Indian Journal of Marine Sciences
Vol. 18, December 1989, pp. 251-258

Distribution and abundance of phytoplankton in Visakhapatnam harbour

M N V Subrahmanyam & P V Bhavanarayana
Department of Zoology, Andhra University, Visakhapatnam 530 003, India

Received 20 April 1989; revised 25 September 1989

Impact of domestic and industrial effluents on the horizontal, vertical and temporal distribution of phytoplankton and nanoplankton communities was studied. Members of Cyanobacteria, Chlorophyceae and Euglenophyceae and resistant species of Bacillariophyceae and Dinophyceae were found in different stations of the harbour. The abundance of both phytoplankton and nanoplankton decreased from surface to 4 or 6 m depth and nanoplankton was not found at 6 m in Visakhapatnam harbour.

Maximum production of phytoplankton in Visakhapatnam coast is restricted to two periods—first during January-April, coinciding with the period of upwelling and second during August-October coinciding with the period of turbulence when large scale mixing takes place between river waters and the deeper nutrient rich subsurface waters[1,2]. Phytoplankton of the coastal waters have been studied in detail[3,4].

Preliminary observations have been made on the distribution and abundance of *Oscillatoria nigroviridis*[5] and on the blooms of *Skeletonema*[6] in the entrance channel of Visakhapatnam harbour. The present paper deals with the phytoplankton communities of Visakhapatnam harbour.

Materials and Methods

Area of investigation and station locations are shown in Fig. 1. Of the stations, st I is the most polluted area and st II receives domestic sewage.

Seawater (2 l) was collected from surface and different depths (4 and 6 m) of all stations for phytoplankton analysis. Surface samples were collected from April 1984 to March 1986 while samples from 4 and 6 m depth were collected from December 1984 to March 1986. Phytoplankton, concentrated by centrifuging at 3000 rpm for 15 min, was examined to identify the nanoplankton and delicate forms, and later was preserved using formaline (4-5%). Cells present in 1 ml subsamples were counted in a Sedgwick-Rafter cell. Depending on the density of cells, the sample was further diluted to a known volume, and counting was done using diluted sample. From the average values of two counts, the cell number was calculated. Nanoplankton was not included in the estimation of relative abundance since all these organisms were counted as a single group. Species diversity (D) was estimated using the formula[7]:

$$D = \frac{S-1}{\log_e N}$$

where S is the number of phytoplankton species, and N is the total number of individuals in the collection.

Results

Abundance—Percentage values estimated from all samples (sts I-VI) are shown in Table 1. *Skeletonema costatum* was the most dominant (81.01%) while *Cyclotella meneghiniana* contributed to 8.36%. For *Peridinium cerasus*, *Nitzschia longissima* and *Ankistrodesmus falcatus*, the percentage contribution varied from 1.88 to 2.73. Percentage contribution of most of the others was < 1 (Table 1).

