Comparison of Soil Phosphorus Storage in the Ridge and Slough Landscape in Water Conservation Area 3A (WCA3A) of the Everglades

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Abstract

The Everglades ridge and slough system is an integral part of conservation in the Everglades and has been negatively affected by anthropogenic factors including hydrological modification and excessive nutrient inputs. Research is needed to understand how ridges and sloughs store nutrients in relation to each other in order to maintain the stable state system. The intent of this research paper is to compare the TP storage in ridges and sloughs to aid the conservation effort of the system that is currently underway. Two cores were taken from central WCA3A, one from the center of a ridge and one from the center of a slough. The samples were analyzed in 2 cm increments for Total Phosphorus (TP) and five metals (Ca, Cu, Fe, Al, and K). The ridge core contained nearly twice as much TP as the slough core. If the ridge and slough cores that were sampled are indicative of TP concentrations in their respective landscape features, then ridges are major integrators of TP in the Everglades.

Introduction

For thousands of years, rain water has fallen over the Everglades watershed and naturally flowed to Lake Okeechobee and south, curving southwest to Florida Bay. Today, the Everglades is broken into hydrologically and ecologically disjointed and isolated sections by anthropogenically imposed systemic modifications (Childers et al., 2003; Osborne et al., 2011). Much of the water that was historically received by the Everglades has been diverted to the sea through canals or pumped out for potable and agricultural use. Historically, the Everglades was an oligotrophic system that received nutrients mostly through rainfall (ombrotrophic). Today, most of the Everglades has been negatively impacted by nutrient inputs and hydrological manipulation, which has affected the stabilization of the ridge and slough landscape (Ogden 2005; Bruland et al., 2007; Richardson 2010). Prior to drainage, the water input to the Everglades was approximately 81% from rain (Harvey and McCormick 2009), today rainfall accounts for approximately 61% of water input to WCA3A (SFWMD 1992). The ridge and slough landscape comprised more than half of the original Everglades prior to drainage, which started in the late 19^{th} century and peaked in the mid-20^{th} with the Central and Southern Florida Water Project (C&SF Project) (Richardson, 2010; Craft and Richardson, 2008; Larson et al., 2011). Approximately 65% of the original area of the Everglades has been lost since drainage began (Craft and Richardson, 2008). Since breaking the Everglades system into isolated sections with a system of levees and canals for flood protection and agricultural and residential uses, it has been realized that the Everglades and other wetlands systems provide valuable economic and ecological benefits when allowed to exist unmodified. Now there is a major effort to reverse the damage that has been done and return pre-drainage hydrological conditions to the Everglades.

The ridge and slough topography is the most recognizable feature of the historic Everglades landscape. Ridge soils, known as Everglades peat, are comprised of brownish black organic soils deposited by decomposing sawgrass (Cladium jamaicense). Everglades peats have a low mineral content and are less flooded than the surrounding lower land where the black Loxahatchee peats of sloughs are found (Bruland et al., 2007). Ridges are generally monotonically covered in Cladium and are oriented in an elongated fashion parallel to the flow of water. Sloughs are the depressed landscape feature adjacent and oriented parallel to ridges that act as major flow paths for water. Sloughs comprise approximately 67% of the WCA3A landscape and have a 29% higher flow rate than ridges, resulting in 86% of the water of WCA3A flowing through sloughs (Bruland et al., 2010; Harvey et al., 2009). The surfaces of the slough soils are on average 1 meter below the height of the ridge soil surface. Underlying the peat of the Everglades is a relatively flat limestone surface that gently slopes towards the Gulf of Mexico at Florida Bay. Since the underlying geology does not itself cause variability in the surface elevations at the landscape scale, hypotheses have been formulated to account for the corrugated ridge and slough surface pattern.

The mechanisms for maintenance and development of the ridge and slough topography in the Everglades are presently being studied for elucidation. The Everglades system, evolving for the past 5,000 years, started out much wetter than present conditions and consisted of a mostly slough topography (Craft and Richardson, 2008). The ridge and slough landscape have existed for at least the last 2,700 years (Bernhardt and Willard, 2009). Flow paths may have originally developed by the random deposition of peat and sediment along the general sheet flow path from Lake Okeechobee south to the Florida Bay (Larsen et al., 2007). During relatively drier periods, vegetation could have colonized the deposited peat and sediment and helped to stabilize that deposit, eventually becoming a ridge feature. The fluctuating and connected hydrology of the Everglades watershed was instrumental in creating the conditions necessary to promote the creation of the ridge and slough topography (Richardson, 2010). Restoration of the historical flows may be necessary to return the stability and functionality of the system.

