Mechanisms Behind Salt Water Induced Peat Collapse: Exploring new techniques for measuring changes in organic soil stability

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Abstract The goal of this research was to quantify the effects of salt water intrusion on freshwater wetland organic soils through field observations and laboratory experiments. Three *Cladium* spp. dominated wetlands from Cedar Key Scrub State Reserve were chosen as field sample locations due their location on the landscape and their potential to display a natural range of high, medium, and low salt water influence. Wetland soil characteristics, such as pH, conductivity, bulk density, organic matter particle size distribution , shear wave velocity, and small strain shear modulus (G_{max}) estimates were measured from 10cm soil cores and compared between wetland sites. Additionally, soil was collected in collars and soaked under various water treatments (salt-water (36ppt), brackish (11ppt and freshwater 2ppt) and measured for their rate of swelling. . The high salinity influenced wetland had the greatest level of conductivity, pH, bulk density, and lowest shear wave velocities, and was composed of smaller particle sizes. The low salinity influenced wetland soil was observed to have swelling due to saltwater additions. Swelling increased for all treatments from weeks 2-6, but the salt-water treated soil had a significantly greater increase in swelling (0-1.5cm) compared to the freshwater only treatments. Both fieldand experimental results suggest that salt-water additions could be increasing the degradation/erosion of freshwater soil through the destruction of larger particles, resulting in a decrease in the soils shear modulus.

Introduction

Peat soils (histosols) are predominantly composed of organic matter with low amounts of inorganic substances. Their accretion and persistence is believed to depend mostly on environmental conditions in which the soil is formed (Schmidt et al. 2011). Because of this, changes to the protective environmental conditions can have catastrophic effects.. For example, the susceptibility of freshwater peat soils to saltwater intrusion is another factor to consider in the context of shifting environmental conditions associated with climate change. “Approximately 150,000 km^2 of Histosols are below 5mMSL elevation and vulnerable to sea level rise” (Henman and Poulter 2008). These organic wetland soils sequester large amounts of carbon and are susceptible to peat collapse (rapid loss of vertical height in freshwater peat soils) due to salt-water intrusion, as more fresh water is diverted form wetlands for human use. This is compounded by climate change factors, specifically sea level rise and increased occurrence and magnitude of storm surges... The carbon lost from these wetlands due to this process can be transported to the ocean and cause eutrophication. If eutrophication persists, this carbon will be mineralized into carbon dioxide,contributing to the pool of greenhouse gases in the earth’s atmosphere. As greenhouse gases increase, a domino effect ensues, causing the temperature of the planet to rise which leading to ocean water to expand in area which contributes to higher sea levels (Wigley 1987). This forms a cycle with increased encroachment of storm surges causing further freshwater peat collapse to occur.

When peat collapse occurs, pockets of water in the landscape are formed resulting in a loss of unique habitat which affects species that are dependent on the presence of organic soil at an adequate height to grow. There is also a loss of wetland functions such as water purification, flood mitigation, and carbon sequestration, as well. Protecting these soils is important, but how to protect them is not necessarily easy since the mechanism or suite conditions that causes peat collapse is still unknown.

Several theories exist as to why this occurs. . One hypothesis is that the addition of sulfate may allow for increased soil decomposition and be a mechanism that initiates peat collapse. This would be similar to subsidence observed in the Everglades after drainage, which introduces oxygen, an electron acceptor, into the soil and accelerates microbial respiration (Tate 1980). Instead of the addition of oxygen to induce subsidence, saltwater has high levels of sulfate, another electron acceptor used in the absence of oxygen, that can also increase microbial respiration and potentially lead to the decomposition of peat soils (Hackney and Yelverton 1990).

Other theories have suggested that the death of wetlands plants due to increased salinities is the mechanistic cause to peat collapse because the soil is more vulnerable to erosion after plant die-off. Furthermore, the role of collapsing plant roots was examined by DeLaune et al. (1994) who noted that collapsing plants roots, resulted in a decrease in soil volume causing subsidence. Although decreased soil volume was not observed in Chambers et al. (2013), there was a decrease in soil density correlated to saltwater intrusion. Saltwater additions were also observed to cause a loss in vertical height of freshwater peat soil which inhibits plant establishment, reducing carbon inputs and soil formation creating a positive feedback loop until what was once a wetland becomes a flooded pond (DeLaune 1994). We believe that sulfate induced subsidence is most likely occurring from salt water intrusion, but it is not occurring fast enough to explain the quickly occurring event of peat collapse. Additionally, peat collapse is occurring but plants are often still present and alive in these affected soils, and rather it is the soil around them is eroding away. Our hypothesis is that sodium from salt water is having a dispersing effect on organic soil particles. Dispersing particles cause a decrease in aggregates allowing for more access and or dissolution/suspension of the once occluded carbon. This allows carbon to be susceptible to greater decomposition, decreasing the stability of the soil through the loss of larger aggregates. Saltwater may be disrupting the aggregates of the peat soil, allowing for increased rates of decomposition as well as increased risk of erosion.

Our hypothesis of sodium induced dispersion as a mechanism for peat collapse is analogous to what occurs to sodic clay soils experiencing freshwater inundation. With highly charged clay soils such as montmorillinite, there is an attraction of cations to the negatively charged surfaces. When there are several (four to nine) montmorillonite clay particles that are saturated with calcium a tactoid is formed (Frenkel et al, 1978). These formations are more compact and behave as one larger individual particle. The dispersion a tactoids develops with the addition of sodium as it can invade between the tactoids outer layer and interact with montmorillinites particle surfaces like calcium but sodium has a much larger diffuse double layer or hydration sphere then calcium which increases the repulsion between particles of the tactiod. This results in the loss of the larger tactoid structure and a release of smaller dispersed particles (Frenkel et al, 1978) Soil organic matters highly charged surfaces within aggregates could be interacting with sodium in the solution in a similar way as a highly negatively charged clay particle. The same way the addition of sodium disperses highly expansible phyllosilicates the freshwater organic soils aggregates could be dispersed with the help of sodium and lead to the formation of peat collapse.

There are many possibilities as to why salt water can be accelerating peat collapse but for this study, we want to observe if salt-water peat collapse has measurable differences in the field and if they can be recreated in the lab. The objective of this study was to monitor freshwater soil height changes under various levels of salt water additions and to observe soils across a transect of wetlands from areas of high to lower levels or salt water inundation have differences in mechanical properties and size distributions.

Methods

Study Site

Samples were collected at Cedar Key Scrub State Reserve in Levy County, Florida (Figure 1). The three wetlands sampled were selected because of their similar sawgrass plant community (*Cladium* spp.) and soil types (Placid and Samsula soils (web soil survey)). Although similar sample sites were located at different distances from the edge of the salt marsh. This allowed for a transect to be sampled across multiple wetlands that ranged from high levels of saltwater intrusion to an area of less salt water intrusion. The three wetlands sampled were designated as A (29.19208, -83.03349), B (29.19300, -83.03259) and C (29.1965, -83.02761)(Figure 2). Wetland A was the closest in distance to the salt marsh, while wetland C was located furthest from the salt marsh acting and was used as a control site. Wetland B was relatively equidistant from Wetlands A and C. Samples for the first experiment, pH, conductivity, bulk density, and loss on ignition measurements were collected on 12/15/2017 and a second sampling was conducted 3/4/2018.

Soil Characterization Methodology

For soil characterization, three core tubes (10cm diameter PVC pipes) were pushed into to the soil until refusal at each wetland site. Twelve 10cm tall collars were also collected using 10cm diameter PVC pipes to be used in the swell experiment, and 70cm diameter PVC pipes were used for collecting soils cores used for particle size analysis and shear velocity measurements. Fifteen cores were collected for the bender experiment and ten cores collected for the particle size analysis experiments.

Laboratory Analysis

Soil bulk density, pH, and loss on ignition (LOI) of collected soils were measured in the laboratory and compared between wetlands. Soils were extracted from the 10cm diameter coring tubes and sectioned off at every 5cm. The number of 5cm sections varied depending on how depth of each core sample.