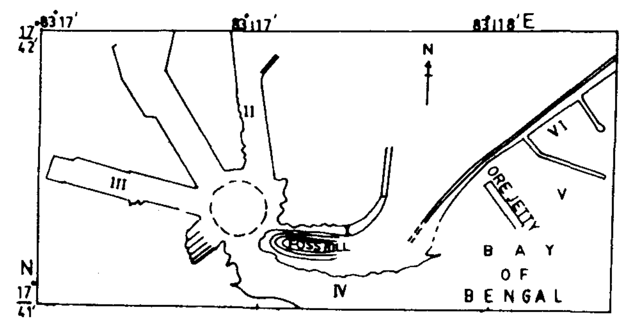

Fig. 1—Stations locations

Table 1—Relative abundance of phytoplankters in the Visakhapatnam harbour

Phytoplankter	% Frequency	Phytoplankter	% Frequency
Chlorophyceae		(b) Pennales	
Ankistrodesmus falcatus	1.88	*Navicula longa*	0.07
Pediastrum duplex	0.01	*Nitzschia palea*	0.05
P. simplex	0.01	*Thalassionema nitzschioides*	0.04
Scenedesmus quadricauda	0.01	*Pleurosigma elongatum*	0.03
Euglenophyceae		*Amphiprora gigantea*	0.01
		Amphora lineolata	0.01
Euglena acus	0.02	*Bacillaria paradoxa*	0.01
Bacillariophyceae		*Diploneis weissflogii*	0.01
(a) Centrales		*Gyrosigma balticum*	0.01
Skeletonema costatum	81.01	*Nitzschia closterium*	0.01
Cyclotella meneghiniana	8.36	*N. grunowii*	0.01
Thalassiosira decipiens	0.61		
Chaetoceros pelagicus	0.44	Dinophyceae	
Rhizosolenia alata	0.07	*Peridinium cerasus*	2.73
Biddulphia mobiliensis	0.07	*Prorocentrum micans*	0.67
Coscinodiscus centralis	0.06	*Peridinium breve*	0.45
Bacteriastrum varians	0.01	*Ceratium furca*	0.01
Chaetoceros affinis	0.01	*C. tripos*	0.01
C. curvisetus	0.01		
Coscinodiscus excentricus	0.01		
Ditylum brightwellii	0.01	Cyanobactria	
Lauderia anulata	0.01	*Oscillatoria nigroviridis*	0.52
Leptocylindrus danicus	0.01	*Microcystis aeruginosa*	0.08
Melosira moniliformis	0.01	*Oscillatoria margaritifera*	0.06
Planktoniella sol	0.01	*O. laete-virens*	0.05
Rhizosolenia stolterfothii	0.01	*Arthospira massartii*	0.01
(b) Pennales		*Lyngbya majuscula*	0.01
Nitzschia longissima	2.02	*Merismopedia glauca*	0.01
Asterionella japonica	0.17	*Spirulina major*	0.01
Thalassiothrix frauenfeldii	0.16		
Nitzschia seriata	0.12		

Distribution—Distribution of different groups of phytoplankton varied from one station to the other (Table 2). Species of Chlorophyceae and Cyanobacteria were abundant in st I and decreased in other stations. Twenty-one species of Bacillariophyceae were seen in st I and their number increased in sts V and VI, which are away from the polluted channels of the inner harbour. There were no variations in the species of Dinophyceae and Euglenophyceae occurring in the 6 stations. The mean cell numbers, belonging to these 5 classes calculated from 2 y data, are given in Fig. 2. The cell number of green algae and Cyanobacteria in sts III-VI was minimum, and *Euglena acus* was not recorded in st VI. The cell density of centrale diatoms was more in sts II-IV, and pennate diatoms in st I, while in other stations, the standing crop of these 2 groups of diatoms decreased. Though there was no marked difference in the species of the Dinophyceae recorded in all the 6 stations (Table 2), the standing crop of this group was maximum in st II.

Table 2—Station-wise distribution of different classes of plankton in the Visakhapatnam harbour

Class	Species number					
St. No.	I	II	III	IV	V	VI
Chlorophyceae	6	5	3	3	2	2
Euglenophyceae	1	1	1	1	1	0
Bacillariophyceae	21	21	24	28	30	32
Dinophyceae	4	5	5	4	4	5
Cyanobacteria	9	6	5	4	3	3
Total	41	38	38	40	40	42

