```
910 GOTO 200
920 END
930 '
940 FOR I = SL-1 TO 1 STEP-1
950 N(I) = (X2 (I + 1) *N(I + 1) + C(I) *
    X2 (I + 1)
960 NEXT I
970 RETURN
980 '
990 PRINT "NUMBERS CAUGHT IS MORE
    THAN POPULATION!"
1000 PRINT
1010 PRINT "FOR F/Z = " ;:PRINT USING
    "#.####'; J
1020 A$ = INPUT$(1)
1030 CLS: GOSUB 1150
1040 RETURN
1050 '
1060 FOR I = 1 TO NL-1
1070 E(I) = C(I) / (N(I) - N (I + I))
1080 E(NL) = C(NL)/N(NL)
1090 F(I) = M*E(I)/(1-E(I))
1100 Z(I)=F(I)+M
1110 NEXT I
1120 F(NL) = M* E(NL)/(1-E(NL))
1130 Z(NL) = F(NL) + M
1140 RETURN
1150 '
1160 CLS
1170 ESTOP = J-EINC
1180 DELX = ABS (E (NL)- ESTART)
1190 'PRINT DELX:D$ = INPUT$ (1)
1200 IF DELX < = .0001 THEN J = ESTOP:
    GOTO 630
1210 IF DELX > .0001 THEN 1220
1220 EMIN = J
1230 EMAX = J + EINC
1240 EINC = .0001
1250 ESTART = E(NL)
1260 GOTO 490
1270 RETURN
```

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DISTRIBUTION OF NUTRIENTS IN A BAR-BUILT ESTUARY, SOUTH WEST COAST OF INDIA

ABSTRACT

Temporal variations of principal inorganic nutrients were monitored in Thengapattanam estuary, a bar-built system on bimonthly basis at four selected stations (8° 14'N; 77° 11'E), during 1994. The estuary was characterised by the absence of tidal influence during the pre and postmonsoon seasons owing to the build up of sand bar at the mouth. Seasonal precipitation and salinity stratification apparently controlled the availability of major nutrients in the water column. Annual variations in nutrient concentrations were nitrate : 5.72-23.19 µg at N.I.-1; nitrate: 0-0.67 µg at N.I.-1; phosphate : 0.14-1.61 µg at P.I.-1 and silicate : 5.31-110.29 µg ατ Σι.1^{-1}. *N* : P showed an annual variation between 9.21 and 41.73 with occurrence of optimum ratios (= 16) about the monsoon season.

THE DISTRIBUTION and variability of principal plant nutrients (N, P & Si) in estuaries largely determine the biomass and productivity of phytoplankton. Detailed studies on the source, sinks and turnover pattern of these inorganic elements in estuaries have great scope in understanding the fishery potentiality of such systems (Fisher *et. al.*, 1988). Observations on short term variations in these nutrients are found helpful in monitoring their turnover in

the estuarine photic zone (Jordan *et. al.*, 1991). Bar-built estuaries manifest unique pattern of mixing which make the study of nutrient dynamics in these systems more interesting. Reports on nutrient distribution in tropical bar-built estuaries are scanty (Anila Kumary and Abdul Azis, 1992). An annual study carried out on the distribution of nutrients in Thengapattanam estuary is presented in this communication.

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Study Area

The Thengapattanam estuary (8° 14' N: 77° 11' E) is a bar-built system formed by the confluence of River Thamiraparani (Kanyakumari district) with the Arabian sea at Erayumanthurai in the southern end of the west coast of India. The location of a weir across the river at Mankadu limits the length of the estuary to 7.2 km. Freshwater drainage is predominant during monsoon season and the estuary mouth remains closed during the rest of the year. On the basis of previous observation on salinity (Vareethiah, 1989), four study sites were fixed along the stretch of the estuary: *station 1* at Mankadu (head of estuary) representing freshwater zone; station 2 at Ganapathiyankadavu and station 3 at Vykallor both representing tidal zone and station 4 at Erayumanthurai representing gradient zone about 400 m ahead of the estuary mouth (Fig. 1)

