Analysis of sedimentary organic carbon and phosphorus levels in Rice Lake, Whitewater WI

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Prepared in conjunction with the Whitewater-Rice Lakes Management District

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Abstract

The overall objectives of this study were to: 1.) Measure sediment column organic carbon (OC) and phosphorus (P) concentrations throughout Rice Lake to determine uniformity or heterogeneity of OC and P in the sediment, and 2.) Quantitatively estimate Rice Lake's total volume/mass of OC and P laden sediments. To do this core samples were taken at 29 locations across Rice Lake using a livingstone piston corer. Each sediment sample was measured, dried, weighed, and then chemically analyzed. Sediment samples were analyzed in 10 cm intervals and then processed for OC using loss on ignition, and measured for P on an inductively coupled plasma optical emissions spectrophotometer. The average core length measured 21.99 cm while bulk density of the cores increased from 0.218 g/cm^3 in the upper sediment to 0.708 g/cm^3. Concentrations of OC and P were highly variable not only spatially across the lake but also within the sediment column as well. Average OC concentrations were 0.314 g/g, 0.340 g/g, and 0.323 g/g in the upper (0-10cm), middle (10-20cm), and lower (>20cm) sediment layers, respectively. Average sediment P concentrations were 781 mg/kg, 722 mg/kg, and 619 mg/kg in the upper, middle, and lower sediment layers, respectively. Despite a decreasing average trend in P at different sediment depths, there was variability both spatially within the lake and at different depths. The total amount of P in all of the sediment layers measured is estimated to be 245 kg, meanwhile the total amount of OC within the layers sample is estimated to be 121.6 metric tons.

Introduction

Rice Lake (Walworth County WI) is a 144-acre drainage lake with a maximum depth ranging from 10 to 11+ ft (WI Department of Natural Resources, n.d.; SEWRPC 2017), and is classified as a "eutrophic" lake by the WI DNR (n.d.). It is used recreationally, hosting a boat landing, and 48+ residences directly in contact with the lake shore (SEWRPC 2010; W-RLMD, 2021). The lake was created by damming Whitewater Creek just below Whitewater Lake, with a significant portion of what is now Rice Lake having flooded over wetland and farmland (SEWRPC 2017; Sivek 2021). Rice Lake was estimated to be accumulating at least 45 pounds of phosphorus (P) per year since 1990, from external P loading sources including precipitation, near-lake drainage, and groundwater inflow (Goddard & Field 1994). A recent study (SEWRPC 2017) estimated that P loading in Rice Lake has increased to 52 pounds per year. However, these studies did not quantify how much P is exported from current lake management practices such as weed harvesting and removal. In addition, internal P loading may also contribute to the total quantity of P delivered to the lake water column could lead to eutrophication (Penn et al. 1995). Thus, reassessing and ground truthing whole lake P estimates and previous measurements from 1990-91 are imperative to better understand: 1) have lake management practices decreased P loading within Rice Lake? and 2) has P loading within Rice Lake significantly changed over the past 30 years? Answering these questions will not only help determine to what extent the whole lake and watershed P dynamics have changed, but also help guide current and future lake management decisions.

Lake beds heavy in wetland vegetation like that of Rice Lake may continually accumulate P due to wetland vegetation playing a significant role in P storage. Floating macrophytes absorb P directly from the water column, but due to rapid turn over, this storage is short term and much of the stored P is released back into the water during vegetative decomposition (Reddy and DeBusk 1998; Reddy et al. 1999). What is not immediately released then begins the formation of organic sediment. As aquatic algae and plant populations die and fall to the lake basin, they begin to decay, and as these accumulate and lithify, once swampy sediment becomes black, soft organic carbon–heavy sediment (Littke and Zeiger 2020). Said sediment type is far more likely to contain greater levels of total P, as its once algae and plant components utilized P as their limiting nutrient. As this cycle continues, a sink for these nutrients is created in the lake basin (Cole et al. 2007, Battin et al. 2009). These sequestered nutrients may then be released back to the water column through processes such as bioturbation by macro and micro fauna (Shull 2009) or under anoxic conditions (Tammeorg et al. 2022). Phosphorus in its various forms is the main nutrient correlated with lake productivity, but high levels of P can lead to hyper-eutrophication, oxygen depletion, and increased algae blooms. Some harmful algal blooms release toxins that contaminate drinking water, causing illnesses for animals and humans in the surrounding areas (EPA 2021). Thus, determining the sediment concentrations of both

P and Organic Carbon (OC) throughout the upper layers of lake sediment is essential to help guide the Rice Lake property owners in determining how P changes throughout the lake sediment.

Methods

Sample collection

Using Google Earth and a Garmin GPS unit, Rice Lake was divided into 50 sections. These sections were labeled alphanumerically (A-E, 1-10). One sediment core was collected at each traversable section using a Livingstone piston corer and a pontoon boat graciously provided by Mike Lindenmuth. Fourteen samples were collected on 5/11/2022, while the remaining 16 were collected on 6/2/2022. Coordinates of each collection site were recorded using GPS (Figure 1). Upon collection, samples were wrapped, then placed in a cooler for transportation to the lab. Samples were stored at 4°C in lightless conditions to reduce oxidation and photosynthesis. All core samples were analyzed within 48 hr by drying, then processed within 7 days.

Processing and Analysis of Sediment Cores

Length of cores was recorded once while wet and then each core was then cut into the top (0-10cm), middle (10-20cm), and bottom (>20cm). Each section was subsequently oven dried at 100°C for 48 hours. These subsamples were ground, homogenized, weighed, and then combusted at 550°C for 3 hrs– organic carbon being represented as the total weight lost via LOI once reweighed at 58% (Heiri et al. 2001). Dried subsamples were then acid digested following the methods of (Ostrofsky 2012). Briefly, sub samples were digested with 5mL of HNO_3, 1mL of H_2O_2, and 140 µL of yttrium in a Mars 6 Microwave using the CEM Easyprep Standard Vessel Assembly. Included in each digestion cycle were two controls, one blank vessel– containing all ingredients, but no subsample, and one vessel containing #2704 Buffalo River Sediment standard reference material. The vessels were set to ramp to 200°C for 35 minutes. The contents of each vessel were placed in test tubes which were filled to a standard of 14mL with DI water. Samples were then analyzed for P using Inductively Coupled Plasma Optical Emission Spectra.

