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Phytoplankton diversity, biomass, and production

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6.1 INTRODUCTION

Phytoplankton, chlorophyll *a* (Chl), and primary productivity (PP) are important determinants of the standing stock and organic productivity of an estuary. These variables have often been utilized to evaluate the overall health of an estuarine ecosystem and in management strategies to ensure sustainable use of the estuaries. Earlier investigations on the three variables in the Mandovi and Zuari estuaries include studies by Devassy and Goes (1988, 1989) and Krishnakumari *et al.* (2002), who proposed a three-season regime in the biology of the estuaries; other authors noted a similar pattern in primary production (Dehadrai and Bhargava 1972; Bhat-tathiri *et al.* 1976; Devassy 1983). More recently, in 2002–2003, field observations were carried out to measure phytoplankton composition, Chl, and PP in the two estuaries to develop an estuarine and coastal zone management plan for Goa. In this chapter, we use these data to describe the spatial and temporal variability of these three variables with the objective of gaining insight into the processes regulating primary productivity in this estuarine ecosystem.

6.2 OBSERVATIONS

Water samples for phytoplankton taxonomy and cell counts, Chl, and rates of PP were collected at stations $M_1, M_2, M_3, M_4, M_5, M_6,$ and M_7 in the Mandovi and $Z_1, Z_2, Z_3, Z_4,$ and Z_5 in the Zuari (Map A). The sampling schedule is shown in table 6.1. The stations covered a 40 km stretch in each estuary. During each set of observations, eight samples at 3-hour intervals were collected during a 24-hour period, thus nearly covering a tidal cycle. The variation among the eight samples provided an estimate of the change seen at a location owing to horizontal movement of water parcels due to the tide. The observations carried out in September 2002 are considered to be representative of conditions at the end of the high runoff of the summer monsoon during June–September. The April–May 2002 observations, on the other hand, are representative of conditions at the end of the dry season from October to May, prior to the onset of the wet season.

For phytoplankton taxonomy and cell counts, 500 ml water samples were fixed with a few drops of Lugol's iodine, preserved in 3% buffered formaldehyde, and then stored in dark and cool conditions until the time of analysis. Prior to microscopic analysis, samples were concentrated to 5–10 ml by siphoning the top layer with a tube covered with a 10 μm Nyltex filter on one end. Sample concentrates were transferred to a 1 ml capacity Sedgwick-Rafter and counted using an Olympus[®] Inverted microscope (Model IX 50) at 200 \times magnification. Phytoplankton cell identifications were based on standard taxonomic keys (Tomas 1997). The results are expressed as numbers of cells l^{-1} .

Chl was measured by filtering 500 ml water samples on to 47 mm glass fibre filters (Whatman[®] GF/F), which were extracted overnight in 10 ml of 90% acetone under cold and dark conditions. Chl concentrations in the extracts were determined with a Turner Designs[®] 10-000R fluorometer (JGOFS 1994). Acidification of the extracts allowed corrections for phaeophytin. The fluorometer was periodically calibrated with a spectrophotometer according to protocols recommended in JGOFS (1994).

Table 6.1 Schedule of observations in the Mandovi and Zuari estuaries.

Nature of tide	Sampling time	
	Mandovi	Zuari
Spring	28 (13:00h) to 29 (22:00h) April 2002	30 (12:00h) April to 1 (22:00h) May 2002
Neap	5 (12:00h) to 6 (22:30) May 2002	7 (11:00h) to 8 (22:00h) May 2002
Spring	5 (10:50h) to 6 (10:00h) September 2002	7 (11:00h) to 8 (10:00h) September 2002

Primary productivity was estimated using the ^{14}C technique under simulated *in situ* conditions (JGOFS 1994). At the end of the incubations in running surface seawater that lasted 24 hours, samples were filtered on to 47 mm, 0.45 micron cellulose nitrate filters, which were then exposed to HCl fumes and then transferred to liquid scintillation vials containing 10 ml of scintillation cocktail. The activity in each vial was determined in a Wallac[®] Scintillation Counter (Model no. 1409). All counts were quench-corrected prior to determinations of PP.

6.3 CHL, PHYTOPLANKTON CELLS, AND PP

Figure 6.1 gives Chl measured during spring, and neap tide measurements of April and May 2002. The two measurements were separated by about a week in each estuary. The figure shows that, except for one or two locations, the variations in Chl over the one-week period were not significant. In general, values of Chl were higher towards the upstream end of the Zuari, whereas the highest values in the Mandovi

