

THE ROLE OF SURFACE SEDIMENTS IN  
PHOSPHORUS IMMOBILIZATION

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ABSTRACT

Surface sediments of Lake George, New York exhibit high microbial productivity and phosphorus retentive characteristics. Retention of nutrients (Nitrogen or Phosphorus) within the microbiota and its associated organic matter may aid in the role of oxidized surface sediments as a sink for nutrients within an oligotrophic lake. Sediment incubations and nutrient ratio analysis suggests competition for phosphorus between the benthic and pelagic environments.

INTRODUCTION

The understanding of the role of sediments in lake phosphorus dynamics is necessary to comprehend the functioning of lake systems. Traditionally, aerobic oligotrophic lake sediments have been considered a sink while anaerobic sediments in eutrophic lakes have been regarded a source for nutrients to the water column (Lee, 1970; Mortimer, 1971). Mortimer developed the concept of the oxidized microzone to account for these differences where ferric iron sequestered phosphate in an oxidized microzone at the sediment surface in an oligotrophic lake. Increased decomposition rates in deep waters of eutrophic lakes during the productive summer season causes anoxia that destroys the oxidized microzone and reduces iron to the ferrous form. This results in the release of phosphate that was formerly immobilized as ferric phosphate in the sediments. We have examined biological activity and organic matter sequestering of inorganic phosphorus in oligotrophic Lake George to illustrate the importance of these factors in the role of sediments as a sink for phosphorus (Gallepp, 1979).

## MATERIALS AND METHODS

Our quantification of microbial activity in Lake George environments (Table 1 and 2) utilized a modification of the Wright and Hobbie (1965) heterotrophic potential method for the water column (Clesceri and Garber, 1973) and sedimentary (Clesceri and Dazé, 1975) microflora. Nutrient chemistry on Millipore filtered (0.45 $\mu$ m) HgCl<sub>2</sub> preserved samples employed the autoanalyzer and the ascorbic acid method for phosphate; phenate method for ammonium and cadmium reduction method for nitrate (APHA et. al., 1971). Unless otherwise indicated, all measurements were carried out using sediments from 9 meters in Smith Bay in the north basin of Lake George. These are sublittoral sediments with Nitella flexilis as the only macrophyte present.

Other experimental measurements (Fig. 1, Table 2) were done during July and August at 20°C (+2.0 degrees of ambient). Flocculent layer surface sediments were sampled using a horizontal Van Dorn sampler bounced off the bottom a few times to resuspend the sediments. These flocculent sediments were concentrated by gravity settling and siphoning off the supernatant. Visual observations and repeated redox measurements indicated that the flocculent layer was approximately one centimeter deep. Sampling for measurements of microbial activity on the consolidated sediment samples (Table 1) utilized an Ekman dredge. These samples did not recover an intact surface flocculent layer and took a five centimeter sediment bite (Henningson, 1974). A Kajak-Brinkhurst corer was utilized to recover an intact sediment core to perform the experiment illustrated in Fig. 1.

The phosphorus uptake potential profile (Fig. 1) was the result of the incubation of various phosphorus enriched systems containing one gram of fresh sediment or gravity concentrated flocculent layer for three days under aerobic (shaken) conditions. Uptake was determined as the difference between initial and final incubation concentration in the supernatant normalized to sediment dry weight.

<sup>32</sup>P turnover was measured according to Lean (1973). Humic substances were extracted at pH 14 under an N<sub>2</sub> atmosphere according to Khan (1969) while iron/calcium fractions were extracted using EDTA according to Viner (1977).

## RESULTS AND DISCUSSION

It is our contention that microbiological activity may aid the retention of nutrients in oxidized surface sediments by incorporation into biomass. We have quantified microbial productivity (V<sub>max</sub>)

Table 1  
Vertical Distribution of Microbial Activity as Measured by  
Glucose  $^{14}\text{C}$  Uptake in Lake George, New York

Date	$V_{\text{max}}$ ( $\mu\text{g C m}^{-2} \text{ hr}^{-1}$ )	Sample
6-12	684	Pelagic Zone (18 m avg.)
7-12	492	
8-2	1231	
8-22	884	
9-13	915	
10-4	1421	
11-7	922	
5-1	2344	Surface Sedi- ments at 9 m (1 cm)
5-26	1450	
6-11	4408	
6-23	2526	
7-13	2414	
8-17	3801	
5-25	0.426	Sediments at 9 m (top 5 cm)
6-5	0.573	
7-10	0.867	
7-24	0.936	
8-7	1.026	
8-21	0.513	

Table 2  
Heterotrophic Potential of Selected Phosphorus Enriched  
Sediment Sections