Whole Lake C and P Calculations

To estimate the total amount of Rice Lake OC and P the following equations were used:

Equation 1 (volume of lake sediment):

$$\textit{Area of Rice Lake (144 acres) x } 4.044E^{7}\ cm^{2} \textit{ per acre x height of layer (X cm)}$$

**10 cm was used as the height for the first sediment layer, 8.827cm for the second layer as not all cores had more than 20 cm, and 5.09 cm was use for the bottom layer*

Equation 2 (OC or P amount in core layer):

Volume of lake sediment (Equation 1) x average bulk density x conc. of element in sediment layer

Mapping Distribution:

ArcGIS Pro was used to display the collected data from Rice Lake. Inside the geodatabase, a shapefile was made to display all core samples in the lake. Using data from the attribute table, a spatial analysis tool, IDW (Inverse Distance Weighted) was used to interpolate concentration gradients for each core sample in relation to others. The IDW tool was run using a power of 2 and a cell size of 11.

Results

Core Length, Bulk Density, and Horizons

The sediment cores averaged 21.9 cm in length and 146.3 g in mass with no clear sedimentary horizons for any of the cores (Table 1; Figure 2). Cores ranged from 12 to 39 cm in length with medium to large (>20 cm) cores deriving from the periphery of Rice Lake and shorter cores concentrating in the central portion of the lake. The average bulk density (g/cm^3) of the cores increased from the top to the bottom of the cores, indicating compaction over time and accumulation of sediment material (Table 1). Based on bulk density calculations it is estimated that within the top (20-30cm) of sediment in Rice Lake there is a total of 370.3 metric tons of sediment (organic and inorganic). However, bulk density varied greatly across all depths, most likely due to the pooling of sediments across large (10 cm) and sometimes small (1 cm - bottom of the cores) intervals. More precise sampling at 1 to 2 cm intervals for each core would greatly increase the resolution of the measurements. As there were no clear horizons the cores were separated into the top 10 cm of the core, the middle 10 - 20 cm, and then >20 cm before drying. Unlike similar lakes in area (i.e. Lake Lorraine) there were no visible changes from organic rich sediment to inorganic sediments such as marl or clay. Thus, selection of the different layers for chemical analysis was guided with the intention to determine if there were chemical changes between the upper, middle, and lower sections of the cores.

Organic Carbon in Lake Sediment

The average OC in the top layer (0 – 10 cm) of the sediment sampled was 0.314 g/g, 0.340 g/g in the middle layer (10 – 20 cm), and 0.323 g/g in the lowest layer (>20 cm) (Figure 3). Organic C ranged from 0.06 to 0.55 g/g in the top layer, 0.01-0.52 g/g in the middle layer, and 0.02-0.51 g/g in the bottom layer of sediment with no clear (Figure 4). However, in order to fully understand how much OC is stored in the different layers, OC was calculated for the different layers by multiplying the total weight of each dry layer by the g/g measurement of OC and the subsequent volume of the core section. In the top of the sediment, average OC density was 0.05 g/cm^3, the middle (10 – 20 cm) layer was 0.08 g/cm^3, and the bottom was 0.28 g/cm^3 (Figure 4). There are greater concentrations of OC in the middle and bottom layers as those sediments on average are high in OC and have a greater bulk density. This would suggest that even at depth in Rice Lake sediment there are significant concentrations of OC. Using equations 1 and 2 to calculate the total amount of C within the three layers of sediment in the whole lake yields: 27.7 metric tons of OC in the top layer, 42.3 metric tons of OC in the middle layer, and 54.3 metric tons of OC in the bottom layer. It is estimated that in the top 20-30cm of the sediment at Rice Lake there is a total of 121.6 metric tons of OC. One must keep in mind that these numbers are estimates based on averages of the whole lake. In reality there is significant variability of OC across the lake as well as within the different layers of sediment (Figure 7).

Phosphorus in Lake Sediment

Phosphorus in the top sediment layer averaged 781 mg P/kg, 722 mg P/kg in the middle layer, and 619 mg P/kg in the bottom layer (Figure 8). However, P ranged from 129 to 1325 mg P/kg in the top sediment layer, 176 to 1272 mg P/kg in the middle, and 151 to 1228 mg P/Kg in the bottom layer (Figure 9). In the top of the sediment, the average P density was 0.177 mg/cm^3, the middle was 0.181 mg/cm^3, and 0.410 mg/cm^3 for the bottom sediment layer (Figure 10). Similar to OC, the density of P increases in the bottom layers due to the increase in bulk density of the material. Although the concentrations and densities measured were spatially variable (Figures 9 and 11), there were some patterns of P concentrations that emerged. For example, the Northeastern part of the lake had lower P than the central and southern part of Rice Lake in all sediment layers (Figure 12). However, the outliers for both C and P came from different cores. The P load across the top, middle, and bottom sediment of Rice Lake is estimated to be 68.9, 79.2, and 97.7 kg P, respectively. Thus, the sediment (top 20 to 30cm) with Rice Lake represents a net sink of 245.8 kg of P.

Summary

Despite the changes in C and P of individual cores, the overall averages of all three layers were similar. Given the history of the Rice Lake originating as a flooded marsh, the lack of any visible horizons is not surprising. However, that the middle and lower sediment levels have as much or more C and P is somewhat interesting and details the potential internal loading of both elements within Rice Lake. Although the average P concentration decreased from top to bottom due to increased bulk density the average density increased. This suggests that the removal of the top layer may not limit the amount of total P available to resuspend into the water column. However, it remains unknown what fraction of the total P is bioavailable in each sediment layer. Sedimentation rates should also be determined to calculate the rate of OC and P loading within the sediment. In addition, a new OC and P budget should be undertaken to estimate both the external and internal load. These types of studies can specifically determine what lake management practices need to be implemented to decrease the OC and P load within Rice Lake.

