THE PALEOLIMNOLOGY OF LAKE SEMINOLE, GA: PHOSPHORUS, HEAVY METALS, CYANOBACTERIA AND TWO INVASIVE SPECIES

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Abstract. Lake Seminole is a large reservoir formed by damming the Chattahoochee and Flint Rivers. Current management objectives focus on decreasing the dense population of the invasive plant, *Hydrilla verticillata*, which can cover 55% of the lake. We collected a sediment core from each side of the lake in order to reconstruct the allochthonous inputs and ecological responses since the dam was constructed. Results show that the Chattahoochee side of the lake has experienced multiple periods of differing heavy metal inputs but has maintained a constant *Hydrilla* population. The Flint side of the lake has stored large amounts of phosphorus in the sediments as well as maintained a dense population of the cyanobacterium, *Lyngbya sp*., in concert with the *Hydrilla* population. In addition, sediment cores contained substantial numbers of the invasive clam, *Corbicula fluminea*. These findings suggest that the two sides of Lake Seminole are different depositional and benthic environments while maintaining similar and dense *Hydrilla* populations.

Introduction. The flux of sediments in the rivers of the USA has dramatically changed in the past century due to human influences. Land-use changes such as agriculture and urbanization can impact the amount of sediments as well as sediment composition (Smith et al. 2001). Likewise, fragmentation caused by dam and reservoir construction greatly decreases the sediment flux to the oceans by trapping around 13% of river sediments (Syvitski et al. 2005). One river system in Georgia that has been highly impacted by both land-use and fragmentation is the Apalachicola-Chattahoochee-Flint (ACF) River Basin.

The ACF river basin comprises 51,281 km^2, includes over 2.6 million people, and is the primary focus of the water wars between Georgia, Florida, and Alabama (Couch et al. 1996). The Chattahoochee River begins its headwaters in the north Georgia mountains, moves through the metropolitan areas of Atlanta and Columbus and possess a large amount of industry within its watershed. In addition, 22 sewage treatment plants and 13 dams are located on this highly regulated river. Conversely, the Flint River Basin contains only 2 dams and 4 sewage treatment plants within its highly agricultural watershed. These two rivers meet and form Lake Seminole at the Jim Woodruff Lock and Dam.

Lake Seminole, GA, is a large (152 km^2) and shallow (mean depth 3m) reservoir formed by the joining of the Chattahoochee and Flint Rivers. The lake was established in 1957 and drains 44,625 km^2 of Georgia and Alabama. Currently, the lake is dominated by a dense population of the aquatic macrophyte, *Hydrilla verticillata*. *Hydrilla* is an invasive species that overtakes native aquatic plants, chokes boat lanes, alters fish communities and constrains recreational activities of lake visitors. The Army Corps of Engineers has attempted to decrease *Hydrilla* presence using chemicals as well as the insect, *Hydrellia pakistanae*, which eats the aquatic plant. Although attempts are made to decrease *Hydrilla*'s presence, these measures have had little success in decreasing the overall distribution of the plant. In addition, it is not known how the plant arrived in Lake Seminole, when it developed or what factors maintain the population's dominance. Since Lake Seminole is the confluence of two rivers that drain distinctly different watersheds (Flint River-agricultural, Chattahoochee River-industrial), research is needed to investigate the different materials being delivered from these watersheds and how these materials have influenced or altered the primary producer community in Lake Seminole.

The goal of this study was to reconstruct a history of Lake Seminole in regards to the lake's primary producer ecology and input of materials from the two distinct watersheds. Sediment cores were collected from each arm of the lake and various proxies were measured to investigate two specific aims: 1) Based on the sedimentary record, what are the differences between materials deposited in the two arms of the lake? 2) Are changes in the primary producer community linked to certain inputs from the river watersheds?

