Report as of FY2006 for 2006GA110B: "Characterizing Nutrient Releases from Southeastern Piedmont Lake Sediments"

Publications

Project 2006GA110B has resulted in no reported publications as of FY2006.

Report Follows

Final Technical Report – GA2006110B

Internal Loading of Phosphorus in Lake Allatoona

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Date: February 28, 2007

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Acknowledgements

This project was supported by a grant from the Georgia Water Resources Institute at the Georgia Institute of Technology, 06HQGR0080, subagreement R7113-G2, project GA2006110B.

Elena L. Ceballos developed and completed most of the laboratory research tasks for this project under my direction. Several people generously contributed their time, ideas, laboratory space and equipment to this project. For this I am indebted to Professor William Miller of Crop and Soil Sciences, Professor Marshall Darley of Plant Biology, Professor Brian Binder and PhD-candidate Christopher Burbage of Marine Sciences, Professor Jeffrey Dean, researchers Paul Montello and Gisele Dean, and Professor Scott Merkle of the Warnell School of Forestry and Natural Resources at the University of Georgia.

Project Type

Deposition of sediments in lakes is an ongoing, storm- and disturbance-driven process, which is exacerbated by increasing watershed urbanization. The internal loading, or recycling, of nutrients in lake sediments is known to be significant, and increases as the lake matures. (Lake maturity refers to the length of time since the lake was constructed or formed by natural processes.) In many cases, internal loading is initially low and there is net accumulation of nutrients in benthic sediment. Over time, however, the deposition of nutrients reaches equilibrium with releases, and continued sequestration of lake sediments is not seen. In addition, if external loading of nutrients is reduced, then releases from lake sediments continues, and thus can cause long-term eutrophication in the absence of external loading.

Current state regulatory programs focus on reducing and minimizing watershed loading to reduce or prevent lake eutrophication in Georgia. While it is clearly important to reduce external nutrient loading to lakes, it is equally important to understand and characterize the release and recycling of sediments within lakes. This project is a pilot laboratory study designed to quantify the effects of internal loading, such as algal blooms, anoxic conditions and alkaline pH, in response in a southeastern Piedmont impoundment.

Background

Cultural eutrophication (CE) of lakes is the accelerated nutrient enrichment resulting in detrimental ecological effects such as algal blooms, lake anoxia and toxic metal release from sediments (Fang et al., 2005). CE is a common occurrence in Piedmont impoundments in Georgia, as well as lakes and impoundments throughout the world. It often results in water unsafe for agricultural use, recreation and drinking.

To reduce CE of local Piedmont impoundments, recent regulatory controls for nutrients were established as part of the Clean Lakes program and court-ordered total maximum daily loads (TMDLs). These regulatory efforts focus on the reduction and minimization of point-source watershed nutrient inputs, primarily phosphorus, into lake systems, as P is the limiting nutrient in Piedmont impoundments. Thus, reductions in phosphorus loading are expected to improve lake water quality.

However, in the Piedmont, as well as worldwide, many lakes continue to experience algal blooms and lake anoxia after sources of external loading are discontinued. The process of nutrient desorption from sediments, known as internal loading, has been identified to be a source of algal-available P, as well as other nutrients. The conditions under which internal loading takes place are region-specific as they vary based on local physical, chemical and biological conditions.

The purpose of our research is to quantify changes in algal biomass in response to internal loading in Southeast Piedmont impoundments. We propose a series of mesocosm experiments and batch tests to quantify internal loading of P and increases in algal biomass due to two mechanisms of internal loading (mixing, alkaline pH) in SE Piedmont impoundments. We will use these findings, along with estimates of external loading, field physico-chemical data and sediment characterization data, to evaluate potential appropriate remediation strategies to minimize detrimental algal blooms in SE Piedmont impoundments.

Project Scope and Introduction

Regional reservoirs within the Piedmont region of the southeastern U.S. are used to meet municipal and industrial water supply, wastewater dilution, recreation, and hydroelectric power generation needs of nearby communities. Poor water quality conditions caused by lake eutrophication adversely affect the use of reservoir waters to meet these needs. In addition, poor water quality also adversely affects native and introduced aquatic species by reducing their ability to forage, reproduce, and respire.