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Tables and Figures

Table 1. Length of sediment cores collected at Rice Lake and bulk density of the dry sediment in the top (0 - cm), middle (10 - 19.9cm), and bottom (>20cm) of the cores

Core ID	Core L (cm)	Bulk Density g/cm^3	Bulk Density g/cm^3	Bulk Density g/cm^3
A4	24.5	0.204	0.484	1.968
A5	27.5	0.542	0.509	0.363
A9	24.5	0.116	0.106	0.170
A10	25	0.170	0.156	0.498
B3	27.5	0.558	0.489	0.557
B4	31	0.174	0.890	0.738
B5	30.5	0.260	0.705	1.519
B7	24	0.148	0.288	0.762
B8	17	0.162	0.135	-
B9	21.2	0.118	0.203	1.529
C2	39	0.461	0.461	0.441
C3	13	0.148	0.125	-
C4	12.5	0.027	0.019	-
C5	19.5	0.075	0.058	-
C6	16.5	0.122	0.208	-
C7	18.5	0.159	0.443	
C8	23.5	0.172	0.084	0.361
D1	21.5	0.478	0.442	1.307
D2	19	0.167	0.221	-
D3	20.5	0.157	0.218	*
D4	19	0.161	0.183	-
D5	17.5	0.077	0.154	-
D6	17	0.120	0.136	-
D7	21	0.155	0.127	0.515
E1	23	0.130	0.215	0.662
E2	22	0.799	0.390	1.194
E4	16.5	0.199	1.229	-
Average	**21.99**	**0.218**	**0.307**	**0.708**

*Not enough measurable material existed to get a reliable bulk density measurement.

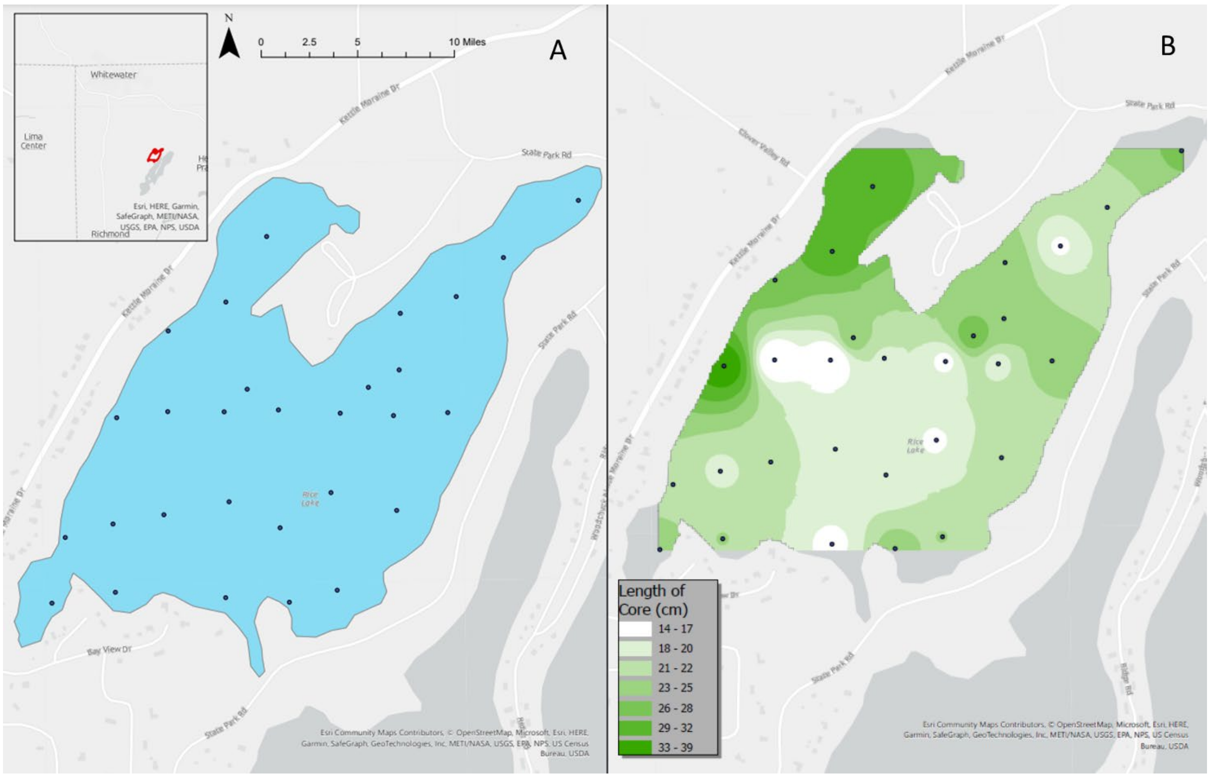

Figure 1. Map of Rice Lake showing the collection sites (A) and depth distribution of each core taken at each site (B).

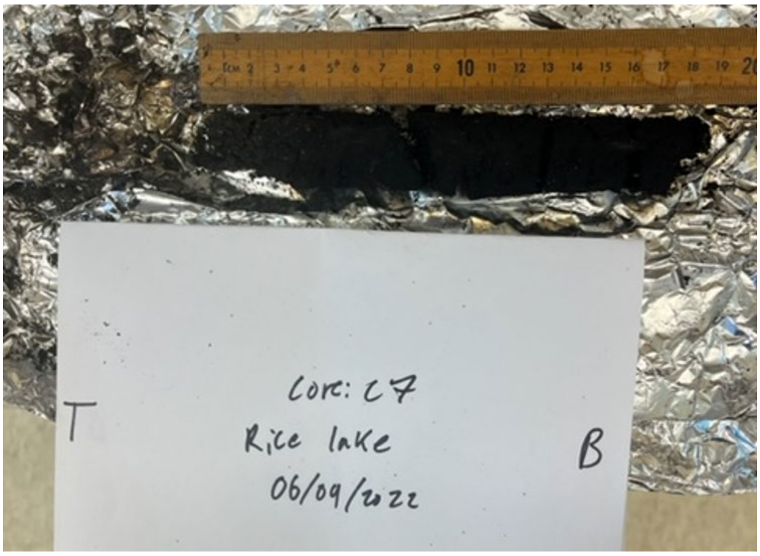

Figure 2. Example sample core from sampling location C7 before drying, with no clearly identifiable sedimentary horizons within the core.

