

Distribution of phytoplankton along an environmental gradient off Kakinada, East Coast of India

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In the present study phytoplankton distribution and species composition was examined on a salinity gradient from River (R), River Mouth (RM) and coastal water (RF) at surface and subsurface layers along the coast off Kakinada, East Coast of India. Average numerical abundance of phytoplankton at R, RM and RF are 336 nos.mL⁻¹, 150 nos.mL⁻¹ and 169 nos.mL⁻¹ respectively. Percentage contribution of each group of phytoplankton was in the order: Pinnate diatoms > Cyanophyceans > Centrales > Prasinophyceans. However, total phytoplankton species at surface and subsurface water at all the stations showed presence of 52 and 24 species respectively. At the group level, cyanophyceans were significant at RF locations. Pennate diatoms were more at the remaining locations. Species *Oscillatoria limosa* was found to be abundant at both the surface and subsurface water with 340 filaments.mL⁻¹ and 488 filaments.mL⁻¹ respectively. *Thalassiothrix longissima* was found to be maximum at surface water but absent in subsurface water. Wide variation in evenness values (0.16-0.910) suggests uneven distribution of species along the environmental gradient.

[Keywords: Kakinada, Phytoplankton, Distribution, Environmental gradient, Surface and subsurface water]

Introduction

Coastal water receives a large volume of freshwater inputs from the rivers, suspended particulate matters, sediments and nutrients¹. In such regions, freshwater helps in stabilizing the water column by salinity stratification². Freshwater influx induces estuarine characteristics over large areas of the bay, which impedes exchange between the surface and sub-surface waters with consequent impact on biological processes. Phytoplankton composition is affected by various environmental factors such as pH, light, temperature, salinity and nutrients³. Besides their importance as the primary producers in the food webs and ensuring ecological balance, species of phytoplankton are useful indicator of water quality⁴. The relative availability of nutrient plays a major role in inducing the community structure of phytoplankton⁵. Thus, the coastal ecosystem exhibit definite pattern of phytoplankton variability depending on the environmental gradient.

Coastal water of the east coast of India has been reported as highly dynamic and characterized by the low surface salinity regions due to immense freshwater inputs through excessive precipitation over evaporation and river discharge⁶. In general the

information on phytoplankton of the Indian Ocean is scanty. Overall, the successional pattern of phytoplankton communities in relation to nutrient variation will help to understand the ecosystem functioning⁵. Phytoplankton productivity can be predicted based on the three basic variables: phytoplankton biomass, biomass specific carbon assimilation rate and light availability⁷.

A study on plankton diversity using biotic indices is an important aspect to understand the functioning of system dynamics⁸ (Kanan *et al*⁸). Though the coastal areas are ecologically important for fishery and other marine product harvesting, extensive studies in relation to phytoplankton dynamics are still lacking⁹. In the present communication, we have attempted to study the distribution and abundance of phytoplankton along an environmental gradient in relation to physico-chemical parameters off Kakinada, east coast of India.

Materials and Methods

The study was carried out at 19 stations off Kakinada, located along the east coast of India. Geographical position of the stations lies between 16°41.17' N to 16°44.07' N in latitude and

82°15.18'E to 82°42.26'E in longitude (Table 1). Water quality parameters of the stations were measured using CTD and standard laboratory methods. Samples were collected from 19 stations located in the river (5), river mouth (6) and reference point (8), along the coast of Kakinada, east coast of India. Samples were collected in a 2 litre bottle and Lugols iodine was added and stored until further analysis in the laboratory. For taxonomic identification, a research microscope (Olympus, Japan) with X400 was used. All identifications were carried out according to Subrahmanyam¹⁰, and Santhanam *et al.*¹¹. Quantitative analysis was carried out using a Sedgewick Rafter counting chamber under a binocular stereoscopic microscope. Phytoplankton diversity was determined by using Shannon and Wiener's index represented by H', Pielou's evenness index represented by J' and Margalef species richness represented by d' implemented in PRIMER.

