

Nutrients of the Cochin Backwater in relation to environmental characteristics

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Abstract

The nutrient distribution of the Cochin Backwater was studied at 6 stations throughout the year. The depth profiles of phosphorus (inorganic and organic), nitrogen (nitrate and nitrite) and silicon, showed a marked seasonal rhythm, induced by the local precipitation and land runoff. Changes in other environmental features such as temperature, salinity, dissolved oxygen, pH and alkalinity were small during the pre-monsoon period when the system remains marine-dominated, and large during the monsoon period when the estuary becomes freshwater-dominated. Seasonal changes in the hydrographical conditions of the adjoining coastal waters of the Arabian Sea which influence the backwater system have been discussed.

Introduction

Investigations on nutrients were carried out as part of a programme on the hydrography and primary productivity of the Cochin Backwater, which began in June 1965. The main objective of this programme has been to collect sufficient information on seasonal changes in the environmental features, for a proper understanding of plant and animal communities which occur under naturally fluctuating environmental conditions of this estuary.

Prior to the inception of these investigations, the work done on the hydrography of backwaters has mainly been on temperature and salinity distribution (BALAKRISHNAN, 1957; RAMAMIRTHAM and JAYARAMAN, 1963; GEORGE and KARTHA, 1963), and on seasonal abundance of zooplankton (GEORGE, 1958).

More recently, a series of papers have dealt with the estimation of plant pigments (QASIM and REDDY, 1967), benthic fauna (DESAI and KRISHNAN KUTTY, 1967), light penetration (QASIM et al., 1968) and problems related to organic production (QASIM et al., 1969). No previous account has appeared on the nutrients of this tropical estuary.

Methods

Six stations were selected in the estuary (Fig. 1) for the collection of water samples at fortnightly intervals, generally from 3 different depths (surface, mid-depth and bottom) unless the station was shallow, in which case the mid-depth was omitted. A plastic bucket was used to collect water samples from the surface, and a Van Dorn sampler at depths. Samples for the analysis of nutrients were transferred immediately to suitable polythene bottles and analysed the same day. The values for each fortnight were averaged to find the monthly means at each station. The methods of analysis were as follows:

Inorganic phosphate-P was analysed by the method of WOOSTER and RAKESTRAW (1951), using an SP 500 Unicam Spectrophotometer for measuring optical density at 700 m μ in 10 cm cuvettes, with distilled water in the reference path. The values were not corrected for salt error. For total phosphorus, the method of HANSEN and ROBINSON (1953) was followed, with extinction measurements at 700 m μ . Nitrate-N was measured by the method given by STRICKLAND and PARSONS (1960) and for nitrite-N the method used was of BENDSCHNEIDER and ROBINSON as described by STRICKLAND and PARSONS (1960). Silicate-Si was measured by the modified method of ROBINSON and THOMPSON (1948), with absorbancy measurements at 404 m μ as suggested by BARNES (1959), using the standard solution of potassium chromate buffered with borax.

The other parameters such as temperature, salinity, dissolved oxygen, pH, and alkalinity were measured by using the standard procedures suggested by BARNES (1959) and STRICKLAND and PARSONS (1960).

Description of the area

Some introductory remarks on the backwaters, which are located along Latitude 9° 58' N and Longitude 76° 15' E, have been made earlier (QASIM and REDDY, 1967). The backwaters, as the name implies, include a chain of shallow brackishwater lagoons and swamps, hundreds of miles long, which extend into the central part of the Kerala State, S.W. India. The main sources of fresh water in these backwaters are two large rivers—the Periyar on the north and the Pampa on the south—and a small river called the Muvattupuzha which flows about midway between the two (Fig. 1). At several points the backwaters have either permanent or temporary connections with the sea. These backwaters, in association with the adjoining low-lying lands, paddy fields and a network of canals, form an extensive source of prawn and fish cultivation. The northern portion of the backwaters, adjacent to the Cochin Harbour, which has been the main area of investigation, is called the "Cochin Backwater(s)". It has a permanent connection with the Arabian Sea, about 450 m wide, which forms the main entrance to Cochin Harbour. This region is subjected to regular tidal influence and has all the characteristics of a typical estuary. It runs almost parallel to the mainland and, after encircling many densely-populated islands, finally terminates

further south, in a large lake called the Vembanad Lake (Fig. 1).

Cochin Harbour, situated as it is on one of the islands (Willingdon Island), is surrounded on all sides by channels (Fig. 1), which are being constantly dredged to permit passage to shipping. Because of the influence of harbour and land, the entire area around Willingdon Island becomes polluted.

The depth of the backwater varies considerably from one station to the other. Along the main channel (station 1), it is maintained at about 10 to 12 m for

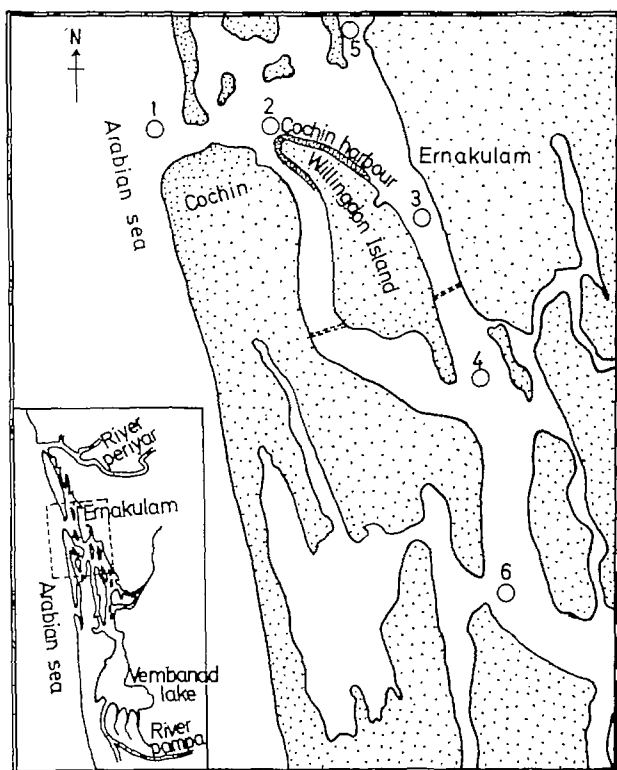


Fig. 1. Location of stations 1 to 6 in the Cochin Backwater (India) which has its main connection with the Arabian Sea. The inset shows the entire Cochin Backwater system with its riverine and marine connections. The system terminates in Vembanad Lake. The portion marked by dotted lines has been enlarged in the adjacent map

navigational purposes, while at other stations it ranges from 8 m (stations 2 and 3) to 6 m (station 4). At stations 5 and 6 the depths are only 3 and 4 m, respectively. The condition of the substrata at all the stations is predominantly muddy, except at station 1 where it is sandy.