Sediment section	Phosphorus level	Specific Heterotrophic potential dpm/mg dry wt. $\pm 95\%$ CI
Flocculent layer	No phosphorus	38.8 $\pm$ 35.8
	500 ugP/l	765.2 $\pm$ 102.8
0-2.54 centimeters	No phosphorus	73.4 $\pm$ 100.0
	500 ugP/l	165.0 $\pm$ 54.6
2.54-5.0 centimeters	No phosphorus	361.2 $\pm$ 32.4
	500 ugP/l	267.8 $\pm$ 32.4
5.0-7.5 centimeters	No phosphorus	3.0 $\pm$ 28.6
	500 ugP/l	62.8 $\pm$ 31.0

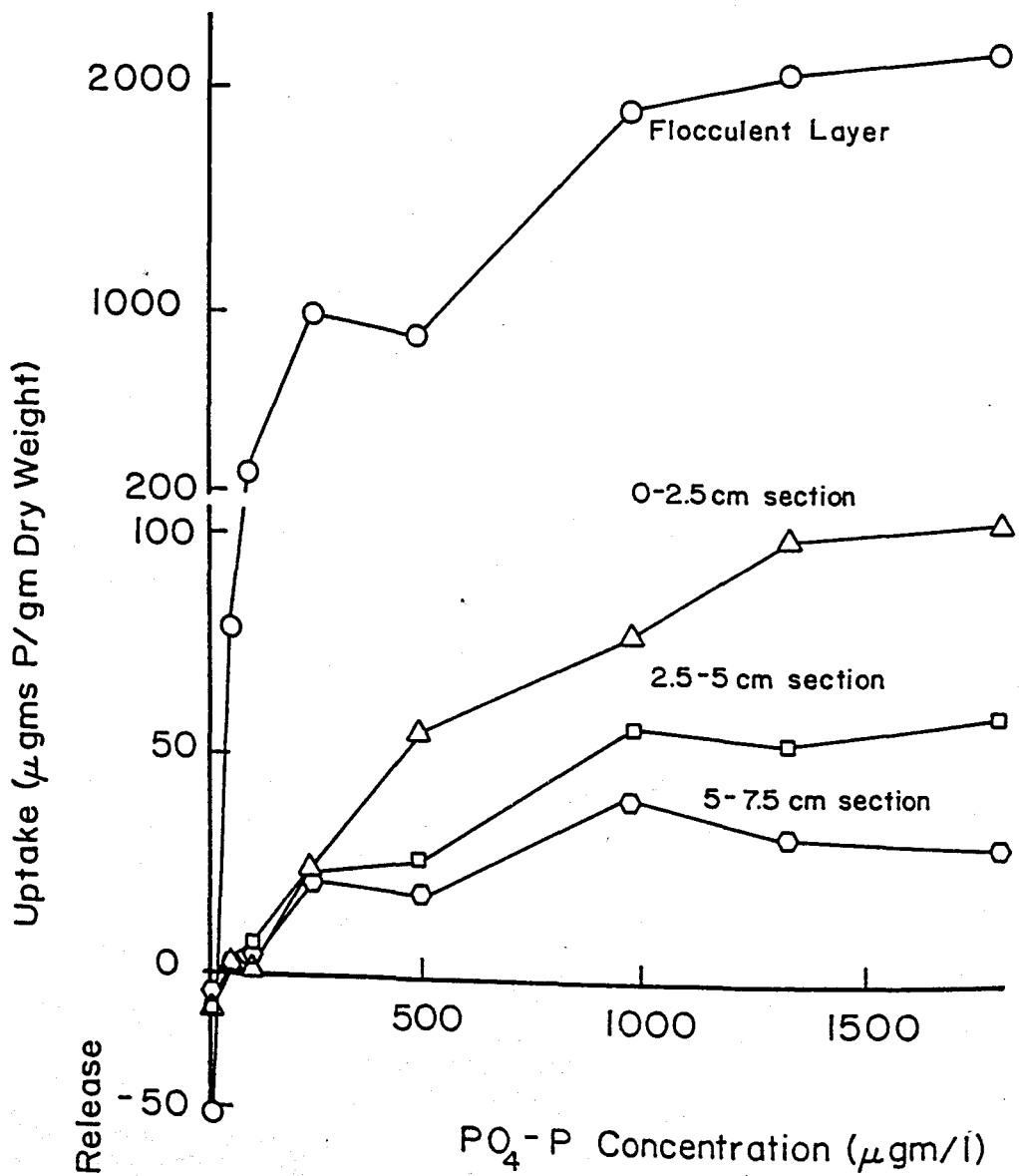


Figure 1. Uptake (or release) of phosphorus ( $\mu\text{g P/gm dry weight}$ ) as a function of P concentration in sublittoral (9 m depth) Lake George sediment layers.

in various compartments of soft water oligotrophic Lake George (Clesceri and Dazé, 1973; Clesceri and Garber, 1973). Results of these measurements are listed in Table 1. One centimeter of surface sediment is approximately two times more productive than eighteen meters of water column and four orders of magnitude more productive than the deep (5 cm) sediments. The surface sediments are therefore the major site of microbial metabolism within Lake George during the summer growing season.

