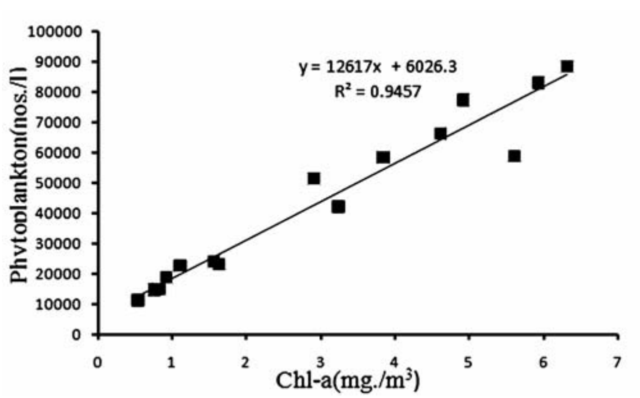

Fig. 3—Regression line between chlorophyll *a* and phytoplankton density

followed by diatoms (Table 3). Decline in diatom population in post monsoon might be due to nutrient limitation[57]**.** Cyanobacterial group was represented by *Oscillatoria* spp. only (6390 Nos./L). Presence or evolution of cyanobacterial members might be due to low N:P in ambient water[58]. High concentration of P and a low N:P supply ratio is favorable for the proliferation of cyanobacteria[59]. So, there may be any external source of nutrients from the surrounding area due to anthropogenic influence by nearby hatcheries and Gopalpur town. This type of high cyanobacteria number was also observed in Mahanadi estuary during post monsoon and summer (2004-05) where there were higher PO_4 concentration compared to other seasons[39].

Species composition in three seasons showed the dominancy of different species groups in different seasons. This might be attributed to change in environmental variables specially nutrients and temperature in different seasons[60,61]. Genus like *Chaetoceros, Coscinodiscus, Nitzschia, Rhizosolenia, Ceratium, Prorocentrum, Surirella, Thalassiothrix, Thalassionema, Noctiluca, Bacillaria, Cyclotella, Gyrosigma, Chlorella* etc were common in all seasons but with different composition[39,40]. Species *Amphora leneolata, Diploneis weissiflogii, Fragilaria oceanica, Stephanopyxis turis, Triceratium favus* etc were found only in premonsoon period.

Perusal of literature regarding earlier studies on phytoplankton spectrum of the study area revealed one published manuscript in 1992 in which authors Choudhury and Panigrahy had reported of 63 diatoms, 10 dinoflagellates, 7 green algae and 4 cyanobacteria. Present study recorded 77 diatoms, 14 dinoflagellates, 5 green algae and 2 cyanobacteria throughout different seasons. An increase in species diversity of diatoms and dinoflagellates can be noticed in the present study compared to the earlier. Increment in diatom species diversity indicates a good ecological sign[62]. Decrease in cyanobacterial members justifies the above though one species of this group i.e. Oscillatoria spp. outbursted in more number during postmonsoon sampling which might be due to some anthropogenic influence[57]. Present observation did not come across any type of phytoplankton bloom during the study period though diatom blooms[14,63].

Diversity index analyses were performed to determine the variations in community structure of the study area in order to find out a relation between degree of pollution and variation in population structure in case of pollution. Water quality can be reflected by means of alterations in phytoplankton community structure, its type of distribution and the percentage of ecosensitive species in plankton spectrum[57]. In our study most of the univariate diversity indices *viz.* Pielou’s evenness (J’) and Simpson’s dominance (D) have shown little variation among seasons indicating homogenous distribution of species in the ecosystem. Though the Shannon Weiner Diversity index (H’) was found highest in post-monsoon season but degree of variation of this index throughout the study period was quite low (3.76-3.79) with a gradual increasing trend from premonsoon to postmonsoon. Species diversity index values recorded for all seasons were comparatively higher than that of the observations of Gharib *et al.*[57] at coastal stations of southeastern Mediterranean Sea. So it can be assumed a healthier less polluted ecosystem due to, high H′ values[57,64]. However Shannon Weiner Diversity index (H’) was highest in post-monsoon season with cyanobacterial dominance. Though cyanobacterial group dominated the plankton profile, different diversity indices were not varied so much as compared to other seasons due to the fact of maintenance of continuous diversity by other phytoplankton groups with respect to other seasons.

