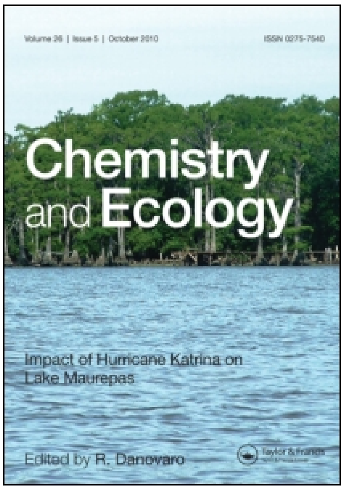

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Seasonal and tidal impact on the organic compounds and nutrients distribution in tropical mangroves, Kerala, India

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Seasonal and tidal impact on the organic compounds and nutrients distribution in tropical mangroves, Kerala, India

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Seasonal changes in the concentration of nutrients and various organic compounds were studied in the waters surrounding mangroves and in the marshy areas of mangroves. Higher amounts of nutrients and organic compounds were observed during low tide. This is due to the remineralisation of plant detritus in this area. High concentration of carbohydrates, proteins, chlorophyll and phosphate were observed during monsoon, which can be attributed to the leaching of plant detritus as well as the land run-off. During pre-monsoon and post-monsoon high tannin and lignin concentration was noted. A 24-hour sampling was also done to study the tidal impact on the concentrations of various organic compounds and nutrients in this ecosystem. Even though a tidal impact was observed, a clear picture was not reported in this study.

Keywords: Mangroves; Coastal waters; Productivity; Plant detritus; Diagenesis; Dissolved organic matter

1. Introduction

The coastal lines of the world are bordered by zones of fringing wetlands, such as salt marshes in temperate latitudes and mangroves in the tropics. In general, such wetlands are located between the terrestrial watersheds that are sources of nitrogen and the receiving estuarine waters which are generally subject to eutrophication [1]. In coastal environments where sedimentary inputs are large, microbially-mediated benthic remineralisation of such debris is a major recycling pathway and can supply a significant fraction of the nutrient requirements of primary producers in overlying waters [2]. This stepwise breakdown of complex organic substrates into soluble inorganic species of carbon, nitrogen and phosphorus which may be released by the benthic system into the overlying water [3]. Coastal waters throughout the world are being affected by anthropogenic inputs of nutrient elements, of organic matter that undergoes bacterial degradation consuming dissolved oxygen and releasing nutrients, and of potentially toxic trace metals. These inputs are directly related to increase human population density, agriculture and industrial development in coastal regions. Considering the global

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carbon cycle and the major role played by the ocean, it seems that the coastal zone must be considered as an especially important area [4]. Though representing only a small surface of the marine realm (about 8%), it is the most productive area of the ocean (more than 25% of total marine production, [5]). The cycling and final sequestration of organic matter in estuaries and coastal zone is controlled by different processes, among which microbiological ones play a key role with regard to production, degradation and mineralization of organic matter [6]. The importance of dissolved and particulate organic detrital matter to the metabolism of aquatic ecosystems has not been fully explored [7]. Dissolved organic matter comprises most of the reduced carbon in aquatic ecosystems and provides energy and carbon sources for the metabolism of heterotrophic bacteria. It is known that humic substances dominate the dissolved organic matter of stream water and play an important role in the metabolic pathways of the ecosystem. Saline marsh contained 2.2 and 4.2 times more organic and mineral matter than inactive fresh marsh [8]. The high productivity of the coastal zone is mainly related to the influence of the river inputs, enriching the coastal waters in nutrients and organic matter, and to the close coupling between the water and sediment assuring a rapid reutilization of regenerated elements. The type of flora in the water shed, the distribution and abundance of wetland and littoral plants, and the pathways of release of detrital organic material into the water body have different effects on overall rates of eutrophication and development of aquatic ecosystems. Of the four gross compartments into which marine matter may be categorized (inorganic/organic, particulate/dissolved), the dissolved organic fraction remains the least well documented. In this paper seasonal and tidal impacts on some hydrological and organic compounds were studied in three mangroves and their connecting canals.

2. Material and methods

2.1 *Study area*

The Cochin estuary includes a system of interconnected lagoons, bays and swamps penetrating the mainland and enclosing many islands extending approximately 500 km^2. The backwater around Cochin is located between Lat. 9° 40′–10° 12′N and Long. 76° 10′–76° 30′E. and this estuary is connected with the Arabian Sea by a permanent opening (450 m wide) through which tides act within the estuary. The area of investigation and the station locations are reported in figure 1. The wetlands of Kerala was a large mangrove swamp centuries ago, modified into settlements, agricultural fields, filtration ponds and prawn culture fields by anthropogenic activities. Nowadays, mangrove ecosystems are divided in isolated patches along the banks of this estuary. They cover an area of 260 ha. As many other mangrove ecosystems, this area is also subjected to the increased of human influences. The characteristics of these stations are summarized as follows:

Mangalavanam is a patchy mangrove area in the centre of the city of Kochi. This mangrove forest is a small bird sanctuary, located in the centre of the city behind the High Court of Kerala. It lies 4 km to the south of Kochi. It is the seat of many exotic and rare varieties of migratory birds. This is an almost closed system with a single marrow canal linking to the estuary and even though it is a protected area, the canal connecting this to the estuary is polluted by an urban drainage system. This forest during high tide was indicated as 1H and at low tide as 1L, the canal connecting to this forest at high tide was indicated as 2H and at low tide as 2L in the graphs and tables. During low tide, the system is completely drained of water.

