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Phytoplankton community structure along offshore transects of some Indian estuaries of east coast: An experience with a summer cruise

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This paper is based on the analyses of samples collected during a summer cruise onboard CRV 'Sagar Paschimi' (Cruise no.09/11) from 1st to 8th of April 2011. Species composition, abundance and distribution of phytoplankton, and water quality parameters (transparency, water temperature, salinity, pH, dissolved oxygen, nutrients *viz*. NO_2, PO_4 and chlorophyll-*a*) were examined in this study. A total of 123 phytoplankton species were identified. Of total, 86 species of diatoms from 44 genera, 22 species of dinoflagellates from 10 genera, 5 species of green algae from 5 genera, 4 species of cyanobacteria from 4 genera, 2 species of cocolithophores from 2 genera and 1 species of silicoflagellate were identified. Phytoplankton communities were found to vary from transect to transect. Highest and lowest values for species diversity index are associated with Godavari and Gosthani transects respectively. The highest phytoplankton abundance was found at transect Krishna (26680 cells/l) and the lowest at Godavari (9480 cells/l). *Thalassiothrix longissima* was quantified as the dominant species among diatoms and *Dinophysis caudata* among dinoflagellates. Abundance of bloom forming species *Asterionellopsis glacialis* was observed at transects Godavari & Mahanadi. Diversity and evenness indices of phytoplankton were found highest at Godavari transect. There exhibited a linear relationship between chlorophyll-*a* and phytoplankton abundance at all the transects with deviations at Gosthani and Godavari.

[**Keywords:** Phytoplankton, Diversity, Composition, Chlorophyll, non-metric multi-dimensional scaling]

Introduction

Major primary productions in the ocean are contributed by tiny free floaters *i.e.* phytoplankton. Phytoplankton 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. Fate of commercial fisheries is mainly determined by these primary producers[3,4]. Since phytoplankton are capable of quantifying changes in environmental parameters even at global scale, some of these organisms can be used as bio-indicators to monitor water quality of an area[5]. Growth of phytoplankton is generally nutrient limited[6]. Good proliferation of plankton can be observed in coastal areas where nutrient rich river water mixes with sea. In Indian tropical waters, rich supply of nutrients into the euphotic zone from bottom through upwelling triggers phytoplankton blooms[7]. Productivity of Bay of Bengal is relatively less than that of Arabian Sea[8]. The difference in productivity is caused by strong stratification due to a barrier layer formed by supply of large quantities of freshwater either through river or precipitation[9], which impedes the transfer of nutrients into euphotic zone from deep[10]. Ananthan et al. (2008)[11] observed gross primary production in Ariyankuppam Estuary and coastal area of Pondichery, which attained maximum during the summer. A thorough examination of literature on phytoplankton studies in Bay of Bengal revealed that most of the works are limited either to estuaries, backwaters or coastal waters[12-17]. Hence, a study on phytoplankton was done along offshore transects of 7 estuaries in the eastern coast of India during a summer month to bring out their pelagic status.

Materials and Methods

Bay of Bengal, a marginal sea of Indian Ocean is always under the influence of monsoons, tropical cyclones and depressions. In the present study, offshore transects of 7 estuaries namely, Pennar, Krishna, Godavari, Gosthani, Rushikulya, Devi and Mahanadi along east coast of India were selected to see any variability in certain ecosystem parameters (Fig. 1). These rivers drain huge quantities of fresh water and sediments to the Bay especially in monsoon periods and thus play a major role in sediment dynamics, current pattern, surface circulation, fishery diversity and productivity of coastal water.

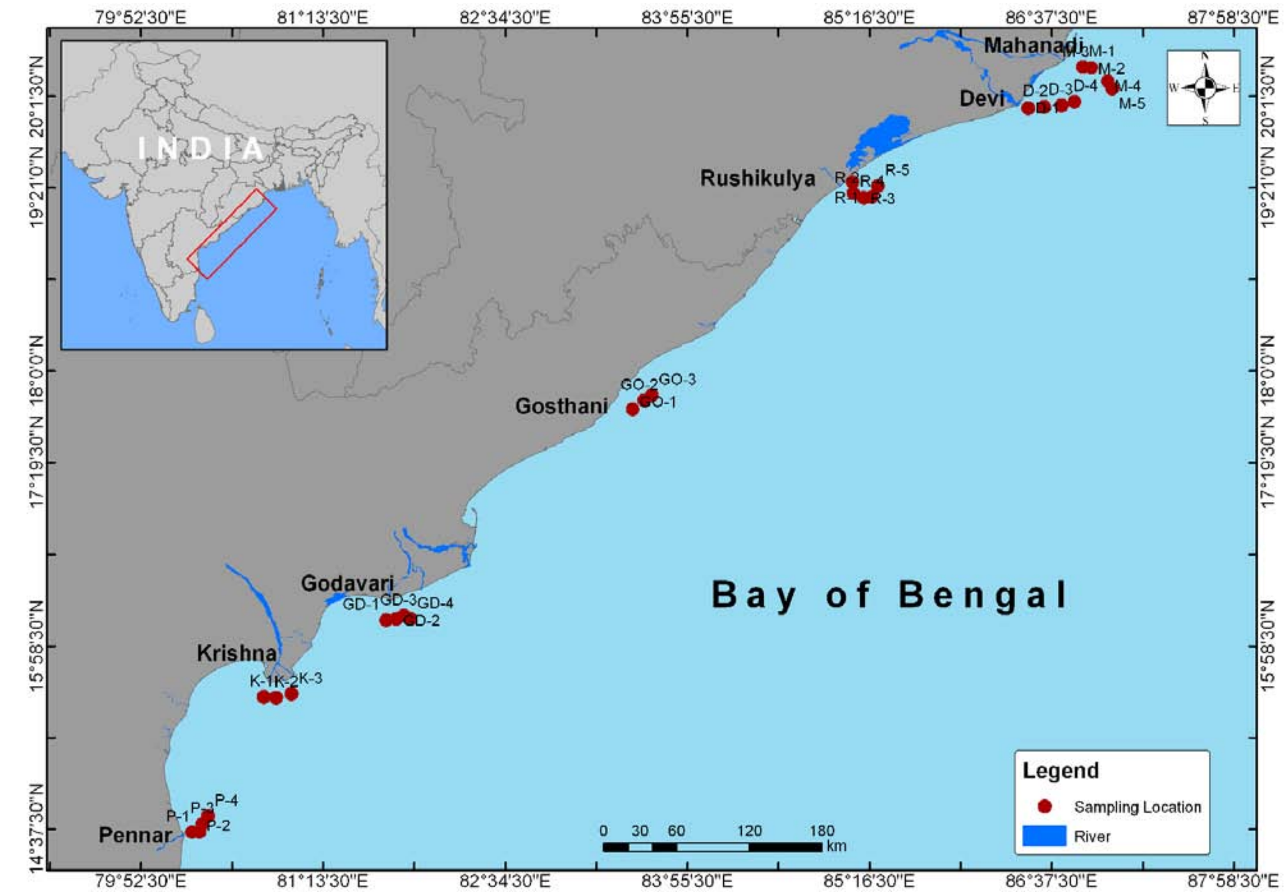

Fig.1—map of Indian east coast indicating sampling sites (P: Pennar, K: Krishna, GD: Godavari, GO: Gostani, R: Rushikulya, D: Devi, M: Mahanadi)

The survey was carried out onboard MoES research vessel CRV '*Sagar Paschimi*' (Cruise No.09/11) during 1-8 April 2011 jointly by Integrated Coastal and Marine Area Management (ICMAM), Chennai and Indian National Centre for Ocean Information Services (INCOIS), Hyderabad. Samples were collected from the 7 offshore transects comprising 28 stations (Table 1).

