

Distribution, abundance and diversity of phytoplankton in the inshore waters of Nizampatnam, South East coast of India

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Distribution, abundance and species assemblages of Phytoplankton were studied from inshore waters of Nizampatnam, South East coast of India in March 2007. Significant spatial variations in temperature, pH, salinity, dissolved oxygen (DO), nitrites (NO₂) –N, nitrates (NO₃) –N, phosphate (PO₄) –P, silicate (SiO₄) – (Si) were monitored. A total of 90 species of phytoplankton (net hauls) represented by 5 groups were identified at nine stations, collected along three transects during low tide. Percentage contribution of each group of phytoplankton was in the order: Bacillariophyceans > Dinophyceans > Cyanophyceans > Euglenophyceans. *Pleurosigma angulatum*, *Navicula sp.* were dominant species in the study area. Bray - Curtis similarity and group average clustering, recommended identifying two assemblages of phytoplankton in the study area. High diversity of phytoplankton in the present area suggests stable environmental conditions.

[**Keywords:** Composition, Distribution, Species, Assemblages, Phytoplankton, Nizampatnam]

Introduction

Phytoplankton is one of the biological components that initiate the marine food chain by serving as food to primary consumers like zooplankton, fish etc.,¹. The marine ecologists have used biotic and abiotic factors in the structuring phytoplankton community operating on a relatively local scale². The diverse forms and size of phytoplankton play important ecological role in the ecosystem³. Phytoplankton abundance and composition of an aquatic ecosystem are governed by various physico-chemical factors⁴. Baseline data on environmental parameters are prerequisite for understanding the ecological changes observed in biotic parameters. There is good information available on phytoplankton distribution of coastal waters of east coast of India⁵⁻⁸. There is however very little information available on distributional pattern and depth distribution in ratio to physico-chemical parameters in coastal areas. The present paper deals with the species composition and quantitative abundance of phytoplankton in relation to physico-chemical parameters in coastal areas.

Material and Methods

Phytoplankton samples were collected from nine sampling stations located in three transects (North, Central and South) during low tide (Fig. 1). Sampling was carried in three depth (<5 m, 5-10 m, >10 m) in

inshore waters of Nizampatnam, in March 2007 (Fig. 1). Surface samples consisted of both net hauls (30 µm mesh size) and 2 litre unit samples collected with the help of a Niskin sampler. Physico-chemical parameters of surface waters such as Temperature, pH, Salinity, DO, Turbidity, NO₂ –N, NO₃–N, PO₄–P, SiO₄–Si were also analysed from each station using standard methods (Parson, 1984)⁹. All net hauls were fixed in Lugol's Iodine solution and stored until further analysis in the laboratory. For taxonomic identification, a research microscope (Olympus, Japan) with x400 was used. Species identification was carried out according to Subrahmanyam¹⁰.

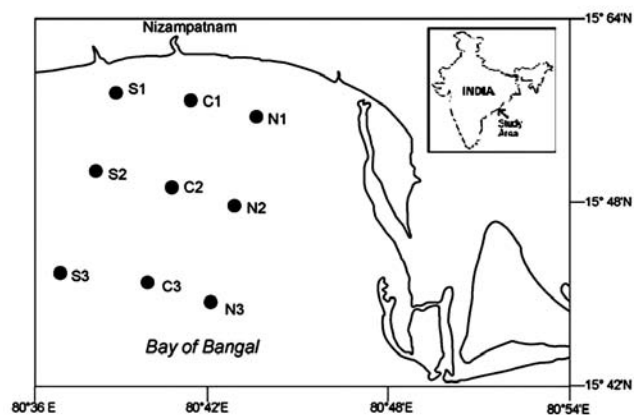


Fig. 1—Map Showing the sampling area of Nizampatnam, South East Coast of India

Phytoplankton (quantitative) enumeration was carried out on unit samples fixed in Lugol's iodine and species abundance was estimated using a Sedgewick Rafter counting chamber following a standard protocol¹¹. Phytoplankton diversity was determined based on three indices namely Margalef, (*d*), Shannon-Wiener, (*H'*) and the evenness component (*J'*) implemented in PRIMER.

Results and Discussion

Physico-chemical Parameters

Phytoplankton distribution and abundance in tropical waters were varied remarkably due to seasonal environmental fluctuation. In order to assess their distribution and abundance it is essential to study physico-chemical parameters of the study area. Variations in hydro-chemical parameters of study area are shown in Table 1. Surface temperature varied from 28.28–29.16°C while, it was 27.96 - 28.46°C at bottom. Salinity varied from 30.15 to 31.15 psu at surface while at bottom it was varied from 32.54 to 33.25 psu. *pH* Values ranged between 7.78-8.11 in the surface and bottom waters of the study area. The variations of *pH* between surface and bottom waters are marginal and these values can be compared with that of clean tropical coastal waters. DO showed variation from 5.38 to 8.43 mg/l in the entire study region. High concentrations of DO values and less variation in surface and bottom waters indicate