The slough and ridge stable state system are maintained by positive and negative feedbacks including lignin content of vegetation, flow rates, fire frequencies, and decomposition rates (Ogden, 2005; Larsen et al., 2011; Cohen et al., 2010). Sawgrass on ridges provides a more recalcitrant material that breaks down at a slower rate than the more labile vegetation of sloughs, made up of predominantly water lilly (Nymphaea odorata). A positive feedback occurs when the vegetation growing on the ridge eventually dies and is accreted as peat. Organics and sediment carried by the water of sloughs end up entrained in ridge edges downstream, which is a mechanism for ridge expansion (Larson et al., 2007). Ridges are kept from constant expansion by other factors including higher oxidation rates than sloughs, more frequent fires, and increased flow rates of slough as ridges expand (Larson et al., 2010). Ridges have a higher rate of oxidation than the inundated sloughs but the ridge soil also has a higher lignin content from the vegetation present there and a primary productivity approximately 8 times higher than sloughs (Daoust and Childers, 1998; Larson et al., 2011). The soils in sloughs have lower decomposition rates because of lower oxygen levels on the soil surface, lowering vegetative biomass present in slough soil, but enzyme activity is greater (Larson et al., 2011). Florida's natural weather fluctuations affect the hydroperiod prior to which is also thought to benefit the heterogeneity of the ridge and slough system.

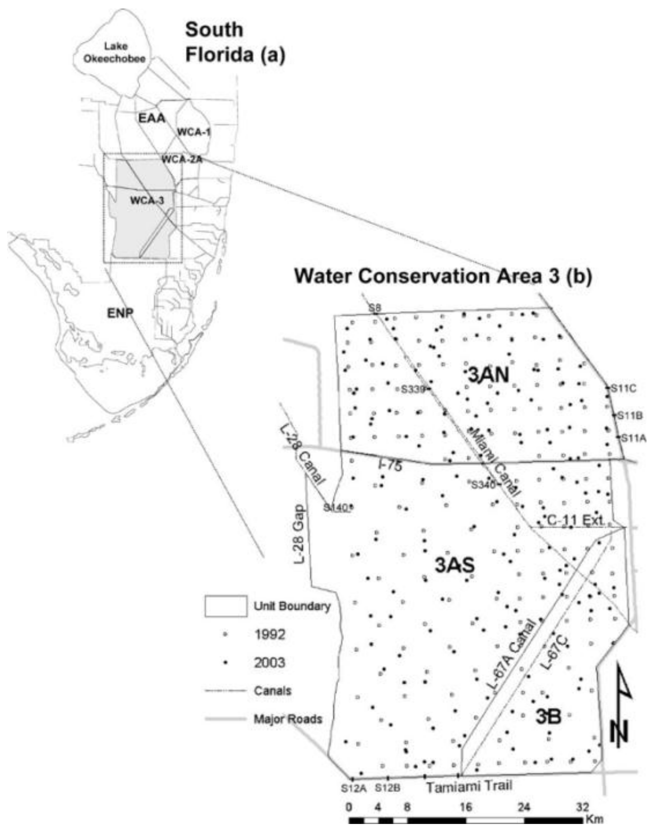


Figure 1. WCA3 figure borrowed from *Bruland et al., 2007*.

Phosphorus transport and storage are a major topic in Everglade's conservation because of the anthropogenic nutrient inputs to the system, the system's historic nutrient poor status, and the long duration of phosphorus once it enters the system. Phosphorus concentration in the water column changes dramatically over time, whereas, the phosphorus concentration in soil is used to determine long term phosphorus trends (Reddy and DeLaune, 2008). Phosphorus does not form a gas under normal conditions; therefore, there is not a quick path for phosphorus removal. Phosphorus inputs have caused local changes to vegetation and algal composition. Those changes affect the composition and stability of the peat accreted by vegetation and algal decomposition. Phosphorus is known to decrease with depth in a soil profile. The labile forms of phosphorus are found near the soil surface and become more recalcitrant further down the profile. Typically the labile forms are found near the surface because that is where biological activity results in TP use and cycling (Reddy and DeLaune, 2008). As the phosphorus in the top layer becomes depleted, a new layer of surface litter is deposited containing the labile phosphorus, burying the layer that has been depleted.