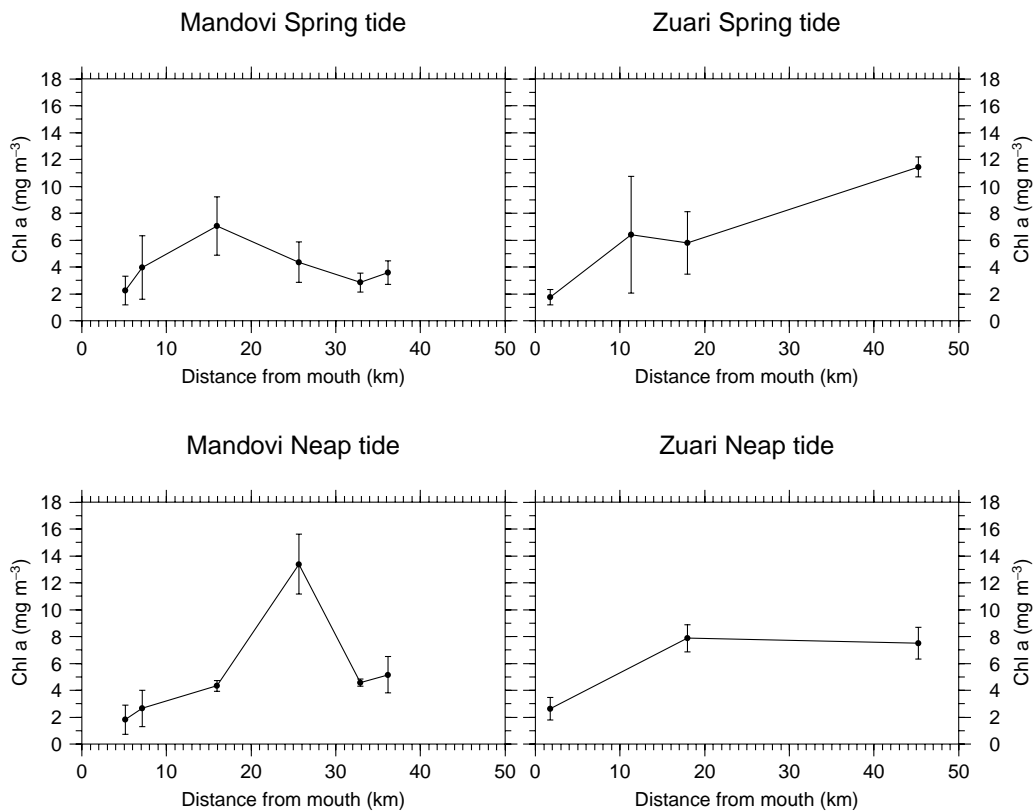


Figure 6.1 Comparison of spring and neap tide phytoplankton biomass in the Mandovi and Zuari estuaries during April–May 2002.

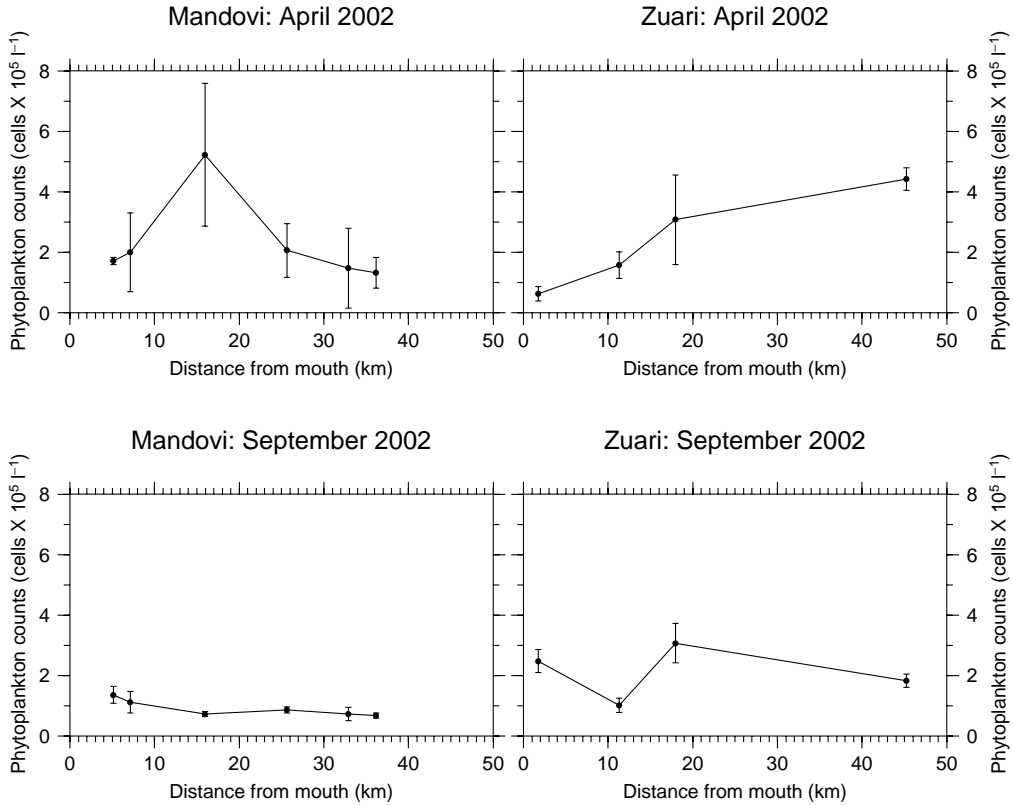


Figure 6.2 Phytoplankton cell counts in the Mandovi (left panels) and Zuari (right panels) during April (top) and September (bottom) 2002.

were in the middle portion at a distance of 15 to 25 km from the mouth. Figure 6.2 gives phytoplankton cells during the spring tide observations of April 2002 and September 2002. The number of cells was generally lower during September than during April.

Taxonomic groups of the phytoplankton identified in the Mandovi and Zuari rivers are presented in tables 6.2 and 6.3. In April, diatoms such as *Nitzschia* spp. and *Synedra* sp. dominated the freshwater zone of the Mandovi (table 6.2a), while *Rhizosolenia* spp. and *Coscinodiscus* spp. were abundant in the high-salinity zone. In the Zuari, the diatoms *Nitzschia* spp. and *Bacteriastrum* sp. were the dominant organisms in the low-salinity region, while *Coscinodiscus* spp. was the important species in the high-salinity region (table 6.2b). In September 2002, *Synedra* sp. and *Nitzschia* sp. prevailed in the freshwater zone, while *Dinophysis* spp. and *Coscinodiscus* spp. were predominant in the high-salinity zone of the Mandovi (table 6.3a). In the Zuari estuary during this time of the year, the freshwater stations were dominated by *Pheodactylum* sp., while the saline stations showed the preponderance of *Biddulphia* sp. and *Rhizosolenia* spp. (table 6.3b).

Table 6.2(a) Dominant phytoplankton species during April 2002 in the Mandovi.

Station nos.	Dominant species		
M ₁	<i>Peridinium</i> sp.	<i>Prorocentrum</i> sp.	<i>Synedra</i> sp.
M ₂	<i>Nitzschia</i> spp.	<i>Melosira</i> sp.	<i>Actinocyclus</i> sp.
M ₃	<i>Nitzschia</i> spp.	<i>Melosira</i> sp.	<i>Synedra</i> sp.
M ₄	<i>Rhizosolenia</i> spp.	<i>Coscinodiscus</i> spp.	<i>Nitzschia</i> spp.
M ₅	<i>Rhizosolenia</i> sp.	<i>Nitzschia</i> sp.	<i>Chaetoceros</i> spp.
M ₆	<i>Rhizosolenia</i> spp.	<i>Coscinodiscus</i> spp.	<i>Chaetoceros</i> spp.
M ₇	<i>Coscinodiscus</i> spp.	<i>Cerataulina</i> sp.	<i>Dinophysis</i> sp.

