TIDAL CYCLE AND THE ENVIRONMENTAL FEATURES OF COCHIN BACKWATER (A TROPICAL ESTUARY)

BY S. Z. QASIM AND C. K. GOPINATHAN

(Biological Oceanography Division, National Institute of Oceanography, Ernakulam, Cochin-11, South India)

Received April 15, 1969

(Communicated by Dr. N. K. Panikkar, F.A.SC.)

ABSTRACT

In the Cochin Backwater the tides are of a mixed, semidiurnal type with a maximum range of about 1 m. Two high and two low watermarks occur each day, with an appreciable difference in range and time. The various environmental features such as temperature, salinity, dissolved oxygen, pH, seston, nutrients, alkalinity and chlorophyll are greatly influenced by the tidal rhythm. The differences in almost all these parameters are more marked at the surface than at the bottom. The magnitudes of variation are not consistent and largely depend upon the time of the year.

Diurnal changes in dissolved oxygen followed the course of daily sunlight intensity. Gross primary production gave a similar day and night cycle. Because of high turbidity in the estuary, the primary production was much higher at the surface than at 1 m.

INTRODUCTION

IT is well known that an estuarine system reflects the balance of forces of both marine and freshwater. This is primarily induced by the tidal incursion (Ketchum, 1951), the patterns of circulation (Cameron and Pritchard, 1963) and the rate of inflow of freshwater in relation to lower and upper reaches of the estuary (Preddy, 1954). Although salinity changes in estuaries induced by the tidal cycle have been studied fairly extensively in many parts of the world, little emphasis has been given to changes in other environmental features which occur concurrently with the salinity variation. Moreover, in such estuaries where the range in flood and ebb tides is small and the tidal cycle somewhat complicated, reliable observations on the magnitude of variation in the environmental features are few.

In recent years, since the Cochin Backwater has been a centre of intensive studies on the hydrography and primary productivity, it was considered important to obtain informations on the range of variation in the hydrographical features with the tidal rhythm.

PROCEDURE AND METHODS

Figure 1 shows a portion of the backwater where two stations were worked during the tidal surveys. The area shown in Fig. 1 includes the Cochin Harbour (Lat. 9° 58′ N. and Long. 76° 15′ E.) which is connected with the Arabian Sea by a channel, about 450 m wide. The estuary includes a chain of brackish water lagoons and swamps, commonly called the 'Backwaters' which receive freshwater from several large rivers.

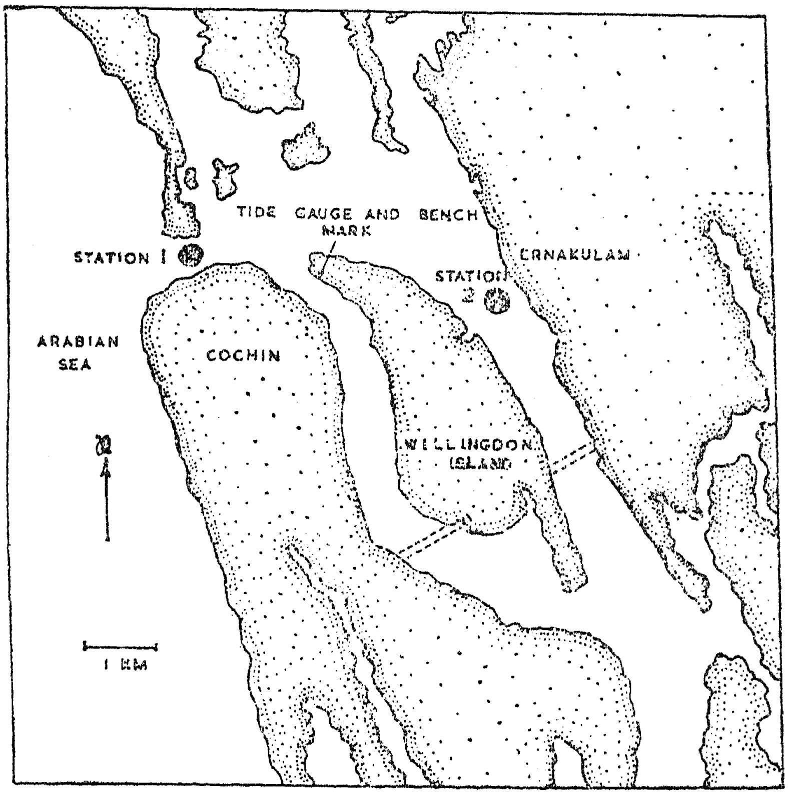

FIG. 1. Map showing the station positions in the Cochin Backwater where tidal surveys were made.