MATERIAL AND METHODS

Water samples were collected from the surface and bottom of each station on fortnightly cruises during 1994 and sub samples were analysed for nutrients. The water samples were immediately filtered through a millipore membrance filter (0.45 μ). Separate glass bottles

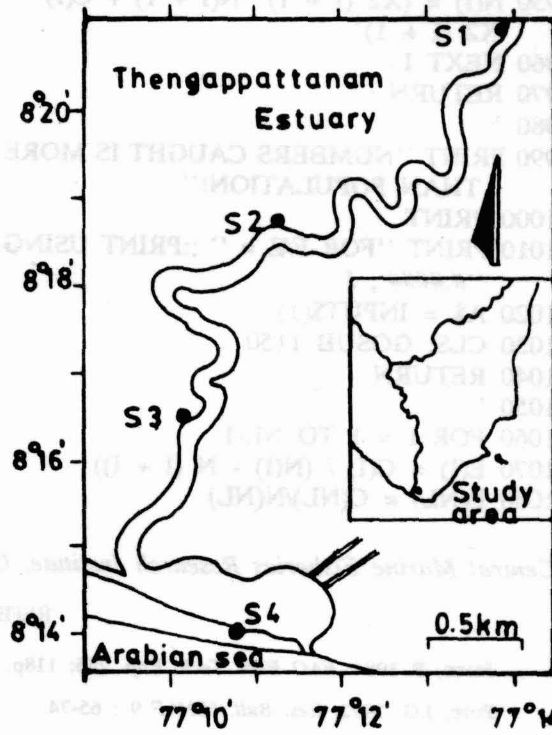

FIG. 1 *Sampling Stations.*

were used to keep sub samples for phosphate estimation. All analyses were made in duplicate and within two hours after sampling.

Rainfall and river discharge data were obtained from the public works department; the estuary mouth was monitored during regular cruises. Mohr Knudson's titrimetric technique (Grasshoff *et. al.*, 1983) was followed for the salinity estimation. Strickland and Parson's (1968) methods were followed for determination of nitrate and nitrite. A modification of Murphy and Riley's (1962) method (Grasshoff, *et. al.*, 1983) was followed for the estimation of phosphate. Mullin and Riley's (1955) method was followed for the determination of silicate.

Results and Discussion

Rainfall, river discharge and nature of estuary mouth:

Monthly rainfall during the year varied between 5 and 767 mm with an annual mean of 212.38 ± 229.78 mm. Monthly river discharge ranged from 17.5 to 283.8 Mm^3 (annual mean: 99.1 ±71.63 Mm^3) and the recorded temporal variations are shown in Fig. 2. On seasonal scale, monsoon season recorded of mean rainfall of 296 mm followed by the postmonsoon with a mean precipitation of 210.9 mm. The river discharges were generally high during the monsoon and postmonsoon periods. The mouth of the estuary remained closed with the build up of sand bar during the premonsoon and

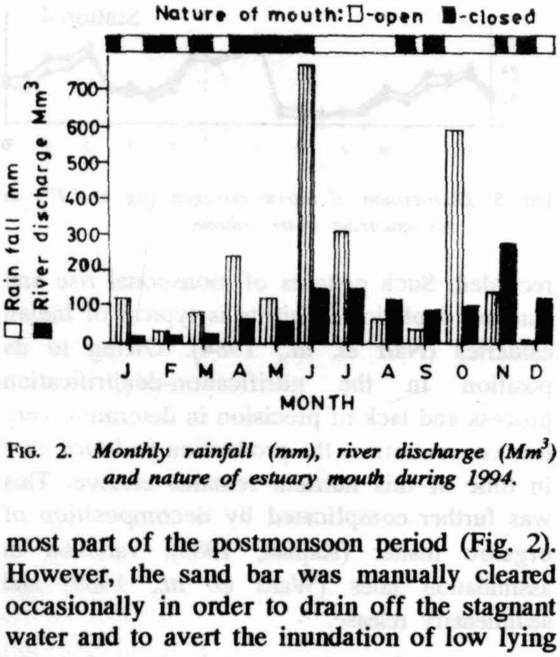

FIG. 2. *Monthly rainfall (mm), river discharge (Mm^3) and nature of estuary mouth during 1994.*

most part of the postmonsoon period (Fig. 2). However, the sand bar was manually cleared occasionally in order to drain off the stagnant water and to avert the inundation of low lying areas along the lower reaches of the estuary.