Table 6.2(b) Dominant phytoplankton species during April 2002 in the Zuari.

Station nos.	Dominant species		
Z ₁	<i>Bacteriastrum</i> sp.	<i>Nitzschia</i> spp.	
Z ₂	<i>Coscinodiscus</i> spp.	<i>Melosira</i> sp.	<i>Nitzschia</i> spp.
Z ₃	<i>Nitzschia</i> spp.	<i>Thalassionema</i> sp.	<i>Rhizosolenia</i> sp.
Z ₄	<i>Nitzschia</i> spp.	<i>Isthmia</i> sp.	<i>Coscinodiscus</i> sp.
Z ₅	<i>Coscinodiscus</i> spp.	<i>Ceratulina</i> sp.	<i>Nitzschia</i> spp.

Table 6.3(a) Dominant phytoplankton species during September 2002 in the Mandovi.

Station nos.	Dominant species		
M ₁	<i>Synedra</i> sp.	<i>Enotia</i> sp.	<i>Nitzschia</i> spp.
M ₂	<i>Nitzschia</i> spp.	<i>Navicula</i> spp.	<i>Synedra</i> sp.
M ₃	<i>Synedra</i> sp.	<i>Nitzschia</i> spp.	<i>Dinophysis</i> sp.
M ₄	<i>Thalassiosira</i> sp.	<i>Dinophysis</i> sp.	<i>Synedra</i> sp.
M ₅	<i>Thalassiosira</i> sp.	<i>Dinophysis</i> sp.	<i>Nitzschia</i> spp.
M ₆	<i>Dinophysis</i> sp.	<i>Nitzschia</i> spp.	<i>Peridinium</i> sp.
M ₇	<i>Coscinodiscus</i> spp.	<i>Rhizosolenia</i> spp.	<i>Nitzschia</i> spp.

Table 6.3(b) Dominant phytoplankton species during September 2002 in the Zuari.

Station nos.	Dominant species		
Z ₁	<i>Phaeodactylum</i> sp.	<i>Distephanus</i> sp.	<i>Navicula</i> spp.
Z ₂	<i>Phaeodactylum</i> sp.	<i>Nitzschia</i> spp.	<i>Peridinium</i> sp.
Z ₃	<i>Planktoniella</i> sp.	<i>Coscinodiscus</i> sp.	<i>Phaeodactylum</i> sp.
Z ₄	<i>Biddulphia</i> sp.	<i>Nitzschia</i> spp.	<i>Thalassiosira</i> sp.
Z ₅	<i>Rhizosolenia</i> spp.	<i>Chaetoceros</i> spp.	<i>Ceratulina</i> sp.

Table 6.4(a) Diversity index during April 2002 in the Mandovi. In the table the samples that were collected at the beginning of the 24-hour period of observations are shown in the column named "0 hours". The next sets of samples were collected 6, 12, and 18 hours later and are identified accordingly.

Station nos.	0h	6h	12h	18h
M ₁	2.8	–	–	–
M ₂	1.7	2.3	3.4	1.7
M ₃	2.5	2.5	2.2	3.0
M ₄	3.3	3.1	–	2.5
M ₅	2.5	2.1	2.1	2.2
M ₆	3.2	2.6	2.5	2.1
M ₇	3.2	3.0	2.8	2.2

Table 6.4(b) Same as table 6.4(a), but for September 2002.

Station nos.	0h	6h	12h	18h
M ₁	1.08	–	–	–
M ₂	1.5	2.1	2.1	1.5
M ₃	1.4	2.3	2.1	–
M ₄	2.8	2.8	2.8	2.8
M ₅	2.8	2.7	2.9	2.4
M ₆	3.2	2.7	2.3	3.3
M ₇	3.4	3.2	3.0	3.3

Diversity indices, which give a measure of phytoplankton species diversity during a 24-hour period of observation, are presented in tables 6.4 and 6.5. Although the overall range of values did not vary appreciably between the two rivers, subtle differences were observed between the two. In the Mandovi, for instance (table 6.4a),

Table 6.5(a) Diversity index during April 2002 in the Zuari. In the table, the samples that were collected at the beginning of the 24-hour period of observations are shown in the column named "0 hours". The next sets of samples were collected 6, 12, and 18 hours later and are identified accordingly.

Station nos.	0h	6h	12h	18h
Z ₁	0.92	–	–	–
Z ₂	1.82	1.69	1.72	1.96
Z ₃	1.53	1.73	1.95	1.95
Z ₄	2.61	2.61	2.34	2.14
Z ₅	2.24	3.25	2.24	2.25

Table 6.5(b) Same as table 6.5(a), but for September 2002.

Station nos.	0h	6h	12h	18h
Z ₁	2.03	–	–	–
Z ₂	1.18	1.48	1.27	3.03
Z ₃	2.74	2.52	2.30	2.87
Z ₄	3.15	2.72	2.50	–
Z ₅	3.24	3.48	2.95	3.08

*– indicates samples not collected.

a low diversity index of 1.7 at station M₂ in April 2002 was the result of a *Nitzschia* bloom in the freshwater zone. However, at all other stations, a diversity index > 2 was observed, indicative of the diverse nature of phytoplankton in April 2002. During September, phytoplankton populations at stations M₁, M₂, and M₃ were characterized by a low diversity index (< 2.0). These three stations supported blooms of *Synedra* sp. and *Nitzschia* spp. During April, the low value of 0.92 in the Zuari was due to the dominance of *Bacteriastrum* sp. and *Nitzschia* spp. at St. Z₁ (table 6.5a). The low diversity index at Z₂ in September was due to *Coscinodiscus* spp. and *Melosira* sp. blooms (table 6.5b).