In all, 5 tidal surveys were made at the two stations by using a boat from the beginning of a 24-hour or a 12-hour cycle. Table I shows the dates, stations and the tidal heights of the survey. Of the 5 surveys, four were done during the spring tide and one during the neap tide. Before each survey, a tidal curve was drawn using the tide table as a general guide which was checked by regular tidal measurements throughout the observation. The differences in the tidal height between the observed and predicted tides were fairly well marked and ranged from 5 to 25 cm. During the tidal cycle either two-hourly or one-hourly observations were made on temperature, salinity, oxygen, pH, alkalinity, seston, nutrients and chlorophyll. A plastic bucket was used to collect water samples from the surface and a Van Dorn sampler at depths. The methods of various estimations were the same as described elsewhere (Sankaranarayanan and Qasim, 1969).

TABLE I

Dates and tidal heights during the five surveys at the two stations. Each survey represents a particular season of the year

Survey	Station	Date and state of tide	Height tide (predicted) cm	Maximum range cm	Mean level cm	Season
1	2	12– 1–1966 (Spring)	HHW 100 HLW 56 LHW 69 LLW 19	81	61	Post-monsoon (September–January)
2	2	19– 9–1966 (Spring)	HHW 100 HLW 60 LHW 93 LLW 24	76	69	Monsoon (June–September)
3	1	12/13–12–1966 (Spring)	LHW 87 LLW 11 HHW 111 HLW 64	100	68	Post-monsoon (September–January)
4	2	29– 4–1967 (Spring)	LHW 84 LLW 20 HHW 100 HLW 64	80	66	Pre-monsoon (February–May)
5	2	3– 5–1967 (Neap)	HLW 59 LHW 68 LLW 53 HHW 89	36	67	Pre-monsoon (February–May)

TIDES

The Indian Tide Tables published by the Geodetic and Research Branch, Survey of India, give data on the tides of Cochin Harbour area.

In addition to these, some records of the tides are maintained by the Cochin Port authorities. As an example, a typical tidal drawing for the first fortnight of January 1967, using the above two informations, is given in Fig. 2 A, together with phases of the moon. The height of the water level indicated in Fig. 2 A is with reference to zero level which is 1·19 m below a bench mark at the Willingdon Island, Cochin (*see* Fig. 1).