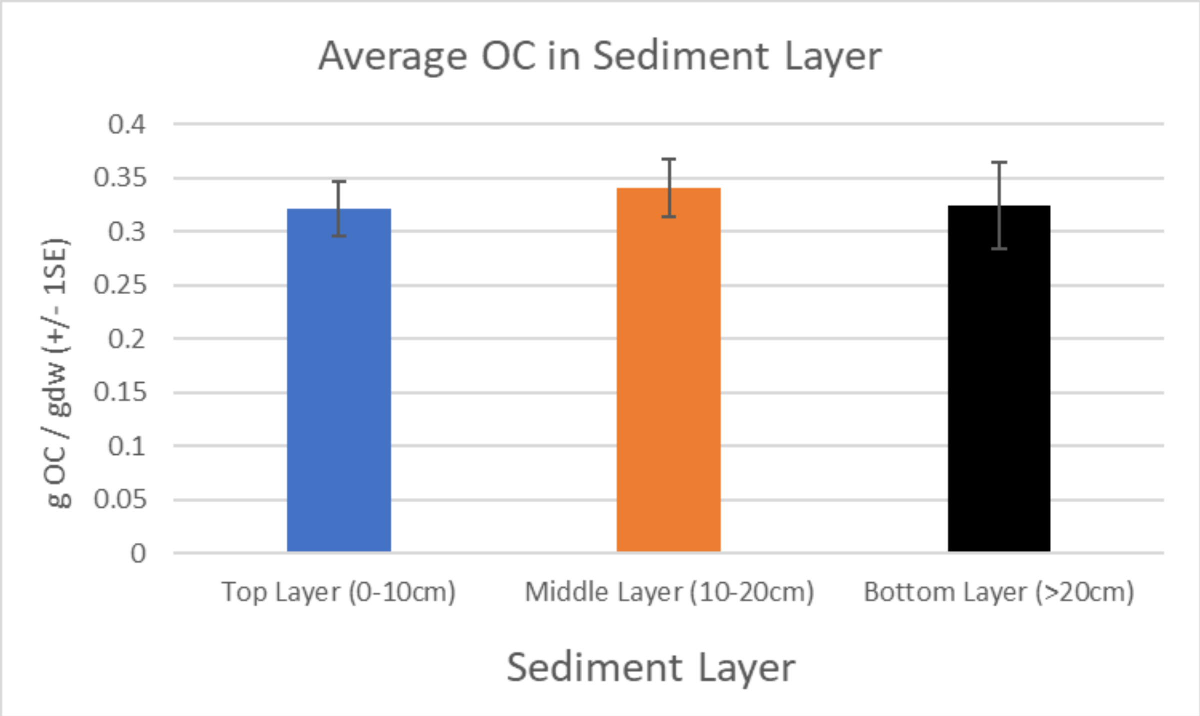

Figure 3. The average organic carbon (OC) concentrations in g OC/gram dry weight (gdw) across Rice Lake in three sedimentary sections.

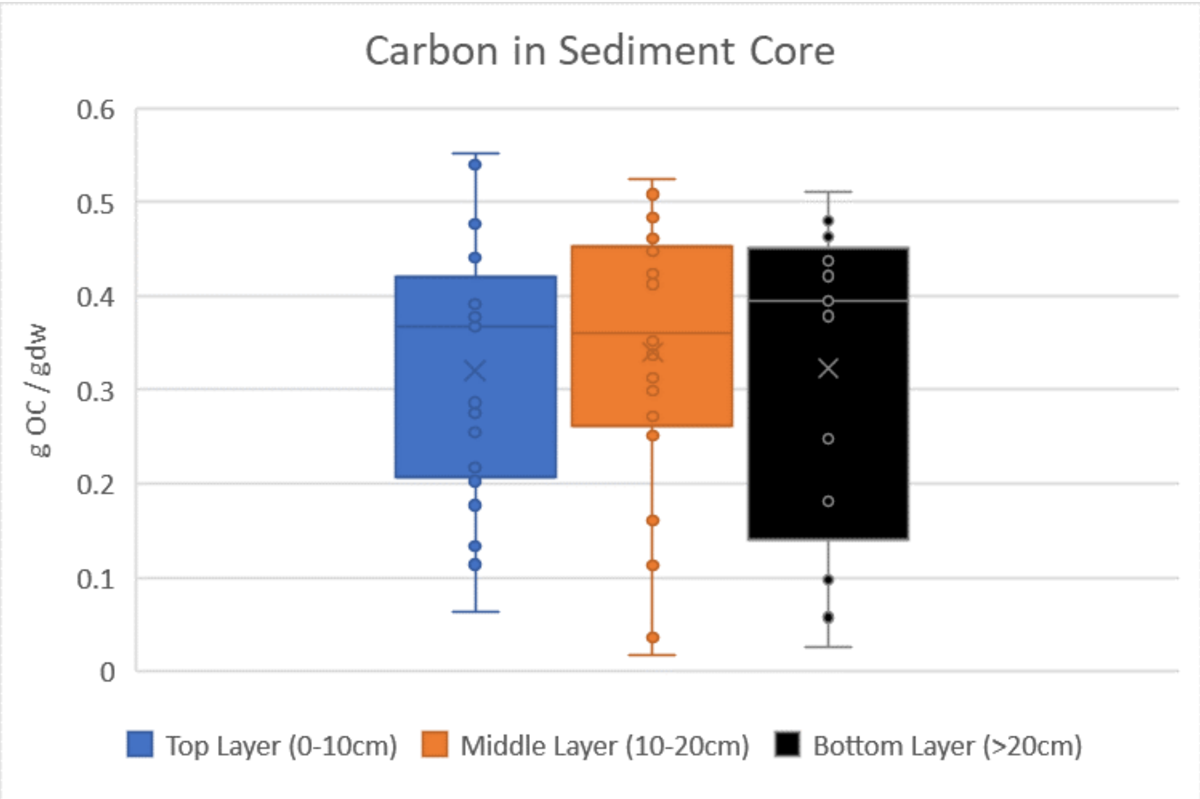

Figure 4. Boxplots for the top, middle, and bottom layers of Rice Lake sediment with quartiles and data distribution of the OC concentration (g OC/gdw).

