Kenya Journal of Sciences Series B (1989) 10(1-2): 47-61

Nutrients distribution patterns in Tudor estuary (Mombasa, Kenya) during rainy season

J.M. Kazungu
Kenya Marine and Fisheries Research Institute
P.O. Box 81651, Mombasa, Kenya

Frank Dehairs and Leo Goeyens
Lab. of Analytical Chemistry
Free University of Brussels
Pleinlaan 2
1050 Brussels, Belgium

SUMMARY

Nutrients distribution pattern for the Tudor Creek, covering the period April, May, June and July 1986 was investigated. At the beginning of the rainy season (April), a salinity gradient with low values upstream and high values towards the open sea was evident -- giving the creek estuarine characteristics. After the rainy season, salinity values were more-or-less uniform throughout the creek. The low salinity waters near the river mouths had high nutrient concentrations which decreased gradually towards the open sea. The highest nutrient concentrations were recorded in May which also corresponded with the rainfall peak. Though river runoff is shown to be the main source of nutrients in Tudor estuary, the Coast General Hospital's sewage system (CGHSS) is also identified as a possible local source of nutrient supply into the estuary. However, its effect is not noticed during the peak of the rainy season due to the rich nutrient waters from rivers upstream. Conservative mixing of phosphates and nitrates is shown to persist in May. However, after the heavy rains, non-conservative mixing is noticed mainly due to the reduced freshwater nutrient input and nutrient loading by the CGHSS.

INTRODUCTION

A nutrient element is defined as one which is functionally involved in the processes of living organism. Though the term has been applied almost exclusively to silicon, phosphorus and inorganic nitrogen, strictly speaking, other major constituents of sea water, together with many essential trace metals are also nutrient elements. Silicon, phosphorous and inorganic nitrogen occur in sea water in low concentrations and at times are known to act as limiting factors for phytoplankton growth. Availability of these elements therefore plays an essential role in controlling primary productivity.

Tudor Creek (fig. 1), which is approximately 20 km long forms the north-eastern boundary of the Mombasa island. The characteristics of the creek are such that during the rainy season, a salinity gradient develops due to river drainage system upstream. The creek then acquires estuarine characteristics. However, immediately after the rainy season, salinities become more or less uniform

© The Kenya National Academy of Sciences

throughout the creek due to reduced freshwater input from the rivers. Because of these seasonal changes, different water types are likely to exist within the estuary. Revis and Okemwa (1988); report that certain copepod species are common in certain areas of the estuary and not in others. This could be evidence of the existence of different water types within the estuary. Though a lot of work has been done on zooplankton distribution in the creek (Kimaro 1987; Revis and Okemwa (1988); Reay and Kimaro 1984) very little is known about nutrients distribution therein. Norconsult (1975) is the only available report on nutrients distribution in Tudor Creek. However, the report is not comprehensive since all their nutrient sampling stations were close to the open sea and did not extend deeper into the creek. The land surrounding the rivers and tributaries that feed Tudor creek are intensively cultivated for agricultural production and substantial amount of fertilizer is used in this area during the long rainy season. In 1986 about 2850 kg of a fertilizer commonly known as N:P:K:, 20:20:0: (containing 20% nitrogen, 20% phosphorus, 0% potassium) was used. Also used was about 710 kg of triple super phosphates (TSP) which contains approximately 46% phosphates (Mr O. Adede, Kilifi District Agricultural Officer, personal communication). Some of the fertilizer used is washed into the rivers during the rainy season and ultimately find their way into the creeks. Effects of such inputs on the pelagic communities of the receiving creek waters are little known and represent one of our long-term research goals.

The main objective of the present paper is to report on the influence of river drainange on the nutrients distribution within Tudor Creek. This is part of an ongoing Kenya/Belgium project on the identification of various water types within the Tudor and Kilindini estuaries.

MATERIALS AND METHODS

Figure 1 shows sampling stations of the Tudor estuary. Station A1 represents the open sea water, while station A6 is the farthest station upstream-near the river mouth.

Water samples were chemically fixed immediately after collection and stored in ice boxes at temperature below 5^{o}C. On return to the laboratory, phosphate and silicate samples were analysed immediately, while nitrate samples were deep frozen and analysed the following day. Nitrate samples were collected in one liter bottles and fixed with 1 ml mercuric chloride (50g/1000 ml) before being put into the ice box. Samples for the phosphate and silicate determinations were collected in one liter plastic bottles and fixed with 5 ml chloroform. Salinity determinations were done using the Knudsen titration method where the water sample is titrated against standardised silver nitrate solution (Strickland and Parsons 1968). Quantitative detrmination of nitrates, phosphates and silicates was done spectrophotometrically as described by Parsons, Maita and Lalli (1984). A Shimadzu UV-150-02 Double-Beam spectrophotometer was used for the absorption measurements.

All surface samples were collected at about 30 cm below the water surface during low tides on board a small shallow boat of about 7 m long. Samples at 5 m depth and below were collected using a Nansen water sampler. However, station A4 and A5 were so shallow (less than 5 m depth) and so only surface samples were analysed for these two stations.