At Cochin, the average maximum atmospheric temperature ranges from 28° to 34 °C and the minimum from 20° to 25 °C. The daily temperature has a maximum in April/May and a minimum in July/August. The rainy season in the Cochin area extends from June to September, when there is a strong South West monsoon, and again from late October to early December, which is the period of the North East monsoon.

The annual rainfall at Cochin, based on the average of the past 10 years, is about 3,200 mm, of which nearly 75% occurs from late May or early June to September. The prevailing winds are south westerly from June to September and north easterly during late October and November. For the rest of the year the direction of the winds keeps changing. The mean wind velocity is approximately 6 to 8 miles/h.

At Cochin, the daily solar radiation on bright days is approximately 600 kilolux hours, and on uniformly cloudy days about 150 kilolux hours. Maximum solar radiation reaches the surface from December to March, and minimum from June to September. Radiation intensity ranges from 250 to 500 g cal/cm²/day. Underwater illumination in the backwater is considerably reduced throughout the year and attains minimum values during the monsoon months because of high turbidity. Seasonal variation in the attenuation coefficient (k_{10}) ranges from 0.7 to 4.15 and the Secchi disc visibility from 0.5 to 1.5 m. The tides in the backwater are of a mixed type, predominantly semidiurnal, whose maximum range is about 1 m.

Results

Nutrients

The seasonal variability of the nutrients in the backwater demands an understanding of the freshwater discharge into the system, which is chiefly controlled by the spectacular regime of the rainfall during the monsoon months. This provides a general mechanism underlying not only the nutrient distribution, but also the other environmental features. The area under investigation remains marine-dominated for about 6 months, and then, rather suddenly, becomes freshwater-dominated for the rest of the year. The far reaches of the estuary, both at the northern and southern ends, close to the river basins, remain almost freshwater-dominated throughout the year, except for a brief period just before the monsoon, when the level of the rivers, especially in the Periyar, decreases considerably and the salt water penetrates into the river basins. The other feature of importance is the short-term changes brought about by tidal oscillations, but these remain reasonably constant throughout the year, except perhaps during extraordinary changes in meteorological conditions.

Inorganic phosphorus: Seasonal cycle of the inorganic phosphorus at all the stations has been shown in Fig. 2, from which it can be seen that, during the period when homogenous conditions prevail, i.e. from January to April, phosphorus values are low and there is very little difference in the values at various depths, except at stations 5 and 6, where conditions (due to shallowness) even in these months hardly remain persistent. Towards May and June, when the pre-monsoon and monsoon showers set in, the phosphorus values attain their first peak. The difference in the depth profile also becomes well marked. The values

increase from the surface to the bottom and this seems to be true for all stations. This probably indicates that the phosphorus contribution of the estuary is largely dependent upon external sources such as land drainage and freshwater runoff. However, if a direct relationship between the inorganic phosphorus and freshwater discharge does exist, one would expect maximum values at the surface, where brackish water remains undisturbed (see section B), and decreasing values towards the bottom. However, from the data obtained, the reverse seems to be true, indicating that there may be some other mechanism for phosphorus enrichment in the estuary.

The phosphorus values, after attaining their first peak, decline sharply, suggesting that further runoff from the land does not increase phosphorus concentration. Following this decline, another peak appears during August to September, which does not remain consistent at all the stations. At some stations a third peak appears in October, the occurrence of which does not seem to coincide with the preponderance of rain.

Organic phosphorus: Fig. 3 shows the values of organic phosphorus at two different depths of the various stations. The organic phosphorus was estimated by difference. It can be seen from the figure that the values were much higher than those of the inorganic phosphorus. There was no well defined seasonal rhythm in the distribution of organic phosphorus. Short pulses of high and low phosphorus occurred at different times of the year. During several months the values at the surface and at the bottom were almost alike, indicating an homogenous distribution of organic phosphorus throughout the water column; but at other times of the year, the surface values showed an inverse relation to those at the bottom. In general, organic phosphorus at the bottom was greater than at the surface. Since highly turbid conditions prevail in the estuary, it seems that much of the organic phosphorus remains adsorbed with silt and other inert material. Its inconsistent distribution, therefore, in the water column, may be because of the uneven distribution of suspended material. A greater occurrence of organic phosphorus at the bottom provides further evidence that it remains bound to the stirred-up sediment.

A correlation between the distributions of organic and inorganic phosphorus will reveal that there is always more inorganic phosphorus at deeper layers than at the surface. Similarly, organic phosphorus occurs in larger quantities at the bottom. This raises the possibility of organic phosphorus being decomposed at deeper layers, where the water remains stagnant and anaerobic conditions develop (see "Discussion"), into inorganic phosphorus which gradually moves up to the surface. The apparent relationship, therefore, between inorganic phosphorus and the freshwater discharge, may be due to a silt-loaded influx of water containing large quantities of dissolved and particulate organic matter, whose

ultimate decomposition probably occurs at the bottom.