Salinity:

Salinity of the surface water at various stations ranged from 0.05 to 7‰ (S1), 0.2 to 2.6‰ (S2 and S3) and 0.08 to 7.7‰ (S5); in the bottom waters the respective ranges were 0.02 to 3.4‰ (S1), 0.01 to 20.4 ‰ (S2), 0.5 to 21.6‰ (S3) and 2.1 to 26.8‰ (S5). Limnetic conditions in the monsoon season due to heavy land drainages and strong haloclines during the other periods thanks to the build up of sand bar in the month were noteworthy features of the estuary. Unlike major Indian estuaries wherein complete scouring of salinity never occurs during floods (Shynamma and Balakrishnan, 1973; Devassy, 1983), the estuary under study manifested typical freshwater conditions during monsoon period. Regular tidal incursion was a rare phenomenon and mixing was nearly absent in times of tidal influx (Fig. 3). Highest mean salinity occurred in the premonsoon period.

Nitrate:

Nitrate concentration in the surface water annually varied between 3.02 and 23.7 µg at. $N.1^{-1}$ at station 1, 3 and 23.3 µg at. $N.1^{-1}$ at station 2, 2.86 and 22.9 µg at. $N.1^{-1}$ at station 3 and 3.78 and 23.1 µg at $N.I.^{-1}$ at station 4.

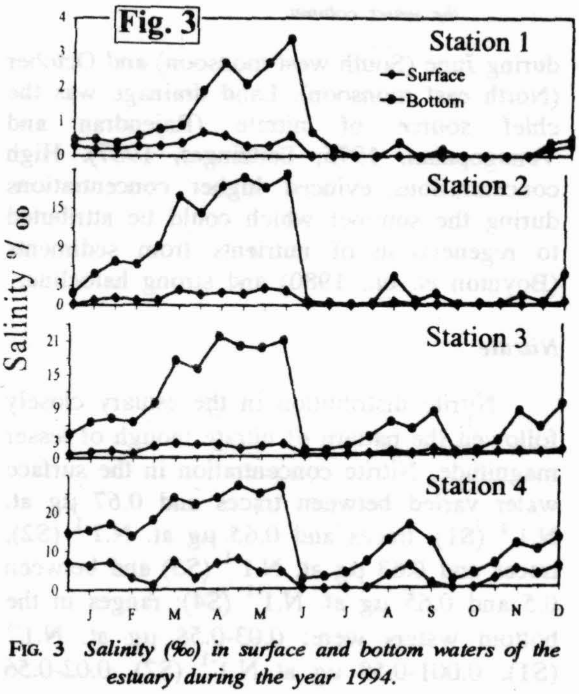

FIG. 3 *Salinity (‰) in surface and bottom waters of the estuary during the year 1994.*

Ranges in the bottom water of the respective station were 5.36-22.7, 5.66-20.1, 5.72-19.8 and 7.66-2.13 μg at N.I^{-1} (Fig. 4). Nitrate distribution in the estuary revealed two peaks