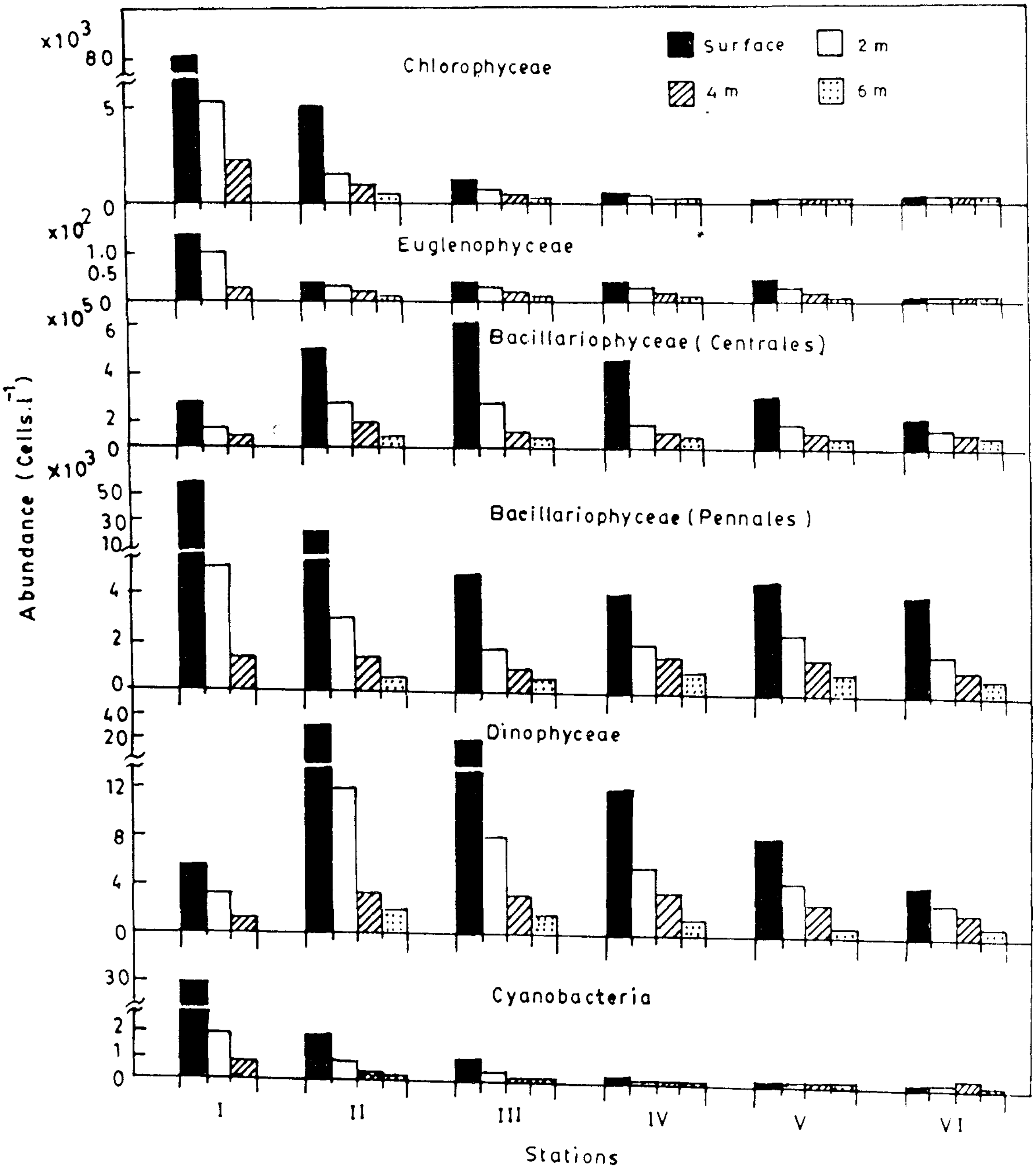

Fig. 2—Depth-wise distribution of 5 classes of phytoplankton at different stations

The mean value of total algal crop (both phytoplankton and nanoplankton), sampled from surface to 6 m water column in Visakhapatnam harbour (Fig. 3) was very high in sewage polluted st I with a mean value of 19.07×10^5 cells.l^{-1} and it decreased gradually in other 5 stations. Lowest standing crop (23,969 cells l^{-1}) was in fishing harbour (st VI). Diurnal variations also occurred and the cell number was 2 to 6 times higher in the afternoon (1500-1700 hrs) than in the morning (0900-1100 hrs).

Station-wise differences in abundance of some important phytoplankters and total nanoplankton are given in Figs 4 and 5. Three types of distribution can be seen in the planktonic forms depending on the degree of pollution. The standing crop of *Nitzschia longissima* and *Oscillatoria nigroviridis* was maximum in st I and and it decreased gradully from sts II-VI. Similarly all nanoplanktonic forms were very abundant in st I with a mean cell density of 49.61×10^5.l^{-1}, and their standing crop decreased gradually from sts III to