A solution was created by adding 20g of soil from each 5cm section to 20mL of water, which was then centrifuged for 30 min. The supernatant was then poured off into a beaker and A 7pros™ pen was used to measure pH of the solution, while an Ohaus™ ST10C-B 0-1999 uS/cm or ST10C-C 0.00-19.99 ms/cm was used when measuring conductivity. Different conductivity meters were used depending on the salinity range. Dry bulk density was done on the entire 5cm soil sections weighing after being dried at 70°C until a steady weight was reached (Chambers et al. 2013). One gram of dried soil was sampled from each 5cm depth and used for mass loss on ignition (LOI). “Organic matter % was estimated by LOI where dry soils were combusted at 550 C for 5-hours and final weight was subtracted from initial weight” (Chambers et al. 2013)

Mineralogy Methods

40g of dried 2mm sieved soil from wetland C at 20-25cm depth. X-ray diffraction (XRD) analysis was performed on soil deeper in the vertical profile due to higher mineral content. Originally, a sample from 0-5cm depth was scanned by XRD, but interference from very high organic matter content precluded effective mineral detection and identification. Since we were interested in determining the presence of expansible phyllosilicates in the soil, we removed the sand by wet sieving to increase the probability of observing other minerals besides quartz in the silt and clay fractions. This was accomplished by placing samples in a sonic bath, sonicating repeatedly at 30 sec intervals, and transferring six aliquots of approximately 150 mL of water and soil until all soil was transferred to 0.05 mm sieves. Material that held up on the sieve was washed until the leachate was essentially clear (after about 1000 mL of wash water). A rubber policeman was used to aid in disaggregating silt and clay particles. The < 0.05-mm material was allowed to settle, after which the excess supernatant was decanted. Two vacuum filtration mounts with 0.45µm Millipore filters were used to filter out silt and clay (<0.05 mm) particles under suction. Material remaining on the filters was saturated under suction with approximately 25 mL of M KCl or M MgCl solution. The K- and Mg-saturated retentates were rinsed with deionized water to wash out the entrained salt solutions. The filters with retentates were left to dry for half a minute to become slightly tacky for mounting on a glass slide. The transfer to a glass slide was involved placing the wet Millipore filter face-down onto the slide, rolling the bottom side of the filter with a glass rod, and then slowly peeling off the filter leaving the sample on the glass slide.

XRD analyses (Harris and White, 2008) were conducted using a computer-controlled x-ray diffractometer (Ultima IV X-Ray Diffractometer, Rigaku Corporation, Japan) equipped with stepping motor and graphite crystal monochromator. Scans were conducted from 2-30º 2θ at a rate of 2° 2θ min^{-1} using Cu Kα radiation. After analyzing with XRD, the amorphous glass slide caused too much background noise to analyze so the K and Mg samples were put on a specially cut quartz crystal mount with a drop of water and mixed into a homogenous slurry that was left to dry. The crystal mount allowed for a clearer interpretation of the peaks so these results were used for the analysis instead of the glass mounted results.

Swell Experiment Methodology

Soils were collected from Wetland C because it was not impacted by salt water intrusion. Twelve surface soil collar samples were collected from the same area of the wetland (lat/long: 29.1965, -83.02761) and then separated into three groups of four cores to undergo different water treatments. The 10cm cores and collars were collected in areas that were free of vegetation if possible. To help with the collars ability to cut into the soil, the top layer of litter was removed and the core was pressed firmly into the soil. Cores were shoved down until flush with the soil surface.. Cores were extracted using bare hands or a sharp shooter shovel to ensure that it remained intact. Cores were then pushed down slightly until the top of the soil was over the top of the collar by 1 cm. Then the bottom and top were leveled off with a spatula and/or plant pruning shears. A PVC cap placed on the bottom sharpened side of the core. Cores were hydrated with water on site and stored in zip lock bags.

Cores were put into non-draining planting containers and submerged into various concentrations of freshwater/salt water. For the swell experiment, water from the University of Florida greenhouses were used along with Cedar Key ocean water. Soil collars were submerged into water filled plant containers and left to sit for weeks at a time. Containers were refilled with freshwater from the greenhouse each week to replace water lost to evaporation. The treatments were either collars saturated in water that was 100% from the greenhouse water-freshwater treatments, 100% Cedar Key salt water -salt water treatments 1/3 amount salt water and 2/3 greenhouse water - brackish water treatment.

Soils were left to sit submerged in the water for a total of 8 weeks and measured once a week for amount of swelling above the container. Soil swelling was determined by height measurement as all sides except the top of the soil was enclosed by the PVC pipe and the PVC cap on the bottom. Soil height was measured from the top of the container to the top of the highest mass of soil using a ruler, after being drained of water.

Linear regression was used in R to compare differences of the slopes in the rate of growth between each treatment type.

Bender Element Methods

Five pvc cores with a diameter of 69.35mm were taken from each of the three wetlands. Soils were extracted in the lab and then cut into 0-10cm and 10-20cm sections using a stainless steel spatula to separate the samples and scissors to cut twigs and roots, as needed. Samples were measured after the initial sectioning to determine the actual length (cm). The total volume of each section was then calculated f using the equation for the volume of a cylinder, $V = \pi r 2 h$, with a radius of 34.7mm . Samples were left to drain on a counter for a few minutes before being put into an aluminum pan and placed on a scale to determine mass.. The field density was calculated by taking the mass of the soil sample and dividing it by the calculated cylinder volume.

The bender element settings were set at a frequency of 55 Hz and an amplitude of 2.0V with the machine input of 27.5 resulting in a total of about 50V. The generating bender element extended 9.8mm from the platform and the receiving electrode extended 10.58mm from the base resulting in a total of 20.38mm deducted from the samples volume to account for the actual distance between bender elements once embedded into the samples. The calculated length between bender element was used for determining the shear wave velocity measurement. The soil sample was placed onto the receiving bender element, oriented with the bottom end down and without supports as the organic soil was able to hold it's shape without assistance. The generating element was placed on the top of the soil carefully to ensure it would remain balanced. A close eye was kept on the samples as samples would slouch and fall apart if larger sticks were present or if left standing for a long period of time.

Two pulses were generated at a time to measure the shear wave velocity of the samples. The generating line was measured right at the start of the generated pulse and the receiving lines arrival was measured as the first large peak. The estimations of the shear modulus (Gmax) was calculated from $G_{max}=\rho V_s^2$, where ρ is density of the soil sample and V is the shear wave velocity. The end results were converted into Mpa.

The statistics for these measurements were done using Microsoft excel.

Laser Diffraction Particle size analysis comparison between wetlands

For the measurements we used a LS 13 320 Laser Diffraction Particle Size Analyzer from Beckman Coulter with running water 7.2 L/min. Three 70mm diameter cores were taken from each wetland and sectioned into two depths, starting from the surface 0-10cm and then taken from 10-20cm. These sectioned cores were then cut into four pieces, across the middle in both directions, and two of the best 1/4th sections (no large sticks or large plant roots) were kept and the rest were thrown out. All of the kept sections were put into a bag with the other sections taken from the same depth and wetland and mixed to create one homogenous bag of soil sample. Two homogenously mixed sample bags were obtained from each of the three wetlands at two depths 0-10cm and 10-20cm. The bagged samples were kept refrigerated until they could be analyzed for particle size.

Fifteen grams of the bagged soil samples was taken out was wet sieved through a 2 mm mesh sieve with 800 ml of di water into a 1000ml beaker. They then sat for one day and were then measured with the Laser Diffraction (LD) Particle Size Analyzer three separate times. The measurement was repeated three times for each wetland/depth samples to observe the amount of variation within measurements that might occur.

To collect a consistently mixed sample between the three measurements, a mixing plate was used to create a vortex. Samples for measurement were collected by dipping a 80ml beaker into the middle of the vortex and dumping out all of the contents within the 80ml beaker into the particle size analyzer. To catch any tiny debris stuck to the glass a Di squirt bottle was used over the LD machine to wash out the beaker completely.

An obscuration rate of 8-12% was used for both measuring a consistent amount of sample and for optimum particle size analysis reading. This method allowed for a consistent amount of sample between wetlands to be measured regardless if one wetland happened to have more sand or water, because samples were added until an equal amount of light was obscured. This obscuration rate was also used because it had been found to be the ideal rate for measurements to be taken on this machine. If the obscuration rate was not at 8% another scoop was taken from the vortexed sample and added into the LD machine. If the sample was above 12% the entire sample in the LD machine had to be thrown out and be redone. This was important because every time a scoop was taken from the vortexed sample the entire contents collected had to either be put into the LD machine or dumped back into the beaker if it looked like it was going to be too much sample. Pouring only a partial amount of the scooped sample would result in selection for smaller particles that do not sink as quickly to the bottom of the beaker and would skew the measurement taken. For this reason, the entire scooped sample taken from the vortex had to be put into the machine and if it ended up being to much the whole sample would be thrown out.

Method dispersion experiment

For the particle size analysis experiment, we wanted to observe if dispersion of particles could be induced with application of a dispersant and measured using LD particle size analyzer. The machine used was the same LS 13 320 Laser Diffraction Particle Size Analyzer from Beckman Coulter with running water 7.2 L/min. The soil samples for this experiment came from two 70mm diameter cores taken from the Cedar Key Scrub Reserve wetland C, which was the least likely wetland to have been affected by salt-water intrusion. The samples were separated at two depths and the two core sections at the same depth were mixed homogenously together.

For this experiment, two water treatments were used. Samples collected from the same soil were subjected to either a Di only water solution or a 2.5% sodium hexametaphosphate Di solution. For the dispersed samples 5ml of sodium hexametaphosphate at 5% concentrations and 5ml of di water were added to a falcon tube with a wet soil sample. The samples and solution were mixed on a vortexer for several seconds and left to sit for an entire day. After sitting the samples were run through the LD machine and measured for their particle size distributions every 15 minutes for up to an hour.