Vypeen, the largest single stretch of mangrove in Kerala has an area of approximately 101 ha. This mangrove area is regularly inundated by the semi diurnal rhythm of Cochin barmouth; the tidal waters bring in lot of fish seed of commercially valuable prawn species. The mangrove

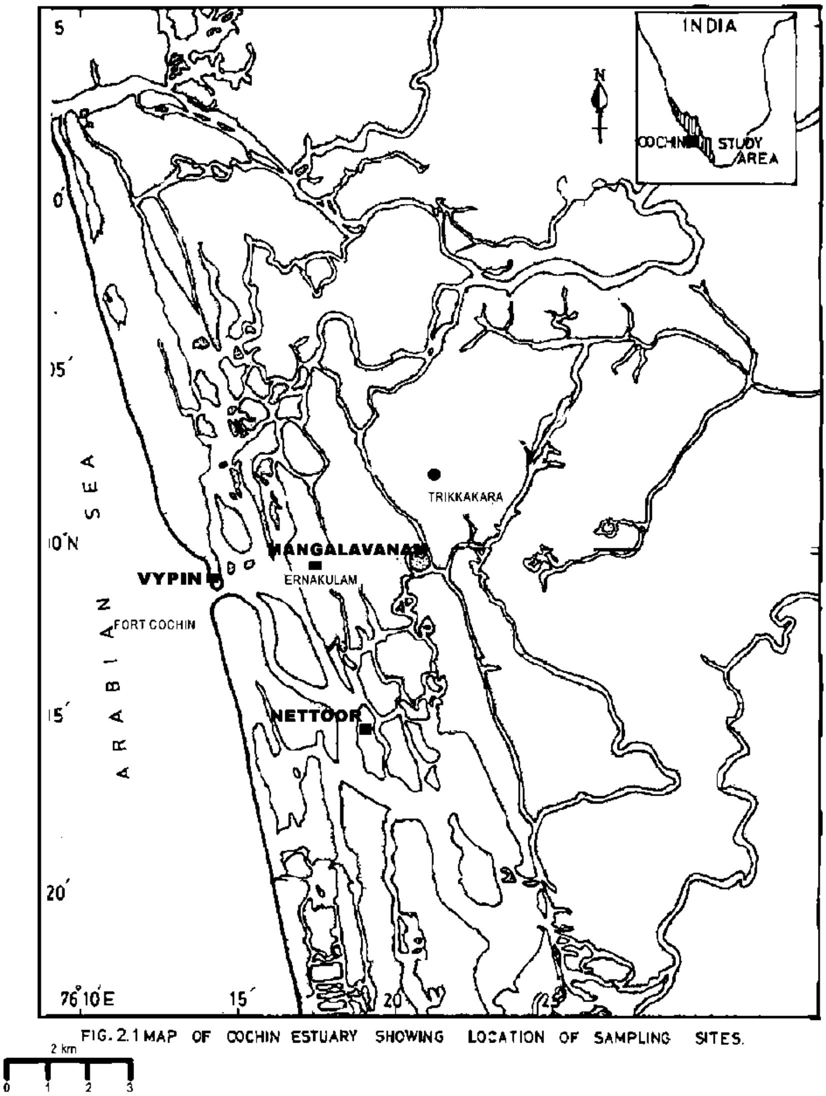

Figure 1. Map of Cochin estuary showing location of sampling sites.

vegetation consists primarily of Avicennia and some occasional growth of Rhizopora. This is the only site in Kerala where one can see mangroves right along the accreting seacoast but the anthropogenic pressure, including the proposed gas Thermal plant, represent a danger for the existence of these mangroves. This is a typical fringed, semi-enclosed system; this forest was marked as 3 and its connecting canal as 4 in the graphs and tables.

Nettoor is a vanishing mangrove ecosystem. It is facing the major threat of land reclamation for construction of roads and buildings. During inter-monsoon periods, when the seawater inundates the area, prawn is cultivated and the chemmeenkettu is another form of agro-silvi aquaculture prevails in this area. This is an open system stressed by human activities. This forest and its connecting canal are reported as 5 and 6, respectively in the graphs and tables. Both Vypin and Nettoor are not completely drained of water during low tide and are surrounded by human settlements so that the chemistry of these areas are highly influenced by anthropogenic activities.

2.2 *Sampling*

Water samples were collected from the surface of the stations (figure 1) at bimonthly intervals from November 1999 to November 2000. The collection period was divided into three seasons: monsoon (June, July, August and September), post-monsoon (October, November, December and January) and pre-monsoon (February, March, April and May). Water samples were collected using a clean plastic bucket and kept frozen until analysis. All analyses were done in duplicate. pH was measured *in situ* and temperature was measured using a sensitive thermometer. The salinity of the water samples was estimated using the Mohr-Knudsen method [9]. Modified Winkler method was used for the estimation of dissolved Oxygen [9]. Alkalinity of the water samples was estimated by method [9] and chlorophyll by method [10].

Water was filtered through GF/C filter paper and heated at 500°C for two hours. All hydrochemical parameters were estimated spectophotometrically using UV-VIS Hitachi 150-20 after converting each of the species into required colored substances. Nitrite was converted to an azo dye with sulphanilamide and N- (1-naphthyl) ethylene diamine dihydrochloride [11]. Nitrate was reduced to nitrite using copper-coated Cadmium column and estimated as nitrite [9]. Formation of phospho- molybdate complex using ascorbic acid as reductant was used for phosphate determination [9]. The protein content was analyzed by the method suggested by [12] and carbohydrates by phenol-sulpuric acid method [12]. Hydroxylated aromatic compounds (tannin and lignin) were estimated by the method detailed in ref. [13] and modified by Nair [14].

3. Results and discussion

Water is of obvious importance in an aquatic system. There are a number of processes and factors that affect the rates of materials transport, mixing and circulation in mangrove wetlands. These heavily vegetated intertidal wetlands, when submerged, are very shallow and the maximum water depth is ca 2 m in the swamps. The swamps are drained by small tidal creeks (mangrove creeks) that emphasize the link between mangroves and the coastal waters. This link suggests that a mangrove swamp is not an oasis, which is neither land nor sea, but is an important buffer depending on both the land and the sea. It enriches the coastal waters and provides an important forestry and fisheries resource. For the effective management of this ecosystem the understanding of its hydrograph and of the adjacent waters is essential.

