The Biology of the Indian Ocean

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2.4

Productivity of Backwaters and Estuaries

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The main reason why the backwaters and estuaries have been included in the Symposium on "The Biology of the Indian Ocean" is that, in certain regions of the Indian Ocean, the backwaters with their associated river system form a fairly large part of the inshore waters and influence the hydrography of the coastal water considerably. The term "backwater" or "backwaters" is of local origin and refers to a system of shallow, brackish-water lagoons and swamps found in Kerala State along the SW coast of India. They occupy an area of hundreds of square kilometers. Although the backwaters have their own physiography and geomorphology, most of them behave like estuaries. The areas which are close to the permanent connection with the sea are influenced by the regular tidal rhythm and have been referred to as tropical estuaries (QASIM et al., 1969; SANKARANARAYANAN and QASIM, 1969).

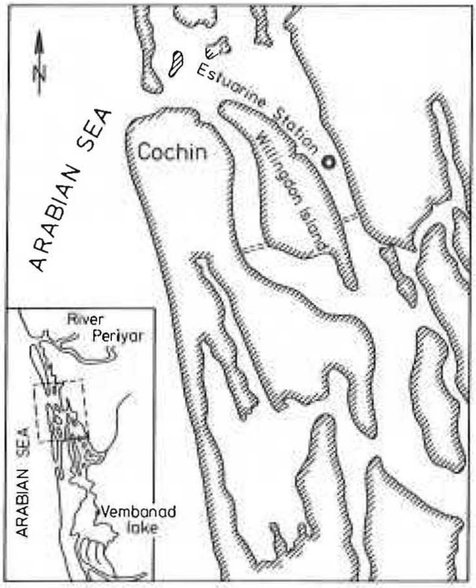

Fig. 1. Map showing a portion of the backwaters around Cochin. The estuarine site to which the data refer has been indicated by open circle. Inset shows the backwater system with its marine and freshwater connections

Fig. 1 shows the backwaters around Cochin, the main area under investigation for several years. The connection between the Arabian Sea and this backwater is maintained by a channel, about 450 m wide, which forms an entrance to Cochin harbour. Several rivers, irrigation channels and sewers open into this backwater which terminates in a large lake called Vembanad Lake. The area is accessible to all types of craft, including ocean-going vessels (to the harbour). The backwater is intensely polluted and most of the area is less than 3 m deep, except for the shipping channels which are dredged to a depth of 10 to 12 m.

I. Environmental Features

The hydrography of the backwater is largely influenced by two main factors: the short-term changes induced by the tides and the seasonal changes brought about by the monsoon system. The magnitude of variation within the backwater largely depends upon the place of observation (nearness to the sea or freshwater source). In this communication, therefore, descriptions are provided of the environmental features at a site where conditions remain typically estuarine (Fig. 1). The changes in the different parameters can be summarized as follows:

1. Tides

The tides at Cochin are of a mixed, semidiurnal nature. Two high and two low watermarks occur each day and differ in height (Fig. 2). The influence of tides on some of the environmental features has been described by QASIM and GOPINATHAN (1969).

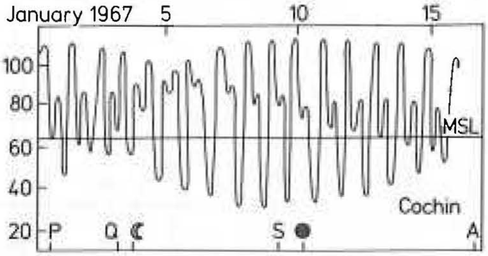

Fig. 2. Tidal cycle at Cochin during the first fortnight of Jan. 1967. The phases of the moon have also been indicated, MSL: mean sea level

Temperature, salinity, dissolved O_2, pH, seston, nutrients, alkalinity and chlorophyll are all influenced by the tides. The magnitude of variations is dependent upon the seasons when the observations are made.

2. Light Penetration

The backwater receives maximum solar radiation ($500-580$ g cal cm^{-2} day^{-1}) from January to April and minimum ($250-300$ g cal cm^{-2} day^{-1}) in July and August (Fig. 3). The decrease in solar radiation is largely dependent upon cloudiness (QASIM, BHATTATHIRI and ABIDI, 1968).