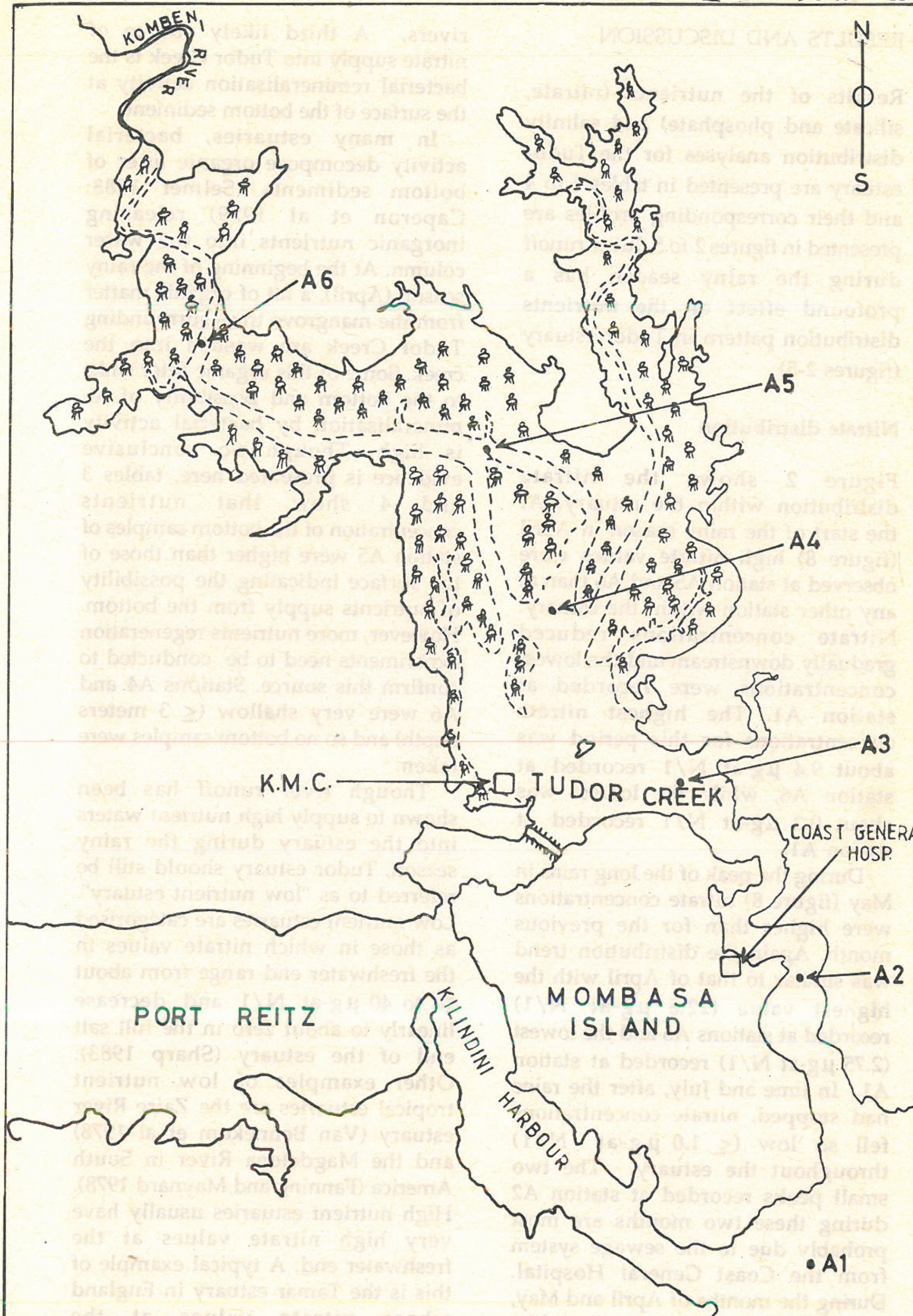

Figure 1. Sampling stations (A1-A6) of the Tudor estuary

RESULTS AND DISCUSSION

Results of the nutrients (nitrate, silicate and phosphate) and salinity distribution analyses for the Tudor estuary are presented in tables 1 to 4 and their corresponding profiles are presented in figures 2 to 5. River runoff during the rainy season has a profound effect on the nutrients distribution pattern in Tudor estuary (figures 2-5).

Nitrate distribution

Figure 2 shows the nitrate distribution within the estuary. At the start of the rainy season in April (figure 8) high nitrate values were observed at station A5 and A6 than at any other station within the estuary. Nitrate concentrations reduced gradually downstream and the lowest concentrations were recorded at station A1. The highest nitrate concentrations for this period was about 9.4 µg-at N/1 recorded at station A6, while the lowest was about 0.2 µg-at N/1 recorded at station A1.

During the peak of the long rains in May (figure 8) nitrate concentrations were higher than for the previous month. Again the distribution trend was similar to that of April with the highest value (22.6 µg-at N/1) recorded at stations A6 and the lowest (2.75 µg-at N/1) recorded at station A1. In June and July, after the rains had stopped, nitrate concentrations fell so low ($\leq$ 1.0 µg-at N/1) throughout the estuary. The two small peaks recorded at station A2 during these two months are most probably due to the sewage system from the Coast General Hospital. During the months of April and May, the sewage effect is overshadowed by the high nutrient waters from the rivers. A third likely source of nitrate supply into Tudor Creek is the bacterial remineralisation activity at the surface of the bottom sediment.

In many estuaries, bacterial activity decompose organic litter of bottom sediments (Selmer 1988; Caperon et al 1979) releasing inorganic nutrients into the water column. At the beginning of the rainy season (April), a lot of organic matter from the mangrove trees surrounding Tudor Creek are washed into the creek. Some of this organic litter sinks to the bottom and possibility of remineralisation by bacterial activity is high. Though no conclusive evidence is presented here, tables 3 and 4 show that nutrients concentration of the bottom samples of station A5 were higher than those of the surface indicating the possibility of nutrients supply from the bottom. However, more nutrients regeneration experiments need to be conducted to confirm this source. Stations A4 and A6 were very shallow ($\leq$ 3 meters depth) and so no bottom samples were taken.

Though river runoff has been shown to supply high nutrient waters into the estuary during the rainy season, Tudor estuary should still be referred to as "low nutrient estuary". Low nutrient estuaries are categorised as those in which nitrate values in the freshwater end range from about 10 to 40 µg-at N/1 and decrease linearly to about zero in the full salt end of the estuary (Sharp 1983). Other examples of low nutrient tropical estuaries are the Zaire River estuary (Van Bennekom et al 1978) and the Magdelena River in South America (Fanning and Maynard 1978). High nutrient estuaries usually have very high nitrate values at the freshwater end. A typical example of this is the Tamar estuary in England whose nitrate values at the freshwater end ranges between 100

Table 1. Nitrate, phosphate, silicate, salinity and standard deviation readings for the April (22/04/86) sampling in Tudor estuary

Station	NO^-_3 µg-at N/1	S.D.	PO^{3-}_4 µg-at P/1	S.D.	Si µg-at Si/1	S.D.	Salinity S‰
A1 (0m)	0.15	0.03	0.30	0.03	4.00	0.19	36.26
(10m)	0.37	0.03	0.50	0.02	3.50	0.11	36.26
A2 (0m)	1.60	0.07	0.70	0.03	5.00	0.21	36.26
(10m)	1.38	0.06	0.70	0.03	5.13	0.20	36.15
A3 (0m)	3.10	0.02	0.70	0.02	13.40	0.50	34.9
*(10m)	2.77	0.05	0.51	0.09	13.01	0.47	34.21
A4 (0m)	3.40	0.05	0.95	0.07	20.00	0.47	32.25
A5 (0m)	9.25	0.08	1.20	0.05	70.00	0.63	12.41
*(5m)	-		0.95	0.09	-		-
A6 (0m)	9.25	0.17	1.51	0.11	71.50	0.47	1.11

Table 2. Nitrate, phosphate, silicate, salinity and standard deviation readings for the May (22/05/86) sampling in Tudor estuary