Distribution of pH during different seasons is given in figure 2. During all the three seasons, pH in the three ecosystems was in the alkaline range. Values fluctuated between 7.1 and 8.3 during monsoon among all the forests. The maximum was observed in station 5 and minimum in station 3. Except for station 3, all forests exhibited pH lower than the canals which connect these to the estuary. During pre-monsoon, waters around the forest 1H were highly alkaline compared to values reported for all the forests and remained higher than the adjacent water masses. The values ranged between 7.7 and 8.1 and remained almost the same in all the three forests during post-monsoon (ranging from 7.4 to 7.6). However the pH of the water masses was higher than of the forests during this season. The three ecosystems studied showed considerable differences in their ranges of pH and the increasing of pH value was due to the increasing of photosynthetic activities. In fact, in regions in which photosynthetic activity was high, undersaturation with respect to carbon dioxide could occur and the pH could rise. The high primary production during pre-monsoon was reported by previous studies [15, 16] and a

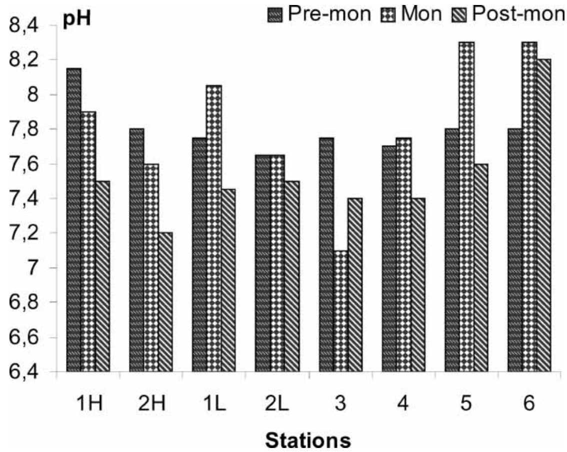

Figure 2. Seasonal variation of pH.

higher value of pH in station 1L during monsoon was reported by Imelda and Chandrika [17]. The seasonal distribution of the salinity in all stations is reported in figure 3. The salinity of water in and around all the three ecosystems was in the fresh water range during monsoon. In the forests values ranged between 0.3 ppt and 3.8 ppt (at station 3 and station 1H, respectively). The fresh water was dominant in the forests 1H and 3 during this season even though station 3 was more saline than the canal. The low salinity during this season was due to the heavy rains that caused high fresh water discharges into the systems. During pre-monsoon the salinity was very high, ranging from 14 ppt to 25 ppt at station 5 and station 3, respectively). Compared to the canals, all forests showed high salinity values during this season except in station 6 and

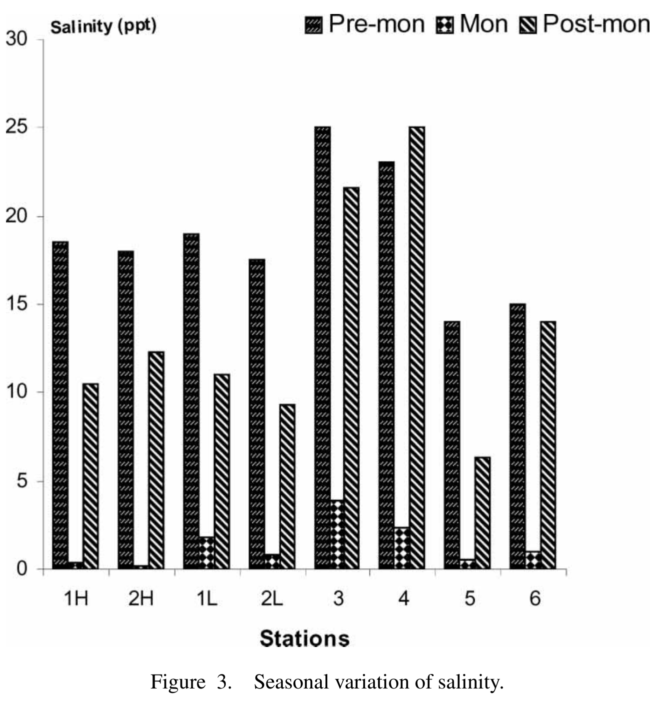

Figure 3. Seasonal variation of salinity.

the causes of this pattern were due to the excessive evaporation and decreasing of tidal water. During post-monsoon among the forests, salinity values ranged between 6.3 ppt and 21.6 ppt; the highest value was reported at station 3 and the lowest at station 5. All forests except 1L reported less saline than data results from the canals during this season. Thus there were evident seasonal differences during the monsoon, post-monsoon and pre-monsoon periods according to the trends reported by refs. [17, 18]. The seasonal distribution of oxygen is reported in figure 4. All the three ecosystems and the adjacent water bodies were rich in oxygen during monsoon. The values varied between 1.64 ml l^{-1} and 5.9 ml l^{-1} in the forests (at station 3 and 5, respectively) and the canal 4 was richer in oxygen than the forest 3 (values 2.6 ml l^{-1} and 1.5 ml l^{-1}, respectively) during monsoon. However, at stations 5 and 6, the forest 5, showed higher value of oxygen than the adjacent water body (5.9 ml l^{-1} and 5 ml l^{-1}, respectively). All systems reported oxygen deficiency during pre-monsoon whereas oxygen was not detected in station 1L during pre-monsoon and post-monsoon. The concentration of oxygen was higher in all nearby waters except for station 3 during both seasons. Excessive demand for hydrogen or electron acceptors under such conditions resulted in a rapid depletion of oxygen in the sediment and a remineralization via a sequence of anaerobic modes of respiration [19]. The hydrology of wetlands, including the frequency and duration of tides, as well as the amount of organic matter present, determined the oxygen availability in wetlands. This trend was comparable to what was reported in other mangrove ecosystems in Kerala [20].

The seasonal profile of alkalinity is reported in figure 5. During monsoon the alkalinity of water was higher, ranging between 5.2 and 7.1 mmoles l^{-1} in the forests. The maximum was observed at station 3 and the minimum at station 1 H. During this season all forests except 1L exhibited lower values than the adjacent water bodies. The amount of alkalinity was comparatively lower in the forests than in the canals except at 1H during pre-monsoon. In this season the alkalinity increased from 0.5 mmoles l^{-1} to 1.8 mmoles l^{-1} at 1H and 1L, respectively. During post-monsoon in the forests (with the exception of station 4) the same trend was observed and the values ranged between 0.4 mmoles l^{-1} and 1.4 mmoles l^{-1}. Bates [21] reported lower values of alkalinity in the open ocean during summer and higher values during winter and spring. In Summer in the mixed layer, alkalinity concentrations were typically lower than in the winter when the mixing of fresher layers occurred and evaporative fluxes were reduced.