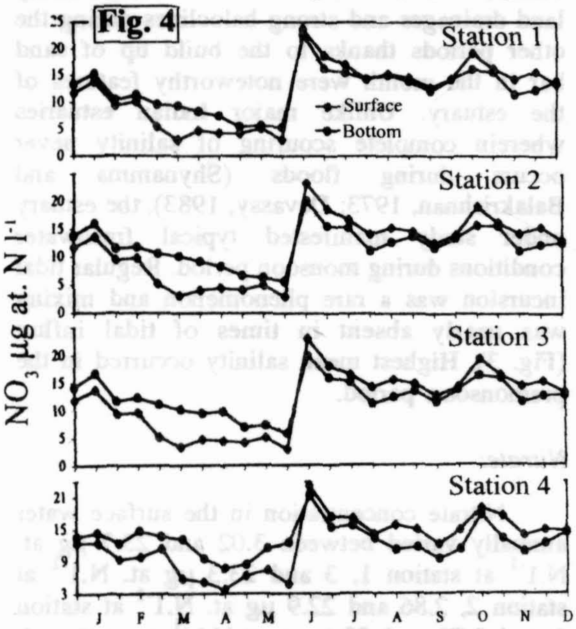

FIG. 4 *Distribution of nitrate nitrogen (μg at.N.I^{-1}) in the water column.*

during June (South west monsoon) and October (North east monsoon). Land drainage was the chief source of nitrate (Rajendran and Venugopalan, 1975; Seitzinger, 1987). High concentrations evinced higher concentrations during the summer which could be attributed to regeneration of nutrients from sediments (Boynton *et. at.*, 1980) and strong halocline.

Nitrate

Nitrite distribution in the estuary closely followed the pattern of nitrate though of lesser magnitude. Nitrite concentration in the surface water varied between traces and 0.67 μg at. N.1^{-1} (S1), traces and 0.65 μg at. N.1^{-1} (S2), traces and 0.63 μg at. N.1^{-1} (S3) and between 0.5 and 0.65 μg at. N.1^{-1} (S4); ranges in the bottom waters were: 0.03-0.58 μg at. N.1^{-1} (S1), 0.001-0.58 μg at N.1^{-1} (S2), 0.02-0.56 μg at N.1-1 (S3) and 0.09-0.58 μg at N.1^{-1} (S4). The monsoonal drainages apparently resulted in the highest concentration of nitrite following which period a steady decline was

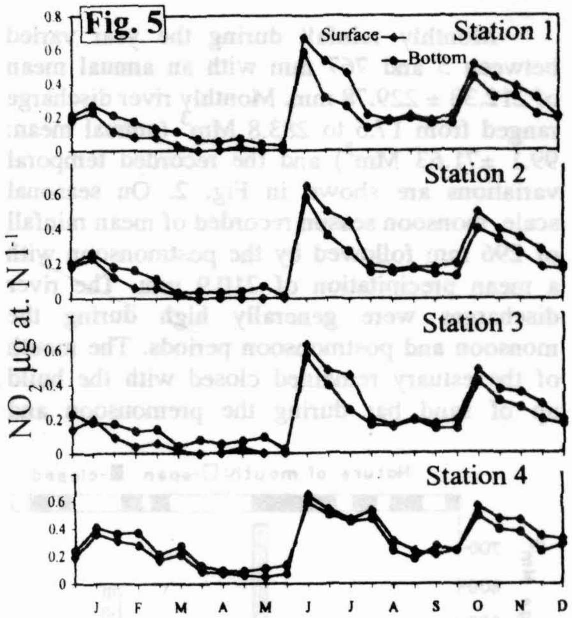

FIG. 5 *Distribution of nitrite nitrogen (μg at.N.I^{-1}) in the estuarine water column.*

recorded. Such patterns of monsoonal rise and summer depletion in nitrite is typical of Indian estuaries (Nair *et. al.*, 1984). Owing to its position in the nitrification-denitrification process and lack of precision in determing very low concentration, the production and turn over in time of this nutrient remains elusive. This was further complicated by decomposition of organic matter (Kaplan, 1983), variation in assimilation rates (Ward *et. al.*, 1989) and sedimentary release.

Phosphate:

Annual distribution of phosphate phosphorus in the surface water varied between 0.13 and 1.63 μg at.P.1^{-1} (Station 1), 0.11 and 1.61 μg at.P.1^{-1} (Station 2), 0.13 and 1.61 μg at.P.1^{-1} (Station 3) and between 0.23 and 1.65 μg at.P.1^{-1} (Station 4); ranges in the bottom waters of respective stations being 0.23-1.51 μg at P.1^{-1}, 0.19-1.48 μg at.P.1^{-1}, 0.15-1.49 μg at.P.1^{-1} and 0.37-1.56 μg at.P.1^{-1}. Phosphate distribution in the estuary remained salinity-influenced, Maximum phosphate concentration occurred towards the head of the