Conclusion

Phytoplankton species composition and their relative abundance were studied in Gopalpur creek during pre-monsoon, monsoon and post-monsoon seasons with different hydrographic parameters. Water temperature has shown significant variation ($p < 0.01$) among seasons while salinity and *p*H have shown significant variation ($p < 0.05$) among stations. Change in *p*H of the creek water is to be further studied to understand whether it is being attributed due to the natural or anthropogenic influence. Chlorophyll ***a*** and phytoplankton density have shown significant variation ($p < 0.01$) among seasons while the variation among stations was not significant. Phytoplankton species composition was found dissimilar in the three seasons. Maximum diversity was found in post monsoon (Shannon-Wiener diversity index). Pielou's evenness (J') and Simpson's dominance have shown little variation among seasons. This study was particularly aimed at the status of phytoplankton community structure during different seasons. But the controlling factors of season-wise and station-wise fluctuation in phytoplankton population as well as species composition shall be further studied with relation to nutrients especially the Redfield ratio and anthropogenic generated factors.

Reference

1 Chisholm, S W, Stirring times in the Southern Ocean, *Nature*, 407 (2000) 685–687.

2 Marzeion, B, Timmermann, A, Biophysical feedbacks in the tropical Pacific, ***J. Clim.***, 18 (2005) 58– 70.

3 Kitsiou, D & Karydis, M, Development of categorical mapping for quantitative assessment of eutrophication, ***J. Coast. Conserv.***, 4 (1998) 33-42.

4 Kitsiou, D. & Karydis, M., Marine eutrophication: a proposed data analysis procedure for assessing spatial trends, ***Environ monit Assess***., 68 (2001) 297-312.

5 Venneaux J, Basic principles for determination of ecological criteria for hydro-biocenoses of running water, in: ***Principles and methods for determining ecological criteria on Hydrobicenoses*** edited by R Amavis and J Smeets (Pergamon Press, Oxford) 1976 pp.199-202.

6 Wu, J T, Phytoplankton as bioindicator for water quality in Taipei, ***Bot. Bull. Academia. Sinica*** 25 (1984) 205-214

7 Nielsen, S L, Sand-Jensen, K, Borum, J, & Geertz-Hansen, O, Phytoplankton, nutrients, and transparency in Danish coastal waters, ***Estuaries***, 25 (2002) 930–937

8 Grenz, C, Cloern, J E, Hager, S W, Cole, B.E., Dynamics of nutrient cycling and related benthic nutrient and oxygen fluxes during a spring phytoplankton bloom in South San Francisco Bay (USA), *Mar Ecol Prog Ser* 197 (2000) 67–80

9 Elliot, J A, Irish, A E & Reynolds, C S, Predicting the spatial dominance of phytoplankton in light limited and incompletely mixed eutrophic water column using the PROTECH model, *Freshw. Biol.* 47 (2002) 433–440

10 Buzzi, F, Phytoplankton assemblages in two sub-basins of Lake Como, *J Limnol*, 61 (2002) 117-128

11 Gouda, R & Panigrahy, R C, Diurnal variation of Phytoplankton in Rushikulya estuary, east coast of India, ***Indian J. Mar. Sci.***, 18 (1989) 246-250

12 Gouda, R & Panigrahy, R.C, Ecology of phytoplankton in coastal waters of Gopalpur, East coast of India, ***Indian J. Mar. Sci***., 25 (1996) 81-84

13 Panigrahy, R C. & Gouda R, Occurrence of the bloom of the Diatom *Asterionella glacalis* (Castracane) in the Rushikulya Estuary, East coast of India. *Mahasagar Bull.* 23 (1990), 179-182

14 Choudhury, S B. & Panigrahy, R C, Seasonal Distribution of Phytoplankton in the Coastal Waters of Gopalpur (Orissa), *International J. Eco. Environ. Sci.,* 18 (1992) 131-138.

15 Gouda, R & Panigrahy, R C, Diurnal variation of Phytoplankton in Rushikulya estuary, east coast of India, ***Indian J. Mar. Sci.***, 18 (1989) 246-250

16 Sasamal, S K, Panigrahy, R C & Misra, S., Asterionella blooms in the northwestern Bay of Bengal during 2004, *Int. J. Rem. Sens.*, 26 (2005) 3853-3858.

17 Mohanty, A K, Satpathy, K K, Sahu G, Sasmal, S K, Sahu, B K & Panigrahy, R C, Red tide of *Noctiluca scintillans* and its impact on the coastal water quality of the near-shore waters, off the Rushikulya River, Bay of Bengal, *Curr. Sci.*, 93, (2007) 616-618.

18 Choudhury, S B & Panigrahy, R C, Seasonal distribution and behavior of nutrients in the creek and coastal waters of Gopalpur, east coast of India, *Mahasagar*, 24 (1991) 81-88

19 Satapathy D & Sahu H K, Seasonal distribution and abundance of Macrobenthos in relation to certain hydrobiologocal features of Gopalpur Creek, Bay of Bengal, in: ***Current and Emerging Trends in Aquaculture*** edited by P.C Thomas, (Daya publishing House, New Delhi) 1998 pp.393-396

20 Mishra, P, Mohanty, P K, Murty, ASN, Sugimoto, T, Beach profile studies near an artificial open-coast port along south Orissa, east coast of India, *J Coastal Res* special issue 34 (2001) 164–171

21 Gouda, R & Panigrahy, R C, Monthly variation of some hydrographic parameters in the Rushikulya Estuary, *Mahasagar*, 26 (1993) 73-85

22 APHA, *Standard methods for the examination of water and waste water*, (21st edition, American Public Health Association, New York) 2005. pp. 1368.

