Spatio-temporal dynamics of orthophosphate with implications for limitation of phytoplankton growth in north basin of Lake Biwa, Japan

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Orthophosphate (PO_4-P) is the main chemical form of phosphorus (P) for phytoplankton growth, often considered as a limiting nutrient for primary production in freshwater ecosystems. However, few information on accurate measurements for PO_4-P concentrations in epilimnion of meso- and oligotrophic lakes due to lower than the detection limit (60 nM) of soluble reactive P using traditional spectrophotometrical method. In the present study, we measured PO_4-P concentrations using ion chromatography with a detection limit of 5 nM, and determined truly vertical distribution of PO_4-P throughout the year with other abiotic and biotic environmental factors in north basin of Lake Biwa, to accurately understand biogeochemical processes of P in this mesotrophic lake.

Field investigations were conducted monthly from April to December 2018 at station K4 (35º19'9.6"N, 136º11'2.7"E; 50 m deep). Phosphate enrichment experiments were also made at each sampling occasion to clarify P limitation for phytoplankton growth. Lake water including phytoplankton assemblage collected from epilimnion (0–20 m) was enriched with 1 μM of PO_4-P (+P) and incubated together with untreated one (control) for 2 days under ambient light and temperature conditions. To evaluate the effect of potentially nutrient-rich bottom water, the filtered bottom water was mixed with untreated epilimnion water including phytoplankton at 1:1 (+B) was incubated at the same conditions as the +P treatment. Phytoplankton growth rate (g) was calculated with equation of $g=\ln(C_t/C_0)/2$, where C_0 and C_t are chlorophyll *a* (chl. *a*) concentrations at start and end of the experiment, respectively.

Water temperature increased in the epilimnion from May, and strict thermocline was developed from June to September. Chl. *a* concentrations increased from June to July in 10–20 m, and from October to November in 0–20 m. PO_4-P concentrations were always low, <20 nM, in the epilimnion from April to June. The concentrations below 30 m increased up to 140 nM in May, but decreased after that until July. In August and September, the concentrations increased up to 30–40 nM even in the epilimnion probably due to disturbance by typhoon. The concentrations below 30 m increased with depth, and the highest values were frequently observed near the bottom, up to 220 nM. On average throughout the water column, PO_4-P concentrations were 24–48 nM from April to June, then slightly increased up to 73 nM until September, being constant, 50–63 nM until December.

Total P, total dissolved P, dissolved organic P and particulate P exhibited similar spatio-temporal distributions, but different pattern from those of PO_4-P. NH_4-N increased in 10–20 m from May to July, whereas the NO_3-N increased in the hypolimnion as season progressed. Sestonic C:N:P ratios suggested a terrible P deficiency in July and October when phytoplankton biomass increased.

Phosphate enrichment experiments showed that phytoplankton in the epilimnion was mostly limited with P for its growth. Phytoplankton g in control varied −0.05-0.08 d^{-1}, being always lower than those in +P (−0.04-0.44 d^{-1}) and/or +B (−0.04-0.49 d^{-1}) treatments except for November and December. In November, no growth was found even in +P treatment. This might be caused by nitrogen limitation because of <6 μM of NO_3-N in the epilimnion. The g of control was similar as that of +P and +B (ca. 0.1 d^{-1}) in December, indicating that P deficiency for phytoplankton growth was relaxed until December by vertical convection.

We firstly determined completely vertical distributions of PO_4-P in north basin of Lake Biwa from spring to winter, and detected 20–40 nM of PO_4-P in the epilimnion. Phosphate enrichment experiments showed that 20 nM of PO_4-P might be critical concentration for phytoplankton growth in the lake. No phytoplankton growth even in +P treatment in November implied that nitrogen limitation for phytoplankton growth will be possible in Autumn. Further study for clarify this will be needed.

Keywords: Orthophosphate dynamics, Phosphorus limitation, Phytoplankton growth rate, Ion chromatography, Biogeochemical processes, Freshwater ecosystem