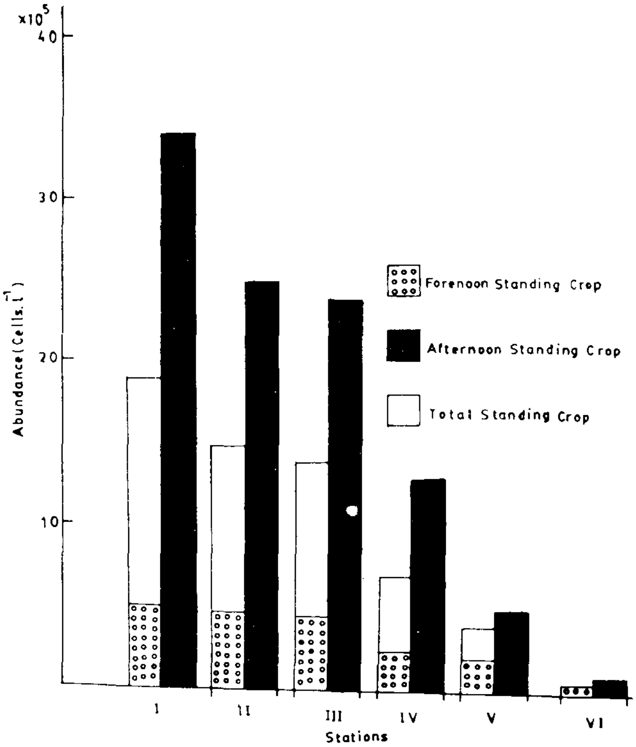

Fig. 3—Diurnal distribution of phytoplankton in different stations

VI. This type of distribution was also seen in other forms such as *Ankistrodesmus falcatus*, *Oscillatoria margaritifera*, *Microcystis aeruginosa* and *Thalassiosira decipiens* (Fig. 5). The second type of distribution was found in forms like *Skeletonema costatum*, *Cyclotella meneghiniana* and others. The surface mean standing crop of *S. costatum* increased from 2.28×10^5 chains l^{-1} in st III. From st IV, the cell density decreased and lowest value of 33,000 chains l^{-1} was estimated in st VI. The standing crop of *Cyclotella meneghiniana* also followed the same trend. Maximum cell density of dinoflagellates like *Peridinium cerasus* and *Prorocentrum micans*, occurred in st II instead of st III and it decreased markedly from st IV. The cell density of less common forms such as *Chaetoceros pelagicus* and *Peridinium breve* increased from sts I-III or IV, and later it decreased in sts V and VI (Fig. 5). The third type of distribution was seen in *Nitzschia seriata*, *Biddulphia mobiliensis*, *Coscinodiscus centralis* and *Rhizosolenia alata* with minimum cell number in st I and maximum in st V. In *Asterionella japonica*, maximum crop was observed in st VI indicating that these forms can grow in stations away from the polluted channels of the harbour.

Vertical distribution—Mean values of standing crop of phytoplankton and nanoplankton estimated at different depths are plotted in Figs 2, 4 and 5 to show vertical distribution. In general, phytoplankton and nanoplankton were abundant in surface waters of Visakhapatnam harbour (Fig. 2) and their abundance decreased with depth. Minimum number of phytoplankton was recorded at 6 m and surprisingly nanoplankton was not seen at this depth. However, in the less common species certain variations were observed in the vertical distribution. For example in *Biddulphia mobiliensis*, *Rhizosolenia alata*, *Asterionella japonica*, *Thalassionema nitzschioides*, *Navicula longa*, *Spirulina major*, *Euglena acus* and *Thalassiosira decipiens*, the cell density decreased with depth. Gradual or sudden decrease in the cell number was observed from surface to 6 m depth in *Nitzschia seriata*, *Thalassiothrix frauenfeldii*, *Ankistrodesmus falcatus* and *Chaetoceros pelagicus*. Certain forms like *Microcystis aeruginosa* and *Spirulina major* were seen up to 4 m in the harbour waters. In *Coscinodiscus centralis* the cell number was more at 2 m than in the surface and deeper layers of the water column. In *Pleurosigma elongatum* cell number increased with depth and maximum number was recorded at 6 m.

Monthly changes in species diversity—Monthly mean values of species diversity calculated for 6 stations are shown in Table 3. For comparison, species diversity indices estimated for the phytoplankton of coastal waters is also shown in the last column of the Table. In polluted harbour waters, species diversity was less in all months of the year and the yearly mean index value ranged from 1.53 to 2.22 bits per individual in sts I to VI. In unpolluted open waters, the species diversity values were 3.4 times higher than in harbour waters (Table 3).

Discussion

Composition and taxonomic diversity of phytoplankton vary in relation to the quality of the water and certain resistant types are reported in polluted habitats. Members of Cyanobacteria, Chlorophyceae and Euglenophyceae have been observed as dominant and most common forms[5,8-11] in waters polluted by sewage or organic matter. At Visakhapatnam, blue-green algae are more abundant in sewage receiving waters of st I. Taslakian and Hardy[11] have observed that blue-green algae and dinoflagellates occur abundantly in sewage polluted waters and diatoms in clear waters away from the major sewage outflow. Similar trend can be seen in the data presented in Table 2. Cyanobacteria and Chlorophyceae members are more in sewage polluted st I and diatoms are