Results

Overall phytoplankton distribution varied along with environmental gradient. The hydrological parameters exhibited distinct variation in the three categorized study zones. The environmental parameters like temperature, salinity and dissolved oxygen increased from river to river mouth and to sea while other factors like pH and BOD decreases as we move from river to sea (Table 2). Average

concentration of the nutrient is more along the river locations. It led to the production of more phytoplankton in the river locations. Average value of NO₃, PO₄ and SiO₃ in the river was 3.34, 1.03 and 37.9 µmol/l, respectively. In the river mouth the average value of nutrient was NO₃ 1.75, PO₄ 0.29 and SiO₃ 12.37 µmol/l. The N: P ratio in the reference point was found to be higher than that of the river and river mouth which may be due to the slow regeneration of NO₃ compared to PO₄ Table 3.

There were as many as 52 species of phytoplankton represented by 6 groups namely dinophyceans, cyanophyceans, chlorophyceans, euglenophyceans, Prymnophyceans, and prasinophycean. It varied between 84 nos.l⁻¹ (RF2) and 493 nos.mL⁻¹ (RF7) in which the observed mean being 275.9 nos.mL⁻¹. Pennale diatoms formed the bulk (57.1%) of the population followed by cyanophyceans (17.9%), Centrales (15.9%) and prasinophycean (3.9%). Others like tintinnids, chlorophyceans, euglenophyceans, prymnophyceans, and prasinophycean were relatively poorly represented and formed merely 5.2% of the population (Fig.1).

Cylindrotheca closterium (24.3%), *Oscillatoria limosa* (13.2%) and *Navicula pelliculsa* (12.8%) were the most important taxa. Spatial difference in the composition of phytoplankton between surface and subsurface water as well as between differing areas

Table 1—Station locations with latitude and longitude

Stations	Latitude (°N)	Longitude (°E)
R1	16°44.073'N	82°20.443'E
R2	16°43.342'N	82°19.463'E
R3	16°42.354'N	82°18.494'E
R4	16°42.200'N	82°16.297'E
R5	16°42.225'N	82°15.180'E
RM1	16°42.836'N	82°22.966'E
RM2	16°42.802'N	82°23.531'E
RM3	16°42.780'N	82°23.531'E
RM4	16°42.496'N	82°24.064'E
RM5	16°42.227'N	82°24.046'E
RM6	16°43.046'N	82°24.105'E
RF1	16°42.539'N	82°38.408'E
RF2	16°42.314'N	82°40.081'E
RF3	16°42.204'N	82°40.898'E
RF4	16°41.675'N	82°41.052'E
RF5	16°41.172'N	82°40.975'E
RF6	16°42.541'N	82°41.195'E
RF7	16°43.332'N	82°41.347'E
RF8	16°42.088'N	82°42.265'E

Table 2—Environmental parameters of the selected stations

Stations	Temp. (°C)	Salinity (PSU)	pH	DO (mg/l)	BOD (mg/l)
R1	25.2	22.0	8.23	5.29	2.41
R2	25.1	24.4	8.31	6.33	2.48
R3	25.1	20.3	8.27	6.41	2.50
R4	25.0	22.5	8.34	6.33	2.43
R5	25.1	25.1	8.43	6.68	2.42
RM1	24.5	31.5	8.44	6.57	1.07
RM2	24.9	31.9	8.45	6.49	1.35
RM3	24.6	24.6	8.43	6.31	0.60
RM4	24.9	29.2	8.46	6.70	1.07
RM5	24.9	27.4	8.42	6.63	1.15
RM6	24.3	24.5	8.40	6.34	1.25
RF1	28.8	33.9	8.13	7.89	4.62
RF2	29.4	33.9	8.17	6.94	1.73
RF3	28.6	33.4	8.18	6.23	1.73
RF4	28.7	33.8	8.21	6.54	1.21
RF5	28.2	34.5	8.22	7.00	2.02
RF6	29.0	34.1	8.20	7.08	2.37
RF7	28.7	34.0	8.16	6.92	2.55
RF8	28.6	33.7	8.20	7.04	1.08

