

Phytoplankton Community Structure and Succession in a Tropical Estuarine Complex (Central West Coast of India)

V. P. Devassy and J. I. Goes

National Institute of Oceanography, Dona Paula, Goa 403 004, India

Received 19 November 1987 and in revised form 8 June 1988

Keywords: phytoplankton; tropical regions; estuaries; abundance

The seasonal distribution of phytoplankton in the Mandovi–Zuari estuarine complex (central west coast of India) from November 1979 to October 1980 is described. Of the 82 species of phytoplankton recorded, diatoms (63 species) showed an overwhelming predominance over dinoflagellates (14 species), blue-green algae (three species) and green algae (two species). Among the several factors affecting phytoplankton, the commencement of the south-west monsoon results in a drastic change in hydrographic conditions which are instrumental in the transformation of the phytoplankton population size and structure. The great variability in the ecosystem is amply illustrated by species succession.

Introduction

Communities are recognized as recurrent organized systems of organisms responding in a related way to changes in the environment (Legendre & Legendre, 1978). Any disturbance in the environment produces changes in many growth variables of an individual, which ultimately leads the community to become reorganized (Smayda, 1963). Under such conditions, certain adaptations, which include physiological, morphological and cytological changes, enabling a species or a group of species to thrive, lead to the phenomenon called succession. Thus succession of an organism or a group occurs when environmental conditions are conducive for their proliferation. Therefore, abrupt changes occurring within the environment are associated with a group of organisms replacing the others. Apart from the above, the distribution and abundance of individual species may also be affected by regional circulation patterns which influence their dispersal, accumulation and isolation (Smayda, 1978).

Along the vast coastline of India there are a number of small and large estuaries and backwaters. The Mandovi–Zuari estuarine complex is a major one situated along the central west coast. The average flushing time of this estuarine complex has been calculated to be of the order of 50 days during the non-monsoon months, decreasing considerably during the south-west monsoon period (National Institute of Oceanography, 1981). It is evident that this area is strongly influenced by the south-west monsoon. During this period, a large quantity of freshwater is added to the estuaries, resulting in low saline conditions, very high turbidity and greatly reduced light levels. Devassy (1983) observed

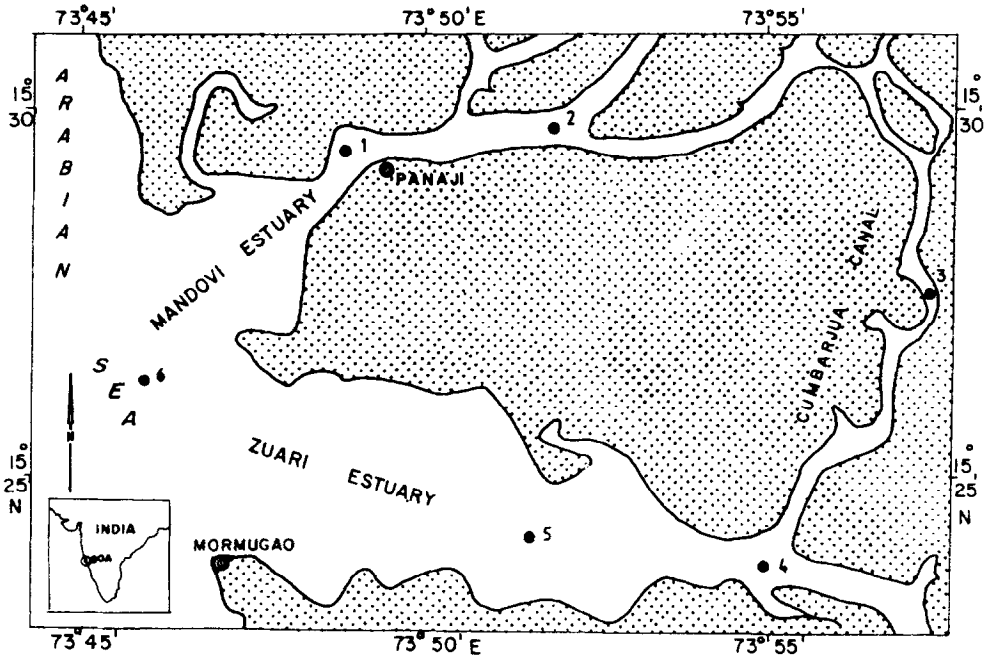


Figure 1. Map showing location of study area and sampling stations (●).

that the changes associated with the onset of the monsoon have a marked effect on the phytoplankton dynamics of this estuarine complex. Based on this, the year has been divided into three seasons, *viz.* pre-monsoon (February–May), monsoon (June–September) and post-monsoon (October–January). Although this estuarine complex is known for its high biological productivity (Devassy, 1983; Selvakumar *et al.*, 1980; Parulekar *et al.*, 1980), phytoplankton organisms that sustain the food chains in these waters have remained largely unknown.

In this study a detailed examination of the temporal dynamics of phytoplankton has been made. In addition, phytoplankton community structure and succession are discussed in relation to the prevalent environmental conditions. The works of Subrahmanyam (1946, 1959), Gopinathan (1974), Devassy and Bhattathiri (1974) and Devassy and Bhargava (1978) allowed characterization of the phytoplankton flora.

Materials and methods

Monthly samples extending over a period of 12 months were taken at six stations: two each in the Mandovi and the Zuari and one each in the Cumbarjua canal and the coastal waters (Figure 1) during the period 1979–80. Observations at the coastal station could be carried out only for eight months during fair weather, because during the south-west monsoon all coastal traffic beyond an imaginary line between Mormugoa head and Aguada light house is prohibited every year. All observations were carried out during the high-tide phase.

Collections were made with the help of 5-1 Niskin samplers. Phytoplankton samples were collected in 500-ml plastic bottles, fixed in 1% Lugol's Iodine and preserved in 3% buffered formaldehyde. The samples were allowed to settle for three days, the supernatant

solution removed and the sedimented sample counted in triplicate in a Sedgwick Rafter Plankton Counting Chamber under a stereoscopic binocular microscope.