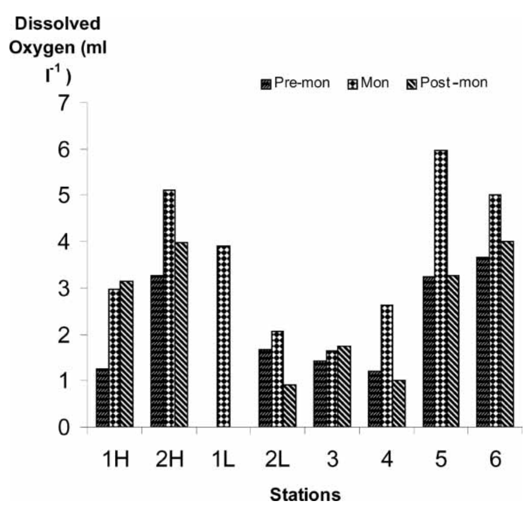

Figure 4. Seasonal variation of dissolved oxygen.

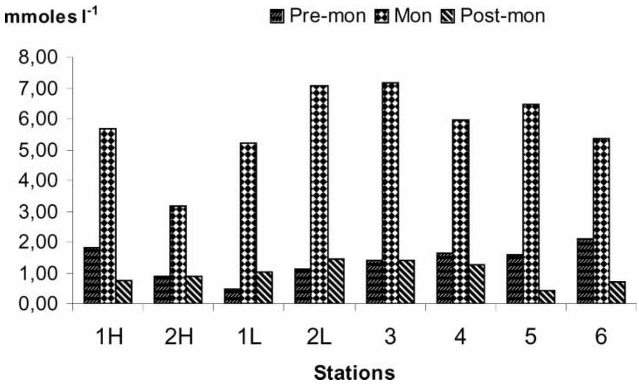

Figure 5. Seasonal variation of alkalinity.

Seasonal variations of chlorophyll a in the three mangrove systems and their connecting canal are reported in figure 6. During pre-monsoon, the concentration of chlorophyll a of the forests ranged from 3.1 $\mu g\,l^{-1}$ to 11.6 $\mu g\,l^{-1}$ at station 5 and 1L, respectively. All forests were richer in chlorophyll than the canals except for station 3. However during the monsoon, canals exhibited higher values for chlorophyll than the forests except for station 2L. Chlorophyll was high in the canals 4 and 6 compared to in the forests 3 and 5. During the post-monsoon, the concentrations ranged from 4.4 μgl^{-1} to 8.5 μgl^{-1} in forests 5 and 1H, respectively. During this season, canals were also richer in chlorophyll than the forests except for 1L.

According to Biamchi *et al.* [22] high POC:chlorophyll a ratios (<1463) during pre-monsoon indicated that most of the chlorophyll was degraded. The predominantly low chlorophyll a concentrations were mainly due to the inputs of degraded vascular plant detritus and due to periphyton and phytoplankton [22]. During the high in-flow periods, the high values observed were due to phytoplankton. Even though the concentration of chlorophyll in these ecosystems was less when compared to the reported values, it was in the range reported in the Schedt estuary (table 1).

The seasonal variations of nitrate are reported in figure 7. Analysis of the seasonal distribution of the dissolved nitrate concentrations showed a peak in the monsoon season at all stations. Since this was the high in-flow period, the source of nitrate was the land run-off and the resulting concentration was higher in the forests than in the canals except at station 4. The values ranged from 11.9 $\mu g\,l^{-1}$ to 38.7 $\mu g\,l^{-1}$ in the forests and higher concentrations of nitrate were observed at stations 2H, 1L and 2L during post-monsoon (values 51.9, 38.2 and

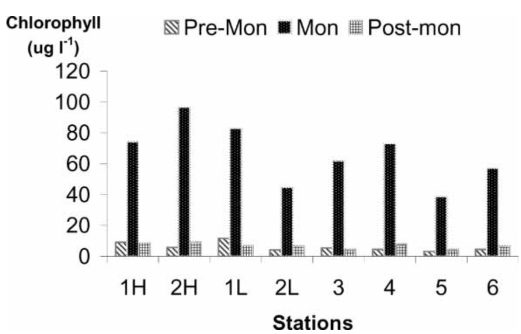

Figure 6. Seasonal variation of chlorophyll.

Table 1. Earlier reported values of chlorophyll ($\mu g\, l^{-1}$).

No	System	Range	Reference
1.	Algae of Arabian Sea	42	[40]
2.	Alton. Water. Saffolk UK	34–95	[41]
3.	Scheldt Estuary	1–93	[42]
4.	Georges Bank	4–5	[43]
5.	Cochin Harbour Area	33.95	[44]
6.	Coastal areas of Orissa	0.27–5.98	[45]
7.	Eastern Arabian sea	32.53	[46]
8.	Bay of Bengal	8–24	[47]
9.	Magalavanam	4.2–96.6	Present study
10.	Vypin	4.5–72.86	Present study
11.	Nettoor	4.4–57.06	Present study

38.2 $\mu g\, l^{-1}$, respectively) whereas lower values were observed during pre-monsoon. During this season higher values were also reported in forests except for at station 4. The maximum value was observed at station 1H during high tide and the minimum at station 3 (34.7 $\mu g\, l^{-1}$ and 3.4 $\mu g\, l^{-1}$, respectively). Nitrate concentrations in these mangroves were lower than values reported in the Cochin backwaters [16] (table 2: 1–7 $\mu g\, l^{-1}$). Nitrogen was present in low concentrations in particulate materials mainly in the form of intact mangrove plant detritus which was exported from the system through tidal action [23]. Concentrations of dissolved organic and inorganic forms of nitrogen in the mangrove and near shore waters were also consistently low even when we compared our results with the tidally dominated mangrove ecosystem at Hichinbrook island, Australia, which received virtually no fresh water or terrestrial input [24]. Previous studies of this forest [23] had strongly suggested that nitrogen supply was growth-limiting even if years of monitoring of the system had suggested no indication of long-term and continuous degradation of the nitrogen nutritional status. According to Simpson [25] under low-flow conditions, the river discharge entering the estuary was exported by evapotranspiration through the mangrove system and the net flow discharge from the estuary was small. This was reflected in the pre-monsoon values. Flux studies in mangrove sediments of Termino Lagoon, Mexico, suggested that dissolved inorganic N in tidal waters was trapped in the first centimeters of the sediment surface [26]. High inorganic N demand in decomposing leaf litter might regulate an efficient recycling of nitrogen that could serve as a mechanism for nutrient conservation [27–29].