The high turbidity prevailing in the estuary greatly reduces light penetration. Fig. 4 gives the pooled data of percentage transmission at various depths in 3 different seasons:

February–May (premonsoon), June–September (monsoon) and October–January (postmonsoon). For convenience, the 2 monsoons (SW and NE) have been referred to as monsoon and postmonsoon seasons. During the monsoon season, as a result of considerable inflow of freshwater, the turbidity in the backwater increases and the light penetration falls to about 20% of the incident illumination at 1 m and 1% at 3 m (mean $k = 1.37$). During the postmonsoon season light penetration increases somewhat (32% at 1 m and 1% at 4 m (mean $k = 1.18$), but in the premonsoon season it again falls

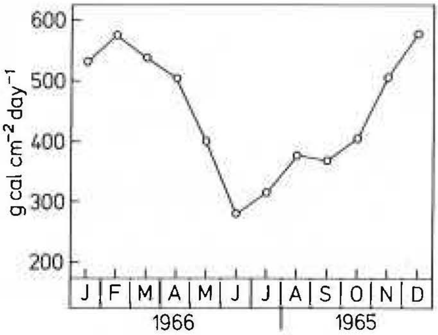

Fig. 3. Average values of solar radiation at Cochin in different months of the year 1965–66

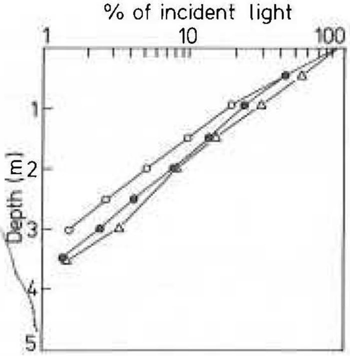

Fig. 4. Light penetration in Cochin Backwater. The values of percentage transmission at different depths have been pooled into 3 seasons. Open circles: monsoon season (June–September); open triangles postmonsoon season (October–January); closed circles: premonsoon season (February–May)

(24% at 1 m and < 1% at 4 m; mean $k = 1.36$). The compensation depth, which is taken as 1% of the surface illumination, ranges between 2 and 6 m during the year.

The seasonal variability of other environmental factors is also chiefly controlled by the monsoon cycle. The backwater remains seawater-dominated for about 6 months, and then, with the commencement of rains, it becomes freshwater-dominated and continues to remain so with varying degrees for the next 6 months. The changes in other environmental features are also divisible into premonsoon, monsoon and postmonsoon seasons (SANKARANARAYANAN and QASIM, 1969).

3. Temperature

During the premonsoon season of maximum solar radiation and warm weather, the temperature throughout the water column remains uniform and records its maximum. With the onset of rains in May, the water temperature decreases and a clear thermal gradient develops in the water column (Fig. 5). The difference in temperature from the surface to the bottom may be more than 5° C. The thermal gradient persists until about September.

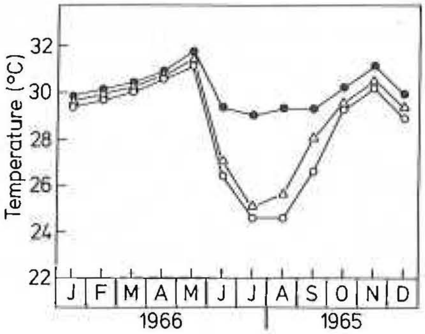

Fig. 5. Average monthly values of water temperature at 3 different depths of the backwater. Surface: closed circles; mid depth: triangles; bottom: open circles

4. Salinity

The salinity remains homogeneous throughout the water column during the premonsoon season, indicating that the water is well mixed (Fig. 6). During the monsoon months large quantities of freshwater enter the estuary, resulting in low salinity water at the surface and denser water at the bottom. Because of a clear stratification which exists during the monsoon months, the surface and bottom waters remain quite distinct. The stratification is broken up during the postmonsoon months when homogeneous conditions are gradually restored.

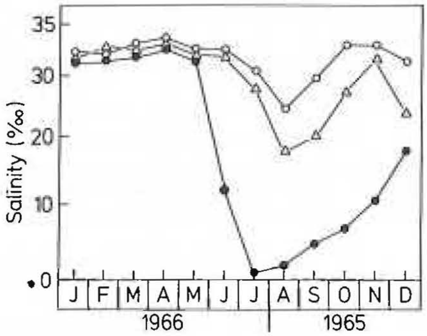

Fig. 6. Average monthly values of salinity at 3 different depths of the backwater. Symbols as in Fig. 5

5. Oxygen

The dissolved O_2 shows little change at different depths during the premonsoon season. With the start of the monsoon rains, the O_2 values at the surface increase, but at deeper layers a decrease in the dissolved O_2 is noticed (Fig. 7). The vertical gradient normally continues until marine conditions in the backwater are restored.

