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Simulation of sludge-dredging effects in controlling nutrient release of Lake Kasumigaura with large-size core samples

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Abstract——Nutrient release from the dredged and undredged sediments in Lake Kasumigaura were simulated under the laboratory control conditions with large-size core samples. It was found that phosphate and ammonia release fluxes are less in aerobic than those in anaerobic. In different simulated dredged depth, the phosphate release showed large divergence in the anaerobic than in the aerobic. There was a larger accumulated release of phosphate and ammonia at actual dredged (St. B) than the undredged (St. A) in anaerobic condition. This showed that the sludge-dredging was effective of controlling phosphorus and nitrogen release. A preliminary assessment is drawn from the experiments that the sludge-dredging work in Tsuchiura Bay of Lake Kasumigaura can reduce about 15.9% of phosphate and 56.2% of ammonia release from the sediments respectively.

Keywords: sludge-dredging; nutrient release; aerobic and anaerobic conditions; core samples; Lake Kasumigaura.

1 Introduction

Sediments play an important role in eutrophication in closed water-bodies such as lakes and bays. Lennox (Lennox, 1984) reported that it required a long period of time to improve the eutrophic status of Lough Ennell, an Irish Lake, because of internal loading of nutrients from sediments following control of the external loadings. Several restoration techniques have been developed to combat the effect of this internal nutrient load from the sediments. Some techniques are based on the prevention of anoxia, as in hypolimnetic aeration (Taggart, 1982), which prevents anoxic phosphorus release from the sediment. Another restoration method is hypolimnetic withdrawal, which is based on the forced discharge of nutrient-rich bottom water in lakes with anoxic hypolimnia, while surface outflows are dammed (Gertrud, 1987).

Sludge-dredging technique, which digs nutrient-rich sludge or sediments out of lake bottom and removes them, is a costly but practical one. It can mechanically dredge nutrient-rich sludge that often concentrates in a river mouth and bay so as to reduce internal nutrient loadings of the waters. Since 1975, a vast scale sludge-dredging work has been performing in Lake Kasumigaura, Japan. It is estimated that 7.2 million m^3 sludge in the up 30 cm depth will be dredged from the lake to the end of this century, in which the dredged area will account for one-fifth of the whole lake (Aizaki, 1994).

Lake Kasumigaura is a shallow eutrophic lake situated in the middle of Japan. Its total surface area is 214 km^2 with a mean depth of 4m. It has a catchment area of 1950 km^2 with surrounding paddy fields of 473 km^2. In its water and sediment there are higher concentrations of phosphorus and nitrogen. As most of the external nutrient loading is controlled, it is imperative to reduce the internal nutrient loading to improve its water quality and trophic status. In order to preliminarily evaluate the effect of sludge-dredging work completed in Tsuchiura Bay, we, using core samples, studied nutrient release across the interface of the dredged and undredged sediments under the laboratory control conditions.

2 Materials and methods

Ten large-size acrylic-glass tubes (110Φ× 500 mm) were used in the experiments. Sediment samples were taken from the three sites in Lake Kasumigaura. First position, St. A, is sludge-dredged at Tsuchiura Bay. Facing east about 500m from St. A is an exactly undredged position, St. B. The third, St. C, is located in the center part of the open lake and also undredged. The characteristics of the surface sediments and their interstitial water are presented in Table 1. Six to ten core samples (110Φ×200—250 mm) were collected in the site, whose positions were fixed by a transit with screen, on the first and tenth of February, 1995, respectively. The bottom water was simultaneously collected for each site and filtrated through glass fibre filters (Whatman GF/F) on arriving the laboratory. To examine the release effect under as natural a condition as possible, special care was taken to get undisturbed cores. The samples were carried to the laboratory with overlying water and with rubber stoppers tightly capped leaving no free space. The experiments were started within 6h after the collection. All release tests were carried under 20℃ in a constant temperature chamber. Two or three undisturbed cores were prepared for aerobic and anaerobic conditions, in which the overlying water was replaced by the filtrated original bottom water and maintained by bubbling air or N_2-air for 30 min. prior to the beginning of the tests. The ammonia in outflow gas was adsorbed in bottles holding 0.1 mol/L H_2SO_4 and collected at every sampling time, in which 75—100 ml of overlying water was drawn by a syringe from 3 cm above the sediment surface, immediately measured with DO meter and filtrated through the filter for analysis. The filtrated original bottom water, stored in dark at 4℃, was carefully added in the same sampled volume followed by sampling.