Figure 8 shows the seasonal variation of nitrite in the three ecosystems. Seasonal variation showed a maximum peak in the monsoon in all stations. Maximum concentration of nitrite

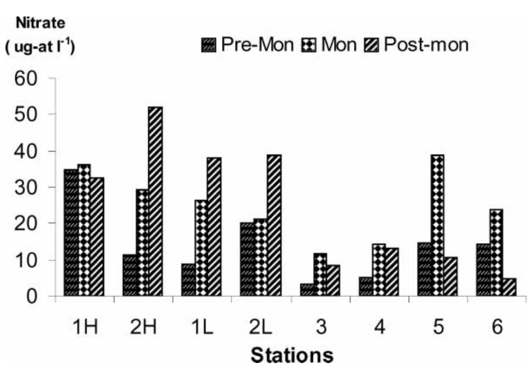

Figure 7. Seasonal variation of nitrate.

Table 2. Earlier reported values of nitrate-N (μg- at l^{-1}).

No	System	Range	Reference
1.	Kusheswarasthan Wetland	160–500	[48]
2.	Kuttanad Wetlands	1.69–19.26	[49]
3.	Bay of Bengal	1–30	[47]
4.	Veli mangroves	0.88–25.34	[20]
5.	Cochin Backwaters	0.82–71.6	[14]
6.	Cochin Estuary	0.63–25.41	[50]
7.	Mangalavanam	8.6–51.9	Present study
8.	Vypin	3.4–14.3	Present study
9.	Nettoor	4.8–57.06	Present study

was observed in all forests during all seasons except at station 4 where a high amount was observed in the canal. During low tide, the concentration was high in both forest and the canal. The value ranged between 0.9 $\mu g\,l^{-1}$ and 22.1 $\mu g\,l^{-1}$ at station 3 and 1L, respectively and this variation might be due to river run-off. Abnormally high values were observed at station 1L and 2L whereas no high variations were observed during pre-monsoon and post-monsoon period. The values in the forests varied between 0.7 $\mu g\,l^{-1}$ and 1.6 $\mu g\,l^{-1}$ during post-monsoon and between 0.9 $\mu g\,l^{-1}$ and 2.8 $\mu g\,l^{-1}$ during pre-monsoon.

Earlier reported values are reported in the table 3. Comparatively high values were observed at stations 1L and 2L. Thomas and Johnson [30] hypothesized that high nitrate and nitrite values at low tide were caused by nitrification within the tidal water or tidal creek sediments. The shallow deep and the favorable conditions for anaerobic digenesis contributed to increase the values at 1L and 2L.

Figure 9 shows the seasonal variation of phosphate. During monsoon, a higher amount of phosphate was observed in the canals than in the forests except for at stations 5 and 3, and

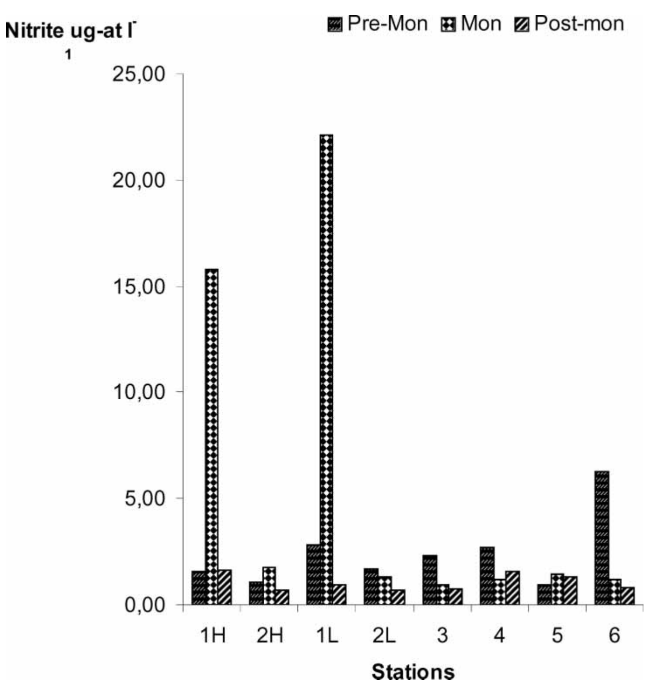

Figure 8. Seasonal variation of nitrite.

Table 3. Earlier reported values of NO_2 (μg- at l^{-1}).

No.	System	Range	Reference
1.	Bay of Bengal	0.01–0.5	[51]
2.	Kuttanad Wetlands	0.17–0.79	[49]
3.	Kayamkulam	0.00–0.07	[52]
4.	Cochin Backwaters	0.30–8.30	[14]
5.	Cochin Estuary	0.63–6.68	[50]
6.	Mangalavanam	0.67–15.8	Present study
7.	Vypeen	0.9–2.6	Present study
8.	Nettoor	0.8–6.3	Present study

was due to the river run off. The values observed were higher than the earlier reported values (table 4). Untawalal [18] reported 0.5–1.5 μg l^{-1} of phosphate in mangroves in Mandovi and Zuari estuaries whereas [20] reported higher concentration (21.6 μg l^{-1}) in Veli mangroves which could be due to the mixing of sewage with the canal water. During post-monsoon among the forests, maximum concentration (27.52 μg l^{-1}) was reported at station 1L during low tide. During the pre-monsoon the values ranged between 1.51 and 11.83 μg l^{-1} (in the forests at stations 1H and 3, respectively). Higher concentrations were observed in the forests than in the canal during these two seasons. In the pre-monsoon and post-monsoon, higher PO_4^{3-} concentration at 1L was reported during low tide and was due to the decomposition of organic phosphate and due to the partial drying of the swamp and consequent exposure of the land. The color of the water changed from clear to dark, when the tide changed from high to low. The positive relationship between clear water conditions and phosphorus retention was supported by the observations from the Lake Engelsholm [31]. The seasonal profile of proteins, (figure 10) showed high concentrations in all stations during monsoon. Except in the canal 2H, all forests showed higher values than their connecting canals. The same trend was observed during post-monsoon whereas in the pre-monsoon higher values of protein were detected in canals except for at station 6. Monsoonal peaks in the forests suggested that the soluble proteins were leached from the decaying leaf litter and the decomposition of phytoplankton and of the vegetation, which contained a high amount of proteinaceous materials, contributed to the protein concentration. A decrease in the concentration during pre-monsoon might be due to the preferential utilisation of protein by the benthic organisms and to the N-compounds incorporated into humic matter through various humification pathways [32].

