INTERNAL LOADING IN SOUTHEASTERN PIEDMONT IMPOUNDMENTS

Elena L. Ceballos[1] and Todd C. Rasmussen[2]

AUTHORS: [1]Graduate student and [2]Associate Professor, Warnell School of Forestry and Natural Resources, The University of Georgia, Athens, Georgia 30602.

Abstract. In Piedmont impoundments in Georgia, as well as lakes and impoundments throughout the world, accelerated eutrophication of lakes causes detrimental ecological effects such as algal blooms, lake anoxia and toxic metal release from sediments. It often renders water unsafe for agricultural use, recreation and drinking.

To reduce the eutrophication 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. These regulatory efforts focus on the reduction and minimization of point-source watershed nutrient inputs, primarily phosphorus, into lake systems, as phosphorus is the limiting nutrient in Piedmont impoundments. 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. Internal loading has been identified to be a source of algal-available phosphorus, 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 from resuspended sediment in Lake Allatoona, Georgia. The results of a mesocosm experiment are used to evaluate potential appropriate remediation strategies to minimize detrimental algal blooms in Southeastern Piedmont impoundments.

BACKGROUND

Lake eutrophication is a natural phenomenon of chemical, physical and biological change due to sedimentation and nutrient inputs over geologic time scales. Accelerated nutrient enrichment from anthropogenic sources is called cultural eutrophication, and is a significant national water quality problem that can lead to adverse ecological effects, such as algal blooms. The mineralization of these algal blooms can cause hypolimnetic anoxia (Wetzel, 2001; López-Archilla et al., 2003), which is known to cause fish kills (Kann and Smith, 1999) and toxic metals release from lake sediments (Fang et al., 2005). Accelerated eutrophication is a common occur-rence 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.

Sources of nutrients include discharges from point-sources, such as wastewater treatment facilities, as well as stormwater runoff from non-point sources, such as farms and communities. Current nutrient control strategies focus on regulating point source inputs, yet the control of non-point source inputs has not been addressed.

Nutrient loading from external (allochthonous) sources is widely assumed to be the primary cause of accelerated eutrophication. However, many lakes have continued to experience algal blooms and lake anoxia after sources of external loading were discontinued (Böstrom et al., 1988; Koussouris et al., 1997; Wetzel, 2001; Sondergaard et al., 2003). In lake systems with low concentrations of orthophosphate in water and high concentrations in sediment, internal (autochthonous) loading is the main mechanism providing phosphorus to algal biomass. For example, Santiago and Thomas (1992) found that in Lake Geneva, Switzerland, internal phosphorus loading was inhibited when the orthophosphate concentration in the water was above approximately 14 µg/L.

Lake Allatoona is a US Army Corps of Engineers reservoir located northwest of Atlanta, Georgia. The reservoir was constructed in January 1950 for purposes 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 watershed area upstream of the dam is 1110 mi^2 and contains one large tributary (the Etowah River), and several smaller tributaries.

Preliminary tests confirm that primary production in Lake Allatoona is phosphorus limited. Molar ratios of inorganic nitrogen ($N = NO_3+NO_2+NH_3$) and soluble reactive phosphorus (P) in waters indicate P limitation. As a general rule, N:P ratios below approximately 10:1 indicate N limitation. N:P ratios between 10 and 12.1 generally indicate possible co-limitation. N:P ratios above 12 indicate P limitation (Miller, 1978). Water samples taken from three sites in the lake and its tributaries in July of 2005 were found to have N:P ratios >19-37, indicating phosphorus-limitation (Because all samples had soluble reac-

tive phosphorus below detection limits, these ratios were calculated using the detection limit, which is 0.05 mg/L.).

Total maximum daily loads of nutrients, particularly phosphorus, have been implemented for point sources within the watershed. Yet, seasonal algal blooms develop in the lake in summer and early fall. The lake also receives very high sediment loads from the Etowah River and its other tributaries.

Internal loading is believed to be contributing to the accelerated eutrophication of Lake Allatoona. The high concentration of iron in sediments provides abundant sorption sites for the algal-available form of phosphorus, orthophosphate. Whether the sediments are a source or a sink for P depends on the equilibrium between the water and sediments. As lake water orthophosphate content is negligible, sediment phosphorus is believed to be the primary source of algal-available phosphorus. Resuspension of benthic sediments can accelerate phosphorus release (Koski-Vähälä and Hartikainen, 2001).

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 to increase navigability of the lake. An important question is whether this dredging affects lake water quality. Dredging may reduce internal loading by removing the source of excess phosphorus, yet it may also result in the resuspension of clay and silt-sized particles. If desorption of phosphorus from the finer materials occurs, then this action may degrade water quality.