Phosphorus is thought to be more highly concentrated in ridge soils when compared to slough soils due to a greater influence of the mechanisms that cause peat and nutrient accumulation on ridges, some of which were mentioned earlier. Peat mining is possibly a major mechanism for nutrient accumulation in ridges. Peat mining is a hypothetical process where evapotranspiration and plant metabolism cause the vegetation to draw phosphorus and other nutrients, concentrating the nutrients on the landmass where the vegetation is growing, in this case ridges (Wetzel, 2009). One indication of peat mining would be a greater concentration of TP in the ridge core vs the slough core. The TP concentration in the ridge core may also be balanced by other factors such as the advective flow of P from the ridge to the surrounding slough during drought due to the mounding of the water table under the ridge (Larson et al., 2007) and dispersal of TP during a fire event. Fire is an important event in ridge soils that keeps woody vegetation from invading, releases stored nutrients, and gives Everglades peat its dark coloring (Kushlan, 1990).

Materials and Method

The system of canals, levees, and dikes currently used in the Everglades channel and impound water and have resulted in constant flooded conditions in some areas (southern WCA3A) and dry conditions in others (northern WCA3A) (Bruland, 2007). In the central portion of WCA3A, the hydrology is most similar to historic conditions and the landscape features have been relatively well conserved, compared to the north or south. This study used cores from central WCA3A to compare how the healthy ridge and slough features store phosphorus and metals.

Two cores were taken from WCA3A, from the surface down to the underlying limestone. The ridge core measured 102 cm in length and the slough core measured 76 cm in length. The cores were completed with a 3 m long and 5 cm diameter PVC soil corer. The cores were extruded from the PVC corer and sectioned in 2cm increments, placed in pre-weighed bags, weighed, and macerated. 70.5 to 97.0 grams of the macerated soil from each 2-cm depth interval was placed on a pre-weighed tin which was then weighed and dried. Bulk density was determined by dividing the dry weight by the volume of the 2cm core. Each sample was then analyzed for total phosphorus (TP), potassium (K), copper (Cu), iron (Fe), and aluminum (Al).

Loss on ignition (LOI) was measured for each sample. High LOI measurements (> 80%) were found in most of the samples, which was expected in the organic peat soils. There was a major decrease in the ridge LOI at the 80 to 100 cm interval because of increased limestone sediments. LOI generally decreased further down the soil profile as higher weight, more recalcitrant materials, were encountered.

Loss On Ignition (%)		
	Ridge	Slough
Average	81.5	87.7
Median	89.5	89.9
SD	16.1	7.2

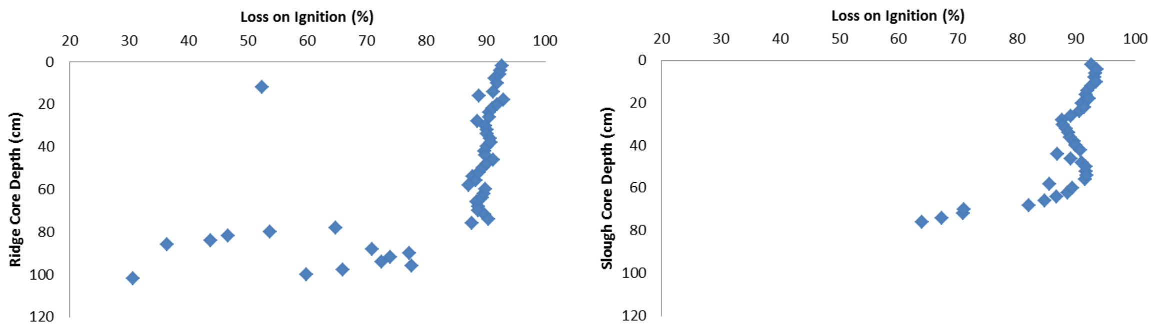


Figure 2. Loss on ignition (LOI) in ridge core (left) and slough core (right).