Methods. One sediment core was collected from each side of Lake Seminole representing the input of the

Chattahoochee and Flint Rivers, respectively (Fig. 1). Prior to core collection, soft sediments were measured to determine areas of sediment deposition. Both sites were dominated by *Hydrilla* and a piston-coring system was used to collect undisturbed sediment cores (Fisher et al. 1992). The 50 cm cores were extruded and sliced at 1 cm intervals to 20 cm depth, at which point the interval depth was increased to 2 cm for the remainder of the core. A portion of the wet material was separated for gravimetric analysis. Gravimetric analysis included wet and dry mass and loss on ignition at 550°C. The remaining sample material was freeze-dried and ground into fine powder with a mortar and pestle for photosynthetic pigments, total phosphorus, metals, organic carbon and nitrogen analysis.

Photosynthetic pigments (chlorophylls and carotenoids) were measured using an HPLC system following the methods of Leavitt and Hodgson (2001) and Waters et al. (2012) designed particularly for sedimentary pigments. Dried sediment samples were extracted with a solvent mixture of acetone, methanol and water mixed in an 80/15/5 ratio, which contained an internal standard (Sudan II; Sigma Chemical Corp., St. Louis, MO) and the extractions were injected into a Shimadzu HPLC system following the mobile phase and time sequence of Leavitt and Hodgson (2001). Chlorophylls and carotenoids were separated by passing through a Rainin Model 200 Microsorb C_{18} column and measured using a photodiode array detector set at 435 nm and 665 nm. Pigment identification was made using retention times of known standards and pigment specific spectra recorded by the detector. Pigment concentrations are expressed as nmol pigment/g OM and calculated by comparing peak areas against standards of known concentration. For total phosphorus and metal analysis, sediment subsamples were digested with H_2SO_4 and $K_2S_2O_8$ and measured using an autoanlyzer with a single channel colorimeter. For total carbon and nitrogen analyses of sediment organic matter, sediment subsamples were acidified with diluted HCl to remove carbonate and washed with copious amounts of deionized water. Samples were analyzed using a CHN analyzer.