Then the homogenous soils left over were air dried for a week and sifted through a 2mm sieve. 0.5 grams of soil was measured out and put into falcon tubes with the same process performed for the wet samples but were done again for the dry samples.

Analysis for the experiment results and measurements were done using Microsoft excel.

Results

Table 1. Bulk density of peat soil samples from Cedar Key Scrub State Reserve

There cores were taken at each wetland and sampled every 5cm down to a depth of 15 cm. All soils had increasing bulk density with depth. Two tailed tests compared all samples within each wetland down to six inches depth. Wetland A & C had a significant difference in bulk density with a p value of 0.02 and Wetland A & B also had a significant difference with p value 0.002. Wetland B and C were not significantly different. LOI was taken from the dried bulk density samples of WC1 and had a decreasing % OM with depth.

Figure 3. Top: The pH of soil samples collected from each wetland. Wetland C (the most inland) had the lowest levels of pH while the wetland A had higher overall pH values.

Bottom: Conductivity of soil samples collected from each wetland. Wetlands B and C (more inland) had lower overall conductivity compared to wetland A

Figure 4. Swell Experiment of Wetland C soil subjected to different levels of saltwater.

From weeks 2-6 the change in slope of freshwater to salt-water treatment height growth is significant p=1.98e-07. The change in the slopes value from freshwater to brackish was not statistically significant p=0.076. Saltwater had a pH of 7.01, Brackish had pH of 7.48, and Freshwater had a pH of 8.36. Rainbow sheens were observed in the salt water treatment starting at week 2 and rainbow sheen was observed in the brackish treatment at week 3. No rainbow sheen was observed in the freshwater treatments throughout the experiment.

Figure 5. Comparison of mineralogy of Cedar Key Wetland Samsula soil clay and silt fraction taken from 10-25cm depth.

The XRD results showed a large amount of quartz in the silt to clay fraction of this soil sample but also the presence of kaolinite, a hydroxyinterlayered mineral (HIM) and an unknown mineral.

Bender Element Experiment Results

Figure 6. Top graph: Density g cm-3 of each core sample by wetland at a depth of 0-10cm

The field densities of samples 0-10cm depth from wetland C are lower than the other two wetlands from the same depth

Bottom graph: Density g cm-3 of each core sample by wetland at a depth of 10-20cm

Wetland A samples collected from 10-20cm depth were greater than the samples collected for wetlands B and C at the same depth

Figure 7. Top graph: Shear wave velocity measurement mm/s of each core sample by wetland at a depth of 0-10cm

From the 0-10cm depth, shear wave velocity of samples collected from wetland A were consistently lower then samples collected from the other wetlands except for core number 2 in wetland B which is slightly lower. Wetland C has higher shear wave velocity values except for core 1 where wetland B has a higher value.

Bottom graph: Shear wave velocity measurement mm/s of each core sample by wetland at a depth of 10-20cm

From depth 10-20cm the shear wave velocity is lowest at wetland A except in core 2 where wetland B has a lower value. Wetland C has the highest values except in core 5 where wetland B has a higher value.

Figure 8. Top graph: Gmax estimates by core sample in each wetland at a depth of 0-10cm

From depths 0-10cm the Gmax is lower for samples collected from wetland A compared to the other wetlands which have more high and low values.

Bottom graph: Gmax estimates by core sample in each wetland at a depth of 10-20cm

From depth of 10-20cm wetland A samples are more consistently low while the other two wetlands have more high and low values.

Table 2. T Tests comparing Gmax, velocity and density between wetlands by depth

At 0-10cm wetland C has different densities then the other wetlands. Wetland A and Wetland C were significantly different in velocity. At 10-20cm Wetland C has a different density then the other wetlands. From 0-20cm Wetland C was significantly different from the other two wetlands. Wetland C and Wetland A had significantly different shear wave velocities. The estimated Gmax for Wetland A samples were significantly different from the other two wetlands

Table 3. Average values and confidence interval for each wetland by depth for density, shear wave velocity and estimated Gmax

Wetland C tended to have lower average densities at top at 0-10cm and 10-20cm. Velocity was lowest at both depths in wetland A and increased from wetland B to Wetland C. The confidence interval for velocity at wetland A was lower for both depths 0.23, 0.26 g cm-3 compared to wetlands C and B. The Gmax estimate was lowest at both depths in wetland A 1.01, 1.14 Mpa and increased from wetland B to Wetland C. The confidence interval for the

Gmax estimate at wetland A was lower for both depths 0.19, 0.18 compared to wetlands C and B.

Particle Size Analysis

Figure 9. Top graph: The average particle distribution of Wetland C, the least affected by salt-water intrusion at 0-10cm and 10-20cm with standard deviation bars

The particles are large in this sample at both depths with peaks at ~700um and ~200um. The lower depth has less % volume of sample at the ~700um peak and has a larger % volume in particle sizes less then ~500um. This lower depth has an organic soil composition shifting towards the left indicating that the lower depth has an increase in finer particles sizes and a decrease in the larger particle sizes.

The standard deviation bars are bigger in the large particle sizes greater then ~700um then the standard deviation bars in particle sizes less then ~90um suggesting that there is a lot more variation in the larger particle sizes.

Middle graph: The average particle distribution of Wetland B at 0-10cm and 10-20cm with standard deviation bars

The particles are large in this sample at both depths with peaks at ~600um and ~200um. The lower depth has less % volume of sample at the ~600um peak and has a greater % volume in particle sizes around ~50um. This lower depth has an organic soil composition shifting towards the left indicating that the lower depth has an increase in finer particles sizes and a decrease in the larger particle sizes.

The standard deviation bars are bigger in the large particle sizes ~1000um compared to the standard deviation bars ~90um suggesting that there is a lot of variation in the larger particle sizes.

Bottom graph: The average particle distribution of Wetland A, the most salt water affected, at 0-10cm and 10-20cm with standard deviation bars

The particles are large in this sample at both depths with peaks at ~600um and ~90um. The lower depth has less % volume of sample at the ~600um peak and has a greater % volume in particle sizes less then ~100um. This lower depth has an organic soil composition shifting towards the left indicating that the lower depth has an increase in finer particles sizes and a decrease in the larger particle sizes.

The standard deviation bars are smaller throughout both of these samples suggesting the organic matter particle size distribution is more homogenous.

Figure 10. Top graph: The average particle distribution of all three wetland from at 0-10cm with standard deviation bars

From samples collected at 0-10cm depth, Wetland C has greater % volume of large particle sizes from ~700-600 um, wetland B is the next highest and then wetland A has the least % volume in the larger diameter particles. Wetland C also has a lot more variation in the very large particle sizes greater then ~600um, wetland B also has some variation in these larger particle sizes but wetland A has very little variation.

Conversely Wetland A has a greater % volume in the particles less then ~90um, with wetland B has the next highest % volume and wetland C containing the lowest % volume of smaller particles. Microaggergates are less then 250um so wetland A has a larger % volume of microaggergates and wetland C has a larger % volume in the macroaggergate category. There is a gradient shifting to the left, with larger particles in wetland C, smaller particles in wetland A and wetland B in-between both extremes.

Bottom graph: The average particle distribution of all three wetland from at 10-20cm with standard deviation bars

From samples taken 10-20cm. Wetland C has greater % volume of large particle sizes that are greater then ~600 um, wetland B is the next highest % volume and wetland A has the least % volume in these larger size particles. Wetland C also has a more variation in the very large particle sizes greater then ~600um, wetland B also has a lot of variation in these larger particle sizes and wetland A has the least. Wetland B and C have more variation in the larger particle sizes then wetland A.

Conversely Wetland A has a greater % volume in the particles less then ~90um, with wetland B having the next highest % volume and wetland C containing the lowest % volume of these smaller particles. Wetland A has a larger % volume of microaggergates and wetland C has a larger % volume in the macroaggergate category. There is a shifting to the left, with larger particles in wetland C, smaller particles in wetland A and wetland B is half way from both.

Figure 11. Top graph: Particle size distribution with time by water treatment of wetland C soil 0-10in, with samples kept field moist

In this graph several variables were measured such as the effect of disturbance over time and sodium hexametaphosphate dispersed sample (indicated in red as Na) vs DI only water treated samples (indicated in blue with no suffix). This graph was put onto a larger % volume scale so it can be compared later with dried samples taken from the same location and depth.

The Di treated samples have greater % volume of large diameter particles (~700um) and a smaller amount of smaller (~120um) particle sizes compared to the Na treated samples. The Na treated samples particle size distribution appears to be shifting the distribution slightly to the left.

The increase of time within the machine results in a slight and steady shift in particle sizes to the left of the distribution regardless of water treatment. With time running through the machine the larger particles are being broken up into smaller ones.

Bottom graph: Particle size distribution with time by water treatment of wetland C soil 0-10in, with dried samples

The drying of the soil resulted in a very different size distribution pattern for the same soil that remained different even after running through the LD for one hour. Compared to the samples that were kept wet the % volume of the large particle diameters are much greater and there is only a decrease in % volume after the initial large peak while the wet soil has a bimodal shaped distribution. Drying of the soils had a dramatic change on the particle size composition in these organic soil samples.