Surface seawater temperatures using a Thermometer; transparency using a Secchi Disc, pH using a Digital pH reader (HANNA) and salinity using a Refractometer were recorded at each station. Water samples at each station were analyzed for dissolved oxygen (DO) and nutrients (nitrite and phosphate). Chlorophyll-*a* concentration were estimated using UV-Visible double beam spectrophotometer (Perkin Elmer-λ35) following the methods of Strickland and Parsons (1972)[18]. A single factor ANOVA was applied to each of these above parameters using MS Excel 2007 to find out any significant difference among the offshore transects of the 7 estuaries.

Table 1. Sampling period, location and depth of stations

Transect	Transect Code	Station Code	Date of sampling	Time	Position		Depth (m)
					Lat(N)	*Long(E)*	
Pennar	T-1	P-1	02/04/2011	10:30	14°36.16′	80°15.13′	25
	T-1	P-2	02/04/2011	11:40	14°36.15′	80°18.39′	50
	T-1	P-3	02/04/2011	13:30	14°39.77′	80°19.72′	84
	T-1	P-4	02/04/2011	14:20	14°43.31′	80°22.14′	200
Krishna	T-2	K-1	03/04/2011	10:30	15°36.16′	80°46.93′	25
	T-2	K-2	03/04/2011	11:45	15°35.81′	80°52.48′	50
	T-2	K-3	03/04/2011	13:00	15°37.46′	80°59.37′	100
Godavari	T-3	GD-1	04/04/2011	11:00	16°10.09′	81°41.54′	25
	T-3	GD-2	04/04/2011	12:00	16°10.64′	81°45.98′	50
	T-3	GD-3	04/04/2011	13:00	16°12.06′	81°49.37′	100
	T-3	GD-4	04/04/2011	14:00	16°10.60′	81°52.30′	200
Gosthani	T-4	GO-1	05/04/2011	10:30	17°43.10′	83°31.20′	51
	T-4	GO-2	05/04/2011	11:45	17°46.98′	83°36.25′	50
	T-4	GO-3	05/04/2011	13:00	17°49.27′	83°39.64′	50
Rushikulya	T-5	R-1	06/04/2011	10:00	19°23.48′	85°08.90′	25
	T-5	R-2	06/04/2011	11:00	19°18.44′	85°09.15′	52
	T-5	R-3	06/04/2011	12:00	19°16.56′	85°13.81′	66
	T-5	R-4	06/04/2011	13:00	19°16.88′	85°17.50′	86
	T-5	R-5	06/04/2011	14:15	19°21.63′	85°20.21′	64
Devi	T-6	D-1	07/04/2011	10:20	19°56.29′	86°27.02′	25
	T-6	D-2	07/04/2011	11:30	19°56.83′	86°33.96′	37
	T-6	D-3	07/04/2011	12:45	19°57.48′	86°41.81′	48
	T-6	D-4	07/04/2011	14:10	19°59.05′	86°47.65′	65
Mahanadi	T-7	M-5	08/04/2011	10:00	20°04.73′	87°04.40′	100
	T-7	M-4	08/04/2011	11:10	20°08.05′	87°02.47′	53
	T-7	M-3	08/04/2011	12:20	20°14.06′	86°55.19′	41
	T-7	M-2	08/04/2011	13:15	20°14.06′	86°55.19′	29
	T-7	M-1	08/04/2011	14:10	20°14.38′	86°51.29′	24

Phytoplankton samples (1L) were collected from surface by bucket hauling in clean plastic bottles from surface at each station and immediately preserved with 1% Lugol's iodine and 3% neutralized formaldehyde solution. Investigation of phytoplankton involved determination of species composition and abundance. The fixed water samples were finally concentrated to 80 ml by sedimentation. In the laboratory, phytoplankton identification was made with the aid of an inverted microscope (Make: Cippon; Model No.21033) in different magnifications *viz*. 40X, 100X, 400X from the plankton concentrate. A Sedgwick Rafter counting chamber was used as a platform for qualitative and quantitative estimation of phytoplankton. The phytoplankton abundance was articulated as cell numbers per liter (cells/l). Phytoplankton species were identified using standard references[19-28]. Data obtained from sampling were processed for various qualitative and quantitative estimations namely species composition and biomass.

Phytoplankton community structures were analyzed using standard univariate statistical indices, *viz*., species richness (d), Shannon's diversity index (H′), Simpson's dominance index (D) and Shannon's evenness index (J′) and multivariate method *i.e.* non-metric multi-dimensional scaling (nMDS) on the abundance of all the species[29].

The statistical bio-indices are calculated as follows:

Species Richness [d] = $(S - 1)/\ln N$[30]

S = number of taxa

N = number of individuals

Species Diversity: Shannon Diversity Index [H'][31]

$$H' = \sum_{i=1}^{s} - (P_i * \ln P_i)$$

H = the Shannon diversity index

P_i = fraction of the entire population made up of species i
S = number of species encountered
∑ = sum from species 1 to species S

Species Evenness [J'][32]
J = H / In S
H = Shannon – Wiener diversity index
S = total number of species in the sample

Species Dominance: Simpson's Dominance Index (D)[33]
$D = \sum (pi)^2$
D= Simpson's Dominance Index
P_i = fraction of the entire population made up of species i

Results

During the course of this study, water transparency ranged from 6 m to 45 m with an average of 19.12 m. At Mahanadi transect, transparency reading was recorded from 10 m to 17 m with a mean value of 15 m. Water was found to be more transparent at Krishna and less at Pennar. The study revealed that transparency was more at higher depths in all transects (Table 2). Sea Surface Temperature (SST) varied from 27.86 ^{0}C to 28.29^{0}C with an average of 28.11 ^{0}C. Lowest and highest SST were observed at Rushikulya transect. The pH ranged from 7.9 to 8.1 with an average of 8.0 in all sampling transects. Maximum (8.1) was recorded at Krishna and Devi and the minimum (7.9) was recorded at Mahanadi transect. There was no significant variation observed between the sites (Table 2). Salinity varied from 33.0 to 35.0 psu with an average of 34.5 psu. Lower salinity values were obtained in northern transects (Table 2). Dissolved oxygen ranged from 6.40 to 8.90 mg.L^{-1} with an average of 7.58 mg.L^{-1} in all transects. Highest dissolved oxygen was recorded at Rushikulya (Table 2). The Nitrite (NO_2) concentration in the study area showed well marked spatial variation and it ranged from 0.40 to 0.75 µmol/l with an average of 0.65 µmol/l. The lowest and highest values were associated with Rushikulya and Devi respectively (Table 2). Phosphate (PO_4) ranged from 1.41 to 2.04 µmol/l with an average of 1.90 µmol/l during the study period. Phosphate exhibited lower value off Rushikulya. The highest phosphate concentration was observed at Devi followed by Godavari (Table 2). Chlorophyll-*a* concentration (mg.m^{-3}) of the seawater ranged from 1.51 to 8.53 mg.m^{-3} with an average of 4.08 mg.m^{-3} in all transects. Highest chlorophyll content was associated with Devi transect (2.64 mg.m^{-3}) (Table 2).

