Bulletin of Plankton Society of Japan Vol. 27, No. 1, pp. 27-36, 1980

Biochemical Changes of Sedimented Matter in Sediment Trap in Shallow Coastal Waters[1),2)]

K. ISEKI[3)], F. WHITNEY AND C.S. WONG[4)]

Ocean Chemistry Division, Institute of Ocean Sciences, Sidney, B.C., Canada

Abstract

Decomposition, carbon uptake and biochemical changes of sedimented matter, which was mainly composed of phytoplankton cells and fecal pellets of zooplankton, collected by sediment traps were examined both in situ and in laboratory experiments in order to evaluate the distorting effect upon actual quantities and qualities of sedimented matter during collection. In situ carbon uptake had negligible effect on gross sedimentation even if a trap was suspended in shallow waters (13 m) in Saanich Inlet, B.C., Canada, due to poor penetration of solar radiation and shading effects by trap. However, decomposition rate gave a significant effect, showing a considerable loss against sedimentation rate.

It was suggested to select a suitable suspension period of sediment trap in order to minimize distorting effects. It was also recommended to use preservatives to inhibit biochemical processes for a long term suspension of trap.

Sediment trap is one of promising approaches for evaluating vertical mass transport of various elements in the sea (WIEBE et al. 1976, ISEKI 1977). However there are still several technical difficulties remained in the sediment trap approach which should be urgently solved.

The first difficulty is the design of trap, which was greatly clarified by GARDNER (1977) by extensive experiments in a laboratory flume and in natural bodies of water, under various current conditions ranging from tranquil to highly advective, using various types of traps. He showed that open cylinders with a length to width ratio approximately 2-3 will give representative fluxes, and open funnels underestimated the actual flux in moving water but a placing baffle on top of a funnel could improve the trapping efficiency. HATA (1979) obtained a similar results using different types of traps suspended in Uranouchi Bay, Japan. Besides the design difficulty, possible biochemical alteration of collected materials during suspension (HATA 1979) was another difficulty, to which has been paid less attention. Since falling particles are sometimes accumulated in great concentration in the trap during collection and subsequently active decomposition process associated with highly accumulated organic matter takes place, the sample collected may be altered both qualitatively and quantitatively. Actually KNAUER et al. (1979) detected H_2S in unpreserved trap materials. Such possible biochemical changes may occur considerably in a funnel type trap because of its great concentrations of the sedimented matter. In shallow coastal or tropical waters, biochemical changes may be significant because of rapid decomposition activity due to rich organic matter or high temper-

[1)] Accepted May 22, 1980.

[2)] 沿岸域の垂下セディメント・トラップ中での沈殿粒状物の生化学的変化

[3)] 現住所：井関和夫，東北大学農学部 (Present address: Faculty of Agriculture, Tohoku University, Sendai)

[4)] Please address all correspondence to: C.S. WONG, Institute of Ocean Sciences.

ature. Autotrophic growth occurring in the trap may cause additional changes.

In the present study, decomposition and algal growth in sediment trap were examined in situ and in laboratory experiments. Observations were carried out in Saanich Inlet, a fjord on the southeast side of Vancouver Island, British Columbia, Canada.

Materials and Methods

Materials falling through the water column were collected using sediment traps consisting of duplicate PVC cylinders of an inside diameter of 12.5 cm and a height of 48 cm (ISEKI et al. unpublished). A baffle grid (1.3 cm square for each compartment and 5.0 cm in height) was placed at the opening of each cylinder to reduce distorting effect of current in the upper part of the cylinder. An another baffle grid was placed in the sampling chamber (0.7 liter) which was set on the bottom of each cylinder to prevent disturbance or aggregation of collected particles.

Three experiments were performed at two field stations in Saanich Inlet (48°39.6′N, 123°29.6′W and 48°39.6′N, 123°27.9′W); first two in the summer of 1978 (Exps. I and II) and the other in the spring of 1979 (Exp. III). Traps were suspended at 13 m for 1 or 4 days in the Exps. I and II and 10, 20, 30 and 50 m at 6–8 day suspension intervals from March 6 through April 24 in the Exp. III. Seawater-sedimented matter mixture was used for the experiments by thorough gentle mixing the seawater-sedimented matter collected in each sampling chamber.