river (R), river mouth (RM) and reference point (RF) were marked. In surface water, there were 52 species (Table 4); abundance varied between 99 nos.ml⁻¹ (RF5) and 388 nos.ml⁻¹ (R2), the mean being 278 nos.ml⁻¹. *Cylindrothyca closterium* (29.1%), *Navicula peliculosa* (9.5%), *Oscillatoria limosa* (8.5%) and *Thalassiothrix longissima* (7.5%) contributed to over 50% of the population. In subsurface water, there were 24 species (Table 5); abundance was relatively low and varied between 84 nos.ml⁻¹ (RF2) and 493 nos.ml⁻¹ (RF7); mean being 246 nos.ml⁻¹. *Oscillatoria limosa* (37.0%) and *Navicula peliculosa* (29.5%) were predominant

species that contributed to 66.5% of the population. Groupwise, cyanophyceans were important in both surface and subsurface water.

Phytoplankton composition in the different segments of the study area is as follows. At the river locations, the abundance ranged from a minimum of 226 nos.mL⁻¹ (R1) to a maximum of 388 nos.mL⁻¹ (R2), the mean being 336 nos.mL⁻¹. The predominant species were *Thalassiothrix longissima* (25.1%), *Navicula peliculosa* (13.8%), *Thalassiosira subtilis* (9.05%) and *Thalassionema nitzschiodes* (5.48%). At the RM stations, the abundance varied from a minimum of 107 nos.mL⁻¹ (RM3) and to a maximum of 204 nos.mL⁻¹ (RM5), the observed mean being 149 nos.mL⁻¹. *Navicula peliculosa* (21.5%), *Skeletonema costatum* (17.3%), *Thalassionema nitzschiodes* (12.0%) and *Nitzschia longissima* (7.0%) were the predominant taxa. In RF locations, the abundance ranged from a minimum of 84 nos.mL⁻¹ (RF2) to a maximum of 493 nos.mL⁻¹ (RF7), the observed mean being 211 nos.ml⁻¹ (Table 5). *Oscillatoria limosa* (32.5%), *Navicula peliculosa* (16.8%) and *Rhizosolenia styliiformis* (5.06%) were the important taxa. At the group level, cyanophyceans were significant at RF locations. Pennate diatoms were more at remaining locations.

Some of the species are abundantly available at the surface and subsurface water of all the locations (Fig. 2). The species *T. longissima* whose numerical abundance was 504 nos. mL⁻¹, was found to be the most abundant in surface water but it was unavailable at the subsurface water whereas *O. limosa* was abundantly found in subsurface water as compared to surface water whose numbers are 488 nos.ml⁻¹ and 340 nos.mL⁻¹ respectively along all the locations of the sampling area. Based on the Bray–Curtis similarity and group average clustering it was possible to distinguish the phytoplankton population (50% similarity) into six distinct assemblages at surface and four distinct assemblages at subsurface water. In surface water, river and river mouth locations formed a distinct group while reference point form another distinct group (Fig 3a&3b and 4a&4b).