Lake Allatoona is a U.S. Army Corps of Engineers reservoir located in northwest Georgia. The impoundment was constructed in January 1950 for uses including flood control, hydropower generation, water supply, recreation, fish and wildlife management, water quality, and navigation. The surface area of the reservoir, when full, covers approximately 12,010 acres, the maximum depth at the dam is 145 feet, and the storage volume is approximately 367,500 acre-feet. The watershed area upstream of the dam is 1110 mi^2 and contains one large tributary (the Etowah River), and several smaller tributaries (the Little River, Noonday Creek, and Allatoona Creek).

Lake Allatoona, like many of Georgia's reservoirs, experience seasonal algal blooms. These blooms are typically during the warm season (June through September) and are attributed to increased eutrophication from nutrient enrichment, primarily phosphorus (P), as P is the limiting nutrient in Southeastern Piedmont impoundments (Raschke, 1994). Causes of eutrophication for Lake Allatoona include phosphorus loads from watershed sources, including point and nonpoint sources. Point loads generally consist of soluble nutrients, while nonpoint loads consist of both soluble and particulate sources. Soluble loads are likely to become sorbed to suspended and bed sediments, as well as lost via biological uptake, while in transit to the lake.

In response to concerns about lake eutrophication, nutrient limits have been established for Lake Allatoona tributaries. Total maximum daily loads (TMDLs) are required by a federally mandated program, which sets pollution limits for degraded waters. For Lake Allatoona, TMDLs have been

established for chlorophyll *a* within the Little River Embayment. Waste load allocations (WLAs) have also been established for total phosphorus for the embayment.

Suspended and bed sediments from influent tributaries accumulate in the upper reaches of the reservoir, primarily in the upper northeastern part of the lake near the Etowah and Little River inlets, forming depositional features including deltas and levees. These areas receive substantial inputs of sediments and nutrients from point and nonpoint sources. In addition, legacy sediments from historic sources have accumulated, providing long-term sources of sediment-related nutrients. These sediments may contribute to lake eutrophication by release of sediment nutrients.

Dredging of nutrient-rich lake sediments has been proposed as a management tool for reducing within-lake nutrients. Small-scale dredging in Lake Allatoona has been conducted primarily for increasing navigability of the lake. Blankenship Sand operates dredges to remove sediment (primarily sand) from North Georgia lakes and rivers, including Lake Allatoona and its tributaries. Sediment dredging involves a mobile, floating, diesel-powered suction dredge with a cutting head. Dredged materials are transported either to the shore or to a waiting clamshell barge that carries the sediments to an in-lake holding area that is re-dredged to the shoreline.

Dredged materials are separated into four parts, i) a rubble fraction containing trash, large woody materials and stones, ii) a sand fraction that is accumulated in sand piles, and then loaded into road transport vehicles using front-end loaders, iii) a tailings material composed of settleable solids (fine sands, silts and clays) that accumulate in holding (sedimentation) ponds, and iv) a tailwater containing some of the clay fraction that is returned to the lake.

An important question is whether this dredging affects lake water quality. The dredging of sediments may reduce internal loading by removing internal sources of lake nutrients. While dredging may remove sand-sized particles from sediments, it may also result in the resuspension of clay and silt-sized particles during initial dredging, with subsequent return of suspended solids to the lake. If desorption of P from these finer materials occurs, then this action may degrade water quality. Yet, it is also possible that these finer materials may remove P from the water

column by sorption and subsequent sedimentation. Removing within-lake sediments may benefit lake water quality by reducing the potential release of nutrients and toxic metals from these sediments.

Stakeholders would like to develop a program that would provide financial incentives for removal of lake phosphorus. Therefore, data documenting sediment phosphorus content is needed. Yet, not all phosphorus in sediments contributes to eutrophication and its resulting negative affects. If a phosphorus trading policy is to be implemented to improve lake water quality, a method of determining algal-available benthic sediment phosphorus is needed.

Research Objectives

This project examines the possible benefits of removing benthic lake sediments on lake water quality. The key concerns are the total amount of P and the potentially algal-available P in lake sediments. There were several goals for this study:

(1) The first goal was to assess Lake Allatoona sediment composition and water quality. This was achieved by field data collection and sediment and water analyses.

(2) The second goal was to evaluate whether sediment removal by dredging would reduce algal biomass. This was achieved by a laboratory mesocosm study of sediment resuspension.

(3) The final goal was to assess the amount of algal-available P in lake sediments. A laboratory algal assay in which algae were grown in flasks with sediment as the sole source of P is currently being conducted to meet this goal.

