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The phosphorus release pathways and their mechanisms driven by organic carbon and nitrogen in sediments of eutrophic shallow lakes

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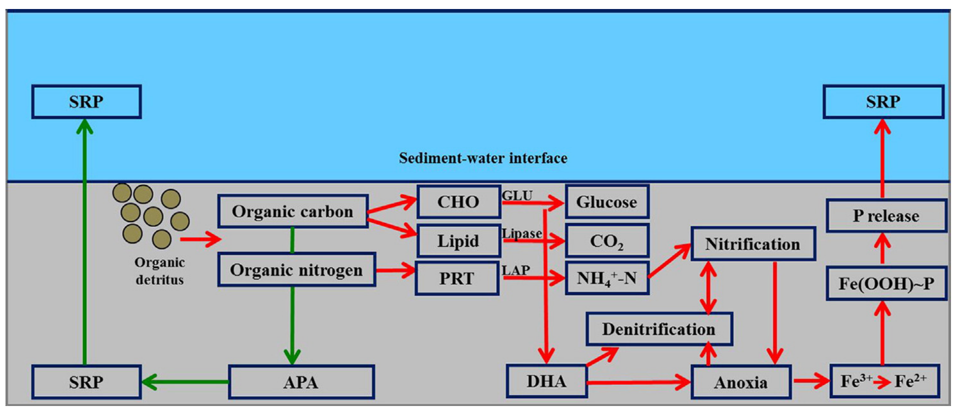
HIGHLIGHTS

- Organic carbon and nitrogen enrichment stimulates phosphorus release.
- The pathways included anaerobic release and phosphatase production.
- The anaerobic status is related to organic carbon decomposition and nitrification
- Phosphatase is secreted to supply P consumption.
- Carbon, Nitrogen and Phosphorus cycles are coupled.

GRAPHICAL ABSTRACT



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ABSTRACT

To reveal phosphorus (P) release pathways from sediment and their mechanisms induced by organic matter enrichment, 116 sampling sites (including surface water and sediment) in 29 shallow lakes with different eutrophic degrees in Wuhan city, China, were investigated from July 2011 to November 2011. Empirical relationship and structural equation model indicated that the decomposition of total organic matter (TOM), including proteins (PRT), carbo-hydrates (CHO) and lipids (especially PRT) mediated by extracellular enzymes, accelerated the formation of anaerobic status. On the other hand, coupled nitrification-denitrification caused by ammonium (NH_4^+-N) accumulation due to PRT decomposition further aggravated anaerobic status and nitrate removal in terms of the increase of dehydrogenase activity (DHA). As a consequence, ferric iron was reduced to ferrous iron and soluble reactive phosphorus (SRP) was released from iron-bound phosphorus (Fe(OOH)~P) in sediments. In addition, extracellular alkaline phosphatase can be induced by organic carbon and nitrogen on condition that the input of nitrogen (N) and carbon (C) exceeded by far that of P. Taken together, enrichment of N and C can result in P release through the formation of anaerobic status and alkaline phosphatase production. Hence, we indicated that a close coupling existed among C, N and P cycles.

1. Introduction

Eutrophication is a widespread problem in lakes, which is caused by over-enrichment with P and N (Carpenter et al., 1998) and increased

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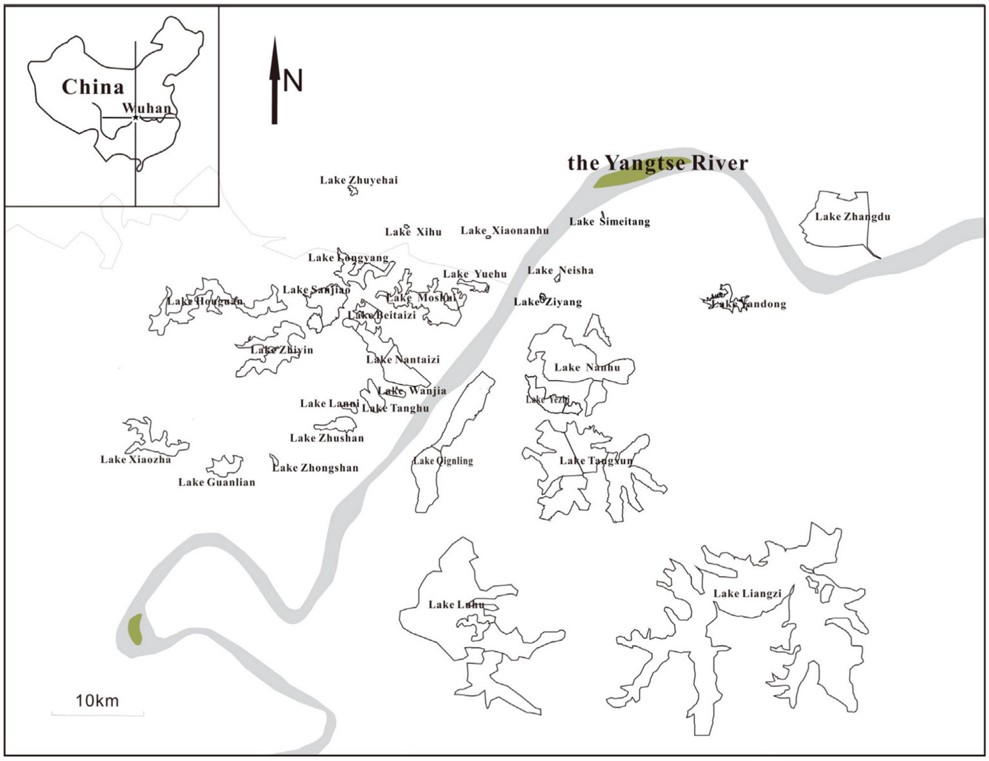