Average bulk density was determined to be 0.1292 g/cm^3 in the ridge core samples and 0.1092 g/cm^3 in the slough core samples. Bulk density for both ridge and slough tended to increase with depth. When comparing the average bulk density of the top 20 cm with the average bulk density of the bottom 20 cm of the ridge and slough cores, a gain of 0.1346 was seen in the ridge and 0.0326 was seen in the slough. The increase can be attributed to compaction and an increase in heavier recalcitrant materials and limestone sediment. The increase in ridge bulk density appears to be more gradual.

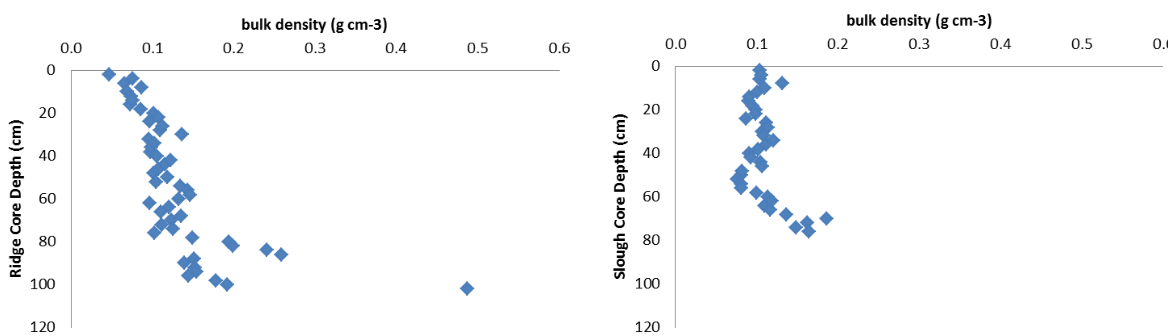


Figure 3. Bulk density in ridge core (left) and slough core (right).

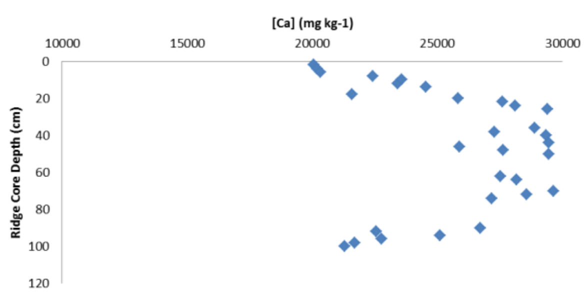
Correlations were analyzed between TP and K, TP and Ca, TP and Cu, TP and Fe, and TP and Al for both the ridge and slough cores. The highest correlation in the ridge core was a negative correlation between TP and Ca with a correlation coefficient of -0.3211. The highest correlation in the slough core was also a negative correlation between TP and Ca with a correlation coefficient of -0.6163. Also, a moderate positive correlation was indicated between TP and Cu in the slough core.

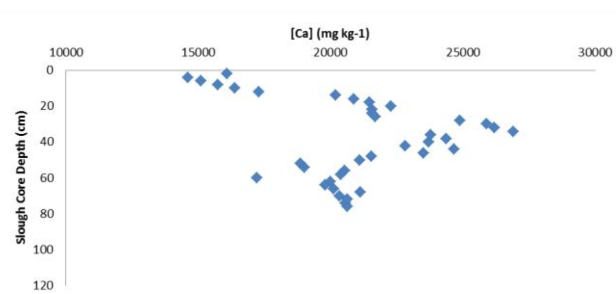
The ridge core had a higher mineral content than the slough core. The ridge contained more of each metal as a sum total than the slough, except for Fe, which was in a higher concentration in the slough core; however, the slough had a higher concentration on the average per sample. When the metal versus depth graphs for ridge and slough samples were compared, each metal showed a similar pattern in both the ridge and slough, except for the graphs for Cu. The graphs for Cu vs depth were very distinct in the ridge and slough cores with concentrations in the slough remaining close to 9.5 mg/kg down the entire profile (SD= 0.41) and concentrations in the ridge profile changing widely with depth (SD= 10.9).