23 Strickland, J D H & Parson T R, A practical handbook for seawater analysis, *Bull. Fish. Res. Bd. Canada*, 167 (1972) 1-311.

24 Cupp E E, *Marine plankton diatoms of the West coast of North America* (University of California Press Berkeley, California) 1943, pp. 235.

25 Newell G E & Newell. R C, *Marine Plankton- A Practical Guide.* (Hutchinson Educational Ltd ; London) 1977, pp 244.

26 Verlencar X N & Somshekar D, ***Phytoplankton identification manual*** (National Institute of Oceanography, Goa, India) 2004, pp 35.

27 Margaleaf R, Temporal succession and spatial heterogeneity in phytoplankton, in: ***Perspectives in Marine Biology*** edited by B. Traverso (University of California Press, California) 1960 pp. 323-349

28 Shannon C E & Weaver W, ***The Mathematical Theory of Communication*** (University of Illinois Press, Urbana) 1963, pp.117

29 Pielou, E C, The measurement of diversity in different types of biological collections, ***J. Theoretical Biol.,*** 13 (1966) 131-144.

30 Simpson, E H, Measurement of diversity, ***Nature,*** 163 (1949) 668.

31 Mitra, A, K C. Patra and R C Panigrahy: Seasonal variations of some hydrographical parameters in a tidal creek opening into the Bay of Bengal. ***Mahasagar Bull***., 23 (1990) 55-62

32 Reddi, K R, Jayaraju, N, Suriyakumar, .I & Sreenivas, K, Tidal fluctuation in relation to certain physico-chemical parameters in Swarnamukhi River estuary, East coast of India, ***Ind. J. Mar. Sci.*** 22(1993) 232-234

33 Achary, M S, Sahu, G, Mohanty, A K, Samatara, M K, Panigrahy, S. N, Selvanayagam, M, Satpathy, K K, Prasad, M. V. R. & Panigrahy, R C, Phytoplankton abundance and diversity in the coastal waters of Kalpakkam, East Coast of India in relation to the environmental variables , ***The Bioscan,*** 2 (2010) 553-568

34 Perumal, N V, Rajkumar M, Perumal, P & Rajasekar, K T, Seasonal variations of plankton diversity in the Kaduviyar estuary, Nagapattinam, southeast coast of India, ***J. Environ. Biol.***, 30 (2009)1035-1046.

35 Sarupria, J.S & Bhargava, R. M. S., Seasonal distribution of chlorophyll-a in the exclusive economic zone (EEZ) of India, ***Ind. J. Mar. Sci.***, 27 (1998) 292-297

36 Raghuprasad, R, Plankton calendars of the inshore waters at Mandapam, with a note on the productivity of the area, ***Ind. J. Fish.***, 5 (1958)170-188

37 Sridhar, R, Thangaradjou, T. & Kannan, L, Spatial and temporal variations in phytoplankton in coral reef and seagrass ecosystems of the Palk Bay, southeast coast of India, ***J. Environ. Biol.***, 31 (2010) 765-771

38 Palleyi, S, Kar, R N & Panda, C R, Seasonal Variability of Phytoplankton Population in the Brahmani Estuary of Orissa, India J. Appl. Sci. Environ. Manage., 12 (3) (2008) 19 - 23

39 Naik, S, Acarya, B C & Mohapatra, A, Seasonal variation of phytoplankton in Mahanadi estuary, east coast of India, ***Indian J. Mar. Sci.***, 38 (2009) 184-190

40 Madhav, V G & Kondalarao B, Distribution of phytoplankton in the coastal waters of east coast of India, ***Indian J. of Mar. Sci.***, 33 (3) (2004) 262-268.

41 Bosak, S., Buric, Z., Djakovac,T. & Vilicic, D., Seasonal distribution of plankton diatoms in Lim Bay, northeastern Adriatic Sea, *Acta Bot. Croat*., 68 (2) (2009), 351–365.

42 Rajasegar, M., Physico-chemical characteristics of the Vellar estuary in relation to Shrimp farming, ***J. Environ. Biol***., 24 (2003) 95-101

43 Mahapatro D, Panigrahy R C, Naik S, Pati S K and Samal R N, Macrobenthos of shelf zone off Dhamara estuary, Bay of Bengal, ***J. Oceanog. Mar. Sci***., 2 (2) (2011) 32-42

44 Saraswat, R, Kouthankar M, Kurtarkar, S, Nigam, R, & Linshy, V N, Effect of salinity induced pH changes on benthic foraminifera: a laboratory culture experiment, ***Biogeo. Dis.***, 8 (2011) 8423-8450

45 Saad, M A H, Limnological studies on the Nozha Hydrodrome, Egypt, with special reference to the problem of pollution, ***Sci. Total. Environ.*** 67 (1987) 195-214.

