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In-situ study on nutrient release fluxes from shallow lake sediments under wind-driven waves*

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Abstract: An *in-situ* benthic device to measure nutrient fluxes across the sediment-water interface has been developed and successfully used to study both static and dynamic fluxes of nutrients in Dianshan Lake, China. The result shows that the surface sediments of Dianshan Lake were resuspended under wind-driven waves. DOC entered into overlying water only when sediments were resuspended. The average DOC flux was 105.78 mg/(m^{2}d), while the static and dynamic POC fluxes were 48.22 mg/(m^{2}d) and 10 273.20 mg/(m^{2}d), respectively. Ammonia and nitrate had no significant release, and the dynamic flux of TN was 87.11 mg/(m^{2}d). The release of phosphorus was the most evident, and the dynamic fluxes of SRP and DTP were 20.22 mg/(m^{2}d) and 21.78 mg/(m^{2}d), 2.2 and 2.0 times higher than the static fluxes, respectively. Dissolved phosphorus was released mainly as SRP, and phosphorus release from the sediments in Dianshan Lake cannot be ignored.

Key words: shallow lake, wind-induced wave, hydraulic disturbance, nutrient fluxes, *in-situ* experiment

Introduction

Dianshan Lake is located in the downstream of the Taihu Lake basin (31°04′N-31°12′N, 120 °53′E-121°01′E), west of Shanghai, China. The monthly averaged water temperature in Dianshan Lake ranges from $\leq 0\,^{o}$C to 10°C in winter, to $> 22\,^{o}$C in summer, and between 10°C -22°C in spring or autumn. The annual average wind speed in Dianshan Lake is 3.7 m/s with the monthly average of 3.8 m/s-4.1 m/s from February to May, and 3.0 m/s-3.5 m/s from September to December. It has a surface area of 62 km^2 with maximum length of approximately 14.5 km and width of 8.1 km. Dianshan Lake is a shallow water body with average depth of 2.1 m and maximum depth of 3.6 m. It is one of the five largest natural freshwater lakes in China and a major source of drinking water for Shanghai[1]. However, with the rapid economic development in Shanghai and adjacent provinces, the water quality in Dianshan Lake has deteriorated in recent years with increasing eutrophication and frequent algal blooms[2].

As a result of excessive anthropogenic nutrient loading, especially nitrogen and phosphorus, algal blooms in lakes[3-5]. Controlling nutrient input is the most effective way of reducing the risk of algal blooms[6], and great efforts have been made to reduce the external nutrient loading to Dianshan Lake. When the external sources are under control, the nutrients stored in the sediments would become the main sources of nutrients in lake[7-9]. Kang et al.[10,11] studied nutrient concentrations and distribution characteristics in Dianshan Lake sediments, and found that total pho-

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sphorus contents, ranged from 266 mg/kg to 1 146 mg/kg, and carbon and nitrogen contents were significantly higher than those values of twenty years ago. As a potential pollution source, the impact of the sediments on water quality and internal nutrient recycling cannot be ignored. Hence, it is important to quantify the nutrient fluxes across sediment-water interface and enhance our understanding of the governing processes.

Currently, the studies on nutrient release from the sediments mostly focus on laboratory experiments, such as using beakers, conical bottles and other small containers for static release experiments, or using flumes for dynamic release experiments to simulate dynamic conditions. Laboratory experiments are relatively easy to operate and control, and the results have greatly enhanced our understanding of the nutrient release from the sediments. But in the process of sediment collection and transport, the original structure and layer of the sediments are easily disturbed, and the environmental conditions such as biological communities, temperature and redox potential may also change. It is difficult to mimic the *in-situ* nutrient fluxes by laboratory experiments. The *in-situ* monitoring method of nutrient release fluxes from sediments mainly includes box culture and continuous flow culture. The former uses a box incubator. A box with open bottom is vertically put into sediments surface to form a closed environment, and then pollutant flux from sediments is monitored within the incubator. The latter is an open system. Overlying water constantly and continuously flow through a certain area of the bottom sediment, and pollutant flux from the sediments is estimated by the difference of the pollutant concentration between inflow and outflow water. The two methods usually cannot be used to study the impact of external factors such as storms on pollutant release from sediments. The equipment that we designed here belongs to the box culture method. In order to study the impact of external storms on nutrient flux from sediments, we punched series holes on the upper panel of the underwater box, and by opening or closing the holes, we can assess how nutrient flux from sediments may be affected by waves generated by external storms.

Currently, there are no reports on nutrient release from Dianshan Lake sediments using *in-situ* methods. Chao et al.[12-14] had continuously monitored the vertical profiles of nutrient concentrations in Taihu Lake under different waves, nutrient concentration variation characteristics, and the contribution of nutrient release caused by wave turbulence. These studies were not carried out in a closed system above the lake sediments, and therefore could be only used to qualitatively assess the effects on nutrients release from the sediments under different wave disturbances without nutriant fluxes. In this study, we designed a device to study nutrient flux across water-sediment interface by *in-situ* monitoring, and successfully applied it in Dianshan Lake. The *in-situ* experiment was conducted at the southeast corner of Dianshan Lake (GPS location: 31°04′40.65″, 120°58′08.57″). The area was originally used for caged fish culture. In order to improve water quality in Dianshan Lake, fish cage culture was banned by the government.

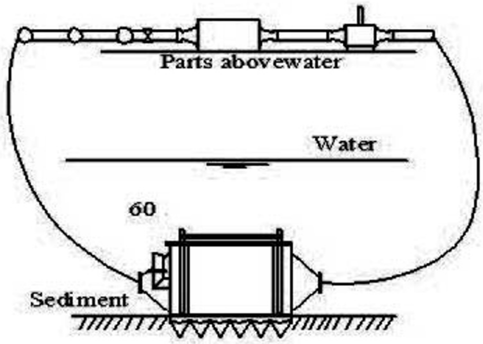

Fig.1 Schematic sketch of the benthic *in-situ* system

1. Experimental device and methods

1.1 *In-situ* measurement device

To obtain the nutrient fluxes across the sediment-water interface, we developed an *in-situ* benthic equipment using acrylic boxes. It is made up of an above water box, an underwater box, a variable set of tubes to connect its inflow and outflow end, a pump, a flow meter and a set of probes for water temperature, pH, redox potential and turbidity measurements (Fig.1). Each part is tightly connected by flexible pipes. The water in the underwater box is pumped into the above water box, and the circulation is maintained by the pump to ensure that water contained in the underwater box is thoroughly and continuously mixed. The above water box is a cylinder, the length and diameter is 0.25 m and 0.18 m, respectively. The box has four holes in upper panel to place electrodes for measuring physical parameters. The underwater box is a cuboid, its length, width and height is 0.90 m, 0.60 m and 0.64 m, respectively. The box has an opening at the bottom (0.54 m^2), a vertical cutting edge, and exterior flanges. The underwater box was carefully pushed into the sediment until the flanges rested on the sediment surface, preventing further penetration. To increase the flow rate above the sediment-water interface, the underwater box is separated into three units. Afterwards the ambient water was pumped through the system with a maximum flow rate of 1.5 m^3/h which corresponds to a flow velocity of 0.013 m/s within the unit. The total volume of the system is 0.35 m^3.

The sediment-water interactions play an important role in nutrient cycling. Nutrients release into overlying water in two ways: static release without sedi-