Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Pearl Lake, Minnesota

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OBJECTIVES

The objectives of this investigation were to 1) determine rates of phosphorus (P) release from sediments under laboratory-controlled anoxic (i.e., anaerobic) conditions and 32) quantify biologically-labile (i.e., subject to recycling) and refractory (i.e., biologically inert and subject to burial) P fractions for sediments collected in Pearl Lake, Minnesota.

APPROACH

Laboratory-derived rates of P release from sediment under anoxic conditions: Triplicate sediment cores were collected by Wenck Associates from the deep basin of Pearl Lake in Early June, 2012, for determination of rates of P release from sediment under anoxic conditions. All cores were drained of overlying water and the upper 10 cm of sediment was transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Surface water collected from the wetland was filtered through a glass fiber filter (Gelman A-E), with 300 mL then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems consisted of the upper 10-cm of sediment and filtered overlying water contained in acrylic core liners that were sealed with rubber stoppers. They were placed in a darkened environmental chamber and incubated at a constant temperature (20 ^{o}C). The oxidation-reduction environment in the overlying water was controlled by gently bubbling nitrogen (anoxic) through an air stone placed just above the sediment surface in each system. Bubbling action insured complete mixing of the water column but did not disrupt the sediment. Anoxic conditions were verified using a dissolved oxygen electrode.

Water samples for soluble reactive P were collected from the center of each system using an acid-washed syringe and filtered through a 0.45 µm membrane syringe filter (Nalge). The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition.

These volumes were accurately measured for determination of dilution effects. Soluble reactive P was measured colorimetrically using the ascorbic acid method (APHA 2005). Rates of P release from the sediment (mg m^{-2} d^{-1}) were calculated as the linear change in mass in the overlying water divided by time (days) and the area (m^2) of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

Sediment chemistry: The upper 10 cm of an additional core collected from the same station was sectioned for analysis of moisture content (%), sediment density (g/mL), loss on ignition (i.e., organic matter content, %), loosely-bound P, iron-bound P, aluminum-bound P, calcium-bound P, labile and refractory organic P, and total P (all expressed at mg/g). A known volume of sediment was dried at 105 ^{o}C for determination of moisture content and sediment density and burned at 500 ^{o}C for determination of loss-on-ignition organic matter content (Håkanson and Jansson 2002). Additional sediment was dried to a constant weight, ground, and digested for analysis of total P using standard methods (Plumb 1980; APHA 2005).

Phosphorus fractionation was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (loosely-bound P), bicarbonate-dithionite-extractable P (i.e., iron-bound P), sodium hydroxide-extractable P (i.e., aluminum-bound P), and hydrochloric acid-extractable P (i.e., calcium-bound P). A subsample of the sodium hydroxide extract was digested with potassium persulfate to determine nonreactive sodium hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P was calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P. Refractory organic P was estimated as the difference between total P and the sum of the other fractions.

The loosely-bound and iron-bound P fractions are readily mobilized at the sediment-water interface as a result of anaerobic conditions that result in desorption of P from sediment and diffusion into the overlying water column (Mortimer 1971, Boström 1984, Nürnberg 1988). The sum of the loosely-bound and iron-bound P fractions are referred to as redox-sensitive P (i.e., the P fraction that is active in P release under anaerobic and reducing conditions). In addition, labile organic P can be converted to soluble P via bacterial mineralization (Jensen and Andersen 1992) or hydrolysis of bacterial polyphosphates to soluble phosphate under anaerobic conditions (Gächter et al. 1988; Gächter and Meyer 1993; Hupfer et al. 1995). The sum of redox-sensitive P and labile organic P are collectively referred to a biologically-labile P. This fraction is generally active in recycling pathways that result in exchanges of phosphate from the sediment to the overlying water column and potential assimilation by algae. In contrast, aluminum-bound, calcium-bound, and refractory organic P fractions are more chemically inert and subject to burial rather than recycling.

