

TABLE 2 — CORRELATION MATRICES FOR VARIOUS PARAMETERS AT SURFACE AND IN THE COLUMN

	Surface			Column			
	Primary productivity	Phytoplankton	Phosphate	Primary productivity	Phytoplankton	Phosphate	Nitrate
Phytoplankton	0.52	—	—	-0.58*	—	—	—
Phosphate	-0.58*	0.21	—	-0.49	0.039	—	—
Nitrate	0.08	0.025	0.67†	-0.24	-0.22	0.859‡	—
Zooplankton	—	—	—	0.43	0.066	-0.193	0.076

Level of significance: \*10%, †5%, ‡1%.

0.1 to 0.5 gC/m<sup>2</sup> while the surface productivity from 100-250 mgC/m<sup>2</sup>; her data were limited to the winter months only. Nair<sup>4</sup> calculated the production rate for offshore waters of the Bay as 0.19 gC/m<sup>2</sup>. The present measurements give a comparable average of 0.16 gC/m<sup>2</sup>/day.

Primary production in the Bay of Bengal is relatively low as compared to the Arabian Sea<sup>4</sup>. This can be attributed to (i) topographical feature like the narrow continental shelf, (ii) meteorological feature like the heavy cloud cover and (iii) certain oceanographic features. The Bay of Bengal, as a whole, is more or less an estuarine sea with an average salinity of 30-34‰. A number of major rivers open into the Bay both from east and west sides, bringing in huge quantities of inorganic and organic material which lower the transparency of the waters to a considerable extent, thus limiting photosynthesis. Upwelling in the Bay is less intense and limited compared to the Arabian Sea. The heavy river discharge offsets the offshore transport of surface waters caused by winds and thus damps upwelling. The other oceanographic mixing processes (vertical advection, diffusion etc.) that transfer the subsurface nutrients to the euphotic zone are also less intense in the Bay as there is a greater degree of stratification and stability due to the river discharge and concomitant lowering of salinity in the surface waters.

The author is grateful to Dr S. Z. Qasim for his valued criticism, to Dr R. Sen Gupta for making available the nutrient data and to Capt. K. L. Chopra, officers and crew of *INS Darshak* for ship-board facilities.

References

1. *Galathea Report*, Vol. 1, Copenhagen (Galathea Committee), 1957-1959, 49.
2. *Anton Bruun cruise 1: Final cruise report* (Woods Hole Oceanography Institute, USA), 1964.
3. BARBANERD, B. & KREY, J. (Compilers), *Indian Ocean — Collected data on primary production, phytoplankton pigments and some related factors* (Inst. Meersk. Univ. Kiel), 1974, 521.
4. NAIR, P. V. R., *Central Mar. Fish. Res. Inst. Bull.*, No. 22 (1970), 56.
5. STRICKLAND, J. D. H. & PARSONS, T. R., *A handbook of seawater analysis*, *Bull. Fish. Res. Bd. Can.*, 167 (1968), 311.
6. *Marine climatological summaries*, Vol. 5 (India Meteorological Department, Controller of Publications, New Delhi), 1965, 442.
7. LA FOND, E. C. & LA FOND, K. G., *Bull. natn. Inst. Sci. India*, 38 (1968), 164.
8. SANKARANARAYANAN, V. N. & REDDY, C. V. G., *Bull. natn. Inst. Sci. India*, 38 (1968), 148.
9. LA FOND, E. C., in *Encyclopaedia of oceanography* edited by R. W. Fairbridge (Reinhold Publishing Corp.), 1966, 110.

10. *Handbook to the International Zooplankton Collections of IIOE*, Vol. 1 (I.O.B.C., Cochin), 1969.
11. KABANOVA, YU. G., *Okeanologiya*, 8 (1968), 270.

Biodegradation of Organic Matter in Sea Water

A. RAJENDRAN

National Institute of Oceanography  
Dona Paula 403004, Goa

Received 1 December 1977

Biodegradation of 3 different biological materials (*Trichodesmium erythraeum*, Lucifer and mixed plankton) was studied to estimate their rate and extent of decomposition in surface sea water under controlled laboratory conditions. Rate of decomposition during the first 20 days was approximated by the 1st order Kinetics. Rate constants for the degradation suggested that there were 3 stages in the microbial decomposition and that 2 labile organic fractions and a refractory organic fraction could be identified. Approximately, 15-20% of the initial dissolved organic matter (DOM; fraction F<sub>1</sub>) was oxidized. The other labile fraction F<sub>2</sub> was about 30-45% of the total DOM. The refractory portion was about 40% and it was resistant to biological oxidation. Rate constant for F<sub>1</sub> of *T. erythraeum* was 0.0331 day<sup>-1</sup> and of Lucifer was 0.0723 day<sup>-1</sup> and for mixed plankton, it was 0.1188 day<sup>-1</sup>.