Results

Monthly variations in surface phytoplankton (diatoms, dinoflagellates and other algae) at the different stations are presented in Figure 2. A total of 63 diatom species belonging to 37 genera, 14 dinoflagellate species of eight genera, three species of blue-green algae and two species of green algae were encountered (see Table 1). In Table 2, seasonal abundance of the various groups of phytoplankton in the Mandovi, Cumbarjua canal, the Zuari estuary and the coastal station are presented. The taxonomic composition clearly showed an overwhelming predominance of diatoms in the estuarine complex, except for during the month of September, during the late monsoon period, when a dinoflagellate bloom of *Ceratium furca* contributed 72.5 and 77.6% of the total phytoplankton crop at stations 4 and 5, respectively. The other algae (three species of blue-green algae and two species of green algae) formed an insignificant component in the estuarine complex, although during May an unidentified blue-green alga surpassed all other phytoplankters and contributed as much as 90.6, 90.2 and 65.4% of the total phytoplankton at stations 1, 2 and 3, respectively. At the coastal station (station 6) massive blooms of *Trichodesmium erythraeum* accounted for over 90% of the total phytoplankton during March and April. Cell numbers (expressed as $\times 10^3 \text{ l}^{-1}$) fluctuated from 4.75 (July) to 1369.0 (October) in the Mandovi, 7.5 (August) to 489.5 (May) in the Cumbarjua canal, and from 7.5 (August) to 356.0 (December) in the Zuari. At the coastal station, the highest and lowest counts of phytoplankton recorded were 85.25 (January) and $1251.25 \times 10^3 \text{ l}^{-1}$ (April), respectively.

In the Mandovi estuary two peaks in phytoplankton cell counts were observed, one in May and the other in October, and the lowest values during July and August. In the Cumbarjua canal also, two peaks were observed with the primary peak in February and the secondary one in May. Here again during the peak monsoon months, very low concentrations of phytoplankton were recorded. In the Zuari, phytoplankton exhibited a tridmodal peak, one each in October, December and February. The post-monsoon period showed the highest number of species of diatoms and dinoflagellates and the highest cell counts. A sharp decline in phytoplankton cell numbers was observed during the monsoon season. In the coastal region, peaks were observed during December, April October. The major peak in April was due to the occurrence of the blue-green alga *T. erythraeum*.

During the pre-monsoon season, the diatom *Fragilaria oceanica* and an unidentified blue-green alga were the predominant forms in the Mandovi estuary and contributed 90.3 and 82.2% of the total population, respectively. The unidentified blue-green alga dominated in the Cumbarjua canal and comprised 90.6% of the phytoplankton crop. The most abundant forms in the Zuari were *Nitzschia* spp., *Coscinodiscus* spp., *Skeletonema costatum*, *Bacillaria paradoxa* and *T. erythraeum*. The latter was the most abundant form in the coastal waters forming massive blooms during the pre-monsoon and contributing to 92.2% of the phytoplankton population.

An intense bloom of the diatom *F. oceanica* occurred in the Mandovi estuary during September which accounted for 94.4% of the total phytoplankton. During July and August when the monsoon was at its peak, the phytoplankton composition was qualitatively and quantitatively scanty. The diatoms *Nitzschia closterium*, *F. oceanica*, *Leptocylindrus danicus* and species of *Coscinodiscus* and *Navicula* were moderately

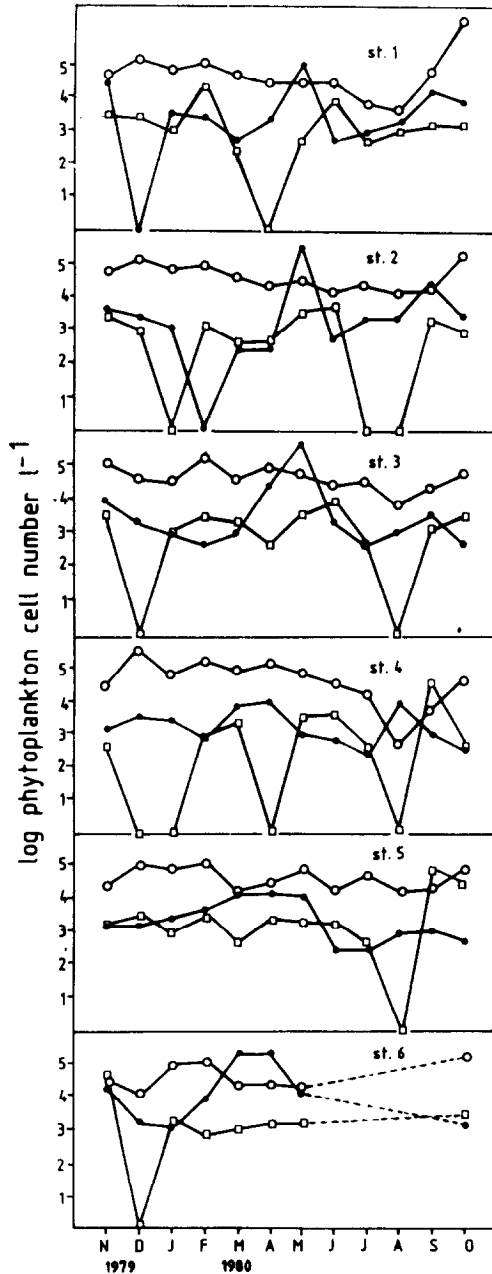


Figure 2. Monthly variations in surface phytoplankton: (○) diatoms; (□) dinoflagellates; (●) other algae.

abundant in the Cumbarjua canal. In the Zuari, blooms of the euryhaline diatom *S. costatum* accounted for 83.5% and the dinoflagellate *C. furca* for 77.6%.