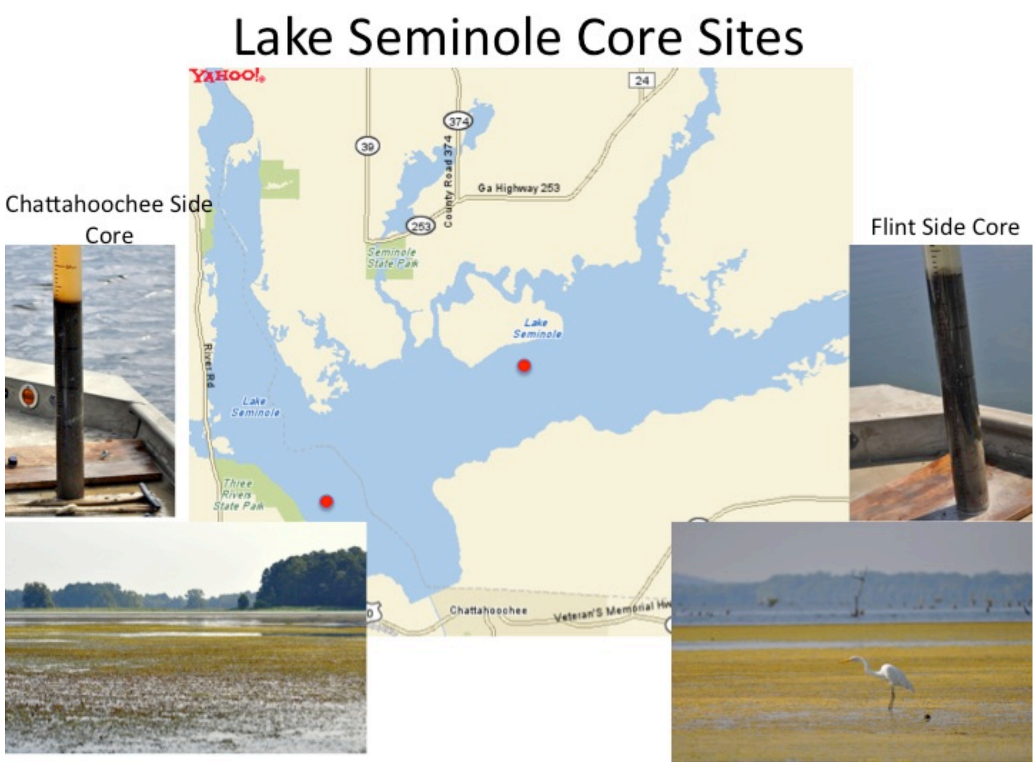

Figure 1. Map of Lake Seminole showing coring sites and cores for the each arm of the lake. Pictures of *Hydrilla* show conditions of lake where cores were taken.

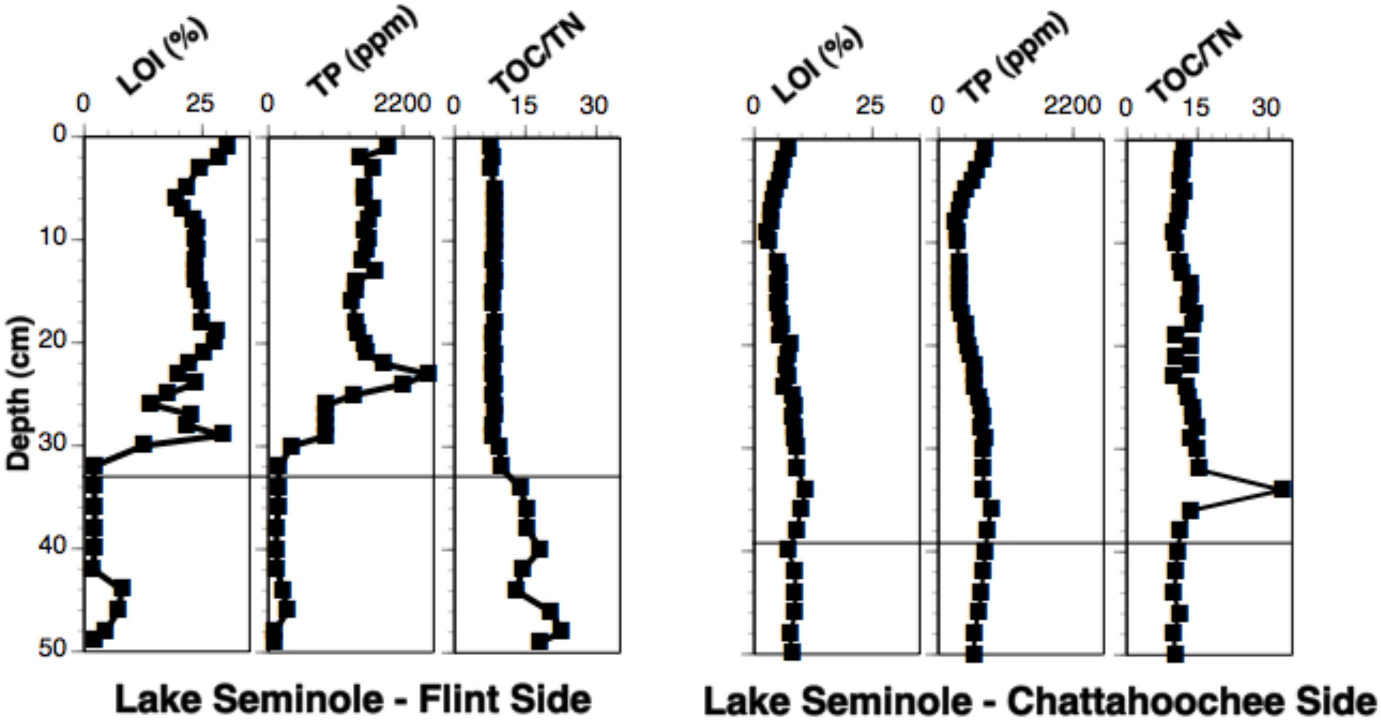

Figure 2. Organic matter (LOI), phosphorus and TOC/TN ratios for sediment cores collected in Lake Seminole, GA. Lines show separation of reservoir sediments (top) and river sediments (bottom).