Nitrate-nitrogen: Seasonal changes in nitrate-N have been shown in Fig. 4. It is clear from the figure that, for most of the year, there is little or no nitrate-N. This is particularly evident from October to April, when predominantly marine conditions prevail in the estuary. From May onwards the values begin to rise reaching as high as 25 to 35 $\mu\text{g-at/l}$ during July, August and September. Such an instantaneous concentration of nitrate-N seems entirely due to freshwater discharge and land runoff (EWINS and SPENCER, 1967). There is little difference between the nitrogen cycle observed at the surface, mid-depth and bottom, suggesting that the distribution of nitrate-N is homogenous throughout the water column in all seasons. Minimal values of nitrate-N, when the conditions in the estuary are predominantly marine, suggest that the contribution of nitrogen from the sea is very little. The striking similarity in the nitrogen cycle at all the stations suggests that a uniform contribution of nitrogen from external sources is maintained throughout the estuary. However, it is of interest to note that the values are not uniformly high throughout the rainy season which extends with varying intensities from May to November. The occurrence of abnormally high values during July to September suggests that these are associated with the early part of the monsoon when the freshwater influx is maximum, and that any further freshwater discharge in subsequent months does not add to the nitrogen contribution.

Nitrite-nitrogen: The nitrite-N, at all the stations, shows a trimodal cycle (Fig. 5). The peaks occur during a period when the system remains freshwater-dominated. However, there are some notable differences in the cycle of nitrite-N with that of nitrate-N. Firstly, the values of nitrite-N are not homogenous throughout the water column, except during the period when the conditions in the estuary are marine, i.e. from December to April. Secondly, during the monsoon months, the values at the surface become significantly lower than those at deeper layers, which cannot be explained in terms of freshwater discharge alone. Finally, the values of nitrite-N are much lower than those of nitrate-N.

These features clearly suggest that the nitrite-N may be formed as a result of decomposition of organic nitrogen—an explanation which is somewhat similar to that of the phosphorus cycle. Since nitrite-N is a transitory stage in the nitrogen cycle of the system, its progressive decrease from the bottom to the surface may suggest its possible conversion into nitrate-N.

Silicate-silicon: The silicon values remain low from December to April and become very high during the monsoon months (Fig. 6). That the silicate-Si cycle is entirely dependent upon the freshwater discharge is clearly evidenced by the fact that the values decrease from the surface to the bottom, showing a typically inverse relationship with the salinity profile (Fig. 8). Maximum values recorded during July and

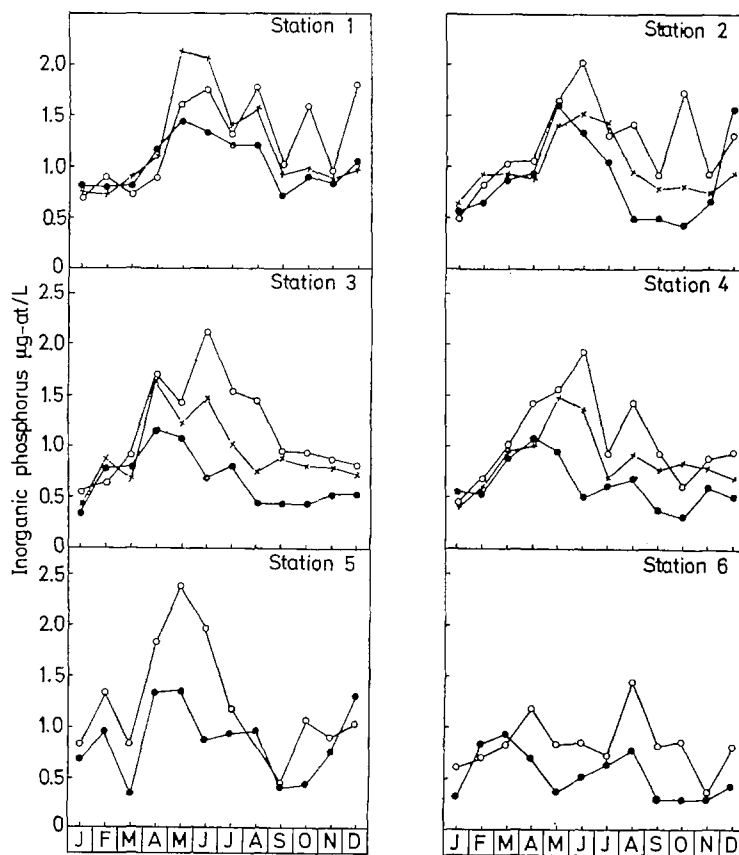


Fig. 2. Distribution of inorganic phosphorus at stations 1 to 6 of Cochin Backwater during 1965 and 1966. Surface: closed circles; mid-depth: crosses; bottom: open circles

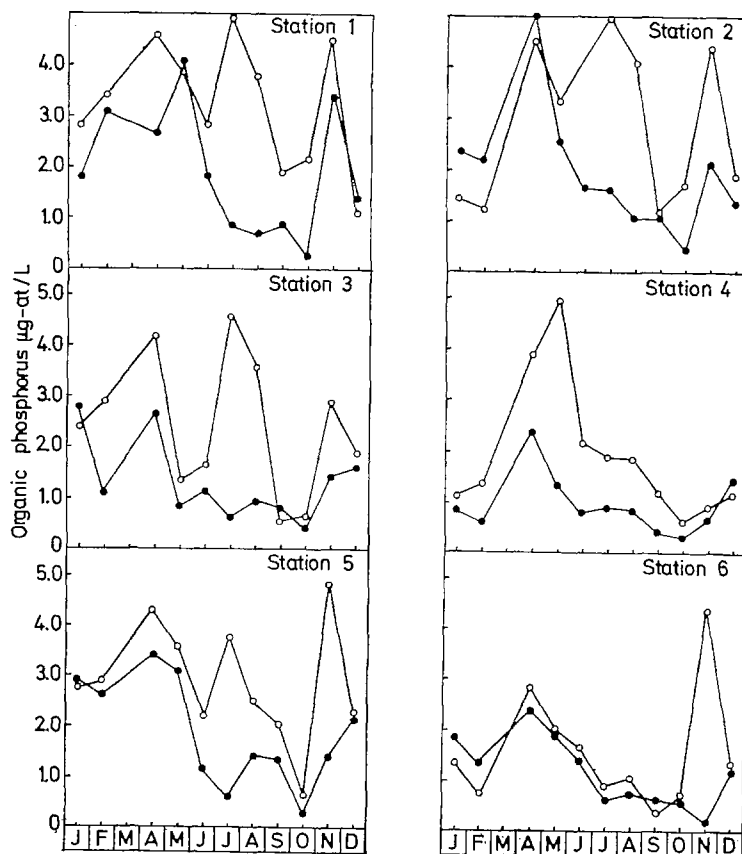


Fig. 3. Distribution of organic phosphorus at stations 1 to 6 of Cochin Backwater during 1965 and 1966. Surface: closed circles; bottom: open circles