During the post-monsoon season, *N. closterium* (54.6%) was the dominant form in the Mandovi during this period. *L. danicus* and species of *Nitzschia*, *Coscinodiscus* and *Rhizosolenia* were the dominant forms in the Cumbarjua canal. *Chaetoceros curvisetus*,

TABLE 1. List of phytoplankton species recorded in the Mandovi-Zuari estuarine complex

Diatoms	<i>Pleurosigma aestuarii</i> Brebisson
<i>Amphiprora gigantea</i> Grunow var. <i>sulcata</i>	<i>P. angulatum</i> W. Smith
(O'Meara) Cleve	<i>P. elongatum</i> W. Smith
<i>Asterionella japonica</i> Cleve	<i>Planktoniella sol</i> (Wallich) Schutt
<i>Aulacodiscus</i> sp.	<i>Rhabdonema</i> sp.
<i>Bacillaria paradoxa</i> Gmelin	<i>Rhizosolenia alata</i> Brightwell f. <i>indica</i>
<i>Bacteriastrium hyalinum</i> Lauder	<i>R. robusta</i> Norman
<i>Bellerrochea malleus</i> (Brightwell) van Heurck	<i>R. stolterfothii</i> Pergallo
<i>Biddulphia mobiliensis</i> Bailey	<i>R. styliformis</i> Brightwell
<i>B. sinensis</i> Gray	<i>Schroederella delicatula</i> (Pergallo) Pavillard
<i>Chaetoceros curvisetus</i> Cleve	<i>Skeletonema costatum</i> (Greville) Cleve
<i>C. lascinosus</i> Schutt	<i>Stephanopyxis palmeriana</i> (Greville) Grunow
<i>C. lorenzianus</i> Grunow	<i>Streptothecha thamensis</i> Shrubsole
<i>Coscinodiscus centralis</i> Ehrenberg	<i>Surirella fuminensis</i> Grunow
<i>C. excentricus</i> Ehrenberg	<i>Thallassionema nitzschoides</i> Grunow
<i>C. marginatus</i> Ehrenberg	<i>Thallassiothrix frauenfeldii</i> Grunow
<i>C. oculus iridis</i> Ehrenberg	<i>Thallassiosira subtilis</i> (Ostenfeld) Gran
<i>C. radiatus</i> Ehrenberg	<i>Triceratium favus</i> Ehrenberg
<i>Coscinodiscus</i> sp.	Unidentified pennate diatom
<i>Coscosira</i> sp.	
<i>Cyclotella meneghiniana</i> Kutzling	Dinoflagellates
<i>C. striata</i> (Kutzling) Grunow	<i>Ceratium furca</i> Ehrenberg
<i>Ditylum brightwellii</i> (West) Grunow	<i>C. lineatum</i> Ehrenberg
<i>D. sol.</i> Grunow	<i>C. macroceros</i> Ehrenberg
<i>Eucampia zodiacus</i> Ehrenberg	<i>Dinophysis caudata</i> Kent
<i>Fragilaria oceanica</i> Cleve	<i>Dinophysis</i> sp.
<i>Gyrosigma balticum</i> (Ehrenberg) Rabenhorst	<i>Exuviella</i> sp.
<i>Grammatophora undulata</i> Ehrenberg	<i>Gonyaulax</i> spp.
<i>Hemiaulus sinensis</i> Greville	<i>Noctiluca scintillans</i> (Macartney)
<i>Hemidiscus</i> sp.	<i>Ornithocercus</i> sp.
<i>Leptocylindrus danicus</i> Cleve	<i>Peridinium depressum</i> Bailey
<i>L. minimus</i> Gran	<i>P. divergens</i> Ehrenberg
<i>Licmophora abbreviata</i> Agardh	<i>Peridinium</i> sp.
<i>Melosira moniliformis</i> (Muller) Agardh	<i>Prorocentrum micans</i> Ehrenberg
<i>M. sulcata</i> (Ehrenberg) Kutzling	<i>Prorocentrum</i> spp.
<i>Navicula longa</i> (Gregory) Ralfs	
<i>N. membranaceae</i>	Other algae
<i>Navicula</i> sp.	Blue-green algae
<i>Nitzschia bilobata</i> W. Smith <i>r. minor</i> Grunow	<i>Trichodesmium erythraeum</i> Ehrenberg
<i>N. closterium</i> (Ehrenberg) W. Smith	<i>T. thiebautii</i> Gomont
<i>N. longissima</i> (Brebisson) Ralfs	Unidentified blue green algae
<i>N. migrans</i> Cleve	
<i>N. panduriformis</i> Greg. var. <i>continua</i> Grunow	Green algae
<i>N. seriata</i> Cleve	<i>Chlorella</i> sp.
<i>N. sigma</i> W. Smith var. <i>indica</i> Karsten	<i>Tetraselmis gracilis</i>
<i>Nitzschia</i> sp.	Flagellates
<i>Phaeodactylum tricornerutum</i>	

species of *Nitzschia*, *Coscinodiscus* and *Rhizosolenia* and the flagellate *T. gracilis* were the abundant forms in the Zuari.

Succession of species

Some of the more important forms (i.e. those representing >10% of the total phytoplankters numerically) included in Figure 3 give clear evidence of succession. A conspicuous feature of the succession patterns observed was the presence of *L. danicus* at all

TABLE 2. Seasonal abundance of diatoms (DT), dinoflagellates (DF), other algae (OA) and total phytoplankton (TP) (all values expressed as $\times 10^3$ cells l^{-1})

	Post-monsoon				Pre-monsoon				Monsoon			
	DT	DF	OA	TP	DT	DF	OA	TP	DT	DF	OA	TP
Mandovi	250.63	1.63	7.22	259.48	69.56	1.41	67.97	138.94	88.75	2.00	2.90	93.65
Cumbarjua	64.25	2.13	2.88	69.26	93.88	3.90	116.75	214.53	86.88	2.75	1.63	91.26
Zuari	95.53	7.15	2.16	104.84	85.56	2.66	5.44	93.66	22.32	19.19	0.76	47.72
Coastal	95.13	13.38	6.00	114.51	40.13	1.18	140.13	181.44	—	—	—	—

the stations during November 1979. During the ensuing months, this form was generally replaced by the pennate diatoms *Nitzschia seriata*, *N. bilobata*, *N. closterium* and *Navicula membranaceae* at almost all stations. The other conspicuous forms were the chain-forming diatoms *Schroederella delicatula* at station 3 and *C. curvisetus* at stations 3, 4, 5 and 6.