46 Ingole, B S & Parulekar A H, Role of salinity in structuring the intertidal meiofauna of a tropical estuarine beach: Field evidence, ***Indian J Mar Sci***., 27 (1998) 356–361

47 Pip, E, Chlorophyll Concentrations in Relation to Environmental Parameters in Different Situations in Shoal Lake (Manitoba-Ontario). ***Int. Rev. der gesamten Hyd. und Hydro***. 73 (1988), 417–429.

48 Onyema, 1 C, Okpara, C U, Ogbebor, C I Otudeko, O. & Nwankwo, D I, Comparative studies of the water chemistry characteristics and temporal plankton variations at two polluted sites along the Lagos lagoon, Nigeria, ***Ecology, Environment and Conservation.***, 13 (2007) 1 – 12.

49 Polat, S &Piner, M P, Seasonal variation in biomass, abundance and species diversity of phytoplankton in Iskenderun Bay (North Eastern Mediterranean), ***Pak. J. Bot***., 34 (2002) 101-112.

50 Türkoğlu, M, Temporal variations of surface phytoplankton, nutrients and chlorophyll a in the Dardanelles (Turkish Straits System): a coastal station sample in weekly time intervals, ***Turk. J. Biol,***. 34 (2010) 319-333

51 Maynard, N G, Relationship between diatoms in surface sediments of the Atlantic Ocean and the biological and physical oceanography of overlying waters, ***Paleobiology***., 2 (1976) 99-121.

52 Damotharan, P, Perumal, N V & Arumugam, M, Seasonal variation of physico-chemical characteristics in point Calimere Coastal waters (South East Coast of India), ***Middle-East J. Sci. Res.***, 6 (4) (2010) 333-339.

53 Ei-Gindy, A A H. & Dorghan, M M, Interrelation of phytoplankton, chlorophyll and physico-chemical factors in Arabian Gulf and Gulf of Oman during summer, ***Indian J. Mar. Sci***., 21(1992) 257-261.

54 Margalef, R, Life-forms of phytoplankton as survival alternatives in an unstable environment. ***Oceonol. Acta***. 1 (1978) 493-509

55 Margalef R, Estrada M & Blasco D, Functional morphology of organisms involved in red tides, as adapted to decaying turbulence, in: ***Toxic Diniflagellate Blooms*** edited by D Taylo and H Seliger (Elsevier, New York) 1979 pp.89-94.

56 Sasamal, S K, Panigrahy, R C & Misra, S, Asterionella blooms in the northwestern Bay of Bengal during 2004, ***Int. J. Rem. Sens.***, 26 (2005) 3853-3858.

57 Gharib, S M, El-Sherif, Z M, Abdel-Halim, A M, Radwan, A. A., Phytoplankton and environmental variables as a water quality indicator for the beaches at Matrouh, south-eastern Mediterranean Sea, Egypt: an assessment, ***Oceanolog.***, 53 (2011) 819–836.

58 Smith, V H, Low nitrogen to phosphorus ratios favor dominance by blue-green algae in lake phytoplankton, ***Science*** 221 (1983) 669–671.

59 Simpson, E H, Measurement of diversity, ***Nature***, 163 (1949) 668.

60 Huang, L M, Chen, Q C. & Wong, C K, Distribution of Chlorophyll-a and its relation to environmental factors in the Zhujiang estuary, *Collected Oceanic Works* , 20 (1997a) 39-46

61 Huang, L M, Chen, Q C, Yin, I Q, Wen, W Y, He, Y Q & Wang, H X, Basic organisim composition and environment status of Zhujiang estuary and adjacent waters, ***Mar, Env, Sci***, 16 (1997b) 1-7

62 James, B K & Adejare, L I, Nutrients and Phytoplankton Production Dynamics of a Tropical Harbor in Relation to Water Quality Indices, ***J. American Sci.*** 6 (9) (2010) 261-275.

63 Mishra, S, Sahu, G, Mohanty, A K, Singh, S K & Panigrahy, R C, Impact of the Diatom Asterionella glacialis (Castracane) Bloom on the Water Quality and Phytoplankton Community Structure in Coastal Waters of Gopalpur Sea, Bay of Bengal, ***Asian Journal of Water, Environment and Pollution***, 3 (2006) 71-77

64 Wilhm J L, Biological indicators of pollution, in: ***River ecology, Studies in Ecology*** edited by B.A. Whitton, Vol. 2 (Blackwell Science Publication, London) 1975 pp. 375–403.