

Organic detritus of a tropical estuary

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Abstract

Organic detritus of the Cochin Backwater (India) is largely composed of fine silt and sand particles around which organic matter adheres and forms aggregates. In addition to plankton, large quantities of benthic algae, rooted plants, animal matter, suspended soft mud and the material brought down by the rivers and land runoff constitute the main sources of detritus. Detritus sedimentation in the estuary attains its maximum from April to June. Detritus forms a major portion of seston, while phytoplankton productivity constitutes 0.1 to 1.0% of settled detritus. Detrital pigments include degraded chlorophyll (phaeophytin), which has a marked seasonal variation; detrital carbon, phosphorus and nitrogen show little change during the year. The caloric value of detritus, calculated from protein, carbohydrate and lipid fractions and also from total carbon, indicates that sedimented detritus does not have a high nutritional value. However, being a readily available material, its entry into the food chain seems to increase the efficiency of energy transfer from one trophic level to another.

Introduction

The present communication gives a quantitative estimation of settled detritus and its chemical composition in the Cochin Backwater, India, a tropical estuary which has been studied for different aspects of hydrography during the period 1965/1970. With a considerable reduction in the euphotic zone of this estuary, following an increase in the turbidity of water (QASIM et al., 1968), a large fall-out of plant and animal material occurs almost continuously (QASIM et al., 1969; QASIM, 1970). This material, which has commonly been termed "detritus" (KREY, 1961a; TREVALLION, 1967), remains at first in suspension and is then deposited on the sediment as a superficial layer. DARNELL (1967) has defined organic detritus as "all types of biogenic material in various stages of microbial decomposition." A clear distinction, however, exists between suspended and settled detritus — the former occurs regularly in the plankton and the latter forms a part of the sediment (KENCHINGTON, 1970). While only a portion of the daily contribution of detritus, on reaching the bottom of the estuary, would seem to be decomposed and recycled, the remainder will enter into the food chain as an important source of energy for filter and bottom feeders. In earlier studies, it has been shown that

organic detritus forms a large proportion of the suspended material (FOX et al., 1952; KREY, 1961a, 1964). An assessment, therefore, of the quantity of detritus, its rate of sedimentation and chemical characteristics, would form an important prerequisite in studies of organic productivity although, conventionally, plankton and detritus are treated as separate entities — the former as living and the latter as dead or inert material (KREY, 1961b). Much of the earlier work on suspended organic matter in the sea has been comprehensively reviewed by PARSONS (1963) and more recently by RILEY (1970).

Procedure and methods

Continuous collections of detritus were made every fortnight for a period of one year (October 1969/September 1970) using an apparatus of the kind described and figured by TREVALLION (1967). The apparatus included an anchoring block to maintain a polythene collecting jar with a closing device, when suspended in an upright position at a particular depth (for details of the apparatus and its operation see TREVALLION, 1967). The collecting jar in the present apparatus was so adjusted that it came very close to the anchoring block and was thus kept at 0.5 m above the bottom. The apparatus was installed in the Cochin Backwater at a fairly well-sheltered site. The depth of the water at the site was 2 to 3 m, depending upon the tidal height.

Samples of detritus settled in the jar were collected at fortnightly intervals. Since the quantity of collected material was large, sub-samples were taken for further analysis. The collected material was at first made up to 1 l in a container by adding filtered sea water and, from this, a small quantity was pipetted out, diluted and examined under a microscope. Aliquots of 10 ml were then taken from the sample, after shaking the container thoroughly, and these were filtered through Whatman GF/C pads for analysis of chlorophyll. The relative proportion of chlorophyll *a* to degraded chlorophyll (phaeophytin) in the detritus was determined by measuring at the same wavelength (6650 Å), on a spectrophotometer, the optical density

of the acetone extract before and after acidification (STEELE and BAIRD, 1968).

Two sub-samples of 100 ml each were again drawn from the total material. These were centrifuged, washed with distilled water, dried at 60 °C and weighed. The weight of the two sub-samples agreed very closely, and the average of the two was used for computing the quantity of detritus from the mouth area of the collecting jar and expressing it as dry weight/cm²/month or as dry weight/m²/day.