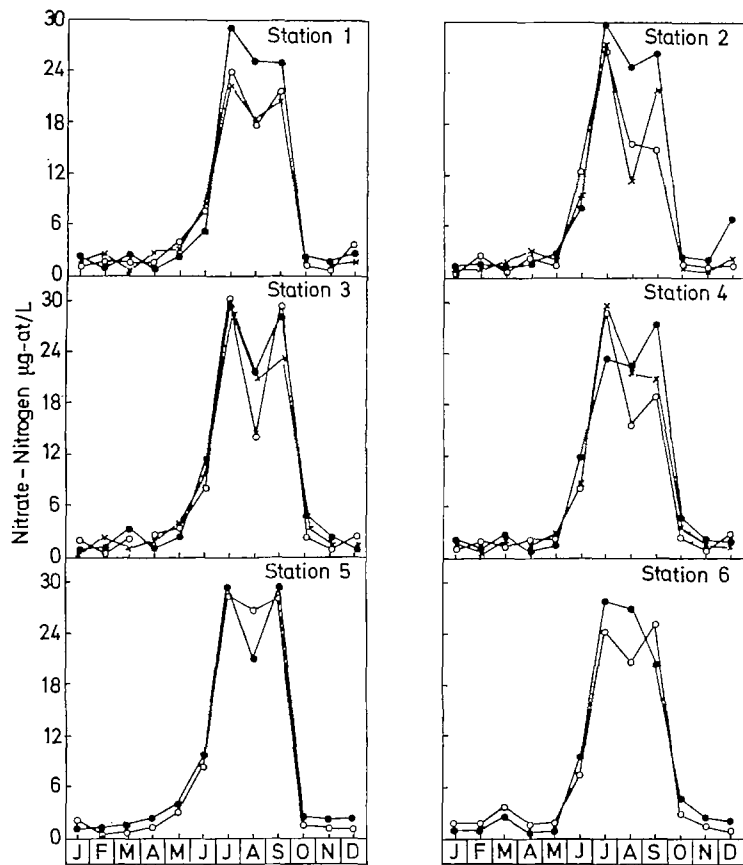


Fig. 4. Distribution of nitrate-nitrogen at stations 1 to 6 of Cochin Backwater during 1965 and 1966. Surface: closed circles; mid-depth: crosses; bottom: open circles

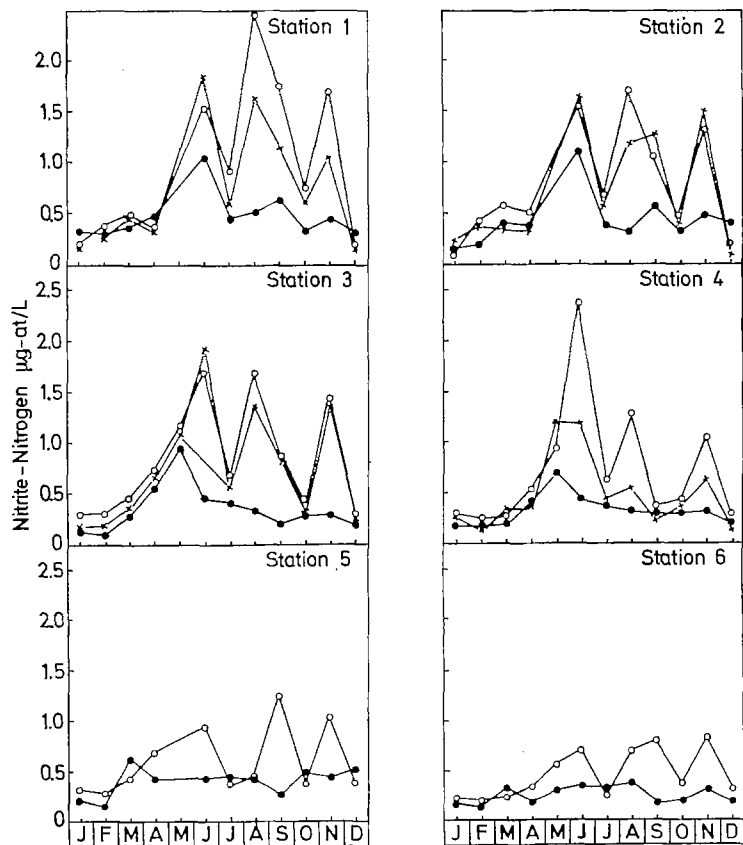


Fig. 5. Distribution of nitrite-nitrogen at stations 1 to 6 of Cochin Backwater during 1965 and 1966. Symbols as in Fig. 4