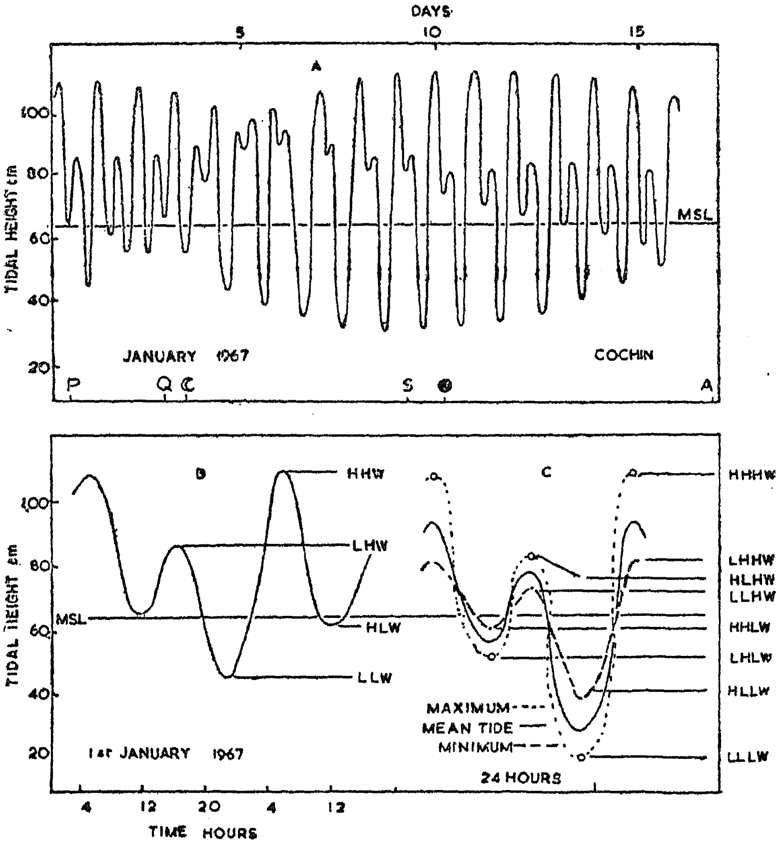

FIG. 2. (A) Tidal curve at Cochin during the first fortnight of January 1967 showing mixed, semidiurnal tides, along with phases of the moon. (B) Tidal cycle on January 1, 1967 showing two successive high and low tides. (C) Diagrammatic representation of the highest and lowest elevations of the tides in relation to mean tides. In all the figures the mean sea-level (MSL) is indicated by a horizontal line at about 64 cm.

As can be seen from Fig. 2 A, the tides of this region are of a mixed type, predominantly semidiurnal (Dietrich, 1965). Two high and two low watermarks occur each day with a substantial difference in range and time. A portion of the marigram for Cochin on January 1, 1967 shows the variations in the elevation with time (Fig. 2 B). It is clear from Fig. 2 B that two successive high and two low waters appear each day which differ in height. These are the higher high water (HHW), the lower high water (LHW), the higher low water (HLW) and lower low water (LLW)—Fig. 2 B. As these watermarks again vary in surface elevations, within half a lunar month, eight watermarks can be distinguished with the tides. Figure 2 C shows these marks as the highest higher high water (HHHW), the lowest higher high water (LHHW), the highest lower high water (HLHW), the lowest lower high water (LLHW), the highest higher low water (HHLW), the lowest higher low water (LHLW), the highest higher low water (HHLW) and the lowest lower low water (LLLW).

From station 1 to station 2 there is a time-lag of about 10 minutes in the tidal height and at each station the tidal current at the surface lags behind the height by about 2 hours.

A general picture of the outgoing and incoming tidal oscillations in the backwater can be given as follows: During the ebb, freshwater is discharged from the estuary into the sea and similarly during the flood, sea water penetrates deep into the estuary. However, at the time of excessive rainfall (monsoon months), the conditions become somewhat different. With a continuous flow of freshwater, more and more freshwater gets accumulated in the estuary, since with the ebb it cannot escape fast enough into the sea. Therefore, with the flood, when the sea water rushes into the estuary, more and more freshwater from the top layer escapes into the sea to avoid flooding, leaving behind simply a tongue of sea water at the bottom and freshwater at the top, both quite distinct.

RESULTS AND DISCUSSION

While describing the results of the 5 tidal surveys, it seems important to point out that although these surveys were made at different times of the year, they represent three distinct seasons. For instance, the survey made in September is typical of the monsoon season which lasts from June–September. Similarly, the two surveys of December and January depict conditions of the post-monsoon season (October–January) and the surveys of April and May represent the pre-monsoon season (February–May)—*see* Table I. This division of the year, though arbitrary, fits in well with the seasonal changes in the hydrographical conditions described recently (Sankaranarayanan and Qasim, 1969).

Temperature.—The results of the observations on temperature have been shown in Fig. 3 A, from which it can be seen that the changes follow the tidal rhythm. The variations in temperature are small and fall within a range of about 1–2° C. With the flood, the temperature tends to decrease as the water is drawn from the cooler sea and towards the end of the ebb, it increases when warmer water from the river-basins and upper reaches of the estuary is brought in. Such tidal-controlled changes in temperature are distinct during the monsoon months, but in other months, warmer weather and heating of the surface water by solar radiation greatly overshadow the small changes in temperature such as are induced by the tides.

Salinity.—Figure 3 B shows the vertical salinity gradients in relation to tidal cycles. During the period February-May, little freshwater enters the estuary, and therefore, the vertical salinity gradients are not well marked. However, during this season, at the end of the ebb, since more freshwater from the upper reaches flows into the lower parts of the estuary, it results into a slight decrease in salinity at the surface layers. At the end of the flood, the water undergoes mixing and the differences in the vertical salinity gradient decrease and eventually disappear. The difference in salinity with the tide during these months is about 2‰ at the surface and 1‰ at the bottom (Fig. 3 B).

