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Eutrophication induced changes in benthic community structure of a flow-restricted tropical estuary (Cochin backwaters), India

*[a]Martin G. D., [a]Nisha P. A., [a]Balachandran K. K., [a]Madhu N. V., [a]Nair M., [a]Shaiju P., [a]Joseph T., [a]Srinivas K., [b]Gupta, G. V. M.

[a]National Institute of Oceanography, Regional Center, P.B.No 1913, Cochin- 682018, India

[b]Integrated Coastal and Marine Area Management-Project Directorate, Ministry of Earth Sciences, NIOT campus, Chennai - 601032, India

*Corresponding author:martinnio@gmail.com (Martin G.D)

Phone: +914842390814

Fax: +914842390618

Abstract

The influence of anthropogenic loading on the distribution of soft bottom benthic organisms of a tropical estuary (Cochin backwaters) was examined. The industrial activities were found to be high in the northern and central part of the estuary, where dissolved inorganic nitrogen (DIN > 210 µM) and phosphorus (DIP > 6.5 µM) have caused high abundance of chlorophyll '*a*' (up to 73 mgm^{-3}) and accumulation of organic carbon in sediments (up to 5%). Principal component analysis distinguished 3 zones in the estuary. The central zone (Z1) was characterized by organic enrichment, low species diversity and increased pollution tolerant species. The deterioration of the estuary is indicated by an increase in the nutrients and chlorophyll levels by 6-fold during the last few decades. Flow restrictions in the lower estuary have lead to a 4-fold increase in sediment organic carbon over the period of three decades. The changes have caused a reduction in the benthic diversity followed by an invasion of opportunistic polychaetes (*Capitella capitata*), indicating a stress in the estuary.

Key words: Eutrophication, nutrient enhancement, anthropogenic loads, macrobenthos, pollution assessment, Cochin estuary.

1. **Introduction**

Globally, coastal and estuarine waters are influenced by eutrophication due to excess supply of nutrients from industrial and domestic activities (Barmawidjaja et al. 1995; Tsujimoto et al. 2006). Intensive algal production can bring about the internal organic loading, which are capable of inducing heterotrophic conditions and severe oxygen depletion in the downstream sectors (Ganier et al. 1999). Moreover, this can accelerate the productivity cycles and may even alter the trophic composition (Cardoso et al. 2004).

The impact of eutrophication on benthic community are difficult to identify when correlation occur between environmental variants such as salinity, temperature, eutrophication and hypoxia (Gustafsson and Nordberg 1999; Tsujimoto et al. 2006), sediment texture and organic carbon (Ganesh and Raman 2007). Hence, an evaluation of sedentary organisms such as benthos is essential in assessing the environmental quality of a region, as they are exposed to potential toxicants (Pocklington and Wells 1992; Gorostiaga and Diez 1996).

Cochin backwaters (also known as Vembanad Lake), constitutes one of the largest wetlands (256 km^2) along the west coast of India (Fig. 1). The backwaters sustained rich bio-resources in the pristine condition, but has undergone ecological degradation due to increased industrialisation and urbanisation (Arun 1998; Menon et al. 2000). The wetlands area has reduced from 365 km^2 in the beginning of the 19th centaury to 256 km^2 due to large-scale reclamations (Gopalan et al. 1983). Anthropogenic activities increased from the mid 70's are generating 104 x 10^3 m^3 of industrial and 260 m^3 of domestic wastes per day, which are being released directly into the estuary without treatment (Balachandran et al. 2006; Martin et al. 2008). Several incidences of fish mortality are reported in the estuary due to indiscriminate discharges (Venugopal et al. 1980; Bijoy and Aziz 1995; Naqvi et al. 1998). In this article, we examine the impact of anthropogenic loadings on the macrobenthic communities of the Cochin backwaters.

2. **Materials and Methods**

2.1 Study area

Cochin backwaters form a complex micro tidal estuary receiving 2 x 10^{10} m^3y^{-1} of fresh water through six rivers (Srinivas et al. 2003). The annual rainfall of the region is around 320 cm, of which, nearly 60% occurs during the summer monsoon (June-September). During premonsoon (February-May), the increased tidal activity and the topography reduce flushing characteristics of the estuary considerably (Balachandran et al. 2006).