It may be seen that species richness (Margalef diversity, d) and the Shannon-Wiener index H' were lower in RF as compared to the other two locations (Table 6). Diversity indices in different segment is moderate at all the locations (RF=0.69, R=0.78, RM=0.78); Evenness (J') varied between 0.16-0.94

Table 3—Composition of nutrients along the sampling stations

Stations	NH ₃ (µmol/l)	NO ₂ (µmol/l)	NO ₃ (µmol/l)	PO ₄ (µmol/l)	SiO ₃ (µmol/l)
R1	1.02	0.70	3.88	1.09	34.7
R2	1.02	0.60	3.62	1.14	38.6
R3	0.89	0.63	3.96	1.04	32.1
R4	0.84	0.67	4.51	0.76	41.7
R5	1.05	0.74	0.74	1.14	42.4
RM1	0.32	0.14	1.22	0.28	6.94
RM2	0.49	0.12	0.97	0.33	14.1
RM3	0.38	0.12	1.43	0.33	10.7
RM4	0.24	0.12	2.36	0.19	10.4
RM5	0.30	0.16	2.23	0.23	16.5
RM6	0.46	0.17	2.34	0.39	15.6
RF1	0.58	0.15	7.70	0.72	26.3
RF2	0.29	0.18	6.80	0.77	11.0
RF3	0.62	0.15	3.40	0.86	14.5
RF4	0.58	0.09	9.02	0.59	10.4
RF5	0.94	0.20	5.55	0.54	7.96
RF6	0.38	0.18	3.58	0.59	19.7
RF7	0.36	0.24	5.93	0.32	9.57
RF8	0.34	0.09	5.03	0.59	14.3

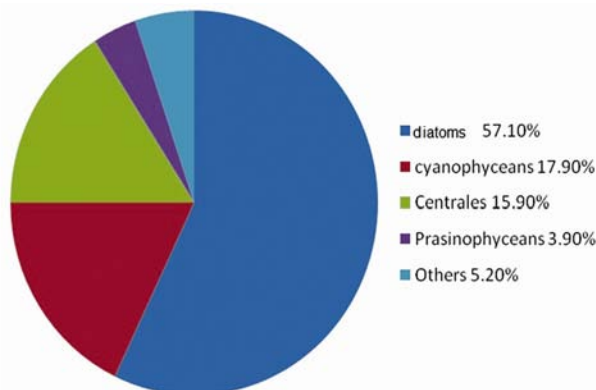


Fig 1—Phytoplankton: Overall group abundance (%) in the inshore water off Kakinada during the study

Table 4—Phytoplankton numerical abundance (nos.ml⁻¹) in surface water at the selected locations off Kakinada, east coast of India