Field data collection and laboratory experiments were conducted to achieve the following specific objectives:

(4) Gain a general understanding of Lake Allatoona sediment composition, especially with regards to differences based on sediment particle size

(5) Assess changes in water quality and algal biomass that may be caused by current dredging methods, including sediment resuspension and sediment removal

(6) Determine if there is a correlation between the results of chemical extraction of P in sediments and algal-available P as determined by algal assay

(7) Make recommendations for future studies to assess potentially algal available phosphorus in sediments of Lake Allatoona

This study focuses on quantifying phosphorus in Lake Allatoona nutrient cycling. Of specific concern is how the cycling of nutrients is affected by lake dredging. Laboratory mesocosm and batch experiments were performed to quantify changes in water quality and algal biomass in response to current dredging methods.

Materials and Methods

This study focuses on how internal loading is affected by lake dredging.

Mesocosm Experiment

Six clear acrylic columns were used to investigate the interaction between sediment and lake productivity. The columns were 122 cm high by 26.7 cm in diameter. The bottom ends were sealed using a PVC cap with an embedded o-ring to prevent leakage.

Sediment collected from Noonday Creek embayment was used for these column experiments. A slurry of approximately 20 L of sediment and 40 L of water was created using a blunger (mixing tool) in a 75 L container. Equal amounts of the slurry were transferred to four of the six columns. All columns were filled to a total height of 111 cm with water collected from Lake Herrick, a local impoundment on the University of Georgia campus. A single control column was filled with lake water to a total height of 111 cm. The columns were allowed to reach equilibrium over a period of eight weeks. After settling, the sediment depth was approximately 21 cm in experimental columns.

The columns were maintained in a 12:12 light:dark cycle illuminated by GE wide-spectrum plant and aquarium fluorescent grow lamps. After four weeks the fluorescent lamps were replaced with three GE R400 Multi-vapor lamps such that two columns shared a single light source. A small water pump was placed approximately 25 cm below the surface in each column to circulate water at a rate of approximately 1.5 L per minute. Lake water was added as needed to compensate for evaporative loss.

Three columns were mixed with a blunger: two containing sediment and the control without sediment. The two experimental columns containing sediment were mixed until they held 20-22 g/L suspended solids as read by an ASTM soil hydrometer. Two columns containing sediments were left undisturbed. Temperature, specific conductance (SC), pH, and dissolved oxygen (DO) were measured using a Hydrolab Quanta. Soluble reactive phosphorus (SRP) was measured on

0.22 um filtered water by a colorimeter, turbidity by a turbidimeter, and chlorophyll a (Chl *a*) using a fluorometer. All were measured daily between 5 and 8pm for 14 days.

Batch Experiments

The purpose of batch experiments is to quantify potentially algal-available phosphorus (PAAP) in Lake Allatoona sediment, and to compare these results with the results of chemical extractions in effort to find a correlation between chemical extraction and algal assay. Also of interest is whether greater turbidities support higher algal biomass than lower turbidities.

Collection of sediments

Sediments used for particle-size distribution, sorption isotherm, desorption studies and algal assay were collected from approximately 0.5-m below the sediment surface in the Noonday Creek Embayment. Sediments were air-dried at room temperature and sieved through a 2mm (10 mesh). Particle size distribution was determined by micropipette method (Miller and Miller 1987).

PO_4^{3-} Sorption Isotherm

To quantify the maximum sorption capacity of sediments used for algal assay, a sorption isotherm was performed by adding 50mL 0, 2.5, 5, 10, 15, 20, 30, 40 50 and 60 mg/L PO_4^{3-} solution to 0.5 g sediment. Samples were incubated at 21°C in a 40rpm end-over-end shaker for 12 hours and centrifuged at 3700rpm for 10 minutes. 20mL of supernatant was filtered through 0.22µm filters, and the samples diluted to approximately 0.01-0.5 mg/L concentration. The SRP concentrations of the diluted samples were measured using the ascorbic acid method (Eaton et al., 2005) and read by spectrophotometer.

Sediment desorption with iron-impregnated filter papers

Plant available phosphorus was measured by extraction with iron-impregnated filter papers (Sparks, 1996).