Similar to the field moist samples the Di treated samples have greater % volume of large diameter particles (~700um) but less in smaller (~500um) diameter particles compared to the Na treated samples. The Na treated samples particle size distribution appears to be shifting the distribution to the left.

The increase of time within the machine results in a slight steady shift in particle sizes to the left of the distribution with time regardless of water treatment time. With time running through the machine, the larger particles are being broken up into smaller ones. In this case the % volume of the Di water treated samples at ~700um is greater than the Na treated samples but after 60 minutes the Di samples were at about the same % volume as the Na treated samples at time 0. The effect of the water treatment is more dramatic in the dried soil samples compared to the soils kept field moist.

Table 4. The pH of each soil solution by depth and treatment after one day

In the Di only added samples, the wetlands showed a decrease in pH with depth and the pH in wetland A had a higher range 6.76-6.73, then wetland B 6.01-5.53 and wetland C 6.17-5.88. Wetland C and B had an increase of pH in Na treated samples and wetland A had a decrease in pH occur from Na treated samples.

Discussion

To show that these wetlands do experience different levels of saltwater intrusion, pH and conductivity were recorded. The results showed that wetland soil pH and conductivity mostly decrease with distance from the salt-water as we had expected. Soil pH (top graph of Figure 3) was highest at Wetland A and decreased as the wetlands went inland. Soil conductivity (bottom graph of Figure 3) was also highest in wetland A and wetlands B and C, had very similar values. These results suggest that wetland A had been the most salt water affected of the wetlands because it had greater pH and conductivity. Wetland C had the lowest pH and both wetland A and B had similarly low conductivties. Salt water has a higher density so it may leach out of a wetland more readily which is why we did not see much of a difference from wetland B and C. From these field observations we saw that these wetlands provided an adequate amount of variation of salt water influence for further comparison in this project.

There was found to be a significant difference in the bulk density between wetland A and the two other wetlands (Table 1) Wetland A & C with p = 0.02 and Wetland A & B with p = 0.002. Chambers et al. (2013) found that the brackish marsh soil in their study had higher bulk density and lower organic matter content when compared to freshwater marsh soils. This can be caused by an increased mineral percentage in these soils cuased by differences in deposition across a land scape or because of increased organic matter decomposition. Salt-water inundation into wetland A may have had an influence on the soils composition since there was a significant difference in bulk density from this site. A higher bulk density could also be a result from a loss in pore spaces due to the destruction of aggregates because of sodium dispersion. During field sampling it was observed that wetland A soils were noticeably softer and easier to push a core tube into during the collection compared to sampling at either wetlands B and C.

When it comes to agriculture sodic soils, soils with high levels of sodium, they are found to have an increased density then reclaimed soils (Hussain 2001). Often times the replacement of sodium with other cations such as with the use of gypsum or in calcareous soils the use of sulfuric acid, an increase in the porosity, void ratio, water permeability and hydraulic conductivity of the soil occurs and a decrease in bulk density (Hussain 2001). The differences observed in these organic soil samples dried bulk densities can be a result of similar mechanisms that causes issues in clay soils composed of expansible phyllosilicates.

The effect of sodium on expansible phyllosilicates can be detrimental to soil structure. For this reason the minerology of the soil in the Samsula soil from Cedar Key State Preserve was measured to see if this mineral could be causing the negative effects observed by salt water intrusion. The position of the peak at approximately 14 Å did not differ significantly with potassium-(from here on out K) or magnesium (from here on out Mg) saturation (Figure 5). This peak is most likely not indicative of montmorillonite, which would be expected to shift to a lower d spacing with K saturation. The peak is likely from a hydroxyl interlayer mineral (from here on out HIM), which would not shrink or swell appreciably in response to the hydrated radius of the saturating cation due to the constraining effect of nonexchangeable hydroxy-Al polymer “props” in the interlayers.

In the future, if further investigation is needed to determine the presence or absence of montmorillonite vs HIM, a glycerol treatment could be used to further confirm whether a smectite (like montmorillonite) is present. However, for the purposes of this project the K and Mg-saturated mounts were enough to strongly indicate that the phyllosilicate present in the sample was a HIM which would not result in swelling to occur when inundated with sodium.

After observing differences between the wetlands pH, conductivity and bulk density an experiment was conducted on the least salt water affected soils to observe if salt water could induce swelling on the soil and it was observed that statistically greater soil swelling had occurred in the soils treated with high levels of salt water at 36ppt saltwater compared to the control soil treated freshwater with 2ppt (Figure 4). There can be several reasons for the swelling occurring in the soil but the observation of the soil swelling has implications in that salt water can reduce the contact between particles leading to less stable soils.

In shrink swell clay soils the "Expansion and contraction of particles can shift and crack the soil mass and create or break apart aggregates"(USDA 1996). Aggregate stability is the ability of the soil to resist destruction from forces such as water (USDA 1996). Therefore this swelling observed can be an indication of soil destabilization. There have been significant effects of bulk density on soil strength (Zhang et al. 2001).

Although bulk density was not measured before and after the swelling occurred in this experiment, it can be assumed that soil swelling would result in decreasing bulk density since the mass is the same but the volume has increased but this is the opposite of what was observed in the field. It appeared that after six weeks the 36ppt sea water treated samples started to shrink in overall height (Figure 4). Maybe at a certain point of swelling the soil becomes so weakened that it collapses. This would then lead to a higher bulk density after salt water intrusion. It would be interesting for a future study extended the time of this type of swell experiment to observe if organic soil samples consistently start to shrink after a certain point in time.

An unexpected observation was made during this swell experiment in that saltwater treated cores formed a rainbow sheen (that shatters) when touched on the water surface after the first week of saturation. This sheen was then noticed in the brackish treatment after the second week but there was never development of this surface sheen in the freshwater only treated soils throughout the whole experiment and this was the water treatment that experienced the least amount of swelling. Both the salt water and brackish treatment had more swelling, although only the saltwater had a measurable significant difference compared to the control, they both produced a surface sheen. This rainbow sheen is produced by *Leptothrix discophora* is responcible for creating rainbow sheens on water surfaces as it is a bacteria that oxidizes iron and manganese (Kunoh 2015). This bacteria utilizes reduced iron and manganese which means there must have been soluble Fe coming from either the waters solution or is released from the soil.

The interaction of microbes, sulfur and soil structure could be related because of the effect it can have on irons redox state. “Conversion between the redox states is often catalyzed by bacteria. The organisms involved in these conversions can therefore be considered important geomicrobial agents” (Ehrlich 1990; Corstjens et al. 1992). The role of aggregates in stabilizing organic matter is prominent (Schmidt et al. 2011) and there has been found to be an important relationship with iron on soil aggregates and soil carbon stability in upland soil systems.

In the 2017 study by Huang and Hall they found that increasing moisture levels of upland agricultural soil did not increase soil organic matter as expected. The flooding of soils is believed to reduce mineralization of organic matter but in this case they observed a loss of iron held soil aggregates (as iron goes from Fe3+(s) to Fe2+(l) in anoxic conditions) allowing for more organic matter mineralization (Haung and Hall 2017). More research should be done to see how the role of iron is related to the structure of the soil and if there is a relation to peat collapse.

There can be several different ways salt water can induce the releas of iron. The most simplest way is that “Organic matter mineralization releases organic Fe” (Willet et al. 1989; de Mello et al. 1998; Velázquez 2005) and sulfate may be causing greater amounts of organic matter mineralization (Lamers 1998). An increased amount of Fe is released from decomposition of organic matter because of salt waters ability to increase decomposition. In this case Fe is more of a by product of other mechanisms of peat collapse. But the presence of sulfide can further impact on iron in the soil. Sulfide can reduced oxidized iron hidden within the soil and releasing reduced soluble iron into the solution (Afonso and Stumm 1992). Or sulfur can behave as an electron shuttle between sulfur reducing microbes to indirectly also reduce and solubilize iron in the soil (Lohmayer 2014).

The structural decomposition by the microbial community could be a mechanism to further study to determin if the mechanism of peat collapse is more biotic or abiotically caused.

To do this a similar swell experiment could be conducted with a control vs fumigated version to compare if the microbial community in the control has a significant influence. Also the swell experiment should be applied to different wetlands across a natural gradient of salt water influence to see if soils already affected by saltwater are less likely to swell more if they have already have been salt affected.

One limitations of this experiment and with other experiments performed in this research is that the process of collecting wetland soils with tubes and collars is destructive to the structure of the soil which may influence the results. Finding a way to measure in field over time would be ideal. Another aspect that is very important and was not measured in the swell experiment was pH week by week. PH has a major effect on organic soil properties. By applying the water treatments with different pH levels it may have affected the zero point charge on particle surfaces influencing the way they interact with ions such as sodium.

In conclusion of this swell experiment we observed an increase in soil volume related to salt water inundation and the field sampled soil showed a possible relationship between the amount of salt water intrusion and the structure of the soil.