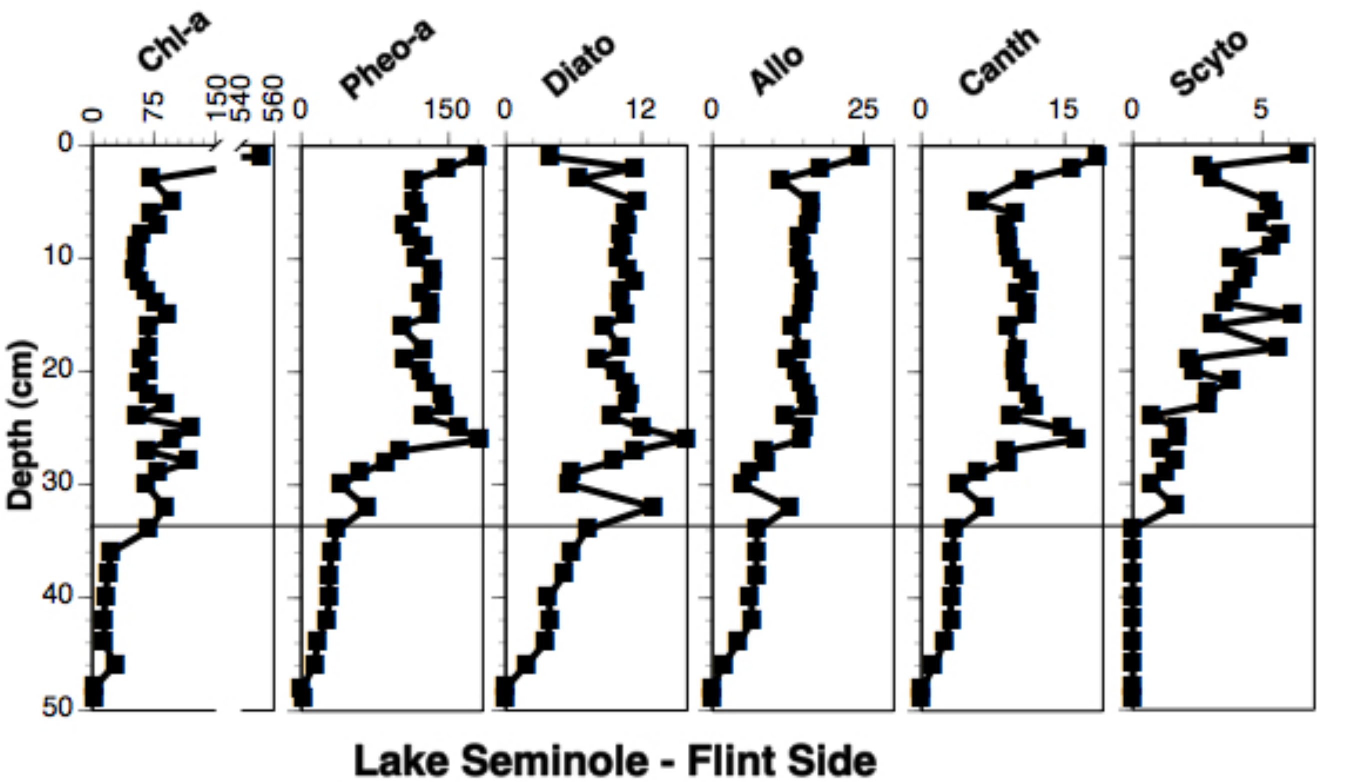

Figure 3. Photosynthetic pigments for the Lake Seminole core Flint Side. Chl-a is chlorophyll a and represents total primary productivity. Pheo-a is pheophytin a and is a degradation product of chlorophyll. Diatoxanthin (Diato) represents diatoms, alloxanthin (allo) represents cryptophytes, and canthaxanthin (cantha) and scytonemin (scyto) represent cyanobacteria. All pigments are reported as nmol pigment g-1 org. matter. Line shows separation of reservoir sediments (top) and river sediments (bottom).