Carbon uptake activity of sedimented matter was measured by the light and dark bottle method using ^{14}C. After the addition of 0.1 ml $NaH^{14}CO_3$ solution (5 μCi) into a 4 ml seawater-sedimented matter mixture kept in 5 ml culture tube, the sample was incubated in situ for 24 h and/or in a cold room at 8 Klx under fluorescent light for 17.5 h. After the incubation each sample was immediately filtered through a HA Millipore filter. Radioactivity was counted by a Beckman LSC-100 liquid scintillation counter.

Decomposition rate of the sedimented matter was determined either by the increase of CO_2 or by the decrease of O_2 during incubation. In the Exp. I when the former method was applied, the mixture of 700 ml was added to 125 ml Erlenmeyer flasks with ground glass stopper, overflowed by about half the container volume and incubated in the dark at surface water temperature (15°C) for 24 h. Before the incubation, 100 mg of $HgCl_2$ was added into two flasks as blank. After the incubation, 1 ml sample was removed from each flask with a syringe, injected into 1 ml sulphuric acid in a 5 ml glass ampule through a rubber septum and purged with nitrogen. CO_2 released was then analyzed by an infra-red analyzer (0524B Total Carbon Systems, Oceanography International Corp.). In the Exp. III when the O_2 method was applied, sedimented matter was incubated as the same way at surface temperature (7.0–7.6°C) for 18 h. Flasks were attached to a rotating wheel which inverted the sample every half a minute and prevented sedimentation. Oxygen was determined by the Winkler procedure.

After passing through a 0.5 mm Nitex netting to remove zooplankton carcasses and molts, chlorophyll *a* and pheopigments was determined by the fluorometry using a Turner fluoro-

meter (STRICKLAND & PARSONS 1972), particulate organic carbon (POC) and nitrogen (PON) retained on Whatman GF/C glass fiber filters were by using a Perkin-Elmer Elemental Analyzer (Model 240), and dry weight retained on a 1.0 μm Nuclepore filter was measured. A part of the sample was preserved by Lugol solution for microscopic observation.

Results and Discussion

Inorganic Carbon Uptake in Sedimented Matter

Inorganic carbon uptake within one cylinder of sediment trap was 47.6 μgC(cyl·24 h)$^{-1}$ in the light and 44.3 μgC(cyl·24 h)$^{-1}$ in the dark. This indicates that diel increase of POC was only 1% in a cylinder, or suggests two possibilities that light energy reaching the cylinder was little or photosynthetic organisms in the sedimented matter had lost their activity. Sedimented matter was then incubated under 8 Klx in the laboratory in order to evaluate potential photosynthetic activity of the organisms. The latter was about 6 times higher compared to the in situ activity (Table 1).

TABLE 1. AMOUNTS (ΔN_1, ΔN_2) AND RATES (μ_1, μ_2) OF INORGANIC CARBON UPTAKE IN SEDIMENTED MATTER DURING IN SITU AND LABORATORY INCUBATIONS. INCUBATION PERIODS WERE 24 H IN SITU AND 17.5 H IN LABORATORY.

	In situ uptake		In laboratory		Amount of sedimented matter	
	ΔN_1 μgC(cyl·24 h)$^{-1}$	μ_1 d^{-1}	ΔN_2 μgC(cyl·17.5 h)$^{-1}$	μ_2 d^{-1}	N_0 μgC·cyl^{-1}	μ_2:μ_1
Light*	47.6	0.011	224	0.068	4411	6.2
Dark	44.3	0.010	35.1	0.011	4411	1.1
L-D	3.3	0.001	189	0.058	4411	58.0

* Duplicate variation was less than 8%.

In the Exp. II, sedimented matter was incubated inside and immediate outside the trap suspended. Carbon uptakes were 4655±381 dpm and 2325±13 dpm for light and dark tubes, respectively outside the trap. In this experiment (Exp. II), no significant difference was also observed between light and dark tubes inside the trap.

Assuming that the carbon uptake process is logarithmic with time, the uptake rate, (μ, day^{-1}) of sedimented matter during incubation (t, day) is approximated as

$$\mu = 1/t \cdot \ln [(N_0 + \Delta N)/N_0], \qquad (1)$$

where N_0 is the initial amount and ΔN is the increased amount of sedimented carbon during t days. Delta N is determined by the uptake of inorganic carbon. The carbon uptake rates were 0.010–0.011 d^{-1} in the dark in all experiments and 0.001 d^{-1} in the light dependent (presumably photosynthetic uptake) in situ condition, which were negligibly low. Whereas the light dependent uptake in the laboratory reached to 0.058 d^{-1}.