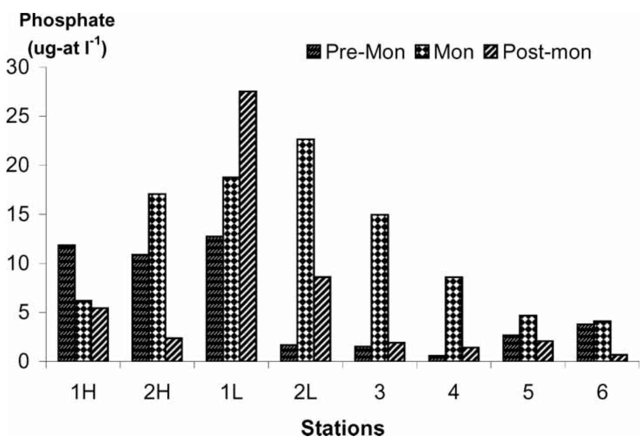

Figure 9. Seasonal variation of phosphate (μg-at l^{-1}).

Table 4. Earlier reported values of PO_2- P(μ g- at l^{-1}).

No	System	Range	Reference
1.	Kusheswarasthan Wetland	0.16–0.5	[48]
2.	Kuttanad Wetland	2.4–7.15	[49]
3.	Bay of Bengal	0.02–1.1	[47]
4.	Kumarakom Mangroves	0–0.40	[20]
5.	Cochin Backwaters	0.40–9.30	[14]
6.	Cochin Estuary	0.27–11.61	[50]
7.	Mangalavanam	2.4–27.5	Present study
8.	Vypin	0.6–14.9	Present study
9.	Nettoor	0.7–4.7	Present study

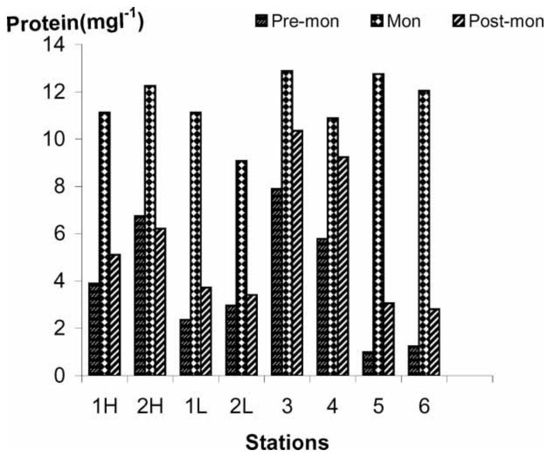

Figure 10. Seasonal variation of protein (mg l^{-1}).

Figure 11 shows seasonal changes in the distribution of dissolved carbohydrates. High concentrations were observed at all stations during monsoon and higher values were reported in the forests than in the canals. The maximum concentration was observed in the forest at station 1 during high tide and the values ranged between 21.6 mg l^{-1} and 56.7 mg l^{-1} in forests 3

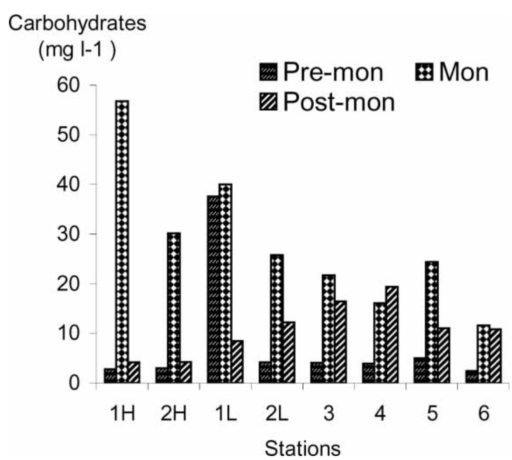

Figure 11. Seasonal variation of carbohydrates (mg l^{-1}).

and 1H, respectively. The concentration of carbohydrates decreased during pre-monsoon and post-monsoon. However, during post-monsoon, the amount of carbohydrates was high in the canals than in the forests except for station 5. In the forests, the concentration ranged between $4.2\,mg\,l^{-1}$ and $16.4\,mg\,l^{-1}$ (at stations 1L and 1H, respectively). Higher concentration was observed in the forests than in the canals during this season also except for at station 1H. The concentration of carbohydrates in this area was not comparable with values reported in table 5. The observed peaks in the monsoon period in the forests might be mainly due to the leaching of dead and decayed leaf litter. Partly of it might be due to the land drainage and due to bacterial action on particulate carbohydrate of planktonic origin in the water [33]. Lowest values were observed in the pre-monsoon except for at station 1L. The concentration of dissolved components, which were discharged in the decaying process of sediments and flushed into the water column, was high during low tide. Due to the reduced tidal flow, the leaf litter remains accumulated in the forest itself. This could increase the concentration of soluble leachates. According to [34] a significant fraction of the polysaccharide loss from a variety of vascular plant tissues occurs due to solubilisation rather than the microbial mineralization. Compositionally, glucose was the most abundant sugar in the hydrolysate mixtures from the attached and submerged leaves [35]. Virus infection and phytoplankton cell lyses were also considered as causes of dissolved organic matter and polysaccharide accumulation. Experimentally this has been demonstrated with the formation of marine snow after the addition of concentrated virus like particles [36].

Seasonal variation of tannin and lignin is reported in figure 12. Among the forests high concentrations were reported at stations 3 and 5 during pre-monsoon whereas low values were observed at all stations during monsoon. A maximum amount of tannin and lignin was observed in all forests except for canal 4. During the post-monsoon season a higher amount was noted in canals except for the forests 1L and 3. The leaves of most of mangroves species contained a great amount of tannin and lignin during pre-monsoon [37] and their concentrations were high in the system during this season. This was mainly due to the high low tide value of the canal. Even though there was considerable amount of tannin and lignin in the mangrove leaves, the concentration was very low in water due to the low solubility of those species in water and to their negligible release in the water. Values were comparable with that reported in Cochin mangroves (table 6). The significance of seasonal variations was analyzed statistically using ANOVA two-way. Seasonal variations of salinity, dissolved oxygen, alkalinity, phosphate, protein and carbohydrates were significant at 0.05 level. Variations of pH, nitrite, nitrate and tannin and lignin were not significant during different seasons (>0.05).