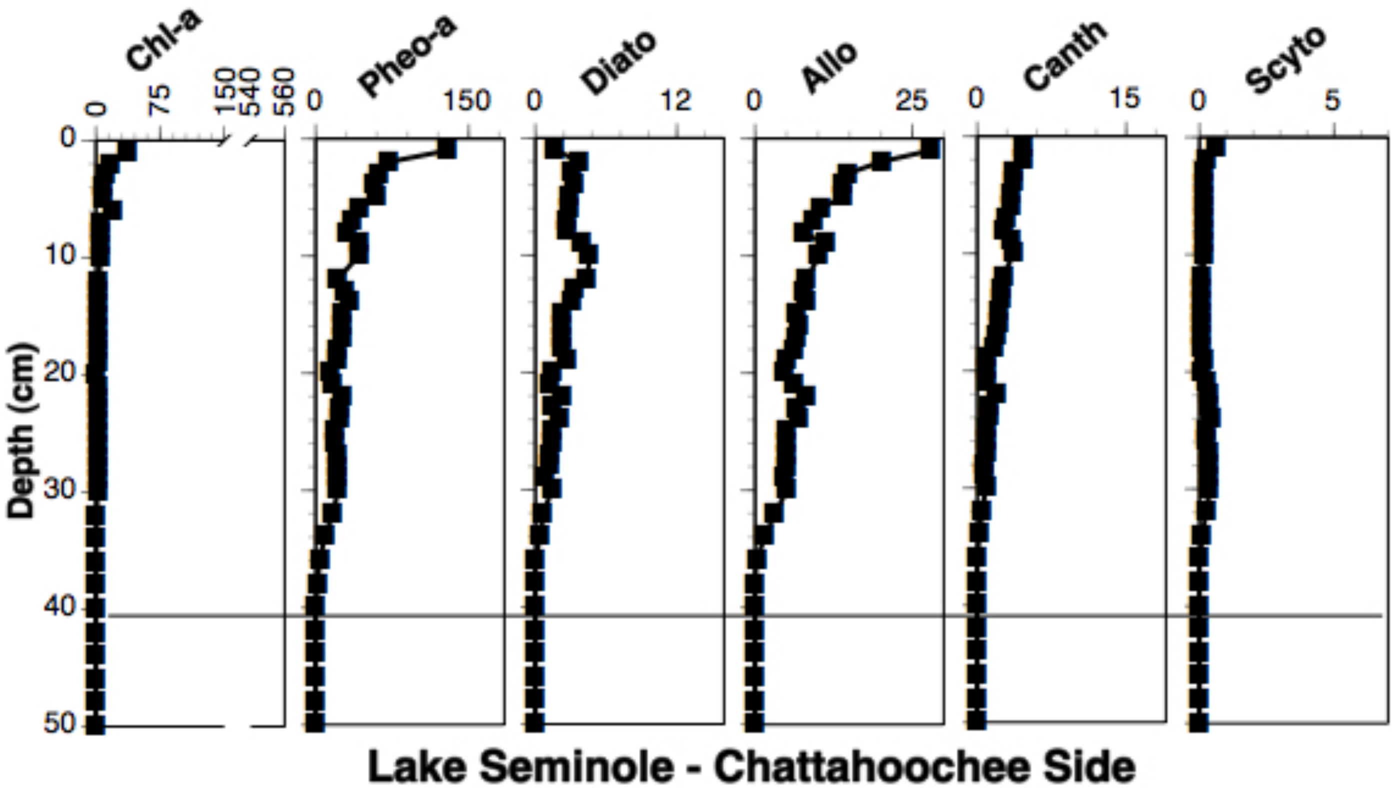

Figure 4. Photosynthetic pigments for the Lake Seminole core Chattahoochee Side. Chl-a is chlorophyll a and represents total primary productivity. Pheo-a is pheophytin a and is a degradation product of chlorophyll. Diatoxanthin (Diato) represents diatoms, alloxanthin (allo) represents cryptophytes, and canthaxanthin (cantha) and scytonemin (scyto) represent cyanobacteria. All pigments are reported as nmol pigment g-1 org. matter. Line shows separation of reservoir sediments (top) and river sediments (bottom).

