ZOOBENTHOS EFFECT AND THE ROLE OF ZOOBENTHOS IN THE NITROGEN METABOLISM IN A SHALLOW EUTROPHIC LAKE.

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ABSTRACT

Effects of zoobenthos, especially chironomid larvae and tubificid worms, usually dominated in eutrophic lakes, on sediment-water interface of lake bottom were discussed with special reference to the role of zoobenthos in nitrogen metabolism in a shallow eutrophic lake, Lake Suwa, Japan. Zoobenthos effect was categorized as five mechanisms; biopumping, nest-making, mixing and buring, excretion and particle redistribution. A highly significant correlation was obtained between nitrogen release rates and total biomass of Chironomus plumosus and Limnodrilus spp. The rates of release accelerated by zoobenthos were compared with some metabolic rates such as sedimentation, primary production, excretion, mineralization.

Keywords: Zoobenthos effect, bioturbation, nitrogen release, chironomids, tubificids

INTRODUCTION

In freshwater bodies, Sugawara (20, 21) firstly suggested the importance of chaoborid and chironomid larvae for the distribution of chemicals and bacteria and heterogeneity in bottom sediment of Lake Takasuga Numa. After Rossolimo (17) described the results of experiments that the chironomid larvae accelerated the release of NH_4 and Fe^{2+} from bottom sediment of Lake Beloe. Many important effects of bioturbation by freshwater zoobenthos on sediment-water interface were reviewed by Petr (15) and Kranzberg (12). The detail experimental results of the tubificid bioturbation in lake sediment were also reported (13). Fukuhara and Sakamoto (5) proposed the new term " Zoobenthos effect" in stead of " Bioturbation" for overall influence of zoobenthos on sediment-water interface including the release of dissolved matter and excretion. Zoobenthos standing crops generally intend to increase with developing eutrophication of lake water, thus the intensity of zoobenthos effect will strengthen with proceeding of eutrophication.

In this paper I summarize the some mechanisms of zoobenthos effect in freshwater bodies, and describe the role of zoobenthos community on nitrogen metabolism, especially release of inorganic nitrogen from bottom sediment of a shallow eutrophic lake, Lake Suwa.

THE MECHANISM OF ZOOBENTHOS EFFECT

In the profundal bottom sediment of the eutrophic lakes, chironomid larvae (genus; Chironomus) and tubificid worms (genus; Limnodrilus) are most dominant species in zoobenthos community (1). Thus two life types of zoobenthos, Chironomus-type and Limnodrilus-type (Fig. 1), should be taken into consideration on the mechanisms of zoobenthos effect.The larvae of Chironomus make U-shaped nest in the sediment in normal condition (Fig. 1A) and evolve actively water flow through their nest tubes by undulating their bodies when they respire or take food in the nest. Pumping

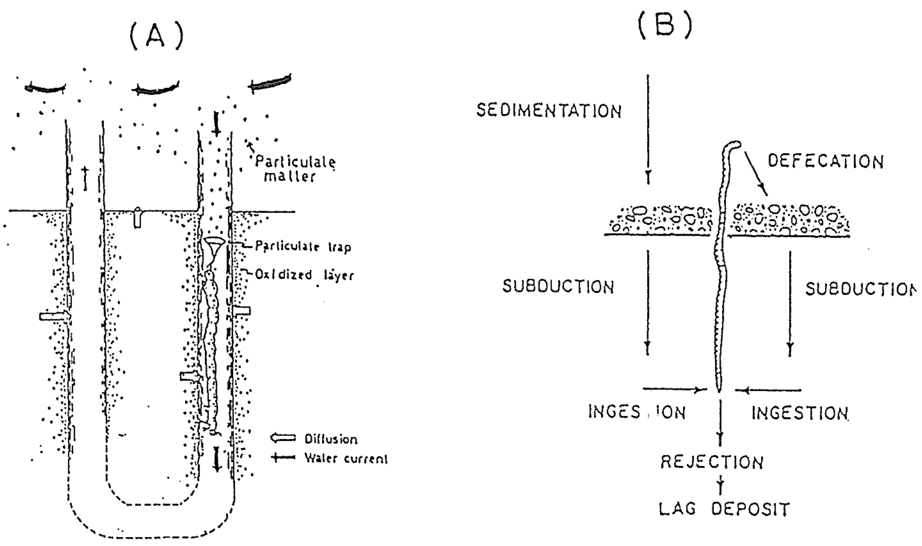

Fig. 1. Schematic life type of Chironomus larvae (A) and Limnodrilus (B, 13).