2.2 Sampling and analysis

Water and sediment samples were collected from 56 stations covering the entire estuary during April 2005 (Fig.1). Water samples were collected from 1 m depth using 5 L Niskin sampler (Hydrobios), kept in ice, brought to the laboratory and analyzed within six hours of sampling. Diurnal observations (at 2 hr interval) were additionally carried out at four different regions in the estuary (A, B, C, D) simultaneously during the same period. Station A was in the northern part of the estuary situated between two tidal inlets (Cochin and Azhikode). Station B represented the northeast estuary receiving industrial effluents through the River Periyar. Station C was in the central part of estuary and D in the southern part of estuary. For all the diurnal observations, water samples were collected from 0.5 m below the surface, mid depth and 0.5 m above the bottom at every 2 h interval. The samples for dissolved oxygen were fixed onboard and later analyzed according to Winkler's method (Grasshoff et al. 1983). Salinity was measured using precalibrated salinometer (Digi Auto3G, accuracy ± 0.001). Water samples were filtered and analyzed for various nutrients using a spectrophotometer (Shimadzu 1650PC) following standard procedures (Grasshoff et al. 1983). Another 500 ml sample was passed through Whatman GF/F filter paper (pore size 0.7 µm), the retained chlorophyll *a* was extracted in 90% acetone in dark for 24 hrs and the extinction was measured using spectrophotometer (Strickland and Parsons 1972). The pH was measured using an ELICO LI610 pH meter (accuracy ± 0.01). Sediments were collected (in duplicate) from all the 56 stations using a van Veen Grab (0.48 m^2) and a portion was kept frozen till analysis of texture, carbon and nitrogen. The sediment collected was sieved through 0.5 mm mesh and the organisms retained were preserved in 5 % Rose Bengal stained formalin. Later, the fauna were microscopically identified to the lowest taxonomic (species) level using standard references. The benthos abundance ($ind.m^{-2}$) and their biomass (shell on wet weight in $g.m^{-2}$) were also calculated. In the laboratory, the frozen sediment was dried and subjected to textural analysis following the method of Krumbein and Pettijohn (1938). For the estimation of organic carbon, the freeze–dried, powdered, sieved and homogenized sediment was acidified (50 % HCl) and warmed to remove carbonates. The organic carbon and nitrogen contents of the samples were estimated (in duplicate) in Elemental Analyser (Thermo Finningan, Flash EA1112) using L-Cystine as standard. The precision of the analysis checked against standard reference material (NIST 1941B), was found to be 0.4 ± 0.1 % for C and 0.5 ±0.2 % for N.

2.3. Statistical analysis

Species diversity is a concise expression of how individuals of a species are distributed in subsets of groups. Diversity decreases when one or a few groups dominate in a community, when individuals of a more common group replace those of a rare group or when one or a few groups rapidly multiply. Hence, species diversity can be used as a mathematical tool to compare changes in a community based on the surrounding environment. The benthic assemblages are designated according to the “determining species” to test species diversity (H’) using univariate methods. In the present study, the species diversity was estimated according to the Shannon-Wiener index as, H’ (S) = $\sum [P_i (\log_2 P_i)]$ where, S is the number of species and P_i is the proportion of the sample belonging to i^{th} species. The environmental data and sediment data were separately subjected to principal component analysis (PCA) using PRIMER 5.1 (Clarke and Gorley 2001).

3. **Results**

3. 1 General hydrography

The hydrography was generally indicative of premonsoon, where the waters was warm (33 ± 2°C) and saline (up to 32). The salinity in northeastern estuary (2.29) was lower than that of the south (8.9) estuary (Fig. 2a). The diurnal salinity variation (Fig. 2c) was marginal at stations A (15 ± 0.5) and D (12 ± 0.5), but was significant at stations B (8 ± 4) and C (23 ± 7). The pH (7.35 ± 0.97) showed a similar trend with relatively high values in the central and northeastern region (Fig. 2a). The water column was slightly under saturated in the central and northeastern estuary (< 60%), but remained saturated in the southern estuary (Fig. 2a).

3.2 Distribution of nutrients and chlorophyll a

Nutrients found to be high in the central and northeastern estuary. NH_4-N always contributed 60-80% of the DIN pool where it is high in the northern estuary (up to 108 µM) and it was low (< 10 µM) in the southern estuary (Fig. 2a). NO_3 – N was mainly through the river discharge (Fig. 2a &c). The northeast and central estuary (Stn. B & C) recorded high amount of DIN during ebb tide (21-210 µM), whereas these were observed during intermediate tides in northern (Stn. A 17-80 µM) and southern (D 7-165 µM) estuaries (Fig. 2c). Dissolved inorganic phosphorus (DIP) increased along the salinity gradient (Fig. 2a) with high values (up to 4.37 µM) in the central estuary. The northeast (B) and central estuary (C) consistently showed high DIP irrespective of tides (Fig. 2a&c) but it is found to be low in the northern (A) and southern estuary. Dissolved silicate (DSi) varied inversely with salinity (Fig. 2a), and the north and central estuary exhibited moderate values (14-86 µM). Chlorophyll *a* biomass closely followed the nutrient concentration and showed wide variability (5-49 $mg.m^{-3}$) in the central and northern estuary (Fig. 2 a&c) but high chlorophyll was observed in the north estuary. Times series measurements showed high variability of chlorophyll *a* in the northern stations A and B (3.2-29.9 mg.m^{-3}, 3.1-73.7 mg.m^{-3}) and central estuary C (2.1-36.3 mg.m^{-3}), but in the southern region, it was low D (6.4-11.7 mg.m^{-3}).

3.3. Sediment texture, organic carbon & macrobenthos distribution

The predominant textural classes were clayey silt in north estuary, silty clay in central estuary and silty sand in south estuary (Fig. 2b). The sediment organic carbon was moderately high in the central estuary (up to 5%) where it is found to be low in the southern estuary.

A total of 62 macrobentic species were encountered representing 9 taxa of which, polychaetes, amphipods, bivalves and tanaidaceans formed the most important groups (Table1). In general, the faunal densities were significantly high in the central estuary (avg.2261 ind.m^{-2}) and north estuary (avg.2267 ind.m^{-2}) respectively. In the southern estuary, the sandy texture was preferred by bivalves (density 994 ind.m^{-2}). The polychaetes numerically contributed up to 79 % of the total population, especially in the central estuary. A comparison with an earlier study (Saraladevi, 1986) showed that since 1979, 11 species have disappeared from this region (Table 2).