Sediment desorption into 1-mM $CaCl_2$

Three replicates each of 2, 4, 8 and 16 g air-dried sediment in 45 mL 1-mM $CaCl_2$ solution and three replicates of 24g air-dried sediment in 40 mL 1-mM $CaCl_2$ solution in 50-mL centrifuge tubes were mixed by end-over-end shaker for 24 hours. Samples were centrifuged for 15 minutes at 1500rpm and filtered through 0.45µm syringe filters. The orthophosphate concentrations in the supernatant were measured using the ascorbic acid method (Eaton et al., 2005).

Algal Assays

Media

Two media were evaluated for the P:biomass curve and sediment algal assay. They differ mainly in the concentration of macronutrients. Both media, Bold's Basal Medium (BBM) and Synthetic Algal Nutrient Medium (SANM a.k.a. NAAM) (Miller, 1978) are broad range growth media for algae. When tested in initial P:biomass curves, SANM severely limited biomass of the *S. capricornutum*. BBM was chosen for algal assays because it supports rapid growth of *S. capricornutum*.

When grown in P-free BBM, this alga was determined to be P-limited. To establish that nitrogen was not limiting in P-free BBM, 6 replicates were grown in P-free BBM with the standard concentration of $NaNO_3$ in BBM (2.94mM) and 6 replicates were grown in twice the standard of $NaNO_3$ in BBM (5.88 mM).

P – biomass curve

A biomass curve was made to compare algal densities with varying concentrations of PO_4^{3-}. 77µL P-starved *S. capricornutum* (3,872,000 +/- 5% cells/mL as measured by improved Neubauer hemacytometer; 11.0 raw units fluorescence to make an initial concentration of approximately 3000 cells/mL) was used to inoculate four replicates each of modified BBM with 0, 10, 25, 50 and 100 µmol P. Autoclaved #6 foam stoppers were used to limit contamination while allowing gas exchange.

Samples were incubated on an orbital shaker at 100rpm under continuous illumination by six Philips F40T12/DX Alto 40 W fluorescent lamps until cells reached a stationary growth phase (<10% increase in density over 24 hours).

Fluorescence/ cell concentration curve

A standard curve of cell concentration to fluorescence was made by serial dilution and enumeration of samples by improved Neubauer hemacytometer. These results were used to estimate the concentration of *S. capricornutum* in algal assays.

On-going Research: Sediment P Algal Assay

Much of the P in sediments is not algal-available, and therefore does not contribute to algal blooms or lake anoxia. For this reason an experimental assay used to measure potentially algal available phosphorus (PAAP) of whole sediments was developed. By establishing a standard protocol PAAP from northeastern Lake Allatoona sediments could be compared to PAAP within and among lakes.

The initial assay was developed to test for PAAP under conditions of neutral pH and high redox potential. Our goal is to refine the assay to quantify PAAP under conditions of varying pH and redox potentials, as both conditions affect internal loading of P and are seen in Lake Allatoona from late summer to early Fall.

The algal assay method developed is loosely based on the Algal Assay Bottle Test (AABT), which was developed by the U.S. Environmental Protection Agency (Miller, 1978). Our method deviates from the AABT in the following:

(1) The AABT suggests an initial inoculum of 1000 cells/mL. Our method will use an initial inoculum of 3000 cells/mL as recommended by Schultz et al. (1994). The higher initial concentration results in more rapid increases in biomass, hence more rapid results.

(2) The standard AABT method counted cells using an electronic particle counter, and converted these data to maximum standing crop as dry weight. Our method includes Chl *a* extraction to quantify biomass.

Sand, silt and floating organic matter will be removed from sediment used in this assay because, in lentic systems, these portions of the sediment would settle out of the photic zone quickly, and therefore contribute little P to algal biomass.

Sediments used in this algal assay will not be sterilized because (1) sterilization would change sediment physical and chemical properties, and (2) microbes play a key role in altering non-algal available forms of nutrients to algal-available forms, and (3) lysing of cells would result in the release of cell content nutrients.

Procedure

Sediment clay-sized particles (<2µm) were extracted by mixing of 25g air-dried sediment from Lake Allatoona with 1 liter deionized water for 24 hours in an end-over-end shaker, and removal of supernatant after 24 hours settling time. One liter each of approximately 0, 50, 175 and 350 NTU was made from dilutions of the sediment supernatant. Enough silicate was added to each liter to raise the turbidity of each to approximately 400 NTU. Concentrated phosphorus-free BBM was then added to each liter to reach standard nutrient concentrations. Because light-limited algae contain more Chl *a* per cell than non-limited algae, silicate was added in order to minimize the effect of varying turbidities.