PRIMARY sources of energy of the coastal aquatic ecosystem are available at the producer-decomposer level. Number of dynamic and interacting environmental parameters influence this basic trophic level and control the development and optimization of energy flow. Higher components of the system such as predators, influence production rates within the system with their own variable populations and production dynamics.

Autotrophic productivity and related heterotrophic utilization of organic compounds are greatly influenced by the trace but highly dynamic pool of labile organic substrates. Free amino acids<sup>1</sup> and other growth factors such as vitamins<sup>2</sup> occur in exceedingly low concentrations in sea water but may undergo rapid utilization and synthesis. Degraded hydrolytic products of proteins, carbohydrates and fatty acids generally occur in large quantities within the DOM (dissolved organic matter) pool<sup>3</sup>. In spite of low concentrations, these organic compounds are of major functional and ecological significance for the metabolism of the ecosystem.

Riley<sup>4</sup> has pointed out that major portion of DOM in the open ocean is derived ultimately from phytoplankton in the surface layer. If the allochthonous addition of DOM in estuaries and inshore waters is considered to be of local importance, the major input to the labile fraction of the pelagic pool is from bacterial degradation of plankton and autolysis. The present preliminary report deals with the decomposition of 3 plankton materials during incubation under controlled laboratory conditions.

*Trichodesmium erythraeum* (a blue green alga), Lucifer (a zooplankton form) and mixed plankton were used for decomposition experiments. The materials (about 100 mg) desiccated by freeze drying were suspended separately in 5l fresh surface sea water which was coarse filtered. After mixing well, the suspension was taken in 300 ml sterile oxygen bottles which were sealed securely and incubated at 28°C in the dark.

After selected intervals, the materials were analysed for total nitrogen content in each plankton material, total dissolved organic nitrogen and other inorganic nitrogen compounds by standard procedures<sup>5</sup>. Dissolved oxygen was estimated by Winkler method. pH was also monitored. Glass fibre filters with 0.45 pore size were used for collecting the particulate organic matter.

Rate of decomposition of nitrogen in the experimental material during initial stage has been shown in Fig. 1. The  $\log N_0/N_{0-x}$  was plotted against time in days to present the rate of decomposition where  $N_0$  stands for the initial concentration of total particulate nitrogen and  $N_{0-x}$  is the particulate organic nitrogen in the residual material (detritus and microbes). Log value of the ratio of total particulate nitrogen (TPN) and the total residual nitrogen has been considered as the rate constant of decomposition. The linear relationship during the first

20 days indicate that the decomposition of nitrogen from the cells could be approximated by the first order kinetics, as suggested by Grill and Richards<sup>6</sup>.

Decay constants for the total organic nitrogen in different plankton material are given in Table 1. The rate constant  $K_1$  for the mixed plankton was relatively high compared to the other 2 organic materials. Decay constant  $K_2$  for the decomposition of mixed plankton was also high but that for the other two organic materials, it was more or less the same. Though the rate constants for the labile fractions varied for each biological material in the initial stages of decomposition, they were more or less constant for the decomposition of refractory organic constituent for all the 3 plankton materials and  $K_3$  determined were very low.

From the rate constants for the decomposition, it could be suggested that there are 3 stages in the microbial decomposition of marine plankton, viz. (i) very quick decomposition of soluble organic compounds, (ii) relatively rapid decomposition of labile organic constituent and (iii) very slow rate of decomposition of refractory material. Altogether, there are 2 labile and 1 refractory organic constituents. It is found that approximately 15-20% of the initial organic matter (fraction 1) is oxidized within 10 days. The other labile fraction  $F_2$  is about 30-45%. The refractory portion is about 40% and it is resistant to biological oxidation.

The observations are consistent with those of Grill and Richards<sup>6</sup> for total organic phosphorus, of Ogura<sup>7</sup> for dissolved organic carbon and of Otsuki and Hanya<sup>8</sup> for dissolved organic nitrogen. Grill and Richards<sup>6</sup> developed a mechanism from Kinetic considerations of phosphorus remineralization consisting of a simple 1st order chain process and showed that during the decomposition of diatoms, 2 labile organic fractions and a refractory organic fraction were present. DOM in surface sea water was described by Ogura<sup>7</sup> in terms of 2 labile fractions,  $F_1$  and  $F_{II}$  and refractory one  $F_{III}$ . He found that  $F_1$  ranged from 10-20% of the total DOM and was utilized within the first 50 days.  $F_{II}$  was 30-40% of the total DOM and  $F_{III}$  50-60% of the total DOM was not easily available for microorganisms.