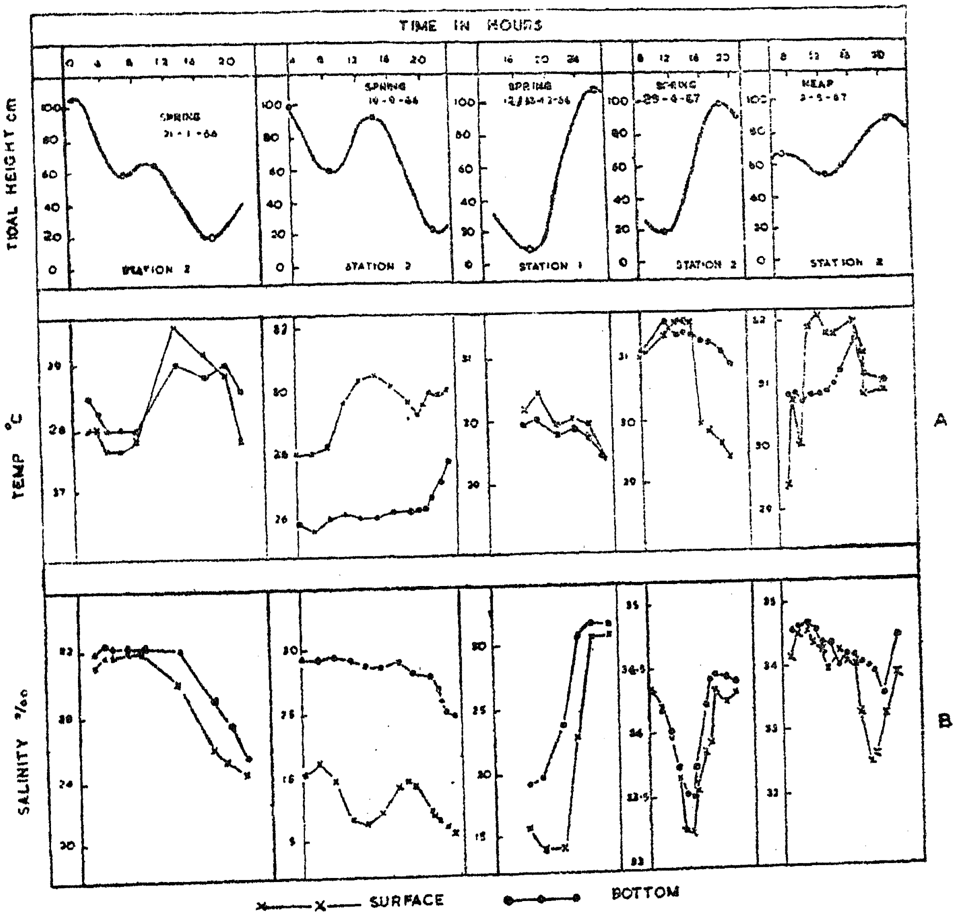

FIG. 3. Drawings of the tidal curves (above) during the five surveys at the two stations in Cochin Backwater. During the tidal cycle the temperature changes at the surface and bottom have been indicated in (A); salinity changes at the surface and bottom in (B).

During the period of monsoon (June–September), large quantities of freshwater enter the estuary, resulting in a very low salinity water at the surface and a denser water at the bottom. In these months the salinity changes induced by the tides are very well pronounced at both the depths, as mixing gets prevented and the brackish water at the surface remains more or less undisturbed. The variations in the salinity with the state of tide in September are of the order of 11‰ at the surface and 9‰ at the bottom.

In December and January (post-monsoon months) the changes in salinity at the surface and bottom were almost alike, as the entire water column gets well mixed. The salinity decreased at the ebb and increased at the flood. During December, the salinity differences at the surface and bottom were 16‰ and 13‰ respectively and during January the difference was about 7‰ at both the depths.

The salinity changes in the backwater corresponding to tidal variations were somewhat similar to what has been reported in many other estuaries (Capstick, 1957; Vasisht, 1965). Rao and Rao (1962) while working in purely marine conditions, along the Waltair coast, Bay of Bengal, have shown a small fluctuation in salinity (0·63‰) induced by the tides; while Rangarajan (1958) has found a salinity difference of 13·4‰ corresponding to high and low water in the Vellur estuary. Similarly, Rao and George (1959) have noticed a difference in the salinity caused by the tides in the Korapuzha estuary. George and Kartha (1963), however, while working in the Ernakulam Channel of the Cochin Backwater have shown that there is practically no influence of tides on the salinity. Our data, on the other hand, obtained from almost the same area clearly show that the tidal influence on the salinity is quite considerable in the lower reaches of the backwater. The magnitude of these variations, however, to a large extent, depends upon the time of the year and the place of observation in the estuary. With an increase in distance from station 1 towards the upper reaches of the estuary, the magnitude of variation progressively decreases, as the time-lag in the tidal height increases and the tidal range decreases.