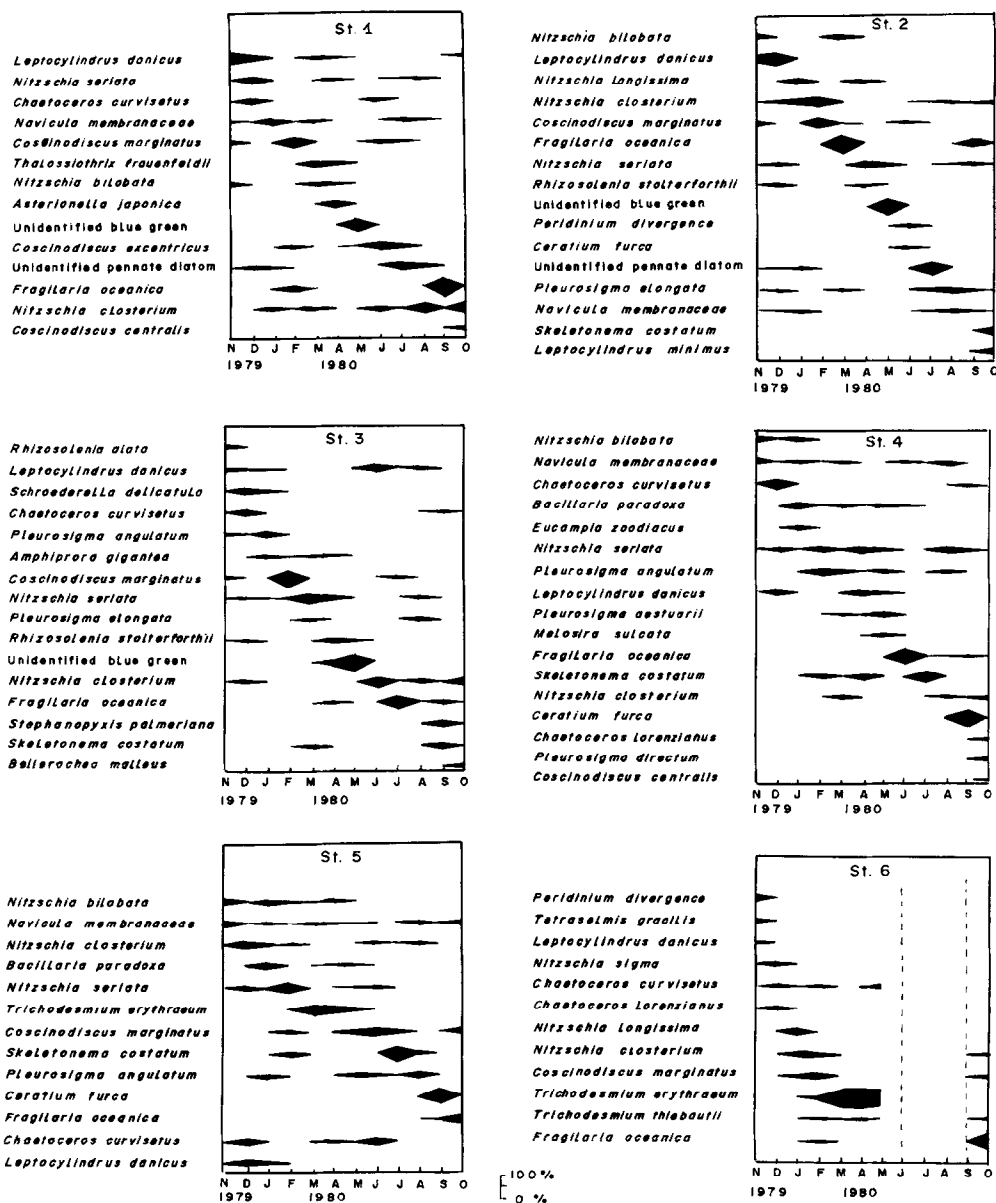
During the premonsoon month of February, the centric diatom *Coscinodiscus marginatus* dominated at stations 1, 2, 3, 5 and 6 and contributed upto 80% of the total phytoplankton at station 3. At station 4, the other important forms were *N. seriata* and *Pleurosigma angulatum*. In the Mandovi estuary and Cumbarjua canal during April and May, the unidentified blue-green alga thrived and accounted for 65% of the phytoplankton crop. During this period a mixed diatom population comprising *L. danicus*, *Pleurosigma aestuarii* and *Melosira sulcata* was encountered at station 4. During March–May, the blue-green alga *T. erythraeum* was very abundant at station 6 and to some extent at station 5. Another blue-green alga *Trichodesmium thiebautii* was also present but in less numbers. With the onset of monsoon, a moderate reduction in salinity was effected as a result of which the high-salinity tolerant forms were immediately replaced by low-salinity tolerant diatoms such as *C. marginatus* at stations 1 and 5. Station 2 was characterized by the presence of two dinoflagellates, *Peridinium divergence* and *C. furca*, and the diatom *C. marginatus*. At station 3, *N. closterium* was the most dominant form, whereas at station 4 it was *F. oceanica* which accounted for approximately 61% of the total crop. During the peak monsoon months, i.e. July and August, an unidentified pennate diatom dominated at stations 1 and 2. At station 3, *F. oceanica* was the dominant form. At stations 4 and 5, the euryhaline form *S. costatum* formed the most important constituent of the phytoplankton crop.

During September a gradual decline in the amount of rainfall resulted in an increase in the salinity regime in the estuaries. The unidentified pennate diatom was succeeded by *F. oceanica* in the following month at station 1. However, at station 3 this form reappeared along with chain-forming diatoms *S. costatum* and *Stephanopyxis palmerianii*. With a gradual increase in salinity, the dinoflagellate *C. furca* proliferated.

During the post-monsoon period, viz. October, *N. closterium* and *Coscinodiscus centralis* replaced *F. oceanica*, whereas at station 3 the unidentified blue-green alga appeared again along with *Bellerochea malleus*. At station 4, the dinoflagellate *C. furca* was completely replaced by *Chaetoceros lorenzianus*, *Pleurosigma directum* and *Coscinodiscus centralis*. At stations 5 and 6, *F. oceanica* was the dominant form.

Cluster analysis

Based on conjoint presence–absence of data, phytoplankton assemblages from representative months during the post-monsoon, pre-monsoon and monsoon periods were clustered



using the Jaccard dissimilarity index, as outlined in Clifford and Stephenson (1975). November was taken as the representative post-monsoon month, April for the pre-monsoon and August for the monsoon. The month of November showed two well-defined clusters: cluster I comprising five subgroups (Figure 4). A conspicuous feature of the cluster analysis is the grouping of dinoflagellates together in cluster II and in sub-group 'a' within cluster I. The remaining sub-groups mainly comprised commonly occurring diatoms.