3.5. Principal Component Analysis (PCA)

In order to classify the estuarine regions with respect to the distribution of benthic organisms, the data collected for water and sediment were separately subjected to principal component analysis (PCA). Three clusters exhibiting similar properties were identified for water environment (Fig. 3). The first cluster (Z1) was characterized by relatively high nutrients and chlorophyll representing 20 stations in the central estuary. Similarly, the second cluster (Z2) exhibited high nutrient and very high chlorophyll representing 7 stations in the north estuary and the third cluster (Z3) was characterized by low nutrients and low chlorophyll representing 25 stations in the south estuary. The 4 river stations remained as a distinct cluster. The PCA results for the sediment also yielded three clusters overlapping with more or less identical clusters obtained for the water column. It is evident from the figure that 62% of stations representing Z1 for water matched in the case of sediment. Likewise, 52% of similarity is retained for Z2 and 77 % for Z3 (Fig. 3). The noticeable point here is that, the central estuary exhibit high organic carbon and nitrogen in sediments, while the high chlorophyll *a* in water was found in the north estuary (Figs. 2 &b, Fig. 4). Sediment enrichment by carbon and nitrogen observed in the north and central estuary was significant, where the texture was mainly clay and benthic diversity was low (Fig.4, Table 1). The situation was different in the south estuary, where the sediment was a mixture of silt and sand containing low organic carbon, supporting a rich and diverse benthic community including bivalves (Table 2, 3).

3.6 Long-term variation in the nutrient loading

An assessment of water quality in the lower reaches of Cochin estuary (Fig.4) showed a 6-fold increase Phosphorus, Nitrogen & chlorophyll concentrations since 1965. It is evident from earlier records that there has been a reduction, both in qualitative and quantitative distribution of benthos in the central estuary (Table 2), where the benthic density of 5796 ind.m^{-2} recorded in 1981 (Saraladevi 1986) has reduced to 2261 ind.m^{-2}. Along with the decline in species density, appearance of a number of pollution indicator and tolerant species is a cause of concern (Table 3). Polycheates with 31 species were the most abundant group (79.75 %) in the central estuary (Z1) with high abundance of Capitellids (37 %) in general {*Capitella capitata* (18 %) in specific}. Interestingly, molluscan species such as *Villorita cyprinoids*, *Paphia papillions*, *Arca* sp. and *Littorina littorea*, which commonly occurred in early 70’s have disappeared from the central and north estuary, evidencing the changes in the region. The species diversity of this zone has also reduced correspondingly from 2.74 - 0.93 (Table 3), and was negatively correlated to sediment organic carbon ($n = 20$, $r = -0.43$, $p < 0.05$).

4. Discussions

The organic enrichment in sediment observed in the Cochin estuary is a sign of environmental deterioration. As a consequence, there has been considerable reduction in the diversity of plankton and macro benthic community since 1980’s. Even though the eutrophication induced changes on macrobenthos is a long term process, in Cochin estuary this seems to be supported by the anthropogenic loadings and it’s complex hydrography. It will be important to examine the interactions between organic enrichment and macrobenthic distribution in the estuary.

The industrial revolution initiated during 1940’s and has intensified after 1970 leading to discharges of effluents (Balachandran et al. 2002, 03; Madhu et al. 2007). The concentration of nutrients and chlorophyll in the Cochin estuary is relatively high, when compared to other estuaries such as Hudson (Clerk et al. 1992), the San Francisco Bay (Flegal et al. 1991), Schedt (Zwolsman 1994), Girode estuary (Irigoien and Castel 1997), Baixada Santista (Braga et al. 2000), and Pearl estuary (Hung et al. 2003). The central estuary exhibits high concentration of DIP released from the suspended sediments (Sankaranarayanan and panampunnayil 1979; Martin et al. 2008). Recent studies shows that the estuary receives 1.37 kg.d^{-1} of inorganic phosphate and 2.69 kg.d^{-1} of inorganic nitrate and the export to the coastal waters is only 0.91 kg.d^{-1} of inorganic phosphate and 1.71 kg.d^{-1} of inorganic nitrate (Hema Naik 2000; Balachandran 2002) indicating that the estuary act as a sink of nutrients.

The high biomass of chlorophyll *a* in the central and the north eastern estuary are possibly due to the enrichment of nutrients by industrial and domestic activities (Jyothibabu et al. 2006; Madhu et al. 2007). The anthropogenic activities aggravated by the weak flushing has lead to an increased production of chlorophyll *a* in the north and central estuary. Moreover, the high organic production are not transferred to the higher tropic level due to the lack of effective grazers, which leads to settling of the execs chlorophyll to the sediment (Jyothibabu et al. 2006).

The quantity and quality of sediment organic matter is influenced by the overlying productivity (Nixon 1995). In Cochin estuary, the high organic enrichment in sediments observed in the central region is probably due to the flow restriction in this region (Balachandran et al. 2005; Martin et al. 2008). There has been a reduction in the exchange volume of the estuary from (126 Mm3/tidal cycles to 35 Mm3/tidal cycles) during the past three decades due to the shrinkage and other engineering modifications in the upstream regions (Gopalan et al. 1983; Jomon and Kurup 1989).This was responsible for elevated levels of toxic metals and organic carbon in this region (Balachandran et al. 2006).