The probable reason of discrepancy in the data of George and Kartha (1963) may lie in the fact that these authors have made random observations on the salinity with reference to tidal height and did not investigate the salinity changes throughout the tidal cycle. Since the tides in the estuary are of a mixed, semidiurnal type and the reversal of the tidal surface current lags behind the tidal height by about 2 hours (*see* above), any observations made at random with reference to tidal height alone would give an incomplete information.

Dissolved oxygen.—From the changes in dissolved oxygen shown in Fig. 4 A it can be seen that the relationship between salinity and oxygen with reference to tide was inverse. The high water was accompanied by a lower dissolved oxygen, and similarly with the ebb, the oxygen values showed a marked increase. During the monsoon months, the variation in the oxygen values was greater at the surface (about 2·5 ml/l) than at deeper layers (1·3 ml/l). These changes suggest that the increase in the oxygen is associated with the incursion of freshwater in the estuary at the ebb.

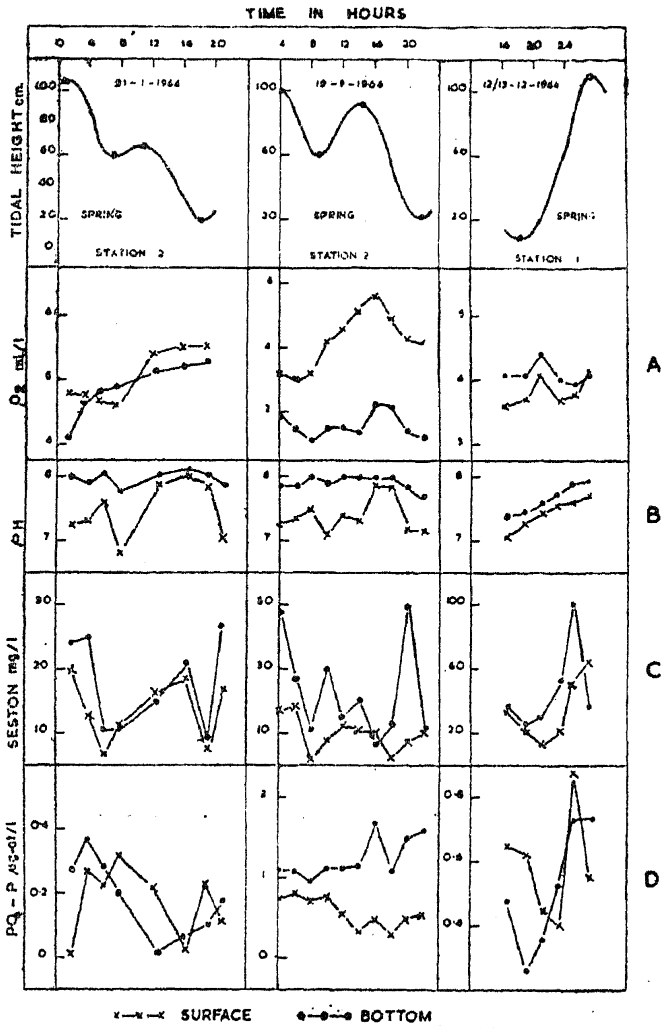

FIG. 4. Changes in dissolved oxygen (A), pH (B), seston (C), and phosphorus (D), at the surface and bottom, during the tidal cycles. The top drawings represent the tidal curves.

Hydrogen ion concentration.—Like the other parameters, the fluctuations in the pH were far greater at the surface than at the bottom (Fig. 4 B). Higher values were recorded at the flood with the incursion of sea water in the estuary and lower values with the flow of freshwater at the ebb. The range in the variation of pH during the tides was 0·25–1·25. It was large during the monsoon month and small in other seasons.

Seston.—The backwater is known for its high seston content which leads to severe limitations in light penetration (Qasim *et al.*, 1968). Intense turbidity occurs during the monsoon months as a result of suspended and dissolved matters brought down by the rivers and land run-off.

Beside the seasonal changes in the seston content, there seems a consistent pattern of seston distribution caused by the tidal influence. Figure 4 C shows two such observations from which it can be seen that high and low values correspond to flood and ebb respectively.