Station	NO^-_3 µg-at N/1	S.D.	PO^{3-}_4 µg-at P/1	S.D.	Si µg-at Si/1	S.D.	Salinity S‰
A1 (0m)	2.80	0.10	0.36	0.01	40.00	0.57	26.00
(10m)	2.69	0.05	0.33	0.04	40.21	0.31	26.31
A2 (0m)	5.20	0.09	0.64	0.03	65.50	0.33	25.07
(10m)	-				-	-	
A3 (0m)	9.30	0.14	0.68	0.05	116.00	0.47	18.53
*(10m)	8.72	0.19	0.68	0.04	108.37	0.47	18.81
A4 (0m)	17.80	0.23	1.27	0.11	163.50	0.61	11.29
A5 (0m)	22.50	0.22	1.64	0.08	186.00	0.55	5.66
*(5m)	22.50	0.20	1.59	0.13	185.36	0.73	5.69
A6 (0m)	28.50	0.09	2.04	0.09	180.50	0.41	0.72

* Maximum depth

Table 3. Nitrate, phosphate, silicate, salinity and standard deviation readings for the June (24/06/86) sampling in Tudor estuary

Station	NO^-_3 µg-at N/1	S.D.	PO^{3-}_4 µg-at P/1	S.D.	Si µg-at Si/1	S.D.	Salinity S‰
A1 (0m)	0.15	0.02	0.22	0.02	4.00	0.13	36.36
(10m)	0.20	0.02	0.42	0.02	6.20	0.40	36.55
A2 (0m)	0.72	0.09	1.02	0.04	7.90	0.31	36.18
(10m)	-		-				36.36
A3 (0m)	0.15	0.01	0.49	0.10	13.80	0.10	35.64
*(10m)	0.60	0.03	0.49	0.03	11.00	0.27	34.56
A4 (0m)	0.40	0.09	0.48	0.07	24.00	0.09	33.84
A5 (0m)	0.18	0.02	0.42	0.01	26.20	0.13	31.85
*(5m)	0.21	0.02	0.62	0.02	26.40	0.21	32.21
A6 (0m)	0.19	0.03	0.62	0.06	58.50	0.29	24.67

Table 4. Nitrate, phosphate, silicate, salinity and standard deviation readings for the July (22/07/86) sampling in Tudor estuary

Station	NO_3^- µg-at N/1	S.D.	PO_4^{3-} µg-at P/1	S.D.	Si µg-at Si/1	S.D.	Salinity S‰
A1 (0m)	0.44	0.09	0.69	0.07	7.46	0.21	35.64
(10m)	-		0.69	0.09	7.38	0.18	36.00
A2 (0m)	1.19	0.11	0.55	0.03	8.60	0.12	35.05
(10m)	1.19	0.15	0.92	0.07	13.01	0.12	35.64
A3 (0m)	0.58	0.08	0.59	0.05	12.12	0.09	35.28
*(10m)	0.76	0.13	1.16	0.09	12.85	0.14	35.64
A4 (0m)	0.28	0.03	1.02	0.11	17.51	0.17	35.64
A5 (0m)	0.13	0.03	0.55	0.02	22.33	0.22	34.92
*(5m)	0.40	0.04	1.06	0.08	24.62	0.37	34.92
A6 (om)	0	0	0.92	0.10	50.51	0.27	33.84

* Maximum depth

and 350 µg-at N/1 (Morris, Bale and Howland 1981).

Though Tudor Creek is a low nutrient estuary, the nutrient values observed during the rainy season are higher than those of the open waters of the western Indian Ocean. Smith and Codisporti (1980) showed that nitrate values of the western Indian Ocean open waters rarely exceed 5 µg-at N/1. The popular upwelling regions off the Somali coast have nitrate values of between 13.1 µg-at N/1 and 19.9 µg-at N/1 (Smith and Cordisporti 1980) which compares very well with nitrate values obtained at the upper end of Tudor Creek during the rainy season. Though Tudor estuary attains more or less same nutrient levels as the upwelling regions off the Somali coast, it might not be equally productive due to high turbidity (Okemwa, unpublished data). The high turbidity is mainly due to the creek being very shallow (≤ 5 meters depth towards the upper end) and having a muddy bottom.

Silicate distribution

Figure 3 shows silicate distribution along the Tudor Creek. Higher silicate concentrations were observed near the river mouth. However, at the beginning of the rainy season in April, the highest concentration was about 71.0 µg-at Si/1 at station A6, while the lowest concentration (3.5 µg-at Si/1) was recorded at station A1. The May silicate profile shows a very pronounced influence of the river runoff into the estuary. Silicate concentrations of above 180 µg-at Si/1 were recorded at stations A5 and A6. Station A1 also had relatively higher values (Ca 22.0 µg-at Si/1) than the previous month. In June and July, after the end of the rainy season, silicate concentration dropped very sharply.

Phosphate distribution

Phosphate distribution pattern was similar to that of silicate. Higher phosphate concentrations were recorded at station A6 in April and May, while station A1 had the lowest during this period (figure 4). High values of about 2.0 µg-at P/1 were recorded at station 6A in May, while in June and July concentrations were below 1.0 µg-at P/1.

The concentration of dissolved inorganic phosphate in the surface waters of the oceans is variable, but over large areas the maximum concentrations are in the range of 0.5 to 1.0 µg-at P/1 (Spencer 1975). Phosphate concentration of the open north Indian Ocean surface waters rarely exceeds 0.5 µg-at P/1 (Ryther