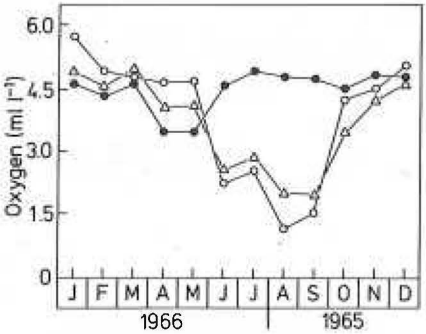

Fig. 7. Average monthly values of dissolved oxygen at 3 different depths of the backwater. Symbols as in Fig. 5

6. Hydrogen Ion Concentration

The pH showed seasonal fluctuation at all depths. The values remain high when conditions are marine and fall progressively as the system becomes freshwater-dominated (Fig. 8).

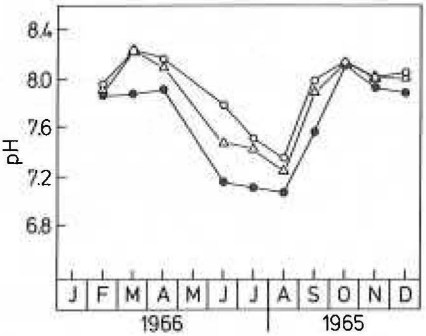

Fig. 8. Average monthly values of pH at 3 different depths of the backwater. Symbols as in Fig. 5

7. Alkalinity

Fig. 9 shows the variation in alkalinity. Like salinity, the alkalinity of the water showed small changes during the premonsoon period and large changes during the monsoon months.

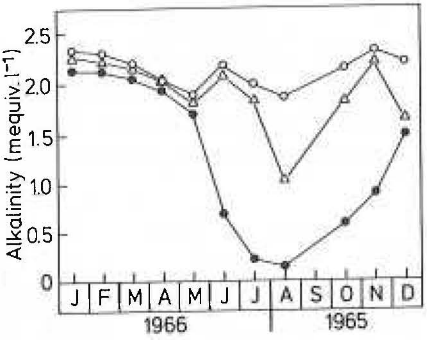

Fig. 9. Average monthly values of alkalinity at 3 different depths of the backwater. Symbols as in Fig. 5

8. Inorganic Phosphorus

During the premonsoon season the inorganic PO_4^{3-}-P at all depths ranges between 0.5 – 1.0 μg-at l⁻¹. From May onwards when the monsoon rains start, the values of the water column are subject to pronounced changes (Fig. 10). The PO_4^{3-}-P concentrations at mid-depth and at the bottom become much higher than those at the surface.

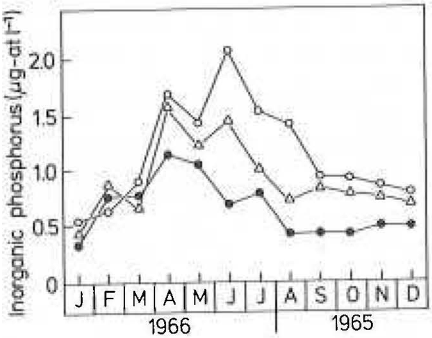

Fig. 10. Average monthly values of inorganic phosphorus at different depths of the backwater. Symbols as in Fig. 5

9. Organic Phosphorus

The amount of organic phosphorus was generally greater at the bottom than at the surface (Fig. 11). Larger fluctuations in the values were noticed at the bottom than at the surface.

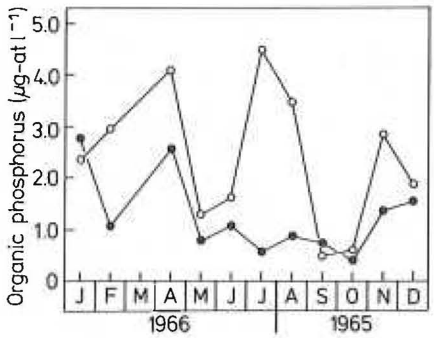

Fig. 11. Average monthly values of organic phosphorus at 2 different depths of the backwater. Surface: closed circles; bottom: open circles

10. Nitrate-Nitrogen

When the backwater remains marine-dominated the values of NO_3^--N are low, but during the monsoon months the values become suddenly high. The distribution of NO_3^--N remains homogeneous throughout the water column in all the seasons (Fig. 12).