Table 2. Physico-chemical parameters off 7 estuaries during summer (April 2011)

	T-1	T-2	T-3	T-4	T-5	T-6	T-7
Transparency (m)	6.00-40.00 (24.25)	15-45 (26.6)	8.00-35.00 (23.75)	12.00-21.00 (17)	13.0-17.0 (16.20)	11.0-19.0 (11.0)	10.0-17.0 (15.0)
Water Temp (°C)	27.8-28.2 (28.1)	28.2-28.3 (28.2)	28.3-29.1 (28.8)	28.5-28.8 (28.7)	27.8-29.7 (29.1)	28.1-28.2 (28.2)	27.9-28.2 (28.0)
pH	8.00-8.10 (8.03)	8.10-8.10 (8.10)	8.0-8.10 (8.05)	8.0-8.0 (8.0)	8.0-8.10 (8.06)	8.10-8.10 (8.10)	7.90-8.10 (8.04)
Salinity (PSU)	34.0-35.0 (34.5)	33.0-35.0 (34.0)	34.0-35.0 (34.5)	34.0-35.0 (34.6)	33.0-35.0 (34.2)	35.0-35.0 (35.0)	33.0-34.0 (33.5)
DO (mg.L^{-1})	6.90-8.60 (7.58)	6.80-7.40 (7.13)	6.80-8.20 (7.63)	7.60-8.10 (7.83)	7.20-8.90 (8.0)	6.40-7.80 (7.30)	6.40-7.60 (7.10)
NO_2 (µmol.L^{-1})	0.62-0.69 (0.64)	0.52-0.71 (0.6)	0.65-0.7 (0.68)	0.5-0.63 (0.56)	0.4-0.57 (0.49)	0.53-0.75 (0.61)	0.58-0.64 (0.62)
PO_4 (µmol.L^{-1})	1.65-1.99 (1.89)	1.88-1.98 (1.91)	1.87-2.03 (1.92)	1.94-2.02 (1.98)	1.41-1.96 (1.72)	1.68-2.04 (1.84)	1.79-1.96 (1.88)
Chl-*a* (mg.m^{-3})	2.65-4.97 (4.08)	5.20-6.21 (3.96)	2.68-7.35 (4.98)	1.62-7.17 (4.6)	2.58-7.49 (5.49)	2.64-8.53 (2.64)	1.51-5.0 (3.0)
Phytoplankton (10^4xCells/L)	19.5-29.1 (4.7)	19.0-39.2 (11.0)	8.2-12.1 (1.8)	9.8-21.9 (6.3)	10.2-29.8 (8.5)	15.8-27.6 (5.1)	11.9-54.0 (18.5)

Phytoplankton composition, distribution and abundance

Spatial distribution of phytoplankton species and community structure was dynamic and variable. Total phytoplankton density in the surface layer was highest (26680 cells/l) near the transect Krishna.

Abundance values increased from Godavari to Mahanadi transect (Fig. 2). Lowest planktonic cell density (9480 cells/l) was recorded at Godavari. Variability of phytoplankton abundance and chlorophyll is shown in Fig. 2.

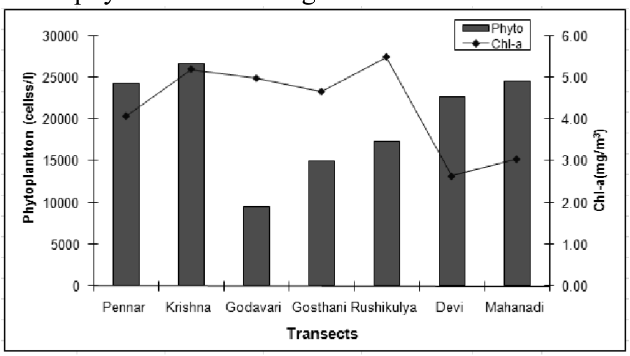

Fig. 2—variability of Chlorophyll-*a* concentration and Phytoplankton abundance

It revealed that variation of phytoplankton abundance is not in consistent with the variation in chlorophyll concentration at all transects. Maximum and minimum phytoplankton abundance was recorded at Krishna and Godavari respectively. A total number of 123 species of phytoplankton were identified from the entire study and they followed the sequence of abundance under six groups: diatoms > dinoflagellates > green algae > cyanobacteria > cocolithophores > silicoflagellate (Table 3 and Fig. 3).

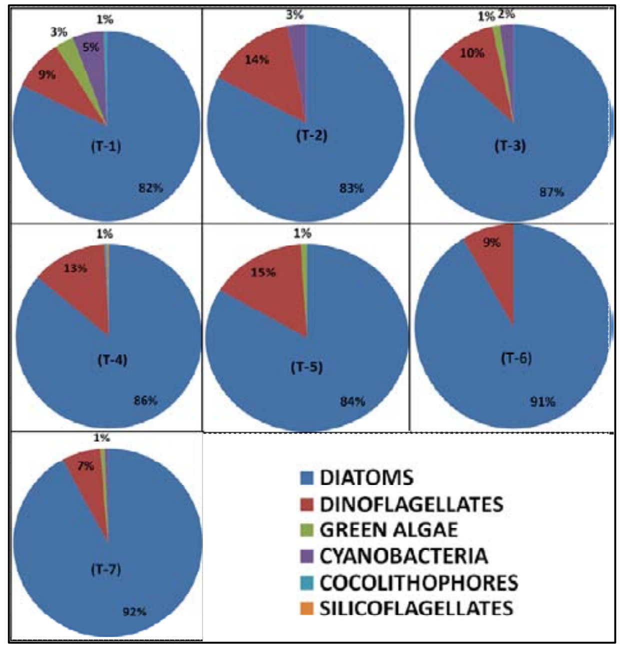

Fig. 3—phytoplankton composition at each offshore transects of 7 estuaries during summer (April 2011)

Among these groups, diatoms and dinoflagellates were not only the dominant species but also well distributed all along the offshore transects. Green algae were recorded from nearly all the transects except for Krishna and Devi. Cyanobacteria was present at four transects whereas cocolithophores and silicoflagellates were restricted their distribution to only one or two stations.

Table 3. Distribution and abundance (Cells/L) of phytoplankton along offshore transects of 7 estuaries during summer

S.No	Taxon	T-1	T-2	T-3	T-4	T-5	T-6	T-7
	DIATOMS							
1	*Actinotychus undulatus* (Bailey) Ralfs 1861	0	0	240	0	0	0	0
2	*Amphora coastatum*	1093	0	270	0	0	340	0
3	*Asterionella* sp, Hassall, 1850	0	0	150	0	64	0	0
4	*Asterionellopsis glacialis* (Castracane) Round, 1990	1090	1377	0	487	128	360	0
5	*Aulacodiscus* sp. Ehrenberg, 1844	0	340	0	0	0	0	0
6	*Bacillaria paxillifera*(O.F.Müller) T.Marsson, 1901	0	0	0	0	16	60	0
7	*Bacillaria* sp, Gmelin, 1791	160	800	0	0	320	0	0
8	*Bacteriastrum delicatulum* Cleve 1897	280	0	0	0	32	0	0
9	*Bacteriastrum hyalinum* Lauder 1864	513	0	120	333	64	0	0
10	*Bellerochea malleus* (Brightwell)Van Heurck 1885	0	0	0	0	32	260	0
11	*Campylodiscus* sp. Ehrenberg 1844	228	267	0	0	0	0	0
12	*Ceratualina pelagica* (Cleve) Hendey, 1937	0	0	60	0	0	0	0
13	*Chaetoceros diadema* (Ehrenberg) Gran 1897	0	0	0	0	80	0	0
14	*Chaetoceros messsanensis* Castracane 1875	0	0	0	0	288	0	0
15	*Chaetoceros affinis* Lauder 1864	0	0	120	0	0	0	0