up and down of water containing dissolved substances is of importance as the release mechanism from sediment. Tubificid worms ingest the deeper mud and defecate on the bottom surface (Fig. 1B). They appear to feed selectively mud particles. Thus translocation of deposit materials, resulting active mixing and buring, and redistribution of particles are going on in sediment where tubificid worms inhabit.

In Figure 2 main mechanisms of zoobenthos effect and resulted affects by these in the freshwater body are summarized.

Biopumping - Acceleration of release of dissolved substances from sediment is mainly caused by biopumping activity of chironomid larvae or tubificid worms (22), with mixing of sediment. The release of inorganic nitrogen and phosphorus was enhanced with increasing density of benthic animals (Fig. 3). Apparent diffusion coefficients of ammonia at the mud-water interface in

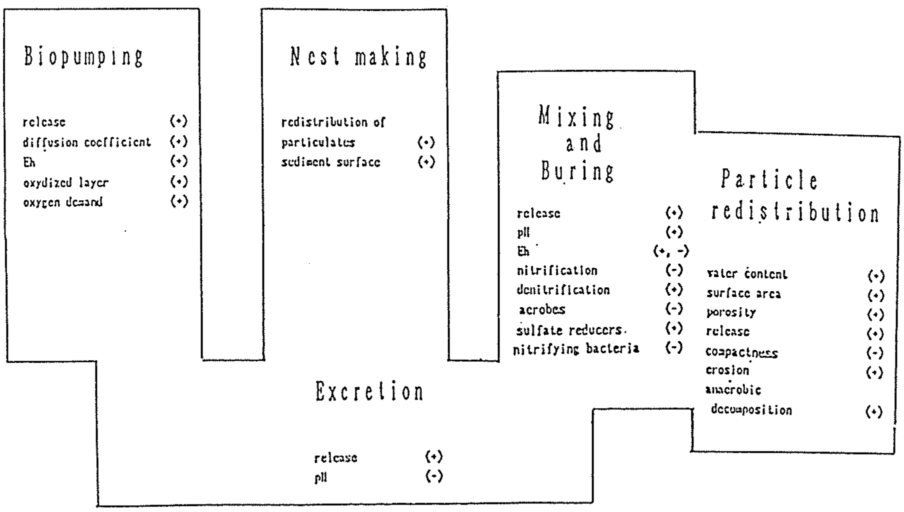

Fig. 2. Mechanisms of zoobenthos effect by freshwater zoobenthos and resulted affects. +; increase or acceleration, -; decrease or suppression.

Table 1. Excretion rates of ammonia and phosphate by some zoobenthos dominated in eutrophic lake with a function of temperature (6, 7).

Species	Excretion rate (P, N; μg/mg dry wt/day, T; °C, W; mg dry body wt) P	N
Chironomus plumosus	Log P = -1.047 - 0.797 Log W + 0.034 T	Log N = 0.154 + 0.895 Log W + 0.022 T
Tokunagayusurika akamusi	Log P = -1.885 + 0.052 T (>15°C)	Log N = -1.185 + 0.054 T (>15°C)
Chaoborus flavicans	Log P = -0.565 + 0.022 T	Log N = 0.200 + 0.017 T
Limnodrilus spp.	Log P = -1.760 + 0.030 T	Log N = -0.945 + 0.047 T
Branchiura sowerbyi		Log N = -0.850 + 0.050 T

microcosms with tubificid or chironomid ranged from 2.6 to $48\times10^{-5} cm^{-2}s^{-1}$ (4). Biopumping activity generally increase the depth of oxidized layer, Eh and pH values in water and sediments.