well-oxygenated and well mixed conditions in these coastal waters. Turbidity values in the water ranged between 0.67-23.3 NTU. The chlorophyll-*a* concentration ranged from 0.24 mg/m³ and 2.07 mg/m³ in the surface and bottom of study area. Nutrients play a vital role in the biogeochemical cycles in the marine environment. Distribution of nutrient is mainly based on season and tidal condition freshwater flow from land sources. The concentrations of NO₂-N and NO₃-N in surface and bottom waters varied between 2.16-5.24 µg/L and 40.0-93.6 µg/L respectively, which are within the acceptable limits of coastal environment. Inorganic PO₄-P was in the range of 25.1-68.4 µg/L in both surface and bottom. SiO₄-Si, one of the major nutrients for phytoplankton growth ranged between 352-685 µg/L in surface and bottom waters and in the present study the levels of silicate are within the moderate limits of coastal environment. Earlier reports suggested wide variation in chlorophyll and nutrient in the Bay of Bengal¹²⁻¹³.

A total of 90 phytoplankton species represented by 5 groups Bacillariophyceans (47) consisting of centrales (26) and pennales (21), Dinophyceans (35), Cyanophyceans (5), Euglenophyceans (3) and Prasinophycean (1) Table 1 were reported. Overall, Bacillariophyceans (pennales 46%; centrales 12%) formed the bulk (58.0%) of the population followed by Dinophyceans (20.0%) and Cyanophyceans

Table 1—Physico-Chemical parameters of Nizampatnam, South East coast of India.

Stations	Depth	Temperature (°C)	<i>pH</i>	Salinity"	DO (mg/L)	Turbidity (NTU)	Chlorophyll <i>a</i> (mg/m ³)	NO ₃ -N (µg/L)	NO ₂ -N (µg/L)	PO ₄ -P (µg/L)	SiO ₄ -Si (µg/L)
N1	S	29.15	8.02	32.6	6.10	ND	1.52	50.4	3.39	25.1	519
	B	28.45	8.04	32.7	6.97	15.7	0.58	72.8	3.08	68.4	366
N2	S	28.96	8.1	32.6	6.25	20.1	2.68	77.4	2.16	33.5	484
	B	28.39	8.11	32.6	5.38	6.10	0.32	93.6	4.86	44.6	543
N3	S	28.43	7.88	33.1	7.85	0.67	1.36	56.2	2.16	25.1	380
	B	28.09	7.86	33.1	7.70	14.0	0.64	79.2	4.62	48.7	485
C1	S	29.03	7.91	32.6	6.25	23.3	1.28	53.5	3.08	41.9	526
	B	28.45	7.94	32.6	7.12	20.5	0.52	52.4	4.48	58.6	437
C2	S	28.75	7.92	32.6	6.97	14.0	0.66	47.7	3.08	37.7	629
	B	28.11	7.89	32.6	6.10	26.2	0.24	67.0	4.00	44.6	685
C3	S	28.52	7.95	33.0	6.25	7.79	0.92	40.0	3.08	39.1	390
	B	27.95	7.93	33.0	6.54	18.1	0.27	71.2	3.39	39.1	485
S1	S	28.66	7.89	32.5	6.83	13.7	2.07	74.7	2.46	39.1	405
	B	27.99	7.8	32.6	6.68	9.49	0.24	83.5	3.39	58.6	501
S2	S	28.79	7.83	32.5	8.43	3.55	1.96	41.2	2.46	39.1	526
	B	27.80	7.82	32.7	6.54	4.74	0.41	47.4	4.62	39.1	505
S3	S	28.27	7.84	33.2	7.99	0.84	0.58	48.9	3.08	40.5	352
	B	28.18	7.78	33.1	6.83	6.67	0.36	69.3	5.24	37.7	466

(17.0%). Similarly, Panda *et al*¹⁴, reported that phytoplankton population of Orissa coast was dominated by Bacillariophyceae and Dinophyceae. Other studies also showed the dominance of diatoms in the phytoplankton population of coastal waters⁷. Euglenophyceans (5.0%) were relatively poorly represented in the samples (Fig. 2). Most dominant species recorded in the present study were *Pleurosigma angulatum*, *Navicula. sp.*, *Oscillatoria limosa*, *Cylindrotheca closterium*, *Nitzschia longissima*, *Ceratium furca*, *Trichodesmium erythraeum*, *Nitzschia sigmaidea*, *Chaetoceros coarctatus* and *Euglena deses* (Table 2). Spatial variation in species composition on a local scale are reported¹⁵. In a study by Madhav & B. Kondalarao⁷, along the East Coast of India 249 species of phytoplankton were identified from 292 stations.

They reported latitudinal variation in the distribution of species. Spatial, differences in composition and number of species of phytoplankton between transects [North (N=32), Central (C=21) and South (S=30)] of

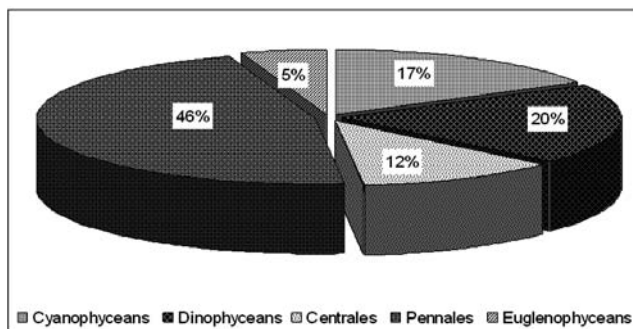


Fig. 2—Phytoplankton: Overall group abundance (%) in the inshore waters off Nizampatnam

Table 2—Phytoplankton species composition of coastal waters of Nizampatnam.