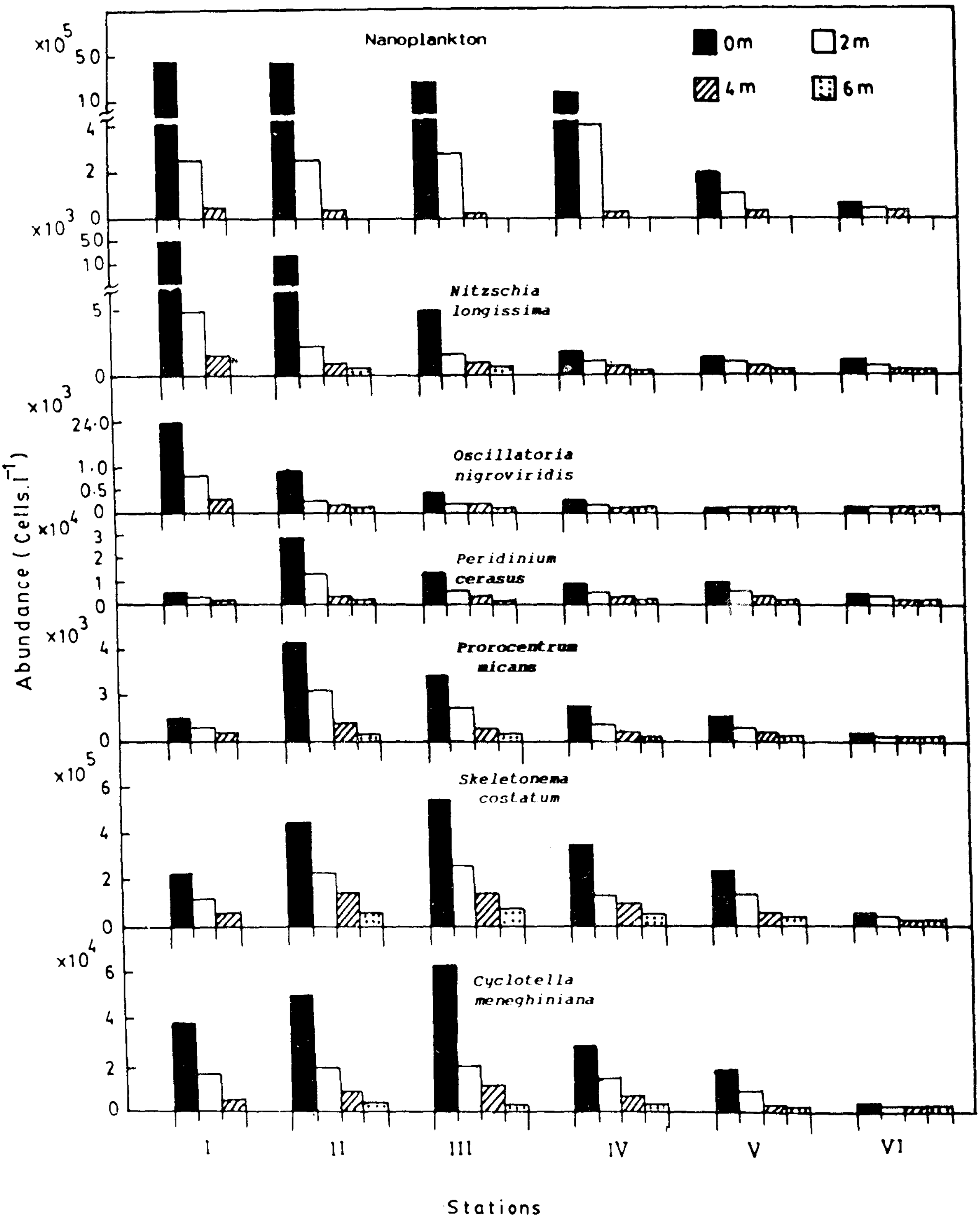

Fig. 4—Vertical distribution of nanoplankton and some most abundant phytoplankton at different stations