Sedimented matter collected at shallow water depths in the Exps. I and II was mainly composed of phytoplankton cells and fecal pellets of zooplankton. The phytoplankton cells

still showed positive photosynthetic activity under the light (Table 1) and were expected to be supplied into the trap through settling of individual algal cells or falling with fecal pellets. JOHANES & SATOMI (1966) demonstrated that some algal cells (*Nitzschia closterium*) still remained their photosynthetic activity after passing through the gut of a herbivorous shrimp *Palaemonetes pugio*.

However actual inorganic carbon uptake of sedimented matter in situ was negligibly small due to poor penetration of solar radiation and a shading effect by baffle-grid and cylinder wall as shown in Table 1. Light penetration in Saanich Inlet in May and September of 1975 (TAKAHASHI & WHITNEY 1977) reduced to 2% or less at 13 m depth. But if a sediment trap which has a wide opening or made of clear materials was suspended at depth having high solar radiation energy, particularly surface water in tropical area, photosynthetic growth might seriously affect the determination of sedimentation rate.

Decomposition of Sedimented Matter

Assuming that decomposition process is logarithmic with time, decomposition rate (k, d^{-1}) of sedimented matter during incubation period (t, day) is approximated as

$$k=-1/t\cdot\ln[(N_0-\Delta D)/N_0], \qquad (2)$$

where N_0 is the initial amount of sedimented carbon and ΔD is the decreased amount of the carbon during t days. In the experiment conducted during 4 and 8 August, N_0, ΔD and t were 4411 $\mu gC\cdot cyl^{-1}$, 2605 $\mu gC\cdot cyl^{-1}$ and 3.9 days, respectively. Decomposition rate, k, was estimated as 0.299 d^{-1} using the Eq. 2, which was about 20 times greater than the inorganic carbon uptake mentioned above. Consequently the inorganic carbon uptake was not taken into account in the following consideration.

Assuming that gross sedimentation rate (F, $mgC(cyl\cdot d)^{-1}$) and decomposition rate of sedimented matter (k, d^{-1}) are constant throughout collection (t, day), apparent sedimentation (A, $mgC\cdot cyl^{-1}$), which is actually obtained as an amount of sedimented matter in a trap, can be expressed with

$$dA/dt=F-kA\,. \qquad (3)$$

Integrating Eq. 3 with time ($t=0\rightarrow t_1$) under the initial condition, $A=0$ at $t=0$.

$$A=F/k\cdot(1-e^{-kt_1})\,. \qquad (4)$$

So, gross sedimentation rate, F, is rewritten as follows:

$$F=Ak/(1-e^{-kt_1})\,. \qquad (5)$$

On the other hand, the observed amount of sedimented matter, A, simply divided by collection time period, t_1, has long been used as sedimentation rate, A/t_1, in which sedimentation process is believed to be linear with time with paying less attention both on decomposition and production which could be logarithmic processes with time. Ratio of gross sedimentation to apparent sedimentation during suspension period is expressed with

$$Ft/A=kt/(1-e^{-kt_1})\,. \qquad (6)$$

This simple ratio is a useful parameter for a comparison between the gross sedimentation and the apparent sedimentation during the collection.

TABLE 2. APPARENT SEDIMENTATION, DECOMPOSITION RATES OF SEDIMENTED MATTER AND RATIOS OF CALCULATED GROSS SEDIMENTATION (*Ft*) TO APPARENT SEDIMENTATION.