	R1	R2	R3	R4	R5	RM1	RM2	RM3	RM4	RM5	RM6	RF1	RF2	RF3	RF4	RF5	RF6	RF7	RF8	Total
<i>Coscinodiscus marginatus</i>	20	13	7	20	26	0	0	7	0	0	0	0	0	7	0	0	0	0	0	100
<i>Actinocyclus sp.</i>	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	20
<i>Chaetoceros peruvianus</i>	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	7
<i>C. lorenzianus</i>	26	7	13	20	7	0	7	0	0	0	0	13	0	33	0	0	0	0	0	126
<i>Rhizosolenia styliformis</i>	0	0	0	0	0	0	0	0	7	0	0	0	0	53	21	0	0	36	2	119
<i>R. stolterfothii</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	18
<i>R. setigera</i>	0	0	0	7	0	0	0	7	0	0	0	0	7	0	0	6	0	0	0	27
<i>Thalassiosira subtilis</i>	26	20	26	40	40	33	13	0	0	7	20	0	7	21	0	6	0	7	266	
<i>T. cormandeliana</i>	7	7	20	7	7	7	0	0	0	0	0	0	0	0	0	0	0	0	0	55
<i>Skeletonema costatum</i>	0	0	0	0	0	0	26	33	33	0	66	0	0	33	0	0	6	0	0	197
<i>Odontella mobiliensis</i>	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
<i>O. pulchella</i>	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
<i>D. sol</i>	0	14	7	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28
<i>Melosira sp.</i>	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	7
<i>Leptocylindrus danicus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	0	6	18	0	57
<i>L. minimus</i>	0	0	0	7	0	0	0	0	0	0	0	0	13	0	0	0	6	0	0	26
<i>Eucampia zodiacus</i>	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	7
<i>Licmophora sp.</i>	0	0	0	0	0	0	0	0	7	0	0	0	0	5	0	0	0	0	0	12
<i>Navicula peliculosa</i>	20	139	20	33	20	20	7	20	33	59	20	0	7	33	0	6	36	0	20	493
<i>Nitzschia sigma</i>	0	7	7	7	20	13	0	7	7	0	0	0	0	0	0	0	0	0	0	68
<i>N. longissima</i>	7	20	20	26	13	0	13	20	7	26	0	0	0	5	0	6	0	0	0	163
<i>Nitzschia sp.</i>	0	0	0	0	0	0	0	0	7	13	20	13	7	0	5	0	6	0	13	84
<i>Pleurosigma elongatum</i>	13	0	0	7	13	13	0	0	0	0	0	0	0	0	0	0	0	0	0	46
<i>P. aetuarii</i>	0	0	7	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	14
<i>Gyrosigma sp.</i>	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
<i>D. smithii</i>	0	7	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
<i>Thalassionema nitzschiodes</i>	0	26	20	33	13	13	46	0	40	26	0	0	0	0	0	0	0	0	0	217
<i>Asterionellopsis glacialis</i>	7	7	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27
<i>Thalassiothrix frauenfeldii</i>	0	0	0	0	0	0	0	0	20	26	0	0	13	0	0	0	0	0	0	59
<i>T. longissima</i>	66	46	112	112	86	0	20	13	7	7	0	0	0	13	5	17	0	0	0	504
<i>Bacillaria paxillifera</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	13
<i>Cymbella sp.</i>	13	7	20	7	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	54
<i>Cocconeis sp.</i>	7	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	20
<i>Surirella sp.</i>	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
<i>Oscillatoria limosa</i>	0	0	0	0	0	0	0	0	7	0	0	7	0	66	64	35	78	24	59	340
<i>O. Formosa</i>	0	0	0	0	0	0	0	0	0	0	0	26	0	13	0	0	0	0	0	39
<i>O. agardhii</i>	0	7	0	0	0	0	0	0	0	0	0	0	0	13	0	29	6	0	0	55
<i>Oscillatoria sp.</i>	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	36	0	49
<i>Nodularia sp.</i>	0	0	7	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
<i>Spirulina sp.</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	12
<i>Merismopedia sp.</i>	0	13	0	20	59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	92
<i>Pediastrum sp.</i>	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	7
<i>Chlorella sp.</i>	0	0	0	7	0	0	0	0	0	0	0	13	13	0	0	0	12	0	0	45
<i>Isochrysis sp.</i>	0	0	0	0	0	0	0	0	0	0	0	26	13	13	0	0	0	0	0	52
<i>Tetraselmis sp.</i>	0	0	0	0	0	0	0	0	0	0	0	86	66	0	11	12	0	0	0	175
<i>Euglena sp.</i>	0	0	0	0	0	0	7	0	0	0	0	7	7	0	0	0	6	0	0	27
<i>Ceratium furca</i>	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
<i>Peridinium sp.</i>	7	13	7	7	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	41
<i>Prorocentrum micans</i>	0	7	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
<i>Gymnodinium sp.</i>	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
<i>Tintinnopsis sp.</i>	7	7	7	7	26	0	7	0	0	7	0	0	0	0	0	0	0	0	0	68
<i>Favella sp.</i>	0	7	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	14
<i>Total</i>	226	388	314	387	365	119	160	107	196	204	113	211	126	350	144	99	162	162	101	3934

Table 5—Phytoplankton numerical abundance (nos.ml⁻¹) in subsurface water at the selected locations off Kakinada Jan 2011