Fig. 1. The distribution map of study lakes in Wuhan City.

organic matter (Nixon, 1995). The research in Lake Rotorua indicated that high organic matter supply rates to the sediments may be important for sustaining high rates of sediment nutrient release (Burger et al., 2007). Except that organic matter can be decomposed into available nutrient to be released directly, P flux from lake sediments can also be controlled by dissolved organic carbon and oxygen availability (Muller

Table 1
The data of water depth, water temperature, transparence, chlorophyll *a* (Chl *a*), total phosphorus (TP) and trophic state index (TSI) of studied lakes.

	n	Mean depth (m)*	Water temperature(°C)	Transparence (m)	Chl *a*(μg L^{-1})	TP(μg L^{-1})	TSIc
Lake Nanhu	7	2.0	31.3 ± 0.8	0.37 ± 0.08	148.28 ± 15.92	620.22 ± 48.04	81 ± 1
Lake Yezhi	3	–	33.1 ± 0.3	0.15 ± 0.05	118.04 ± 14.18	580.67 ± 125.43	83 ± 2
The north area of Lake Qingling	3	1.5	30.0 ± 0.6	0.21 ± 0.01	180.27 ± 32.89	1493.25 ± 77.13	87 ± 1
The south area of Lake Qingling	4	1.5	30.1 ± 0.1	–	25.92 ± 7.83	151.19 ± 142.24	–
Lake Yandong	7	1.2	29.7 ± 0.4	0.85 ± 0.30	13.90 ± 12.41	55.55 ± 25.06	56 ± 9
Lake Ziyang	2	–	36.7 ± 0.6	0.65 ± 0.21	38.31 ± 21.82	853.91 ± 60.32	72 ± 5
Lake Neisha	1	–	35.0	0.70	44.49	144.10	68
Lake Simeitang	2	2.0	32.3 ± 0.1	0.95 ± 0.64	7.94 ± 4.56	86.80 ± 4.50	57 ± 0
The west area of Lake Tangxun	5	2.32	34.2 ± 0.4	0.37 ± 0.04	48.72 ± 24.67	319.64 ± 113.72	73 ± 3
The east area of Lake Tangxun	5	2.32	33.8 ± 0.4	0.38 ± 0.03	25.81 ± 6.69	181.75 ± 70.32	68 ± 2
Lake Xihu	1	2.4	–	0.85	12.90	109.44	60
Lake Zhuyehai	1	2.0	32.2	0.20	89.47	284.87	79
Lake Xiaonanhu	1	2.0	–	0.40	41.60	175.64	71
Lake Nantaizi	6	1.7	29.5 ± 0.2	0.35 ± 0	56.00 ± 16.46	346.11 ± 34.39	74 ± 1
Lake Beitaizi	3	1.8	30.5 ± 0.5	0.50 ± 0	49.66 ± 13.52	203.15 ± 13.37	71 ± 2
Lake Sanjiao	5	2.6	31.0 ± 0.2	0.36 ± 0.05	135.09 ± 41.29	147.39 ± 52.49	77 ± 3
Lake Longyang	5	2.1	30.0 ± 0.1	0.27 ± 0.04	164.22 ± 58.97	1080.33 ± 84.99	82 ± 2
Lake Tanghu	3	1.8	28.6 ± 0.4	0.20 ± 0	33.18 ± 3.84	351.44 ± 54.47	74 ± 1
Lake Wanjia	2	1.8	29.0 ± 0	0.40 ± 0	34.25 ± 2.07	619.48 ± 3.19	73 ± 0
Lake Zhiyin	7	1.9	29.2 ± 0.4	0.38 ± 3	24.58 ± 6.33	124.26 ± 23.94	67 ± 1
Lake Houguan	7	1.14	30.5 ± 0.4	1.10 ± 0.28	10.33 ± 5.09	51.02 ± 14.07	56 ± 4
Lake Gaohu	5	1.55	31.3 ± 0.4	0.20 ± 0	96.83 ± 9.58	207.61 ± 15.14	79 ± 1
Lake Zhushan	4	1.62	26.2 ± 0.1	0.26 ± 0.03	69.51 ± 16.88	299.95 ± 18.64	77 ± 2
Lake Lanni	1	1.9	26.0	0.40	28.46	272.52	70
Lake Zhongshan	1	1.8	26.0	0.40	17.80	227.58	67
Lake Guanlian	2	2.2	–	–	39.80 ± 1.83	543.53 ± 176.67	–
Lake Xiaozha	2	3.0	29.9 ± 0.1	0.20 ± 0	57.10 ± 4.47	94.72 ± 7.48	74 ± 1
Lake Liangzi	8	2.7	27.4 ± 0.5	0.63 ± 0.10	22.24 ± 9.85	63.50 ± 8.50	63 ± 3
Lake Zhangdu	6	1.79	21.0 ± 0	0.50 ± 0.11	13.17 ± 5.22	73.92 ± 16.42	61 ± 4
Lake Daoshuihe	1	–	23.0	–	13.55	189.89	–
Lake Luhu	6	2.27	–	–	45.97 ± 14.42	14.35 ± 2.22	–

"–": no data.
"*": from records of lakes in Wuhan.