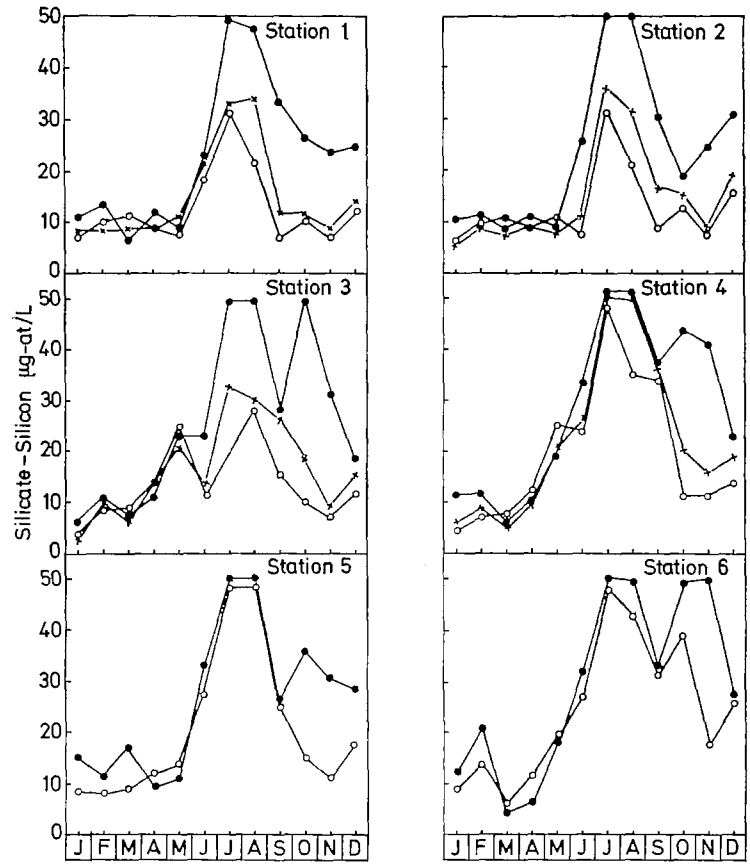


Fig. 6. Distribution of silicate-silicon at stations 1 to 6 of Cochin Backwater during 1965 and 1966. Symbols as in Fig. 4

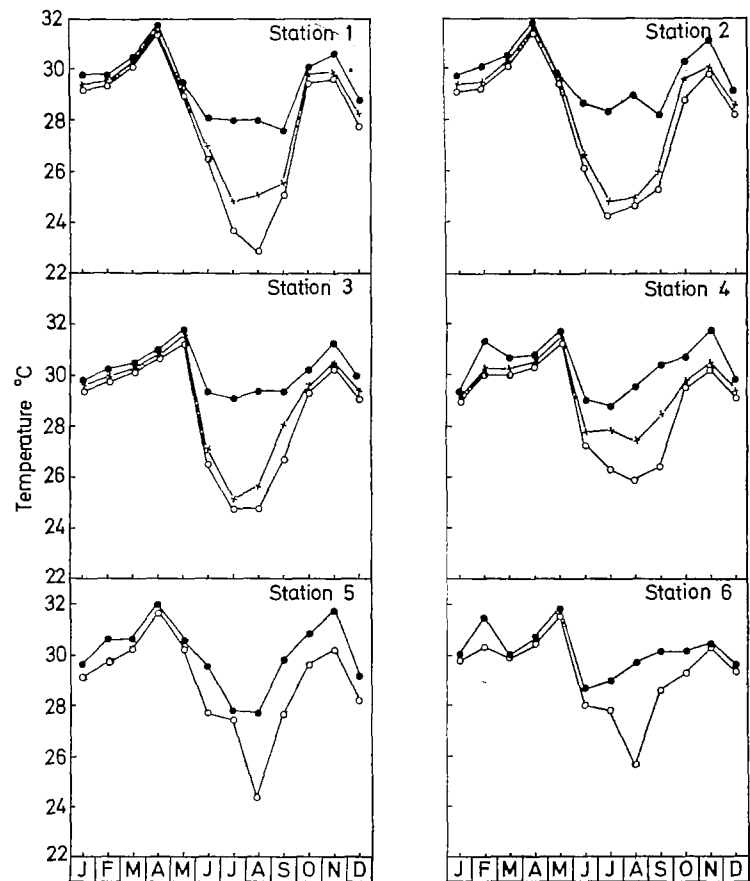


Fig. 7. Seasonal variation in temperature at stations 1 to 6 of Cochin Backwater. Symbols as in Fig. 4

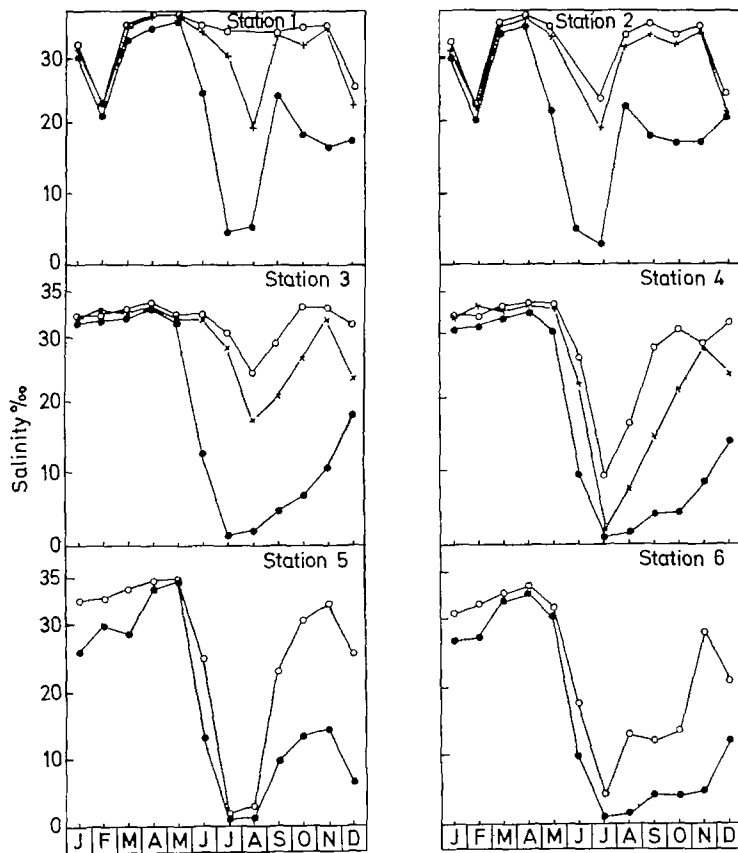


Fig. 8. Seasonal variation in salinity at stations 1 to 6 of Cochin Backwater. Symbols as in Fig. 4