S.N	species	C1	C2	C3	S1	S2	S3	N1	N2	N3
1.	<i>Trichodesmium erythraeum</i>	-	-	-	-	-	+	-	+	+
2.	<i>Oscillatoria limosa</i>	+	+	+	+	+	+	+	+	-
3.	<i>O.limnetica</i>	+	+		+	+	+	+	+	-
4.	<i>Oscillatoria sp</i>	+	+	+	-	+	+	+	+	+
5.	<i>Nodularia sp</i>	-	-	-	+	-	-	+	+	-
6.	<i>Prorocentrum micans</i>	+	+	-	-	-	-	-	-	-
7.	<i>P.rostratum</i>	-	+	-	+	-	-	-	-	-
8.	<i>Amphisolenia bidentata</i>	-	-	-	-	-	-	-	+	+
9.	<i>Dinophysis hastata</i>	+	-	-	+	-	-	+	-	-
10.	<i>D.caudata</i>	-	-	+	-	-	+	-	-	+
11.	<i>D.acuta</i>	-	-	-	-	+	+	-	+	-
12.	<i>D.miles</i>	-	-	+	-	-	-	-	-	+
13.	<i>Dinophysis sp</i>	-	-	-	-	+	-	-	-	+
14.	<i>Ornithocercus thumii</i>	+	+	-	-	-	-	-	-	-
15.	<i>Ornithocercus sp.</i>	-	-	-	+	-	-	+	-	-
16.	<i>Ceratium breve</i>	+	+	-	+	+	+	+	+	-
17.	<i>C.fulcatum</i>	-	-	+	-	+	+	-	-	+
18.	<i>C.furca</i>	+	+	+	+	+	+	+	+	+
19.	<i>C.fusus</i>	-	+	+	+	+	+	+	+	+
20.	<i>C.tripos</i>	-	-	-	-	+	+	-	+	+
21.	<i>C.arietinum</i>	+	+	-	+	-	+	-	-	+
22.	<i>C.trichoceros</i>	+	+	+	+	+	+	+	+	+
23.	<i>C.schmidtii</i>	+	+	-	+	+	-	+	-	-
24.	<i>C.declinatum</i>	-	-	-	-	+	-	-	-	-
25.	<i>C.carriense</i>	+	+	-	+	-	+	-	-	+
26.	<i>C.extensum</i>	+	+	+	+	-	+	+	+	-
27.	<i>C.macroceros</i>	+	-	+	+	-	-	+	+	+
28.	<i>C.vultur</i>	+	-	-	+	-	-	-	-	-
29.	<i>C.inflatum</i>	+	-	+	+	-	-	+	-	+
30.	<i>C.pavillardii</i>	+	+	-	-	-	-	+	-	+
31.	<i>C.symmetricum</i>	-	-	-	-	-	-	-	+	-
32.	<i>Protoperidinium elegans</i>	+	+	+	+	+	-	+	+	+
33.	<i>P.oceanicum</i>	-	-	-	-	-	-	-	-	+
34.	<i>P.longipes</i>	-	-	-	+	-	-	-	-	-
35.	<i>P.depressum</i>	+	+	-	+	+	-	+	+	+
36.	<i>Peridinium granii</i>	+	+	-	-	+	-	-	+	-

Table 2—Phytoplankton species composition of coastal waters of Nizampatnam.—(Contd.)

