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Effects of benthic algae on release of soluble reactive phosphorus from sediments: a radioisotope tracing study

Xiu-feng Zhang [a], Xue-ying Mei [a,b,*]

[a] Department of Ecology and Institute of Hydrobiology, Jinan University, Guangzhou 510632, PR China
[b] College of Resources and Environment, Anhui Agricultural University, Hefei 230036, PR China

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Abstract

To evaluate the effect of benthic algae on soluble reactive phosphorus (SRP) release from sediments in shallow lakes, experiments on SRP release with and without benthic algae in sediment cores and an experiment on SRP uptake by benthic algae were conducted using the radioisotope (^{32}P) tracing method. The dissolved oxygen (DO) concentration in sediment cores was also investigated. The results show that benthic algae effectively reduce the release of SRP from sediments to overlying water. The uptake of SRP by benthic algae, which is the direct way in which benthic algae affect the SRP release from sediments, is low in filtered water and increases with the SRP concentration. However, in the experiment, the increased uptake rate lasted for a short time (in one hour), and after that it returned to a low rate. Benthic algae make the DO concentration and the oxic layer thickness increased, which can indirectly reduce the SRP release from sediments. These findings indicate that benthic algae can reduce the SRP release from sediments in both direct and indirect ways. It seems that the indirect way also plays an important role in reducing the SRP release from sediments.

Keywords: Sediment; Benthic algae; Soluble reactive phosphorus release; Soluble reactive phosphorus uptake; Shallow lake

1. Introduction

In shallow lakes, sediments play an important role in determining water quality due to the fact that a unit volume of water with a larger amount of sediment has a larger sediment surface. Internal release from sediments can maintain high nutrient levels in water even after dramatic reductions in external loading (van der Molen and Boers, 1994; Søndergaard et al., 2003). Phosphorus (P) in sediments, especially soluble reactive phosphorus (SRP), is significant to the internal release of nutrients in shallow lakes (Holdren and Armstrong, 1986). The SRP release in shallow lakes must be considered because it will considerably affect pelagic algae production (Søndergaard et al., 2003; Smolders et al., 2006).

Benthic algae can affect the SRP release from sediments in shallow lakes in direct and indirect ways (Dodds, 2003; Tyler and McGlathery, 2003). Benthic algae can take up SRP from sediments and reduce the SRP release from sediments (Stevenson and Stoermer, 1982; McCormick and O'Dell, 1996), which is the direct way in which the SRP release from sediments is affected. Benthic algae can also indirectly reduce the SRP release from sediments by altering biogeochemical conditions of sediments, such as the dissolved oxygen (DO), because of the algae's location above the sediments. The oxygen produced by benthic algae during the photosynthetic process causes an increased conversion of the Fe^{2+} ions to Fe^{3+} ions in sediments, which forms an insoluble compound with phosphate ions. As a result, the SRP release from sediments is reduced (Dodds, 2003; Carlton and Wetzel, 1988). In previous studies, sediments without

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* Corresponding author.
E-mail address: qxxmxy@163.com (Xue-ying Mei).
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benthic algae activity have been observed to exhibit a P release rate of 1 mg/(m^2·d), whereas those with benthic algal activity have been observed to exhibit a P release rate of 0.1 mg/(m^2·d) (van Luijn et al., 1995).

Although numerous studies of the effect of benthic algae on the nutrient cycle in sediments and water have been conducted (Dalsgaard, 2003; Tyler and McGlathery, 2003; Koschorreck et al., 2007; Spears et al., 2008), and the effect of benthic algae on P release from sediments has been examined (Zhang et al., 2013), few investigations on the effect of benthic algae, grown directly on the sediment surface, on the SRP release from sediments have been conducted. The direct and indirect effects of benthic algae on the release of SRP from sediments have not been well studied, but an understanding of these phenomena would be beneficial to planning for environmental protection relating to P control. Quantitatively separating the processes of benthic algae directly and indirectly affecting the SRP release from sediments using traditional methods is extremely difficult, as they occur simultaneously and at very small scales (Poulíčková et al., 2008).

A carrier-free ^{32}P radiotracer, in the form of $NaH_2^{32}PO_4$, offers a sensitive marker of the ^{32}P activity that can be used to demonstrate the P cycle in the aquatic ecosystem (Noe et al., 2003). In this study, experiments on SRP release with and without benthic algae in sediment cores and an experiment on SRP uptake by benthic algae were conducted. A ^{32}P radiotracer was used to evaluate the SRP release from sediments and the uptake of SRP by benthic algae. The direct and indirect effects of benthic algae on SRP release from sediments in shallow lakes could thereby be evaluated.