RESULTS AND INTERPRETATION

Phosphorus mass and concentration increased linearly in the overlying water column of sediment systems maintained under anoxic conditions (Figure 1). The mean concentration of soluble reactive P was relatively high at the end of the incubation period at 0.73 mg/L (± 0.077 Standard Error). The mean anoxic P release rate was moderate to high at 4.8 mg m^{-2} d^{-1} (n = 3; Table 1), and fell within the lower 25% quartile compared to other lakes in Minnesota (Figure 2). Overall, high rates of anoxic P release coupled with seasonal anoxia during the summer could play an important role in the P budget of the lake.

Pearl Lake profundal sediments exhibited very high moisture content and low sediment density, indicating fine-grained, flocculent sediment (Table 2). Loss-on-ignition organic matter content was moderately high at 36%. Overall, sediment total P concentrations were moderate to low for Pearl Lake sediments compared to other lakes in the region (Figure 3). The biologically-labile (i.e., subject to recycling back to the overlying water column; loosely-bound P, iron-bound P, and labile organic P) P concentration accounted for ~ 56% of the total sediment P, suggesting high recycling potential (Figure 4; Table 1). Redox-sensitive P (i.e., active in anoxic P release from the sediment; loosely-bound and iron-bound P) represented ~48% of the biologically-labile P and ~28% of the total P (Table 1). Iron-bound P dominated the biologically-labile P fraction at ~42% and the concentration of 0.239 mg/g was moderately high. The relationship between iron-bound P and the anoxic P release rate for Pearl Lake also fell within regression relationships developed by Nürnberg (1988) for lakes in North America (Figure 5), suggesting that desorption of P from the iron-bound fraction played an important role in rates of internal P loading in Pearl Lake. Loosely-bound P concentrations were moderately low (Table 1), accounting for only ~ 7% of the biologically-available P concentration. In contrast, labile organic P accounted for ~ 52% of the biologically-labile P in Pearl Lake sediments.

Biologically-refractory P (i.e., more inert to recycling and subject to burial; aluminum-bound P, calcium-bound P, and refractory organic P) represented ~42% of the total sediment P (Figure 4; Table 1). Calcium-bound P and refractory organic P were codominant, accounting for 36 % and 41% of the refractory P fraction. Aluminum-bound P represented 23% of this fraction.

The sediment total iron was low relative to other lakes in Minnesota while total manganese and calcium concentrations fell near the median (Figure 6). The sediment Fe:P ratio was moderate at ~ 4.5. Ratios below 10 may indicate lower iron oxyhydroxide binding efficiency with P under aerobic conditions in the oxidized microzone and the potential for some P release even under oxic conditions, although much lower compared to anoxic P release rates.

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Table 1. Mean (1 standard error in parentheses; n=3) rates of phosphorus (P) release, concentrations of biologically labile and refractory P, and metals concentrations for sediments collected in Pearl Lake. DW = dry mass, FW = fresh mass.

Station	Diffusive P flux	Redox-sensitive and biologically labile P				Refractory P			Total P and Metals			
	Anoxic ($mg\ m^{-2}\ d^{-1}$)	Loosely-bound P (mg/g DW)	Iron-bound P (mg/g DW)	Iron-bound P (ug/g FW)	Labile organic P (mg/g DW)	Aluminum-bound P (mg/g DW)	Calcium-bound P (mg/g DW)	Refractory organic P (mg/g DW)	Total P (mg/g DW)	Total Fe (mg/g DW)	Total Mn (mg/g DW)	Total Ca (mg/g DW)
Central	4.8 (0.6)	0.039	0.239	14	0.298	0.095	0.146	0.168	0.985	4.410	0.603	41.660

Table 2. Textural characteristics for sediments collected in Pearl Lake.