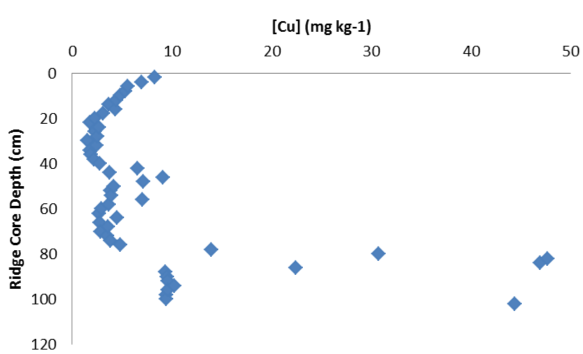
Ridge Correlation Coefficients				
TP and K	TP and Ca	TP and Cu	TP and Fe	TP and Al
-0.1079	-0.3211	-0.2522	0.018857	-0.2134
Slough Correlation Coefficients				
TP and K	TP and Ca	TP and Cu	TP and Fe	TP and Al
-0.0913	-0.6163	0.401266	-0.1990	-0.2109

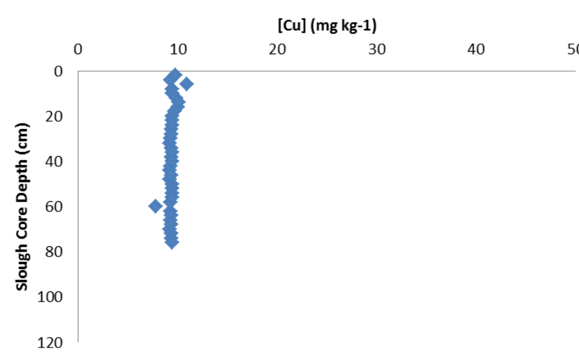
Metals (mg kg-1) in the Ridge Core					
	Ca	Cu	Fe	Al	K
Sum	2,268,313.02	425.26	292,348.99	313,585.31	19,426.96
Average	44,476.73	8.34	5,732.33	6,148.73	380.92

Metals (mg kg-1) in the Slough Core					
	Ca	Cu	Fe	Al	K
Sum	793,508.04	358.09	332,264.18	237,675.04	14,934.05
Average	20,881.79	9.42	8,743.79	6,254.61	393.00