The remaining material was also measured and dried. After drying, the detritus formed flakes which were reduced to fine powder by grinding. Sub-samples of this powdered material were analysed for total phosphorus, carbon, nitrogen, carbohydrate and lipid. The methods used for the various analyses were based on the handbook of STRICKLAND and PARSONS (1968).

The instantaneous concentration of seston in the water column was determined by filtering a known quantity of water taken from two depths, 0 and 5 m, and weighing the dried filters before and after filtration. The seston determinations were also made at fortnightly intervals, and the monthly values for the two depths were combined and calculated for the column of water. The site for the seston measurements was about 20 m away from that of the detritus collection. This was done to avoid any disturbance in the distribution of detritus caused by boat traffic. The site for seston measurements had an average depth of 6 m.

Results

Visual description of detritus

Examination of the detrital material under a microscope showed that it is composed of a substrate of inorganic matter (fine silt and sand) to which organic matter adheres and forms aggregates of irregular shape and size. These aggregates were similar to those described by RILEY (1963), and appeared dark-brown, because of silt, clay, and other mineral particles. The detrital material also contained recognizable remains of both plants and animals. The former included both living and dead cells of diatoms, dinoflagellates and other algae of almost as many genera and species as are found in the phytoplankton crop. Fragments of seaweeds and of higher aquatic and land plants were also abundant. The animal part of the detritus was largely composed of infusorians, foraminiferans, nematodes, carcasses and moults of copepods and other crustaceans, sponge spicules, setae of polychaetes, stems of hydroid colonies, fragments of jelly fish and medusae, pieces of bryozoans, remains of molluscs, frustules of barnacle nauplii and fragments of appendicularians. In almost all the samples, the most abundant component, next to organic aggregates, was faecal pellets. These were of different sizes and shapes and probably belonged to a variety of animal groups.

Seasonal changes in quantity of detritus

The quantity of detritus collected from the Cochin Backwater was much greater than that reported from Southampton Water (TREVALLION, 1967). Monthly variations in the quantity of detritus have been shown in Fig. 1. From the large differences obtained during the year, it is difficult to conclude whether the high values in some months truly indicate a greater formation of detritus in the estuary or if these are due to the collection of stirred-up material from the bottom.

However, if the year is divided into four quarters and the values for each quarter are averaged, some conclusions on the seasonal differences in detritus

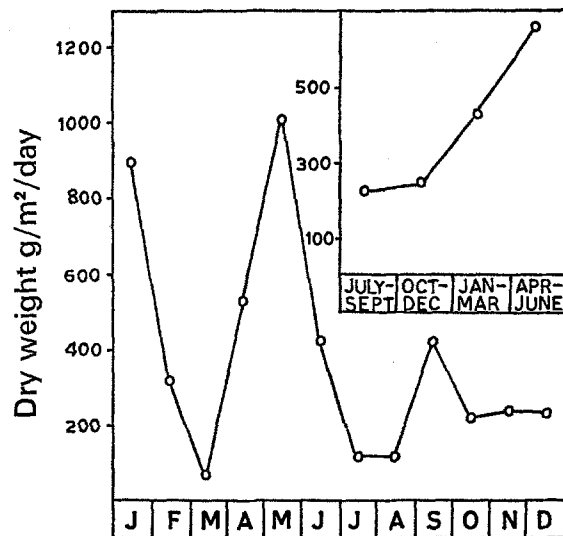


Fig. 1. Cochin Backwater, India. Monthly variation in the quantity of detritus collected. Inset: average values in four quarters, each of 3 months

settlement can be drawn. The values for the four quarters have been shown in Fig. 1 (inset). As can be seen from this figure, quite contrary to expectations, the quantity of settled detritus was low during the monsoon (July/September) and post-monsoon (October/December) quarters, when the turbidity in the estuary was maximum, with Secchi disk readings 0.6 to 1.0 m. This is because of the stratification which develops in the estuary from June to about October, as a result of discontinuity in the vertical profiles of temperature and salinity which probably reduces the settlement rate of detritus substantially. It has been reported elsewhere that, during this season, the surface water becomes "considerably diluted and a clearly defined halocline appears, with brackish water or very nearly freshwater at the top and seawater at the bottom, both remaining undisturbed" (SANKARANARAYANAN and QASIM, 1969). The changes in