Probably with the flood the bottom sediments are stirred up and brought to the surface at the high water. During the monsoon and post-monsoon months the range in the variation of seston was very large.

Nutrients.—Figure 4 D shows the changes in inorganic phosphorus and Fig. 5 A and B give the fluctuations in nitrate-N and silicate-Si in relation to tidal cycle. In September lower values of phosphorus occurred at the

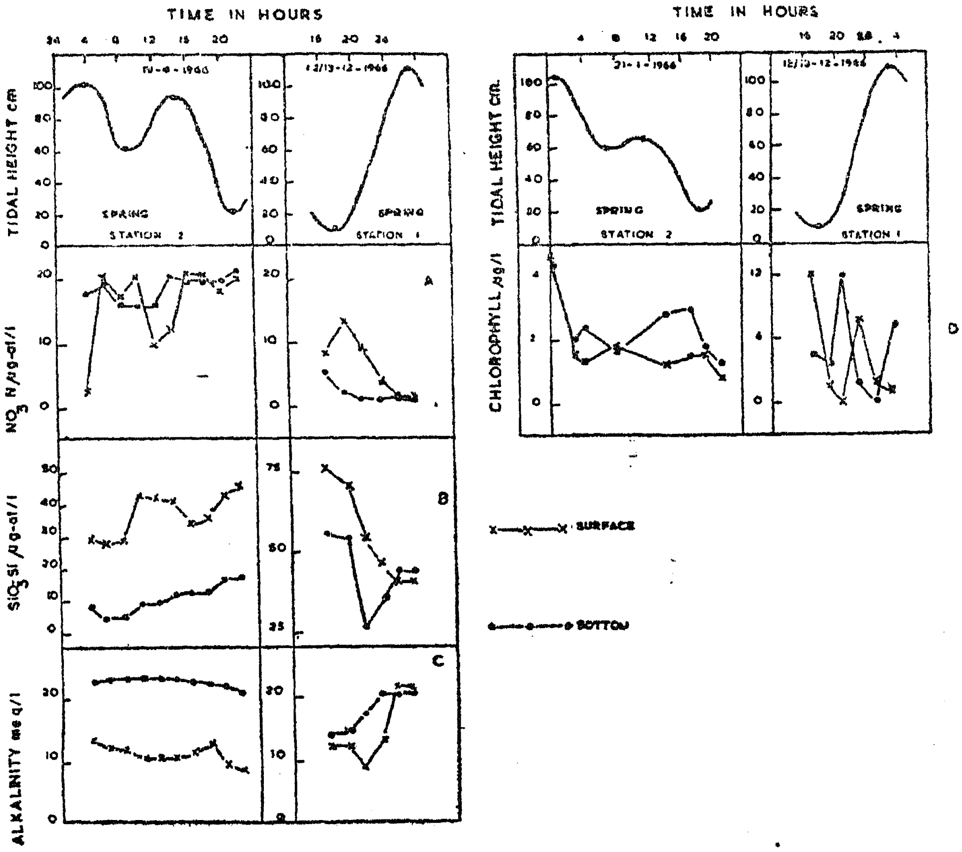

FIG. 5. Changes in nitrate-N (A), silicate-Si (B), alkalinity (C), and chlorophyll (D), at the surface and bottom, during the tidal cycles. The top drawings represent the tidal curves,

surface than at the bottom. In December and January a vertical homogeneity in the phosphorus distribution was noticed throughout the water column. Nitrate–N and silicate–Si were greater at the surface than at deeper layers.

Concentrations of all the nutrients changed with the tides. The values of phosphorus increased at the flood and decreased at the ebb, indicating that phosphorus is accompanied with the incursion of sea water. Nitrate–N and silicate–Si, on the other hand, showed a reverse relationship. High values were accompanied with the ebb showing that the nitrogen and silicon contents are associated with the inflow of freshwater in the estuary. The changes in the nitrate–N and silicate–Si were quite large.

Alkalinity.—The changes in the carbonate alkalinity were almost similar to those of pH (Fig. 5 C). Marked variations were noticed during the monsoon months (September) between the surface and bottom, indicating that the freshwater at the surface remains undisturbed. This was not so in December when the vertical gradient had disappeared and the changes in the alkalinity both at the surface and bottom were almost alike. The alkalinity decreased during the ebb and increased during the flood. A vertical gradient in the alkalinity appeared at the ebb which disappeared towards the end of the flood.