Bender Element

The highly salt water affected soil (Wetland A) was found have greater field bulk densities (different measurements then the dried bulk densities shown earlier, this field bulk density was field wet when measured instead of oven dried for Gmax estimates), lower shear wave velocities and lower estimated Gmax values. These differences found at wetland A compared to the other two sampled wetlands could be a result of the higher level of salt water intrusion.

The shear wave velocity measurement from 0-10cm and combined depths was statistically different between wetland A and wetland C (Table 2) although from depths 10-20 there was not a significant difference. there is a consistent trend that can be seen in the graphs that wetland A had lower shear wave velocities, on average 3.33 m s-1 (Table 3) at both depths compared to wetland B 3.92 m s-1, and wetland C 4.57 m s-1 (Table 3) (Figures 7).

The confidence interval shows that wetland A had less variability 0.13 in the sample measurements compared to wetlands Wetland B 0.60 and C 0.74 (Table 3). The greater variability in the shear wave velocity measurements shows that samples collected from wetland B and C had a variety of soil physical properties while wetland A samples had more consistent results. This might because of random sampling error or be because wetland A is overall more consistently the same when it comes to shear wave velocities. The addition of salt water might have impacted the soils resulting in more similar shear wave velocity results.

The Gmax results show a similar trend as the shear wave velocity measurements. The Gmax estimates used were derived from the field bulk density and shear wave velocity. Wetland A’s Gmax estimate was statistically different at 0-20cm compared to both wetlands. The trend can be seen in figure 8 where Wetland A samples had consistently lower estimate Gmax results compared to wetlands C and B. This can also be seen in comparing the averages from 0-20cm wetland A average was 1.07 Mpa wetland B 1.49 Mpa and wetland C 1.63 Mpa and the confidence interval similarly shows the difference in the consistencies between wetland A samples 0.11 and the other two wetlands B 0.41 and wetland C 1.63 (table 3). A low estimated Gmax means wetland A soil is more likely a weakly compiled soil. The results from these measurements suggest that wetland A has a less stiff soil that may result in higher susceptibility to erosion.

The measurement of the conductivity and pH of the wetlands from the site characterization (Figure 3), found that wetland B and C had lower conductivity and an overall decreasing pH was observed as distance from the salt marsh increased. These patterns can be correlated to observations of lower estimated shear strain in the highly salt water affected wetland.

Bulk density of the wet soil samples were recorded and found to be higher in wetland A vs wetland C (Figure 6). A similar trend was observed in wetland A vs C dry bulk density measurements taken for the field comparisons mentioned earlier in this paper (Table 1). Greater bulk densities were measured in wetland A in both of these measurements. However Wetland C's wet bulk density collected for this experiment was significantly different to wetland B(Table 2), which was not the case in the dry bulk (Table 1) density measurements where wetland B and C were not significantly different. This may have been due to a few of the Wetland C soil cores having not been sealed as well and allowing for more water drainage resulting in the lower values observed in wetland C soils possibly greatly affecting the bulk density comparisons(Figure 6). Comparing the dried bulk densities in this case might be more reliable in this case to observe the differences between these wetlands. This could have influenced some of the wetland C soils Gmax estimates in which bulk density is used for the calculations.

Regardless, the shear wave velocities would not be affected and the differences seen in the estimated Gmax did not change greatly. The Gmax estimates comparing both depths 0-20cm were significantly different in wetland A compared to both wetland B and C (Table 2). Wetland B and A did not have any drained core samples like wetland C so those results would have not been affected and yet despite differences in bulk density wetland B and C were not seen to be statistically different when comparing Gmax estimates from both depths (Table 2). If the Gmax differences observed were an effect of wetland C bulk density, influencing the calculations for Gmax, it would have resulted in just wetland C being more significantly different but instead it is still wetland A that was the most different.

The shear wave velocity measurement from 0-10cm and combined depths, was statistically different between wetland A and wetland C (Table 2). A slightly drier or wet soil should not have an influence on the shear wave velocity as shear waves do not pass through air or water so it is only the solid part of the soil that is being measured. The air-dried soil could possibly influence the aggregating composition of the soil as later in this research we saw when air-drying soil for days, a dramatic influence on particle size and aggregation occurs (Figure 11). Although water had drained out these soils had remained moist in the tubes and were not completely air dried like in the particle size analysis tests. These were just a few considerations noticed when comparing differences in significance between the dry bulk densities and the field wet soils from these wetlands.

The bender element has not been used often for the study of peat soils so there are fewer studies to compare the results with. Ogino et al. 2014 measured shear wave velocity in different types of soils including peat soils. In their study they observed Ebetsu peat which is highly decomposed and mixed with a small amount of clay (Hayashi and Nishimoto, 2005) and Akita peat. The LOI of the Ebetsu peat was 46.5% and Akita ignition loss was 76.5% and the shear wave velocity in the Ebetsu peat was 36.6 m s-1 and Akita peat with 54.0 m s-1.(Ogino et al, 2014)

In comparison our Cedar key Samsula wetland C samples had lower shear wave velocities 4.57 m s-1 (Table 3) but these organic soils might have very different compositions. The Samsula soil for this experiment had an LOI of 93.13-94% from 0-10cm and 87.37% 10-15cm and 51.96% 15-20cm(Table 1).The surface samples of Samsula are much more organic in comparison to the Ebetsu and Akita peat soils but from 15-20cm the cedar Key Samsula soil has a greater amount of inorganic soil compared to the rest of the profile and might be more similar to the Ebetsu and Akita soil in the Ogino et al 2014 study. The Samsula Cedar Key soil from wetland C had a shear wave velocity of 4.60 m/s from 0-10cm and 4.54 m/s 10-20cm which appears to show not much with depth. The sandy discontinuity in the profile could have been wavy and possibly slightly higher in the LOI sampled cores but lower in the samples collected for measurement with the bender element. Still, the overall values for shear wave velocities from wetland C are much lower than the Ebetsu and Akita peat soil estimates perhaps from higher organic matter content in our sampled Samsula soils or higher values due to a greater ratio of clay present in Ebetsu and Akita soils. Clay and sand will have different results on shear wave velocities so not just the amount of mineral soil but the texture of the mineral soil can cause differences between organic soils.

In summary of the measurements in this experiment found that the most salt-water influenced of the wetland was measured to have a lower shear modulus then the other soils and lower shear wave velocity. This has implications for these wetland soils because regardless the mechanism of peat collapse we have observed a greater amount of salt water in wetland A and lower shear wave velocity and Gmax estimates which suggests this affected soil is more weak.

In the future more studies done in the field can provide measurements of mechanical changes during and after storm events. From this, the amount of soil lost could be determined and used to improve predictions on amounts of released carbon for climate change models. Further understanding the mechanical properties within organic soils can become an important tool for understanding of peat collapse in the future such as determining what is the mechanism or how fast it is occurring and can be an important tool in many other studies on organic soils.

Particle Size Analysis

Sodium-induced dispersion was observed on these Samsula soil samples collected from Cedar Key Scrub State Reserve. In both the water treatment experiment (Figure 11) and the field wetland comparisons (Figure 10), it was observed that high levels of sodium was related to a decreasing % volume in larger particles and a conversely increasing % volume of smaller particles in these samples.

The water treatment experiment used a Sodium hexametaphosphate $(NaPO_3)_6$ - (from here on out Na treated) solution vs pure deionized water (from here on out Di treated) samples, and were observed to have a decrease in particle size diameter with the Na treatment compared to the Di treatment when accounting for sampling at the same wetland and depth. A shifting of the distributions to the left in the graphs indicates deflocculation of smaller particles from the larger aggregates (Figure 9). Sodium interacting with the highly charged surfaces of organic matter and inducing the dispersion of these particles is a possible explanation for this.

Our hypothesis of sodium induced dispersion as a mechanism for peat collapse is analogous to what occurs to sodic clay soils experiencing freshwater inundation. With highly charged clay soils such as montmorillinite, there is an attraction of cations to the negatively charged surfaces. When there are several (four to nine) montmorillonite clay particles that are saturated with calcium a tactoid is formed (Frenkel et al, 1978). These formations are more compact and behave as one larger individual particle. The dispersion a tactoids develops with the addition of sodium as it can invade between the tactoids outer layer and interact with montmorillinites particle surfaces like calcium but sodium has a much larger diffuse double layer or hydration sphere then calcium which increases the repulsion between particles of the tactiod. This results in the loss of the larger tactoid structure and a release of smaller dispersed particles (Frenkel et al, 1978) Soil organic matters highly charged surfaces within aggregates could be interacting with sodium in the solution in a similar way that a tactoid of montmorillonite structure is destroyed by the addition of sodium but in freshwater peat collapse aggregates are being dispersed with the help of sodium.

Sodium hexametaphosphate is a commonly used dispersant in soils which is why it was utilized for this experiment. At the right concentrations, it prevents the flocculation of negatively charged colloidal particles such as clay and organic matter. There was almost no inorganic component to this soil and of the inorganic components from the silt to clay fraction from the mineral layer below was absent of expansible phyllosilicates (Figure 5) so the observed changes in these soils are from the effects of sodium hexametaphosphate on soil organic matter. Sodium hexametaphosphate is often used to disperse soil organic matter from particles during laser diffraction texture analysis but the effects of sodium on organic soil measured using a particle size analyzer has not been done before. We expected and observed the dispersion of larger particles.