Station	Moisture Content (%)	Bulk Density (g/cm^3)	Sediment Density (g/cm^3)	Loss-on-ignition (%)
Central	94.4	1.023	0.07	36.0

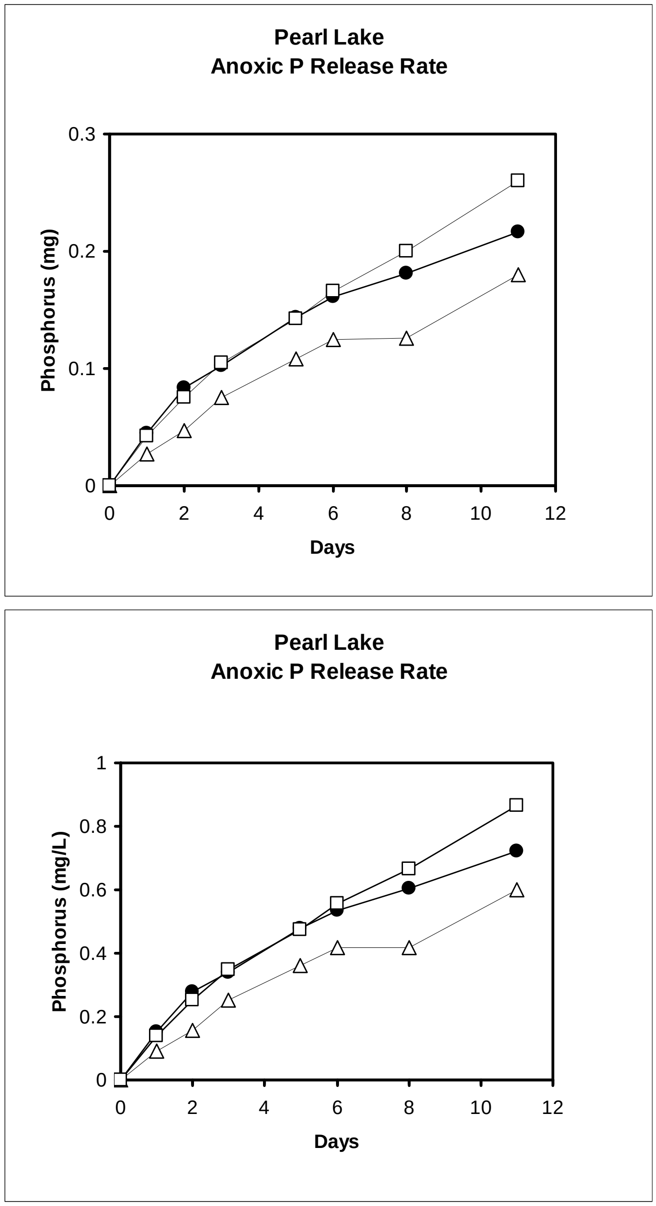

Figure 1. Changes in soluble reactive phosphorus mass (upper panel) and concentration (lower panel) in the overlying water column under anoxic conditions versus time for sediment cores collected in Pearl Lake.