Cluster analysis of phytoplankton species data based on similarity indices for the Mandovi and the Zuari are given in figure 6.3 for the samples collected during April 2002 and in figure 6.4 for the samples collected during September 2002. The figures show that *Nitzschia* spp., *Melosira* sp., and *Synedra* sp. form a cluster with a preference for low-salinity water, while *Coscinodiscus* spp. and *Rhizosolenia* spp. formed another cluster in higher-salinity areas. In the Zuari, in April, *Coscinodiscus* spp. and *Nitzschia* spp. formed a separate cluster indicating their growth preference for the low-salinity zone, whereas the cluster of *Rhizosolenia* spp. and *Thalassiosira* sp. reflected their preference for the saline region. In September, when the salinity in

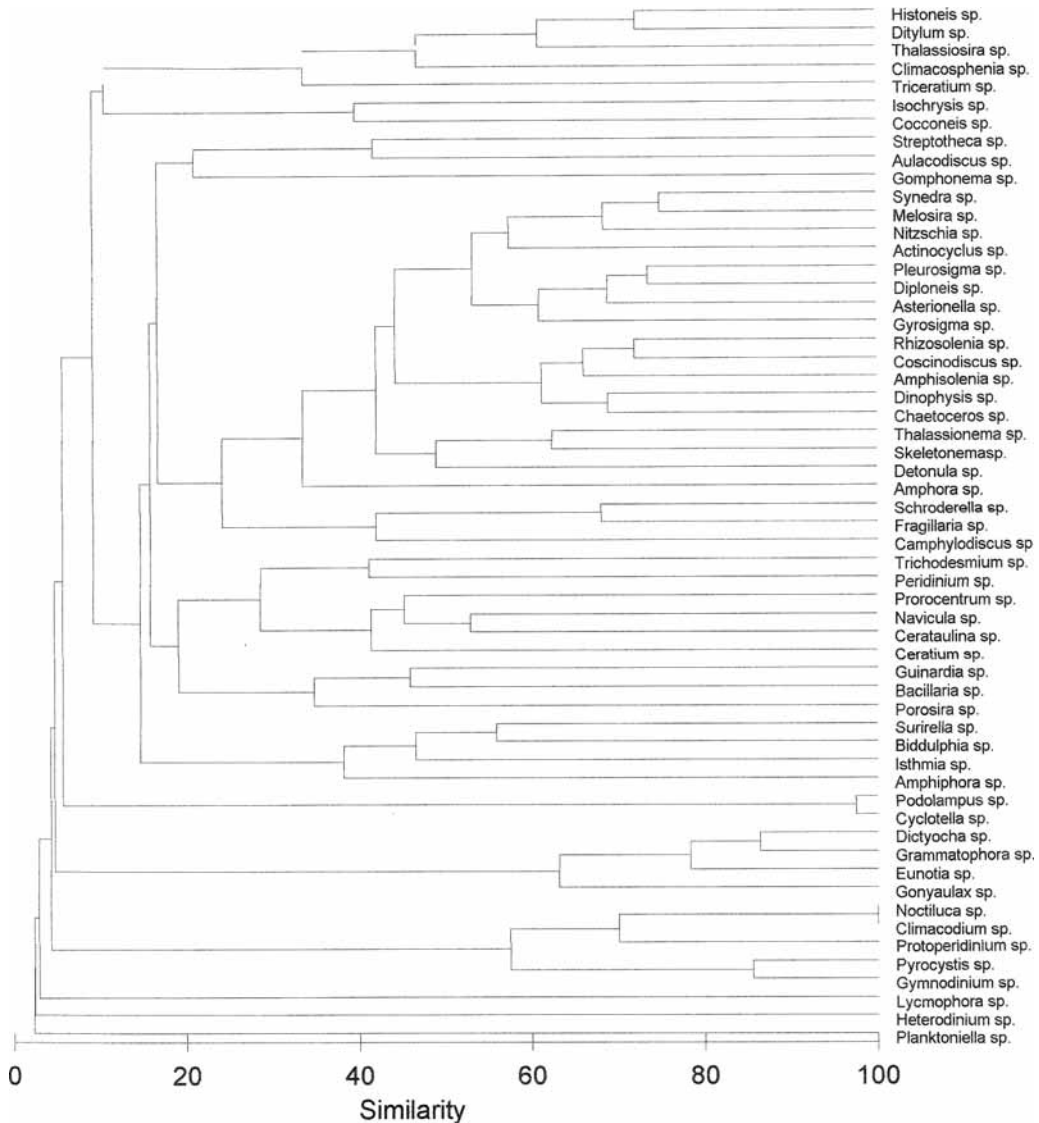


Figure 6.3(a) Phytoplankton similarity index for the Mandovi estuary during April–May 2002.

the Mandovi was low, *Synedra* sp., *Nitzschia* spp., and *Dinophysis* sp. formed a single cluster, reflecting their preference for low salinities (figure 6.4a). In contrast, the cluster of *Coscinodiscus* spp., *Gymnodinium* sp., and *Rhizosolenia* spp. was due to their preference for higher-salinity waters that were present at the mouth of the Mandovi (figure 6.4a). In the Zuari, in September, *Phaeodactylum* sp. and *Distephanus* sp. formed a separate cluster due to their preference for low-saline waters (figure 6.4b). In contrast, the close association between *Rhizosolenia* spp. and *Chaetoceros* spp. was related to their preference for higher salinity.