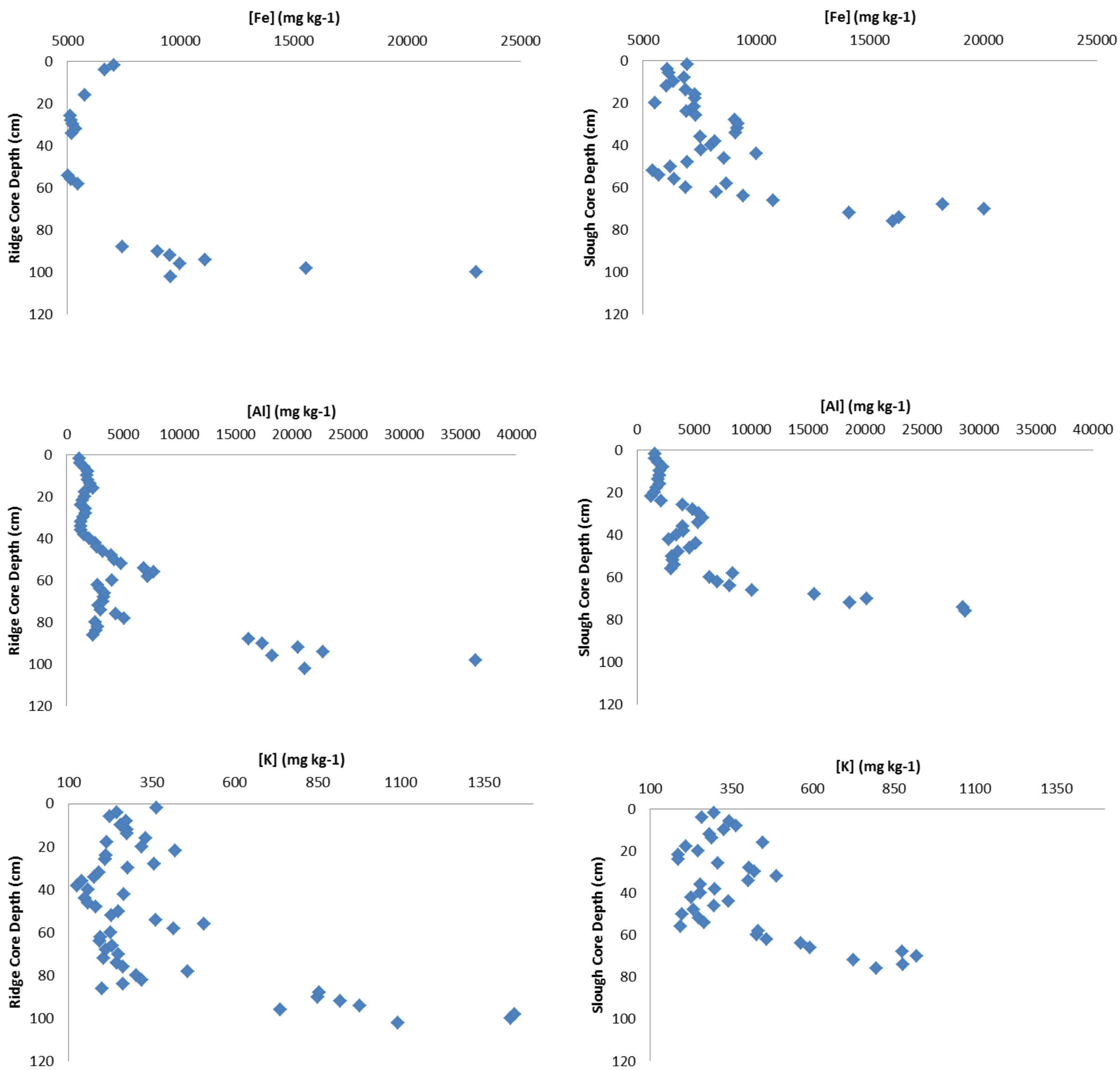


Figure 4. Metals vs depth in ridge core (left) and slough core (right).

TP (mg/kg) in the ridge and slough cores exhibited an expected decrease with depth. The ridge core contained slightly higher levels of TP (mg/kg) at the surface when compared to the slough core. The TP in mg/kg accounts for the bulk density of the soil. When TP is measured in mg, the total amount of phosphorus can be seen down the soil profile. The spike seen at the bottom of the ridge core can be attributed to approaching the phosphorus rich limestone bedrock.

The total amount of TP (mg) in the ridge core was almost twice (1.77 times) the amount of TP in the slough core. When looking at the cores in 20 cm increments, the difference in TP found in ridge and slough increases further down the soil profile. The amount of TP decreases dramatically from the 0-

20cm increment to the 40-60cm increment in the slough core (30.91 mg) compared to the ridge core (20.9 mg).