The purpose of this study was to simulate the effects of benthic sediment removal and resuspension in Lake Allatoona. A laboratory experiment was performed using mesocosms filled with sediment and lake water. Water quality parameters were monitored daily for 14 days.

MATERIALS AND METHODS

Mesocosms were constructed from 26.7-cm outer diameter, 122-cm tall clear acrylic tubes (Spartech Townsend, Des Moines, Iowa). The bottom ends were sealed using a PVC cap with an embedded o-ring (UGA Instrument Shop, Athens, GA) to prevent leakage.

A slurry of approximately 20 L of sediment collected from Noonday Creek and 40 L of lake water was created in a 75-L container. Equal amounts of the slurry were transferred to four of the five 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 (FountainPro, JeanTech Inc., www.fountainpro.com) was placed approximately 25 cm below the surface in each column to circulate water at a rate of approximately 1.5 L per minute.

Two experimental columns containing sediment were mixed until they held 20-22 g/L suspended solids as read by an ASTM soil hygrometer (HB Instrument Co., Collegeville, PA). Two columns containing sediments were left undisturbed. One column without sediment was stirred thoroughly.

Temperature, specific conductance, pH, and dissolved oxygen were measured using a Quanta (Hydrolab, Austin, TX). Soluble reactive phosphorus was measured on 0.22-µm filtered water by a colorimeter (LaMotte, Chestertown, Maryland), turbidity by a turbidimeter (Hach, Loveland, CO), and Chlorophyll a (Chl a) using a fluorometer (Turner, Sunnyvale, CA). Measurements were conducted daily between 5-8^{pm} for 14 days.

RESULTS

Sediment mixing in experimental columns resulted in an immediate drop in pH and DO, followed by a rise in both (Figure 1). pH remained between 8.7 and 10.3, and DO remained between 120-170% saturation from 5 to 10 days after mixing. Planktonic Chl a increased to peak concentration 7-9 days after mixing, while periphyton biomass increased throughout the experiment. Control columns showed no similar rise or fall in Chl a, pH, or dissolved oxygen. pH has been successfully used to estimate algal biomass (Miller et al., 1978; López-Archilla et al., 2003) due to high rates of photosynthesis removing carbonates.

The filamentous green alga *Oedogonium* (Chlorophyta) dominated the algal community in all columns. Long filaments of this alga attached to the walls of the columns. By the end of the experiment (day 13) the *Oedogonium* 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 longer than 10 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 the lake.

The fluorometric measurement of Chl a in the mixed mesocosms was affected by high concentrations of suspended sediment blocking both excitation and emission
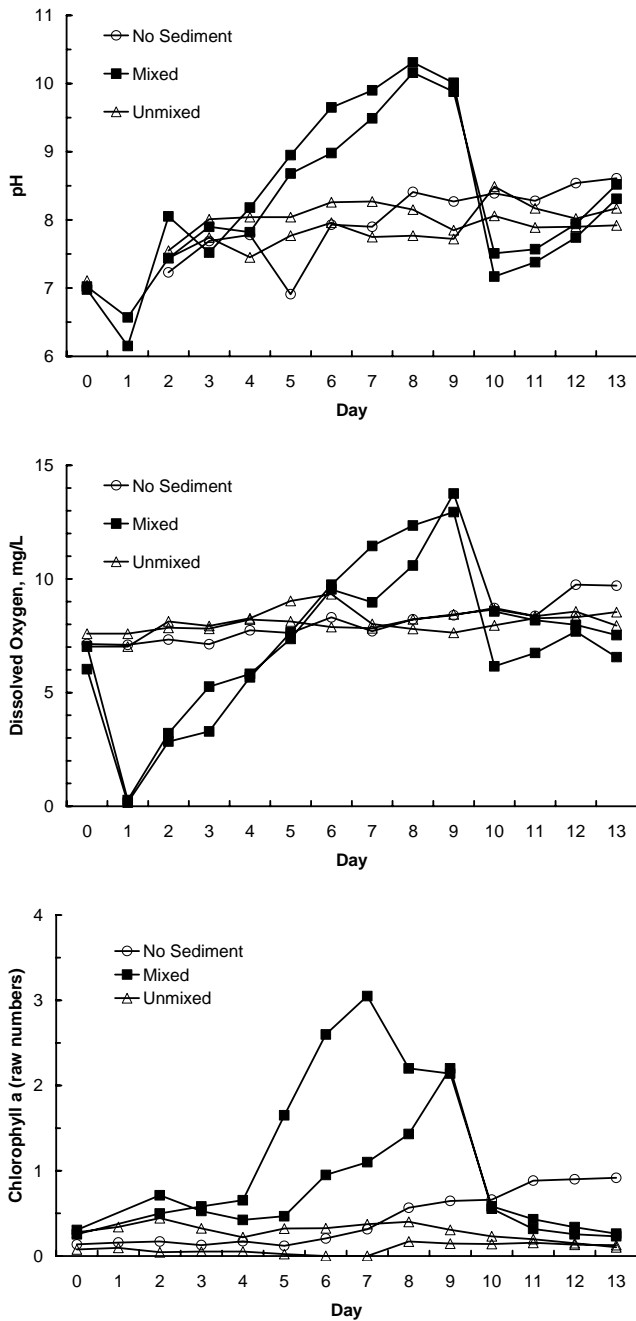
Figure 1. Water quality in mixed, unmixed and sediment-free mesocosms: pH (top), dissolved oxygen (middle), and Chlorophyll *a* (bottom).