The multivariate statistical analysis suggest that environmental factors have significant impact on the macrobenthic distribution in the estuary. Areas of high organic accumulation are characterized by a number of highly opportunistic taxa, while areas of lower organic accumulation were populated by diverse and stable fauna (Table 1). An ideal overlap between pelagic and benthic environment was however not observed because the changes in benthic characteristics are slow (Posey et al. 2006). The wide scatter in the distribution of macrobenthic biomass in the south and north estuary indicates the sensitivity of benthic organisms to environmental changes. There is also an increase in the percentage of deposit feeders (Table 3) compared to other estuaries in the world (see Mojtahid et al. 2008). Organic enrichment in sediments may lead to hypoxia, smothering, faunal depletion and ultimately to an abiotic environment (Pearson and Rosenberg 1978). Regions receiving high organic matter undergo changes in the benthic fauna, and in the present study also, it has led to an invasion by deposit feeders and indicator organisms such as *Capitella capitata* (Ansari et al. 1986). The population dynamics of *C. capitata* have found their early colonization in azoic areas, followed by population explosion, and a rapid decline (Tsutsumi and Kikuchi 1984). The responses of benthic organisms to prolonged environmental stress are reduced size, reduced diversity and domination by a single or group of opportunistic species (Gray 1989). In the present study *Capitella capitata*, *Paraheteromastus tenius* and *Heteromastus similes* having wider distribution contributed to the polychaete density. *Capitella capitata* has been recognized as indicator species in estuarine pollution studies in the tropical and temperate regions (Gangaev 1996; Wlodarskakowalezuk et al. 1998). The characteristic of the central estuary (Z1) was similar, where the benthic community was dominated by this single species. The negative correlation between the diversity indices and sediment carbon is a proof for the deterioration of the estuary due to organic accumulation.

Conclusion

The present study shows that Cochin estuary is influenced by anthropogenic activities, as the increased loading of nutrients in to the estuary has supported consistently high production of chlorophyll *a* in the north and central estuary. The consequent organic enrichment in the sediments in the central estuary has adversely affected the production of benthic organisms, where only tolerant species could survive. The long term enrichment in nutrients and sediment organic carbon indicate eutrophication in the estuary, which may intensify in future, in view of the projected developments. Even though a direct impact of human interventions on environmental quality is not evident, the changes in benthic ecology indicate the stress on the estuary, which needs to be removed.

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Reference

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Characteristics	**Z 1**	**Z 2**	**Z 3**
Total Nitrogen (%)	0.36	0.22	0.01
Sediment Organic Carbon (%)	2.57	2.41	0.89
Biomass ($g.m^{-2}$)	15.40	20.78	43.92
Polychaetes ($ind.m^{-2}$)	2034	1629	499
Gastropoda ($ind.m^{-2}$)	4	4	3
Bivalves ($ind.m^{-2}$)	21	0	493
Tanaidacean ($ind.m^{-2}$)	132	7	2
Decapoda ($ind.m^{-2}$)	0	38	2
Amphipoda ($ind.m^{-2}$)	560	0	8
Isopoda ($ind.m^{-2}$)	11	146	21
Total density ($Ind.m^{-2}$)	2261	2267	994

Table 1. Characteristics of sediment and macrobenthic species (average values) in the central (Z1), north (Z2) and south (Z3) zones of the Cochin estuary.

Species	1981	1996	2005
Polychaetes			
Acistrosyllis constricta	+	+	+
Aphrodita	+	+	-
Branchiocapitella singularis •	-	-	+
Capitella capitata •	+	+	+
Cossura coasta •	-	-	+
Dendronereis aestuarina •	+	+	+
Diopatra neapolitana	+	+	+
Eunice tubifex	+	-	-
Glycera alba	+	-	-
Glycera convoluta	+	-	+
Goniada emirita	+	-	+
Heteromastidus bifidus	+	+	+
Heteromastus similes	+	+	+
Lumbriconereis latereilli	-	-	+
Lumbriconereis notocirrata	+	-	-
Lycastis indica •	+	+	+
Mediomastus capensis •	-	+	+
Nepthys dibranchus	-	+	+
Nepthys polybranchia	+	-	-
Owenia sp.	+	+	+
Paraheteromastus tenuis •	+	-	+
Perinereis cavifrons	+	+	+
Pista indica	+	-	-
Prionospio cirrobranchiata •	-	+	+

Prionospio polybranchiata ●	+	+	+
Amphipods			
Caprellidae	+	+	+
Corophium triaenonyx	+	+	+
Eriopisa chilkensis	-	+	+
G. bonnieri	+	+	+
Grandidierella gilesi	+	+	+
Melita zeylanica	+	+	+
Quadrivisio bengalensis	+	+	-
Mollusc			
Pendora flexosa●	+	-	+
Paphia papillions	+	-	-
Arca sp.	+	-	-
Littorina littoriea	+	-	-
Villorita cyprinoids	+	-	-
Tanaidaceans			
Apseudes chilkensis ●	+	+	+

Table 2. Abundance of ecologically important species during 1981, 1996 and 2005 in Z1 of the Cochin Estuary (Sources : 1981- Saraladevi 1986, 1996- Sheeba 2000, 2005- Present study) (● Pollution Indicator and tolerant species)

Parameters	1981	1996	2005
Average density (ind.m^{-2})	5796	2854	2261
Average biomass (g.m^{-2})	27.8	21.1	15.40
No. of species	76	56	47
Polychaetes (% of total)	59	76	79
Species diversity (H’)	2.74	1.82	0.93

Table 3. Long-term changes (pre monsoon) in the macrobenthos distribution during premonsoon in Z1 (Sources : 1981- Saraladevi 1986, 1996- Sheeba 2000, 2005- Present study).