Excretion - Excreted substances, mainly ammonia and phosphate, by benthic animals, seem to be the direct sources for release materials from sediment. Release of plant-available nitrogen and phosphate from sediment may be especially important in shallow lakes where released matters are introduced directly into the eplimnetic water during summer. Excretion rates of ammonia and phosphate show the temperature dependency under starved condition. Formulae showing the relationship between excretion rate and temperature for some representative benthic animals in eutrophic lakes are tabulated in Table 1.

Mixing and buring - The effect of mixing of sediment is rigidly indistinguishable from that of particle redistribution in sediment. Mixing effect includes overall affects of sediment disturbance. The effect of particle size selection by animal is within the scope of particle redistribution. Mixing of sediment by animals causes the acceleration of release of dissolved materials, increase of pH and Eh values in water and sediments. Bacterial populations undergo effect of mixing and buring by tubificid worms under experimental condition (Fig. 4). The numbers of aerobes and nitrifying bacteria (Table 2)

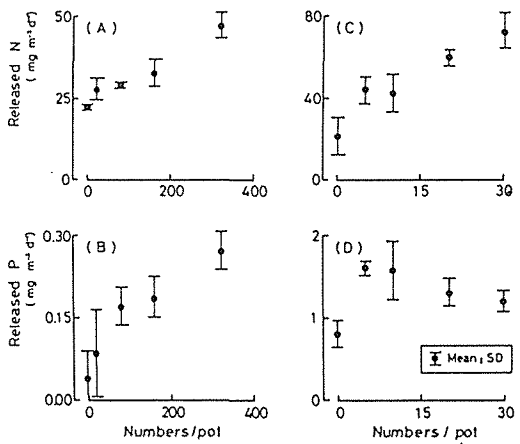

Fig. 3. Release rates of inorganic nitrogen and phosphate as a function of Limnodrilus spp. (A, B) and Chironomus plumosus (C, D) densities (4).

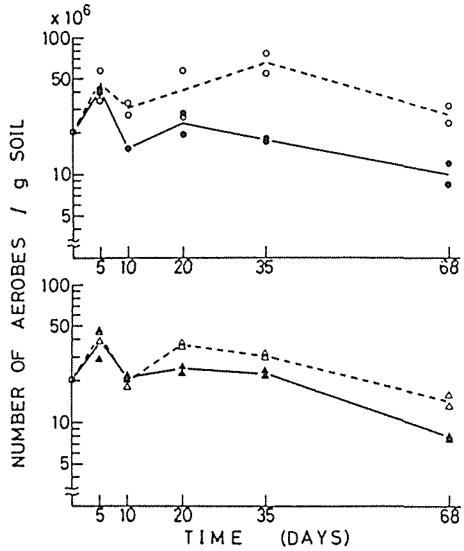

Fig. 4. Viable counts of anaerobes in the submerged soil with and without tubificids (B. sowerbyi). —●—, upper soil with tubificids: —▲—, deeper soil with tubificids: ---○---, upper soil without tubificids: ---△---, deeper soil without tubificids (8).

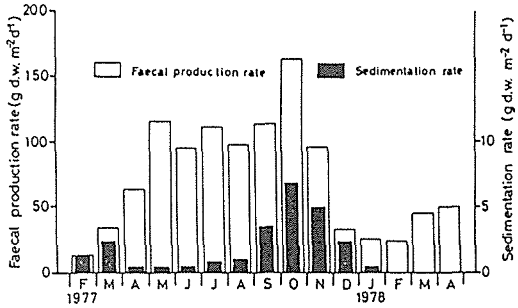

Fig. 5. Seasonal changes in fecal production rates for Limnodrilus spp. and sedimentation rates (14) obtained in Lake Suwa, 1977 at the center of the lake (9).