S.N	species	C1	C2	C3	S1	S2	S3	N1	N2	N3
37.	<i>Peridinium sp</i>	+	+	-	-	-	-	-	-	-
38.	<i>Alexandrium sp</i>	+	-	-	+	+	-	-	-	-
39.	<i>Gonyaulax sp</i>	+	-	-	+	-	-	-	-	-
40.	<i>Diplopsalis sp</i>	-	-	-	-	-	-	+	+	-
41.	<i>Skeletonema costatum</i>	+	-	+	-	+	+	-	+	+
42.	<i>Thalassiosira subtilis</i>	-	-	-	-	-	-	+	+	-
43.	<i>T.pseudonana</i>	-	-	+	-	+	-	+	-	+
44.	<i>Eucampia cornuata</i>	-	-	-	-	+	+	-	-	+
45.	<i>Leptocylindrus dancis</i>	-	+	-	-	-	-	-	-	-
46.	<i>Coscinodiscus marginatus</i>	-	-	+	-	-	-	-	-	+
47.	<i>C.apiculatus</i>	+	+	-	+	+	-	+	-	-
48.	<i>C.radiatus</i>	+	+	-	+	+	-	+	-	+
49.	<i>C.centralis</i>	-	+	+	-	-	+	-	+	-
50.	<i>C.eccentricus</i>	+	+	-	+	+	-	+	+	+
51.	<i>Rhizosolenia castracanei</i>	-	-	-	-	-	-	-	+	+
52.	<i>R.stolterfothii</i>	-	-	-	+	+	+	-	+	+
53.	<i>R.striata</i>	-	+	-	-	-	-	-	-	-
54.	<i>R.robusta</i>	-	+	-	-	-	-	-	-	-
55.	<i>R.hebetata</i>	-	-	-	-	-	-	-	+	-
56.	<i>Bacteriastrum varians</i>	-	-	-	-	-	-	-	+	+
57.	<i>B.comosum</i>	-	-	+	+	+	+	-	-	-
58.	<i>Chaetosceros didymus</i>	-	-	-	-	-	-	+	-	+
59.	<i>Chaetosceros curvisetus</i>	-	-	-	-	-	+	-	-	-
60.	<i>Chaetosceros peruvianus</i>	-	+	-	+	-	-	+	-	+
61.	<i>Chaetosceros coarctatus</i>	-	-	-	+	+	-	+	+	+
62.	<i>Chaetosceros sp</i>	+	+	-	-	+	-	-	-	+
63.	<i>Ditylum sol</i>	-	+	-	-	-	-	-	-	-
64.	<i>Odontella rigia</i>	-	+	-	+	-	-	-	-	-
65.	<i>O.heteroceros</i>	+	-	-	-	-	-	-	-	-
66.	<i>Bacillaria paradoxa</i>	-	-	+	-	-	+	-	+	+
67.	<i>Isthemia enervis</i>	-	-	-	-	+	-	-	-	-
68.	<i>Synedra sp</i>	-	-	-	-	-	-	+	+	-
69.	<i>Asterionellopsis glacialis</i>	-	-	+	-	-	+	-	-	+
70.	<i>Navicula sp</i>	-	+	+	-	+	+	+	+	+
71.	<i>Pinnularia sp</i>	+	+	-	-	-	-	-	-	-
72.	<i>Pleurosigma normanii</i>	+	+	+	+	-	-	+	-	+
73.	<i>P.elongatum</i>	-	+	-	+	+	+	-	-	+
74.	<i>P.angulatum</i>	+	+	+	+	+	+	+	+	+
75.	<i>P.aestuarii</i>	-	-	+	+	-	+	+	+	+
76.	<i>Diploneis sp</i>	-	-	-	+	+	-	-	+	-
77.	<i>Gyrosigma balticum</i>	-	-	+	+	+	+	-	-	-
78.	<i>Gyrosigma sp</i>	-	-	-	+	+	+	+	-	+
79.	<i>Cymbella sp</i>	-	-	-	-	+	+	-	-	-
80.	<i>Amphora sp</i>	-	+	-	-	+	-	+	-	-
81.	<i>Amphiprora alata</i>	-	-	+	+	+	-	-	+	-
82.	<i>Nitzschia sigma</i>	+	+	+	+	-	+	+	-	+
83.	<i>N.sigmoidea</i>	+	+	-	+	-	+	+	+	+
84.	<i>N.longissima</i>	+	+	+	-	-	-	+	+	+
85.	<i>Pseudonitzschia seriata</i>	+	+	+	-	-	-	-	-	-
86.	<i>Cylindrotheca closterium</i>	+	+	+	+	-	+	-	-	+
87.	<i>Euglena deses</i>	+	+	+	+	-	+	+	+	-
88.	<i>Euglena sp</i>	+	-	-	-	-	-	+	-	-
89.	<i>Nephroselmis sp</i>	-	-	+	-	-	+	-	-	+
90.	<i>Eutreptia sp</i>	-	-	-	-	+	+	+	+	-
	No of species	39	42	30	43	38	35	40	40	44

Table 3—Numerical abundance (cells/ml) of Phytoplankton at selected sites in the inshore waters off Nizampatnam, (Unit sample).