Sampling intervals	Suspension period (d) *t*	Depth (m)	In situ temperature (°C)	Apparent sedimentation ($mgC \cdot cyl^{-1}$) *A*	Decomposition rate (d^{-1}) *k*	Ratio of gross sedimentation to apparent sedimentation *Ft/A*
Mar 06-13	6.99	10	6.8	2.11	0.101	1.39
	6.99	20	6.7	3.72	0.015	1.05
	6.99	30	6.6	7.16	—	—
	6.99	50	*	8.50	0.014	1.05
Mar 13-21	8.00	10	7.1	4.03	0.467	3.83
	8.00	20	6.9	4.38	0.036	1.15
	8.00	30	6.7	8.14	0.025	1.10
	8.00	50	*	10.67	0.015	1.06
Mar 21-27	6.01	10	7.2	4.61	0.491	3.11
	6.00	20	7.0	3.66	0.067	1.21
	6.01	30	6.9	4.05	0.035	1.11
	6.00	50	*	4.56	0.024	1.07
Mar 27-Apr 03	6.98	10	7.3	10.22	0.216	1.94
	6.98	20	7.2	8.10	0.034	1.12
	6.98	30	7.0	10.09	0.022	1.08
	6.98	50	*	15.77	0.014	1.05
Apr 03-10	7.00	10	7.5	14.92	0.238	2.05
	7.00	20	7.4	11.74	0.081	1.31
	7.00	30	7.1	11.84	0.055	1.20
	7.00	50	*	—	—	—
Apr 10-18	7.99	10	7.7	25.46	0.243	2.00
	7.99	20	7.6	18.11	0.078	1.34
	7.98	30	7.4	15.90	0.048	1.20
	7.99	50	*	21.41	0.029	1.12
Apr 18-24	6.00	10	7.8	3.87	0.243	1.90
	6.00	20	7.7	3.97	0.036	1.11
	6.00	30	7.5	4.52	0.013	1.04
	6.00	50	*	5.51	0.029	1.09
Mean values for Mar 06-Apr 24		10	7.3	9.32	0.286	2.32
		20	7.2	7,67	0.050	1.18
		30	7.0	9.09	0.033	1.12
		50	*	11.07	0.021	1.08

* not determined; — not obtained

Exp. III was further performed to examine decomposition loss of sedimented matter at 10, 20, 30 and 50 m during spring bloom of 1979. Decomposition rate showed distinct depth-related differences with highest rates at 10 m, ranging from 0.101 to 0.491 d^{-1} and rapid decrease between 10 and 20 m, in range of 0.015 to 0.081 d^{-1} at 20 m and showed further

gradual decrease down to 0.014 to 0.029 d^{-1} at 50 m (Table 2). Each mean of decomposition rates of 10, 20, 30 and 50 m throughout Exp. III were 0.286, 0.050, 0.033 and 0.021 d^{-1}, respectively. Ratio, Ft/A, was in the range of 1.39 to 3.83 at 10 m in each sampling intervals, showing a considerable organic carbon loss during suspension periods (6-8 days). Each mean of the ratio of 10, 20, 30 and 50 m were 2.32, 1.18, 1.12 and 1.08, respectively (Table 2). Above remarkable differences between 10 and 20 m could be attributed to quality differences of sedimented matter and surrounding temperature. During the Exp. III, in situ change in temperature ranged between 6.6 and 7.8°C in the upper 30 m. While temperature at 50 m was not observed here it could be almost the same as at 30 m, according to a hydrographic characteristics in Saanich Inlet (HERLINVEAUX 1962). Thus, temporal and spatial temperature variation during the present experiment was small and considered to be negligible effect on the depth-related differences of decomposition rate.

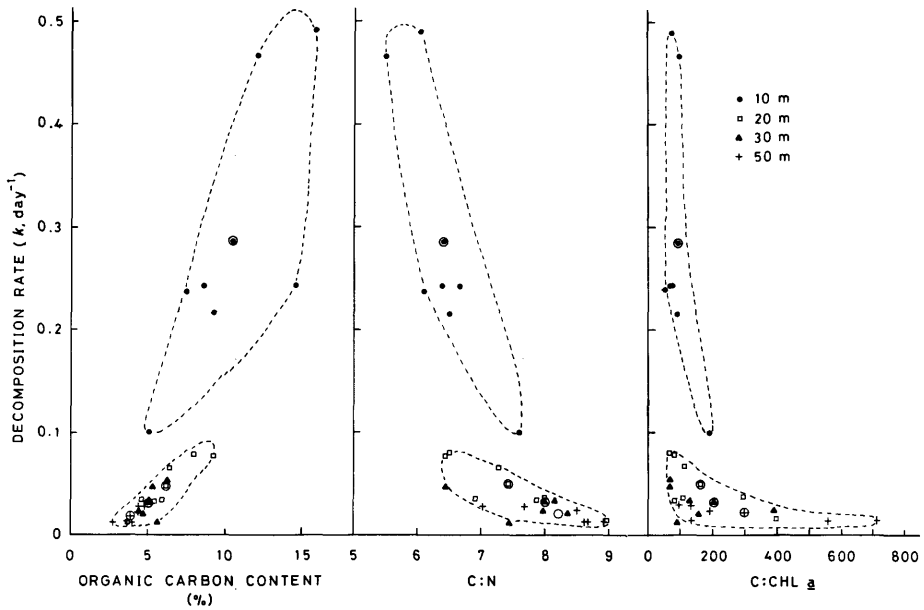

Fig. 1. Relations between decomposition rate and chemical compositions of sedimented matter collected from different depths in the Exp. III. Circled symbols indicate average values.