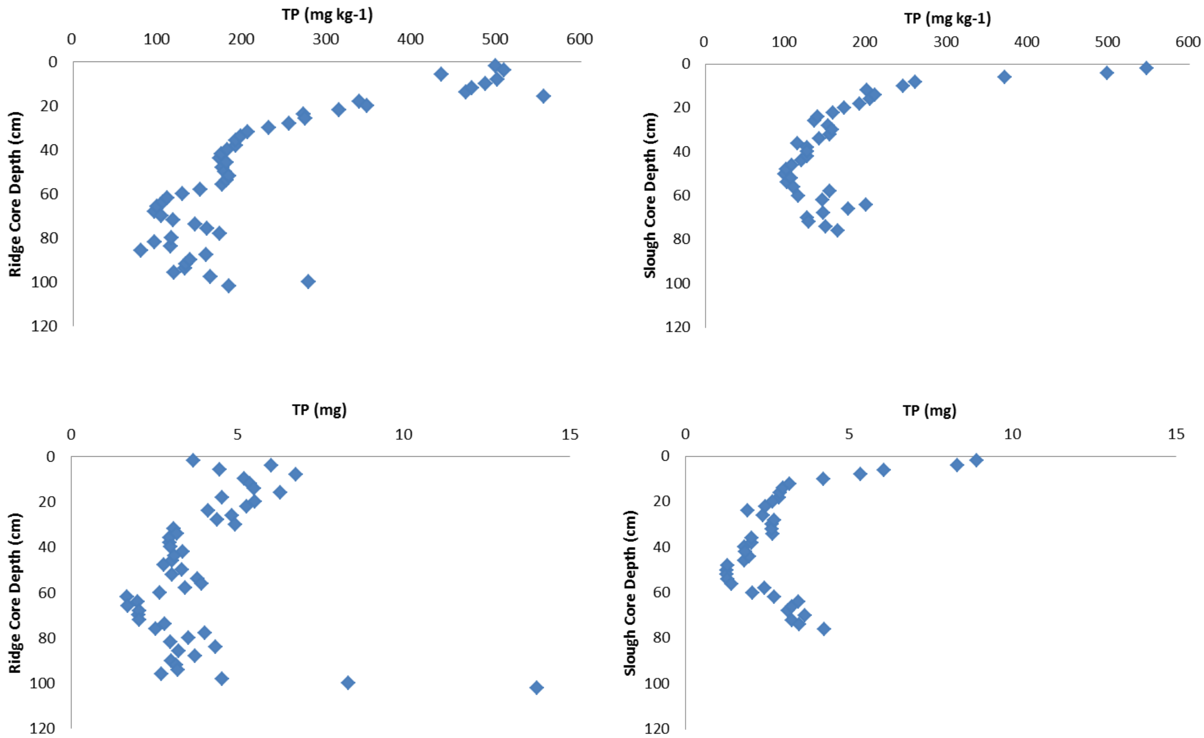


Figure 5. TP in mg and mg kg-1 in both ridge core (left) and slough core (right).

Complete Core (102 cm ridge and 76 cm slough)		
	Ridge	Slough
Sum	202.01	114.20
Avg	3.96	3.01
Median	3.34	2.66
SD	1.98	1.71

0 - 20 cm		
	Ridge	Slough
sum	53.34	47.41
Avg	5.33	4.74
median	5.44	3.70
SD	0.92	2.34

20 – 40 cm		
	Ridge	Slough
sum	38.64	23.16
Avg	3.86	2.32
median	3.65	2.41
SD	0.94	0.35

40 – 60 cm		
	Ridge	Slough
sum	32.44	16.50
Avg	3.24	1.65
median	3.22	1.60
SD	0.41	0.41

Results and Discussions

Although organic and inorganic forms of phosphorus were not determined during the lab analysis, the inorganic portion of phosphorus is areas of WCA3A is likely to be approximately 20 to 50% of the total phosphorus based on past research (Reddy and DeLaune 2008). The inorganic phosphorus in these soils can be bound by metals found in the soil and soil pore water. The high correlation between calcium (Ca) and TP found in the slough and ridge samples, suggests that Ca content is the major metal ion controlling TP solubility. The high correlation between Ca and TP in the soil cores is typical with other data that has shown Ca and Mg are the major metal ions controlling phosphorus solubility in the Everglades (Reddy and DeLaune, 2008). The correlation between Ca and TP is higher in the slough. This is probably caused by the higher amount of calcareous periphyton found in the slough. The calcareous periphyton concentrate Ca to a higher degree in the slough and are known to co-precipitate P and Ca.

The fluctuation in metal concentrations at various depths in both soil profiles indicates some redistribution events have occured. The metals analysis revealed increased metal concentrations (Al, Cu, Ca, K) at an approximate interval of 40 to 60 cm in the ridge core and increased metal concentrations (Al, Ca, K, Fe) at an approximate interval of 20 to 40 cm in the slough core. This could be indicative of a major fire event that burned in both the ridge and slough during a dry period. The metal spike appears in a lower soil depth interval in the ridge core due to more peat accretion having occurred on the ridge since the suspected fire event. Other possible redistribution events could be hurricanes, floods, or droughts; any of which would cause a fluctuation of the distribution of metals in the soil profile. Carbon dating of the cores could be used to determine if specific fluctuations can be attributed to specific historical natural conditions or events.

Total phosphorus (TP) at the surface level in both of the cores approached the maximum TP concentrations seen in wetlands not impacted by excess nutrient loading (Reddy and DeLaune, 2008). Considering the core length of the ridge core was 26 cm longer than the slough core, it is not surprising that generally more TP and metals were detected in the ridge core. The phosphorus concentrations were found to be more strongly concentrated in the ridge core compared to the slough core. This research lacked a spatial aspect that could be used to determine spatial variability. If it is assumed that the concentrations in these two cores reflect the general concentrations found in ridge and slough soils, the mechanisms that caused the redistribution of phosphorus from the slough to the ridge feature must be favored and outweigh the redistribution of phosphorus from the ridge to the slough. It is likely that peat mining and other positive feedback mechanisms occurring on ridges are responsible for the redistribution of phosphorus and minerals to ridges. Additional data would be beneficial in supporting the hypothesis of which feedback processes have caused the increased concentrations of TP seen in the ridge soil.

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