Species	Stations									Total	%
	C1	C2	C3	S1	S2	S3	N1	N2	N3		
<i>Trichodesmium erythraeum</i>	-	-	3	-	-	17	-	-	36	56	4.8
<i>Oscillatoria limosa</i>	10	3	3	7	3	3	7	23	-	59	5.1
<i>Oscillatoria limnetica</i>	3	7	-	10	10	-	3	10	-	43	3.7
<i>Oscillatoria sp</i>	-	-	-	-	-	10	-	-	27	37	3.2
<i>Prorocentrum micans</i>	7	3	-	3	-	-	-	-	-	13	1.1
<i>Dinophysis hastata</i>	7	-	-	7	-	-	3	-	-	17	1.5
<i>D.acuta</i>	-	-	-	-	7	-	-	10	-	17	1.5
<i>D.caudata</i>	-	-	3	-	-	7	-	-	10	20	1.7
<i>Ceratium breve</i>	-	-	-	-	-	-	7	3	-	10	0.9
<i>C. fulcatum</i>	-	-	-	-	-	3	-	-	3	6	0.5
<i>C. furca</i>	7	7	7	10	7	3	10	3	3	57	4.9
<i>C.fusus</i>	-	3	3	-	3	13	7	7	3	39	3.3
<i>C.tripos</i>	-	-	-	-	-	3	-	7	13	23	2.0
<i>Peridinium granii</i>	-	-	-	-	-	3	-	-	7	10	0.9
<i>Alexandrium sp</i>	7	3	-	-	-	-	-	-	-	10	0.9
<i>Gonyaulax sp.</i>	3	-	-	-	-	-	-	-	-	3	0.3
<i>Protoperdinium oceanicum</i>	-	-	-	-	-	-	-	-	7	7	0.6
<i>Skeletonema costatum</i>	-	-	7	-	10	7	-	10	7	41	3.5
<i>Thalassiosira. subtilis</i>	-	-	-	-	-	-	10	7	-	17	1.5
<i>Rhizosolenia stolterfothii</i>	-	-	-	-	3	3	-	3	10	19	1.6
<i>Chaetoceros didymus</i>	-	-	-	-	-	-	7	3	7	17	1.5
<i>Chaetoceros coarctatus</i>	-	-	-	7	7	7	7	7	10	45	3.9
<i>Synedra sp.</i>	-	-	-	-	-	-	10	7	-	17	1.5
<i>Asterionellopsis glacialis</i>	-	-	7	-	-	3	-	-	10	20	1.7
<i>Navicula. sp.</i>	-	10	7	-	13	17	-	13	20	80	6.8
<i>Pleurosigma elongatum</i>	-	10	7	-	7	7	-	-	-	31	2.7
<i>P.angulatum</i>	7	3	13	17	13	17	27	13	20	130	11.1
<i>P. aestuarii</i>	-	-	10	-	-	10	-	7	13	40	3.4
<i>Diploneis sp</i>	-	-	-	-	10	-	-	3	-	13	1.1
<i>Gyrosigma balticum</i>	-	-	-	3	7	3	-	-	-	13	1.1
<i>Amphiprora alata</i>	-	-	-	-	7	-	-	3	-	10	0.9
<i>Nitzschia sigma</i>	-	3	3	-	3	3	-	7	7	26	2.2
<i>Nitzschia sigmoidea</i>	3	7	7	7	3	3	3	13	3	49	4.2
<i>N.longissima</i>	3	7	7	7	7	7	3	7	10	58	5.0
<i>Cylindrotheca closterium</i>	7	10	7	7	7	3	7	3	7	58	5.0
<i>Euglena deses</i>	3	10	-	7	10	-	7	7	-	44	3.8
<i>Eutreptia sp.</i>	-	-	-	-	3	-	7	3	-	13	1.1
Total	67	86	94	92	140	152	125	179	233	1168	100.0

the present study corroborate the earlier reports Table 3. *Pleurosigma angulatum*, *Trichodesmium erythraeum* and *Navicula sp.* in north transect, *Cylindrotheca closterium*, *Pleurosigma angulatum* and *Ceratium furca* in central transect and *Pleurosigma angulatum*, *Navicula sp.* and *Nitzschia longissima* in south transect were dominant (Table 4). The presence of *Gonyaulax sp.* and *Alexandrium sp.*, the two potentially toxic dinoflagellates, in central and south transects warrants attention. Group-wise

Bacillariophyceans particularly the pennate diatoms remained dominant in all transects (Fig. 3). Diatoms (Bacillariophyceae) predominated mostly due to the availability of adequate concentrations of silicate¹⁶.

Overall phytoplankton abundance varied between 67 cells.mL⁻¹ at C1 and 233 cells.mL⁻¹ at N3, the observed mean being 130 cells.mL⁻¹ (Tables 3, 5 and 6). Transect wise, phytoplankton in the north transect ranged from a low 125 cells.mL⁻¹ at N1 to a maximum of 233 cells.mL⁻¹ at N3. The species

Table 4—Phytoplankton distribution (cells.mL⁻¹) in the inshore waters off Nizampatnam along the three (Central, South & North) transects

Characteristic	Transect 1 (N)	Transect 2 (C)	Transect 3(S)
No of species	32	21	30
Abundance (nos.mL ⁻¹)	125-233	67-94	92-152
Range (mean)	(179)	(82.3)	(128)
Dominant genera (%)	<i>Pleurosigma angulatum</i> (11.2); <i>Trichodesmium erythraeum</i> (6.7); <i>Navicula. sp.</i> (6.1); <i>Oscillatoria limosa</i> (5.6); <i>Oscillatoria sp</i> (5.0); <i>Chaetoceros coarctatus</i> (4.5); <i>Ceratium tripos</i> (3.7); <i>Pleurosigma aestuarii</i> (3.7); <i>Nitzschia longissima</i> (3.7)	<i>Cylindrotheca closterium</i> (9.7); <i>P.angulatum</i> (9.3); <i>Ceratium furca</i> (8.5); <i>Navicula. sp.</i> (6.9); <i>Pleurosigma elongatum</i> (6.9); <i>Nitzschia sigmaidea</i> (6.9); <i>Nitzschia longissima</i> (6.9)	<i>Pleurosigma.angulatum</i> (12.2); <i>Navicula. sp.</i> (7.8); <i>Nitzschia longissima</i> (5.5); <i>Chaetoceros coarctatus</i> (5.5); <i>Oscillatoria limnetica</i> (5.2); <i>Ceratium furca</i> (5.2); <i>Oscillatoria limosa</i> (4.8); <i>Trichodesmium erythraeum</i> (4.4);