16	*Chaetoceros coarctatus* Lauder 1864	0	0	0	0	112	820	0
17	*Chaetoceros curvisetus* Cleve 1889	0	0	0	0	112	0	0
18	*Chaetoceros decipiens* Cleve 1873	0	0	0	0	128	0	0
19	*Chaetoceros didymus* Gran & Yendo, 1914	0	0	30	0	0	0	0
20	*Chaetoceros lorenzianus* Grunow 1863	0	0	270	0	256	80	0
21	*Chaetoceros peruvianus* Brightwell 1856	0	0	0	520	256	80	229
22	*Chaetoceros socialis* Proshkina-Lavrenko 1963	0	0	0	0	0	0	1056
23	*Chaetoceros sp.* Ehrenberg, 1844	0	0	0	453	192	120	1080
24	*Climacosphenia moniligera* Ehrenberg 1843	0	320	0	0	0	0	0
25	*Coconeis littoralis* Subrahmanyan 1946	0	0	0	0	0	0	304
26	*Corethron hystrix* Hensen 1887	0	0	0	0	0	0	160
27	*Coscinodiscus centralis* Ehrenberg 1844	0	0	990	0	672	300	0
28	*Coscinodiscus eccentricus* Ehrenberg 1841	468	853	210	1167	848	440	1740
29	*Coscinodiscus granii* Gough 1905	0	0	210	0	0	0	0
30	*Coscinodiscus wailesii* Gran et 1937	0	0	30	0	0	0	0
31	*Cosinodiscus gigas* Ehrenberg 1841	2491	1940	0	0	608	1000	480
32	*Cyclotella meneghiniana* Kutzing 1844	320	0	0	0	0	0	0
33	*Cyclotella striata* (Kützing) Grunow 1880	273	364	90	0	0	0	664
34	*Cylindrotheca closterium* Reimann & Lewin 1964	993	0	0	0	0	0	0
35	*Diploneis weissiflogii* (Schmidt) Cleve, 1894	320	0	0	300	64	0	140
36	*Ditylum brightwelli* Grunow in Van Heurck 1885	600	0	180	0	16	0	452
37	*Ditylum sol* (Grunow) De Toni, 1894	0	767	0	0	112	0	296
38	*Eucampia zoodiacus* Ehrenberg 1839	0	0	0	280	416	660	956
39	*Fragilariopsis oceanica* (Cleve) Hasle 1965	0	0	0	0	0	0	160
40	*Guinardia striata* Hasle & Syvertsen 1996	0	0	150	0	0	0	0
41	*Gyrosigma balticum* (Ehrenberg) Rabenhorst 1853	472	0	0	0	0	0	0
42	*Gyrosigma* sp. Hassall 1845	0	0	90	0	0	0	0
43	*Hemidiscus hardmannianus* Greville	0	0	0	0	48	100	224
44	*Lauderia annulata* Cleve 1873	0	0	210	0	112	400	0
45	*Leptocylindrus danicus* Cleve 1889	792	0	240	0	96	260	0
46	*Leptocylindrus minimus* Gran 1915	0	0	180	0	0	0	764
47	*Licmophora* sp. Agardh 1827	0	0	0	0	0	0	60
48	*Mediopyxis helysia* Medlin & Kühn 2006	0	0	0	0	0	0	444
49	*Melosira sulcata* (Ehrenberg) Kützing 1844	0	320	0	433	0	0	204
50	*Navicula clavata* Gregory 1856	0	1387	0	0	0	0	0
51	*Navicula longa* (W. Greg.) Ralfs ex A. Pritch., 1861	0	0	120	360	0	0	0
52	*Navicula* sp. Bory de Saint-Vincent 1822	0	0	0	0	224	280	0
53	*Nitzschia longissima* (Brebisson) Ralfs 1861	0	0	90	0	128	80	1040
54	*Nitzschia seriata* Cleve 1883	273	0	0	0	0	0	0
55	*Nitzschia sigma* (Kützing) W. Smith, 1853	0	0	0	0	0	240	0
56	*Odontella heteroceros*	1575	988	510	0	320	0	0
57	*Odontella mobiliensis* (Bailey) Grunow 1884	0	0	0	387	464	580	304
58	*Odontella sinensis* (Greville) Grunow 1884	0	0	120	0	160	200	96

59	*Paralia sulcata* (Ehrenberg) Cleve 1873	0	416	0	0	0	0	0
60	*Pinnularia alpina* W. Smith 1853	720	427	240	0	0	0	0
61	*Planktoniella sol* (Wallich) Schutt 1892	0	0	0	0	64	40	176
62	*Pleurosigma angulatum* Smith, 1852	0	0	240	0	0	0	0
63	*Pleurosigma elongatum* W. Smith 1852	0	0	0	527	384	240	288
64	*Podosira glacialis* (Grunow) Jørgensen 1905	0	0	0	0	48	0	0
65	*Pseduonitzschia pungens* Hasle 1993	0	0	0	0	96	0	0
66	*Pseudonitzschia* sp. Cleve, 1883	0	0	0	0	0	0	296
67	*Rhaphoneis discoides* Subrahmanyan	0	427	0	0	0	0	0
68	*Rhizosolenia alata* Brightwell 1858	1521	1480	150	580	96	360	0
69	*Rhizosolenia castracanei* Cleve 1889	0	0	0	300	80	0	0
70	*Rhizosolenia crassispina* Schroeder	0	0	0	267	0	0	304
71	*Rhizosolenia cylindrus* Cleve 1897	1200	0	0	0	0	0	0
72	*Rhizosolenia imbricata* Brightwell 1858	0	0	0	160	416	320	0
73	*Rhizosolenia setigera* Brightwell 1858	780	2064	300	0	0	0	0
74	*Rhizosolenia stolterfothii* H.Peragallo 1888	0	0	0	0	0	0	476
75	*Rhizosolenia stylifromis* Brightwell	760	0	0	0	192	3260	1120
76	*Skeletonema costatum* (Greville) Cleve 1873	1820	1392	270	440	0	0	3628
77	*Stephanopyxis turris* Ralfs in Pritchard 1861	0	0	0	0	176	0	0
78	*Surirella eximia* Greville	0	1367	270	160	0	0	0
79	*Surirella fluminensis* Grunow 1862	488	0	0	0	0	0	208
80	*Synedra formosa* Hantzsch 1863	0	480	300	0	0	0	0
81	*Thalassionema nitzscioides* Mereschkowsky, 1902	98	320	300	467	1664	1500	1728
82	*Thalassiosera* sp. Cleve 1873	0	0	150	0	0	0	0
83	*Thalassiosira rotula* Meunier, 1910	0	0	0	0	0	180	32
84	*Thalassiosira subtilis* (Ostenfeld) Gran 1900	0	0	150	373	0	0	456
85	*Thalassiothix longissima* Cleve & Grunow 1880	618	3921	1020	4860	2368	6860	3008
86	*Thalassiothrix fraunfeldii* (Grunow) Jörgensen 1900	0	0	0	0	2176	1240	0
87	*Triceratium favus* Ehrenberg 1839	0	0	150	0	112	40	0
88	*Triceratium reticulatum* Ehrenberg 1844	0	0	0	0	112	0	0
89	*Triceratium robertsianum* Greville 1866	0	0	0	0	80	0	0
	DINOFLAGELLATES							
90	*Ceratium azoricum* Cleve, 1900	0	0	0	0	32	140	0
91	*Ceratium furca* (Ehrenberg) Lachmann 1858	0	0	0	0	192	680	0
92	*Ceratium macroceros* (Ehrenberg) Vanhöffen 1897	0	0	0	0	64	0	64
93	*Ceratium trichoceros* (Ehrenberg) Kofoid 1908.	280	0	0	0	64	140	0
94	*Ceratium tripos* (O.F.Müller) Nitzsch, 1817	0	0	0	0	64	180	0
95	*Dinophysis caudata* Saville-Kent 1881	841	1427	330	207	96	0	108
96	*Gonyaulax minima* Matzenauer 1933	228	320	0	0	0	0	0
97	*Gyrodinium* sp. Kofoid & Swezy 1921	263	0	0	0	0	0	0
98	*Noctiluca miliaris* Suriray 1816	195	0	0	0	0	0	0
99	*Noctiluca scntillans* Kofoid & Swezy, 1921	0	0	0	0	1184	300	0
100	*Ornithocercus steinii* Schutt 1900	0	0	0	240	16	0	0