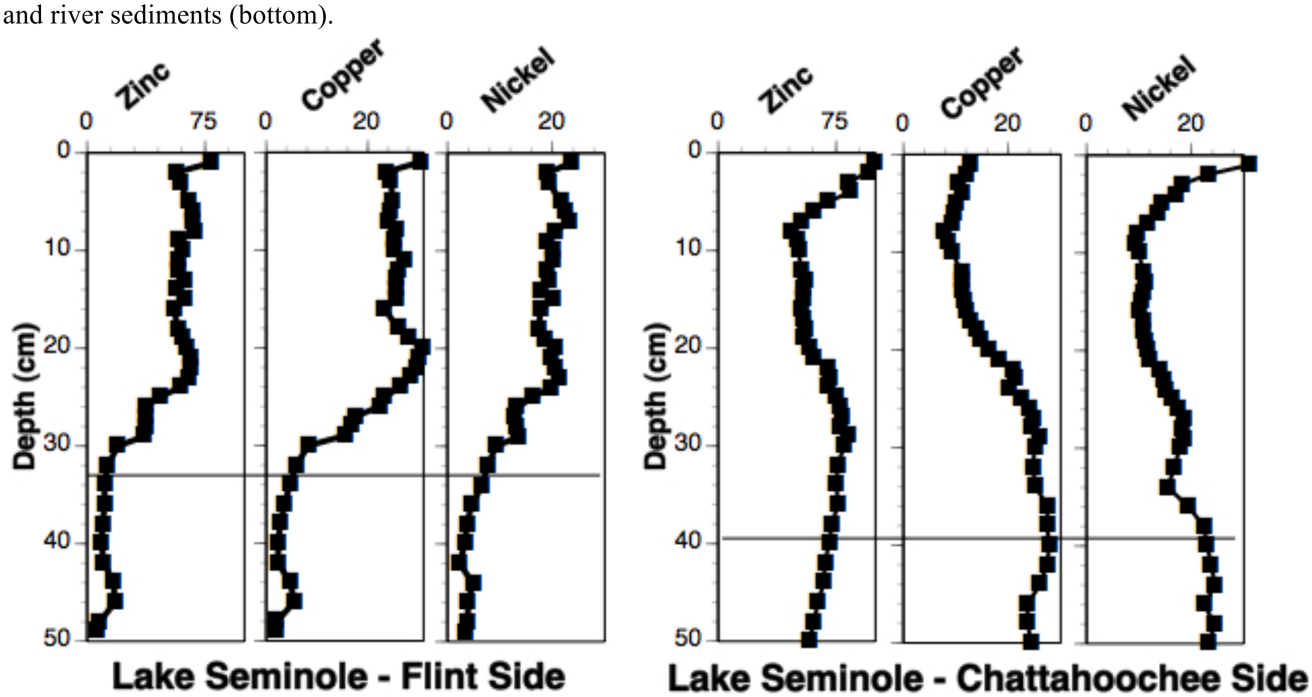

Figure 5. Metal concentrations for sediment cores collected from the Flint and Chattahoochee sides of Lake Seminole. Metals are reported as ppm. Lines show separation of reservoir sediments (top) and river sediments (bottom).