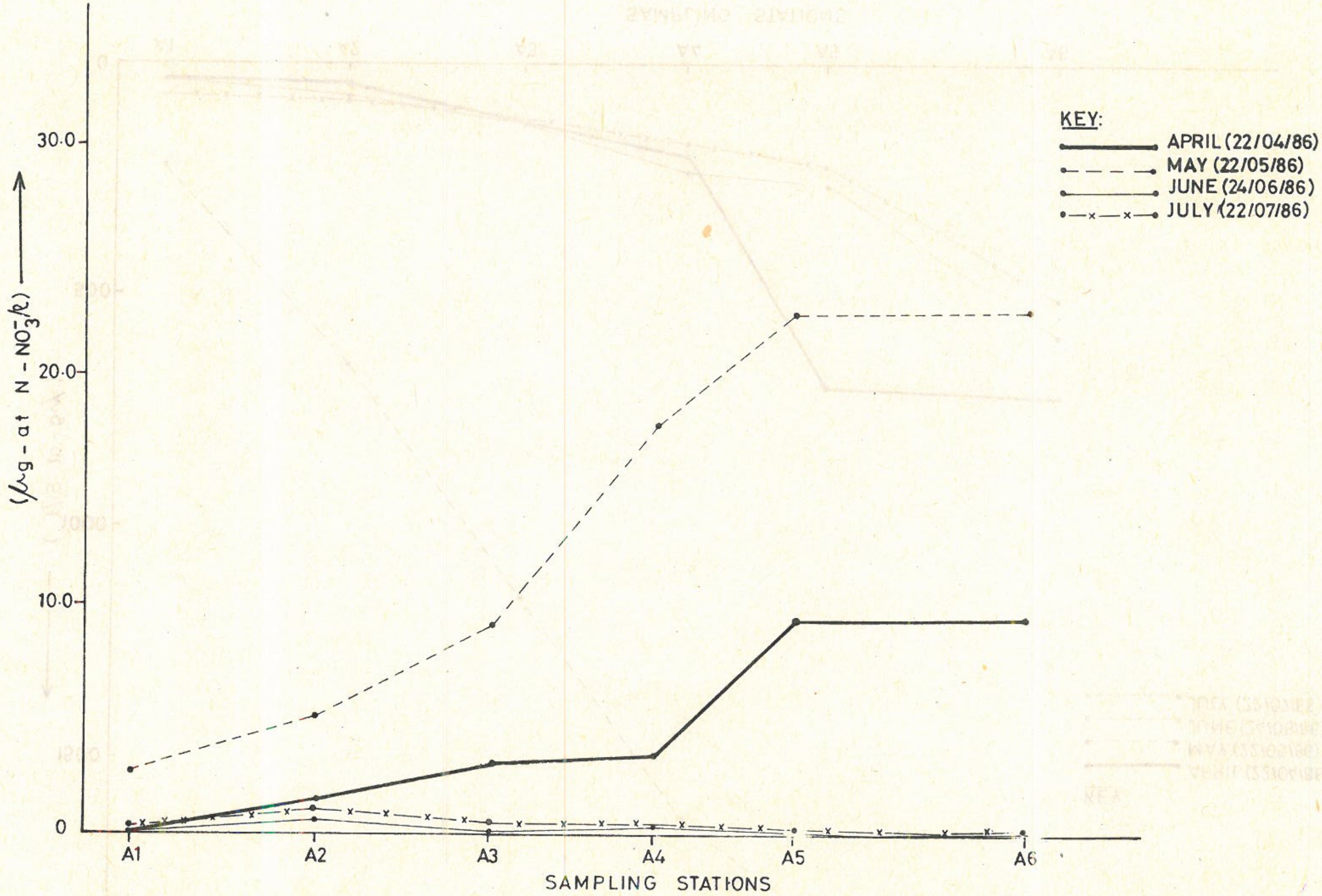

Figure 2. Nitrate distribution paterns in Tudor estuary for April, May, June, and July 1986

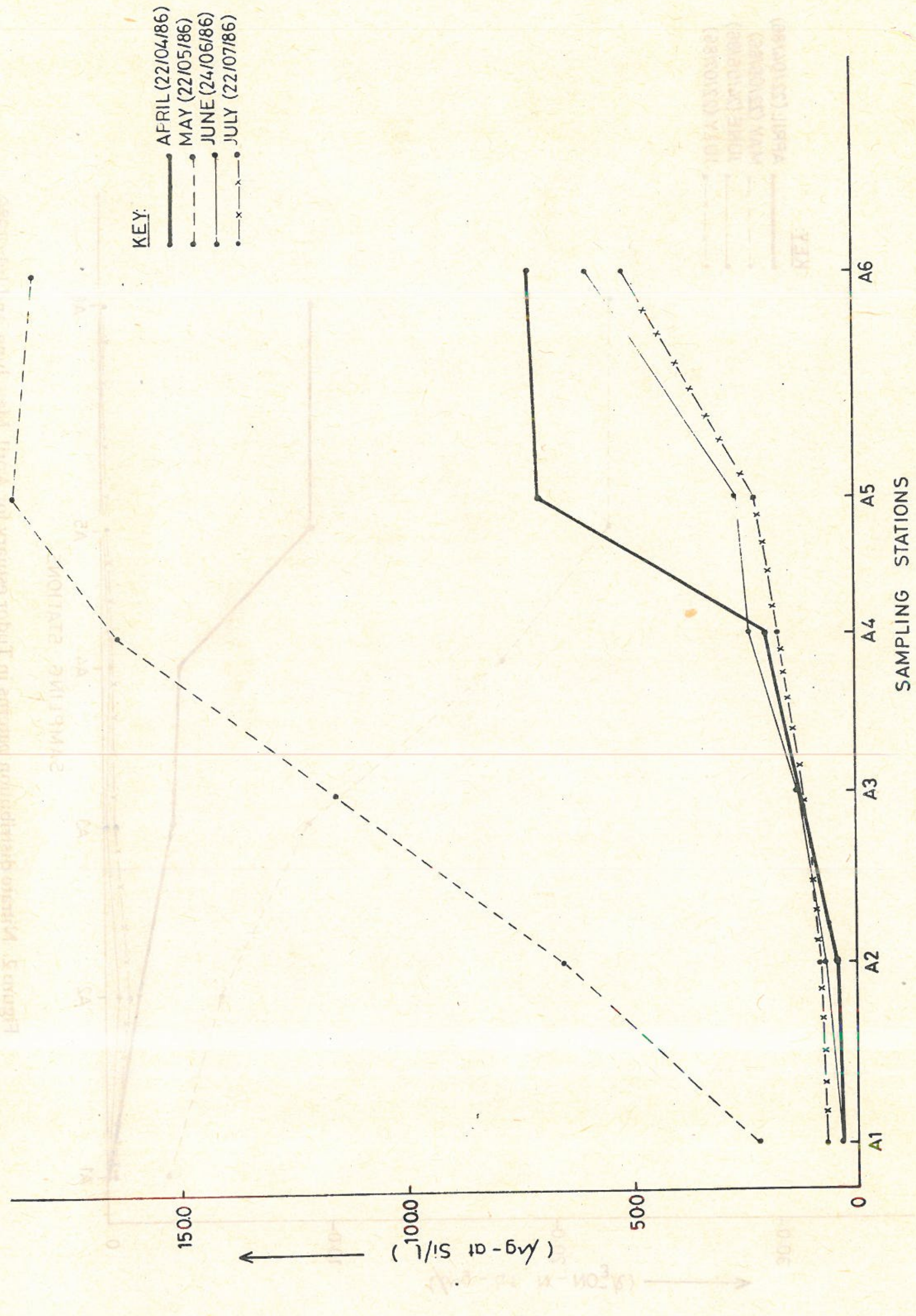

Figure 3. Silicate distribution patterns in Tudor estuary (April - July 1986)