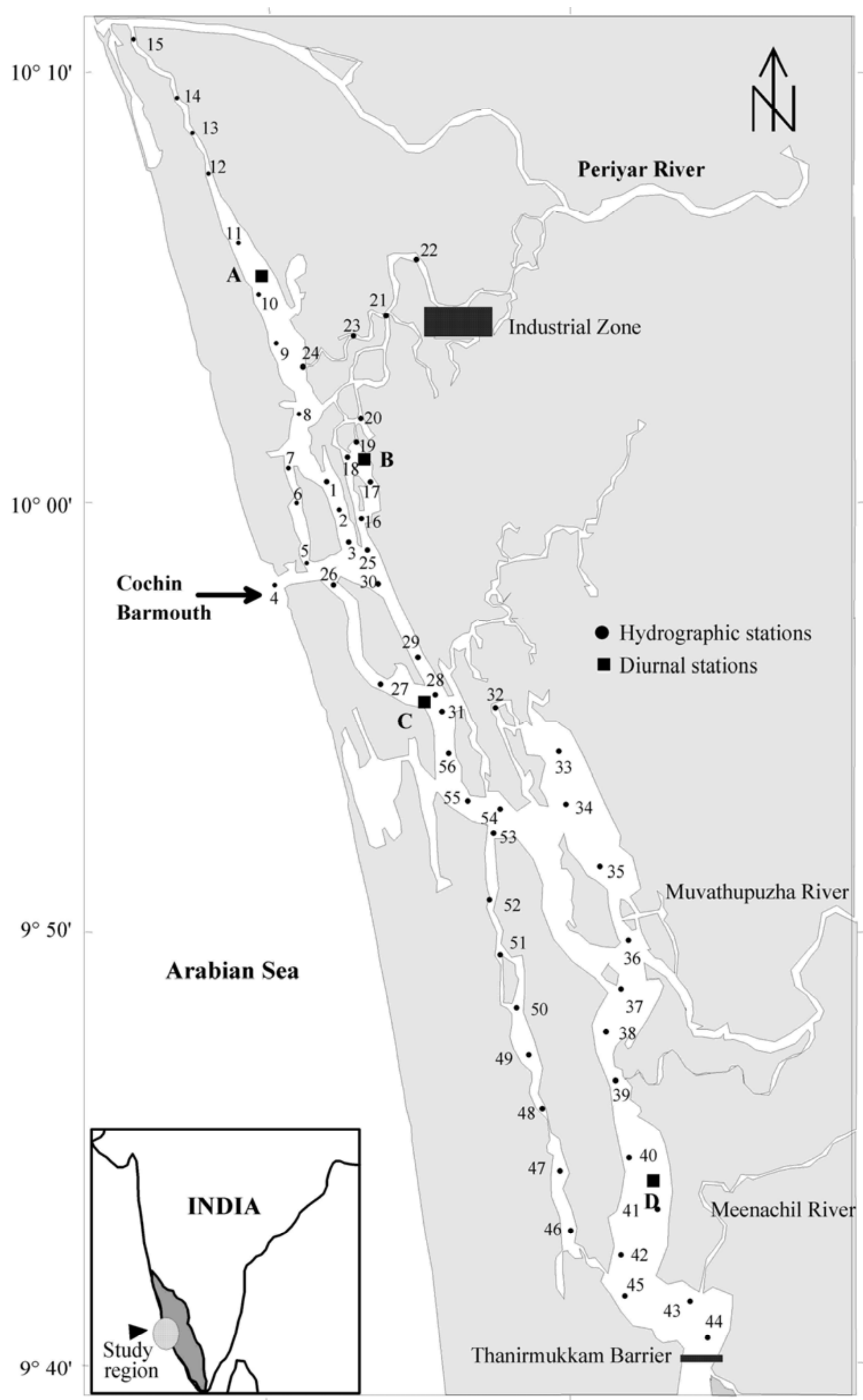
10° 10'
10° 00'
9° 50'
9° 40'
76° 14'
76° 21'
Periyar River
Industrial Zone
Cochin
Barmouth
Hydrographic stations
Diurnal stations
Muvathupuzha River
Arabian Sea
Meenachil River
Thanirmukkam Barrier
INDIA
Study
region
A
B
C
D