Results and Discussion. The core sites chosen for the Chattahoochee and Flint basin cores of Lake Seminole were both shallow sites with soft sediments in dense *Hydrilla* stands. Although limnological characteristics were similar between the two sites, the sediment record was different for most proxies measured. The Chattahoochee side core contained low concentrations of organic matter and phosphorus with high concentrations of metals. These sedimentary characteristics are believed to represent the industrial and urbanized watershed of the Chattahoochee River. The Flint side core contained high amounts of organic matter and phosphorus reflecting the agriculturally dominated watershed. These findings support the need to investigate each major arm of large reservoirs regardless of water column similarities.

The high concentrations of organic matter and phosphorus in the Flint side core were not surprising given the agricultural dominance of the watershed. However, phosphorus has not been viewed as a major nutrient input to the system. Nitrogen has been the primary focus based on previous research (McEntire 2009). Sediment phosphorus levels were high when compared to other hypereutrophic lakes in the SE USA. Lake Apopka, FL, which is a shallow lake know for its algal dominance from phosphorus additions and land use change contains TP concentrations of 1340 ppm, (Kenney et al. 2002) and Lake Griffin, FL currently is dominated by cyanobacteria and contains sedimentary phosphorus concentrations of 1800 (Schelske 1998). The values in the Flint side of Lake Seminole averaged around 1900 ppm since the building of the dam (Fig. 2). The cause of the phosphorus concentrations in the sediments is unknown, but concern over potential for internal loading of phosphorus into the system through the resuspension of sediments does exist and could result from intense storms or periods of high flow.

Pigment concentrations (Fig. 3) and TOC/TN ratios in Flint side sediments suggest an additional primary producer is a main source of organic matter deposition. TOC/TN values averaged below 10 for the parts of the core deposited since the dam was built and suggest material of an algal/bacterial origin (Meyers and Teranes et al. 2001). Values for most pigments measured were high since the dam was built and reflected *Hydrilla* and its associated epiphytes (Chl-a, Pheo-a, Diato, and Allo). In addition, the pigments canthaxanthin and scytonemin suggest that a strong cyanobacterial presence exists within the lake. Canthaxanthin is a pigment known to be present in benthic cyanobacteria (Leavitt and Hodgson 2001), and scytonemin is a UV-Blocking pigment produced in benthic cyanobacteria under intense light environments (Waters et al. 2012). Based on observations, these two pigments suggest that in addition to *Hydrilla*, a strong presence of the benthic cyanobacteria, *Lyngbya sp.* is also present within the lake.

Sediments collected from the Chattahoochee basin of Lake Seminole reflect a industrial and regulated watershed. Organic matter and total phosphorus were lower than sediments in the Flint basin. TOC/TN ratios denote that the organic matter deposited is macrophyte in origin most likely from the dense *Hydrilla* stands. Pigment concentrations were low for most pigments with the highest pigment concentrations (alloxanthin and diatoxanthin) suggesting cryptophytes and diatoms as dominant groups in the primary producer community (Fig. 4). These are the same pigments measured on *Hydrilla* samples collected from Lake Seminole and are believed to be representative of the algal species living around and on the macrophytes. Metal deposition in the Chattahoochee basin followed a similar pattern for most metals measured with high concentrations soon after dam construction and a rapid increase in concentrations in the upper sediments for Nickel and Zinc (Fig. 5). Given the highly dammed and regulated nature of the watershed, these changes in concentration could be a change in inputs or different releases from dams upstream.

Sediment records for the Flint and Chattahoochee basins of Lake Seminole showed that the different arms of the lake have been receiving and depositing different materials since the construction of the dam while maintaining similar water column communities dominated by *Hydrilla*. Since Lake Seminole is a shallow reservoir and capable of intense periods of resuspension, a greater understanding of the origin, delivery and deposition of these materials is needed with particular focus on phosphorus in the Flint basin and metals in the Chattahoochee basin. In addition, photosynthetic pigment analysis of the Flint basin sediments shows extensive coverage of dense mats of the benthic cyanobacteria, *Lyngbya*. This cyanobacteria undoubtedly influences nutrient cycling and food web composition and needs further study.

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