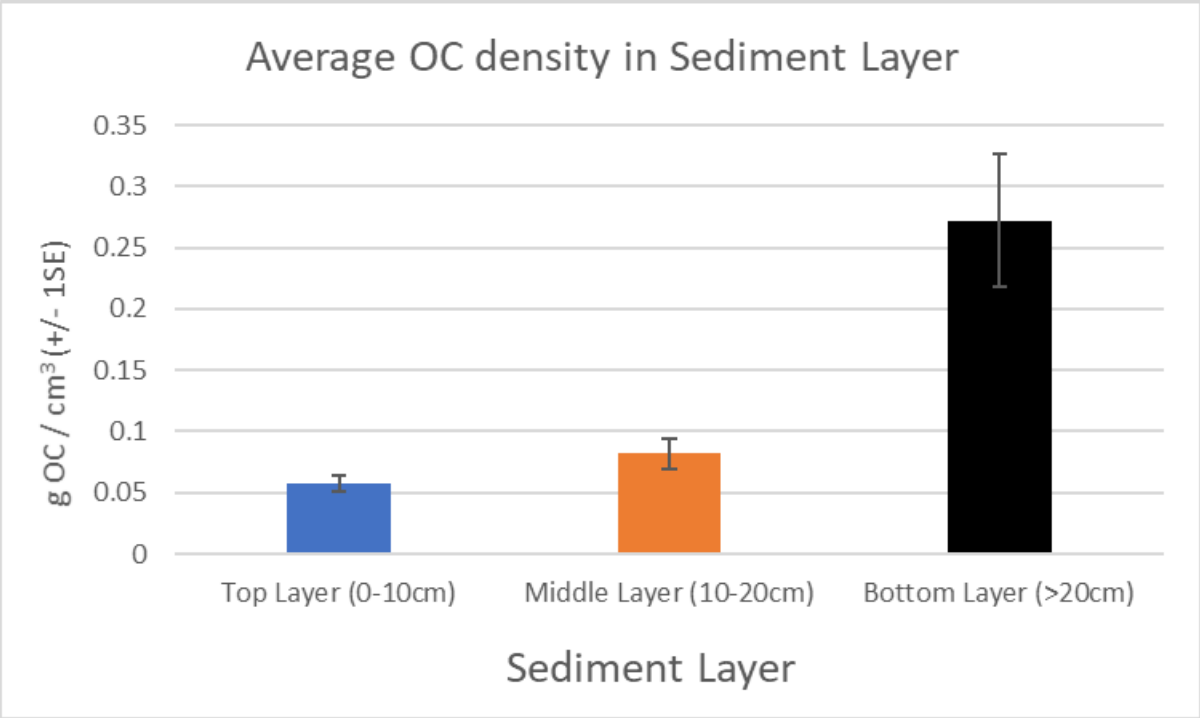

Figure 5. The average organic carbon density in g/cm^3 within Rice Lake in three sedimentary sections.

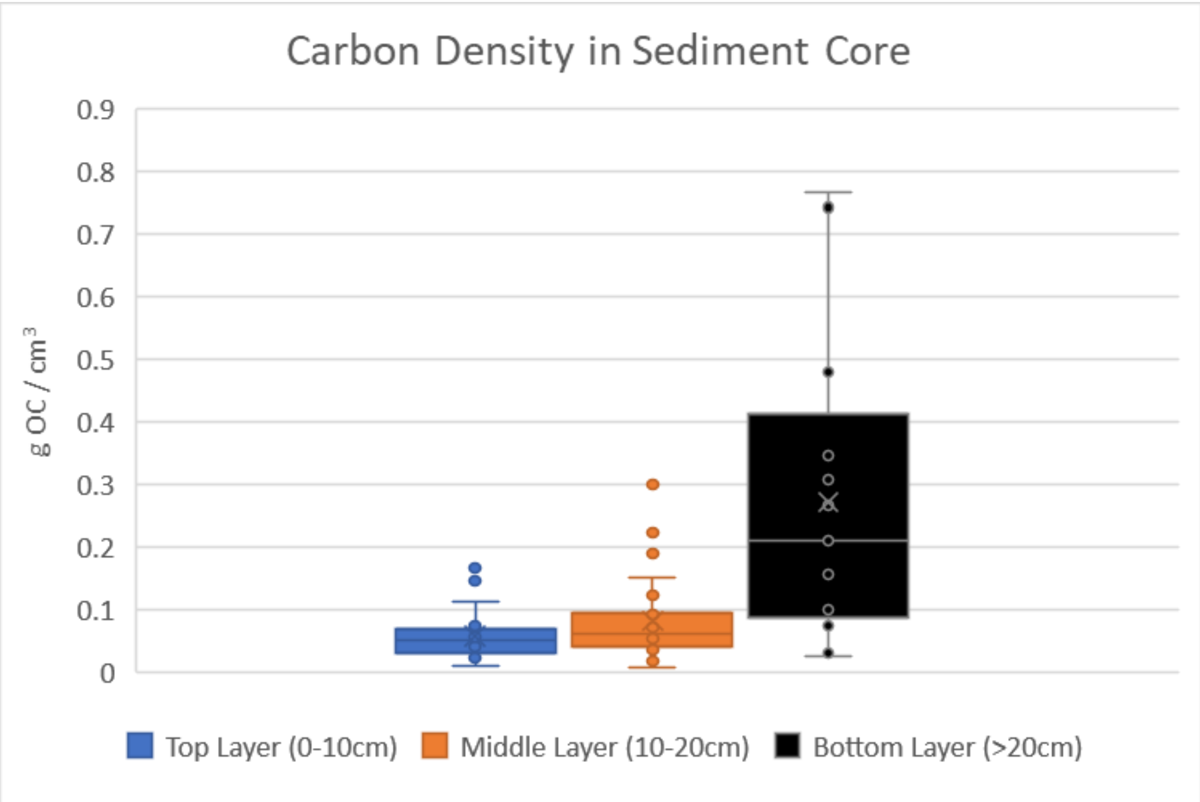

Figure 6. Boxplots for the top, middle, and bottom layers of Rice Lake sediment with quartiles and data distribution of the OC density in (g/cm^3).