101	*Prorocentrum gracile* Schütt, 1895	0	420	0	200	64	0	416
102	*Prorocentrum maximum* Schiller, 1937	0	0	0	0	80	0	128
103	*Prorocentrum micans* Ehrenberg 1834	231	1049	0	600	592	80	120
104	*Prorocentrum rostratum* Stein 1883	0	0	0	0	0	0	144
105	*Prorocentrum scutellum* Schröder, 1900	0	0	0	0	0	0	128
106	*Protoperidinium depressum* Balech 1974	0	0	210	0	0	280	80
107	*Protoperidinium* sp. Bergh, 1882	0	0	180	720	32	0	312
108	*Protoperidinium steinii* Jorgensen 1889	0	0	150	0	16	140	0
109	*Pyrocystis* sp Murray ex Haeckel, 1890	116	480	0	0	80	0	0
110	*Pyrophacus horologicum* Stein 1883	0	160	0	0	80	0	128
111	*Pyrophacus steinii* Schiller 1935	0	0	60	0	16	0	0
	GREEN ALGAE							
112	*Scendesmus* sp. Meyen 1829	0	0	120	0	48	0	0
113	*Chlorella marina* Butcher 1952	533	0	0	0	0	0	0
114	*Cosmarium* sp. Corda ex Ralfs 1848	0	0	0	0	0	0	192
115	*Oocyctis* sp Nägeli ex A.Braun, 1855	256	0	0	0	0	0	0
116	*Pediastrum* sp. Meyen, 1829	0	0	0	0	128	0	0
	CYANOBACTERIA (BGA)							
117	*Merismopedia* sp. Meyen1938	0	0	0	0	0	0	128
118	*Microcystis* sp. Lemmermann 1907	0	468	60	0	0	0	0
119	*Oscillatoria* sp. Gomont 1892	130	340	90	0	0	0	0
120	*Trichodesmium erythraeum* Ehrenberg 1830	1191	0	60	0	0	0	0
	COCOLITHOPHORES							
121	*Phaeocystis* sp. Lagerheim	116	0	0	0	0	0	0
122	*Rhabdosphaera* sp. Haeckel 1894	0	0	0	53	0	0	0
	SILICOFLAGELLATES							
123	*Dictyocha* sp. Ehrenberg 1837	0	0	0	53	0	0	0

Among the diatoms, *Coscinodiscus eccentricus*, *Thalassionema nitzschioides*, *Thalassiothrix longissima* were present at all the transects while *Rhizosolenia alata* was common to the transects except Mahanadi (Table 3). *Asterionellopsis glacialis*, *Coscinodiscus gigas* & *Skeletonema coastatum* were found from 5 transects. Ten diatom members namely, *Odontella* heteroceros, *Odontella mobiliensis*, *Chaetoceros peruvianus*, *Chaetoceros lorenzianus*, *Cyclotella striata*, *Eucampia zoodiacus*, *Leptocylindrus danicus*, *Nitzschia longissima*, *Pleurosigma* sp., *Rhizosolenia styliformis*, were noticed from four transects. Remaining diatom species were recognized from one to three transects.

Many species of dinoflagellate (22 in number) were encountered in this survey. Highest cell count observed during this survey was 3856 cells/l at transect Krishna wherein *Dinophysis caudata* was the dominant species followed by *Prorocentrum micans*. Lowest abundance of dinoflagellates was associated with Godavari transect (930 cells/l) wherein *Dinophysis caudata* was also the dominant species. Among the dinoflagellate group *Dinophysis caudata* was present at 6 transects; *Prorocentrum micans* at 5 transects; *Prorocentrum gracile* and *Protoperidinium* sp. at 4 transects. Other dinoflagellate species were found at 1 to 3 transects. Among dinoflagellates from Pennar to Godavari transects, *Dinophysis caudata* outnumbered other species, but at Gosthani, Rushikulya, Devi and Mahanadi transects respectively *Protoperidinum* sp., *Noctilluca scintillans*, *Ceratium furca*, and *Prorocentrum gracile* were emerged as dominant species.

Of total 89 diatom species, *Thalassiothrix* *longissima* was the most abundant species found at Krishna, Godavari, Gosthani, Rushikulya, and Devi. At Pennar, the most abundant diatom was *Coscinodiscus gigas* whereas at Mahanadi both *Skeletonema coastatum* and *Thalassiothrix longissima* were the dominant species. Other phytoplankton species except *Trichodesmium erythraeum* at Pennar were present in small numbers.

Among the bloom forming phytoplankton species, *Asterionellopsis glacialis* (Diatom) is abundant at all transects except Godavari and Mahanadi, however *Dinophysis caudata* (Dinoflagellate) is identified at all transects except Devi. The abundance of other species at different transects are: *Noctiluca miliaris* at Pennar (only 195 numbers L^{-1}), *Noctiluca scintillans* at Rushikulya (1184 numbers L^{-1}) and Devi (300 numbers L^{-1}); *Microcystis* sp. at Krishna (468 numbers L^{-1}) and Godavari (60 numbers L^{-1}); *Oscillatoria* sp. from Pennar to Godavari, *Trichodesmium erythraeum* at Pennar (1191 numbers L^{-1}) and Godavari (60 numbers L^{-1}) and *Pheaocystis* sp. at Pennar (116 numbers L^{-1}) were observed. Pollution indicating and bloom forming cyanobacterial members such as *Microcystis* sp., *Oscillatoria* sp. and *Trichodesmium erythraeum* marked their presence at Pennar, Krishna & Godavari whereas fully absent from Gosthani to Mahanadi.

Table 4 shows the total abundance of species (N) in four ecosystems (transects) with the measures of Species Richness (d), Shannon Diversity Index (H'), Simpson's Dominance Index (D) and Evenness Index (J'). Species richness of phytoplankton flora was ranged from 27 at Gosthani to 63 at Rushikulya. Average total abundance was from 9480 numbers L^{-1} at Godavari to 26680 numbers L^{-1} at Krishna. Species diversity indeed assumes that individuals are randomly sampled from an independently large population. The index also assumes that all the species are represented in the sample. Species diversity was calculated by using Shannon Diversity Index [H']. This index varied from 2.720 at Gosthani to 3.426 at Godavari. The Simpson's dominance index measures biodiversity based on the probability that two individuals randomly selected from a sample will belong to the same species (or some category other than species). Simpson's Dominance varied from 0.042 at Godavari to 0.129 at Gosthani as well as Devi. Evenness index is also an important component of diversity indices. This expresses how evenly the individuals are distributed among the different species. The evenness index was low (0.755) at Devi and high (0.924) at Godavari.

Table 4. Average univariate measures of phytoplankton community along offshore transects of 7 estuaries during summer (April 2011) [Standard Deviation are given in parentheses]

Transect (Code)	Total species (S)	Total individuals (N)	Species richness (d)	Shannon's diversity Index (H')	Simpson's dominance index (D)	Pielou's Evenness Index (J')
Pennar (T-1)	12.50 (2.08)	24319.50 (4701)	1.14 (0.20)	2.31 (0.20)	0.12 (0.03)	0.92 (0.02)
Krishna (T-2)	12.67 (2.08)	26680 (10958)	1.15 (0.06)	2.36 (0.06)	0.11 (0.01)	0.93 (0.04)
Godavari (T-3)	16 (2.00)	9480 (1788)	1.64 (0.18)	2.64 (0.11)	0.08 (0.01)	0.95 (0)
Gosthani (T-4)	16.33 (4.62)	14927 (6268)	1.61 (0.48)	2.33 (0.36)	0.16 (0.06)	0.84 (0.05)
Rushikulya (T-5)	19.20 (1.64)	17280 (8467)	1.88 (0.12)	2.37 (0.28)	0.15 (0.05)	0.80 (0.08)
Devi (T-6)	15.75 (2.87)	22640 (5132)	1.48 (0.33)	2.25 (0.30)	0.16 (0.05)	0.82 (0.06)
Mahanadi (T-7)	19.00 (4.42)	24521 (18517)	1.80 (0.32)	2.49 (0.27)	0.13 (0.05)	0.85 (0.05)

Discussion

In this study mean transparency value was higher for Pennar, Krishna & Godavari transects indicating that the water was less turbid towards south western Bay of Bengal. Temperature is one of the most important physical parameters influencing the water quality and distribution of biota in all types of coastal ecosystems. Both temperature and salinity considerably affect the bio-geochemical cycling of certain elements[34]. The highest temperature was observed along Rushikulya transect[35]. There was no particular trend observed in the surface water temperature among sampling sites during the study period. The pH remained alkaline during the course of this study at these transects. Earlier studies have depicted that along the western Bay, the average salinity was 33.7 psu up to 16^0N in the surface layer but decreased northwards reaching as low as 29.6 psu at 19^0N[36]. Average salinity was found lowest at Mahanadi among all transects in agreement with the earlier study[37].