Species	R1	RM1	RM2	RF1	RF2	Total	%
<i>Coscinodiscus sp.</i>	13	-	-	-	-	13	1.0
<i>Rhizosolenia styliformis</i>	-	-	-	16	-	16	1.2
<i>T. subtilis</i>	-	20	8	5	-	33	2.5
<i>Skeletonema costatum</i>	20	-	-	16	-	36	2.7
<i>Lithodesmium undulatum</i>	-	-	4	-	-	4	0.3
<i>Navicula peliculosa</i>	66	-	-	323	-	389	29.5
<i>Nitzschia sigma</i>	7	-	-	-	-	7	0.5
<i>N. longissima</i>	7	-	-	-	-	7	0.5
<i>Nitzschia sp.</i>	13	-	-	11	-	24	1.8
<i>Pleurosigma sp.</i>	-	-	-	-	5	5	0.4
<i>Gyrosigma sp.</i>	7	-	-	-	-	7	0.5
<i>Diploneis robustus</i>	13	-	-	-	-	13	1.0
<i>Thalassionema nitzschiodes</i>	-	7	-	-	-	7	0.5
<i>Thalassiothrix frauenfeldii</i>	-	-	4	-	-	4	0.3
<i>Cymbella sp.</i>	-	-	-	11	-	11	0.8
<i>Oscillatoria limosa</i>	-	-	-	16	472	488	37.0
<i>O. agardhii</i>	-	-	-	5	-	5	0.4
<i>Anabaena sp.</i>	-	-	-	11	-	11	0.8
<i>Goleocapsa sp.</i>	-	7	-	-	-	7	0.5
<i>Chlorella sp.</i>	-	13	12	11	-	36	2.7
<i>Isochrysis sp.</i>	-	26	4	15	-	45	3.4
<i>Tetraselmis sp.</i>	-	73	52	11	-	136	10.3
<i>Ceratium sp.</i>	-	-	-	-	5	5	0.4
<i>Peridinium sp.</i>	-	-	-	-	11	11	0.8
Total	146	146	84	451	493	1320	100.0

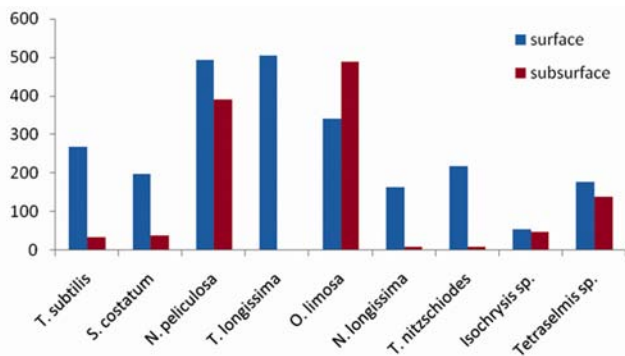


Fig 2—Comparison of some of the abundant species at surface and subsurface water

implying uneven distribution of species at surface and surface water respectively. Observation showed that phytoplankton richness remained moderate throughout all locations at least during the part of the year. Similarly, the high abundance and low diversity inside all locations and the occurrence of *Cylindrotheca closterium* in blooms indicate impacted conditions.