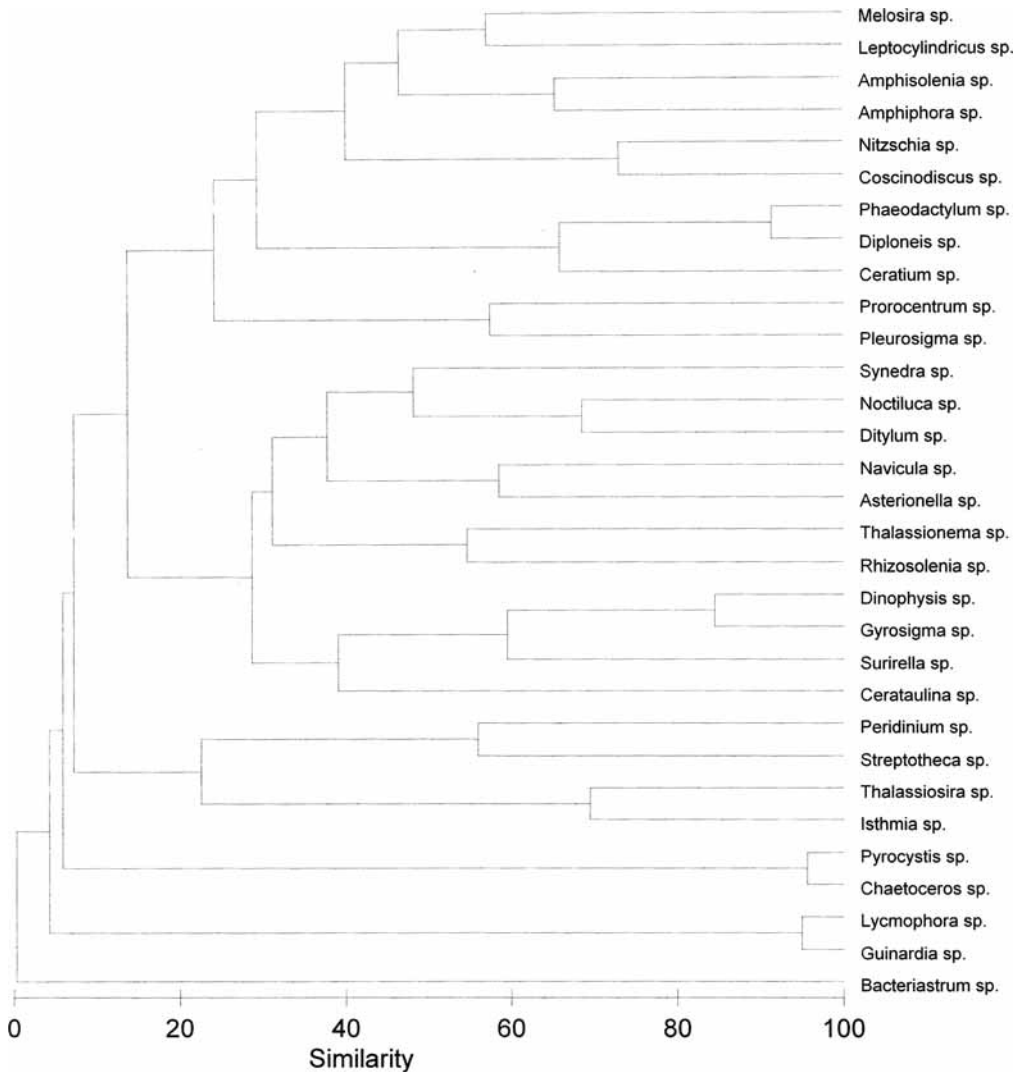


Figure 6.3(b) Phytoplankton similarity index for the Zuari estuary during April–May 2002.

Variations in Chl in each of the rivers closely resembled the variations of phytoplankton cell counts (figure 6.5). Chl concentrations were clearly higher in both the Mandovi and Zuari during April than in September. In April, Chl concentrations varied from 2.24 to 7.05 mgm^{-3} in the Mandovi and from 1.74 to 11.44 mgm^{-3} in the Zuari. During September, Chl *a* in Mandovi varied over a low and narrow range of 0.09 to 1.25 mgm^{-3} and from 1.72 to 3.97 mgm^{-3} in the Zuari. Chl concentrations were $< 2 \text{mgm}^{-3}$ at stations closer to the mouth. A noteworthy feature in the observations was that Chl concentration in the Zuari during April 2002 was highest in the low-saline waters near the upstream end. This was different from