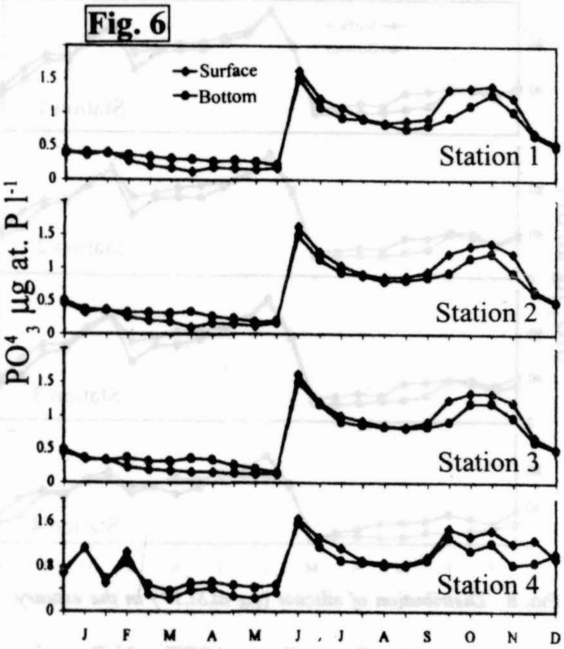

FIG. 6 ***Distribution of phosphorus (μg at.P.l^{-1}) in the water column.***

estuary and on seasonal basis in the monsoon period (Fig. 6). Vertical gradient in phosphate showed temporal shifts : surface water manifested higher concentrations during riverine periods where as during recovery periods the bottom water showed higher concentrations. Suspended sediments in floods harbour phosphate (Ramadhas, 1977) and in summer, bacterial mineralisation from sediments lead to release of phosphate into the overlying water (Taft and Taylor, 1976; Sarala Devi. *et. al.*, 1991).

Nitrate: Phosphate.

N:P fluctuated at the surface water between 10.6 and 38.4 (S1); 11.6 and 41.3 (S2); 11.3 and 41.8 (S3) and 6.66-36.6 (S4); ranges in the bottom waters were 11.1-47.3 (S1), 12-42.2 (S2), 11.7-46.6 (S3) and 8.46-35.5 (S4). N:P distribution in the estuary evinced three distinct phases during the year: the premonsoon phase of higher than optimum (> 16), the monsoon phase of near-optimum (@16) and the post monsoon phase of lower than optimum (16) with occasional deviations (Fig. 7). Headward enhancement of N:P was evident in all seasons. Perhaps a combination of differential rates of phosphate removal from surface and regneration of phosphorus in the bottom layars of water columns effected the alterations in the ratio. Solarzano and Grantham (1975) and Kennish (1990) reported that N:P values greater than 16 was a definite indication of P-limited

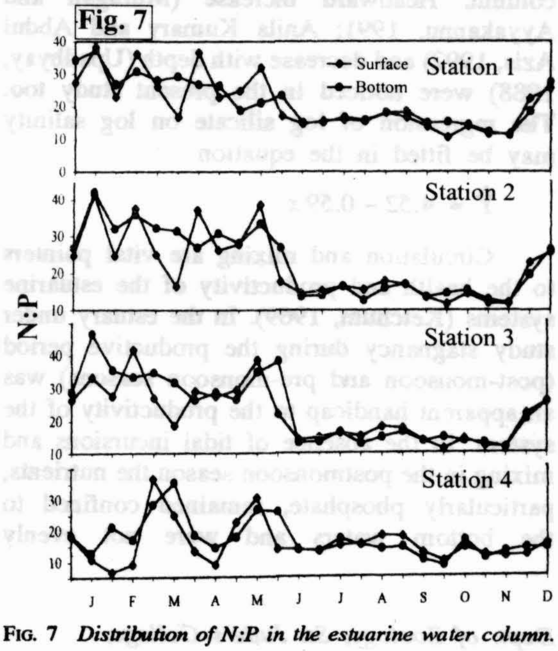

FIG. 7 ***Distribution of N:P in the estuarine water column.***

condition. Thus phosphorus seemed to limit phytoplankton production. The fluctuations in N:P noticed in the present study fell in line with the trends observed by Ramadhas and Sundararaj (1981) in the east coast water.