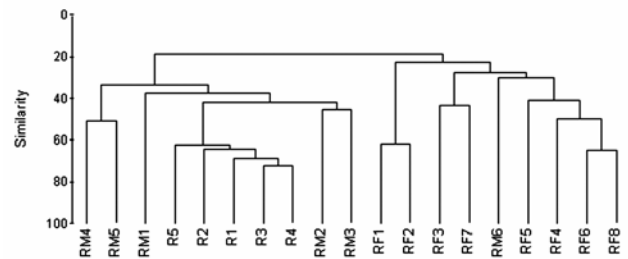


Fig 3a—Phytoplankton assemblage at surface water off Kakinada

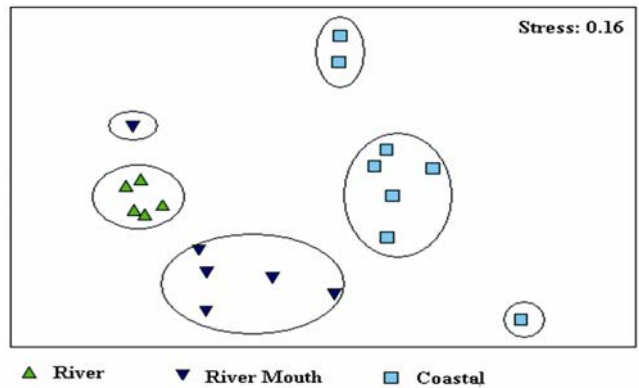


Fig 3b—Phytoplankton assemblage in group at surface water off Kakinada

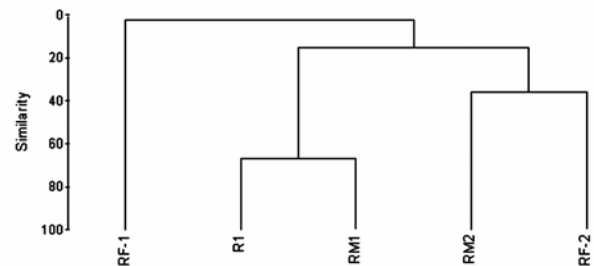


Fig 4a—Phytoplankton assemblage at subsurface water off Kakinada

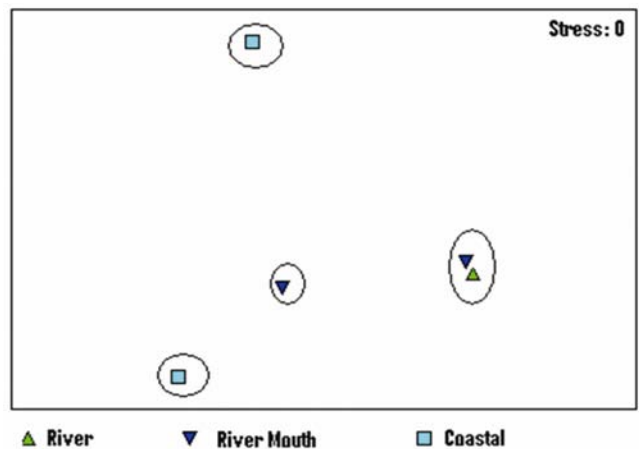


Fig 4b—Phytoplankton assemblage in group at subsurface water off Kakinada

Table 6—Phytoplankton diversity indices at the selected locations in surface and subsurface water off Kakinada

Surface					
Stations	S	N	d	J'	H' (loge)
R-1	13	226	2.21	0.88	2.26
R-2	21	388	3.36	0.8	2.44
R-3	17	314	2.78	0.83	2.35
R-4	19	387	3.02	0.85	2.49
R-5	17	365	2.71	0.87	2.46
RM-1	8	119	1.46	0.94	1.96
RM-2	11	160	1.97	0.89	2.14
RM-3	7	107	1.28	0.92	1.78
RM-4	14	196	2.46	0.89	2.35
RM-5	10	204	1.69	0.9	2.07
RM-6	4	113	0.63	0.79	1.1
RF-1	9	211	1.49	0.84	1.85
RF-2	7	126	1.24	0.78	1.52
RF-3	15	350	2.39	0.91	2.46
RF-4	9	144	1.61	0.79	1.73
RF-5	5	99	0.87	0.9	1.46
RF-6	9	162	1.57	0.73	1.61
RF-7	9	162	1.57	0.91	2
RF-8	5	101	0.87	0.72	1.16
Subsurface					
Stations	S	N	d	J'	H' (loge)
R1	8	146	1.40	0.82	1.71
RM1	6	146	1.00	0.80	1.43
RM2	6	84	1.13	0.69	1.23
RF-1	12	451	1.80	0.51	1.26
RF-2	4	493	0.48	0.16	0.22
Diversity indices in different segments					
Stations	S	N	d	J'	H' (loge)
R	32	336	5.33	0.78	2.71
RM	32	149	6.19	0.78	2.71
RF	34	211	6.17	0.69	2.44