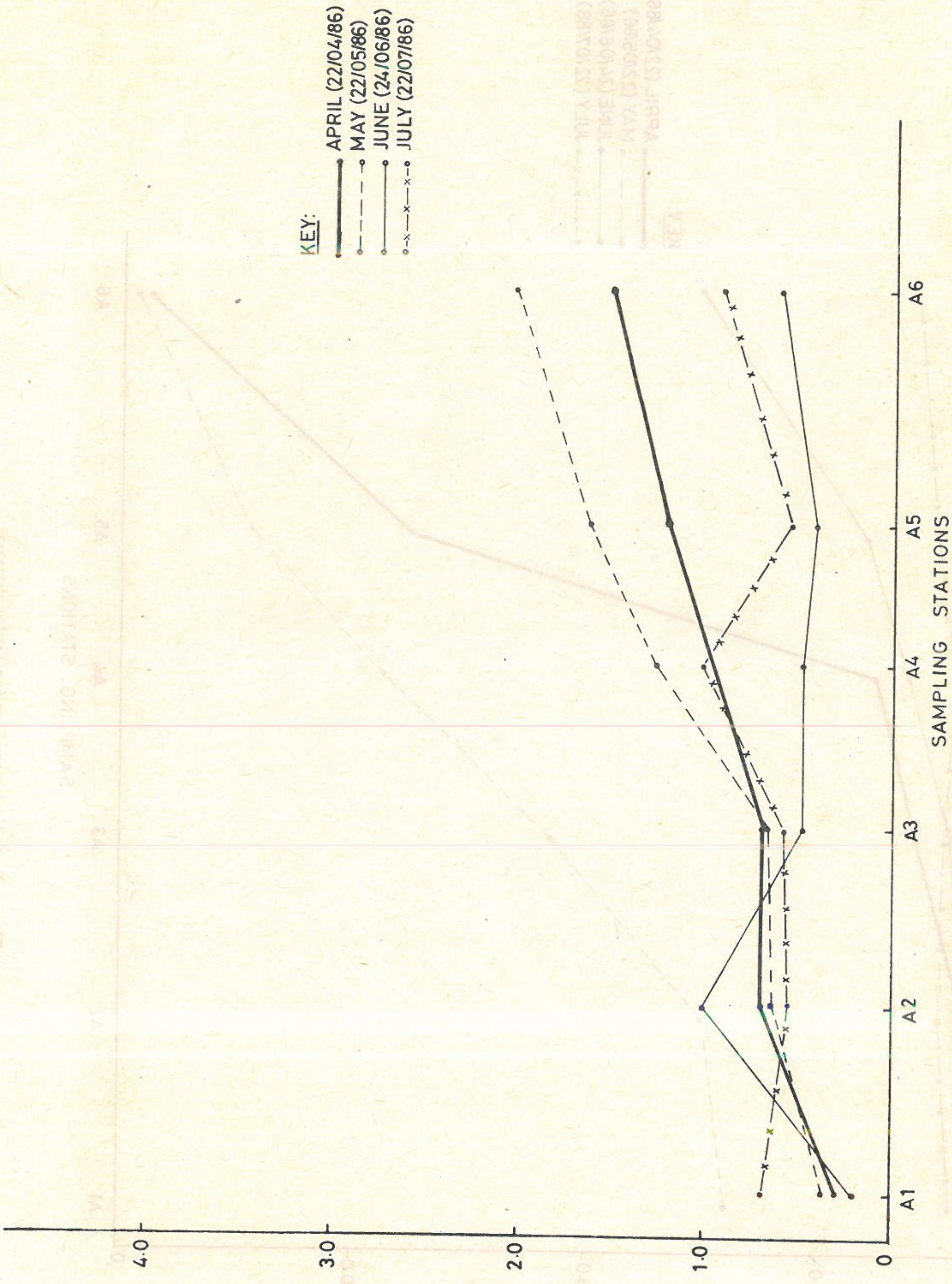

Figure 4. Phosphate distribution patterns (April - July 1986

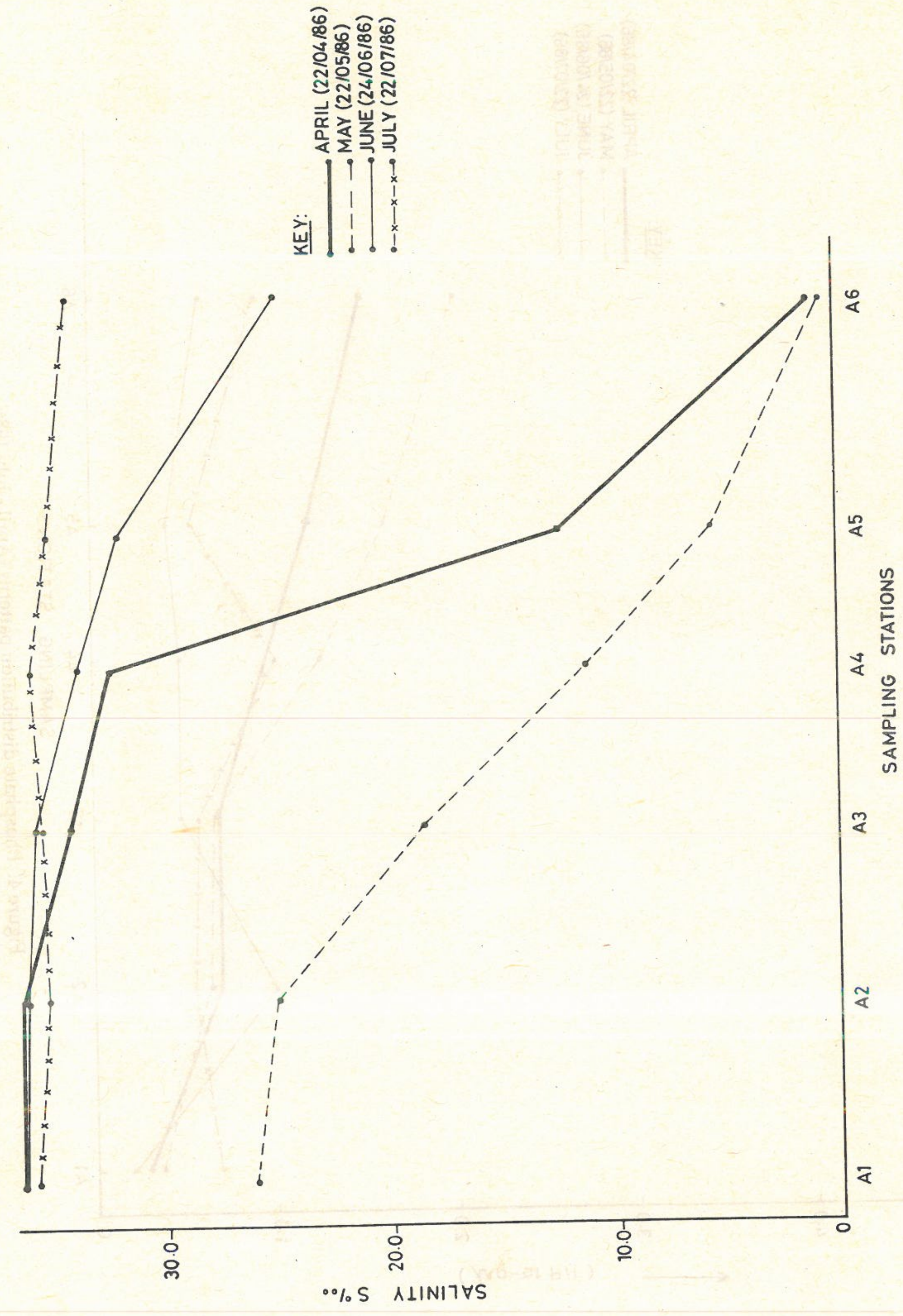

Figure 5. Salinity profiles for Tudor estuary

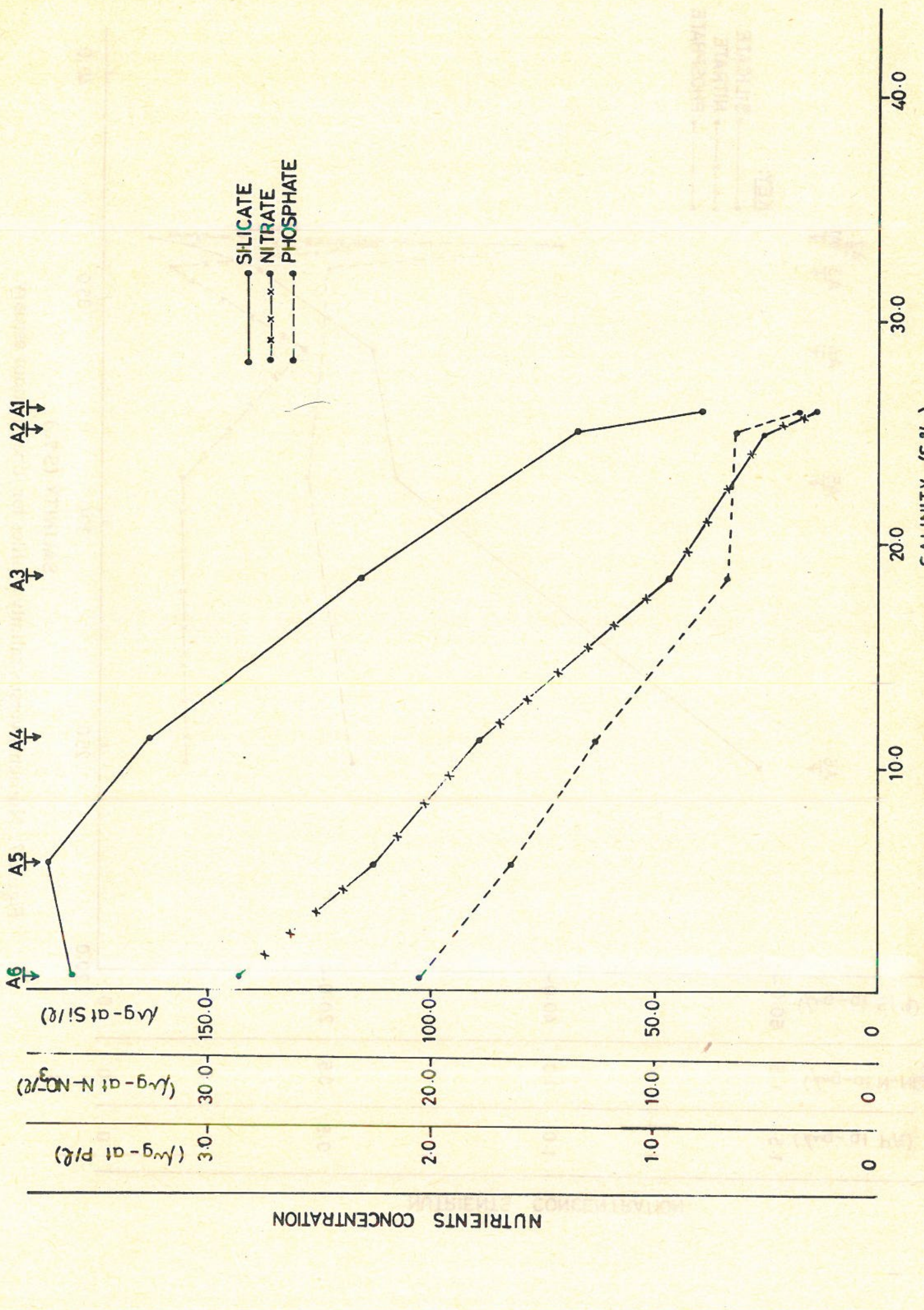

Figure 6. Nutrients versus salinity profiles for May in Tudor estuary