the environmental features at the site where collections of detritus were made (Station 3 of the earlier studies), have been described elsewhere (see SANKARANARAYANAN and QASIM, 1969). During this period, the halocline inhibits mixing, and thus reduces the settlement of detritus. In Chesapeake Bay (USA), it has been shown that the halocline acts as a barrier for the settlement of particulate carbohydrate (BIGGS and WETZEL, 1968). From January onwards, when homogeneous conditions prevail throughout the water column, and the particulate material remains well mixed, the detritus settlement shows a sharp increase. The maximum value obtained for the quarter, April/June, is probably because of the pre-monsoon showers in April/May, and the first few land runoffs which bring in large quantities of material from outside and thus increase the detrital load considerably (QASIM et al., 1969).

Seston and detritus

Table 1 gives monthly variations in the seston content of water which represents the total suspended material, both living and non-living. The seston content was maximum during the period April/August, when heavy rainfall and land runoff brought considerable quantities of silt and sand into the estuary from outside. Also included in the table is the daily rate of settlement of detritus and the ratio between detritus and seston. The variability in the detritus rate and seston, as is evident from the ratios, is very large (Table 1), suggesting that the material already settled at the bottom becomes periodically disturbed because of tidal currents and is then resuspended. This would also lead to a disproportionate distribution of seston from time to time. In the Menai Straits (UK), suspended inorganic matter and detritus have been found

to vary considerably with the state of tides (BUCHAN et al., 1967; KENCHINGTON, 1970). Thus, the stirred-up bottom sediment seems a likely source of settled detritus. This, in addition to the benthic plants and material brought down by the rivers and land runoff from the adjacent areas, accounts for the detritus accumulating in such large quantities.

Detritus and phytoplankton productivity

Gross primary production in the Cochin Backwater has been found to range from 0.53 to 1.52 gC/m²/day (QASIM et al., 1969). The values for different months have been included in Table 1 for comparison with the rates of detritus formation. The quantitative relationship between the two (Table 1) clearly indicates that the rate of phytoplankton production constitutes a small fraction (0.09 to 1.0%) of the rate of detritus sedimentation, and gives an unequivocal proof that the detritus is not entirely of phytoplankton origin. This is in contrast to the detritus from deep-ocean water, where non-living organic matter is derived from the surface plankton and represents refractory remains for a considerably long time through a large column of water (PARSONS and STRICKLAND, 1962).

Chemical composition

Chlorophyll and carbon

In pure chlorophyll *a*, YENTSCH and MENZEL (1963) have found the ratio between unacidified and acidified extract to be 1.7 and, after the pigment has degraded to phaeophytin, the ratio becomes 1.0. Table 2 shows the ratios of unacidified to acidified extracts. As can be seen from the table, except for March and April, the detrital pigments largely include degraded chlorophyll (phaeophytin). The total quantity of pigments

Table 1. Cochin Backwater, India. Seasonal changes in quantity of detritus, settling in jar suspended near bottom of estuary, in relation to total quantity of seston and gross primary production. Values of gross primary production taken from QASIM et al. (1969)

Month	Detritus (g/m ² /day)	Seston (0—5 m) (g/m ²)	Ratio detritus: seston	Gross primary production (gC/m ² /day)	Primary production as percentage of detritus
January	900	99	9.09	0.82	0.09
February	320	57	5.61	0.73	0.23
March	67	6	11.17	0.69	1.03
April	537	160	3.36	1.52	0.28
May	1013	126	8.04	0.80	0.08
June	427	194	2.20	0.53	0.13
July	120	143	0.84	0.99	0.82
August	117	168	0.70	0.65	0.56
September	423	46	9.19	0.865	0.20
October	223	93	2.40	0.84	0.38
November	247	100	2.47	0.35	0.14
December	233	61	3.82	0.40	0.17