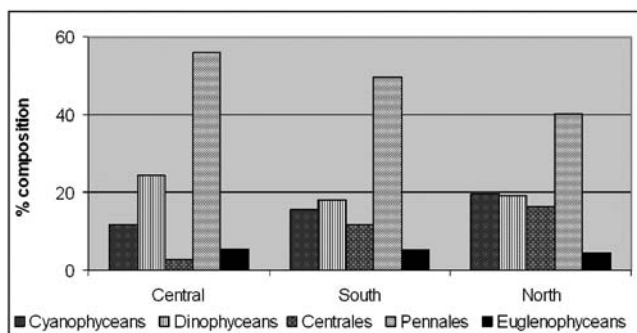


Fig. 3—Phytoplankton: Group abundance (%) along the selected transects in the inshore waters off Nizampatnam

Pleurosigma angulatum, *Trichodesmium erythraeum*, *Navicula sp.*, *Oscillatoria limosa*, *Oscillatoria sp.*, *Chaetoceros coarctatus*, *Ceratium tripos*, *Pleurosigma aestuarii* and *Nitzschia longissima* contributed to half of the total population. In the central transect, abundance ranged from 67 cells.mL⁻¹ at C1 to 94 cells.mL⁻¹ at C3. *Cylindrotheca closterium*, *Pleurosigma angulatum*, *Ceratium furca*, *Navicula. sp.*, *Pleurosigma elongatum*, *Nitzschia sigmaidea*, and *Nitzschia longissima* formed the bulk of population. In the southern transect, phytoplankton abundance varied between 92 cells.mL⁻¹ at S1 and 152 cells.mL⁻¹ at S3. *Pleurosigma angulatum*, *Navicula. sp.*, *Navicula longissima*, *Chaetoceros coarctatus*, *Oscillatoria limnetica*, *Ceratium furca* and *Trichodesmium erythraeum* were the taxa that contributed to nearly 50% of the population (Tables 4 and 5). Mani and Krishnamurthy¹⁷ attributed the abundance of phytoplankton during summer season the increased salinity, pH, high temperature and high intensity of light penetration. Moreover, the environmental parameters were

moderate and also quantitatively promoted the abundance of phytoplankton (Table 2). During summer time the physico-chemical parameters remain high which promoted the phytoplankton production. It is reported that the concentration of phytoplankton in the central area of the bay of Bengal may vary from oligotrophic to eutrophic where the cell counts may reach from as low as 100 to 6000 cell per litre¹⁸.

Depth distribution of phytoplankton recorded different species. Based on the depth there were comparative variations in the number of species ranges between 20-28. The phytoplankton number range between 67-125 cells.mL⁻¹, 86-179 cells.mL⁻¹ and 94-233 cells.mL⁻¹ at <5 m, 5-10 m, and >10 m respectively. It is also widely accepted that phytoplankton species in the surface layer and deeper layer are different¹⁹. Group-wise pennales (Bacillariophyceans) remained dominant at all depths followed by Dinophyceans at <5 m and 5-10 m depth and Cyanophyceans at >10 m depth (Fig. 4). Whereas, *P. angulatum* the only species dominantly occurred in all the 3 different depths (Table 6). It has been proved that during late monsoon, active replenishment of nutrients is possible due to upwelling and land run off which helps in the growth of diatoms²⁰. In the present observation, overall the nutrients (NO₂-N, NO₃-N, PO₄-P, SiO₄-Si) were high in bottom waters then surface waters which was responsible for high phytoplankton abundance at depth 5-10 m and >10 m.

The highest species diversity (3.008) was observed at N2 which also had the maximum number of phytoplankton and chlorophyll concentration. It is noteworthy that index *J* was uniformly high (0.9267-0.9639) for all 9 stations

Table 5—Phytoplankton composition (cells.mL⁻¹) at different stations in the inshore waters off Nizampatnam