Fig. 1

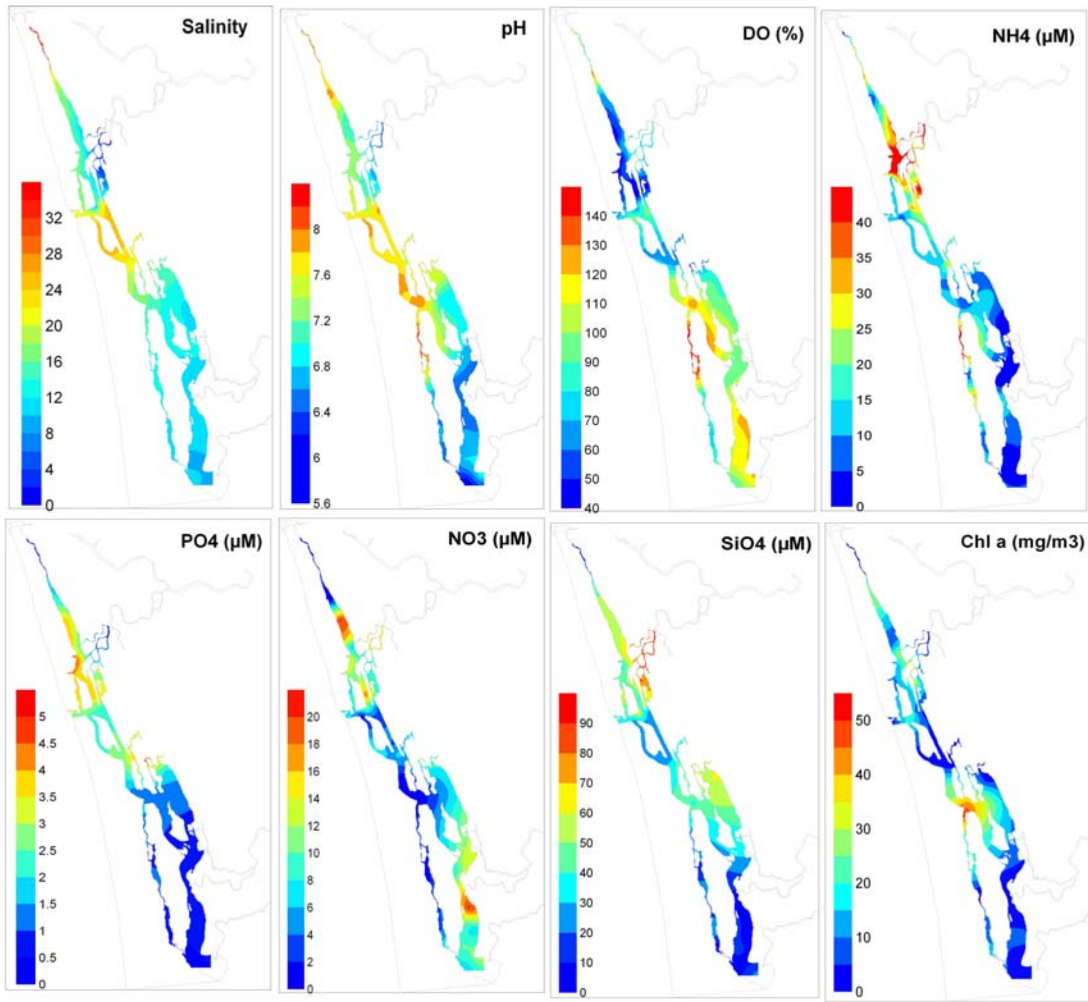
Salinity
32 28 24 20 16 12 8 4 0
pH
8 7.6 7.2 6.8 6.4 6 5.6
DO (%)
140 130 120 110 100 90 80 70 60 50 40
NH4 (µM)
40 35 30 25 20 15 10 5 0
PO4 (µM)
5 4.5 4 3.5 3 2.5 2 1.5 1 0.5 0
NO3 (µM)
20 18 16 14 12 10 8 6 4 2 0
SiO4 (µM)
90 80 70 60 50 40 30 20 10 0
Chl a (mg/m3)
50 40 30 20 10 0

Fig. 2a

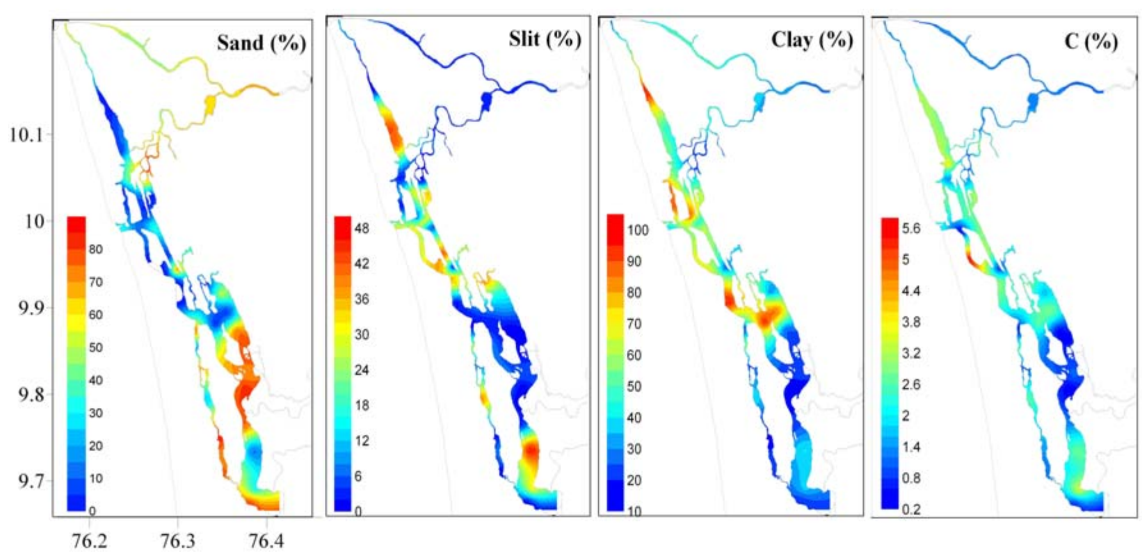
Sand (%)
80 70 60 50 40 30 20 10 0
Slit (%)
48 42 36 30 24 18 12 6 0
Clay (%)
100 90 80 70 60 50 40 30 20 10
C (%)
5.6 5 4.4 3.8 3.2 2.6 2 1.4 0.8 0.2
10.1
10
9.9
9.8
9.7
76.2 76.3 76.4