Triplicates of 100-mL each turbidity in P-free BBM will be placed in 250-mL Erlenmeyer flasks. Each flask will be inoculated with enough *S. capricornutum* to create a starting cell concentration of 3000 cells/mL. Samples will be incubated on an orbital shaker at 100 rpm under constant illumination by Philips F40T12/DX Alto 40-W fluorescent lamps. When cell density reaches a stationary growth phase (<10% increase in density over 24 hours), Chl *a* will be measured using standard methods from Eaton (2005).

To measure Chl *a* in sediments, control triplicates of each turbidity will be incubated without algal inoculum. The mean of these results will be subtracted from measurements of Chl *a* in experimental samples in effort to isolate biomass increase due to internal loading.

Facilities Used

Mesocosm studies were conducted in the Hydrology laboratory in Warnell School of Forestry and Natural Resources. Samples were analyzed in the Hydrology Lab, in the Analytical Chemistry Laboratory in the Institute of Ecology at UGA, the Soil Chemistry Laboratory in the department of Crop and Soil Sciences at UGA.

Algal assays were performed in Dr. William Miller's laboratory in the department of Crop and Soil Sciences at UGA and in Dr. Marshall Darley's laboratory in the department of Plant Biology at UGA. Some preliminary experiments not reported here were conducted in Dr. Brian Binder's laboratory in the department of Marine Sciences at UGA.

Results

Mesocosm experiment

SR in experimental columns resulted in an immediate drop in pH and dissolved oxygen (DO), followed by a rise in both.

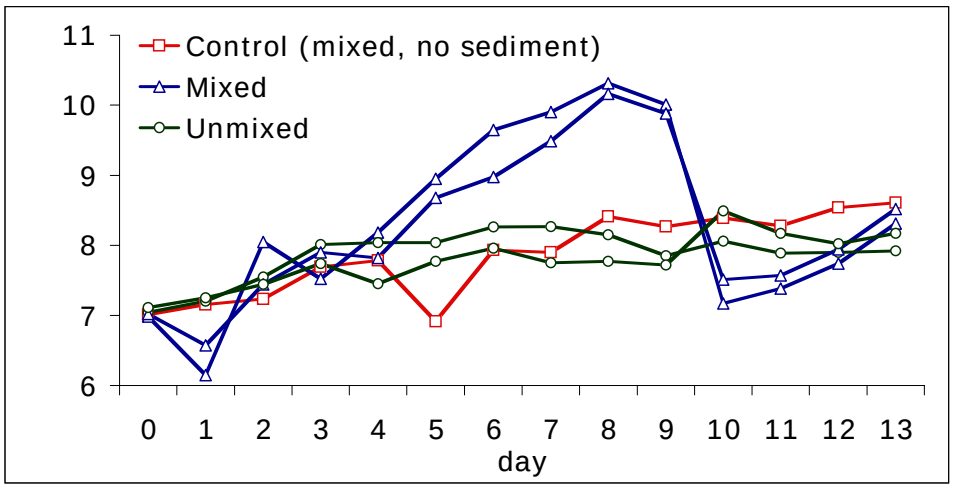

Figure 1. pH as measured at the surface of mesocosms after sediment resuspension.

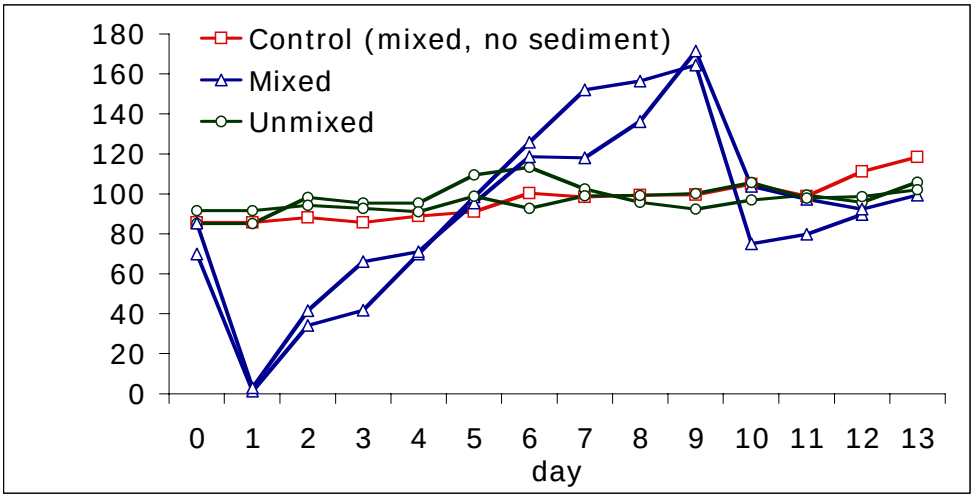

Figure 2. Dissolved O_2 as measured at the surface of mesocosms after sediment resuspension.