We found lowest value of dissolved oxygen at Mahanadi transect followed by the Pennar. The lower values might be due to decrease in air -to- sea O_2 flux and photosynthesis rate[38]. But as a whole the recorded range of DO (8.0-7.10 mg/l) for all transects is above the permissible limit which is a positive sign for optimum ecosystem function and highest carrying capacity[39]. Highest DO was recorded at Rushikulya transect which also agrees with the previous observation[35] (Table 2). The spatial distribution of nitrite (NO_2) concentration in different transects of coastal waters shows the minimum at Rushikulya and maximum at transect Devi. Similar results for nitrite at offshore Rushikulya and Devi transects have also been reported earlier[35,40]. Phosphate was ranged between 1.41 and 2.04 µmol/l with a lower average value of 1.72 µmol/l at transect Rushikulya which is within the lower range compared to previous studies[35]. This might be due low rate of addition of phosphorous by means of re-mineralization of organic matter[41,42]. In our study we found a narrow range (5.50-2.64 $mg.m^{-3}$) of deviation in chlorophyll-*a* concentrations among the transects without showing any geographic pattern[43-45].

Highest chlorophyll content is observed at Devi (2.64 $mg.m^{-3}$). This might be due to the phytoplankton community that contributes maximum to the chlorophyll concentration (Table 2). But previously low mean value of about 0.5 $mg.m^{-3}$ was recorded off Devi estuary by Mishra et al. (2003)[46] during summer.

The phytoplankton population density exhibited a linear relationship with chlorophyll-*a* along most of the transects. A short deviation was observed in the above trend at Godavari transect declining in population density with respect to increasing Chl-*a*. This might be due to the reason of presence of small sized phytoplankton (nanoplankton & picoplankton) which have not been quantified in the present study[47,48,49]. However, Gosthani exhibited contrary result to the above. This might be due to contribution rate of quantified phytoplankton fraction to total chlorophyll-*a* at respective transects[50] (Fig. 3). Variations in salinity, nutrients, physical mixing, and other biological and chemical properties could have caused shifts and changes in the abundance and distribution of phytoplankton species[51,52].

From the dataset given in Table 2, the inter-relationship of the parameters is not understood. Thus single factor ANOVA test was carried out on physico-chemical parameters to know any significant variance of the parameters. From the analysis it was revealed that the variability exhibited in average water temperature and nitrite between the transects ($P<0.05$). Rest of the parameters pH, salinity, DO, Phosphate and Chl-*a* were not significantly varied from transect to transect. Thus in general environmental parameters of the seven estuarine offshore transects were similar to each other (Table 5).

Table 5. Single factor ANOVA of physico-chemical parameters of offshore transects 7 estuaries (*Significant ($P<0.05$)

	F	P-value	F crit
Transparency	1.15	0.37	2.57
Water temperature	**5.04***	0.00	2.57
pH	1.60	0.20	2.57
Salinity	0.55	0.77	2.57
DO	1.46	0.24	2.57
Nitrite	**4.29***	0.01	2.57
Phosphate	1.35	0.28	2.57
Chlorophyll-*a*	0.91	0.50	2.57

Phytoplankton, composition, distribution and abundance

A total number of species (123) belonging to different groups from all transects represent the phytoplankton community of the area. Like other phytoplankton studies in the Bay[53,54] and nearby seas[37], present observation of phytoplankton composition also highlights the dominancy of diatoms followed by dinoflagellates. Green algae, cyanobacteria, cocolithophores and silicoflagellates were quantified as the minor components of the phytoplankton communities[14,54,55,56] (Fig. 2).

Diatoms, namely *Coscinodiscus ecentricus*, *Thalassionema nitzschioides* and *Thalassiothrix. longissima* were common in the transects studied. Other researchers[14,54,56] have also found these species as ubiquitous in the Bay. Other diatoms and dinoflagellates members were also well represented in the communities. Wide distribution of a number of phytoplankton species off the estuarine transects may be due to the unique nature of water quality as observed from analyses of physicochemical parameters. In terms of numbers, *Thalassiothrix longissima* was the most abundant diatom that was present all along the east coast[57,58]. Dominancy observed in this species along with others may be due to the reason that same environmental conditions particularly availability of nutrients during this season favors good proliferation[59]. Generally some bloom forming species like *Asterionellopsis glacialis*, *Dinophysis caudata*, Microcystis sp., Oscillatoria sp, *Trichdesmium erythraeum* and Phaeocystis sp. were observed in high numbers off Pennar to Godavari estuarine transects. Unlike these above species, *Noctiluca scintillans* were totally absent at transects from Pennar to Godavari, Gosthani, and Mahanadi. This species was found in higher number at Rushikulya (1184 number.L^{-1}) followed by Devi (300 numbers. L^{-1}). Mohanty et al. (2007)[35] have also reported this bloom forming species off Rushikulya River during summer. Though bloom forming species marked their presence at transects from Pennar to Godavari, they were still in control as far as their population dynamics are concerned.

Although species richness was highest (1.88) at Rushikulya transect, diversity and evenness were highest for Godavari. Lowest species diversity index and evenness were recorded at Devi and Rushikulya respectively. Since Godavari River brings lot of nutrients[60] and in opposite, Devi and Rushikulya are minor rivers by nature, diversity and evenness were highest for the former as compared to the later transects. Dominancy as opposite to the evenness value; was lowest for Godavari and highest for Gosthani (Table 4). The mean diversity estimated for all the transects is 2.39±0.13 which is more than the observations of Carropo et al. (1999)[61] for Adriatic Sea. But according to Margalef (1978)[62], diversity may close to 5 in oceanic province having low and uniform population density but high species number. Though abundance value is high for transect Devi, the diversity index is relatively low and also supported by high dominance value. This is due to the dominance of few diatomic species *viz. Coscinodiscus gigas*, *Rhizosolenia styliformis*, *Thalassionema nitzscioides* and *Thalassiothirx longissima*. This reason is in accordance with Margalef (1978)[62].

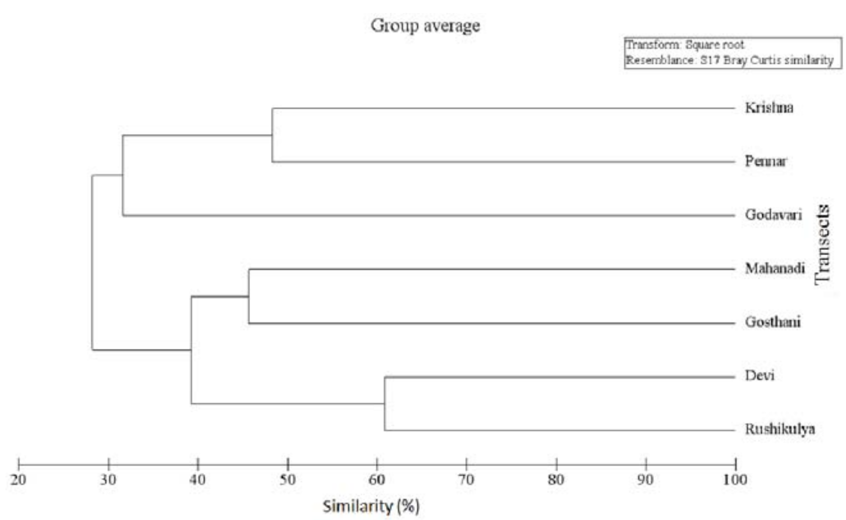

Fig. 4—dendrogram for Bray-Curtis Similarity Index of phytoplankton communities off 7 estuaries during summer (April 2011)