With time, the particles were also broken up physically with increased time flowing through the hydrolics of the LD machine regardless of water treatment type (Figure 11). The water treatments affected the overall starting point of the particle sizes and were more dispersed with time (Figure 11). In the dry soil results, (Figure 7) the Na samples start with a % volume of large diameter particles that is similar to the Di treatment after running through the machine for an entire hour. Disturbance has an effect on organic matter particle sizes but so does the water treatment type applied. As we expected the Na treatment had induced more dispersion of organic matter particles and more particles would be dispersed with increased disturbance/time but it would be interesting in the future to measure in the if a critical level of max dispersion is reached and to compare if that level is different between the two water treatments. It could be assumed from these results if there is a critical level, the Na treatment would reach to that point faster than a freshwater only sample.

There can be other explanations for the increased dispersion of the organic particles besides the effect of sodium interacting with highly charged particles. Sodium hexametaphosphate can have a negative effect on microorganisms within the soil by destroying their membranes and other compounds such as polysaccharides, protein, lipids, chitin (Chagnon and Bradley 2011) all of which are common components within organic soils. The increased degradation of these compounds might also help in the degradation of the larger particles into smaller ones. As the soil organic matter molecules are degraded, they could be fragmenting into smaller pieces. To account for this in the future a similar experiment can be done with Sodium chloride to observe if dispersion still occurs without the help of hexametaphosphate.

An increase in pH from the addition of the sodium hexametaphosphate (a pH of around 8) is greater then the pH of the freshwater wetland B and C (range of 5.53-6.17) and at wetland A (pH range 6.76-6.73) (Table 4). After the addition of sodium hexametaphosphate into solution the PH of the soil solution increased wetland C and B soils (Table 4). An increase in the pH of the samples from the Na treatment could allow for increased decomposition of organic matter particles through less inhibition of phenol oxidase production (un-published Hojeong et al. 2018).

Phenolic compounds have a higher decay resistance from microbial decomposition and can act as a protective barrier around the more decayable compounds. The effect of pH on organic soils has been studied in sphagnum peat bogs. Sphagnum peat is more decay resistant due to the high phenol compounds in the mosses litter and the inhibitory effects of pH on phenol oxidase production. Wetlands with higher pH may prevent the persistence of Sphagnum moss as high pH results in a failure of the decay resistance to phenolic compounds. This results in loss of structural strength which leads to collapse of the typical growth form Sphagnum, in which the dying lower portion of the shoot has an important support function (Tahvanainen and Haraguchi, 2013).

PH is believed to have large effect on the formation and persistence of sphagnum peat soils and in this experiment there, correlation of decrease in particle sizes can be from either sodium addition and/or also the change in pH. These same trends of increased salinity and/ or pH was observed in the field measurements to also have a decreasing particle size diameter in these sampled wetlands. Since both of these variables could be mechanisms for peat collapse the effects of pH and sodium could be separated in future experiments to determine the dominance of one variable over another in causing freshwater peat collapse.

There could also be a synergistic effect of sodium and increased pH on the dispersion and degradation of organic soil. Soil organic matter is mix of all different types of charges due to the variety of proteins and compounds it is composed of. Soil organic matter is known for being highly negatively charged but with increasing pH the soil organic matter can become even more negatively charged as it becomes deprotonated. The increase of the soils cation exchange capacity (increase in negative charged surfaces) allows for more sodium to bind to the particles. In this way salt water may contain two components that can synergistically increase dispersion more than they could on their own.

In summary of the particle size analysis, the wetlands in our study that were selected to represent a natural transect of wetlands across a salt water inundation gradient showed a gradient of change in particle sizes with the least affected wetland having the largest particle sizes and the most affected having the smallest. The water treatment experiment also showed that the breaking up of larger aggregates can be induced with additions of sodium hexametaphosphate. Both of these results show the ability to use LD for particle size analysis to help study organic soils in a way that it has not been done before. In the future the us of an LD particle size analyzer could provide new understandings to the composition of organic soils.

Conclusion

There is an effect of salt-water additions into freshwater soils. In the soil swelling experiment we observed changes to the soils volume due to increasing levels of salinity and in the two water treatments measured with LD particle size analyzer we saw that there was a breaking up of organic particles due to Sodium hexametaphosphate additions. The addition of sodium can be having a dispersing effect on organic matter particles that is deleterious to the soil. In the field we saw that the shear wave velocity was lower in the highly salt water inundated wetland we had studied and there was a gradient of change in particles sizes relating to the distance of the wetland to the salt marsh. There appears to be a loss in the soils aggregation and structure related to the salt-water inundation. The exact mechanism as to why is still in question but our results suggest that sodium and/or pH are having an effect on the rapid loss of organic matter in these soils. Further research to separate these variables would help in uncovering the main mechanism for why peat collapse is occurring. Also the techniques used in this research would be beneficial for future studies of peat collapse as well as for further research to better measure and understand many aspects of organic soils.

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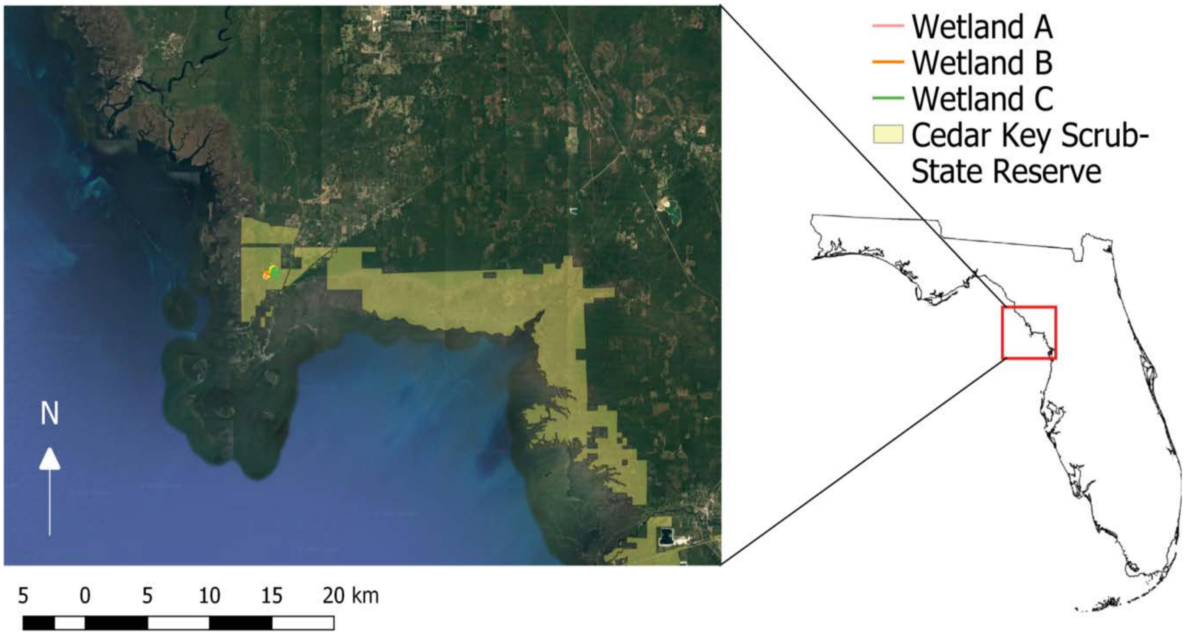
Table 1. Bulk density of peat soil samples from Cedar Key Scrub State Reserve