Fig. 2b

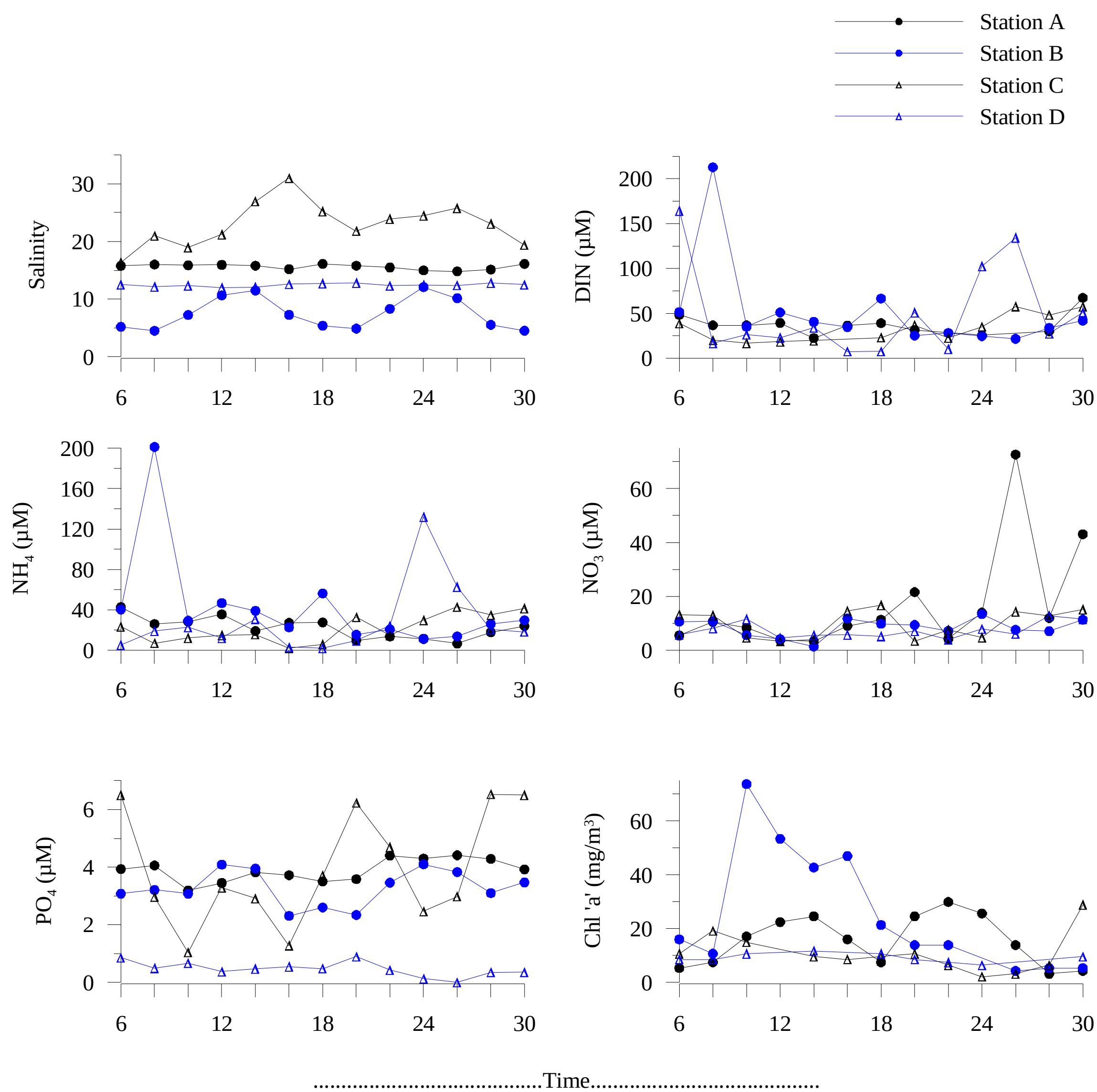
Station A
Station B
Station C
Station D
Salinity
DIN (µM)
NH4 (µM)
NO3 (µM)
PO4 (µM)
Chl 'a' (mg/m3)
....Time.......................................