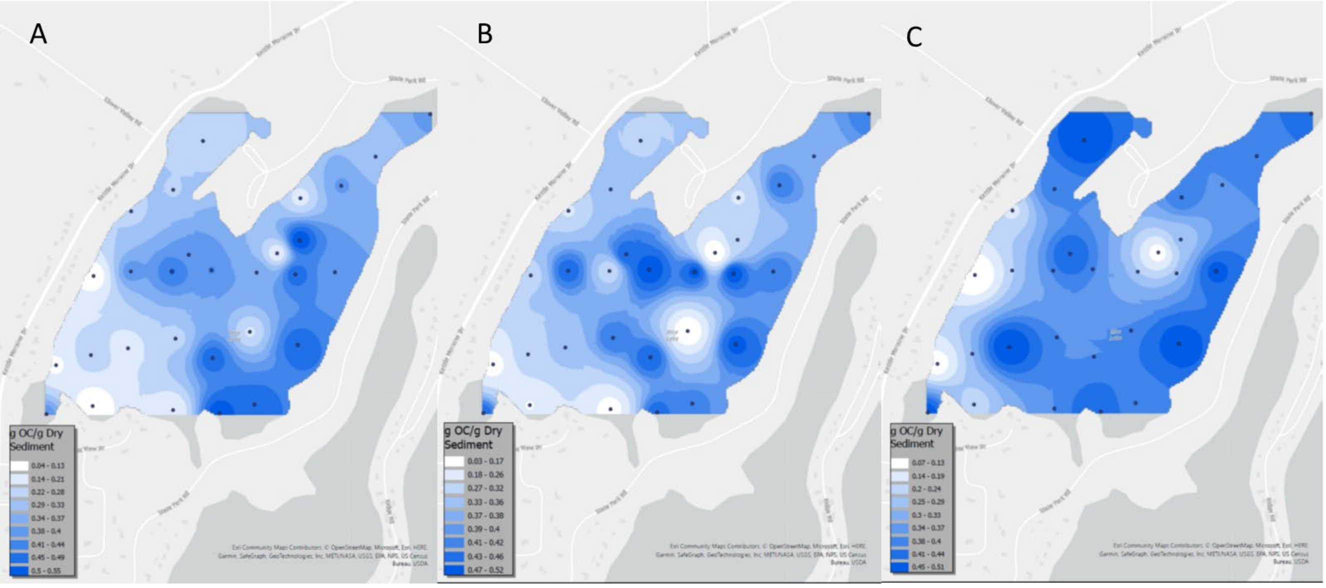

Figure 7. Map of Rice Lake showing the distribution of OC in g/gdw in the top (A), middle (B), and bottom (C) sediment layers.

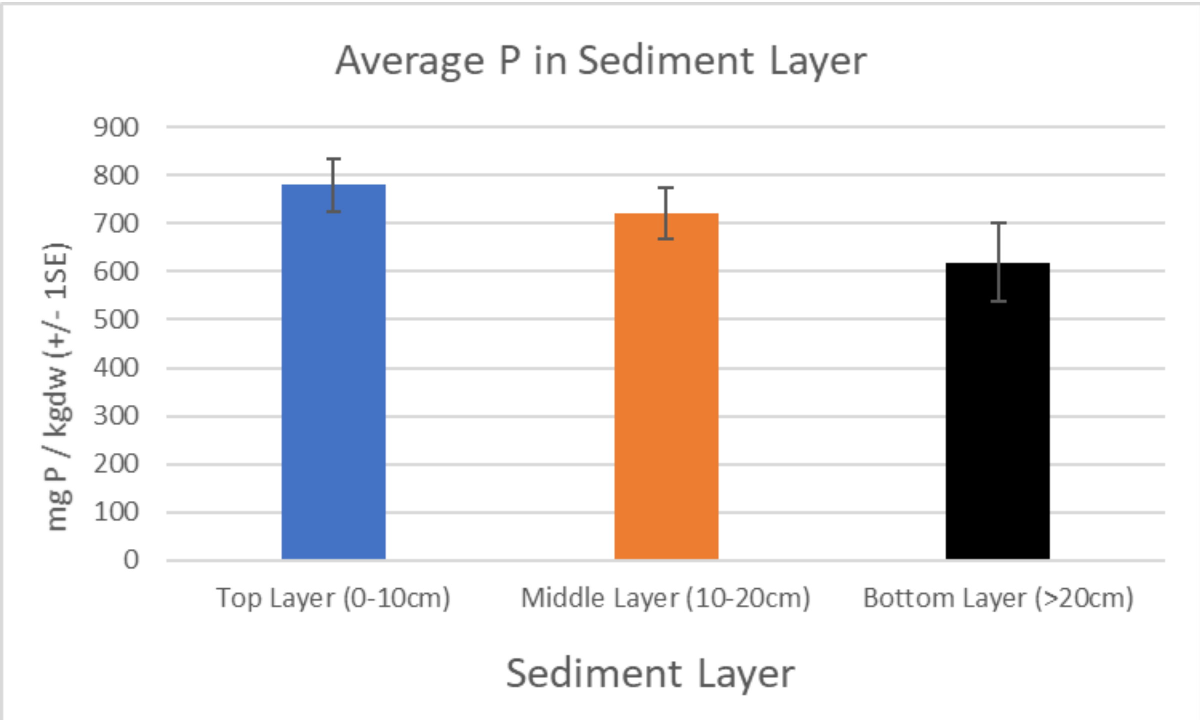

Figure 8. The average phosphorus (P) concentrations in mg/kg across Rice Lake in three sedimentary sections.