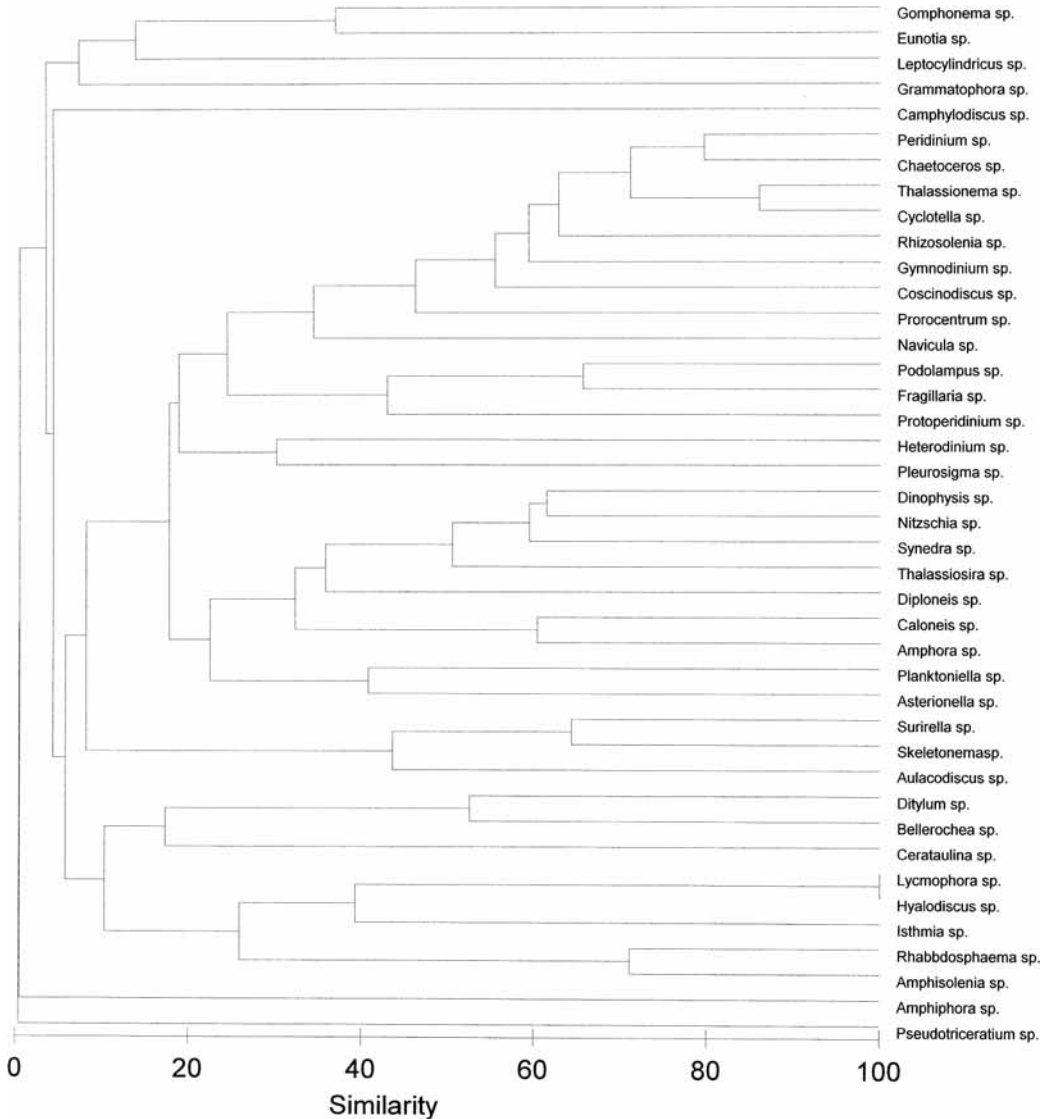


Figure 6.4(a) Phytoplankton similarity index for the Mandovi estuary during September 2002.

the conditions in the Mandovi, where Chl was generally higher in euryhaline (10 to 30 psu) waters, as can be seen in figure 6.5. In the Zuari, Chl increased from mouth to head during April–May 2002, leading to a gradient along the length of the estuary. By September 2002, however, the gradient no more existed (figure 6.5). Unlike the distribution of concentration of Chl, rates of PP in September 2002 did not differ significantly from those in April 2002 (figure 6.6). Variation in the rates of PP over a tidal cycle during September was small, implying that the spatial gradient in PP along the two estuaries was weak at this time.

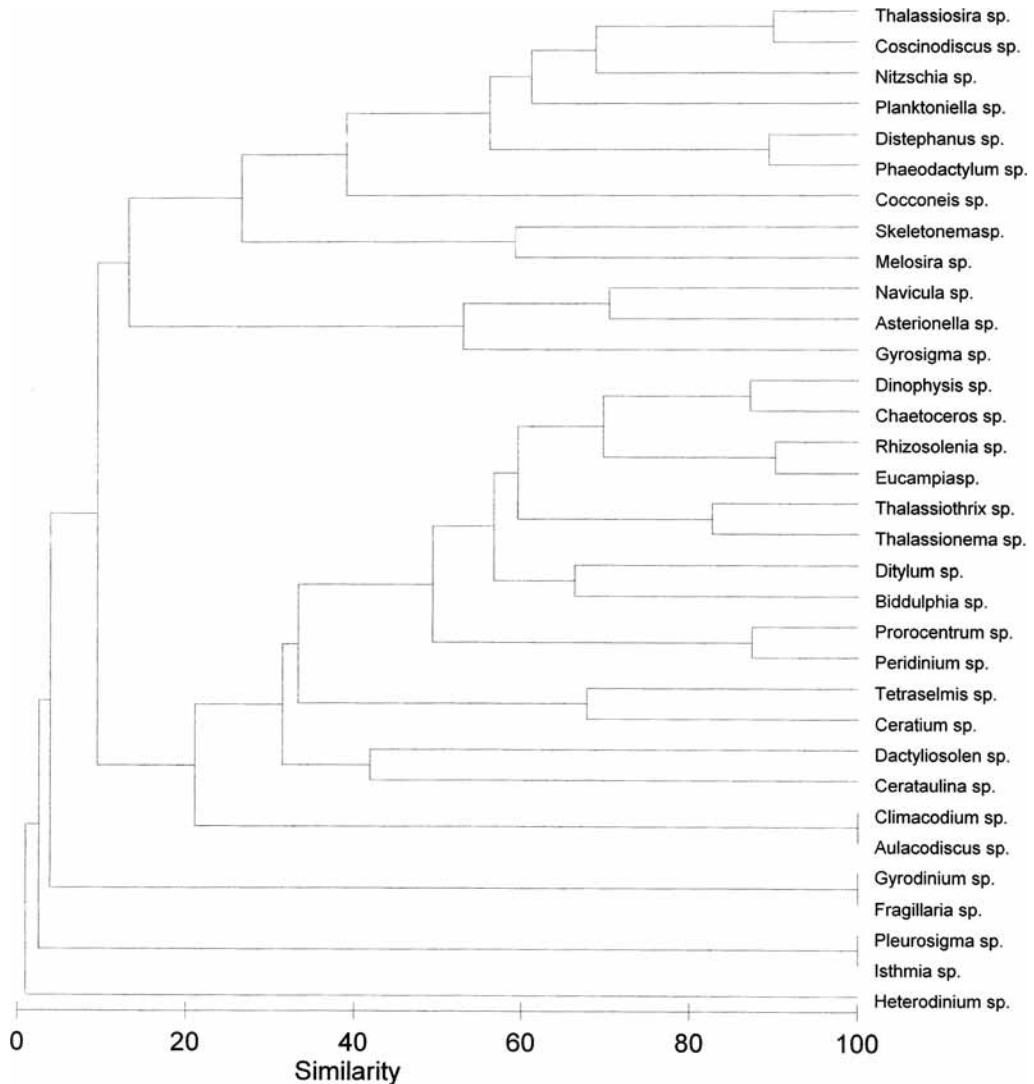


Figure 6.4(b) Phytoplankton similarity index for the Zuari estuary during September 2002.