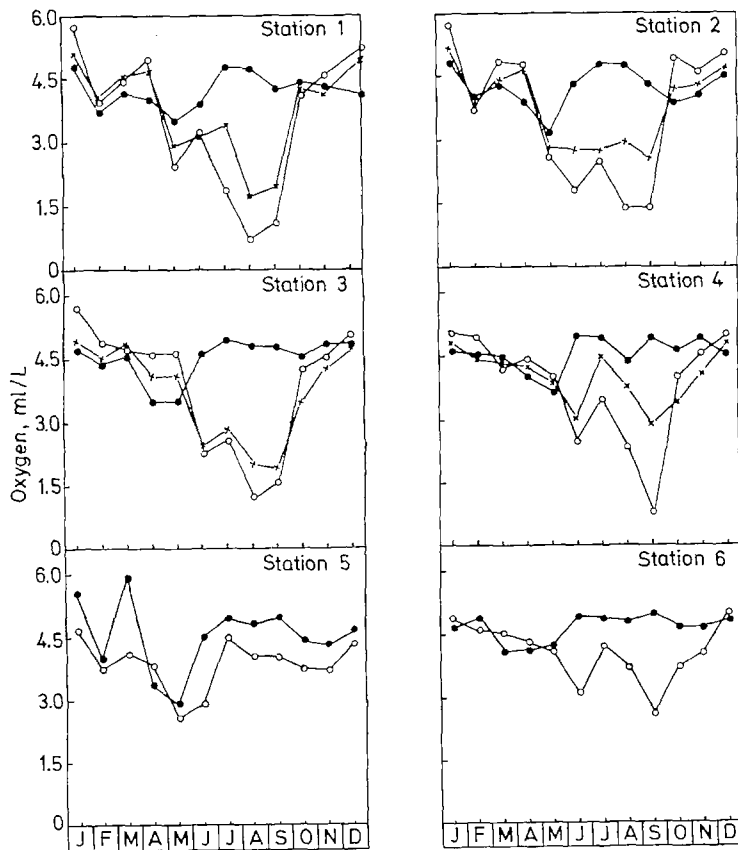


Fig. 9. Seasonal variation in dissolved oxygen at stations 1 to 6 of Cochin Backwater. Symbols as in Fig. 4

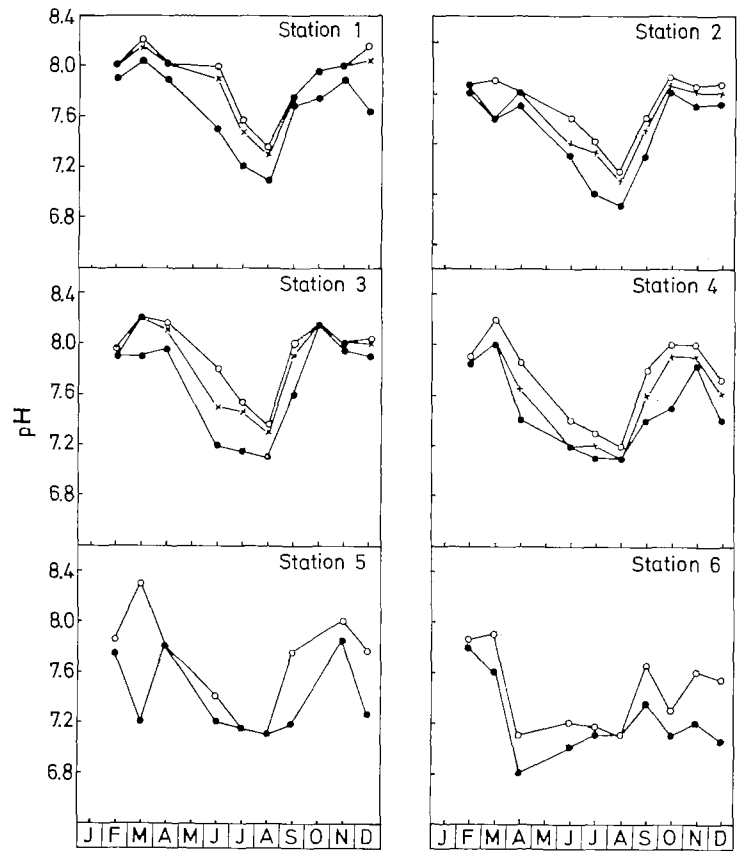


Fig. 10. Seasonal variation in pH at stations 1 to 6 of Cochin Backwater. Symbols as in Fig. 4

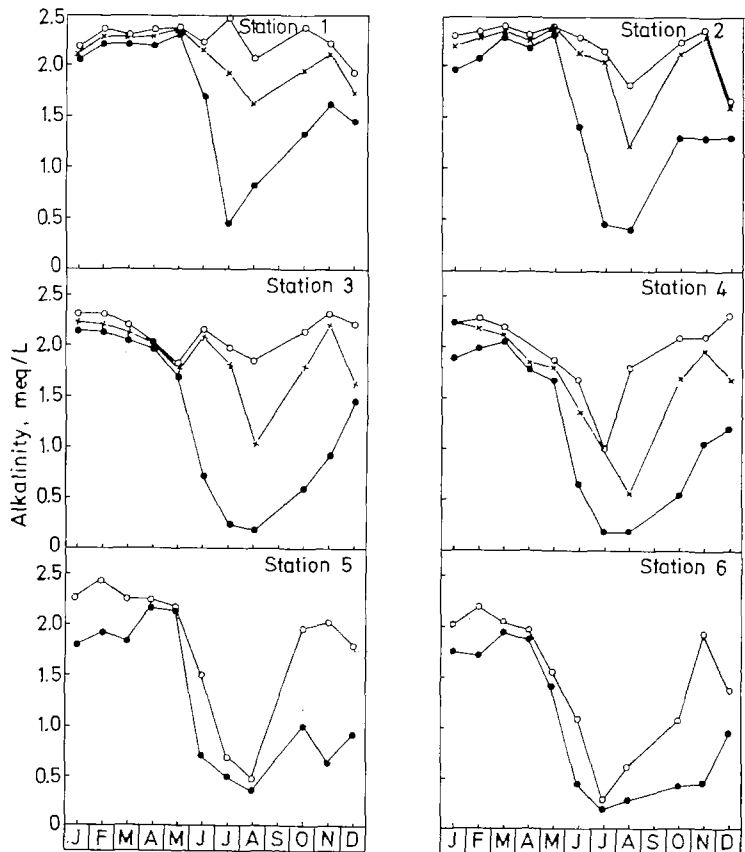


Fig. 11. Seasonal variation in total alkalinity at stations 1 to 6 of Cochin Backwater. Symbols as in Fig. 4

August indicate that the silicon is associated with the heavy silt load of the estuary. The values at those stations which are close to the sea (stations 1 and 2), fall after August but, at other stations away from the sea, they attain a secondary peak during October and November (Fig. 6).