Three different linear relations of the rate of decomposition with the time in the initial stages and their slopes (Fig. 1) indicate different rates of decomposition under laboratory conditions. In all the 3 experiments, linear lines do not pass through the origin. This was also observed by Otsuki and Hanya<sup>8</sup> who explained that some organic compounds in the algal cells were made water soluble when the cells were killed by lyophilization. They used freeze dried biological material to avoid damage to the organic components but found that the loss of DOM from the cells to the medium, could arise

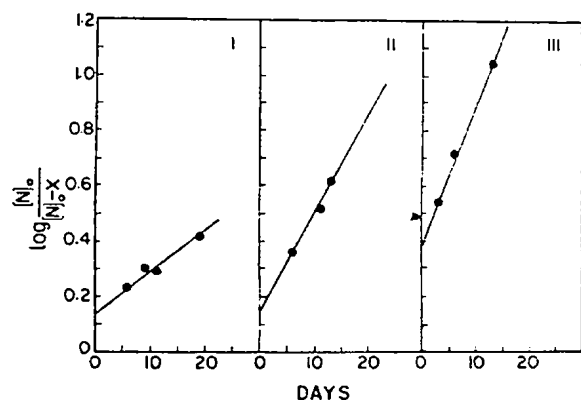


Fig. 1—Rate of decomposition of experimental materials with time [I, *T. erythraeum*, II, Lucifer and III, mixed plankton]

TABLE 1—DECAY CONSTANTS FOR TOTAL ORGANIC NITROGEN IN DECOMPOSITION OF DIFFERENT BIOLOGICAL MATERIALS AT ROOM TEMPERATURE

	Period (days)	$K_1$ day <sup>-1</sup>	Period (days)	$K_2$ day <sup>-1</sup>	Period (days)	$K_3$ day <sup>-1</sup>
<i>T. erythraeum</i>	0-9	0.0331	9-19	0.0221	19-136	0.0036
Lucifer	0-9	0.0723	9-19	0.029	19-136	0.0032
Mixed plankton	0-6	0.1188	6-15	0.041	15-136	0.0035

by this treatment also. In the present study also, the plankton materials used were hard frozen immediately after collection.

Rate constant for decomposition of dead plankton at 25°C was given as 0.044-0.114 day<sup>-1</sup> for total organic nitrogen by Skopintsev<sup>9</sup>. Two labile organic fractions and a refractory fraction ( $K_1=0.0380$ ,  $K_2=0.381$  and  $K_3=0.0174$  day<sup>-1</sup>) were found by Grill and Richards<sup>6</sup> in experiments on decomposition of diatoms. Otsuki<sup>10</sup> found that microbial degradation of dead *Scenedesmus* cells was at a rate of 0.0296 day<sup>-1</sup> for organic carbon and 0.0156 day<sup>-1</sup> for the first 13 days and 0.045 day<sup>-1</sup> ( $K_2$ ) thereafter. However, a very low rate constant for the decomposition of DOC in surface water (0.003-0.005 day<sup>-1</sup>) was observed by Ogura<sup>7</sup> and it was lower by 2 orders of magnitude that was found during the initial stages of the incubation experiment.

Rate constants found in the present experiments agree well with those of Skopintsev<sup>9</sup>, Grill and Richards<sup>6</sup> and Ogura<sup>7,11</sup>. It is worth while to mention that biological processes cannot be expected to follow kinetic laws precisely but that the experimental observations were reconstructed as suggested by Grill and Richards<sup>6</sup> assuming that decomposition proceeds as simple 1st order chain reactions.

Fractions F<sub>I</sub> and F<sub>II</sub> may serve as food for micro-organisms, but F<sub>III</sub> (about 40% of total organic matter) may not be available to the food cycle and it may, however, be transformed into an oxidizable form at the interface of solids such as particulate matter in sea water<sup>12</sup>. Keys *et al.*<sup>13</sup> found that only 10-15% of the total DOM was oxidized after several days at 21°C. Barber<sup>14</sup> observed that about 50% of the concentrated DOM in surface sea water was oxidized in 30 days and that no change was observed in the amount of DOC in concentrates of deep sea water even after 1 or 2 months. Skopintsev *et al.*<sup>15</sup> found that residual 20-30% of organic matter was refractory and decomposed only at slow rate. However, residual carbon in the particulate matter ranged between 43-84% in surface water<sup>16</sup>.