In April four distinct clusters were observed (Figure 5). In cluster IV an aggregation of the high-salinity tolerant forms, *T. erythraeum* and the unidentified blue green-alga, was

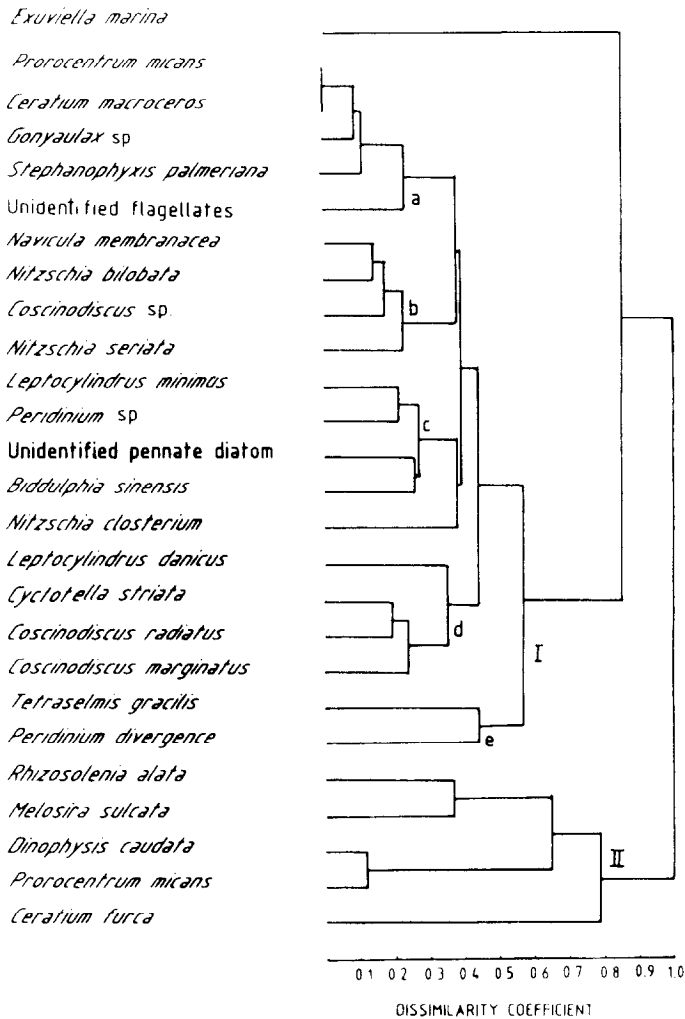


Figure 4. Cluster analysis of the co-occurring phytoplankton groups during November (post-monsoon).

observed. During August two clusters were observed (Figure 6). In cluster I 'b' a distinct aggregation of flagellates was observed.

The association between different stations was studied on the basis of their species composition. Phytoplankton species data from representative months during the post-monsoon (November and December), pre-monsoon (March and April) and monsoon (July and August) were utilized in the analysis. The results are presented in Figure 7.

In November, stations 4 and 5 (situated in the Zuari) showed a great degree of similarity, whereas stations 1 and 2 (situated in the Mandovi) showed close association with station 3 located in the Cumbarjua canal. In December, the coastal waters showed a strong relationship to station 1. At the same time, stations within the Zuari showed a closer relationship to station 3. During March, a similar trend was noticed but with a lesser degree of similarity. In April, stations 3 and 4 were closely associated. The coastal station

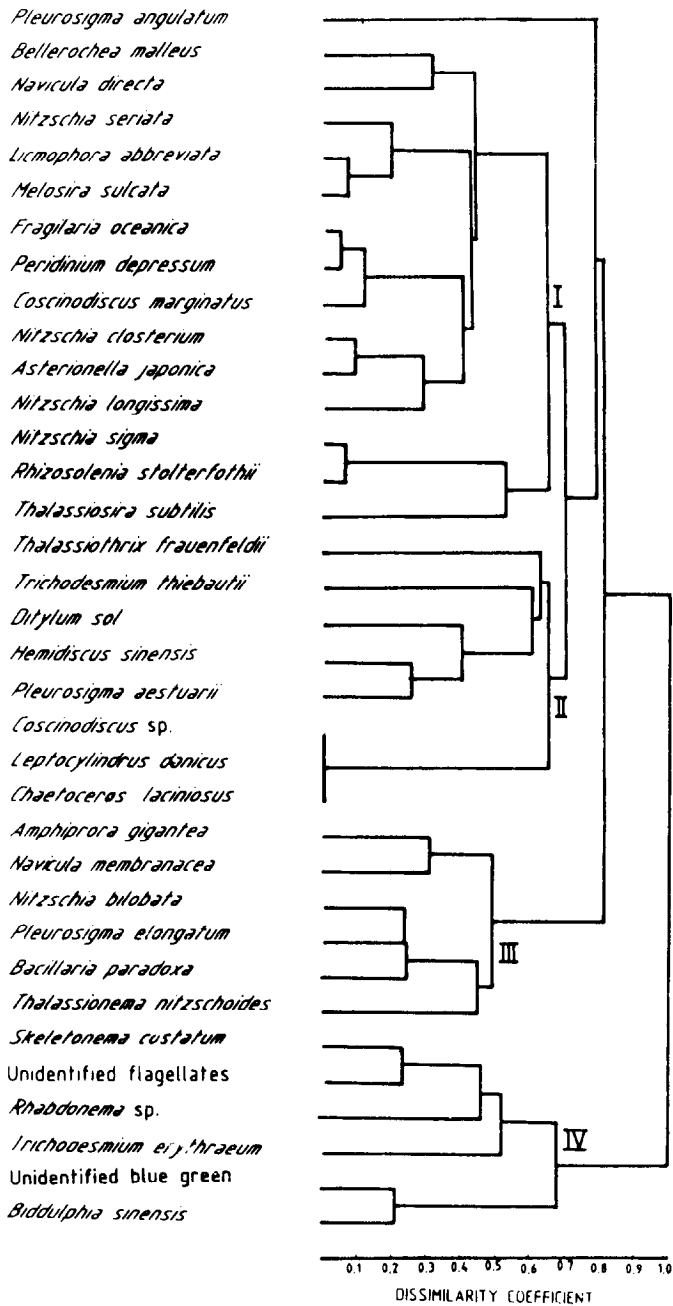


Figure 5. Cluster analysis of the co-occurring phytoplankton groups during April (pre-monsoon).

showed close similarity with stations 1 and 5 during this time. During the monsoon months stations 1 and 2 showed a greater degree of similarity with station 3 situated in the Cumbarjua canal.