pH remained between 8.7 and 10.3, and DO remained between 120% and 170% saturation from 5 to 10 days after mixing (Figs. 1-2). Planktonic Chl *a* increased to peak concentration 7-9 days after mixing (Fig. 3), while periphyton biomass increased throughout the experiment.

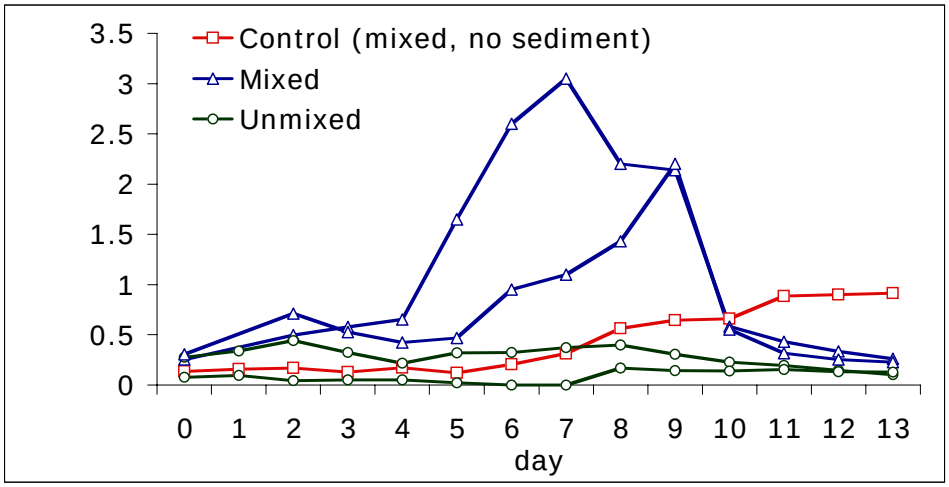

Figure 3. Chlorophyll *a* as measured at the surface of mesocosms after sediment resuspension.

Control columns showed no similar rise or fall in Chl *a*, pH or DO.

The filamentous green alga *Oedogonium* (Chlorophyta) dominated the algal community in all columns. Long filaments of this alga attached to the walls of all columns. By the end of the experiment (day 13) the filaments were shortest, approximately 2 cm, in the column without sediment. The filaments in the unmixed columns containing sediment were approximately 6 cm. The filaments in the mixed column were long enough so that they stretched from the walls of the columns into the center where they wrapped around filaments attached at the opposite wall (>13 cm). The predominance of *Oedogonium* was likely due to the high surface area:volume ratio in the columns giving the alga much more area for attachment than would exist in a lake.

The fluorometric measurement of Chl *a* in the mixed mesocosms was affected by high concentrations of suspended sediment blocking both excitation and emission wavelengths. Therefore, Chl *a* concentration from the mixed columns were likely higher than recorded.

Batch Experiments

Sediment desorption into 1-mM $CaCl_2$

All concentrations were below detection limits (read "0" absorbance).

PO_4^{3-} Sorption isotherm

Maximum orthophosphate sorption capacity was approximately 1200mg PO_4^{3-}-P/kg sediment (Figure 4).