wavelengths. Therefore, actual Chl *a* concentrations from the mixed columns were likely higher than recorded.

DISCUSSION

Nutrient releases from benthic sediments cause increased lake productivity. Laboratory column studies clearly demonstrate that sediments are a source of nutri-ents. Figure 1 shows the response to sediment disturbance and the resulting pore water mixing with the overlying water column. Note that pH, dissolved oxygen, and Chl *a* increase in response to mixing. The increase in pH can be attributed to enhanced photosynthesis due to the abundance of nutrients. Also note that pH exceeds the threshold (approximately pH>8) for phosphorus release from the sediment (Macpherson et al., 1958).

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

The immediate fall in pH and dissolved oxygen 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 dissolved oxygen observed would then be due to gradual resettling of suspended particles and associated microbial biomass. The rise in Chl *a*, pH and dissolved oxygen could be due to the release of nutrients from suspended particles promoting algal growth.

One hypothesis that could account for the increase in Chl *a*, dissolved oxygen and pH in the mixed columns is the reseeding of the euphotic zone with algal spores released from sediments. In this scenario any phosphorus release from resuspended sediments may or may not contribute to the increase in photosynthetic biomass. Regardless of mechanism, benthic sediment resuspension results in increased Chl *a*.

Another 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 an increase in Chl *a*, it would not directly contribute to the rise in pH or dissolved oxygen. Again, the rise and pH and dissolved oxygen were most likely due to increased primary productivity.

The results of this experiment could be strengthened by more accurate measurements of algal biomass. It is likely that fluorometer measurements were confounded by increased turbidity that shielded algae from excitation light. The overall effect (observed?) would be a decrease in Chl *a* measurements. Improved measurements could be achieved by a Chl *a* extraction. A method to quantify Chl *a* of periphyton on column walls is also needed.

LITERATURE CITED

Böstrom B, Andersen J, Fleischer S, Jansson M. 1988. Exchange of phosphorus across the sediment-water interface. Hydrobiologia 170:229-244.

Fang, T., Liu, J.T., Xiao, B.D., Chen, X.G. and X.Q. Xu. 2005. Mobilization potential of heavy metals: A comparison between river and lake sediments. Water, Air and Soil Pollution 161 (1-4):209-225.

Kann, J., V.H. Smith. 1999. Estimating the probability of exceeding elevated pH values critical to fish populations in a hypereutrophic lake. Canadian Journal of Fish and Aquatic Sciences 56:2262-2270.

Koski-Vähälä, J. and H. Hartikainen. 2001. Assessment of the risk of phosphorus loading due to resuspended sediment. Journal of Environmental Quality 30:960-966.

Koussouris, T., Gritzalis, K. and O. Giannakou. 1997. Ecological classification of some rivers in Evritania, Central Greece. Vol. 2, p. 285-288. In 5th Hellenic Symposium on Oceanography and Fisheries. Kavala, Greece, April 15-18.

López-Archilla, A.I., Moreira, D., López-Garcia, P. and C. Guerrero. 2003. Phytoplankton diversity and cyanobacterial dominance in a hypereutrophic shallow lake with biologically produced alkaline pH. Extremophiles 8:109-115.

Macpherson, L.B., Sinclair, N.R. and F.R. Hayes. 1958. The effect of pH on the partition of inorganic phosphate between water and oxidized mud or its ash. Limnology and Oceanography 3(3):318-326.

Miller, W.E., Greene, J.C. and T. Shiroyama. 1978. The *Selenastrum capricornutum* Printz algal assay bottle test. EPA 600/9-78-018. Final Report. U.S. Environmental Protection Agency, Corvallis, OR.

Santiago, S. and R.L. Thomas. 1992. Phytoplankton utilization of phosphorus bound to suspended sediments from selected tributaries to Lake Geneva. Journal of Great Lakes Research 18:372-389.

Sondergaard, M., Jensen, J.P., and E. Jeppesen. 2005. Seasonal response of nutrients to reduced phosphorus loading in 12 Danish lakes. Freshwater Biology 50(10):1605-1615.

Wetzel, R.G.. 2001. Limnology, 3rd edition. Academic Press, San Diego, CA.