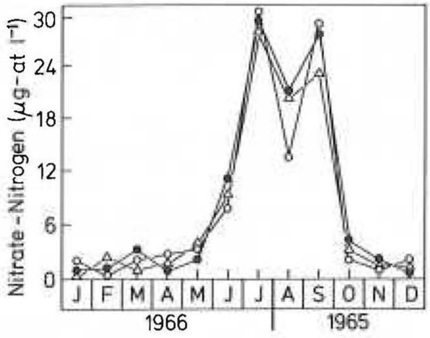

Fig. 12. Average monthly values of nitrate-nitrogen at 3 different depths of the backwater. Symbols as in Fig. 5

11. Nitrite-Nitrogen

Pronounced changes in the NO_2^--N were noticed during the monsoon months (Fig. 13) but these were mostly in deeper layers. The water at the surface showed maximum value in May whereas three peaks of NO_2^--N were recorded at mid-depth and at the bottom (Fig. 13).

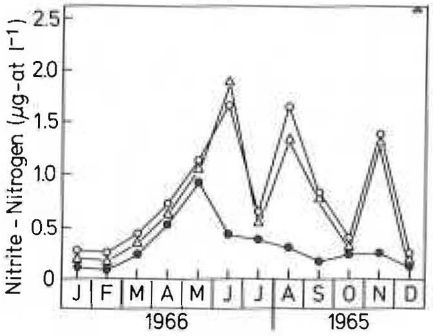

Fig. 13. Average monthly values of nitrite-nitrogen at 3 different depths of the backwater. Symbols as in Fig. 5

12. Silicate-Silicon

The silicon values in the backwater were closely related to the silt-loaded freshwater discharge, thus making the values very high during the monsoon months (Fig. 14).

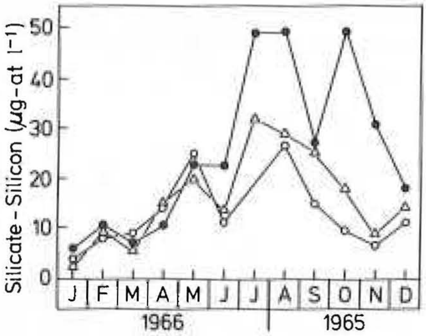

Fig. 14. Average monthly values of silicate-silicon at 3 different depths of the backwater. Symbols as in Fig. 5

II. Rate of Primary Production

The rate of photosynthesis was measured by the light and dark bottle O_2 technique and the ^{14}C method of STEEMANN NIELSEN (1952). The former method gave a measure of gross production and the latter of net production. The factor for converting the O_2 changes to C assimilation was 0.375/PQ, where the value of PQ was taken as 1.2 (STRICKLAND, 1960). Experiments with light and dark bottle and ^{14}C were conducted *in situ*, using a float throughout the year, at the site shown in Fig. 1.

The primary production in relation to depths is given in Fig. 15. The data for different months have been pooled according to the 3 seasons. It is clear from the figure that about 90% of the total production is confined to the topmost layer. Maximum production occurs either at the surface or slightly below. This is because highly turbid conditions prevail in the backwater, more particularly during the monsoon season. Monthly values of gross and net production for the euphotic zone are given in Fig. 16. The average values of respiration for the euphotic zone in different months, calculated from the O_2 decrease in the dark bottle during the light and dark bottle experiments, have also been included in the figure. This was done on the assumption that the rate of respiration in the dark is the same as that during the corresponding period of light in conjunction with photosynthesis.

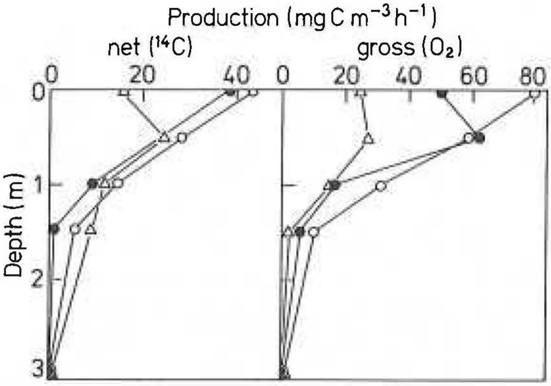

Fig. 15. Primary production (gross and net) in the backwater in relation to depths. The data have been pooled into 3 seasons. Monsoon season: closed circles; postmonsoon season: triangles; premonsoon months: open circles