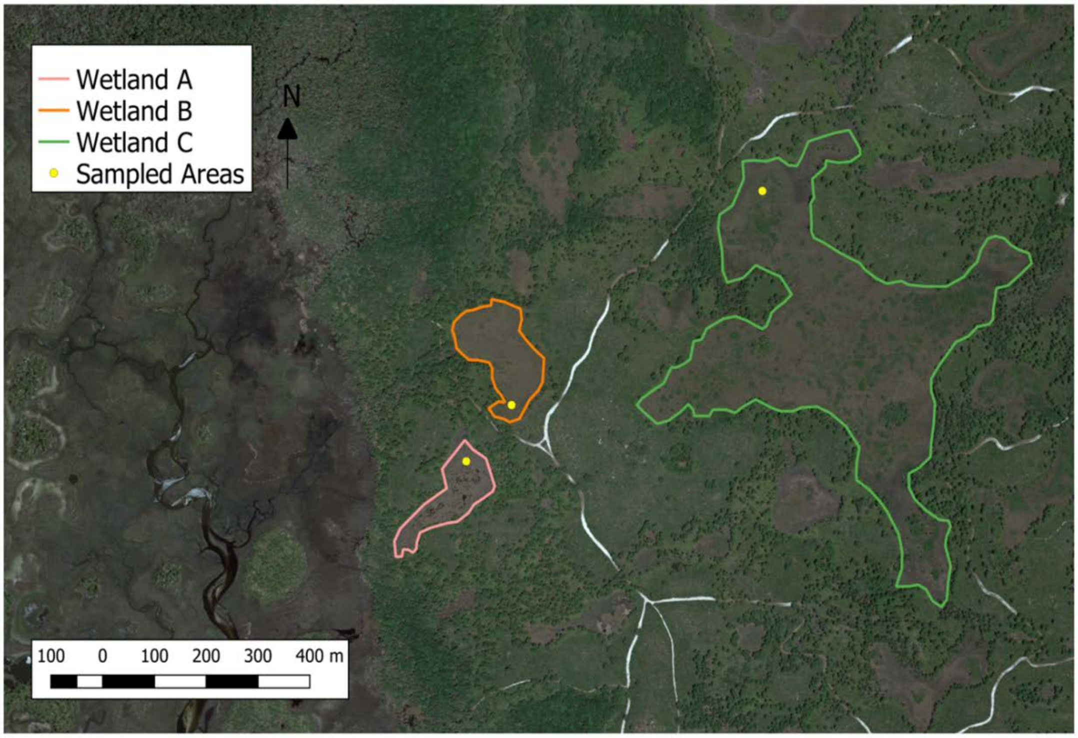
Depth (cm) Wetland Soil Sample Bulk Density (g/cm3)

	WC1	%OM (WC1)	WC2	WC3	WB1	WB2	WB3	WA1	WA2	WA3
0-5	0.05	93.13	0.05	0.05	0.06	0.05	0.05	0.06	0.05	0.05
5-10	0.05	94.0	0.05	0.04	0.06	0.05	0.04	0.07	0.07	0.08
10-15	0.06	87.37	0.05	0.06	0.04	0.05	0.06	0.08	0.09	0.09
15-20	0.09	51.96	0.11	0.06		0.06	0.09	0.07	0.13	
20-25	0.21	47.47	0.11	0.08		0.12		0.09	0.14	
25-30			0.22						0.10	0.25
30-35										0.36



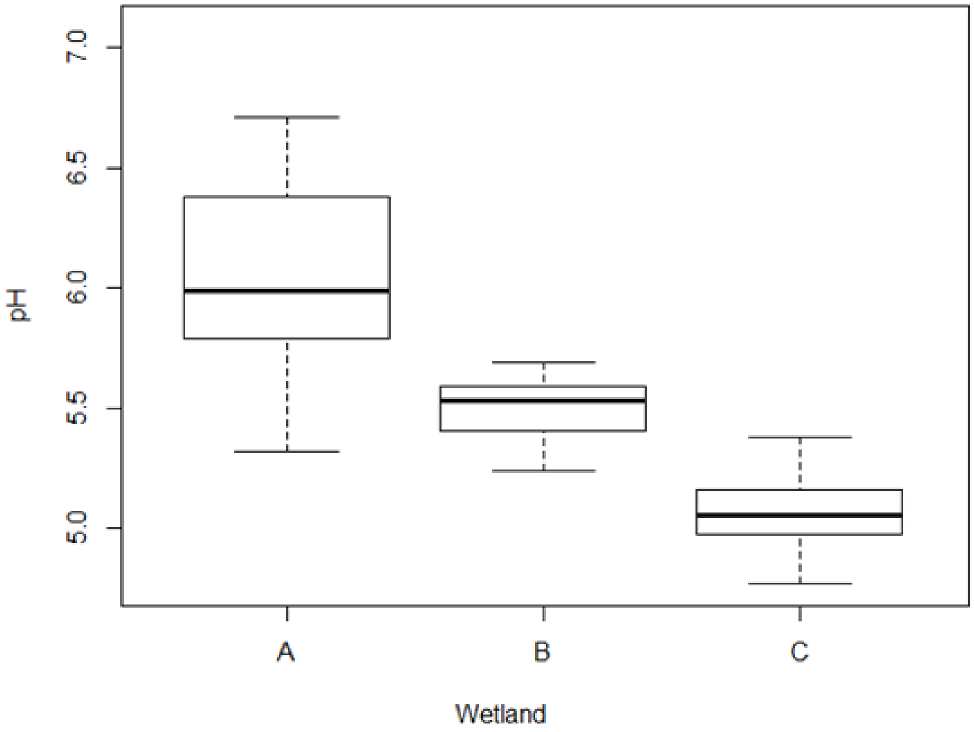
Sources:
Google Earth V 6.2.26613 Cedar Key State Preserve. (Satellite Map) 29 11′32.6″N 83 01′52.43″W, Scale 1:14,617. The Florida Department of Environmental Protection 2018, http://www.earth.google.com [2003]
Florida State Parks Boundaries, (GIS data) Scale 5000000, Florida Department of Environmental Protection Division of Recreation and Parks Office of Park Planning, 2017, http://publicfiles.dep.state.fl.us/OTIS/GIS/data/PARKS_AND_REC_AREAS.zip
The Florida Historical Society. (n.d.). Florida Outline [Infographic] https://myfloridahistory.org/library/florida-outline

Figure 1. Location of Cedar Key State Preserve within Fl



Sources:
Google Earth V 6.2.26613 Cedar Key State Preserve. (Satellite Map) 29 11′32.6″N 83 01′52.43″W, Scale 1:14,617. The Florida Department of Environmental Protection 2018, http://www.earth.google.com [2003]

Figure 2. Map of wetlands location in the north western section of Cedar Key State Preserve


pH
7.0
6.5
6.0
5.5
5.0
A
B
C
Wetland

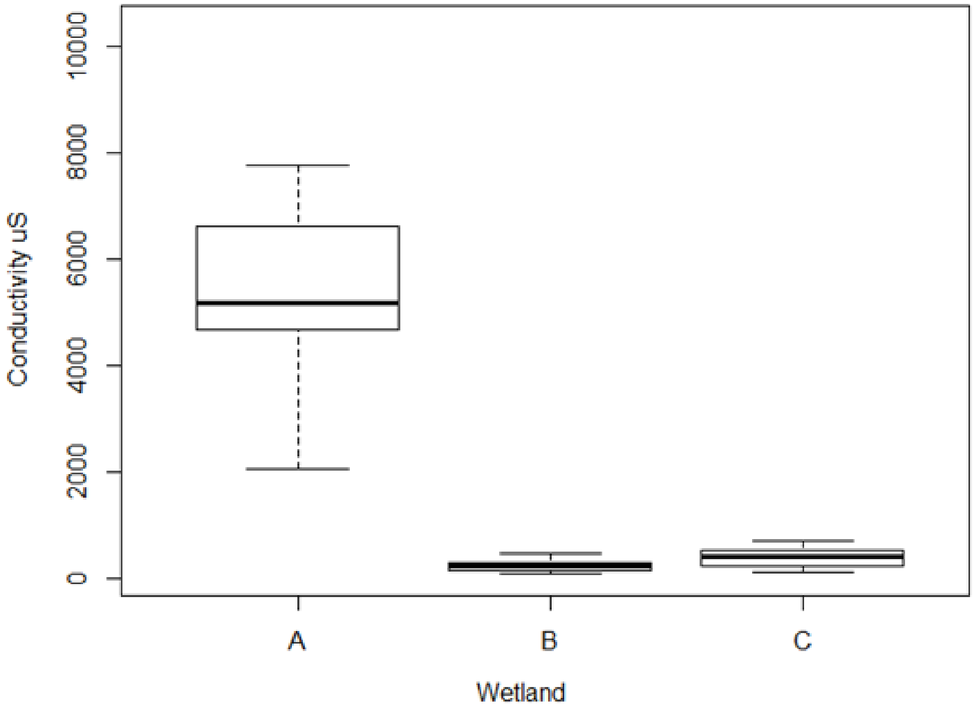

Conductivity uS
10000
8000
6000
4000
2000
0
A
B
C
Wetland

Figure 3. Top: The pH of soil samples collected from each wetland. Wetland C (the most inland) had the lowest levels of pH while the wetland A had higher overall pH values. Bottom: Conductivity of soil samples collected from each wetland. Wetlands B and C (more inland) had lower overall conductivity compared to wetland A