Intertidal sediments were subjected to diurnal drying and flooding which induced the major changes in the local transport of material to and from the sediments. Clearly when the tide had ebbed there was no overlying water present and there could be no dissolved output from the sediment. This resulted in increasing concentrations of dissolved substances that had a source within the sediments, such as ammonium. This pool of high concentration might be released when the water returns to flood the sediment. In contrast, a substance whose source

Table 5. Earlier reported of carbohydrates ($\mu g\,l^{-1}$).

No	System	Range	Reference
1.	Elron estuary	90–1080	[53]
2.	Narragansett Bay	122–156	[54]
3.	Coastal waters of Goa	0.5–29	[33]
4.	Mangalavanam	2700–3990	Present study
5.	Vypin	3900–21600	Present study
6.	Nettoor	2.400–24500	Present study

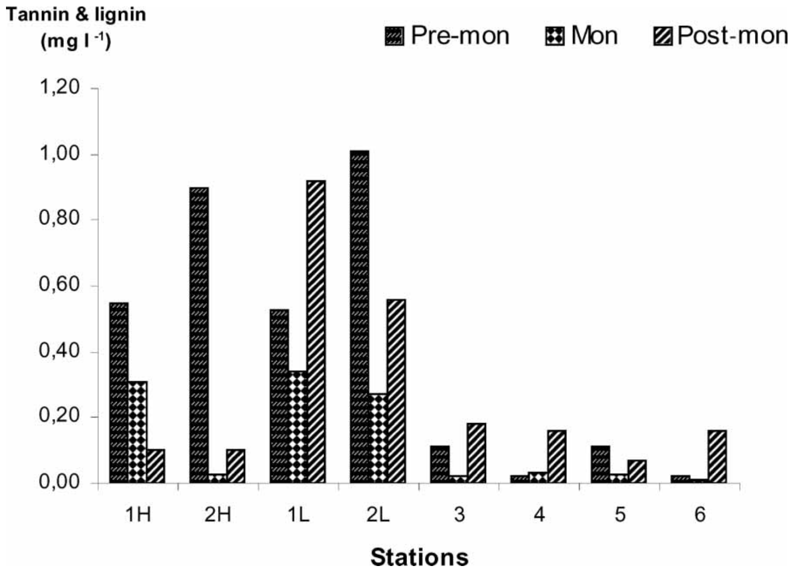

Figure 12. Seasonal variation of Tannin & Lignin (mg l^{-1}).

was the water and was consumed in the sediment might become depleted when the water was not present. Thus sediments were both the sinks and sources of different nutrients and organic compounds and their functions changed with the tide. Changes of some parameters with the tidal cycle are summarized in the figures 13 and 14. Diurnal changes in the oxygen concentrations and other parameters were followed at the forest and canal of station 1. To obtain a complete tidal cycle, sampling was started in the morning and continued until the next morning; samples were collected at intervals of 3 hours. Oxygen values changed with the tides in both forest and canal. Oxygen concentration was not detected in the forest in the early stages and gradually increased according the increasing of the tide. In the canal, even though water was always oxygen rich the values fluctuated with tides. Seasonal variations of salinity in this system were very large, varying from high saline to low saline according to rainfall and evaporation. However, only very small variation according to the tide was noted, due to the negligible concentration of fresh water when compared with the total volume incorporated in each tidal cycle, since the sampling was done during pre-monsoon. pH was in the alkaline range during all the stages of tide both in the canal and forest. Not wide fluctuations were observed in the values except at the canal at 5 p.m., when the pH rose to 9.3 which might be due to any pollutant that entered the water column. Wide fluctuations were shown in the alkalinity values of the forest and not in the canal. In the case of chlorophyll, higher concentrations were observed in the forest than in the canal. Variations in these values of the forest with the tidal

Table 6. Earlier reported values of Tannin and Lignin (mg l^{-1}).

No	System	Range	Reference
1.	Mangroves in Kochi	0.187–1.1676	[55]
2.	Mangrove leaves	3.28–20.02	[37]
3.	West coast of Arabian Sea	0.08–0.147	[56]
4.	Mangalavanam	0.1–0.92	Present study
5.	Vypeen	0.02–0.18	Present study
6.	Nettoor	0.02–0.11	Present study