Table 2. *Cochin Backwater, India. Analytical data for chlorophyll, carbon, phosphorus and nitrogen expressed as percentage of totals for detritus. First column gives rate of detritus sedimentation in each month*

Month	Detritus (g/cm ² /month)	Ratio unacidified to acidified extract	Chlorophyll (% dry weight)	Organic carbon (% dry weight)	Total phosphorus (% dry weight)	Total nitrogen (% dry weight)
January	2.70	1.05	8.57	3.78	0.17	0.47
February	0.96	1.09	5.74	3.77	0.16	0.57
March	0.20	1.25	3.53	3.93	0.11	0.51
April	1.61	1.50	2.42	3.39	0.10	0.48
May	3.04	1.00	1.10	3.78	0.12	0.41
June	1.28	1.00	0.76	3.63	0.08	0.39
July	0.36	1.00	0.67	4.23	0.07	0.40
August	0.35	1.00	1.50	3.69	0.08	0.57
September	1.27	1.00	0.75	4.02	0.07	0.71
October	0.67	1.08	0.44	3.75	0.07	0.46
November	0.74	1.00	1.66	3.84	0.07	0.51
December	0.70	1.19	7.05	4.78	0.16	0.94

present in detritus is also given in Table 2, along with the values of organic carbon, phosphorus and nitrogen. The relative constancy in the values of organic carbon during the year, and large variations in the concentrations of pigments, probably signify that the plant material is not a dominant source of organic carbon. High values of pigments were recorded in December and January, but thereafter the values decreased and reached their minimum during the monsoon months (June/July). Low concentrations of chlorophyll for most of the year (Table 2) indicate that the detrital pigments probably decompose and denature quickly. This is also reflected in the carbon:pigment ratio (by weight) which has a wide range, 0.41:1 to 8.5:1.

Phosphorus and nitrogen

Total phosphorus showed little seasonal change, while the values of total nitrogen revealed some fluctuation during the year (Table 2). The concentration of one does not seem to be dependent upon the other. High nitrogen contents in some months probably suggest increased incorporation of organic matter into the detritus. The ratios of N:P varied from 2.8:1 to 10.2:1 (average 5.5:1), which suggests that the relative proportion of nitrogen and phosphorus is not as variable in detritus as in the water column of the estuary, where the ratios of inorganic N:P (by atoms) range from 1:1 to 99:1 during the year (SANKARANARAYANAN and QASIM, 1969). SEKI et al. (1968) have shown that, in a marine sediment, the decomposition rate of organic nitrogen is relatively rapid, followed by phosphorus and carbon; but in particulate matter kept in suspension, the loss of phosphorus is faster than that of nitrogen.

During the year, C:N ratios in detritus ranged between 5 and 10.5:1 (average 7.6). The ratio was

lowest in December and highest in July. PARSONS and STRICKLAND (1962), in their samples of ocean detritus, found the C:N ratio to range from 5.4:1 in samples near the surface to 2.3:1 in deeper waters. PROVASOLI (1963) suggested that sea water containing humic material of fresh-water origin has a high C:N ratio, nearer to 10:1, which is the ratio in "water humus". The C:N ratios in detritus collected at three sites in Southampton Water had a range of 5 to 17:1, 6 to 16:1, 6 to 12:1 during the entire period of investigation, which lasted 15 months (TREVALLION, 1967). In the western north Atlantic Ocean, MENZEL and RYTHER (1964) gave the ratios (by atoms) in the suspended detritus as 12.5:1 in January and 5.3:1 in April. The ratio at greater depths decreased to 2.5:1. Along the California coast, the average ratio for the entire water column was 12.5:1, with a range of 5.5 to 14.2:1 (HOLM-HANSEN et al., 1966), and in the subtropical waters of the north Atlantic Ocean, the range in ratio was 7.8 to 15.5:1 (GORDON, 1970). Thus, the ratios of C:N found for the estuarine detritus fall within the observed variations, and signify that there are quantitative similarities in qualitatively different situations.