Fig. 2c

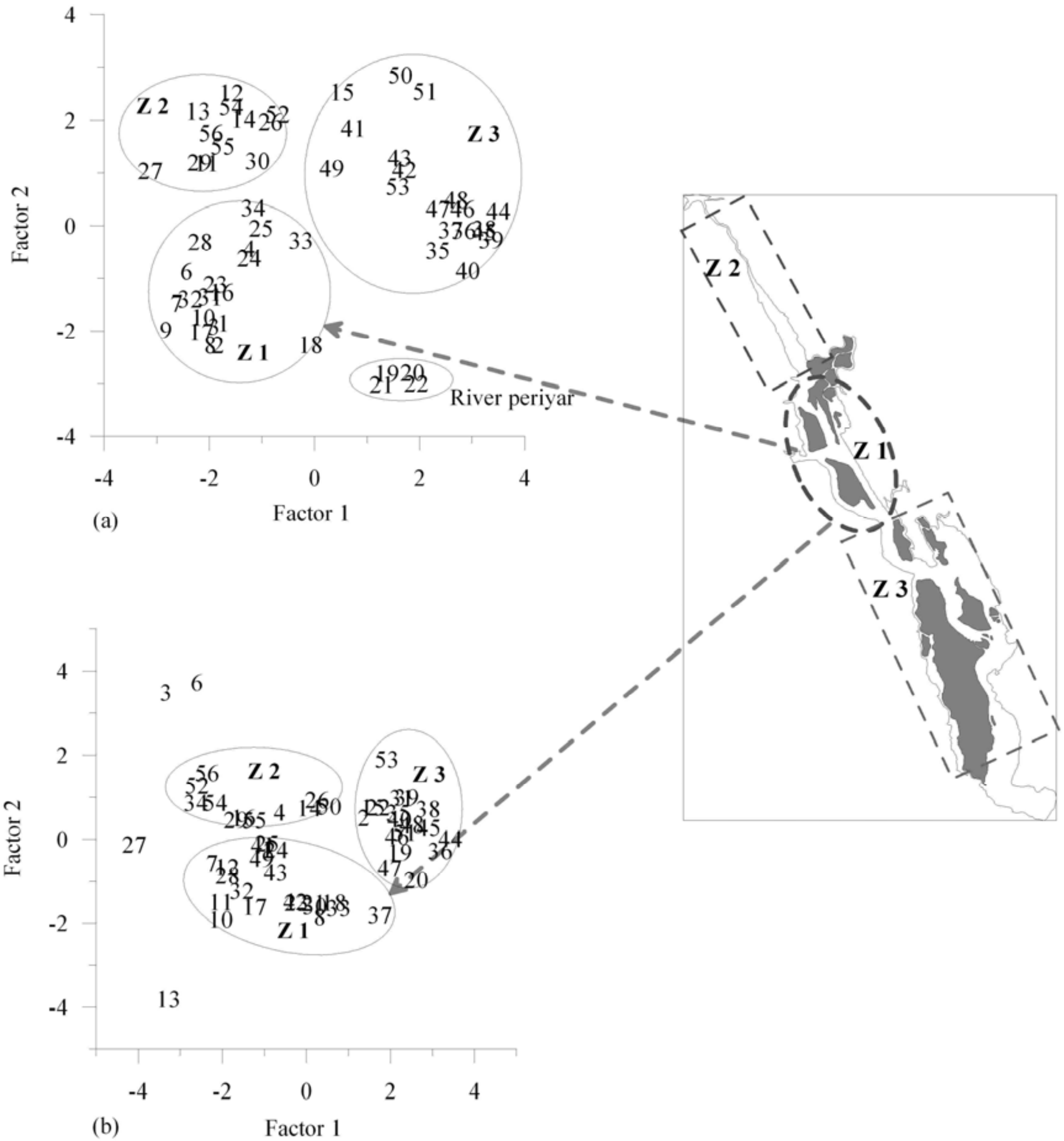

Fig. 3

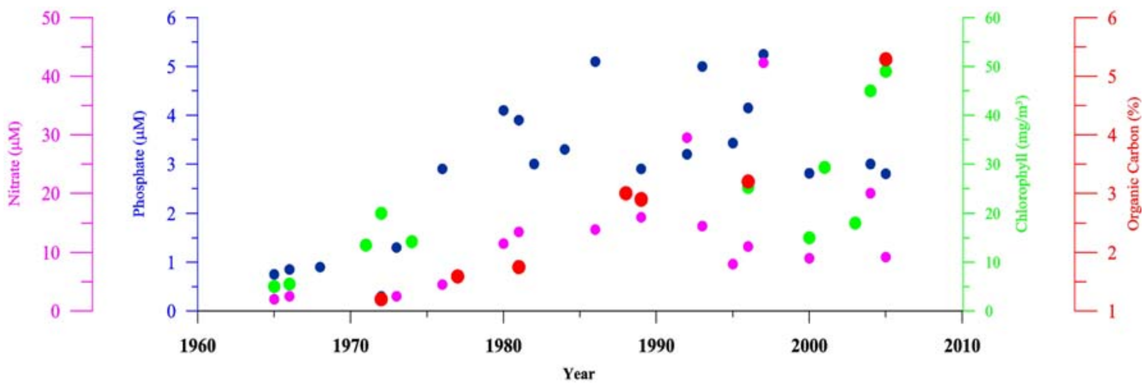
Nitrate (μM)
0
10
20
30
40
50
Phosphate (μM)
0
1
2
3
4
5
6
1960
1970
1980
1990
2000
2010
Year
Chlorophyll (mg/m³)
0
10
20
30
40
50
60
Organic Carbon (%)
1
2
3
4
5
6

Fig. 4