Table 1 Characteristics of the sediments and their interstitial water *

Sample	Item	St. A	St. B	St. C
Sediment	pH	7.57	7.65	7.48
	ORP, mv	−79	−101	−89
	Water content, %	89.09	——	80.30
	Porosity, %	86.71	——	79.44
	TP, % 0−2 cm	1.1	——	1.4
	30−32 cm	0.8	——	0.7
	TN, % 0−2 cm	5.2	——	7.5
	30−32 cm	2.9	——	3.0
Interstitial water, mg/L	PO_4-P	0.042	0.045	0.746
	DTP	0.158	0.203	0.825
	NH_4-N	0.318	0.525	3.150
	DTN	0.346	0.389	4.590
	Fe^{2+}	0.637	1.190	1.835

* TP and TN data were cited the reference (Aizaki, 1984b)

To simulate the effect of dredging depth on nutrient release, several core samples collected at the same time in St. C were cut to form core series with different sediment surfaces in depth. In this 48h experiment aerobic condition was made by keeping the overlying water open to air and anaerobic one by capping stoppers leaving no free space after bubbling with N_2-gas.

The concentrations of phosphate (PO_4-P) and ammonia (NH_4-N) were determined using one set of autoanalyzer (Bran-Luebbe, TRAACS 800).

3 Results and discussion

Variations of the concentrations of phosphate and ammonia in overlying water were measured from the samples collected at aerobic and anaerobic conditions. Both phosphate and ammonia release fluxes are less in aerobic conditions (DO 6.2−7.3 mg/L) than those in anaerobic (DO 0.7−1.1 mg/L), as shown in Fig. 1. This difference is more significant for St. C., in which the mean phosphate release (3.99 mgP/(m^2.d) in anaerobic condition was 8.2 times as much as that in aerobic. Similarly, St. A also had this regularity but not such a great difference as St. C. In aerobic condition, the sample A re-

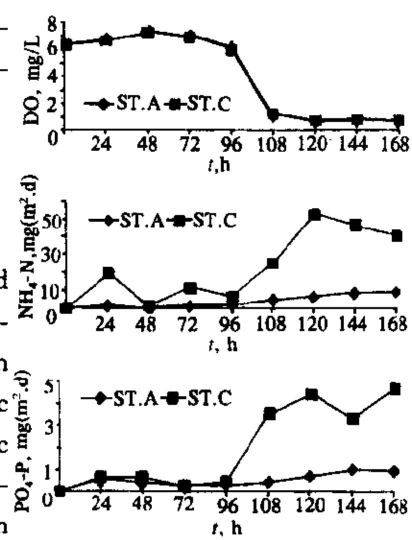

Fig. 1 Nutrient release from the sediments in aerobic and anaerobic conditions, 20℃

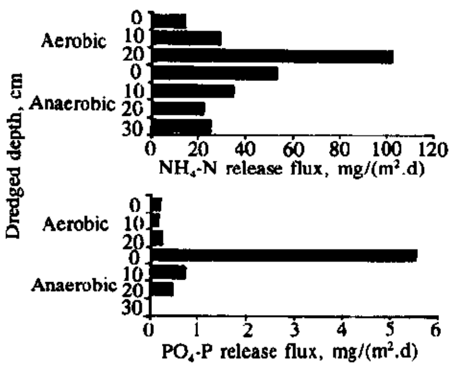

Fig. 2 Nutrient release fluxes in different "dredged" depth

leased smaller ammonia than that of C, nevertheless it did almost as much phosphate as the latter. After simulating the experiment of the sludge release of St. C, we got the release fluxed of phosphate and ammonia in different "dredged" depth (Fig. 2). The phosphate release showed minor fluctuations in the aerobic, but in the anaerobic it showed a large divergence. The release flux (5.52 mgP/(m^2.d)) from undredged sediment is 7.5, 11.2 and 345.2 times as much as those of 10, 20 and 30 cm dredged depth, respectively. In contrast, the ammonia release from the surface showed a clear regularity with the depth in quantity both in the aerobic and anaerobic. In the aerobic condition removing sludge about 20 cm thickness could increase the ammonia release by 7 times, and in the anaerobic, in turn, dredging depressed its release, but not so obviously as phosphate release in anaerobic condition and only 1.2 times decrease after dredging 30 cm deep.