Decomposition rates showed linear relations with carbon content (POC divided by dry weight) but inverse relation with C:N and C:Chl *a* ratios of sedimented matter (Fig. 1). HARGRAVE (1972, 1978) showed a similar close relationship between oxygen consumption and the organic carbon content. All the data points were encircled with two different envelopes; one for the data from 10 m and the other from 20, 30 and 50 m. The lowest decomposition rate of 0.101 d^{-1} within the 10 m envelope was obtained before spring bloom, March 6-13, when C:N (7.6) and C:Chl *a* (189) ratios were both high enough to be comparable to the deeper values. The range of organic carbon content between 5.1 and 7.1% was included in

both groups as shown in Fig. 1. However, decomposition rate of 10 m sample were a few times as large as those of deeper depth samples in the range of the same organic content, which indicated that there were different types of decomposition processes dominated in those of two water layers. Similar trend was also observed for C:N and C:Chl *a* ratios.

Of the identifiable materials, phytoplankton cells, zooplankton carcasses and zooplankton fecal pellets were dominant in sedimented matter at 10 m. It was hard to remove the carcasses and molts completely through a wet sieving of 0.5 mm Nitex netting, because some disintegrated to small pieces even with the most careful gentle sieving. On the other hand, the deeper depth samples were mainly composed by fecal pellets of zooplankton. Most fecal pellets had greenish-yellow color and long cylindrical shape with the length of larger than 1 mm, easily recognized by visual observation. Such large fecal pellets should be voided from *Euphausia pacifica*, abundant zooplankton species in Saanich Inlet. In the daytime, *Euphausia pacifica* is distributed in a deep layer (80–130 m) and their significant fraction migrates to the surface at night (BARY 1966). A great number of fecal pellets should be released into surface layer through their nocturnal grazing, implying the possibility of noticeable diel rhythm of sedimentation rate in the inlet.

The differences of particle composition such as size and structure in sedimented matter could primarily reflect the above depth-related differences of decomposition. Fecal pellet, surrounded by protective peritrophic membrane (GAULD 1957), might be resistant to rapid aerobic decomposition while freshly deposited phytoplankton cells and zooplankton carcasses may be easily degraded by bacterial attack during collection. GOLTERMAN (1964, 1972) observed that algae can be mineralized at the rate of 20 to 30% per day after algal lysis. Other observation (ITURRIAGA 1979) showed phytoplankton homogenate can be mineralized by about 35% and 3% per day at 20°C and 5°C, respectively. For decomposition of zooplankton and its fecal pellets, FOWLER & SMALL (1972) stated that dead euphausiids disintegrate into smaller pieces within days, whereas their fecal pellets remain intact for months. HARDING (1973) also observed killed copepods decomposed within 11 days in Halifax sea water and within 3 days in 22°C Sargasso Sea water. According to HONJO & ROMAN (1978), surface membrane of fresh fecal pellets were degraded within 3 h at 20°C but intact up to 20 days at 5°C. Particle size differences between phytoplankton cells and fecal pellets could accelerate above depth-related difference of decomposition pattern, because particulate oxygen uptake generally was inversely related to particle size (HARGRAVE 1972).

In the Exp. III, decomposition of fecal pellets in sedimented matter should probably be low due to relatively low temperature during spring bloom of the inlet. We noticed partial degradation of fecal pellets after the suspension and a considerable number of pellets were intact under microscopic observation.

Summary of Decomposition Problem on Sedimentation

Fig. 2 illustrates the effect of the decomposition rate, k, on the apparent sedimentation, A, in the course of suspension period (t, day) of a sediment trap. When sufficient time has been allowed for the Eq. 4 to come equilibrium, a steady-state value of A will be reached such that

$$A_{t\to\infty}=F/k\,. \qquad (7)$$

It shows that the larger is k, the lower is F/k and the shorter is the time to equilibrium state. When k and F are 0.40 d^{-1} and 10 mgC(cyl·d)$^{-1}$, F/k approaches the value of 25 mgC·cyl^{-1} as t becomes larger (24.5 mgC·cyl^{-1} on 10 day). On the other hand, when k is 0.10 d^{-1}, F/k approaches the value of 100 mgC·cyl^{-1} on about 40 day (98.2 mgC·cyl^{-1} on 30 day).