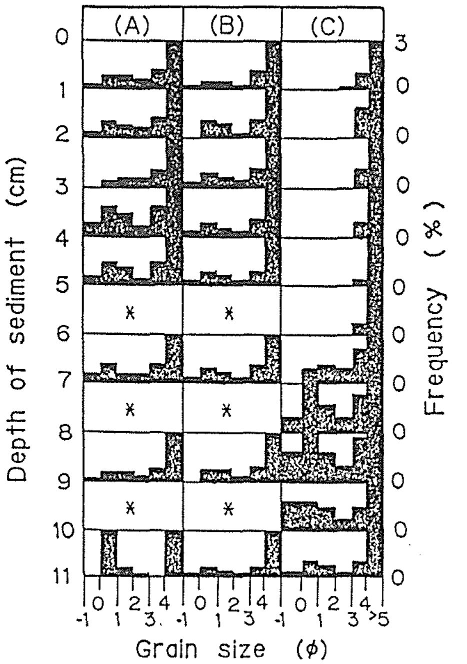

Fig. 6. Grain size distributions of wet-sieved sediment in pots with Chironomus plumosus (B) and Limnodrilus spp. (C), and control (A) after 22 days incubation at 20 °C. The percentages of the particles smaller than 4 φ (=0.062 mm) exceeded three. *: Not determined. (3)

decreased with time in submerged paddy soil, whereas the population of sulfate reducing bacteria increased (8).

Buring of surface sediment is mainly caused by fecal production by tubificids. Fecal production rates (F; mg dry wt per mg wet worm in a day) with temperature (T; °C) are shown as following formulae; Log F= 0.0604T-0.7660 (<15° C) and Log F= 0.0266T-0.2170 (>15° C) (9). The amount of feces produced by Limnodrilus spp. in the profundal region per day ranged from 11.7 to 164.7 g dry wt m^{-2} in L. Suwa. The ratio of fecal production rate and sedimentation rate varied from 9 to 374 (mean 117) (Fig. 5), indicating the active downward transport of freshly sedimented organic matter into the deeper sediment. The accumulation layer of annually sedimented materials is calculated to be 0.7 cm deep and downward transport of the fecal layer is estimated to be 21.8 cm yr^{-1}.

Particle redistribution - As the result of selective feeding of particles by tubificid worms, they continuously accumulated small particles on the surficial sediment. Particles lager than 0.125 mm were buried at a sediment depth of 6 cm by Limnodrilus spp. (Fig. 6). In Lake Suwa, long diatom frustules, large plant debris

Table 2. The number of nitrifying bacteria per g dry weight of the submerged ricefield soil with and without tubificids (8).

		Nitrite former, after 20 d	Nitrite former, after 68 d	Nitrate former, after 20 d	Nitrate former, after 68 d
Control	upper soil (0–1 cm)	2.7×10^3 5.1×10^3	7.9×10^4 4.2×10^4	1.6×10^2 1.7×10^2	1.2×10^3 1.2×10^2
	deeper soil (1–5 cm)	6.3×10^2 1.5×10^3	5.4×10^2 2.9×10^3	3.8×10^1 3.8×10^1	5.1×10^1 5.2×10^1
Tubificids	upper soil (0–1 cm)	4.8×10^1 3.1×10^2	6.1×10^2 6.0×10^1	4.8×10^2 1.6×10^2	– –
	deeper soil (1–5 cm)	1.7×10^3 4.8×10^2	5.6×10^2 3.1×10^1	4.8×10^1 8.3×10^1	– –

–: not detected by the dilution frequency method (< 10 g^{-1}).

and Microcystis flocks were found to accumulate in the deeper layer (6-10 cm) of the sediment. Oligochaetes decrease the compactness of the surface sediment, presumable by increase of water content. A decrease in sediment compactness produces an increase in mud porosity, resulting in enhanced diffusion of dissolved materials from the interstitial water.

Nest-making - Chironomid larvae construct their nest tubes using small particles attached together with mucus-like materials, resulting the particle redistribution and an increase in compactness of surficial sediment.