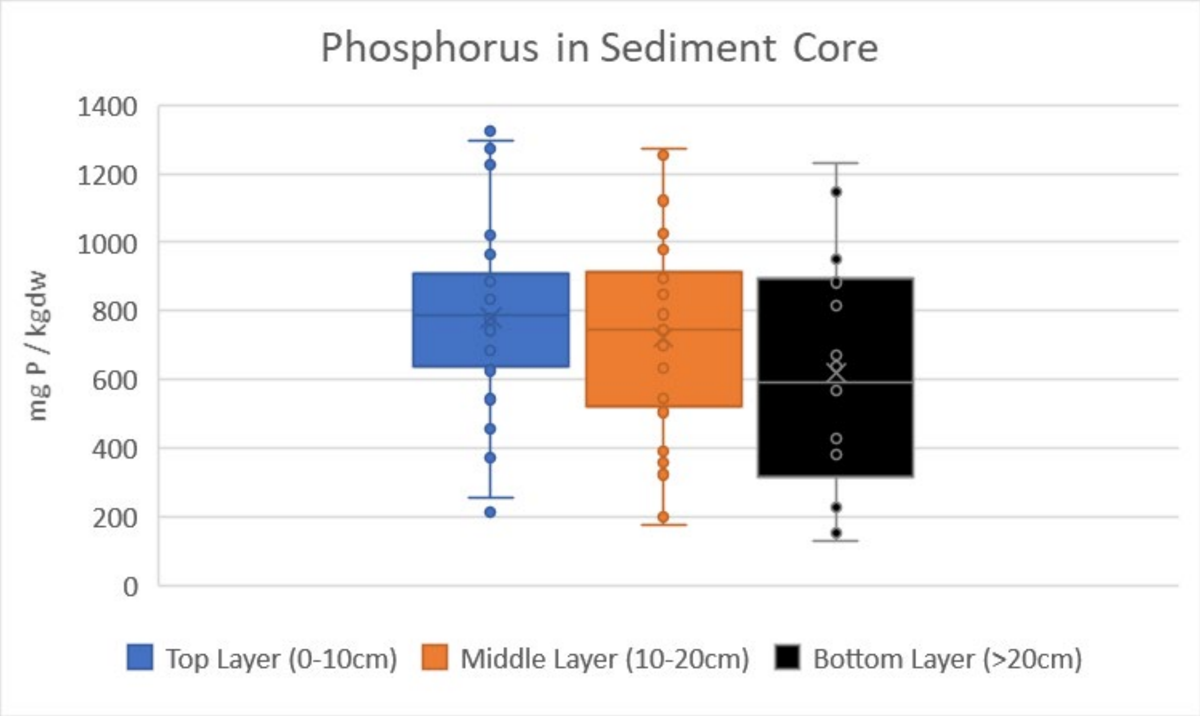

Figure 9. Boxplots for the concentration of P in mg/kg of the top, middle, and bottom layers for th Rice Lake sediment with quartiles and data distribution.

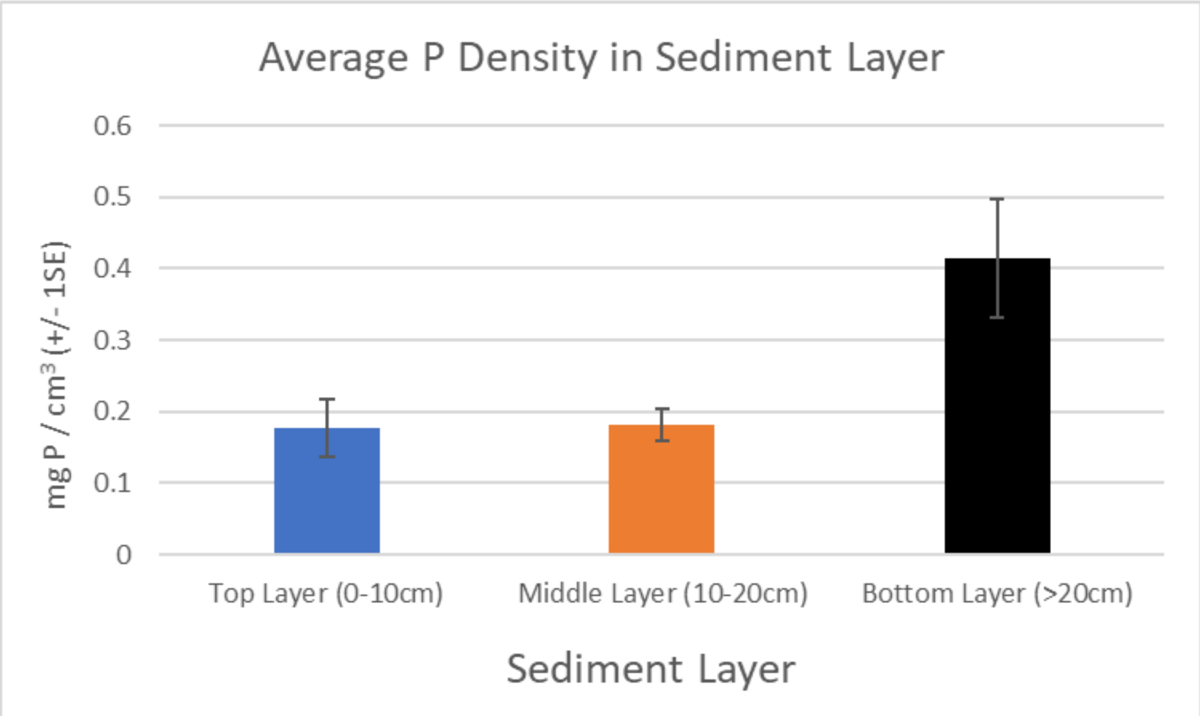

Figure 10. The average phosphorus density in g/cm^3 within Rice Lake in three sedimentary sections.