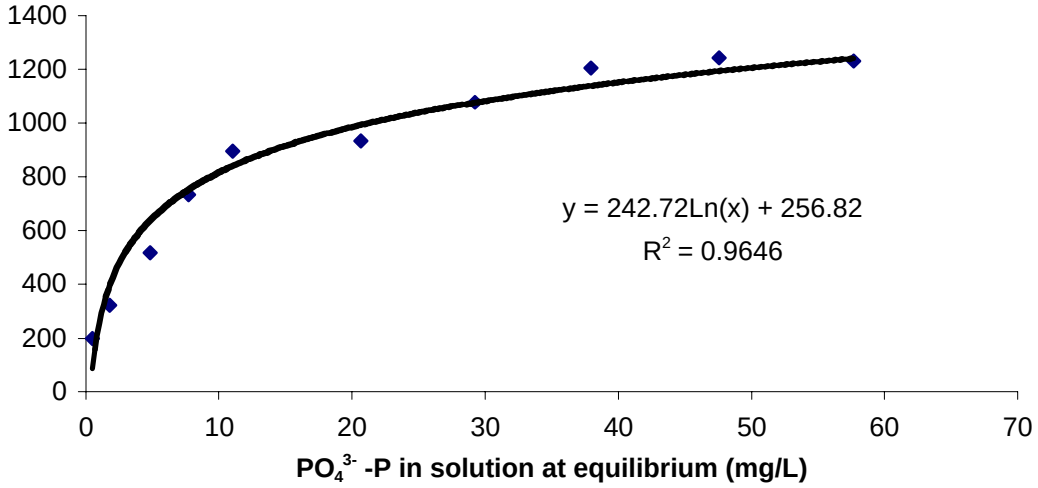

Figure 4. Results of sorption isotherm conducted at 22ºC.

Table 1. Results of particle size distribution analysis.

	% sand	% silt	% clay
sediment	38.5	59.0	2.5
silica	10.8	88.2	1.0

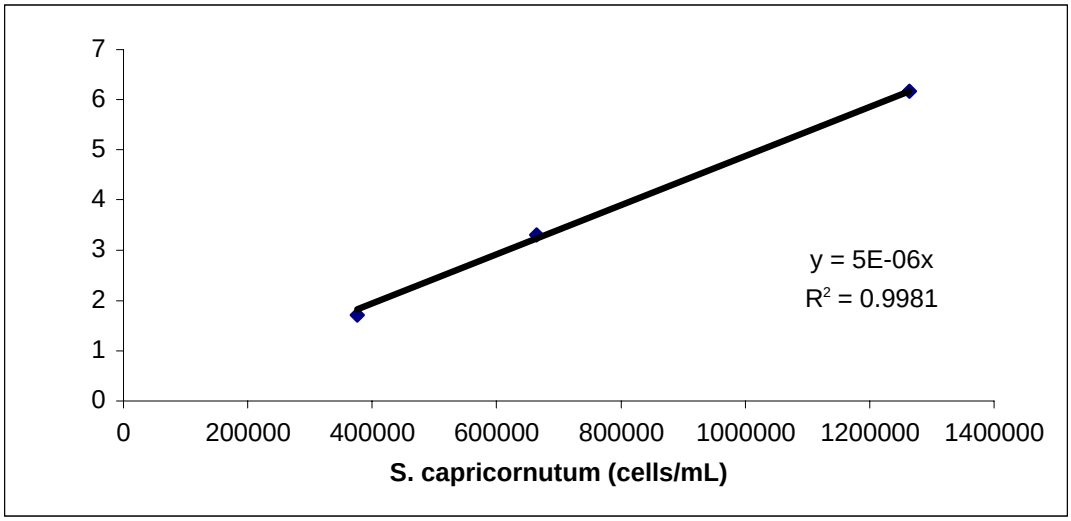

Figure 5. Fluorescence/ cell concentration curve used to estimate cell concentration.

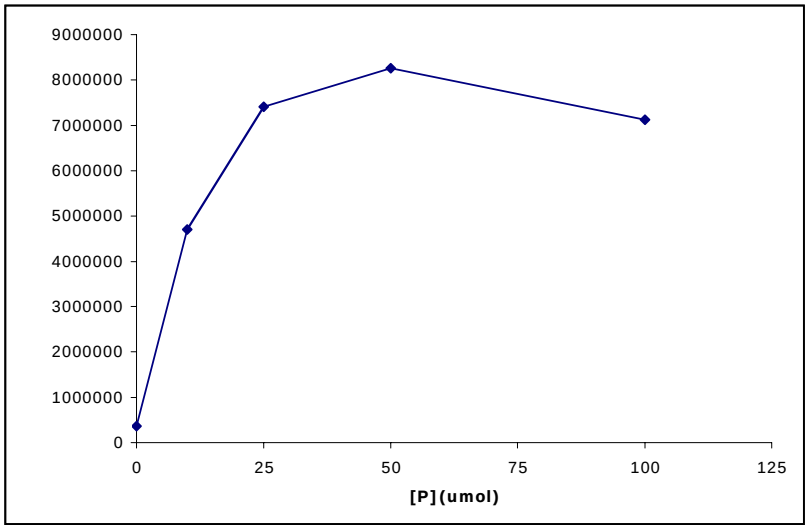

Figure 6. PO_4^{3-} / *S. capricornutum* biomass curve.