Characteristic	Station N 1	Station N 2	Station N 3
No of species	16	24	21
Abundance (nos.ml ⁻¹) range and total	3-27 125	3-23 179	3-36 233
Dominant genera (%)	<i>Pleurosigma angulatum</i> (21.6); <i>Ceratium furca</i> (8.0), <i>Oscillatoria limosa</i> (5.6); <i>Synedra sp</i> (8.0); <i>Thalassiosira subtilis</i> (8.0); <i>Euglena deses</i> (4.9)	<i>Oscillatoria limosa</i> (12.8) <i>Pleurosigma.angulatum</i> (7.3) <i>Nitzschia sigmoidea</i> (7.3) <i>Navicula. sp.</i> (7.3); <i>Dinophysis hastate</i> (5.6)	<i>Trichodesmium erythraeum</i> (15.5) <i>Oscillatoria sp</i> (11.6) <i>Pleurosigma.angulatum</i> (8.6); <i>Navicula. Sp.</i> (8.6); <i>Pleurosigma aestuarii</i> (5.6); <i>Ceratium tripos</i> (5.6)
Characteristic	Station C1	Station C2	Station C3
No of species	12	14	15
Abundance (nos.ml ⁻¹) range and total	3-10 67	3-10 86	3-13 94
Dominant genera (%)	<i>Oscillatoria limosa</i> (14.9) <i>Pleurosigma.angulatum</i> (10.4), <i>Cylindrotheca closterium</i> (10.4), <i>Ceratium furca</i> (10.4), <i>Protocentrum micans</i> (10.4),	<i>Navicula. sp.</i> (11.6); <i>Pleurosigma elongatum</i> (11.6); <i>Cylindrotheca closterium</i> (11.6) ; <i>Euglena deses</i> (11.6); <i>Oscillatoria limosa</i> (8.1	<i>Ceratium furca</i> (15.5), <i>Pleurosigma Sp.</i> (11.9), <i>Pleurosigma angulatum</i> (11.9), <i>Navicula sp.</i> (8.3), <i>Cylindrotheca closterium</i> (8.3)
Characteristic	Station S1	Station S2	Station S3
No of species	12	20	22
Abundance (nos.ml ⁻¹) range and total	3-13 92	3-13 140	3-17 152
Dominant genera (%)	<i>Pleurosigma.angulatum</i> (18.5); <i>Oscillatoria limnetica</i> (10.9); <i>Ceratium furca</i> (10.9); <i>Oscillatoria limosa</i> (7.6); <i>Dinophysis hastata</i> (7.6);	<i>Navicula sp.</i> (9.3); <i>P.angulatum</i> (9.3); <i>Oscillatoria limnetica</i> (7.1); <i>Diploneis sp</i> (7.1), <i>Euglena deses</i> (7.1), <i>Skeletonema costatum</i> (7.1),	<i>Trichodesmium erythraeum</i> (11.2), <i>Navicula sp.</i> (11.2), <i>Pleurosigma.angulatum</i> (11.2); <i>Ceratium fusus</i> (8.6); <i>Oscillatoria sp.</i> (6.6),

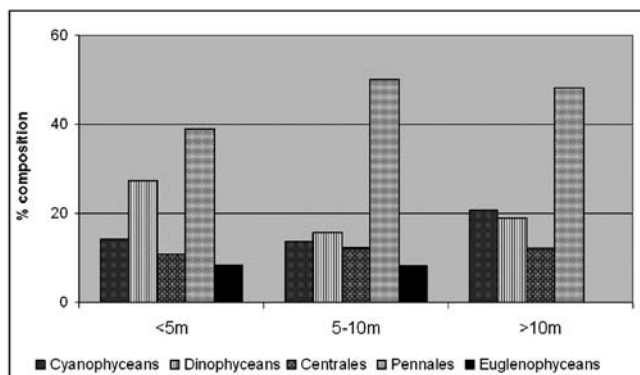


Fig. 4—Phytoplankton: Group abundance (%) at different depths in the inshore waters off Nizampatnam

implying even distribution of species in the coastal waters of study area (Table 7). Based on the Bray-Curtis similarity and group average clustering (PRIMER), it was possible to distinguish the phytoplankton populations (at ~50% similarity) into two distinct assemblages shown in Fig. 5. It appears from the observations that two structurally differing phytoplankton populations exist in these waters attributable to the proximity of land based flows and (i.e. shallow water sites) and those away from such influence in the open Sea (depth >10 m). The findings have shown that there is a general paucity of phytoplankton in the inshore waters of Nizampatnam.

Table 6—Phytoplankton distribution (cells.mL⁻¹) in the inshore waters off Nizampatnam at different depths

Depth/Characteristic	<5 m	5-10 m	>10 m
No of species	20	28	24
Abundance (nos.ml ⁻¹) range and mean	67-125 (94.7)	86-179 (135)	94-233 (159.7)
Dominant genera (%)	<i>Pleurosigma angulatum</i> (18.0), <i>Ceratium furca</i> (9.5), <i>Oscillatoria limosa</i> (8.5) <i>Cylindrotheca closterium</i> (7.4); <i>Dinophysis hastate</i> (6.0) <i>Euglena deses</i> (6.0)	<i>Navicula. sp.</i> (8.9) <i>Oscillatoria limosa</i> (7.2); <i>Pleurosigma angulatum</i> (7.2); <i>Oscillatoria limnetica</i> (6.7) <i>Euglena deses</i> (6.7) <i>Nitzschia sigmoidea</i> (5.7); <i>Nitzschia longissima</i> (5.2); <i>Skeletonema costatum</i> (4.9)	<i>Trichodesmium erythraeum</i> (11.7); <i>Pleurosigma angulatum</i> (10.4); <i>Navicula. sp.</i> (9.2); <i>Oscillatoria sp.</i> (7.7); <i>Pleurosigma aestuarii</i> (6.9); <i>Nitzschia longissima</i> (5.0)

Table 7—Diversity indices of phytoplankton in the inshore waters off Nizampatnam

Sample	S	N	d	J'	H'
C1	12	67	2.616	0.9639	2.395
C2	14	86	2.918	0.9548	2.52
C3	15	94	3.081	0.9634	2.609
S1	12	92	2.433	0.9617	2.39
S2	20	140	3.845	0.964	2.888
S3	22	152	4.18	0.9267	2.864
N1	16	125	3.107	0.9329	2.587
N2	24	179	4.434	0.9464	3.008
N3	20	197	3.596	0.9408	2.819