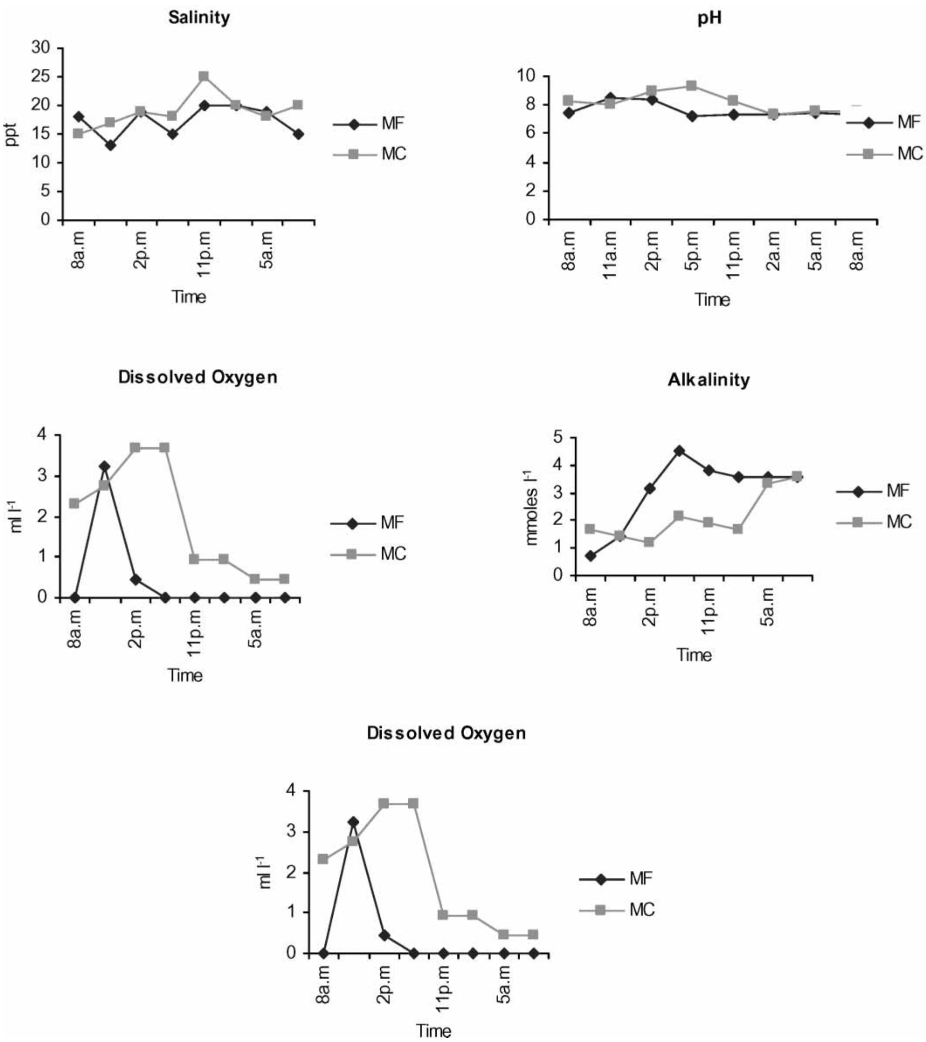

Figure 13. Tidal variation of general hydrographic parameters.

changes were not predominant. This indicated that the main sources of these parameters were the leaf litter and the parts of dead and decayed plant in the system.

The concentration of organic compounds was higher in the forest than in the canal. The concentration of carbohydrates in the forest did not vary much with the tidal cycle but the value of proteins, tannin and lignin widely changed with the tidal discharge suggesting the influence of the tidal water.

Alvarer-Borough [38, 39] generated a 26-h time series of salinity, temperature, oxygen, nutrients, chlorophylls and meteorological variables at the mouth of a bay. However, these investigators realized that sampling for such short periods was like looking at reality through slits, and general conditions could not easily be separated from irregular or episodic events. They emphasized the necessity of taking longer time series, so that the ocean-lagoon relationships could be assessed more rigorously. Due to various limitations, only one tidal cycle was sampled during this study. So the distributions revealed cannot fully reflect the diurnal changes as well as the tidal character of the ecosystem and its adjacent water body.

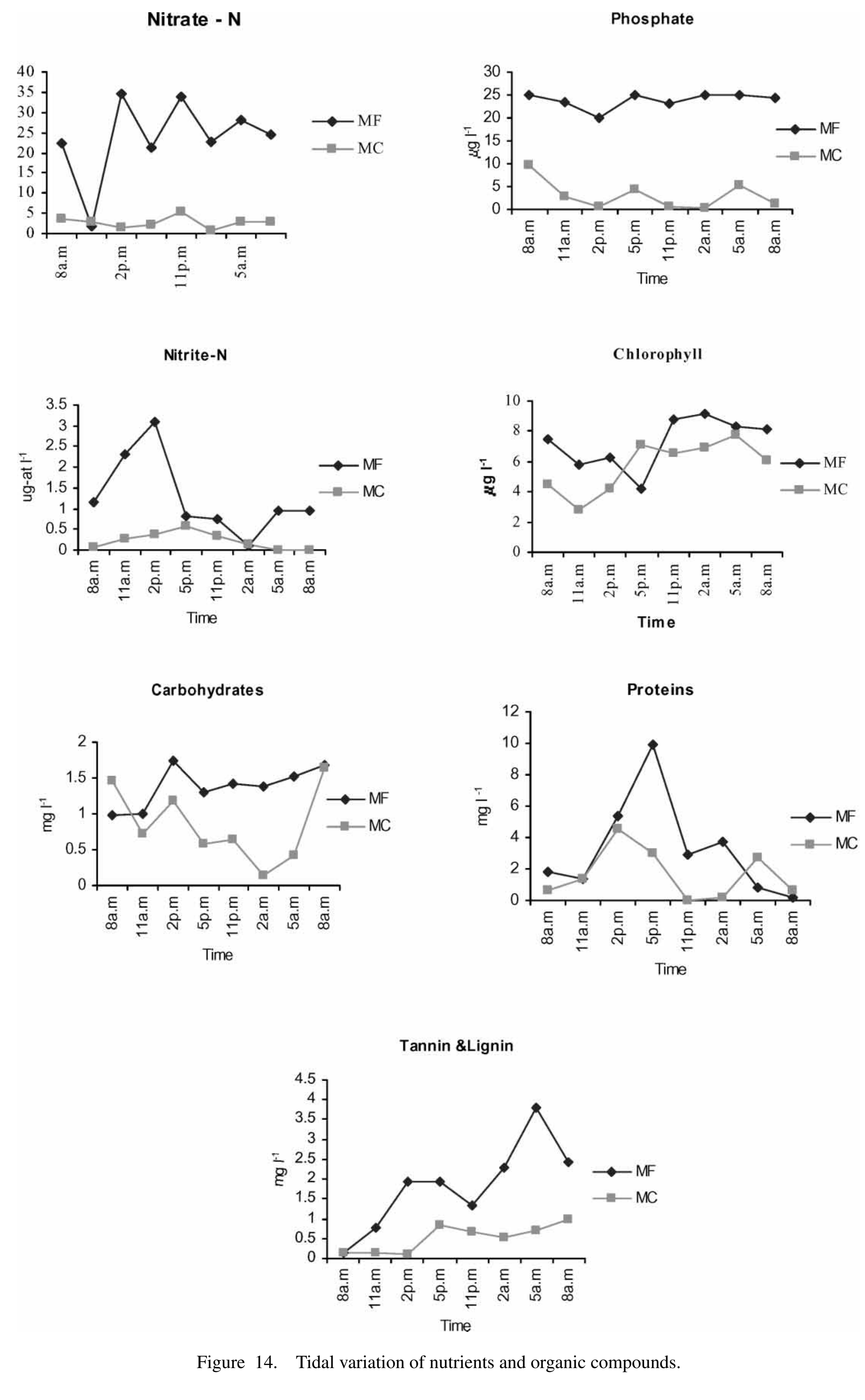

Figure 14. Tidal variation of nutrients and organic compounds.

4. Conclusions

The results of this study suggest the presence of high concentration of organic compounds as well as nutrients in the mangrove ecosystem during low tide. The system was found to be comparatively rich in oxygen during high tide and deficient during low tide. Thus exposing of oxygen consuming leaf detritus to the atmosphere could lead to periods of anoxia in the waters of the system.

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