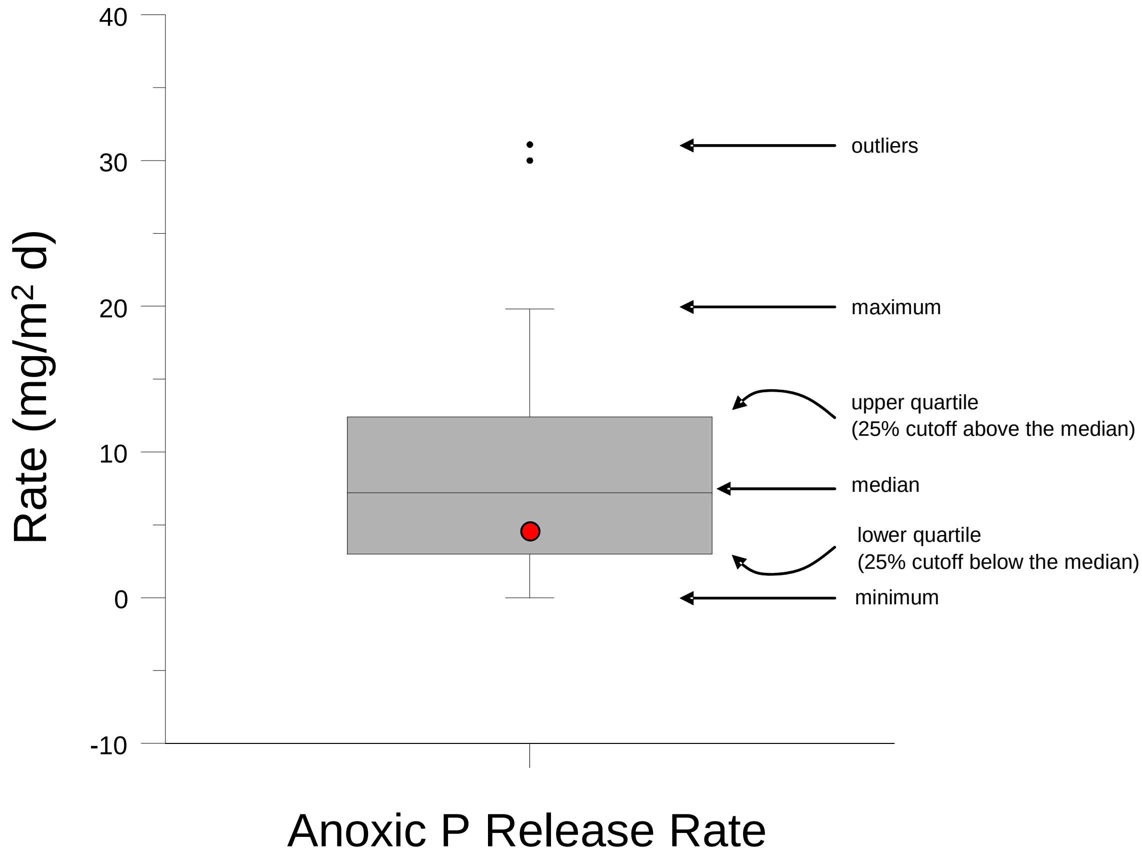

Figure 2. Box and whisker plot comparing the anoxic phosphorus (P) release rate measured for Pearl Lake sediments (red circle) with statistical ranges (n=50) for lakes in the State of Minnesota.