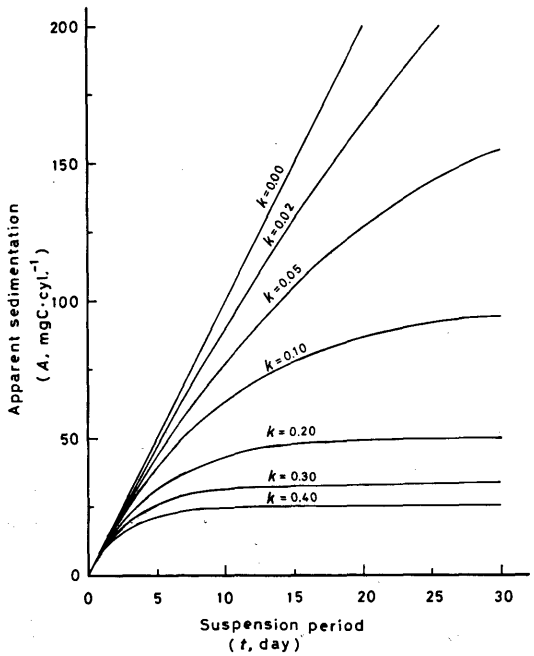

Fig. 2. Changes in apparent sedimentation in the course of suspension period. Decomposition rate (d^{-1}) represents as k.

Fig. 3 shows the relationship between the ratio of gross sedimentation to apparent sedimentation. (Ft/A) and suspension period (t) at different decomposition rates (k). Ft/A is strongly affected by the decomposition rate, k, and it increased with the increasing k and t.

Decomposition rates at 10 m may be overestimated to some extent due to easily oxidizable zooplankton carcasses and molts. However, there is also a possibility that decomposition of readily oxidized substrates had already undergone in the earlier phases of sedimentation in the traps. SAUNDERS (1972) showed a decomposition rate of particulate matter (most probable dead phytoplankton) is 14% per day at the beginning of his experiment and 0.3 to 5% per day after 3 days old detritus.

If decomposition rates are 0.05, 0.10 and 0.20 d^{-1}, the ratios of Ft/A resulted in 1.19, 1.39 and 1.86, respectively, during 7 days collection. In case of 30 days collection Ft/A increased to 1.93, 2.85 and 5.99 under the above decomposition rates, showing a significant underestimation of sedimentation rate by a long term collection. As the value, A, is influenced

by both the decomposition rate and the collection time, it is important to select a suspension period of sediment trap as short as possible in order to minimize organic loss due to decomposition during collection. Particular attention should be paid in coastal warm and tropical shallow waters.

Considering the decomposition effect on sedimented matter, it is desirable to set the suspension period of a trap less than a few days in Saanich Inlet. In case of three days suspension, Ft/A are 1.08, 1.15 and 1.32 under the decomposition rates of 0.05, 0.10 and 0.20 d^{-1}, respectively. It is indispensable to use preservatives for long term suspension in shallow waters in the inlet throughout the year.

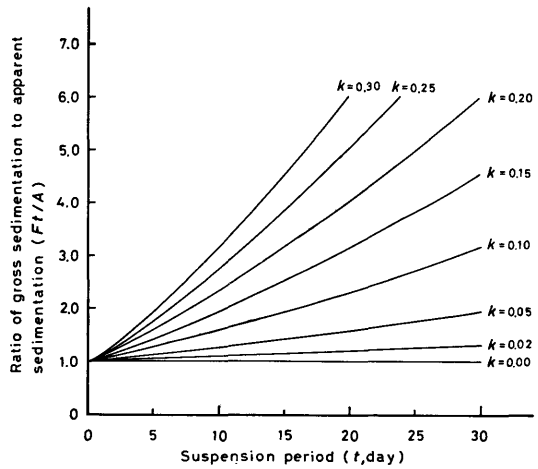

Fig. 3. Changes in the ratio of gross sedimentation to apparent sedimentation (Ft/A) in the course of suspension period. Decomposition rate (d^{-1}) represents as k. Gross sedimentation rate is given as 10 mgC(cyl·d)$^{-1}$.