The ratio of C:P (by weight) ranged from 22.6:1 (lowest) in January to 60.4:1 (highest) in July (average 41:1). MENZEL and RYTHER (1964) found this ratio to vary from 59:1 to 77:1 (average 67:1), while HOLM-HANSEN et al. (1966) reported the range in the ratio for the water column as 25 to 66.6:1 (average 50:1). These findings clearly indicate that the detrital residue is generally poor in phosphorus.

Detritus and bottom sediment

The chemical constituents of detritus and the uppermost layer of mud from the estuary are given in

Table 3. The latter was collected by hand at the lowest tide. A comparison of the values would indicate that, except for chlorophyll, which is a labile substance, the topmost layer of the bottom sediment is chemically similar to that of detritus, which probably indicates that the upper few millimetres of the sediment largely contain settled detritus.

Monthly variations in the phosphorus and nitrogen concentrations in the inshore sediment collected from the Arabian Sea, by using a snapper, are given in Table 4. Relative constancy in the phosphorus values of the sediment throughout the year is quite apparent from the table. The total nitrogen, on the other hand, showed some fluctuation. The concentrations of both

Table 3. *Cochin Backwater, India. Chemical composition of detritus and bottom sediment (topmost layer) from estuary. Each value is mean of 3-4 measurements*

Components (% dry weight)	Detritus (%)	Sediment (%)
Organic carbon	3.73	3.35
Chlorophyll	2.75	0.92
Total nitrogen	0.38	0.33
Total phosphorus	0.16	0.11

Nevertheless, in the absence of a better and more efficient sampling device for the settled detritus, the present method was considered adequate to give a gross quantitative assessment of the total sedimented material.

Protein, carbohydrate and lipid

The values of protein, carbohydrate and lipid obtained from the dried samples of detritus are given in Table 5. Protein was determined from the total nitrogen by applying the conversion factor 6.25. Using the energy factors 5.65 kcal/g dry weight for protein, 4.15 for carbohydrate and 9.40 for lipid (PHILLIPS, 1969), the caloric value of detritus in terms of each fraction was calculated (Table 5), and the total energy content of detritus in different months plotted in Fig. 2. The caloric value of detritus can also be calculated from its carbon content by using the equation given by PLATT et al. (1969) for zooplankton equivalent:

$$\text{cal/g dry weight} = -227 + 152 (\% \text{ carbon}).$$

These values have also been plotted in Fig. 2 for the different months. The energy values calculated from the organic carbon were consistently higher than those determined from the major metabolites (protein,

Table 4. *Arabian Sea (3 miles off Calicut). Seasonal variation in phosphorus and nitrogen contents of inshore sediment*

Components (% dry weight)	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Total-P	0.17	0.16	0.14	0.19	0.13	0.15	0.17	0.16	0.14	0.17	0.17	0.15
Total-N	0.33	0.31	0.49	0.58	0.48	0.60	0.23	0.46	0.24	0.26	0.32	0.39

phosphorus and nitrogen in the sediment seem to be of a similar order of magnitude as in detritus, and these provide further evidence that the uppermost layer of the inshore sediment also contains mostly settled detritus. Alternatively, it would also suggest that the settled detritus might include, in part at least, material stirred-up from the topmost layer of the sediment. This, however, reflects the method of sampling, which does not take into consideration the detrital resuspension. The problem seems to be of a general nature for, in shallow water, a periodic redistribution of soft mud from the bottom occurs (RHODS and YOUNG, 1970). When this material becomes dispersed in the water, organic matter aggregates around each particle, and these particles increase the total detrital load of the water column. The collection technique employed in the present study is by no means perfect.

carbohydrate and lipid). This indicates that the detrital carbon contains additional carbon from sources other than protein, carbohydrate, and lipid. Evidently, the total particulate carbon seems the best single property for measuring the caloric value of detritus.