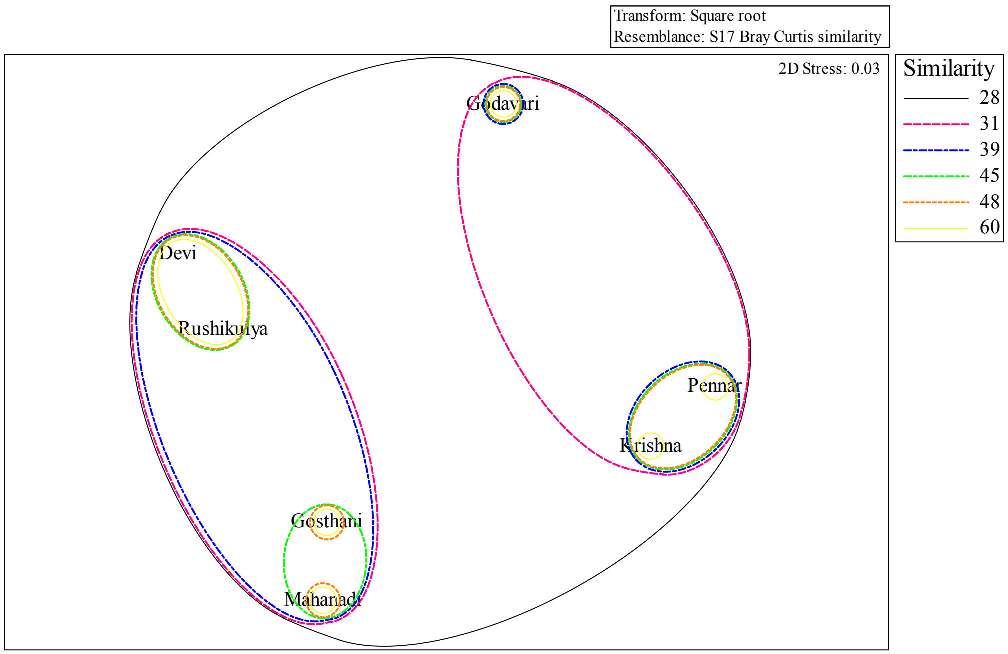

Fig. 5—non-metric multi-dimensional scaling for relation of the phytoplankton composition among offshore transects of 7 estuaries during summer (April 2011)

Dendrogram drawn for Bray-Curtis Similarity index explained the spatial variation in phytoplankton composition of the offshore transects (Fig. 4). From this graph it is clear that offshore transects towards south formed a group independent of northern estuarine transects. This might be due to the fact of low densities, despite maximum species richness, diversity and community evenness[63]. Among the southern transects, (similarity: 31%), Krishna and Pennar formed a distinct group having similarity 48 % (Fig. 5). But for the northern off estuarine transects (Similarity: 39%), there are two distinct groups *viz.* Mahanadi, Gosthani (similarity: 45%) as well as Devi and Rushikulya (Similarity (60%). Similarity between phytoplankton composition of the offshore transects of the 7 estuaries was as high as 28%.

Conclusion

In the present cruise experience, we do conclude that yes, phytoplankton community varies from one offshore transect to another i.e. from one ecosystem to another along east coast of India during the summer period. This study has shown that a number of phytoplankton species live in the Bay of Bengal, and they contribute to the biological diversity of the Bay. According to the observed degree of similarities in species composition found between adjacent offshore estuarine transects and even between two far off places, it can also be concluded that there was no large scale spatial variation of species composition along selected transects spread over the western Bay of Bengal. In the present study similar types of species are identified as reported earlier. This implies there is no loss of biodiversity marked in the present investigation. Further, a thorough seasonal qualitative and quantitative investigation of the phytoplankton floral community in conjunction with nutrient dynamics of the estuarine offshore transects may result in proper understanding about these initiators of marine food chain.

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References

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. Zafar, M., Southwest monsoon effect on plankton occurrence and distribution in parts of Bay of Bengal, *Asian. Fish. Sci.*, 20 (2007) 81-94.
4. Saravanakumar, A., Rajkumar, M., Thivakaran, G.A. & Sesh Serebiah, J., Abundance and seasonal variations of phytoplankton in the creek waters of western mangrove of

Kachchh-Gujarat. *J. Environ. Biol*., 29 (2008) 271-274.
5. James, B.K., Ladgibolu, I.A., Nutrient and Phytoplankton Production dynamics of a tropical Harbor in relation to water quality indices. *J. American Sci.* 6(9) (2010) 26-275.
6. Kannan, L. & Krishnamurthy, K., Nutrients and their impact on Phytoplankton; Marine *Marine Plants, Seaweed Res. Utilization Asso*., (1985) 73-78.
7. McCreary, J.P., Kohler, K.E., Hood, R.R & Olson, D.B., 1996. A four-component ecosystem model of biological activity in the Arabian Sea, *Prog. Oceanogr*., (1996)193–240.
8. Madhupratap, M., Gauns, M., Ramaiah, N., Kumar, S.P., Muraleedharan, P.M., de Souza, S.N., Sardesai, S. & Muraleedharan, U., Biogeochemistry of the Bay of Bengal:Physical, chemical and primary productivity characteristics of the central and western Bay of Bengal during summer monsoon 2001, *Deep Sea Res. Part II*., 50 (2003) 881–896.
9. Vinayachandran, P.N. & Mathew, S. 2003. Phytoplankton bloom in the Bay of Bengal during the northeast monsoon and its intensification by cyclones, *Geophys. Res. Letts.,* 30(2003) 1572.
10. Gomes, H.R., Goes, J.I. & Saino, T., Influence of physical processes and freshwater discharge on the seasonality of phytoplankton regime in the Bay of Bengal, *Cont. Shelf Res.* 20 (2000) 313-330.
11. Ananthan, G., Sampathkumar, P., Soundarpandian, P.& Kanan, L., Phytoplankton composition and community structure of Ariyankuppam estuary and Verampattinam coast of Pondichery, *J.Fish. Aquat Sci*., 3(1) (2008) 12-21.
12. Prakash, K.P., Raman, A., Phytoplankton charcteristics and species assemblage patterns in northwest Bay of Bengal, *Indian J. Mar. Sci.,* 21(1992) 158-160.
13. Gouda, R. & Panigrahy, R.C.,Diurnal variation of phytoplankton in Rushikulya estuary, east coast of India. *Indian. J. Mar. Sci.,* 18(4) (1989) 246- 250.
14. 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.
15. Gouda, R. & Panigrahy, R.C., Phytoplankton in Indian estuaries, *J. Ind. Ocean Stud.,* 7(1) (1999) 74-82.
16. Sridhar, R., Thangaradjou, T., Senthil Kumar, S. & Kannan, L., Water Quality and phytoplankton characteristics in the Palk Bay, southeast coast of India. *J. Environ. Biol*., 27 (2006) 561-566.
17. Choudhury, A. K. & Pal, R., Diversity of planktonic diatoms from West Bengal coast with special reference to taxonomic Accounts, *Phytomorph*. 58 (1&2) (2008) 29-41.
18. Strickland J D H & Parsons T R, 1972. *A practical handbook for seawater analysis*. (Fisheries research board of Canada) 1972, pp. 311.
19. Smith GM, 1950. The *Freshwater Algae of the United States,* (2nd ed. McGraw Hill, New York) 1950, pp. 719.
20. Hendey, N.I., Marine diatoms from West African Ports, *J. Royal Micro. Soc.,*77 (1958) 28-88.
21. Desikachary T V, *Cyanophyta* (New Delhi: Indian Council of Agricultural Research) 1959, pp. 700.
22. Wimpenny R S, *The plankton of the sea* (Faber and Faber Limited, London) 1966, pp. 426.
23. Patrick R & Reimer C W, *The diatoms of the United States exclusive of Alaska and Hawaii (Vol. 1) (*Monograph*,* Academy of Natural Sciences, Philadelphia) 1966, pp.688.
24. Patrick R & Reimer C W, *The diatoms of the United States exclusive of Alaska and Hawaii Vol. 2* (Monograph*,* Academy of Natural Sciences, Philadelphia) 1975, pp.213.
25. Whitford L A & Schmacher G H, *A manual of freshwater algae* (Sparks Press. .Raeigh N.C) 1973, pp.324.
26. Nwankwo D I, *A Practical Guide to the study of algae* (JAS Publishers, Lagos, Nigeria) 2004, pp. 84.
27. Siver P A, Synurophyte algae, in: *Freshwater Algae of North America* edited by J.D. Wehr & R.G. Sheath (Academic Press, Tokyo) 2003 pp. 523-557.
28. Rosowski R, Photosynthetic euglenoids, in: Wehr JD and Sheath RG, editor. Freshwater *Algae of North America. Ecology and Classification* edited by J.D. Wehr & R.G. Sheath (Academic Press, New York) 2003, pp. 383-422.
29. Clarke K R & Gorley R N, *Primer v6: user manual/tutorial* (PRIMER-E, Plymouth, UK) 2006, pp 192.
30. 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.
31. Shannon C E & Weiner W, *The Mathematical Theory of Communication.* (University of Illinois Press, Urbana) 1963, pp. 117.
32. Pielou, P.P., The measurement of diversity in different types of biological collections., *J. Theor. Biol.*, 13(1966) 131-144.
33. Simpson, E.M., Measurement of diversity, *Nature* (1949) 163-688.
34. Mee I D, Coastal lagoons, in: *Chemical Oceanography edited by* J. Riley & R. Chester (Vol.7, Academic Press, New York) 1978, pp. 441-490.
35. Mohanty, A.K., Satpathy, K.K., Sahu, G., Sasmal, S.K., Sahu, B.K. and 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(5) (2007) 616-618.
36. Kumar, S.P., Muraleedharan, P.M., Prasad, T.G., Gauns, M., Ramaiah, N., De Souza, S.N., Sardesai, S. & Madhupratap, M., Why is the Bay of Bengal less productive during summer monsoon compared to the Arabian Sea? *Geophys. Res. Letts.,* 29 (24) (2002) 2235.
37. Mishra, R.K., Shaw, B.P., Sahu, B.K., Mishra, S. & Senga, Y., Seasonal appearance of Chlorophyceae phytoplankton bloom by river discharge off Paradeep at Orissa Coast in the Bay of Bengal, *Environ. Monit. Assess*., 149 (2009) 261–273.
38. Manasrah, R*.,* Raheed, M. & Badran, M.I., Relationships between water temperature, nutrients and dissolved oxygen in the northern Gulf of Aqaba, Red Sea, *Oceanologia*., 48(2) (2006) 237–253.
39. UNESCO/WHO, *Water quality surveys. A guide for collection and interpretation water quality data. Studies and reports in hydrology* (No. 23. United Nation Educational Scientific and Cultural Organization and World Health Organization, Paris) 1978, pp.350.
40. Pradhan, U. K., Shirodkar, P .V. & Sahu, B. K., Physico-chemical characteristics of the coastal water off Devi estuary, Orissa and evaluation of its seasonal changes using chemometric techniques, *Curr. Sci*., 96 (9) (2009) 1203-1209.