6.4 DISCUSSION

Phytoplankton counts in both estuaries were higher in April than in September at the end of the monsoon, when both the estuaries are flushed many times over. As a result of this freshwater flushing and changes in salinity, the two rivers experience the most dramatic changes in phytoplankton species composition, as is evident from the taxonomic data. Phytoplankton counts in the Mandovi during September ranged from $0.68\text{--}1.36 \times 10^5 \text{ cells l}^{-1}$; the range of cell numbers was much larger

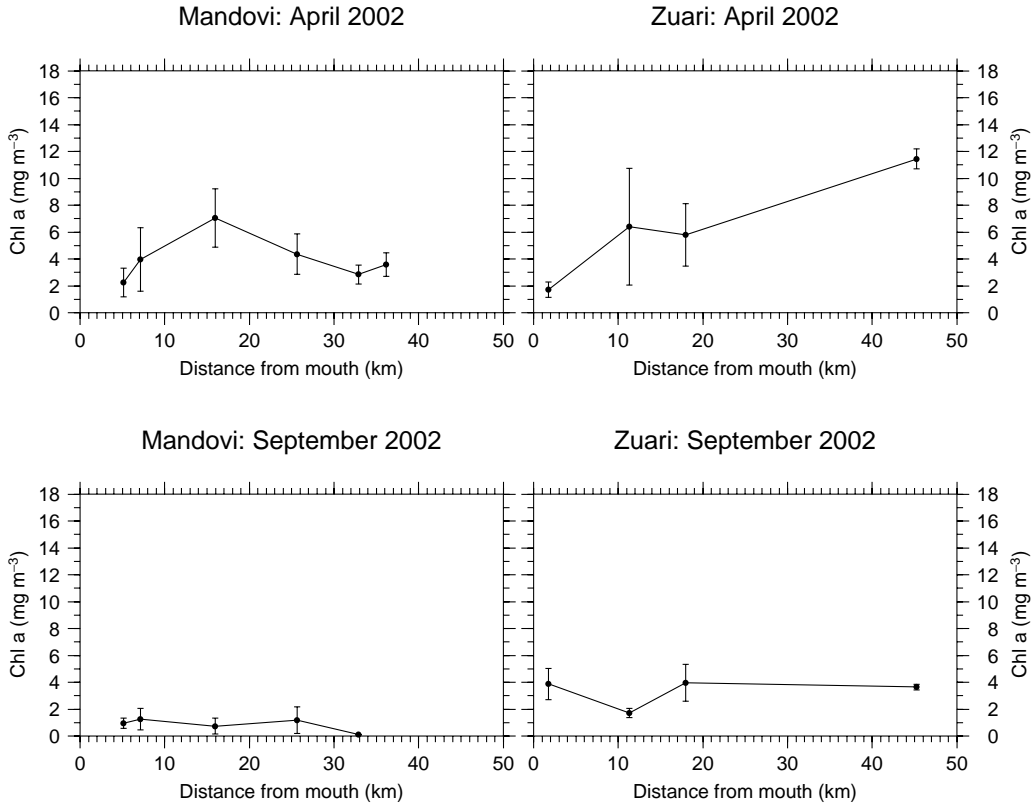


Figure 6.5 Chlorophyll *a* concentration in the Mandovi (left panels) and Zuari (right panels) during April (top) and September (bottom) 2002.

in the Zuari ($1.02\text{--}3.07 \times 10^5 \text{ cells l}^{-1}$), suggesting that the phytoplankton species in the Zuari were more amenable to freshwater as compared to those in the Mandovi. The presence of a prominent community of freshwater phytoplankton was evident from the high Chl values associated with low-salinity waters in the Zuari. These data also revealed a distinct population of euryhaline phytoplankton in the Mandovi, whose biomass was higher by a factor of two in comparison to the euryhaline population in the Zuari. These features are evident in figure 6.7, which gives the distribution of phytoplankton biomass with salinity in the Mandovi and Zuari. In addition, the rates of PP, normalized to unit biomass of phytoplankton, revealed that phytoplankton communities present in the Zuari were photosynthetically more efficient at low salinities than the populations from the Mandovi (figure 6.8). The existence of physiological differences between phytoplankton populations of the Mandovi and the Zuari is important because it suggests that no similarities should be assumed in the biological characteristics of two estuarine ecosystems merely because of geographical proximity.

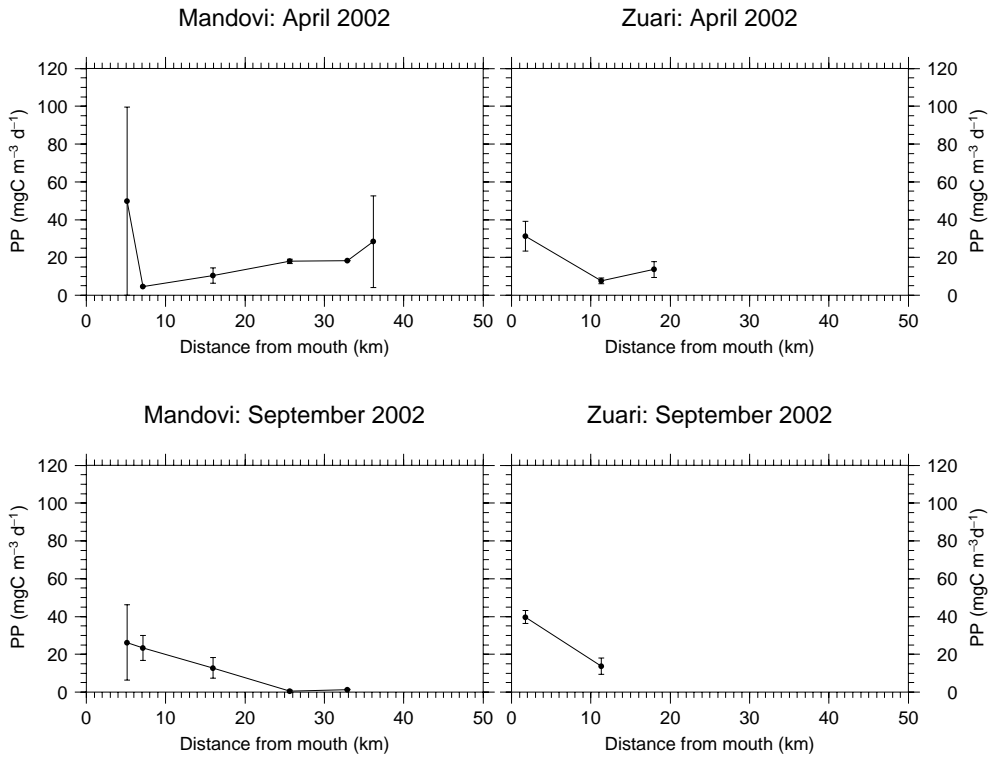


Figure 6.6 Primary productivity in the Mandovi (left panels) and Zuari (right panels) estuaries during April (top) and September (bottom) 2002.