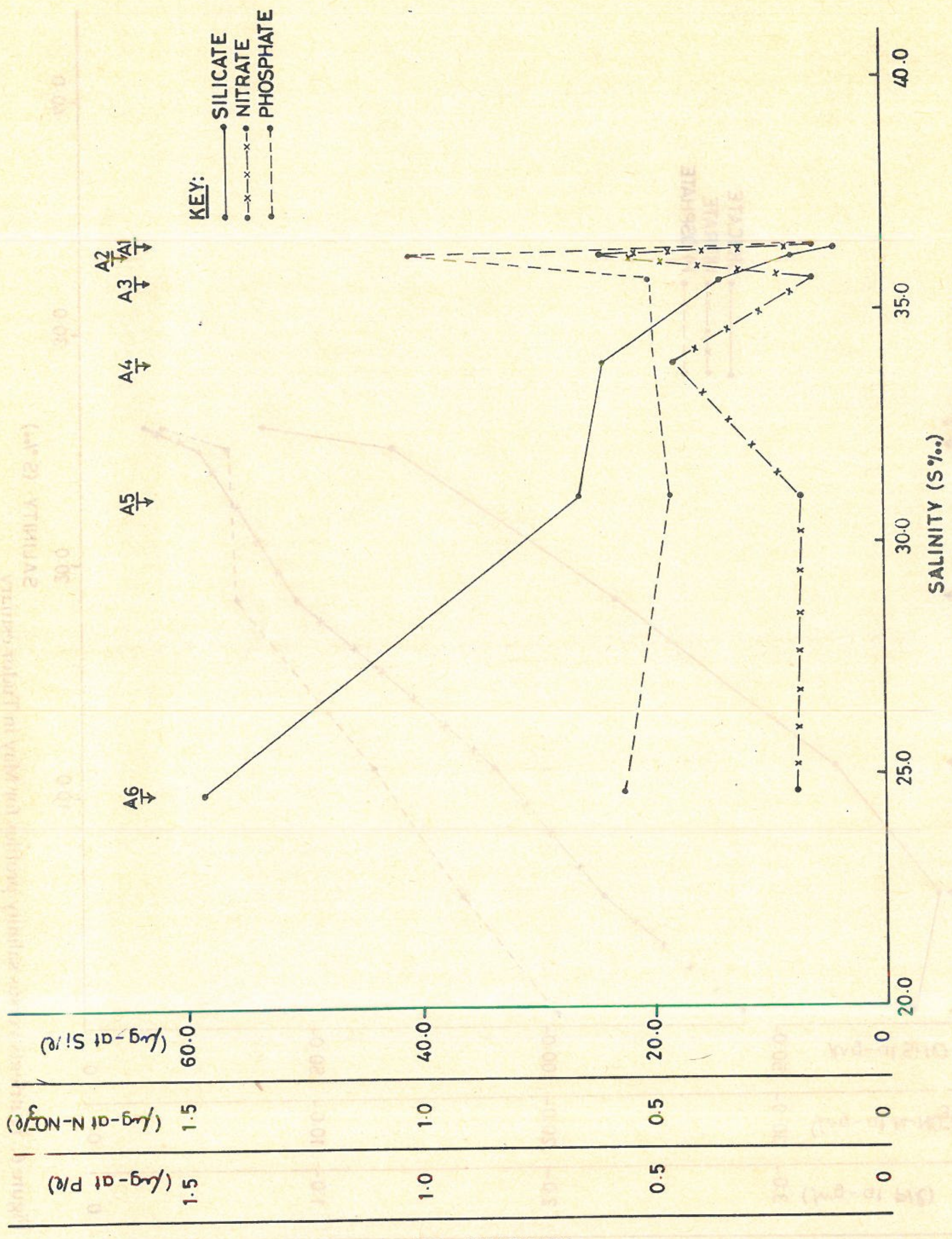

Figure 7. Nutrients versus salinity profiles for June in Tudor estuary

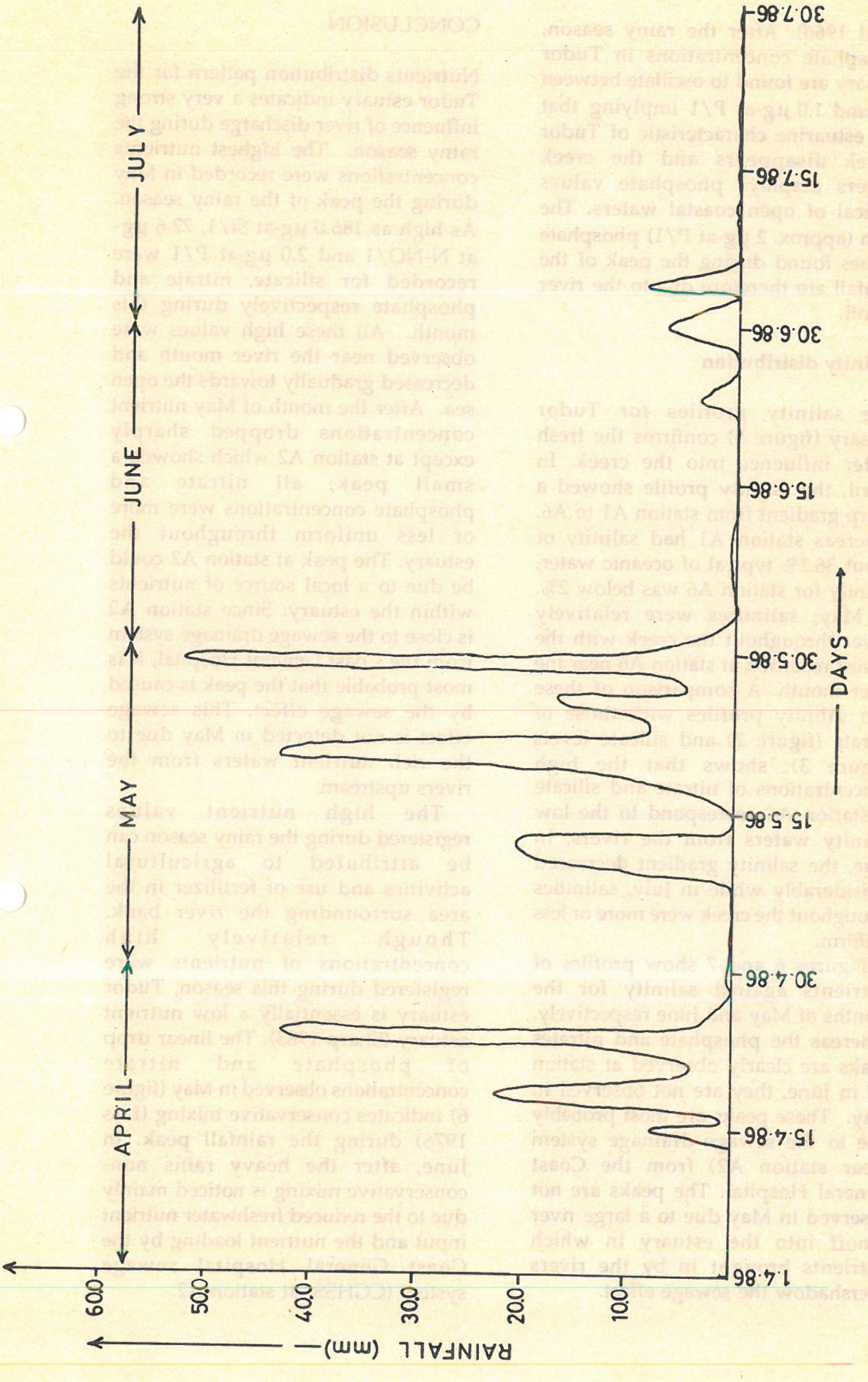

Figure 8. Rainfaall profile covering the period April to July 1986

et al 1966). After the rainy season, phosphate concentrations in Tudor estuary are found to oscillate between 0.2 and 1.0 μg-at P/1 implying that the estuarine characteristic of Tudor Creek disappears and the creek waters displays phosphate values typical of open coastal waters. The high (approx. 2 μg-at P/1) phosphate values found during the peak of the rainfall are therefore due to the river runoff.