41. Postma, H., Exchange of materials between the North Sea and the Waden Sea, *Mar. Geol.*, 40(1981) 199-213.
42. Nixon, S.W., Nutrient dynamics, primary production and fisheries yields of lagoons, *Oceanol. Acta*., 4(1982) 357–372.
43. Qasim S Z, Primary production in some tropical environments, in: *Marine Production Mechanisms* edited by M.J. Dunbar (Cambridge University Press, Cambridge) 1979, pp. 31-70.
44. Bhattathiri, P.M.A., Devassy, V.P. & Radhakrishna, K., Primary production in the Bay of Bengal during southwest monsoon of 1978, *Mahasagar*. 13 (1980) 315-323.
45. Devassy, V.P., Bhattathiri, P.M.A. & Radhakrishna, K., Primary production in the Bay of Bengal during August, 1977, *Mahasagar*., 16(1983) 443-447.
46. Mishra, R.K. & Shaw, B.P., Spatio-temporal variation of optically active substances in the coastal water off Orissa from Rushikulya to Dharma (east coast of India*)*, *Indian J. Mar. Sci*., 32(2) (2003) 133-140.
47. Azov, Y., Seasonal patterns of phytoplankton productivity and abundance in nearshore oligotrophic waters of the Levant basin (Mediterranean), *J. Plankton Res*., 8(1986) 41-53.
48. Berman, T., Azov, Y., Schneller, A., Walline, P. & Townsend, D.W., Extent, transparency and phytoplankton distribution of the neritic waters overlying the Israeli coastal shelf, *Oceanol. Acta*., 9(1986) 439-447.
49. Agawin, N.S.R., Durate, C.M., Agusti, S., Nutrient and temperature control of the contribution of picoplankton to phytoplankton biomass and production, *Limnol. Oceanogr.* 45(2000) 591-600.
50. Polat, S. & Piner, M.P., Seasonal variation in biomass, abundance and species diversity of hytoplankton in the Iskenderun bay (North Eastern Mediterranean, *Pak. J. Bot.,* 34(2) (2002) 101-112.
51. Rabalais, N.N., Turner, R.E., Justic, D., Dortch, Q., Wisemann, W.J. & Sen Gupta, B.K., Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf, *Estuaries.*, 19(1996) 386-407.
52. Pinckney, J.L., Richardson, T.L., Millie, D.F. & Paerl, H.W., Application of photopigment biomarkers for quantifying microalgal community composition and in situ growth rates, *Org. Geochem.*, 32(2001) 585–595.
53. Geeta Madhav, V. & Kondalarao, B., Distribution of phytoplankton in the coastal waters of east coast of India, *Indian J. Mar. Sci*., 33(2004) 262-268.
54. Achary, M.S., Sahu, G., Mohanty, A.K., Samantara, 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.
55. De, T.K., Choudhury, A., Jana, T.K., Phytoplankton community organization and species diversity in the Hooghly estuary, north east coast of India, *Indian J. Mar. Sci.* 23(3) (1994) 152-156.
56. Naik, S., Acarya, B.C. & Mohapatra, A., Seasonal variation of phytoplankton in Mahanadi Estuary, East coast of India. *Indian J. Mar. Sci.,* 38(2) (2009) 184-190.
57. Paul, J.T., Ramaiah, N., Gauns, M. & Fernandes, V., Preponderance of a few diatom species among the highly diverse microphytoplankton assemblages in the Bay of Bengal. *Mar. Biol.*, 152(1) (2007) 63-75.
58. Sawant, S. & Madhupratap, M., Seasonality and composition of phytoplankton in the Arabian Sea, *Curr. Sci.,* 71(1996) 869-873.
59. Buzzi, F., Phytoplankton assemblages in two sub-basins of Lake Como, *J. Limnol.*, 61(1) (2002) 117-128.
60. Sarma, V.V.S.S., Prasad, V.R., Kumar, B.S.K., Rajeev, K., Devi, B.M.M., Reddy, N.P.C., Sarma, V.V. & Kumar, M.D., Intra-annual variability in nutrients in the Godavari Estuary, India, *Cont. Shelf Res*., 30(19)(2010) 2005-2014.
61. Caroppo, C., Fiocca, A., Sammarco, P. & Magazzu, G., Seasonal variations of nutrients and phytoplankton in the coastal SW Adriatic Sea (1995–1997), Bot. Mar., 42(1999) 389–400.
62. Margalef R, Diversity, in: editor. Phytoplankton Manual edited by A. Sournia (UNESCO, Paris) 1978, pp.251-260.
63. Polikarpov, I., Al-Yamani, F. & Saburova, M., Space-time variability of phytoplankton structure and diversity in the north-western part of the Arabian Gulf (Kuwait's waters), Bio. Risk., 3(2009) 83–96.