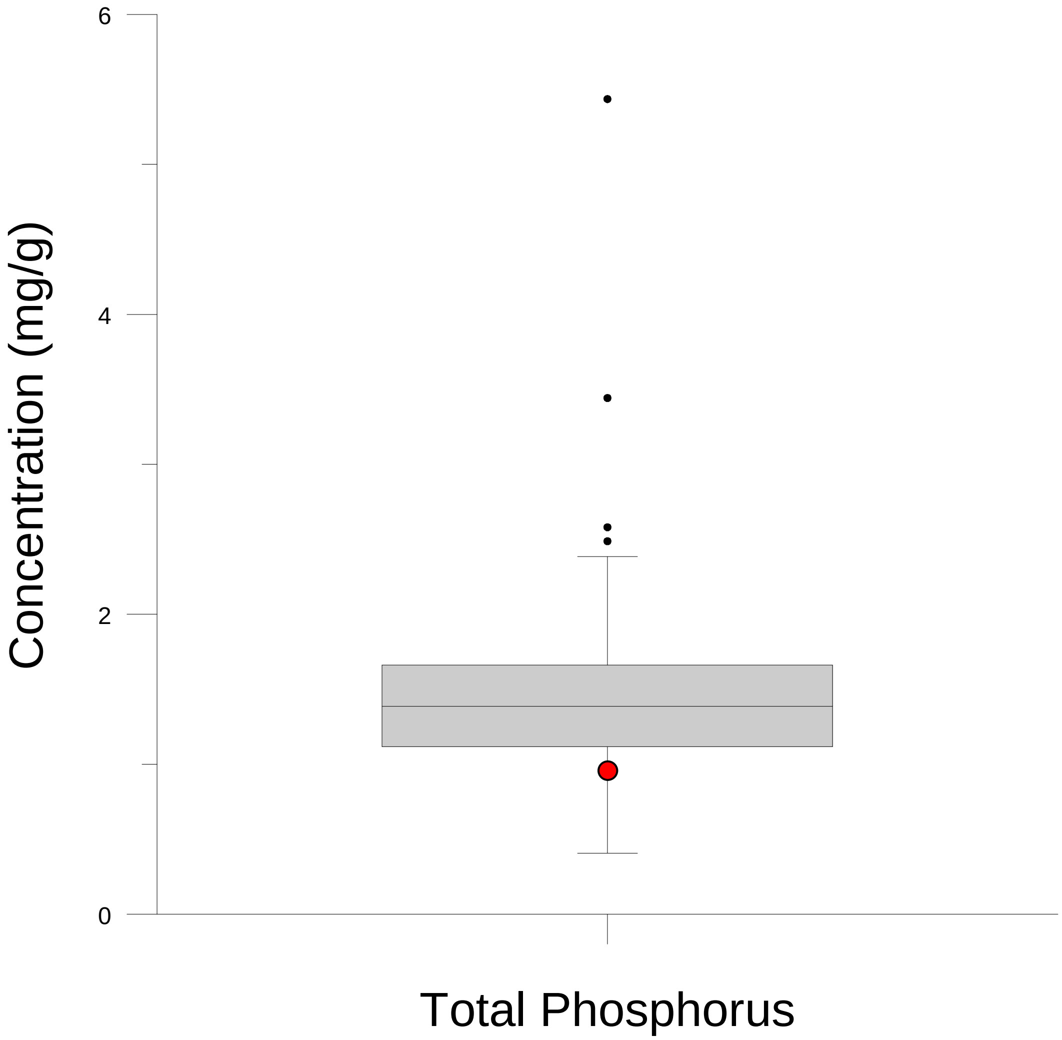

Figure 3. Box and whisker plot comparing the sediment total phosphorus (P) concentration measured for Pearl Lake sediment with statistical ranges (n = 50) for lakes in Minnesota.

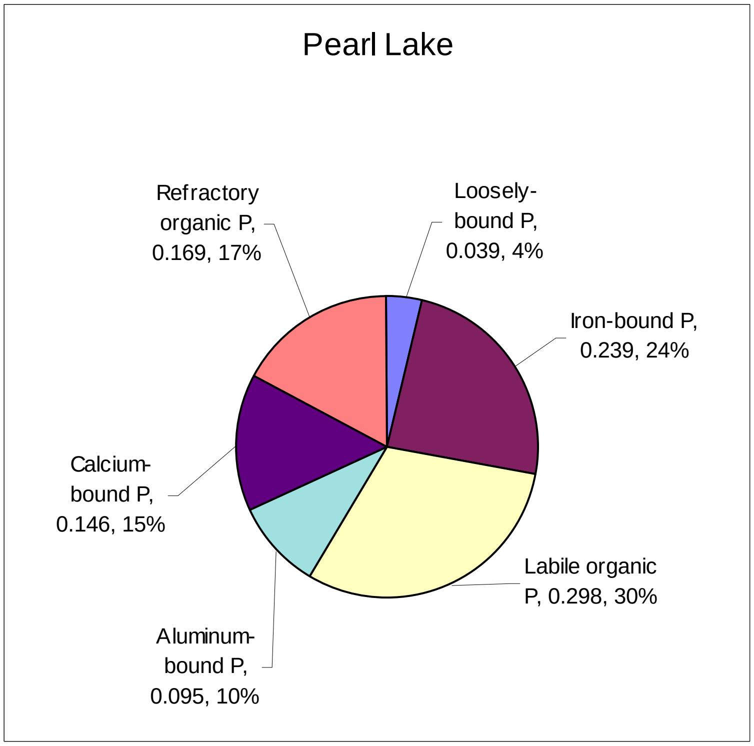

Figure 4. Percent composition of various phosphorus (P) fractions. Numbers below each P fraction label denote the concentration (mg/g dry mass) and percentage of the sediment total P concentration, respectively.