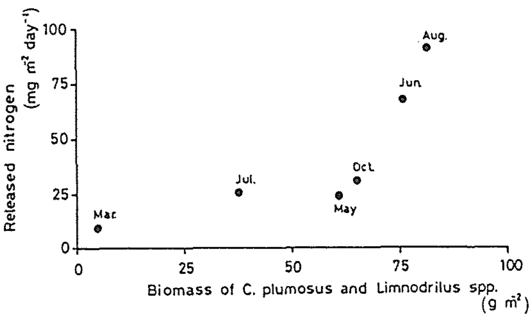

Fig. 7. The relationships between measured inorganic nitrogen release rates and total biomass of Chironomus plumosus larvae and Limnodrilus spp. worms in Lake Suwa, 1971(5).

THE ROLE OF ZOOBENTHOS COMMUNITY IN NITROGEN METABOLISM

Many investigators have shown that phosphorus is of primary importance in regulating phytoplankton growth in various lakes. On the other hand, there is recent information indicating that nitrogen limits phytoplankton production in highly eutrophic lake (2, 18).

Thus quantitative evaluation of the contribution of the zoobenthos community in the nitrogen cycle in a shallow eutrophic lake, Lake Suwa, was conducted in a water column. Table 3 shows some metabolic rates in a water column in term of nitrogen, and also their ratios. Nitrogen release rates showed highly significant correlation ($p<0.05$) with total biomass of Chironomus plumosus and Limnodrilus spp.(Fig. 7), which were dominant zoobenthos in this lake, or biomass of each taxon (multiregression analysis). This suggests that water temperature has less influence on inorganic nitrogen release from sediment, and the biomass of the zoobenthos community is of importance to regulate the inorganic nitrogen release from sediment. The excretion by benthic animals could account for 18.1 to 37.4 % of the total inorganic nitrogen release from sediment, which suggested that the zoobenthos effect is much more responsible for accelerated release of nitrogen from sediment than their excretion. The release rates of inorganic nitrogen to the sedimentation rates of organic nitrogen were relatively constant within the range of 0.5 to 1. This indicated that nitrogen sedimentation balanced well with the inorganic nitrogen release from sediment. The released nitrogen has a potential to sustain 6 to 40% of daily primary production with high values in late June, early August of the Microcystis blooming season, and late October with autumn diatom blooming. The ratios of released nitrogen from sediment to mineralized nitrogen in water column were from 0.35

Table 3. Rates primary production, sedimentation, primary production, release from sediment, mineralization in water column, excretion by zoobenthos and their ratios (5).

Date	Primary production (mg N m^{-2}day^{-1})	Sedimentation (mg N m^{-2}day^{-1})	Release (mg N m^{-2}day^{-1})	Mineralization (mg N m^{-2}day^{-1})	Excretion (mg N m^{-2}day^{-1})	Release / Sedimentation	Release / Mineralization	Release / Primary production	Excretion / Release
18 March	-	-	10.0	-	2.18	-	-	-	0.22
26 May	256	41.0	23.8	57	6.19	0.58	0.41	0.09	0.26
23 June	445	66.6	68.8	150	14.2	1.03	0.46	0.15	0.21
14 July	417	25.7	24.9	71	9.32	0.97	0.35	0.06	0.37
7 August	437	183	90.3	117	16.3	0.49	0.77	0.21	0.18
24 October	73.3	35.3	30.7	75	9.22	0.87	0.41	0.42	0.30

Table 4. Annual primary production, sedimentation, zoobenthos production, excretion rates and removal rate of nitogen by chironomid emergence with their relative values.

			Rate ($g N/m^2/year$)	Relative value (%)	
Primary production			75.6	100	
Sedimentation			22.6	30	100
Zoobenthos production	Chironomids	1.4	5.0	7	22
	Tubificids	3.6			
Removal of nitrogen by chironomid emergence			0.8	1	4
Excretion			4.5	6	20

to 0.77, suggesting that the released nitrogen from sediment is of similar significance to mineralized nitrogen in the water column in sustaining phytoplankton production.