Acknowledgements

The authors would like to express sincere thanks to Dr. M. TAKAHASHI for his valuable advice and critical reading of the manuscript. The authors are grateful to Dr. S. KAWAI for his helpful critical comments on the manuscript. They also thank Miss J. BARWELL-CLARKE and Mr. R. BROWN for their assistance in sampling during a spring bloom in 1979, and Dr. S. NISHIZAWA for his helpful comments on the present work.

Literature Cited

BARY, B. McK., 1966. Backscattering at 12 kc/s in relation to biomass and numbers of zooplanktonic organisms in Saanich Inlet, British Columbia. *Deep Sea Res.*, **13**: 656-666.

FOWLER, S.W. & L.F. SMALL, 1972. Sinking rates of euphausiid fecal pellets. *Limnol. Oceanogr.*, **17**: 293-296.

GARDNER, W.D., 1977. *Fluxes, Dynamics and Chemistry of Particulate in the Ocean.* Ph. D. Thesis, Mass. Inst. Technol./Woods Hole Oceanogr. Inst., 405 pp.

GAULD, D.J., 1957. A peritrophic membrane in calanoid copepods. *Nature, Lond.*, **179**: 325-326.

GOLTERMAN, H.L., 1964. Mineralization of algae under sterile conditions or by bacterial breakdown. *Verh. int. Verein. theor. angew. Limnol.*, **15**: 544-548.

GOLTERMAN, H.L., 1972. The role of phytoplankton in detritus formation. *Mem. Ist. ital. Idrobiol.*, **29** (Suppl.): 89-103.

HARDING, G.C.H., 1973. Decomposition of marine copepods. *Limnol. Oceanogr.*, **18**: 670-673.

HARGRAVE, B.T., 1972. Aerobic decomposition of sediment and detritus as a function of particle surface area and organic content. *Limnol. Oceanogr.*, **17**: 583-596.

HARGRAVE, B.T., 1978. Seasonal changes in oxygen uptake by settled particulate matter and sediments in a marine bay. *J. Fish. Res. Bd Can.*, **35**: 1621-1628.

HATA, Y., 1979. Kaiyo, shutoshite Engan-iki ni okeru Chinkoryushi Hoshuki to sono Hoshubutsu (Sediment trap and its catch, some cases in coastal waters). *Kaiyo Kagaku*, **11**: 996-1002. (In Japanese)

HERLINVEAUX, R.H., 1962. Oceanography of Saanich Inlet in Vancouver Island, British Columbia. *J. Fish. Res. Bd Can.*, **19**: 1-37.

HONJO, S. & M.N. ROMAN, 1978. Marine copepod fecal pellets: production, preservation and sedimentation. *J. mar. Res.*, **36**: 45-57.

ISEKI, K., 1977. *A Study of Vertical Transport System of Particulate Organic Matter in the Sea.* Ph. D. thesis, Tohoku Univ., 138 pp. (In Japanese)

ITURRIAGA, R., 1979. Bacterial activity related to sedimenting particulate matter. *Mar. Biol.*, **55**: 157-169.

JOHANNES, R.E. & M. SATOMI, 1966. Composition and nutritive value of fecal pellets of a marine crustacean. *Limnol. Oceanogr.*, **11**: 191-197.

KNAUER, G.A., J.H. MARTIN & K.W. BRULAND, 1979. Fluxes of particulate carbon, nitrogen, and phosphorus in the upper water column of the northeast Pacific. *Deep Sea Res.*, **26**: 97-108.

SAUNDERS, G.W., 1972. The transformation of artificial detritus in lake water. *Mem. Ist. ital. Idrobiol.*, **29** (Suppl.): 261-288.

STRICKLAND, J.D.H. & T.R. PARSONS, 1972. A practical handbook of seawater analysis (2nd ed.). *Bull. Fish. Res. Bd Can.*, **167**: 1-311. (1st ed. 1968)

TAKAHASHI, M. & F. WHITNEY, 1977. Temperature, salinity, and light penetration structures: controlled ecosystem pollution experiment. *Bull. mar. Sci. Gulf Caribb.*, **27**: 8-16.

WIEBE, P.H., S.H. BOYD & C. WINGET, 1976. Particulate matter sinking to the deep-sea floor at 2000 m in the Tongue of the Ocean, Bahamas, with a description of a new sedimentation trap. *J. mar. Res.*, **34**: 341-354.