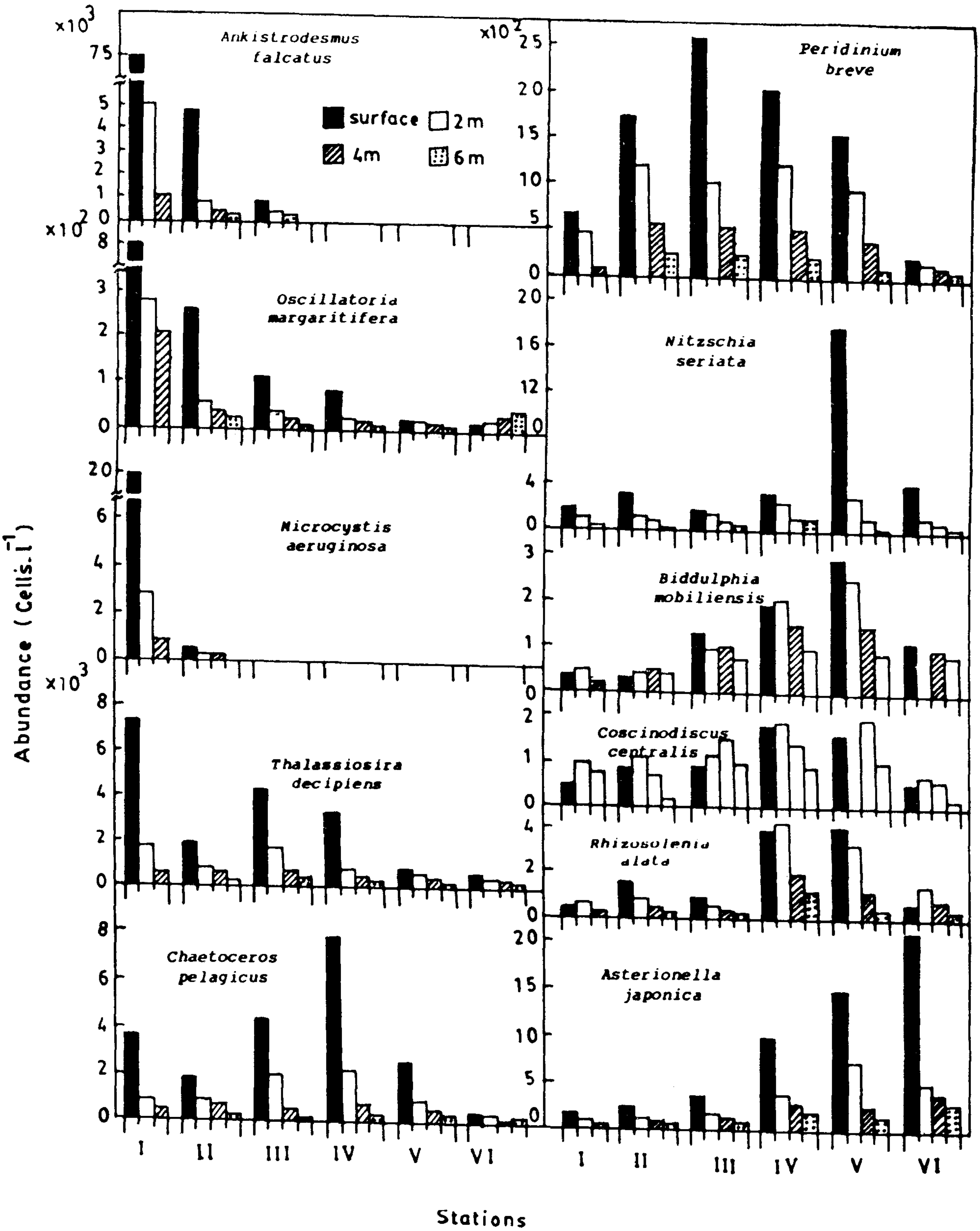

Fig. 5—Vertical distribution of less common phytoplankters at different stations

more in less polluted sts V and VI. Reduction of species and increase in the cell number of 1 or 2 resistant algae are observed by Golubic[12] in polluted coastal environment. In the offshore area of Visakhapatnam, Subba Rao[13] has reported 100 species of phytoplankton. The species number (50) in the Visakhapatnam harbour is lower than in outer coastal waters and excluding nanoplanktonic forms.

In sewage and effluent discharged environments, several workers have reported[14-16] the occurrence of *Skeletonema costatum* in blooming proportions. *S. costatum* is also abundant in Visakhapatnam harbour (Table 1). Next to nanoplankton, *S. costatum* is the dominant member in Visakhapatnam harbour. The relative frequency of other common forms like *C. meneghiniana*, *P. cerasus*, *N. longissima* and *A. falcatus* is very low. In the present study the abundance of *S. costatum* in st IV (5.05×10^5 fil.l^{-1}) is far less than the density reported by Ganapati and Raman[6]. The highest standing stock of *S. costatum* observed in st III (10.64×10^5 cells.l^{-1} is also less than the total number reported by Ganapati and Raman[6].