Discussion and Conclusions

Mesocosms

In this experiment, dredged and non-dredged conditions were compared using mesocosms placed in ambient conditions that simulate the natural setting. Changes in environmental conditions, including DO, pH, and Chl *a* were used to evaluate the effects of benthic sediment removal on the overlying water quality.

The immediate fall in pH and dissolved oxygen (DO) of the experimental sediment-mixed mesocosms after mixing was likely due to the integration of reduced anoxic, acidic sediments with the overlying water. The subsequent rise of pH and DO observed would then be due to gradual resettling of suspended particles and associated microbial biomass. The rise in *Chl a*, pH and DO could be due to the release of P from suspended particles promoting algal growth.

A second hypothesis that could account for the increase in *Chl a*, DO and pH in the mixed columns is the reseeding of the euphotic zone with algal spores released from sediments. In this scenario any P release from resuspended sediments may or may not contribute to the increase in photosynthetic biomass.

A hypothesis that could account for the increase in *Chl a* is that light-limited algae produce more *Chl a* per cell than non-light limited algae. While this effect may account for increase in *Chl a*, it would not contribute to the rise in pH or DO. Again, the rise and pH and DO were most likely due to increase in primary productivity. pH has been successfully used to estimate algal biomass (Miller et al., 1978; Lopez-Archilla et al., 2003) due to the rise in pH under high rates of photosynthesis removing carbonates.

While it has already been established that P limits algal biomass in Lake Allatoona, the fact that a non-diazotrophic (not able to fix N) alga dominated all mesocosms supports the theory that P was also the limiting nutrient in the mesocosms. Theoretically, if N were the limiting nutrient in this system, one would expect N-fixing algae to dominate the algal community. The fact that a

non-diazotrophic alga dominated suggests that N was not limiting. The diatom *Synedra* was abundant as well. This suggests that silica was not limiting.

It is likely that measurements made by fluorometer were confounded by increased turbidity shielding algae from excitation light. The overall effect would be a decrease in *Chl a* measurements. Similar future studies would benefit from a more accurate measurement of algal biomass. A method to quantify *Chl a* of periphyton on column walls is also needed.

Sediment was collected by shovel, and collected sediments were mixed with lake water before being placed in mesocosms. This method could be improved dramatically. Anoxic sediments were mixed with oxic water, thus altering the established microbial community. A more efficient method of collection would be to use a sediment corer. Sediments could then be transferred directly to mesocosms. This would (1) reduce the amount of time necessary for sediment settling and microbial recovery, and (2) result in a microbial community more similar to natural conditions.

Mixing of benthic lake sediments with the overlying pelagic water column is a proposed mechanism for increasing the biological availability of nutrients contained within the sediments. Results from the mesocosm study support the theory that nutrient releases from benthic sediments cause increased lake productivity.

While these experiments are preliminary, results suggest that the removal of lake sediments would decrease the occurrence and severity of algal blooms in Lake Allatoona. However, if the dredging process in Lake Allatoona results in sediment resuspension, then dredging would exacerbate the problem by releasing sediment-sorbed nutrients into the water column, thus making them algal-available.

Batch Experiments

The algal assays performed used sediment from one area of Lake Allatoona solely. Sediment algal assays using sediment from other parts of the lake are needed.

This assay could be modified to more closely represent the natural algal community and lake environment. While the natural algal community is not recommended for this assay, the assay could include other algae found in the lake if they were cultured from a reputable supplier. Using algae from a supplier ensures the repeatability of the assay. Use of several algae in a sediment assay may be especially desirable if pH and/or redox potential is to be manipulated as not all algae can tolerate such changes in their environment.

The assay could also be easily modified to quantify algal biomass in response to mixing regime. For example, one treatment could be sediment and algae left undisturbed, a second treatment would be lightly shaken, and a third treatment total sediment resuspension.

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Meetings and Publications

Ceballos, EL and TC Rasmussen. 2007. Internal Loading in Southeastern Piedmont Impoundments. *Proceedings of the 2007 Georgia Water Resources Conference*, March 27-29, Athens, GA

Research was presented at the American Geophysical Union's 2006 Fall Meeting at the Moscone Center in San Francisco in December 2006, and will be presented at the Georgia Water Resources Conference in March 2007.