2. Experimental setup

2.1. Description of sampling lake

Sediment and water samples were collected from the center of Nanhu Lake, a sub-lake of Huizhou West Lake, which is located in Huizhou City, Guangdong Province, in South China. The lake covers an area of about 120 000 m^2, with an average depth of 1.5 m. The average concentrations of chlorophyll a (Chl a), total phosphorus (TP), and total nitrogen (TN) in the lake are 6.1 μg/L, 0.023 mg/L, and 0.531 mg/L, respectively. The concentration of SRP in the lake water is very low and exceeds the limit of detection. The depth of sediments in the lake is about 20−50 cm. The TP concentration in sediments was 1.047 mg/g in dry weight and the TN concentration in sediments was 1.883 mg/g in dry weight during the study period. In the pore water of sediments, the concentrations of TP and SRP were 0.683 mg/L and 0.015 mg/L, respectively.

2.2. Sediment and water sampling

Twelve sediment samples were collected by hand on March 24, 2010 from the center of Nanhu Lake, using perspex core tubes with lengths of 15 cm and internal diameters of 6.5 cm. Each perspex core tube had an injection hole at 4 cm from the bottom, whose diameter was 5 mm. The sediment core samples, with overlying water, were about 10 cm in thickness. All the perspex core tubes were immediately sealed at the top and bottom with silicone rubber bungs to keep the sediment structure intact. These tubes were then placed into boxes with ice and transported to the laboratory in Jinan University. The bungs on the top of the perspex core tubes were immediately removed when they arrived at the laboratory to allow the gas in the tubes to be exchanged with air. Overlying water in the sediment cores was siphoned from the tubes in order to regulate the thickness of sediment cores to 5 cm from the bottom of the tube, which kept the sediment surface 1 cm above the injection hole in the tube (Zhang et al., 2013). When needed, a ^{32}P radiotracer, in the form of $NaH_2^{32}PO_4$, was injected into the sediments through the injection hole. One hundred and twenty five liters lake water were collected using plastic buckets from the center of Nanhu Lake for the experiments.

2.3. Benthic algae culture

Benthic algae used in the SRP release experiment were cultured in a laboratory and grown in the twelve sediment core samples. Two-hundred milliliters of lake water were carefully poured into each sediment core tube. Four sediment cores were kept in the dark, where no benthic algae would grow. Eight sediment cores were kept in a light−dark cycle of 12 L:12 D, with an average light intensity of 15.8 ± 9.4 μmol/(m^2·s) in daytime and darkness at night, which would lead to abundant benthic algae in two weeks. After the culture of the eight sediment cores, four of these cores with benthic algae were used to measure the Chl a concentration and determine the dominant taxa. The Chl a concentration was measured after the Chl a was extracted by ethanol from the sediment cores at room temperature according to a spectrophotometrical analysis technique from Jespersen and Christoffersen (1987), and the average Chl a concentration was 86 ± 4 mg/m^2. The dominant taxa were found, using a microscope (Hu and Wei, 2006), to be *Oscillatoria tenuis* Ag. and *Navicula* spp. (class Diatom). The other four sediment cores with benthic algae were combined with the four sediment cores without benthic algae to examine the effect of benthic algae on the SRP release rate from sediments.

Benthic algae used in the uptake experiment was grown on sixteen rounded plastic gauzes in a glass tank (50 cm × 30 cm × 40 cm) containing 50 L of lake water. The diameter of each plastic gauze was 65 mm and the mesh size was 2 × 2 mm; the plastic gauzes were suspended below the water surface in the glass tank and formed a substrate for algae growth. To promote algae growth, the calculated doses of 1.5 mg N, as sodium nitrate, and 0.1 mg P, as sodium dihydrogen phosphate, were added into the glass tank per liter water per week (Wolfe and Lind, 2010). The water in the glass tank was kept at 30°C and in a light−dark cycle of 12 L:12 D, with an average light intensity about 100 μmol/(m^2·s) in daytime and darkness at night. After four weeks, there were abundant benthic algae on the plastic gauzes. At the end of the four-week culture period, the benthic algae were transferred to