The author thanks Drs R. Natarajan and V. K. Venugopalan, CAS in Marine Biology, Porto Novo, for facilities and suggestions. Thanks are also due to Dr S. Z. Qasim, Director, for his interest and encouragement. Financial assistance from CSIR, New Delhi, is gratefully acknowledged.

#### References

1. Hobbie, J. E., Crawford, C. C. & Webb, K. L., *Science*, **159** (1968), 1463.
2. Provasoli, L., in *The sea*, edited by M. N. Hill (Interscience Publishers, New York and London), **2** (1963), 165.
3. Vellentine, J. R., *J. Fish. Res. Bd. Can.*, **14** (1957), 33.
4. Riley, G. A., *Adv. mar. Biol.*, **8** (1970), 1.
5. Strickland, J. D. H. & Parsons, T. R., *A practical handbook of seawater analysis*, Bull. No. 167 (Fish. Res. Bd. Canada), 1968.
6. Grill, E. V. & Richards, F. A., *J. mar. Res.*, **22** (1964), 51.
7. Ogura, N., *Mar. Biol.*, **13** (1972), 89.
8. Otsuki, A. & Hanya, T., *Limnol. Oceanogr.*, **17** (1972), 248.
9. Skopintsev, B. A., *Trudy. vses. gidrobiol. obshch.*, **1** (1949), 34.
10. Otsuki, A., *Biogeochemical studies on the production of the dissolved organic matter in relation to food chain of hydrosphere*, Doctoral thesis, Tokyo Metropolitan University, Tokyo, 1968.

11. Ogura, N., in *Biological oceanography of the northern North-Pacific Ocean*, edited by A. Yositada Takenontsi *et al.* (Idemitsu Shoten, Tokyo), 1972, 507.
12. Kailov, K. M. & Finenko, Z. Z., in *Marine food chains*, edited by J. H. Steele (University of California Press, Berkeley and Los Angeles), 1970, 5.
13. Keys, A., Christensen, E. H. & Krogh, A., *J. mar. Biol. Ass. U.K.*, **20** (1935), 181.
14. Barber, R. T., *Nature, Lond.*, **220** (1968), 274.
15. Skopintsev, B. A., Lyubimova, E. M. & Timofeeva, S. N., *Kiev: Gidrofiz Gidvokhm. Issled.*, 1965, 85.
16. Menzel, D. W. & Goering, J. J., *Limnol. Oceanogr.*, **11** (1966), 333.

#### Studies on the Diatom *Amphora coffeaeformis* Agardh: Salinity Changes on Growth & Auxospore Formation\*

G. RAGOTHAMAN† & V. N. R. RAO

Centre of Advanced Study in Botany, Madras 600005

Received 29 August 1977; revised received 15 December 1977

*A. coffeaeformis*, one of the dominant diatoms occurring throughout 2-year period of investigation in the Adyar estuary is usually abundant in waters of intermediate salinities. Laboratory studies on several isolates of *A. coffeaeformis* from this estuary confirm this behaviour. The diatom does not grow very well in fresh water (Reimann medium with no chlorides) but prefers a medium with low chloride (NaCl) levels. When the chloride content is too high growth of the diatom declines. According to the classification of euryhaline diatoms proposed by Desikachary and Rao [*J. mar. Biol. Ass. India*, **14** (1972), 524] *A. coffeaeformis* is meso-euryvalent in its behaviour though it occurs in a wide range of salinity conditions.

**H**YDROBIOLOGICAL studies of the Adyar estuary in Madras revealed that *Amphora coffeaeformis* was one of the dominant diatoms occurring throughout the period of investigation even when the salinity of the waters showed wide fluctuations<sup>1</sup>. Abundance of *A. coffeaeformis* under similar conditions was also reported in river Cooum that runs very close by<sup>2</sup>. Laboratory and field observations indicated that salinity variations besides other uninvestigated hydrological factors seemed to influence abundance of *Cyclotella meneghiniana*<sup>2,3</sup> in the same estuary. It is possible that the ability of *A. coffeaeformis* to tolerate fluctuating salinities might be one of the causes of its continued presence in the Adyar estuary. The behaviour of *A. coffeaeformis* to changes in salinity of the culture medium was studied in the laboratory with a view to understanding its occurrence and abundance in the estuary.

*A. coffeaeformis* did not reach the same abundance as *C. meneghiniana* in the 3 sites of the estuary selected for the study, the maximum reached being only 50% of the total diatom count. But whenever it had shown some abundance (30-40 thousands/ml and above 30% of the total diatom count) the waters

\*Paper forms Part I of the series.

†Present address: Department of Biosciences, South Gujarat University, Surat.