Seasonal changes in the caloric content of detritus were not very well marked. Both the curves in Fig. 2 show random fluctuations, which were small and quite independent of the total quantity of detritus settled in each month (see Fig. 1). This suggests that the energy content of detritus has no relation to the increase or decrease in its total quantity, which is largely composed of silt and mud of very little nutritional value. A substantial increase in the caloric value of detritus in December (Fig. 2), when its quantity was low, suggests that, in this month, the settled detritus was rich in organic matter.

Table 5. Cochin Backwater, India. Analytical data for major metabolites in detritus together with estimates of caloric values from each fraction in different months

Month	Protein		Carbohydrate		Lipid	
	(mg/g dry weight)	($\times 5.65$) (cal/g dry weight)	(mg/g dry weight)	($\times 4.15$) (cal/g dry weight)	(mg/g dry weight)	($\times 9.40$) (cal/g dry weight)
January	29.7	167.80	5.8	24.07	14.1	132.54
February	35.6	201.14	5.0	20.75	7.0	65.80
March	31.8	179.67	4.4	18.26	6.5	61.10
April	30.0	169.50	9.9	41.09	5.5	51.70
May	25.6	144.64	8.2	34.03	2.5	23.50
June	24.3	137.30	7.7	31.96	5.0	47.00
July	25.0	141.25	7.6	31.54	3.5	32.90
August	35.6	201.14	6.7	27.81	3.0	28.20
September	44.3	250.30	7.1	29.47	2.7	25.38
October	28.8	162.72	7.8	32.37	3.6	33.84
November	21.8	123.17	10.5	43.58	3.9	36.66
December	58.7	331.66	4.0	16.60	14.5	136.30

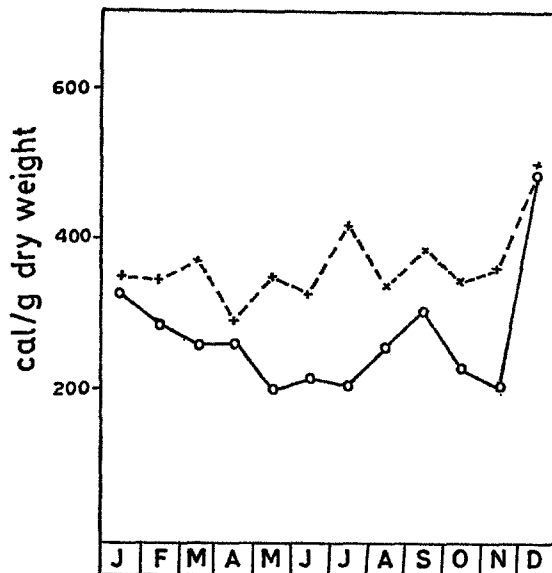


Fig. 2. Cochin Backwater, India. Seasonal variation in caloric content of sedimented detritus. Open circles give total caloric values from protein, carbohydrate and lipid. Crosses indicate caloric values determined from carbon

Discussion

Several authors have documented the importance of detritus as food of estuarine and inshore animals (FOX, 1950; DARNELL, 1961; NEWELL, 1965). Animals consume detritus either by filtering fine particles or by swallowing larger aggregates and mud, or by scraping adhered material from submerged objects. In a recent communication, the filter-feeding benthic communities were broadly divided into suspension feeders and deposit feeders. The former colonize areas with a firm mud bottom, whereas the latter populate soft muddy substrata, where faecal-rich material is readily available in a fluid state as a result of periodic resuspension of bottom mud by tidal currents (RHOADS and YOUNG, 1970).

To determine whether detritus could be of nutritional value to an estuarine animal, the following

experiment was carried out: juvenile specimens of the shrimp *Metapenaeus dobsoni* (MIEBES) were collected from the Backwater. These were kept without food in aquarium tanks for 2 to 3 days, and then dried pellets of detritus were offered as food. The pellets were readily eaten by the shrimp. From the experiment, which was kept going for several months, it became evident that the shrimp could continue to live on detritus almost indefinitely. It moulted several times during the experiment, which indicates that growth had definitely taken place.