Environmental characteristics

Temperature: Records of seasonal changes in temperature have been shown in Fig. 7. An examination of the various curves will reveal that, during the pre-monsoon months when the water is highly saline (Fig. 8), no thermal stratification exists. The temperature during this period (January to April) remains uniform throughout the water column and records its maximum. This seems associated with warmer weather and maximum solar radiation during these months. From May onwards with the onset of the monsoon, the changes in the water temperature become apparent. These are accompanied by a gradual fall at the surface and a very rapid fall at deeper layers during July and August. Thus from June onwards a sharp thermal gradient develops in the estuary, with a maximum difference of more than 5°C in August, which continues with varying degrees till about September to October.

The changes in the depth profile of temperature clearly indicate that the freshwater discharge alone is not responsible for the changes in temperature, since the variations in deeper layers are far more pronounced and rapid than at the surface. Such a rapid change at the bottom cannot occur unless there is an intrusion of a tongue of cold water from the sea into the estuary. The effect of this water is felt, with varying degrees, at all the stations; even though the vertical thermal gradient in shallow regions (stations 5 and 6) is not well marked (Fig. 7).

Salinity: Fig. 8 shows the variation in salinity at different depths of the various stations. Like temperature, during the pre-monsoon months, the salinity shows a vertical homogeneity, so much so that the backwater becomes simply an extension of the adjoining sea. With the commencement of the monsoon rain, which normally starts in May (although in 1966 it was delayed by a few weeks and started in June), the surface water is considerably diluted and a clearly defined halocline develops, with brackish water, or very nearly fresh water at the top and sea water at the bottom, both remaining more or less undisturbed. This pronounced gradient in salinity continues until about October and November, when it is destroyed and homogenous conditions, characteristic of the pre-monsoon months, are restored. In the shallow regions of the estuary (stations 5 and 6) the water offers little resistance to mixing, and therefore the salinity stratification remains less sharp (Fig. 8). The possible mechanism which gives rise to such a pronounced gradient in temperature and salinity has been discussed in the following section.

Dissolved oxygen: Like temperature and salinity the dissolved oxygen shows a pronounced seasonal change (Fig. 9). While at the surface the values are subjected to little fluctuations, at deeper layers a rapid disappearance of oxygen was noticed during the monsoon months. Values as low as 1 to 2 ml/l were commonly observed near the bottom during August, September and October. The existence of a vertical oxygen gradient is an outstanding feature during these months, which disappears when marine conditions begin to occur. Such oxygen changes seem associated with similar changes in temperature and salinity. Like other parameters, the oxygen gradient remains less sharp in the shallow regions (stations 5 and 6).

Hydrogen ion concentration: The pH shows a considerable fluctuation at the surface (Fig. 10). Maximum values with small differences between surface and bottom were recorded from October to about March. During the period of freshwater discharge the values at all depths decreased, reaching a minimum during July and August. It is interesting to note that a clear stratification such as that noticed in temperature, salinity and oxygen, was not observed in regard to pH values. The pH of the entire water column either decreases or increases simultaneously.

Alkalinity: Fig. 11 illustrates the alkalinity profile for different months of the year. The values in the pre-monsoon months indicate little variation but, during the monsoon months, wide fluctuations in alkalinity are noticed, with values as low as 0.4 meq/l at the surface and approximately 2.5 meq/l at the bottom. At stations 5 and 6 the differences between surface and bottom are less pronounced.

Discussion

The foregoing account clearly indicates that the cycle of events in the estuary is fairly regular, making the year divisible into 3 distinct seasons, each of 4 months duration.

1: The stable season, January to April; 2: the monsoon season, May to September; 3: the recovery season, October to December.

The stable season: During this season the upper reaches of the estuary show simple and uniform conditions. There is practically no vertical gradient in various parameters, and the horizontal changes are gradual and uniform. The freshwater discharge is reduced to a minimum and the estuary becomes merely an extension of the adjoining sea, with environmental features almost similar to those of the coastal waters.

The monsoon season: This season is associated with sudden changes from typically marine to brackish-water conditions. With the heavy rain, the estuary becomes a focal point of freshwater discharge, which is considerable and bears a good relation to monthly precipitation and river discharge. During this period,

extremely significant changes occur in the environmental features of the estuary.

The recovery season: During this period there is a general reduction in the freshwater discharge and the marine components of the system begin to develop with the invasion of the sea water from the bottom zone towards the surface. This results in a disappearance of pronounced gradients of properties. Probably, the mechanism involved in mixing the bottom water with the surface water is the formation of internal waves, very similar to that described in Australian estuaries (SPENCER, 1956), which leads to disappearance of stratification within a week after its formation.

The annual changes reported in the environmental features of the backwater will not be complete without mentioning, briefly, the changes occurring in the coastal waters around Cochin. RAMAMIRTHAM and JAYARAMAN (1960), while discussing the hydrography of the shelf waters off Cochin, have divided the sequence of events into 4 seasons, namely (1) the period of the S.W. monsoon (June, July and early August); (2) the period of upwelling (end of August, September and early October); (3) the period of sinking (end of October to February); (4) the period of stable conditions (March, April and probably May). Similarly, in a recent communication, DABBYSHIRE (1967) has distinguished 4 distinct seasons along the Kerala coast, of which the monsoon season is of particular interest with reference to changes in the salinity of surface water. She has shown that a tongue of low-salinity water juts out into the sea at Cochin due to the discharge of fresh water from the backwaters.