Zoobenthos feed the deposited materials on surface sediment and produce their bodies. Some are predated by higher trophic animals, and some are removed from lake by emergence of adult midges. Rough estimation of nitrogen flow through benthic community are shown in Table 4, using the past data (9, 19 22) and Table 3, and conversion factors of 2.8 for chironomid production (11) and 3.5 for tubificid (16). Removal of nitrogen by chironomid emergence was 0.19-0.24 $gNm^{-2}yr^{-1}$ for <u>Chironomus plumosus</u> and 0.02-0.54 $gNm^{-2}yr^{-1}$ for <u>Tokunagayusurika akamusi</u>. These values are similar to those of Lake Kasumigaura (0.30 for <u>C. plumosus</u> and 0.32 for <u>T. akamusi</u>, 11). Removed nitrogen by emergence account for 1 % of net primary production in both year of 1969 and 1971. Production of zoobenthos reached to 22% of sedimented nitrogen. This value was within the range of 3.7to 38.5% summarized by Iwakuma (10).

The importance of released nitrogen from bottom sediment is reported in many lakes, especially in shallow lakes. The feature of nitrogen metabolism in water column in summer season of Lake Suwa, bloomed by <u>Microcystis</u>, is given in Figure 8. The released nitrogen accounts for about 50% of sedimented one, and 15% of total inorganic nitrogen supply by mineralization of particulate matter and dissolved organic nitrogen, release and inflow. About 70% of total inorganic nitrogen supply was fixed by primary production. Excretion by zoobenthos accounts for about 20% in released nitrogen.

CONCLUSION

Zoobenthos affects on sediment-water interface through five mechanisms of the "Zoobenthos effect". The biomass of zoobenthos significantly correlated with released nitrogen rates from sediment, suggesting the importance of zoobenthos biomass for nutrient release from lake bottom sediment, and close relation with the metabolic cycle of nitrogen in a water column. As the standing crop of zoobenthos, chironomids and tubificids, increases with developing eutrophication of lake water, intensity of zoobenthos effect will strengthen in highly eutrophic lakes.

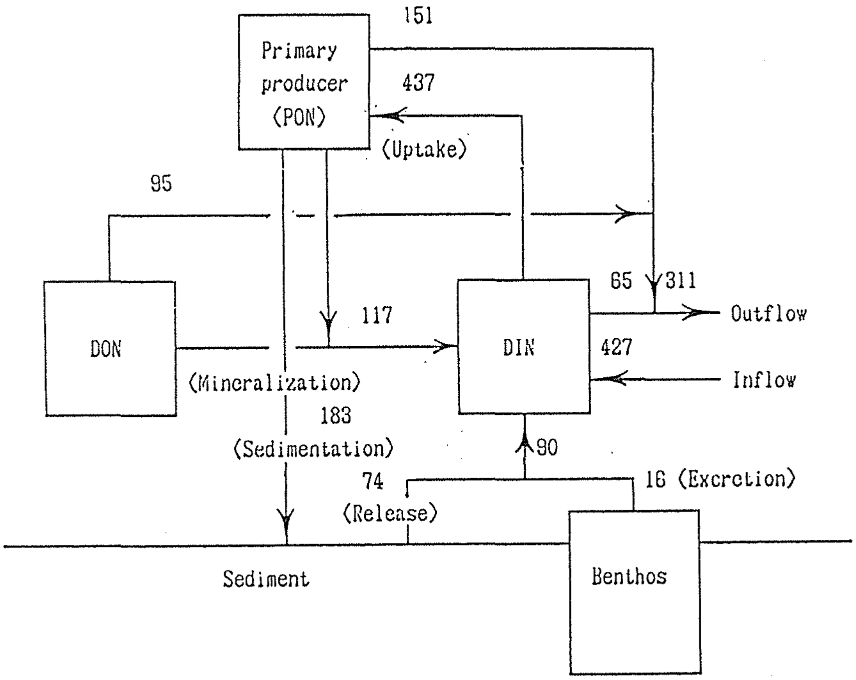

Fig. 8. Nitrogen metabolic rate (mg N/m^2/day) in Lake Suwa on summer time (7 Aug.) of 1971. Outflow rates of nitrogen were calculated using the data of the standing stock of nitrogen in water column (19) and outflow rates of water measured on 20-21 August, 1972 (19). Inflow rate of inorganic nitrogen, measured on 20-21 August, 1972 was cited from Sakamoto et al.(19).

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