Recent developments in the study of detritus decomposition have shown that sedimented organic matter is often of poor nutritional quality. As a consequence of this fact, detritus decomposers may be nutrient limited (Fenchel and Harrison, 1976). Nutrient requirements of surface sediment decomposers can be satisfied in two ways; diffusion from lower sediments or sedimentation from the overlying water column. The most abundant reservoir of nutrients is the pore water of the sediments that are often ten to one hundred times more concentrated in inorganic nitrogen and phosphorus than the overlying waters (Doremus, 1978). Our results suggest that the highly productive microbiota observed in Lake George surface sediments may therefore help retain nutrients within the sediment system by incorporation into biomass. This high productivity may be enhanced by grazing on the microflora as shown by Barsdate et al. (1974) and Fenchel (1977) who observed that microbial grazers increase nutrient turnover in sediment systems.

Measurements of the nutrient uptake potential of Lake George sediments indicated that surface sediments exhibited greater phosphorus retention capability than the lower sediments (Fig. 1). Release at very low concentrations probably was a function of the large concentration gradient between sediments and the liquid phase that affects adsorption equilibria. This is because the phosphate-distilled water experimental solution lacked other ions found in pore waters that would naturally contribute to an adsorption equilibrium between the sediment and pore water. However, this would not affect the comparison of relative phosphorus retention characteristics among the sediment layers. Simultaneous measurements of microbial activity were made with phosphorus additions to 500  $\mu\text{g P/l}$  and with no additional phosphorus for the sediment sections previously shown in Fig. 1 (Table 2). Microbial activity in the flocculent layer was twenty times higher than in the controls. Lower sediments exhibited no significant phosphorus stimulation. Other experiments showed similar stimulation of surface sediment microbial activity measured by oxygen uptake or glucose  $^{14}\text{C}$  incorporation with interstitial water or single nutrient species (Doremus, 1978).

Both biotic and abiotic processes are involved in the retention of nutrients in surface sediments. An analysis of  $^{32}\text{PO}_4$  uptake in surface sediments in antibiotically sterilized (cycloheximide and chloramphenicol) and unsterilized systems showed that phosphorus turnover was 2 1/2 times greater in the biotic (26.4 min) versus the abiotic (66.4 min) system.

Organic matter in surface sediments (25-35% by weight in Lake George) also provides sites for phosphorus immobilization. We have measured  $^{32}\text{PO}_4$  uptake by Lake George sediments and found that four times more phosphorus is sequestered in the humic fraction (25518 dpm/mg dry weight  $\pm$  6278 at 95% statistical confidence) when compared to an iron/calcium fraction (6355 dpm/mg dry weight  $\pm$  1138).

The retentive nature of a particular nutrient species depends on whether it is in limiting quantities. For instance, we have enclosed sediments in dialysis bags and have shown that phosphorus tends to remain constant or accumulate slightly while nitrogen is released from the sediments during a 70 day incubation period in situ. The high retentive capacity of Lake George sediments for phosphorus compared to nitrogen is also reflected in the low nitrogen to phosphorus atomic ratios measured in the sediments (3-16:1). Alternatively, the inorganic N:P atomic ratio in overlying waters in intimate contact with lake sediments is high (34-60:1), because phosphorus is retained preferentially within the sediments. If the demand for nitrogen and phosphorus by phytoplankton is in approximate Redfield (1958) ratio proportions (16:1), benthic remineralization is providing excess nitrogen to the pelagic community. This phenomenon may contribute to the phosphorus limited condition that is often found in lake phytoplankton.

Our results suggest that microbial activity and organic matter aid in the immobilization of phosphorus empirically observed in surface sediments. In theory and practice, it is hard to separate bacteria from the non-living organic detritus as the high turnover of bacteria causes rapid cycling of carbon between the living and dead components of the biodetritus. Similarly, the compartmentalization of phosphorus between the microbial and non-living organic matter is short lived due to its rapid turnover. As our humic substance data suggests, non-living detritus acts as a sorptive site for inorganic phosphorus in addition to a transitory compartment for organic phosphorus.

Our contention that phosphorus is retained by the biodetritus of the flocculent layer ignores the effect of metazoans that utilize the detritus as a food source. Detritivores influence sediment-water exchanges by excretion and burrow irrigation. It

has been recently demonstrated that most of the sediment-water flux observed in intact cores can be accounted for by macroinvertebrate activities (Gallepp, 1979; Holdren and Armstrong, 1980). The detritivores can therefore be thought of as a short circuiting agent for phosphorus trapped in the microbial-detrital complex.

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