Working on diatom communities of polluted habitats, Hendey[17] has classified marine habitats with species diversity values of 0-1 as severely polluted, 1-2 as moderately polluted and 2-3 as slightly polluted. The species diversity values are low and ranged from 1.53 to 2.22 bits/individuals in the 6 stations of the harbour. They are 3 to 4 times less than the diversity values estimated from the plankton abundance of the offshore waters of Visakhapatnam (Table 3). The waters of Visakhapatnam harbour are more polluted than the coastal waters according to the rating given by Hendey[17]. Visakhapatnam harbour can be classified as moderately polluted area.

Increase in phytoplankton production and standing crop is reported by Davis[8], Braarud[14,18] and others as a result of discharge of domestic sewage and industrial effluents. Goodbody[19] has observed 40 fold increase in phytoplankton between open ocean (32.3×10^3 cells.l^{-1}) and the inner Kingston harbour ($1{,}351 \times 10^3$ cells.l^{-1}) at Jamaica with annual abundance of phytoplankton varying from 0.78×10^6 to 1.45×10^6 cells.l^{-1} in Tampa Bay, which receives industrial and municipal waters[15]. High plankton production has been reported by Moraitou-Apostolopoulou and Ignatiades[21] in sewage polluted Elefsis Bay, ranging from 2.6×10^8 to 1.5×10^9 cells.m^{-3}. The chlorophyll *a* standing crop is 10 times greater in sewage polluted coastal waters of Mediterranean[21] and Hongkong[22]. In Visakhapatnam harbour algal standing crop is very high. The annual ranges and mean standing crops of phytoplankton, nanoplankton and total algal crop at surface and 4 m depth are shown in Table 4. In sts I to III, annual range of surface phytoplankton varies from 1.18 to 14.5×10^5 cells.l^{-1} and the mean values range from 4.41 to 6.38×10^5 cells.l^{-1}. In other stations, the standing crop of phytoplankton is less (Table 4). In many earlier investigations on polluted habitats, nanoplanktonic forms are not studied. The station and depth-wise abundance given in Fig. 4 and Table 4 clearly indicate that the standing crop of nanoplankton is more in sewage polluted st I than in st VI. The abundance of total algal crop is several times higher than the cell densities report-

Table 3—Species diversity index at 6 stations of harbour and coastal waters of Visakhapatnam

Month	Stations I	II	III	IV	V	VI	Coastal waters*
Jan	1.19	1.18	1.39	1.40	1.54	1.75	7.76
Feb	1.65	1.53	1.36	1.56	1.88	1.91	8.13
Mar	1.83	1.86	1.43	2.12	2.36	2.76	6.86
Apr	2.45	1.52	2.03	2.49	2.18	2.97	6.65
May	1.44	1.61	1.93	1.96	1.66	2.30	6.90
Jun	1.23	1.38	1.42	1.16	1.25	1.84	6.58
Jul	1.58	1.44	1.42	1.61	1.23	1.92	7.98
Aug	1.74	1.51	1.88	1.37	1.63	2.50	7.36
Sep	2.18	1.30	1.60	1.66	1.79	1.80	6.40
Oct	1.55	1.38	1.75	1.90	1.60	2.14	6.84
Nov	1.96	1.99	1.80	1.32	1.91	2.05	6.08
Dec	1.79	1.64	1.53	1.68	1.41	2.67	7.45
Mean	1.72	1.53	1.63	1.69	1.70	2.22	7.08

*Published data of Subba Rao[13]

Table 4—Annual range and mean values of phytoplankton and nanoplankton in different stations

St No.	Depth (m)	No. of cells $\times 10^5.l^{-1}$ Phytoplankton Annual range	Phytoplankton Mean	Nanoplankton Annual range	Nanoplankton Mean
I	0	1.18-14.15	4.41	0.13-349.0	49.61
	4	0.10-2.66	0.62	0.01-1.69	0.20
II	0	1.63-9.05	5.53	0.77-341.0	46.23
	4	0.19-4.30	1.44	0.01-3.44	0.19
III	0	1.70-10.19	6.38	0.28-212.0	28.87
	4	0.14-3.93	1.38	0.01-3.12	0.18
IV	0	1.21-9.45	4.79	0.19-87.67	13.23
	4	0.11-2.46	0.88	0.01-7.53	0.14
V	0	0.70-4.85	2.75	0.11-13.23	1.66
	4	0.07-1.40	0.51	0.01-3.05	0.11
VI	0	0.06-1.50	0.42	0.03-1.38	0.26
	4	0.02-0.18	0.07	0.01-0.18	0.08

ed in Tampa Bay[15], Kingston harbour[19], and Boston harbour[23]. It is higher than the abundance of *S.costatum* (10×10^5 cells.l^{-1}) reported by Ganapati and Raman[6].