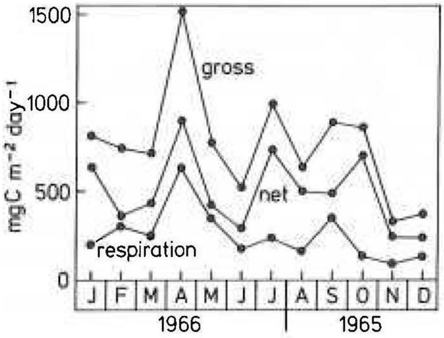

Fig. 16. Seasonal changes in gross and net primary production in the backwater. Community respiration has also been included in the figure. The values of production and respiration refer to the euphotic zone

The column production showed 3 peaks: one in April, the second in July and the third in October. These peaks were of a short duration and amounted to a 3–4 fold increase. Therefore, the backwater behaves like other tropical areas where primary production is reported to go on at a uniform rate throughout the year, with little seasonal increase (MENZEL and RYTHER, 1961). (In temperate regions the seasonal increase in production during the summer months may be 50 times greater than in winter.)

III. Chlorophyll *a* Cycle

Seasonal changes in the chlorophyll *a* concentration are given in Fig. 17. A comparison of the chlorophyll cycle with that of primary production (Fig. 15) reveals that the two are not synchronous. This may be due to the presence of dead and inactive chlorophyll from detrital material and stirred-up sediment (QASIM and REDDY, 1967). The quantity of chlorophyll, which was later found to be predominantly phaeophytin, was much greater during the monsoon months when light penetration in the backwater was greatly reduced (unpublished data).

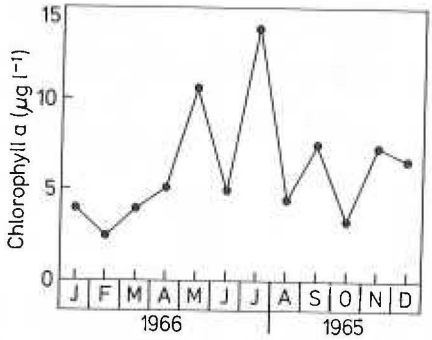

Fig. 17. Average monthly values of chlorophyll *a* in the surface water of the backwater

IV. Assimilation Ratio

The ratio between ^{14}C assimilation and chlorophyll *a* ranged from 0.6 in November to 14.8 in April (Fig. 18). Such a large variation in the ratio further indicates that the entire observed chlorophyll may not be photosynthetically active. The presence of inactive chlorophyll would make the monthly variations in the ratio somewhat different from the seasonal rises and falls of the primary production.

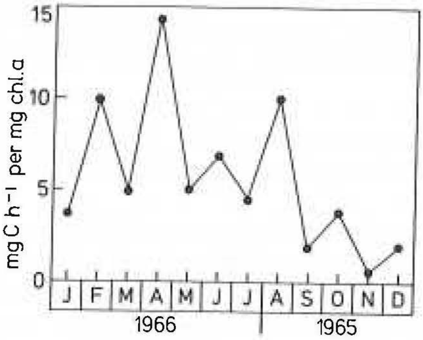

Fig. 18. Average monthly ratios of carbon assimilation to chlorophyll *a* in the surface water of the backwater

V. Primary Production and Environmental Factors

A comparison between the annual cycle of primary productivity and the seasonal variation in the environmental features described above reveals that the peaks in production are independent of the high and low values of solar radiation falling on the surface of water. Monthly variations in total solar radiation are never a limiting factor, although light penetration in the water column is considerably reduced by high turbidity and thus becomes a serious limiting factor for maximum photosynthesis in the backwater. The water temperature seems to have no direct effect on primary production, but changes in salinity are important in favouring phytoplankton productivity. The peaks in primary production occur during the monsoon months when salinity in the backwater is low. The predominant phytoplankton during the monsoon months consists of diatoms and green algae. To test whether low salinity would influence the growth of phytoplankton, the following experiments were conducted:

Several organisms isolated from the inshore areas were cultured in enriched seawater. When the cultures became sufficiently dense, known volumes of these were added to bottles containing seawater of different salinities, 5–35 ‰. These were exposed to constant illumination and their rates of photosynthesis were measured by ^{14}C assimilation (QASIM, BHATTATHIRI and DEVASSY, 1972a). Table 1 shows the range in salinity at which maximum photosynthesis was obtained. It is clear from the table that maximum photosynthesis occurred at low salinities. These experiments confirmed the field observations that organisms are more abundant in areas of low salinity or in seasons when the salinity is rapidly decreasing.