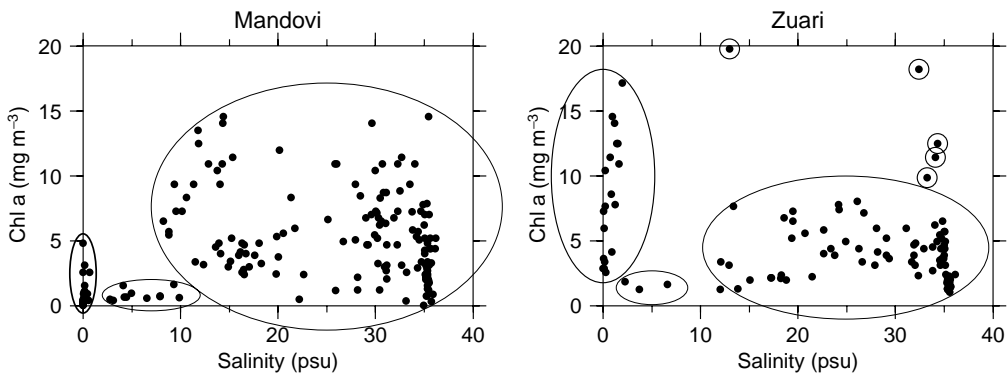


Figure 6.7 Distribution of chlorophyll in relation to salinity. Data plotted are from all the observations that are listed in table 6.1. Points encircled are outliers.

The presence of freshwater-tolerant phytoplankton allows the Zuari to remain more productive upstream, possibly for a greater part of the year. This could make it a net exporter of organic material downstream and perhaps into the coastal waters. By and large, the Mandovi was dominated by a euryhaline population whose

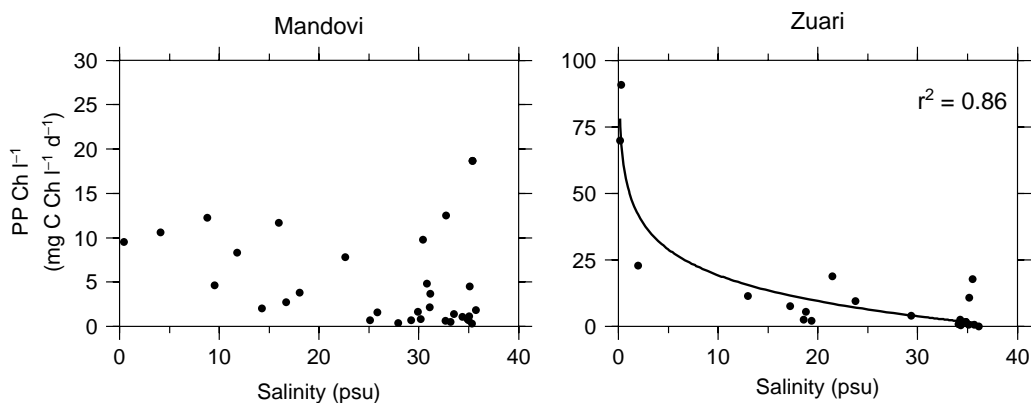


Figure 6.8 Comparison of Chl normalized PP in relation to salinity for the Mandovi (left) and Zuari (right). Data plotted are from all three phases of this study. The curve fitted to the scatter plot for the Zuari and the correlation coefficient shown in the top right corner of the panel indicates the statistical significance of the relationship between the two variables for the Zuari estuary. No such statistically significant relation was apparent between these two variables for the Mandovi estuary.

biomass in both phases of our study was almost twice that of the Zuari. There is evidence from both controlled laboratory experiments (Qasim 1977) and field observations (Devassy and Goes 1989), that coastal tropical marine phytoplankton species are capable of growing at faster rates when transferred to waters with slightly reduced salinity. The adaptability of tropical coastal phytoplankton to salinity reductions corresponding to conditions brought about by tidal mixing and river outflow could explain the higher biomass and production rates midway upstream into the Mandovi. This, together with close similarity to phytoplankton communities at the mouth of the estuary and upstream, could imply that Mandovi is a net importer of organic material.

It may be noted that the cell numbers observed during the present work are much higher than those reported from both the Mandovi and Zuari by Devassy and Goes (1988, 1989). This, however, may simply be attributed to the frequency of sampling, which, in the present study, was much higher than the single monthly samples undertaken by Devassy and Goes (1988, 1989). The phytoplankton species observed during the present work and their diversity in both the Mandovi and Zuari rivers also represent a change from the observations of Devassy (1983) and of Devassy and Goes (1989). The diversity indices of 0.96 during April and of 1.1 to 1.7 during September noted by Devassy and Goes (1989) are much lower than the values observed by us for both the Mandovi and Zuari. Although differences in frequency of sampling between the present study and the studies of Devassy and Goes (1989) could be a factor in the discrepancy of the diversity indices, it is possible that the large presence of *Trichodesmium erythraeum* in April and the blooms of *Fragillaria oceanica* and *Ceratium furca* in September could have contributed to

the lower diversity indices observed by Devassy and Goes (1989). In the present study, we did not observe these species in large numbers.

With growth and turnover rates of less than a day, phytoplankton are very sensitive to changes in the environment, and large variations in phytoplankton species composition are often a reflection of significant alteration in ambient conditions within an ecosystem. This study, undertaken more than a decade after the seminal studies of Devassy and Goes (1988, 1989) and others, indicates that phytoplankton characteristics of the Mandovi and Zuari could be changing. More detailed and systematic investigations of natural and anthropogenic variables that are contributing to changes in phytoplankton physiology and growth are required. Assessing changes in land-use patterns, influx of fertilizers from agricultural runoff, sewage intrusions, etc., in relation to phytoplankton standing stocks and productivity over the years will certainly provide vital information on the health of this estuarine ecosystem. This information will be critical for planning and management strategies required for ensuring sustainable use of the two estuaries. Our study also emphasizes that it may be difficult to extrapolate the findings from a single estuary to other estuaries along the west coast of India in spite of their geographical proximity and similarity in physical features.

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