Silicate:

Silicate distribution in the surface water during the study period ranged from 21.2 to 111µg at.Si.1^{-1} at station 1, from 21.6 to 111µg at.Si.1^{-1} at station 2, from 21.9 to 111 µg at.Si.1^{-1} at station 3 and from 6.28 to 94.4 µg at at station 4; ranges of concentration in the bottom waters were 16.7-109 µg at.Si.1^{-1} S1), 17.1-109 µg at Si.I^{1} (S2), 15.3-108 µg at Si.$^{1\text{-}1}$ (S3) and 4.3-73.2 µg at Si.1^{-1} (S4). Silicate concentration showed marked seasonal patterns; highest concentrations were accompanied by monsoonal drainage (Aston, 1980; Fisher *et. al.*, 1988) and lower levels coincided with the late pre-monsoon (Fig. 8). A linear inverse relationship between salinity and silicate was appafent in the spatial distribution. Salinity stratification inversely influenced silicate distribution in the water column. Headward increase (Murugan and Ayyakannu, 1991; Anila Kumary and Abdul Azis, 1992) and decrease with depth (Upadhyay, 1988) were noticed in the present study too. The regression of log silicate on log salinity may be fitted in the equation

$$\hat{Y} = 4.52 - 0.59\,x$$

Circulation and mixing are vital pointers to the health and productivity of the estuarine systems (Ketchum, 1969). In the estuary under study stagnancy during the productive period (post-monsoon and pre-monsoon seasons) was an apparent handicap to the productivity of the system. In the absence of tidal incursions and mixing in the postmonsoon season the nutrients, particularly phosphate, remained confined to the bottom waters and were not evenly distributed to the photic zone. In the monsoon, though land drainages brought in an enormity of nutrients, their retention peirod was limited owing to ill-pronounced tides. Collected data indicated that surface water salinity was far less than 15‰ during the most part of the year which is unideal for the produciton of tropical phytoplankton

Fig. 8

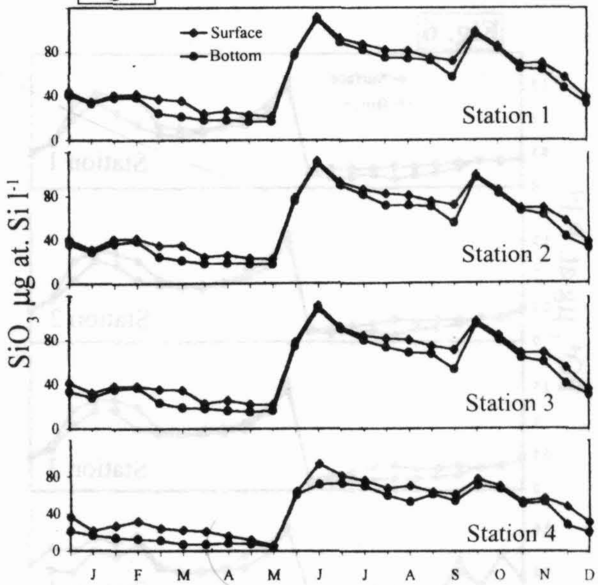

FIG. 8 *Distribution of silicate (µg at.Si.1^{-1}) in the estuary.*

(Qasim, 1972; Ramadhas, 1977). N:P ratios higher -than-optimum (i.e., > 16) recorded in the pre-monsoon season also suggested the *phosphorus-limited condition* of the system. Despite the availability of major plant nutrients in the estuary in required quantity, absence of mixing and circulation apparently affected the potential fertility of the system.

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POTENTIAL PRODUCTIVITY OF MICROBENTHIC ALGAE IN COCHIN ESTUARY

ABSTRACT

Potential productivity of the benthic microalgae in Cochin estuary and their productivity potential in terms of chlorophyll *a* were assessed. The studies concentrated at 5 representative stations for a period of one year recorded the average potential productivity of 57.81 $mgC/m^2/hr$. Based on the ratio of biomass and productivity, the annual potential production of benthic microalgae with an effective shallow area of 22.5 km^2 in the estuary is estimated to be 400,000 tonnes of carbon.