Comparing anaerobic release of actual dredged (St. A) and undredged (St. B) sediments, there was a larger accumulated release of phosphate and ammonia at St. B at unit area than that of St. A (Table 2). It is showed that sludge-dredging work is effective on controlling phosphorus and nitrogen release from the bottom sludge when the overlying water is, or often, in anaerobic situation.

Table 2 Anaerobic release from the dredged (A) and undredged (B) sediments in Tuschiura Bay of Lake Kasumigaura

mg/(m^2.d)

Nutrient	Sediment sample	Time, h				
		3	6	12	24	48
PO_4-P	A	0.071	0.107	0.132	−0.006	−0.067
	B	−0.086	0.372	0.507	0.927	2.576
NH_4-N	A	2.380	3.130	5.72	9.670	24.05
	B	3.340	8.210	17.15	32.56	62.03

In order to compare aerobic with anaerobic release as well as dredged with undredged, all results are listed in Table 3. Better effects are in anaerobic condition, in which, for example, the phosphate release from the dredged sludge surface was reduced by 4 times. In the simulated test that the sludge was dredged 30 cm thickness, the release was decreased by near to 300 times as much as that of the undredged.

For aerobic situation, the sludge-dredging work may not be as effective as that in the anaerobic condition. In the phosphate experiments, not only the release values of both dredged and undredged fluxes are smaller, but also the difference between the two is less significant. In the ammonia release experiments it gives us a perplexing result that the conclu-

Table 3 Nutrient release from the dredged and undredged sediments, mg/(m^2.d)

Condition			Aerobic			Anaerobic	
	Sampling time	Feb. 1	Feb. 10	Mean	Feb. 1	Feb. 10	Mean
PO_4-P	Actual undredged (B)	—	0.226	0.226	—	1.327	1.327
	dredged (A)	0.381	−0.002	0.190	0.757	−0.096	0.330
	Simulated undredged (C)	0.486	0.207	0.346	0.3986	5.532	4.754
	dredged (C)*	—	0.247	0.247	—	0.016	0.016
NH_4-N	Actual undredged (B)	—	41.20	41.20	—	31.03	31.03
	dredged (A)	1.60	34.49	18.04	6.09	11.56	8.82
	Simulated undredged (C)	10.02	13.90	11.96	41.26	53.37	47.32
	dredged (C)*	—	102.30	102.30	—	24.74	24.74

* Excised the upper 30 cm sediments

sion drawn turns out contrary between actual and simulating experiments although the difference is larger. According to the analysis of the data collected between 1981—1983 and 1990—1993, the dissolved oxygen at the bottom water in Lake Kasumigaura is usually over 4.0 mg/L, (i.e. aerobic condition) and seldom (only at the deep area in summer) below 2.0 mg/L (anaerobic or anoxic condition; Aizaki, 1984a; Ebise, 1994). So the sludge-dredging effects should be assessed mainly under aerobic conditions. A preliminary evaluation is drawn from our experiments that the sludge-dredging work in Tsuchiura Bay of Lake Kasumigaura can reduce about 15.9% of phosphate and 56.2% of ammonia release from the sediments, respectively.

Through sludge-dredging work, the old mud surface is replaced by the new one. In Lake Kasumigaura the average daily deposit fluxes of autochthonous matter is 4.0 g/(m^2 · d) (Fukushima, 1984) and the accumulation rate in the recent 30 years is approximately 5—10 mm/a (Otsubo, 1984). After 5—10 years the depositing matter will form a new sediment surface, whose characteristics, including nutrient release, might be another important problem to be assessed.

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