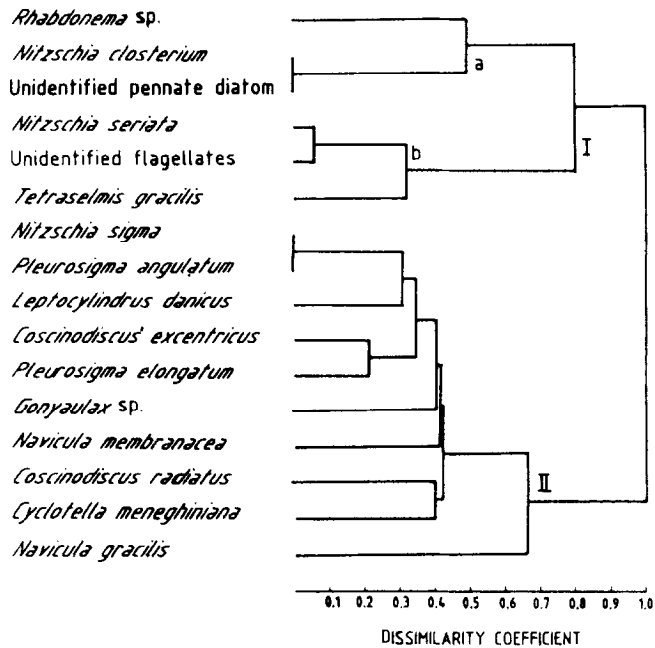


Figure 6. Cluster analysis of the co-occurring phytoplankton groups during August (monsoon).

Discussion

During the course of the present studies, considerable temporal variability in the abundance of different species of phytoplankton at different stations was observed. Surface cell concentrations exhibited wide fluctuations from 4.75 to 1369×10^3 cells l^{-1} , the maximum density occurring during the post-monsoon period. It is evident that this period provided conducive conditions for the proliferation of both diatoms and dinoflagellates. In the Cochin backwater, which is situated on the south-west coast of India, Devassy and Bhattathiri (1974) observed surface densities of phytoplankton varying from 22.2 to 299.7×10^3 cells l^{-1} . In the Vellar estuary on the east coast of India, the maximum surface phytoplankton density was 15×10^3 cells l^{-1} (Santhanam *et al.*, 1975). Thus, as compared to these two estuarine systems, the Mandovi-Zuari estuarine complex sustained a relatively higher phytoplankton population. A conspicuous difference found between the Cochin backwater and the Mandovi-Zuari estuarine complex was the low phytoplankton crop observed in the latter during the peak monsoon months. This depletion in population was mainly due to the heavy freshwater runoff which resulted in flushing of phytoplankton populations. Although this is a feature common to estuarine and backwater environments, in this region the paucity of phytoplankton was a result of the scarcity of freshwater species that would have been expected to replace them as was observed in the Cochin backwater (Devassy & Bhattathiri, 1974).

The Mandovi estuary sustained a higher population as compared to the Cumbarjua canal and the Zuari estuary. A comparison made between the Mandovi, and the Zuari and Cumbarjua canal showed that, most of the time, typical estuarine conditions prevailed in the former. This promoted optimum salinity regimes and conducive conditions for higher phytoplankton production (Devassy, 1983).

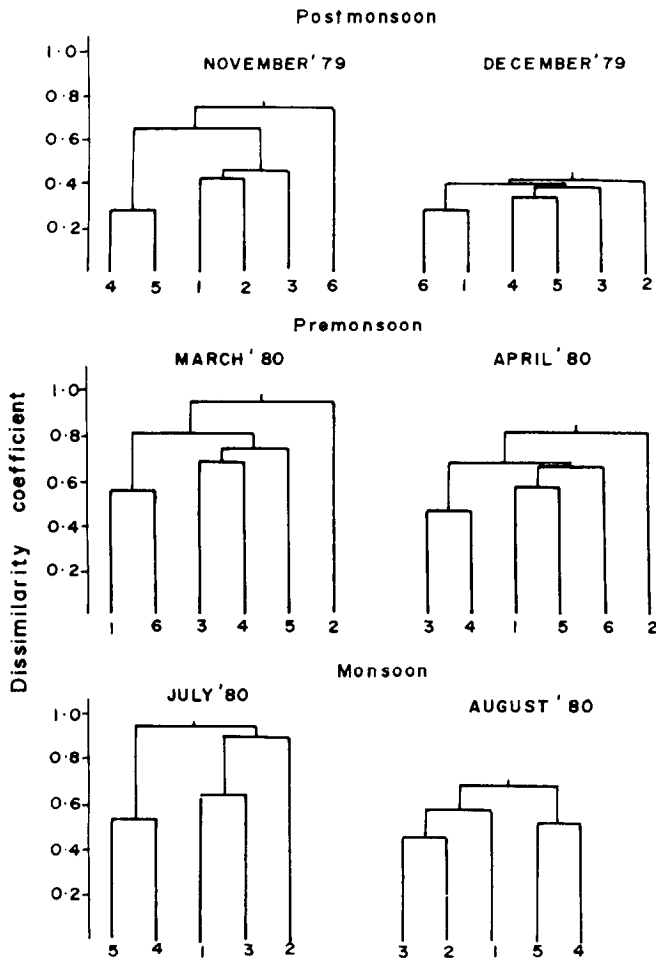


Figure 7. Cluster of stations based on the quantitative phytoplankton data for selected months during the post-monsoon, pre-monsoon and monsoon seasons.

Diatoms formed the most successful group in this estuarine complex and thrived even at very low salinities ($<1\text{‰}$). The diatom *F. oceanica* tolerated a wide range of salinities (2.5–31.5‰). The dinoflagellate *C. furca* formed blooms at salinities between 25.5 and 31.8‰. The unidentified blue-green alga, and *T. erythraeum* preferred high-salinity levels, generally $>32\text{‰}$ for the former and $>34\text{‰}$ for the latter species.