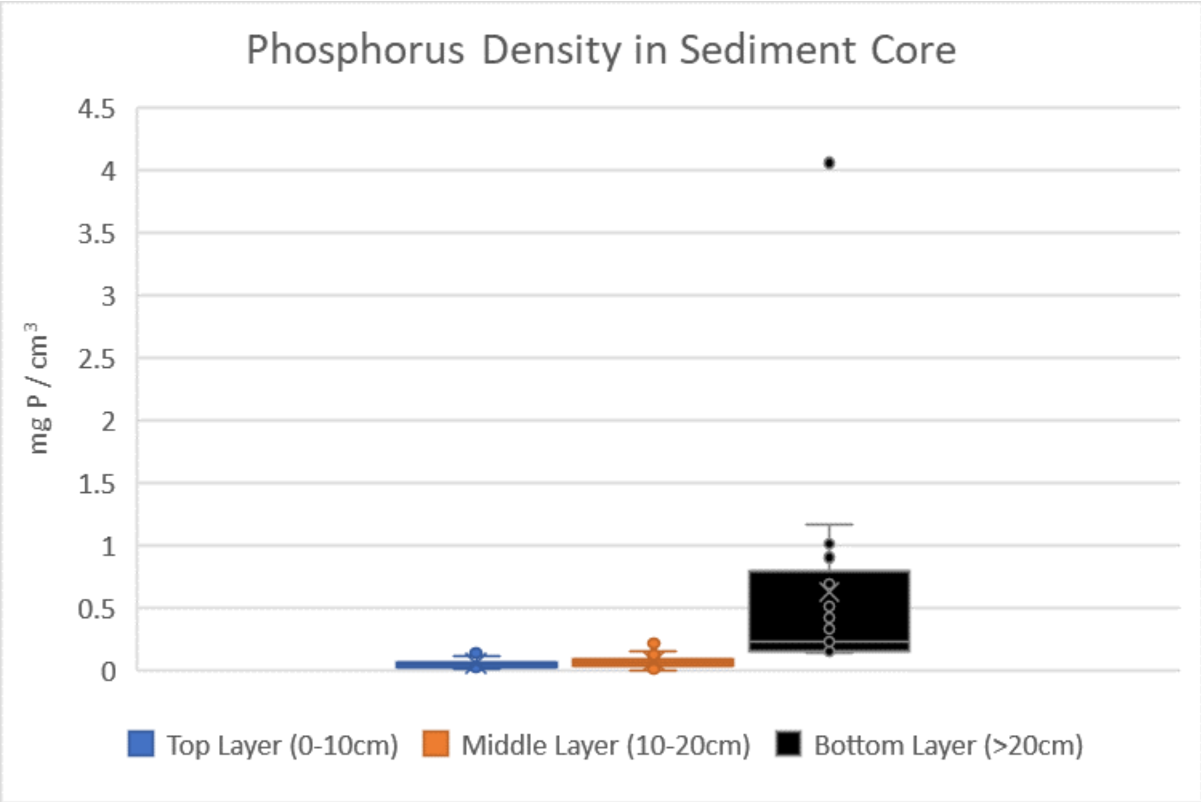

Figure 11: Boxplots for the density of P in mg P/cm^3 of the top, middle, and bottom sediment layers for Rice Lake sediment with quartiles and data distribution. One data point for the bottom layer was considered a significant outlier and not calculated in the average density of P within the sediment layer.

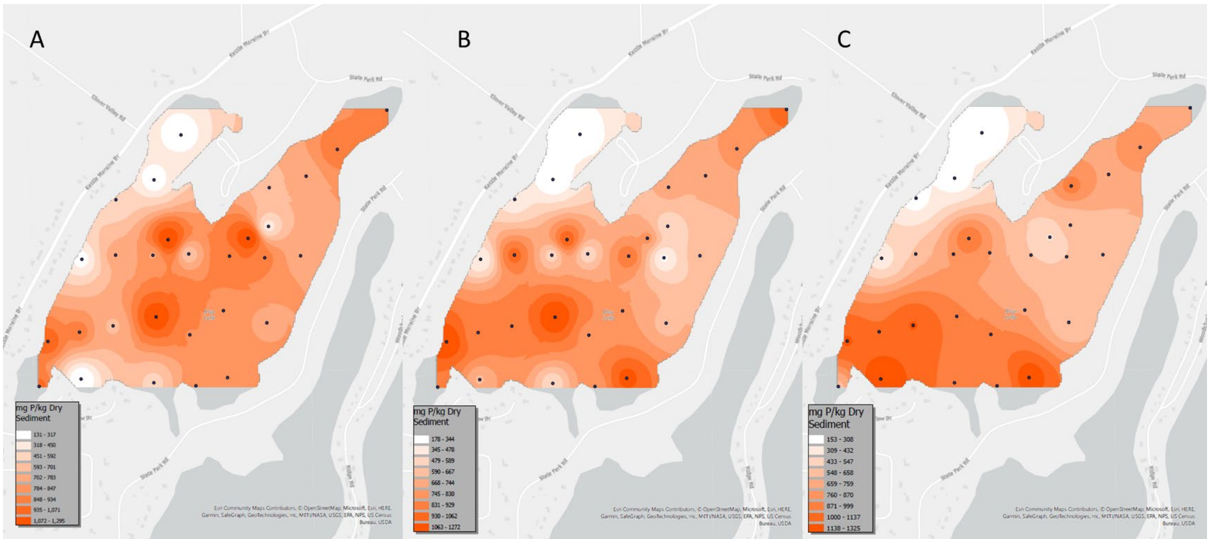

Figure 12. Map of Rice Lake showing the distribution of Pin mg/gdw in the top (A), middle (B), and bottom (C) sediment layers.