Chlorophyll.—The variation in chlorophyll-*a* with the tidal cycle has been shown in Fig. 5 D. With the flood or immediately after the high water, the values decreased and at the low water, the chlorophyll values increased at the surface. Near the bottom, on the other hand, the conditions were reversed, *i.e.*, high and low chlorophyll values coincided with the flood and ebb. This indicates that in the estuary greatest concentration of pigments first appears at or near the bottom during the flood, which, at the start of the ebb, begins to move up towards the surface, reaching its maximum after the low water at the surface. The possibility of detrital chlorophyll associated with the stirred-up sediment may also be a contributory factor to the chlorophyll estimation (*see* Qasim and Reddy, 1967), as the changes in the chlorophyll with the high and low water were quite large.

CHANGES IN PRIMARY PRODUCTIVITY

(*a*) *Diurnal rhythm in photosynthesis.*—The diurnal (24 hr) changes in the *in situ* oxygen of the backwater, on a uniformly bright day, have been shown in Fig. 6 A from which it can be seen that the daily variations in the oxygen concentration were sufficiently large and similar to what has been shown in flowing waters (Odum, 1956). After sunrise the values begin to rise and reach their maximum in the early hours of the afternoon. The magnitude of oxygen changes clearly indicates that it follows the course of sunlight and can be attributed to photosynthetic activity of the phytoplankton organisms. The cycles of oxygen both at the surface and 1 m depth were almost alike (Fig. 6 A).

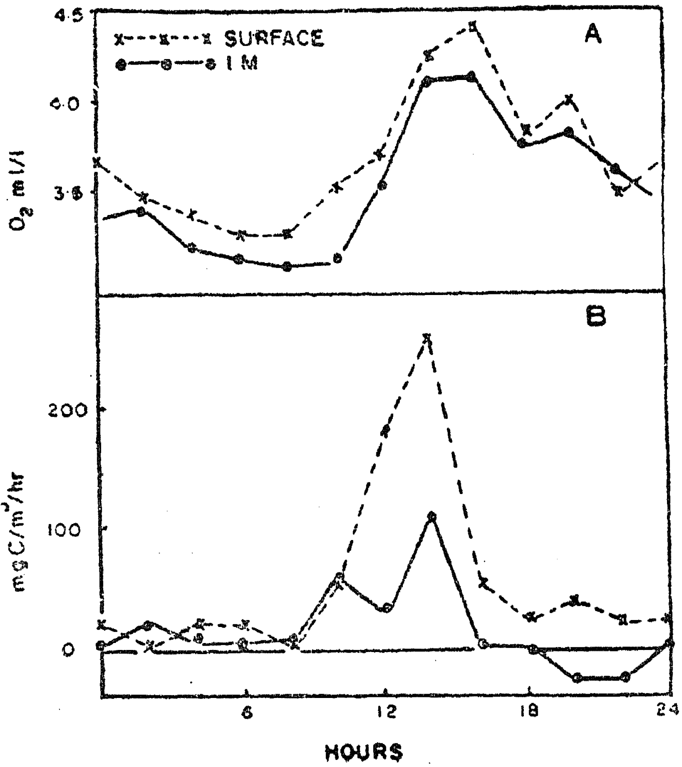

FIG. 6. (A) Diurnal (24 hr) changes in the *in situ* oxygen of the Cochin Backwater at the surface and at 1 m depth. (B) Diurnal variation in the primary production at the surface and at 1 m as obtained by the light-dark-bottle oxygen experiments conducted on 17-3-1965.

Figure 6 B shows gross primary production at the surface and at 1 m depth, obtained from light-dark-bottle oxygen experiments conducted on March 17, 1965. The factor used for converting the oxygen changes to carbon assimilation was 0·536/PQ, where the value of PQ was taken as 1·2 (Strickland, 1960). It is clear from Fig. 6 B that the production curves gave a similar day and night cycle as was observed from the *in situ* changes in oxygen. The summed value of primary production over a day at the surface was 1500 mgC/m^3/day and at 1 m it was about 400 mgC/m^3. The mean of the two gave 950 mgC/m^3/day, which is very near to the averaged values reported earlier for March (Qasim *et al.*, 1969). The marked reduction in the primary production at 1 m is because of high turbidity which reduces the light penetration considerably. Similar results were obtained by using C^{14} technique (*see* Qasim *et al.*, 1969).