The total caloric value of detritus is given in Fig. 2. It indicates that, as compared to suspended detritus (PARSONS, 1963; KENCHINGTON, 1970), animal foods such as zooplankton (BRAWN et al., 1968) and fish (PHILLIPS, 1969), sedimented detritus is of poor nutritional value. Presence of bacteria in association with detritus (ZOBELL and FELTHAM, 1942) probably supplements its nutritional inadequacy. Moreover, being a readily available and universally abundant food, its poor food value is probably compensated for by the large quantities in which it is ingested, very often even by the most carnivorous species of the estuarine community (DARNELL, 1961, 1967).

However, while determining the role of detritus in the marine food chain, the total quantity of detritus present in an environment is not as important as its rate of turnover, i.e., the rate at which it is produced and consumed. It is, at present, not possible to assess this rate, and we are unable to determine how much detrital carbon will actually be incorporated into animal carbon. Normally, a greater abundance of detritus occurs in environments which have a high organic load. Thus, the detritus constitutes an additional pathway between organic production and animal nutrition and helps to increase the efficiency of energy transfer from one trophic level to the other. In a generalized scheme of energy transfer from phytoplankton to zooplankton and fish, detritus forms a fairly large portion of the material in which energy remains tied up; therefore, any

estimate of fish production from plankton alone, without taking into account detritus, will really be an underestimate.

Summary

1. Collections of settled detritus were made continuously in the Cochin Backwater, India, for a period of one year. Detritus largely included dead materials of plants and animals, in addition to large quantities of fine silt and sand around which organic matter adhered and formed aggregates.

2. Living phytoplankton forms a very small portion of detritus. Detrital pigments largely include degraded chlorophyll (phaeophytin).

3. Particulate carbon, nitrogen and phosphorus show a remarkable consistency in detritus throughout the year.

4. The caloric value of settled detritus is much lower than values of animal foods such as zooplankton and fish.

5. Detritus is ingested as food by a wide variety of estuarine animals. It thus constitutes an additional pathway between organic production and animal nutrition.