Table 1. Range in salinity at which maximum photosynthesis occurred in different unialgal cultures of diatoms and flagellates

Organisms	Salinity range ‰
Bacillariophyceae:	
Nitzschia closterium	10–15
Planktoniella sol	15–20
Triceratium favus	10–20
Asterionella japonica	10–20
Chaetoceros lorenzianus	10–20
Coscinodiscus radiatus	10–20
Biddulphia sinensis	10–20
Rhizosolenia styliformis	15–20
Thalassiosira subtilis	14–24
Dinophyceae:	
Ceratium furca	6–10
Dinophysis miles	10–15
Dichtyocha sp.	20–25

Seasonal variations in the concentration of different nutrients have been shown in Figs. 10–14. During the monsoon period the backwater contains very high concentrations of nutrients. These are largely associated with freshwater discharge and land run-off. The annual cycle of primary productivity (Fig. 16) showed only brief pulses of bloom.

There was no substantial increase in the rate of production when the water was rich in nutrients. This indicates that the nutrient requirement of different phytoplankton species is highly variable and that the high concentration of nutrients alone is not conducive to a substantial increase in phytoplankton productivity. This was experimentally verified by taking cultures of the dinoflagellate *Ceratium* and the diatom *Biddulphia* and exposing them to different concentrations of phosphate and nitrate. Their rates of photosynthesis were measured by the ^{14}C uptake as a function of time (QASIM, BHATTATHIRI and DEVASSY, 1972b). The concentrations of PO_4^{3-}-P and NO_3^--N used were 0.5, 1.0, 2.0, 5.0 and 10.0 μg-at l^{-1}. In *Ceratium* the rate of photosynthesis increased with higher PO_4^{3-}-P concentrations and reached its maximum at a concentration of 10 μg-at l^{-1} in about 10 days. A similar situation was found with *Biddulphia* where maximum photosynthesis was attained within 10 days with increasing concentrations of phosphate. However, when different concentrations of nitrate were used in *Ceratium*, maximum photosynthesis was obtained at 0.5 μg-at l^{-1} and any further increase in the concentration of nitrogen inhibited photosynthesis. In *Biddulphia* an increase in the concentration of nitrate led to a progressive increase in photosynthesis. Similar results were obtained when phosphorus and nitrogen were used in a combined state. In *Ceratium* maximum photosynthesis occurred when the concentration of each was 0.5 μg-at l^{-1}, whereas in *Biddulphia* peak photosynthesis was obtained when the concentration of each was 5.0–10.0 μg-at l^{-1}. These experiments indicate that the nutrient requirement of the two species is very different. From these results it can also be postulated that the changing concentrations of nutrients may lead to a succession in the growth of phytoplankton organisms. Such a succession is of common occurrence in the backwater.

VI. Food Chain

The average gross production in the estuary is 280 gC m^{-2} $year^{-1}$ and the net production for days is approximately 195 gC m^{-2} $year^{-1}$ and for days and nights (24 hrs) about 124 gC m^{-2} $year^{-1}$. The estimated annual rate of consumption of the daily net production by the zooplankton herbivores is 30 gC m^{-2} $year^{-1}$ (QASIM, 1970). The rate of consumption is greater during the premonsoon season (46%) than in other seasons (QASIM et al., 1969). This gives rise to a large surplus of primary production which falls to the bottom as detritus. The shallow euphotic zone increases the fallout of basic food material which forms an important link in the food chain (QASIM, 1970). The detritus is consumed by a variety of benthic animal communities and thus leads to several alternate pathways in the food chain (QASIM, 1971).

Continuous collections of detritus falling on the bottom were made throughout the year (QASIM and SANKARANARAYANAN, 1972). The quantity of detritus in the backwater was much greater than that previously reported from the Southampton waters (TREVALLION, 1967) or from the North Sea and Kiel Bay (KREY, 1961). The values in the backwater ranged from 67 g m^{-2} day^{-1} in March to 1013 g m^{-2} day^{-1} in May and amounted to 90–99% of the total phytoplankton productivity. The biochemical composition of detritus and its calorific value were determined (QASIM and SANKARANARAYANAN, 1972). Dried pellets of detritus offered as food to a penaeid prawn *(Metapenaeus dobsoni)* in the laboratory were readily eaten. The prawns lived exclusively on detritus for a long time and moulted several times in aquarium tanks.