Concurrent with the freshwater discharge from the Cochin Backwater during the monsoon months, there is an incursion of cold saline water from the Arabian Sea into the backwater. This water becomes particularly noticeable at the bottom, and has been recognized by RAMAMIRTHAM and JAYARAMAN (1963) as upwelled water from the Arabian Sea, which finds its way into the backwater through the main channel. An examination of various parameters described in this paper will reveal that, during the monsoon period, the bottom layers of the backwater suddenly become cold, saline, oxygen-deficient and rich in nutrients. The explanation, therefore, put forward by RAMAMIRTHAM and JAYARAMAN (1963) that this water could only be the upwelled water from the Arabian Sea, seems valid. If this evidence is accepted, then the problems of eutrophication of the estuary become far more complicated. On one side we have large quantities of nutrients, particularly nitrate and silicate, coming into the estuary with the freshwater discharges which are ultimately drained into the sea. At the same time, there is a constant influx of sea water into the estuary, including the upwelled water during the monsoon months.

Table 1 gives the data of inorganic and organic phosphorus in the backwater as percentages of total

phosphorus for the 3 seasons. As can be seen from the table, the values of organic phosphorus were generally higher than those of inorganic phosphorus, except for the monsoon period, when the two forms of phosphorus were in almost equal proportions. This suggests that, probably, the freshwater runoff brings in both inorganic and organic phosphorus. It is also clear from the table that the inorganic phosphorus increases during the monsoon months and progressively decreases during the post- and pre-monsoon months. For organic phosphorus the reverse seems to be true. In each form of phosphorus there seems no significant difference between the percentages at the surface and those at the bottom, although the individual values of both inorganic and organic phosphorus showed an increase with depth during the monsoon months (Figs. 2 and 3). Such a distribution suggests that the decomposition of organic material at the bottom may be an important factor in phosphorus distribution.

Table 1. *Inorganic and organic phosphorus in Cochin Backwater expressed as percentages of total phosphorus. The range shown at each depth refers to stations 1 to 6 and to three seasons*

Season	Inorganic-P (% of total)		Organic-P (% of total)	
	surface	bottom	surface	bottom
Pre-monsoon (Feb.—May)	25—40	25—35	60—75	65—75
Monsoon (June—Sept.)	40—60	30—60	40—60	40—70
Post-monsoon (Oct.—Jan.)	35—50	25—45	50—65	55—75

The interchange of phosphorus between the bottom and the overlying water may be another feature to be considered. According to MOORE (1930) the phosphorus content of estuarine mud is 50 times greater than that of the water above and, therefore, any stirring up of the sediment would greatly influence the concentration of phosphorus in the bottom layers. In estuaries, the release of phosphorus from the silt occurs at a low oxygen concentration (ROCHFORD, 1951) and at an increased pH (CARETT and GOODGAL, 1954). Such effects may be important in the backwaters, where dissolved oxygen and pH differences from the surface to the bottom are quite considerable during the monsoon months.

The available sources of inorganic nitrogen in an aquatic environment, as is well known, are nitrate, nitrite and ammonia. These are formed as part of the nitrogen cycle, either by oxidation of ammonia or by reduction of nitrate to nitrite and ammonia. The latter process has been referred to as denitrification and has been found to occur both in the water column and in the sediment, at low oxygen concentrations (VACCARO, 1965). Generally, the amount of nitrite in the sea is small as compared to that of nitrate and ammonia, although in temperate waters it shows a

Table 2. Seasonal variation in the nitrogen-to-phosphorus ratio of Cochin Backwater

N:P ratio	January	February	March	April	May	June
Ranges at stations 1 to 6	3:1 to 1:1	1:2 to 2:1	1:1 to 2:1	1:1 to 2:1	1:1 to 3:1	3:1 to 23:1
N:P ratio	July	August	September	October	November	December
Ranges at stations 1 to 6	12:1 to 99:1	9:1 to 80:1	1:1 to 7:1	1:1 to 13:1	1:1 to 7:1	1:4 to 4:1

slight increase in winter (COOPER, 1933). In the backwater both these forms of nitrogen appear at the bottom, presumably as a result of decomposition of organic nitrogen within the sediment.

Table 2 lists the ranges in the N:P ratio by atoms at stations 1 to 6 throughout the period of observation. It is clear from the table that anomalously low and high ratios occur in the backwater. During the stable period (pre-monsoon) the ratios are consistently low, but become abnormally high during the monsoon period, and show no constancy whatsoever during the post-monsoon period. In a recent communication, EWINS and SPENCE (1967) have drawn attention to wide variations in the N:P ratio of the Menai Straits.

The silicon content of the backwater is generally high, which is to be expected because of considerable freshwater discharge and land drainage. High silicate values are associated with low salinity of water and vice versa, indicating that there is an inverse relation between the two.

As has been reported elsewhere (QASIM et al., 1969), the annual cycle of primary production in the backwater has 3 distinct peaks—one in April, the second in July and the third in October. These peaks show only 2 to 3-fold increase. There seems no firm basis, therefore, for believing that the instantaneous concentrations of nutrients as inorganic salts in the estuary provide a significant source of phytoplankton bloom.

Summary

1. In the Cochin Backwater, which is an estuarine area on the west coast of India, the nutrient distribution is largely dependent upon 2 main components—the marine influence and the freshwater discharge.

2. During the period when the system remains predominantly marine, the nutrient concentrations are low and remain homogenous throughout the water column, but during the period of freshwater discharge, high concentrations of nutrients occur, with gradient zones within the system.

3. The heavy rainfall brings about marked changes in temperature, salinity, dissolved oxygen, pH and alkalinity of water; each of these parameters has its own characteristic vertical profile.

4. Large quantities of organic matter are brought into the estuary by the land runoff. These are probably decomposed at the bottom and, as a conse-

quence, seem to have a marked influence on the nutrient distribution.

5. The monsoon period is associated with marked changes in the adjacent coastal waters, whose influence on the backwater greatly complicates the system.

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