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Literature cited

- BIGGS, R. B. and C. D. WETZEL: Concentration of particulate carbohydrate at the halocline in Chesapeake Bay. *Limnol. Oceanogr.* **13**, 169—171 (1968).
- BRAWN, V. M., D. L. PEER and R. J. BENTLEY: Caloric content of the standing crop of benthic and epibenthic invertebrates of St. Margaret's Bay, Nova Scotia. *J. Fish. Res. Bd Can.* **25**, 1803—1811 (1968).
- BUCHAN, S., G. D. FLOODGATE and D. J. CRISP: Studies on the seasonal variation of the suspended matter in the Menai Straits. I. The inorganic fraction. *Limnol. Oceanogr.* **12**, 419—431 (1967).
- DARNELL, R. M.: Trophic spectrum of an estuarine community, based on studies of Lake Pontchartrain, Louisiana. *Ecology* **42**, 553—568 (1961).
- Organic detritus in relation to the estuarine ecosystem. *In: Estuaries*, pp 376—382. Ed. by G. H. LAUFF. Washington, D. C.: American Association for the Advancement of Science 1967.
- FOX, D. L.: Comparative metabolism of organic detritus by inshore animals. *Ecology* **31**, 100—108 (1950).
- , J. D. ISSACS and E. F. CORCORAN: Marine leptocephal, its recovery, measurement and distribution. *J. mar. Res.* **11**, 29—46 (1952).
- GORDON, D. C.: Some studies on the distribution and composition of particulate organic carbon in the North Atlantic Ocean. *Deep Sea Res.* **17**, 233—243 (1970).
- HOLM-HANSEN, O., J. D. H. STRICKLAND and P. M. WILLIAMS: A detailed analysis of biologically important substances in a profile off southern California. *Limnol. Oceanogr.* **11**, 548—561 (1966).
- KENCHINGTON, R. A.: An investigation of the detritus in Menai Straits plankton samples. *J. mar. biol. Ass. U.K.* **50**, 489—498 (1970).
- KREY, J.: Der Detritus im Meere. *J. Cons. perm. int. Explor. Mer* **26**, 263—280 (1961 a).
- The balance between living and dead matter in the ocean. *In: Oceanography*, pp 539—548. Ed. by M. SEARS. Washington, D. C.: American Association for the Advancement of Science 1961 b.
- Die mittlere Tiefenverteilung von Seston Mikrobiomasse und Detritus im nördlichen Nordatlantik. *Kieler Meeresforsch.* **20**, 18—29 (1964).
- MENZEL, D. W. and J. H. RYTHER: The composition of particulate organic matter in the western North Atlantic. *Limnol. Oceanogr.* **9**, 179—186 (1964).
- NEWELL, R.: The role of detritus in the nutrition of two marine deposit feeders, the prosobranch *Hydrobia vulvae*, and the bivalve *Macoma balthica*. *Proc. zool. Soc. Lond.* **144**, 25—45 (1965).
- PARSONS, T. R.: Suspended organic matter in sea water. *In: Progress in oceanography*, Vol. 1, pp 205—239. Ed. by M. SEARS. Pergamon Press 1963.
- and J. D. H. STRICKLAND: Oceanic detritus. *Science*, N.Y. **136**, 313—314 (1962).
- PHILLIPS, A. M. Jr.: Nutrition, digestion and energy utilization. *In: Fish physiology*, Vol. 1, pp 391—432. Ed. by W. S. HOAR and D. J. RANDALL: London: Academic Press 1969.
- PLATT, T., V. M. BRAWN and B. IRWIN: Caloric and carbon equivalents of zooplankton biomass. *J. Fish. Res. Bd Can.* **26**, 2345—2349 (1969).
- PROVASOLI, L.: Organic regulation of phytoplankton fertility. *In: The sea*, Vol. 2, pp 165—219. Ed. by M. N. HILL. London: Interscience 1963.
- QASIM, S. Z.: Some problems related to the food chain in a tropical estuary. *In: Marine food chains*, pp 45—51. Ed. by J. H. STEELE. Edinburgh: Oliver & Boyd 1970.
- , P. M. A. BHATTATHIRI and S. A. H. ABIDI: Solar radiation and its penetration in a tropical estuary. *J. exp. mar. Biol. Ecol.* **2**, 87—103 (1968).
- , S. WELLERHAUS, P. M. A. BHATTATHIRI and S. A. H. ABIDI: Organic production in a tropical estuary. *Proc. Indian Acad. Sci. (Ser. B)* **69**, 51—94 (1969).
- RHOADS, D. C. and D. K. YOUNG: The influence of deposit-feeding organisms on sediment stability and community trophic structure. *J. mar. Res.* **28**, 150—178 (1970).
- RILEY, G. A.: Organic aggregates in seawater and the dynamics of their formation. *Limnol. Oceanogr.* **8**, 372—381 (1963).
- Particulate organic matter in sea water. *In: Advances in marine biology*, Vol. 8, pp 1—118. Ed. by F. S. RUSSELL and M. YONGE. London: Academic Press 1970.
- SANKARANARAYANAN, V. N. and S. Z. QASIM: Nutrients of the Cochin Backwater in relation to environmental characteristics. *Mar. Biol.* **2**, 236—247 (1969).
- SEKI, H., J. SKELDING and T. R. PARSONS: Observations on the decomposition of a marine sediment. *Limnol. Oceanogr.* **13**, 440—447 (1968).
- STEELE, J. H. and I. E. BAIRD: Production ecology of a sandy beach. *Limnol. Oceanogr.* **13**, 14—25 (1968).
- STRICKLAND, J. D. H. and T. R. PARSONS: A practical handbook of seawater analysis. *Bull. Fish. Res. Bd Can.* **167**, 1—311 (1968).
- TREVALLION, A.: An investigation of detritus in Southampton Water. *J. mar. biol. Ass. U.K.* **47**, 523—532 (1967).
- YENTSCH, C. S. and D. W. MENZEL: A method for the determination of phytoplankton chlorophyll and phaeophytin by fluorescence. *Deep Sea Res.* **10**, 221—231 (1963).
- ZOBELL, C. E. and C. B. FELTHAM: The bacterial flora of a marine mud flat as an ecological factor. *Ecology* **23**, 69—78 (1942).

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