As shown in Fig. 4 and Table 4, the density of nanoplankton is very high in surface waters and decreases with depth. Another important feature is that nanoplankton is not found beyond 4 m depth in Visakhapatnam harbour. Nanoplankters like *Tetraselmis gracilis* and *Tetracystis* sp., are phototactic and this response explains their concentration in surface waters, reduction at 2 to 4 m and complete absence at 6 m depth. The depth of euphotic zone varies from 0.8 to 2.63 m in different stations[24], indicating the turbid nature of the water. This high turbidity in Visakhapatnam harbour may also be due to the occurrence of nanoplankton in blooming proportions in the upper layers of the water[25]. Excessive growth of nanoplankters in sts I to IV and reduction in their cell number in less polluted sts V and VI, further suggest that sewage polluted habitats are ideal for the development of nanoplankton.

Acknowledgement

The authors express their gratitude to the authorities of Visakhapatnam Port Trust for permission and providing mechanised boat for collection of water and plankton samples. One of the authors (MNVS) is grateful to UGC, New Delhi, for financial assistance under the Special Assistance Programme, during the tenure of this work.

References

1 Ganapati P N & Murty V S R, *Andhra Univ Mem Oceanogr*, 1 (1954) 125.
2 Ganapati P N, *Mahasagar-Bull Natn Inst Oceanogr*, 6 (1973) 84.
3 Ganapati P N & Satyanarayana Rao T S S, *Proc First All India Cong Zoology*, (1962) 26.
4 Ganapati P N & Subba Rao D V, *Proc Indian Acad Sci*, 48B (1959) 189.
5 Premila V E & Umamaheswara Rao M, *Indian J Mar Sci*, 6 (1977) 79.
6 Ganapati P N & Raman A V, *Indian J Mar Sci*, 8 (1979) 184.
7 Margalef R, *Oceanogr Mar Biol Ann Rev*, 5 (1967) 257.
8 Davis C C, *Ecol Monogr*, 24 (1954) 321.
9 Dutta N, Malhotra J C & Bose B B, in *Symp Mar Freshwater Plankton in Indopacific, Indo-Pac. Fish Counc, Bangkok*, (1954) 35.
10 Golubic S, *Mar Poll Bull*, 1 (1970) 56.
11 Taslakian M J & Hardy J T, *Mar Biol*, 38 (1976) 315.
12 Golubic S, *Europ Symp Mar Biol Archon Suppl*, London, 22 (1971) 293.
13 Subba Rao D V, in *Prof Ganapati Shas Comm Vol*, edited by K Hanumantha Rao (Andhra University, Waltair, India) 1970, 101.
14 Braarud T, *Hvalrad Skr*, 28 (1945) 1.
15 Turner J T & Hopkins T L, *Bull Mar Sci*, 24 (1974).
16 Welch E B, *Pollut Control Fed*, 40 (1968) 1711.
17 Hendey N I, *Fourth symp on Recent and Fossil Marine Diatoms Oslo*, (1977) 355.
18 Braarud T, *Fisheries Development Committee Spl Rep*, (1969) 1.
19 Goodbody I M, *J Sci Res Council Jamaica*, 1 (1970) 10.
20 Moraitou-Apostolopoulou M & Ignatiades, *Hydrobiologia*, 75 (1980) 259.
21 Hardy J T & Jubayli Z, *Environ Poll*, 11 (1976) 195.
22 Thompson G B & Ho J, *Mar Poll Bull*, 12 (1980) 168.
23 Anonymous, *U S Department of the Interior, Federal Water Pollution Control Administration, Technical Advisory and Investigation Branch Rep.* (SSSS Ridge Ave Cincinnati, Ohio) 1968, 1.
24 Subrahmanyam M N V & Bhavanarayana P V (Unpublished data).
25 Bhavanarayana P V & Subrahmanyam M N V, *Proceedings of the International Union of Geodesy and Geophysics*, Vancouver, Canada (1987) Abst No OPS 10-33, 1103.