Because of their euryhaline nature, *F. oceanica*, *N. membranaceae* and *N. seriata* were the most frequently occurring forms in these estuaries. In the Cochin backwater, Devassy and Bhattathiri (1974) and Kumaran and Rao (1975) reported that *S. costatum* was the most dominant diatom in the Cochin backwater. In the Mandovi estuary this organism was abundant only during the monsoon season.

It has been amply illustrated that this estuarine system exhibits a wide range of variation in its environmental conditions (Devassy, 1983), which are naturally also reflected in its flora. In the pre-monsoon season, a period of relatively low nutrient concentrations, phytoplankton with low nutrient and higher temperature requirements thrived well.

During this period, the diatoms *F. oceanica*, *C. marginatus*, *N. seriata* and *N. closterium* were dominant. During March and April, *Coscinodiscus marginatus* and the unidentified blue-green alga dominated in succession. In the coastal region, *T. erythraeum* was the most dominant form. Devassy *et al.* (1978) pointed out that this nitrogen fixing form *T. erythraeum* is able to thrive under low nutrient concentrations and occurs on an annual cycle during the pre-monsoon. These massive *Trichodesmium* blooms, as they die and decay, enrich the coastal environment by releasing nutrients. These nutrients are brought to the estuaries as a result of the tidal oscillations. This is probably one of the most important factors controlling the ecological balance of this ecosystem.

With the onset of the monsoon there was a spontaneous boost in phytoplankton production. This trend of enhanced production was triggered by the pre-monsoonal showers during May and continued through June. Based on experimental evidence, Qasim *et al.* (1972) confirmed that, within limits, waters with reduced salinity supported a greater abundance of phytoplankton in the estuaries. Gopinathan (1974) reported the dominance of *S. costatum* which contributed 68.8%, immediately after or following a break in the monsoon in the Cochin backwater. Subrahmanyam (1959) remarked that a fall in temperature from optimum levels (32 to 25 °C), a slight lowering of salinity (35 to 32‰) and a plentiful supply of nutrients during the early monsoon period lead to intense phytoplankton blooms. Thus the reduction in salinity by itself is not a precondition for the formation of phytoplankton blooms, but rather due to the adaptability of certain phytoplankters to moderate changes in salinity brought about by the south-west monsoon showers coupled with a large input of nutrients.

Following heavy rainfall during the later period of June, enormous quantities of freshwater input led to extensive dilution and stratification. As a result of the high turbidity of the water and cloud cover in the monsoon, light penetration in the water column was restricted. Although increased amounts of nutrients were introduced into the system by land runoff, in the absence of favourable conditions during this time, there was no effective utilization of nutrients until September. This resulted in a low phytoplankton crop during this period. Among the dominant forms occurring during this time, the unidentified pennate diatom and *N. closterium* were able to adapt to considerably lower salinity regimes. A few other forms, such as *Pleurosigma elongatum*, *P. angulatum* and *N. membranaceae*, also appeared in substantial numbers. In the Cochin backwater, Gopinathan (1974) reported maximal abundance of phytoplankters during the peak monsoon season. However, most of the forms observed by him during this period were freshwater forms. These species flourished in the greatly lowered salinity and light regimes and benefitted from the abundant nutrients associated with the increased outflow.

Towards the end of the monsoon period, with a gradual increase in salinity and return of favourable conditions, massive blooms of *C. furca* began to appear. The other dominant forms that occurred during this period were *F. oceanica* and *N. closterium*. During the post-monsoon period, a gradual re-population of the estuarine and coastal waters was observed and an increase in light penetration was also exhibited. During this period, the coastal environment tended to reflect the effect of the process of upwelling, *viz.* increased nutrient levels and enhanced plankton production. In contrast, Raymont (1980) remarked that in many tropical rivers, the nutrient concentrations associated with increased outflow of water was hardly substantial enough to sustain the enhanced production of phytoplankton. Heavy land runoff during the monsoon is also known to introduce sizeable quantities of humic substances into the estuarine and coastal environments (Pant *et al.*, 1984). Prakash and Rashid (1968) demonstrated that humic acids added in small quantities to

dinoflagellate cultures had a marked stimulatory effect on growth. In the Mandovi-Zuari estuarine complex these humic substances would have had a strong influence on the succession patterns of phytoplankton, especially on the appearance and predominance of the dinoflagellate *C. furca* in an otherwise diatom-dominated ecosystem. Besides this, diatoms like *F. oceanica*, *N. closterium*, *C. curvisetus*, *L. danicus*, *N. seriata* and *B. paradoxa* occurred successively in abundance. Raymont (1980) observed that succession may be very obvious in areas subject to monsoons. Qasim *et al.* (1972) observed a succession of diatoms in the Cochin backwater and remarked that the right combination of nutrients may lead to succession in the growth of phytoplankton. In this estuarine system, while nutrients were not generally a limiting factor for phytoplankton (Devassy, 1983), the salinity and transparency of the water column were probably the most important factors controlling phytoplankton growth and succession of the majority of species.

Results of the cluster analysis confirmed the observations made above in the distribution of dinoflagellates and blue-green algal forms. There was a clustering of dinoflagellates during the month of November indicating that these forms responded positively to the presence of humic acids in the environment. Again the proliferation of the unidentified blue-green alga and *T. erythraeum* under conditions of high salinity, low nutrient concentrations and high light intensities was reflected in the clusters of the pre-monsoon month of April. The same was true for August where *T. gracilis* appeared along with flagellates. The clustering of the forms *P. angulatum*, *Coscinodiscus excentricus*, *P. elongatum* and *N. membranaceae*, which are basically benthic in origin, was also distinct. During the monsoon these forms would have been easily dislodged from the sediments as a result of river runoff to be observed in abundance in the water column during the rainy season.