Salinity distribution

The salinity profiles for Tudor estuary (figure 5) confirms the fresh water influence into the creek. In April, the salinity profile showed a sharp gradient from station A1 to A6. Whereas station A1 had salinity of about 36.2% typical of oceanic water, salinity for station A6 was below 2%. In May, salinities were relatively lower throughout the creek with the lowest recorded at station A6 near the river mouth. A comparison of these two salinity profiles with those of nitrate (figure 2) and silicate levels (figure 3), shows that the high concentrations of nitrate and silicate at station A6 correspond to the low salinity waters from the rivers. In June, the salinity gradient decreased considerably while in July, salinities throughout the creek were more or less uniform.

Figures 6 and 7 show profiles of nutrients against salinity for the months of May and June respectively. Whereas the phosphate and nitrates peaks are clearly observed at station A2 in June, they are not observed in May. These peaks are most probably due to the sewage drainage system (near station A2) from the Coast General Hospital. The peaks are not observed in May due to a large river runoff into the estuary in which nutrients brought in by the rivers overshadow the sewage effect.

CONCLUSION

Nutrients distribution pattern for the Tudor estuary indicates a very strong influence of river discharge during the rainy season. The highest nutrients concentrations were recorded in May during the peak of the rainy season. As high as 186.0 μg-at Si/1, 22.6 μg-at N-NO/1 and 2.0 μg-at P/1 were recorded for silicate, nitrate and phosphate respectively during this month. All these high values were observed near the river mouth and decreased gradually towards the open sea. After the month of May nutrient concentrations dropped sharply except at station A2 which showed a small peak; all nitrate and phosphate concentrations were more or less uniform throughout the estuary. The peak at station A2 could be due to a local source of nutrients within the estuary. Since station A2 is close to the sewage drainage system from the Coast General Hospital, it is most probable that the peak is caused by the sewage effect. This sewage effect is not detected in May due to the rich nutrient waters from the rivers upstream.

The high nutrient values registered during the rainy season can be attributed to agricultural activities and use of fertilizer in the area surrounding the river bank. Though relatively high concentrations of nutrients were registered during this season, Tudor estuary is essentially a low nutrient estuary (Sharp 1983). The linear drop of phosphate and nitrate concentrations observed in May (figure 6) indicates conservative mixing (Liss 1976) during the rainfall peak. In June, after the heavy rains non-conservative mixing is noticed mainly due to the reduced freshwater nutrient input and the nutrient loading by the Coast General Hospital sewage system (CGHSS) at station A2.

After the rainy season, the estuary loses its estuarine characteristic and just becomes an extended arm of the Indian Ocean. This is confirmed by the high more or less uniform salinity values (figure 5, July profile) and the low almost-uniform nutrient values observed after the rains.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to Mr. S.O. Allela, Director of the Kenya Marine and Fisheries Research Institute and Prof. Ph. Polk, Director of the Kenya/Belgium Oceanography Project for their valuable suggestions. We would also like to thank the Moi International Airport Meteorological Department for availaing their rainfall data to us.

REFERENCES

Caperon, J., Schell, D., Hirota D., Hirota, J. and Laws, E. (1979). Ammonium excretion rates in Keneoke Bay, Hawaii measured by a N isotope dilution technique *Mar. Biol* 54: 33-40.

Fanning, K.A. and Maynard., V.I. (1978). Dissolved boron and nutrients in the mixing plumes of major tropical rivers: *Neth. J. Sea Res.* 12: 345-354.

Kimaro, M.M. (1987). The composition, distribution and abundance of near surface zooplankton in Tudor Creek, Mombasa, Kenya. M.Sc. thesis. University of Nairobi, Nairobi, Kenya.

Liss, P.S. (1976). Conservative and non-conservative behaviour of dissolved constitutes during estuarine mixing. In *Estuarine Chemistry* (Edited by J.D. Burton and P.S. Liss) New York: Academic Press, pp. 93-130.

Morris, A.W., Bale, A.J. and Howland R.J.M. (1981). Nutrient distributions in an estuary: Evidence of chemical precipitation of dissolved silicate and phosphate. *Estuarine Coastal Mar. Sci.* 12: 205-216.

Norconsult, A.S. (1975). Mombasa water pollution and waste disposal study VI. *Marine Investigations, Norconsult Report 1975.*

Revis, N. and Okemwa, E. (1988). Additional records of species of copepods and their distribution in the coastal and inshore waters of Kenya. *Kenya Journal of Sciences Series B.* 8: 123-127.

Parsons, T.R., Maita and C.M. Lalli, (1984). *A Manual of Chemical and Biological Methods of Seawater Analysis.* Oxford: Pergamon Press, 173pp.

Reay, P.I. and M.M. Kimaro (1984). Surface zooplankton studies in Port Mombasa during the northeast monsoon. *Kenya Journal Science and Technology Series B.* 5: 27-48.

Ryther, J.H., Hall, J.R., Peace, A.K., Bakun A., and Jones, M.M. (1966). Primary organic production in relation to the chemistry and hydrography of the western Indian Ocean. *Limnol. Oceanogr.* 3: 371-380.

Sharp, J.H. (1983). The distribution of inorganic nitrogen and dissolved and particulate organic nitrogen in the sea. In *Nitrogen in the Marine Environment* (Edited by E.J. Carpenter and D.G. Capone). New York: Academic Press, pp. 1-35.

Selmer, J.S. (1988). Ammonium regeneration in the marine environment. Ph.D thesis. Department of Microbiology, University of Goteborg, Sweden.

Smith, S.L. and Codispoti, L.A. (1980). Southwest monsoon of 1979: Chemical and biological response of Somali coastal waters. *Science* 209: 597-599.

Spencer, C.P. (1975). The micronutrient elements. In *Chemical Oceanography* (Edited by J.P. Riley and G. Shirrow), London: Academic Press, 2: 245-300.

Strickland, J.D.H. and T.R. Parsons (1968). *A Practical Handbook of Seawater Analysis.* Ottawa: Fisheries Research Board of Canada, Bulletin 167.

Van Bennekom, A.J. Berger, G.W., Helder, W. and De Vries, R.T.P. (1978). Nutrient distribution in the Zaire estuary and River Plume. *Neth J. Sea Res.* 12: 296-323.