(*b*) *Tidal influence on primary productivity.*—As noted above, with the considerable changes in the environmental factors caused by the state of tide, it is obvious that the values of primary production will also, to a large extent, be dependent upon the tidal rhythm. Since no direct observations were made on the rate of production with reference to tides, it is difficult to say how much the variations would be. The diurnal rhythm in photosynthesis caused by the changes in solar radiation complicates the situation and makes it difficult to study the *in situ* changes in photosynthesis with reference to tides alone. However, if the changes in phosphorus and chlorophyll are used as indices, it is clear that the estimates of primary production would vary many-folds with the state of tide; although no evidence has been obtained to show that the values of even phosphorus and chlorophyll would not be affected by the light conditions. However, taking the existing values of these parameters as a criterion of tidal influence, it seems that the estimates of primary production would be significantly higher at the flood than those made at the ebb. It is therefore suggested that to obtain comparable results on daily and seasonal changes in the rate of production, all observations in a tidal estuary should be made under similar tidal conditions.

ACKNOWLEDGEMENTS

We thank Dr. N. K. Panikkar for his interest in this work, Prof. G. Dietrich for his valuable suggestions, and Mr. V. N. Sankaranarayanan for his active participation in one of the surveys.

REFERENCES

Cameron, W. M. and Pritchard, D. W. "Estuaries," in *The Sea.* Edited by Hill, M. N., Interscience Publ., N.Y., 1963, **2**, 306–24.

Capstick, C. K. .. "The salinity characteristics of the middle and upper reaches of the River Blyth Estuary," *J. Anim. Ecol.*, 1957, **26**, 195–315.

Dietrich, G. .. *General Oceanography, An Introduction,* Interscience Publ., N.Y., 1963, pp. 588.

George, M. J. and Kartha, K. N. K. "Surface salinity of Cochin Backwater with reference to tide," *J. mar. biol. Ass. India*, 1963, **5**, 178–84.

Ketchum, B. H. .. "The exchange of fresh and salt waters in tidal estuaries," *J. Mar. Res.*, 1951, **10**, 18–38.

Odum, H. T. .. "Primary production in flowing waters," *Limnol. Oceanogr.*, 1956, **1**, 102–17.

Preddy, W. S. .. "The mixing and movement of water in the estuary of the Thames," *J. mar. biol. Ass. U.K.*, 1954, **33**, 645–62.

Qasim, S. Z. and Reddy, C. V. G. "The estimation of plant pigments of Cochin Backwater durin the monsoon months," *Bull. mar. Sci. Gulf Caribb.*, 196 **17**, 95–110.

——, Bhattathiri, P. M. A. and Abidi, S. A. H. "Solar radiation and its penetration in a tropical estuary, *J. exp. mar. Biol. Ecol.*, 1968, **2**, 87–103.

——, Wellershaus, S., Bhattathiri, P. M. A. and Abidi, S. A. H. "Organic production in a tropical estuary," *Proc. Inc Acad. Sci.*, 1969, **59**, 51–94.

Rangarajan, K. .. "Diurnal tidal cycle in Vellar estuary," *J. zool. Soc. Indic* 1958, **10**, 54–67.

Rao, S. V. S. and George, P. C. "Hydrology of the Korapuzha Estuary, Malabar, Keral State," *J. mar. biol. Ass. India*, 1959, **1**, 212–23.

Rao, T. S. S. and Rao, V. C. .. "Studies on diurnal variations in the hydrobiological conditions off the Waltair coast," *Ibid.*, 1962, **4**, 23–43.

Sankaranarayanan, V. N. and Qasim, S. Z. "Nutrients of the Cochin Backwater in relation to environmental characteristics," *Marine Biol.*, 1969, **2**, 236–47.

Strickland, J. D. H. .. "Measuring the production of marine phytoplankton," *Bul Fish. Res. Bd. Can.*, 1960, **122**, pp 172.

Vasisht, H. S. .. "The ecology of the estuary of river Wansbeck, U.K.,' *J. mar. biol. Ass. India*, 1965, **7**, 174–97.

1183–69. Printed at The Bangalore Press, Bangalore-18, by M. S. Narayana Murthy, Secretary
Published by B. S. Venkatachar, Editor, "Proceedings of the Indian
Academy of Sciences", Bangalore

Supplement to the

"Proceedings of the Indian Academy of Sciences"

INDEX TO VOL. LXIX (B)

AUTHORS' INDEX

TITLE INDEX