Where;

S-number of species;

N-numerical abundance;

d-Margalef;

J'-evenness and

H'-Shannon diversity

Discussion

It is an established fact that nutrient availability largely determines the diversity of phytoplankton. From the analysis of the average Si:N:P ratio in the entire study area, it was found to be low and could be attributed to enrichment of these nutrients (NO_3 and PO_4 compared to SiO_4) through external inputs. N:P ratio (0.4:0.01) in reference point was found to be higher than that of the river mouth (0.13:0.06) and

river (0.3:0.02) which may be due to the slow regeneration of NO_3 compared to PO_4 . Deficiency in the ratio of nitrogen to phosphate in many inshore areas¹² may suggest that nitrogen is the limiting nutrient for phytoplankton. According to Qasim and Kureishy¹³ the phytoplankton concentration in Bay of Bengal vary greatly and the lowest value in oligotrophic region may come down to less than 500 cells/l. The large variation in the cell count of phytoplankton of the present study are in agreement with earlier report.

In general the information on phytoplankton distribution off Kakinada coast is scanty. Large fresh water influx in the east coast of India shows considerable seasonal variability in the coastal hydrographic condition. Coastal waters of India show little variation in the list of species from season to season but the relative cell number may vary considerably¹³. These authors reported the dominance of diatoms, dinoflagellates along with cyanophytes in the central Bay of Bengal. The dominance of diatoms and cyanophytes in the present study corroborate earlier report. Although the hydrography of this region has been fairly well studied,^{14,15}. The seasonality in the phytoplankton community has received very little attention. In a recent study Madhu *et al*¹⁶ reported lack of seasonality in phytoplankton standing stock in the western Bay of Bengal and no interannual variation in phytoplankton community in response to freshwater input has been observed.

The changes in dominance and diversity of phytoplankton species have been used as indicators of water quality that has promoted for the analysis of this community using strategies like dominant species and their relationship with environmental parameters¹⁵ Gomes *et al.*¹⁷ have stated that changing surface salinity due to fresh water discharge from rivers has tremendous influence on phytoplankton biomass and productivity. This was clearly demonstrated in the distribution of phytoplankton in the present study area where changes in species distribution was seen along the salinity gradient. Over 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 factors¹⁸⁻¹⁹. A similar observation was made in the present study. Abundance of phytoplankton was strongly correlated with nutrient concentration in the present study area. Similar observations were made in other study²⁰.

The environmental gradient in the present study was responsible in the distribution of phytoplankton. According to Qasim *et al.*²¹ low salinity waters support a greater abundance of phytoplankton in natural water. This was also true in the present study. Lack of intense upwelling of this coast is due to the equator ward flow of the freshwater plume which resulted in overwhelming the offshore Ekman transport in the coast of Bay of Bengal, maintaining similar seasonal plankton dynamics¹⁷. Principal components analysis has been used to group the species comprising phytoplankton communities into assemblages characterized by common spatial and/or temporal occurrences under given environmental conditions, water mass type or seasonally changing habitats²². Our findings suggest that the phytoplankton population of our study area were affected by the environmental gradient and with the physico-chemical variables²³.

In the present study, the bulk of phytoplankton was confined to the upper layer which is similar to the other tropical seas²⁴. Detailed analysis of the different taxa suggest that the dominant species of diatoms and dinoflagellates prefer surface water whereas the distribution of other less common taxa is either continuous or discontinuous depending on their cell densities. These variations in the vertical distribution might be due to changes in the hydrological conditions and light requirement of the species as reported earlier.

In conclusion, it can be stated that the overall composition of phytoplankton was found to be higher in the river as compared to the sea. This variation could be attributed to the changes in the environmental parameters specially nutrients along the river, river mouth and the reference point along the coast off Kakinada, east coast of India.

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