S= no. Of species, N= number of individuals, d= species richness, J'= evenness, H'= diversity

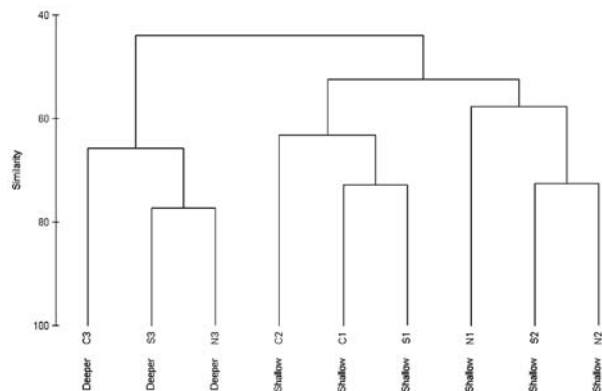


Fig. 5—Phytoplankton Assemblages between shallow and relatively deepwater (>10 m)

The present baseline information of the phytoplankton distribution and abundance would form a useful set of data for further ecological assessment and monitoring

of the ecological sensitive coastal ecosystems of India.

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References

- 1 Qasim S Z, Biological productivity of Indian ocean. *Indian J Mar Sci*, 6 (1977) 122-137.
- 2 Birkeland C, Difference among coastal systems. The controlling influences of nutrient input and the practical implications for management. In: Coastal studies and sustainable development. Proceedings of the COMAR. UNESCO Technical papers in marine sciences. No. 64, UNESCO Paris, (1992) 8-16.
- 3 Kawabata Z, Magendra, S Palanicham, Venugopalan V K, & Tatsukawa R, Phytoplankton biomass and productivity of different size fractions in the Velar estuarine system, southeast coast of India. *Indian J Mar.Sci.*, 22 (1993) 294-296.
- 4 Sin Y, Wetzel L R, & Anderson C I, Spatial and temporal characteristics of nutrient and phytoplankton dynamics in the York River Estuary, Virginia, Analyses of long-term data. *Estuaries*, 22 (1999) 260-275.
- 5 Prakash K P & Raman A V, Phytoplankton characteristics and species assemblage patterns in northwest Bay of Bengal. *Indian J Mar Sci*, 21 (1992) 158-160.
- 6 Gouda R & Panigrahi R C, Ecology of phytoplankton in coastal waters, off Gopalpur, east coast of India. *Indian J Mar Sci*, 25 (1996), 81-84.
- 7 Geetha Madhav V & Kondalarao B, Distribution of phytoplankton in the coastal waters of east coast of india. *Indian J Mar Sci* 33, (2004) 262-268.
- 8 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.

- 9 Parsons T R, Maita Y, & Lalli C M, A Manual of chemical and biological method for sea water analysis; [Pergamon Press; Oxford U.K] (1984) pp 173.
- 10 Subrahmanyam R, A systematic account of the marine plankton diatoms of the Madras Coast. *Proc Indian Acad Sci B*. 25 (1946) 86-196.
- 11 UNESCO, *Phytoplankton manual* (1978) (Ed. A Sournia) pp. 337
- 12 Devassy V P, Bhattathiri P M A, & Radhakrishna K, Primary production in the Bay of Bengal during August, 1977. *Mahasagar - Bulln of Nation Instit of Oceanogr*, 16 (1983) 443-447.
- 13 De Sousa S N, Naqvi S W A, & Reddy C V G, Distribution of nutrients in the western Bay of Bengal. *Indian J Mar Sci*, 10 (327-331).
- 14 Swati S Panda, Dhal N K, & Panda C R, Phytoplankton diversity in response to abiotic factors along Orissa coast, Bay of Bengal. *International J Environm Sci*, 2 (2012) 3-8.
- 15 Devasy V P, & Goes J I, Phytoplankton community structure and succession in a tropical estuarine complex (Central west coast of India) *Estuar. Coast. shelf Sci*. 27 (1988) 671-685.
- 16 Madhupratap M, Gauns M, Ramaiah N, Prasanna Kumar S, Muraleedharan PM, De Sousa 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 II*, 50 (2003) 881-896.
- 17 Mani P & Krishnamurthy K, Variation of phytoplankton in a tropical estuary (Vellar estuary, Bay of Bengal, India) *Int. Revue. Ges. Hydrobiol.*, 74 (1989) 109-115.
- 18 Qasim S Z & Kureishy, T W, Biological diversity in the seas around India: Present status and major threats. *Proceedings of the Indian Academy of Science Supplement*, (1986), 1-17.
- 19 Boonyapiwat S, Distribution, Abundance and Species Composition of Phytoplankton in the South China Sea, Area II: Sabah, Sarawak and Brunei Darussalam, in *Proceedings of the Second Technical Seminar on Marine Fishery Resources Survey in the South China Sea, Area II : West Coast of Sabah, Sarawak and Brunei Darussalam*. Dec. 1998. Kuala Lumpur, SEAFDEC. (1999) 177-196.
- 20 Dehradrai, P V & Bhargava, R M S, Distribution of chlorophyll, carotenoids and phytoplankton in relation to certain environmental factors along the central west coast of India. *Mar Biol*, 17 (1972) 30-36.