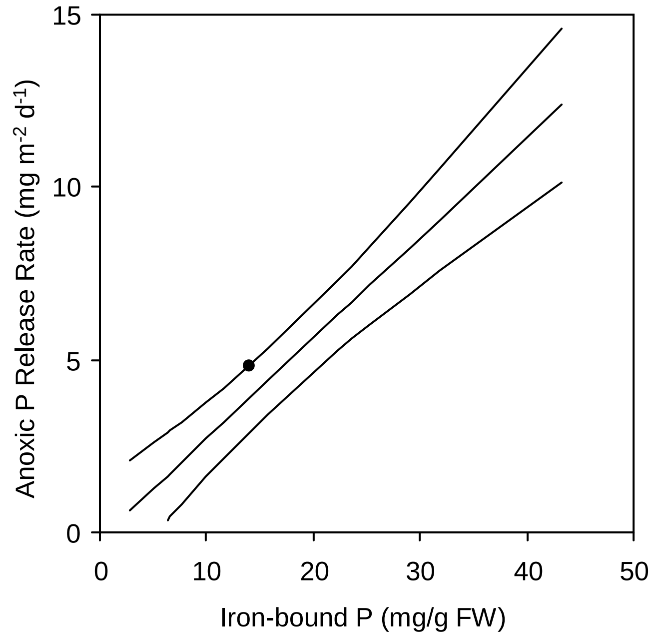

Figure 5. Relationships between iron-bound phosphorus (P; mg g^{-1} fresh sediment mass) and rates of P release from sediments under anoxic conditions. Regression line and 95% confidence intervals are from Nürnberg (1988.)Black circle represents Pearl Lake.

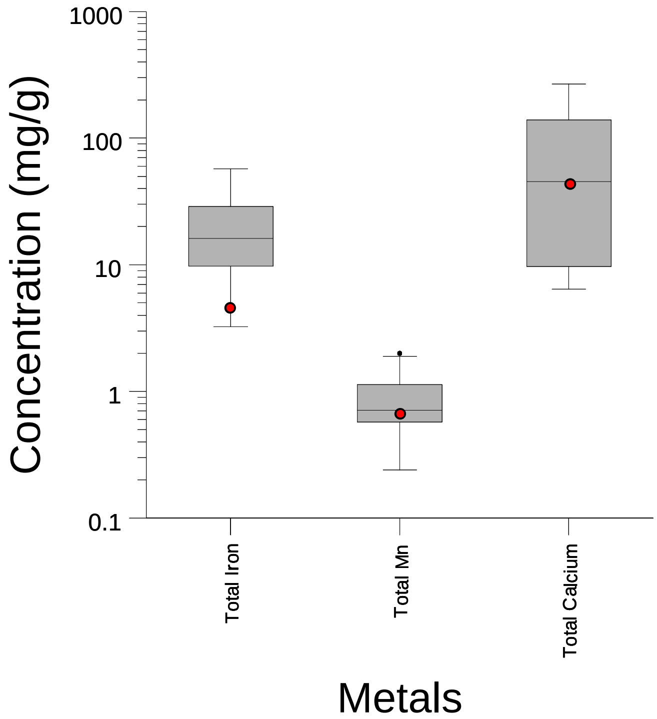

Figure 6. Box and whisker plots comparing various metal concentrations measured for Pearl Lake sediments (red circles) with statistical ranges (n=50) for lakes in the State of Minnesota. Please note the logarithmic scale.