As indicated earlier, the Mandovi-Zuari estuarine complex is an area subject to intense tidal fluctuations which strongly influence the flow patterns through both the estuaries and the Cumbarjua canal interconnecting them. With the onset of the monsoon, however, the combined effects of freshwater flow and tidal influences result in a considerable change in the flow patterns of this estuarine complex as is evidenced by the results of the cluster of stations obtained on the basis of their species composition. During November, which marked the beginning of the post-monsoon season, the clustering of stations 1 and 2 with the low salinity waters clearly suggested that the Mandovi estuary was still being subjected to freshwater runoff and less influenced by the high salinity coastal waters. This is supported by the fact that station 6 maintained its separate identity. Das *et al.* (1972) using current meters and data on salinity and suspended load studied the flow characteristics of the Cumbarjua canal. They noted that during the post-monsoon in the Mandovi estuary, there was a larger proportion of freshwater inflow resulting in lower average salinity values as compared to the Zuari. This is in agreement with the observations made during the month of November. Das *et al.* (1972) also noted that, during the ensuing period between the post-monsoon and pre-monsoon periods when freshwater outfall was reduced, there was a rapid rate of increase in the salinity of the Mandovi estuary which could explain the close degree of similarity between all stations during December. A similar trend was noticed in March with a lesser degree of similarity. During the peak monsoon period, the tidal influence on both estuaries was more pronounced. This was evidenced by the close association of the coastal station (6) and stations 1 and 5 located at the proximity of the former station. The close degree of similarity between stations 3 and 4 suggested an influx of waters from the Zuari end into the Cumbarjua canal. Das *et al.* (1972) observed that the tidal energy at the Zuari end of the canal was 77% as compared to 23% at the Mandovi end

which resulted in flow of waters from the Zuari estuary into the canal and its increased influence on it.

A noteworthy feature observed during the monsoon period was the close association of stations 1, 2 and 3. During this time of the year, Das *et al.* (1972) found that there was a larger volume of freshwater storage in the Mandovi accounting for its greatly lowered salinity and closer resemblance to the low salinity waters of the Cumbarjua canal. They also pointed out that, due to the increased freshwater flow, the tidal influence was nullified, resulting in stratification in the uppermost and subsurface layers.

It is clear, therefore, that the Mandovi-Zuari estuarine complex is an interesting ecosystem where the flow patterns extensively influence the assemblages and dispersal of phytoplankton communities. Furthermore, among the several factors affecting phytoplankton distribution, the commencement of the monsoon results in a drastic change in the hydrographic conditions which are instrumental in the complete transformation of the phytoplankton population size and structure.

Acknowledgements

The authors are grateful to the Director, National Institute of Oceanography, Goa for encouragement and to Mr Raghavan for the help in statistical analysis of data.

References

- Clifford, M. T. & Stephenson, W. (eds) 1975 *An Introduction to Numerical Classification*. New York: Academic Press.
- Das, P. K., Murthy, C. S. & Varadachari, V. V. R. 1972 Flow characteristics of Cumbarjua canal connecting the two estuaries Mandovi and Zuari. *Indian Journal of Marine Sciences* **1**, 95–102.
- Devassy, V. P. 1983 Plankton ecology of some estuarine and marine regions of the west coast of India. Ph.D. Thesis, University of Kerala.
- Devassy, V. P. & Bhargava, R. M. S. 1978 Diel changes in phytoplankton populations in the Mandovi and Zuari estuaries of Goa. *Mahasagar—Bulletin of the National Institute of Oceanography* **11**, 195–199.
- Devassy, V. P. & Bhattathiri, P. M. A. 1974 Phytoplankton ecology of the Cochin backwater. *Indian Journal of Marine Sciences* **3**, 46–50.
- Devassy, V. P., Bhattathiri, P. M. A. & Qasim, S. Z. 1978 *Trichodesmium* phenomenon. *Indian Journal of Marine Sciences* **8**, 168–186.
- Gopinathan, C. P. 1974 Seasonal abundance of phytoplankton in the Cochin backwaters. *Journal of the Marine Biological Association of India* **14**, 568–577.
- Kumaran, S. & Rao, T. S. S. 1975 Phytoplankton distribution and abundance in the Cochin backwaters during 1971–72. *Bulletin of the Department of Marine Science, University of Cochin* **7**, 791–799.
- Legendre, L. & Legendre, P. 1978 Associations. In *Phytoplankton Manual* (Sournia, A., ed.). Paris: UNESCO, pp. 261–273.
- National Institute of Oceanography 1981 Master plan for pollution control of the rivers Zuari and Mandovi. *Technical Report 02/79*.
- Pant, A., Matondkar, S. G. P. & Goswami, S. C. 1984 Biomass relations between phytoplankton and zooplankton in Goa waters. *Indian Journal of Marine Sciences* **13**, 116–118.
- Parulekar, A. H., Dhargalkar, V. K. & Singbal, S. Y. S. 1980 Benthic studies in Goa estuaries. Part III. Annual cycle of macrofauna distribution, production and trophic relations. *Indian Journal of Marine Sciences* **9**, 189–200.
- Prakash, A. & Rashid, M. A. 1968 Influence of humic substances on the growth of marine phytoplankton dinoflagellates. *Limnology and Oceanography* **13**, 598–606.
- Qasim, S. Z., Bhattathiri, P. M. A. & Devassy, V. P. 1972 The influence of salinity on the rate of photosynthesis and abundance of some tropical phytoplankton. *Marine Biology* **12**, 200–206.
- Raymont, J. E. G. (ed.) 1980 *Plankton and Productivity in the Oceans. Volume 1. Phytoplankton*, 2nd edition. Oxford: Pergamon Press.
- Santhanam, R., Krishnamurthy, K. & Sundararaj, V. 1975 Quantitative phytoplankton ecology. *Bulletin of the Department of Marine Science, University of Cochin* **7**, 769–779.

- Selvakumar, R. A., Nair, V. R. & Madhupratap, M. 1980 Seasonal variations in secondary production of the Mandovi-Zuari estuarine system of Goa. *Indian Journal of Marine Sciences*, **9**, 27–34.
- Smayda, T. J. 1963 Succession of phytoplankton and the ocean as an holocentric environment. In *Symposium on Marine Microbiology* (Oppenheimer, C. H. ed.). Springfield, Illinois: pp. 260–274.
- Smayda, T. J. 1978 Biogeographical meaning; indicators. In *Phytoplankton Manual*, (Sournia, A., ed.). Paris: UNESCO pp. 225–229.
- Subrahmanyam, R. 1946 A systematic account of the marine plankton diatoms of the Madras coast. *Proceedings of the Indian Academy of Sciences* **24B**, 85–197.
- Subrahmanyam, R. 1959 Studies on the phytoplankton of the west coast of India. Parts I and II. *Proceedings of the Indian Academy of Sciences* **50B**, 113–187.