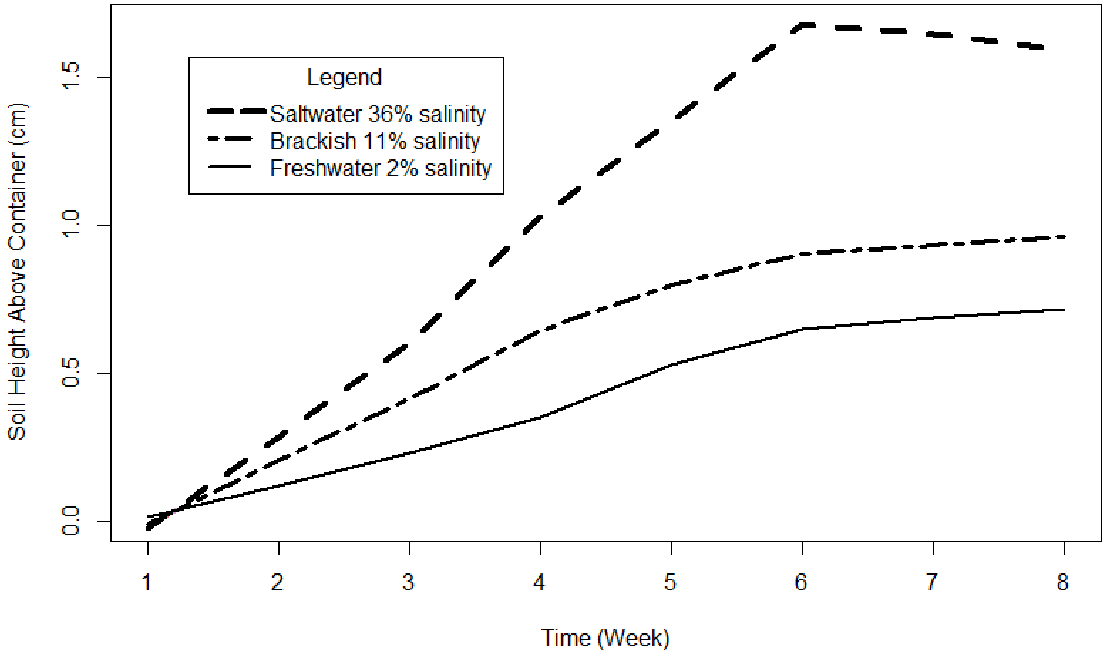


Figure 4. Swell Experiment of Wetland C soil subjected to different levels of saltwater.

From weeks 2-6 the change in slope of freshwater to salt-water treatment height growth is significant p=1.98e-07. The change in the slopes value from freshwater to brackish was not statistically significant p=0.076. Saltwater had a pH of 7.01, Brackish had pH of 7.48, and Freshwater had a pH of 8.36. Rainbow sheens were observed in the salt water treatment starting at week 2 and rainbow sheen was observed in the brackish treatment at week 3. No rainbow sheen was observed in the freshwater treatments throughout the experiment.

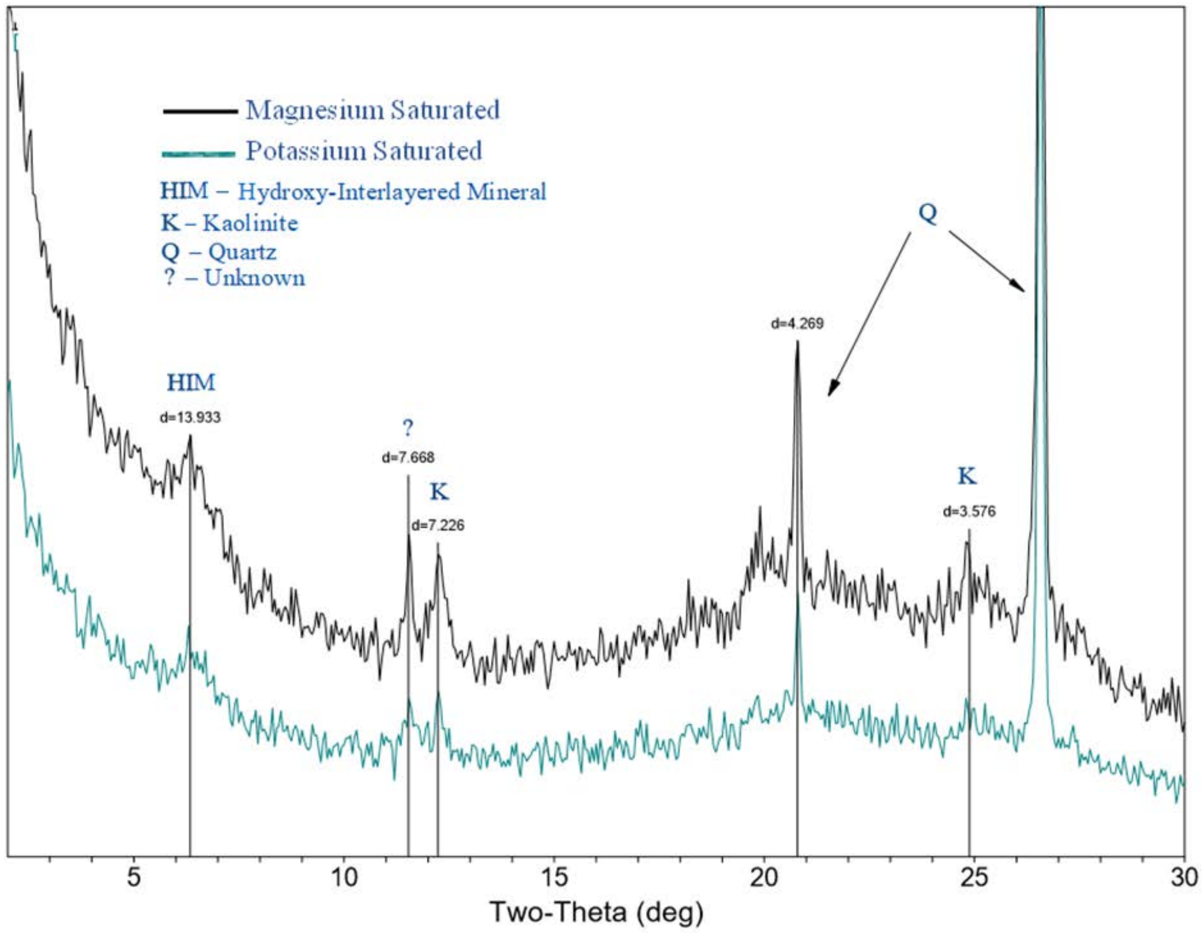


Figure 5. Comparison of mineralogy of Cedar Key Wetland Samsula soil clay and silt fraction taken from 10-25cm depth.

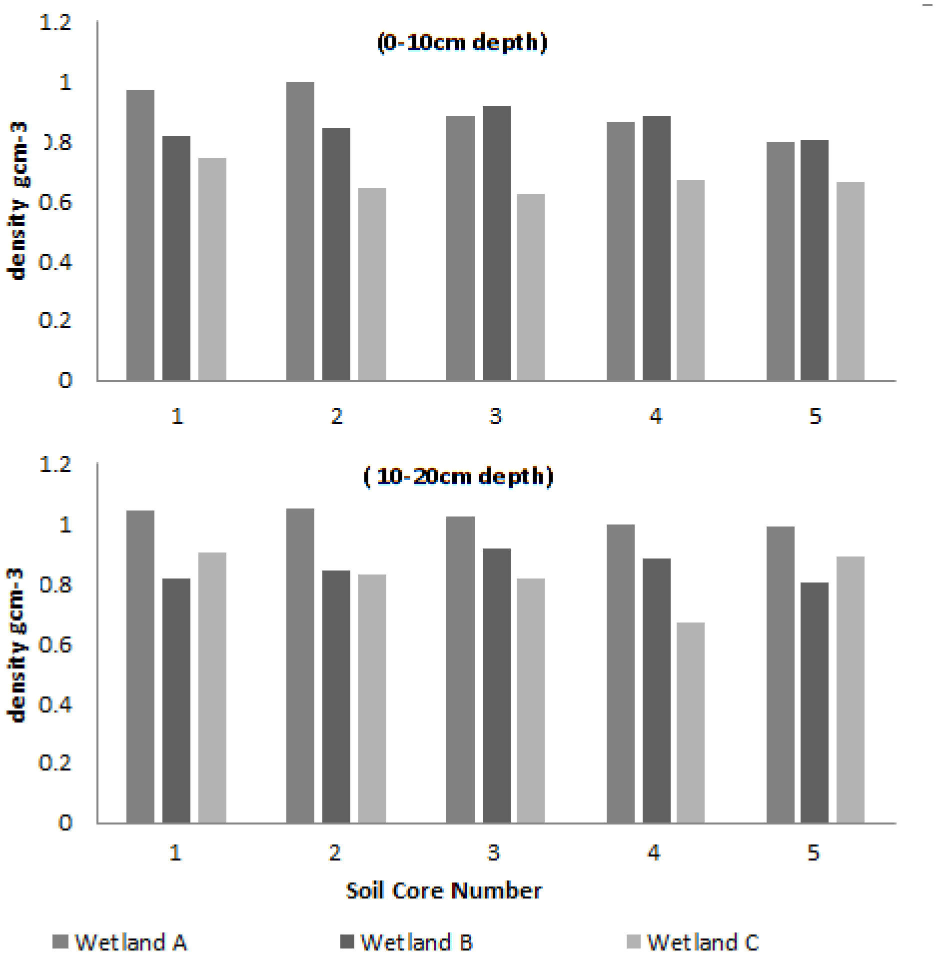


Figure 6. Top: Density g cm-3 of each core sample by wetland at a depth of 0-10cm

Bottom: Density g cm-3 of each core sample by wetland at a depth of 10-20cm

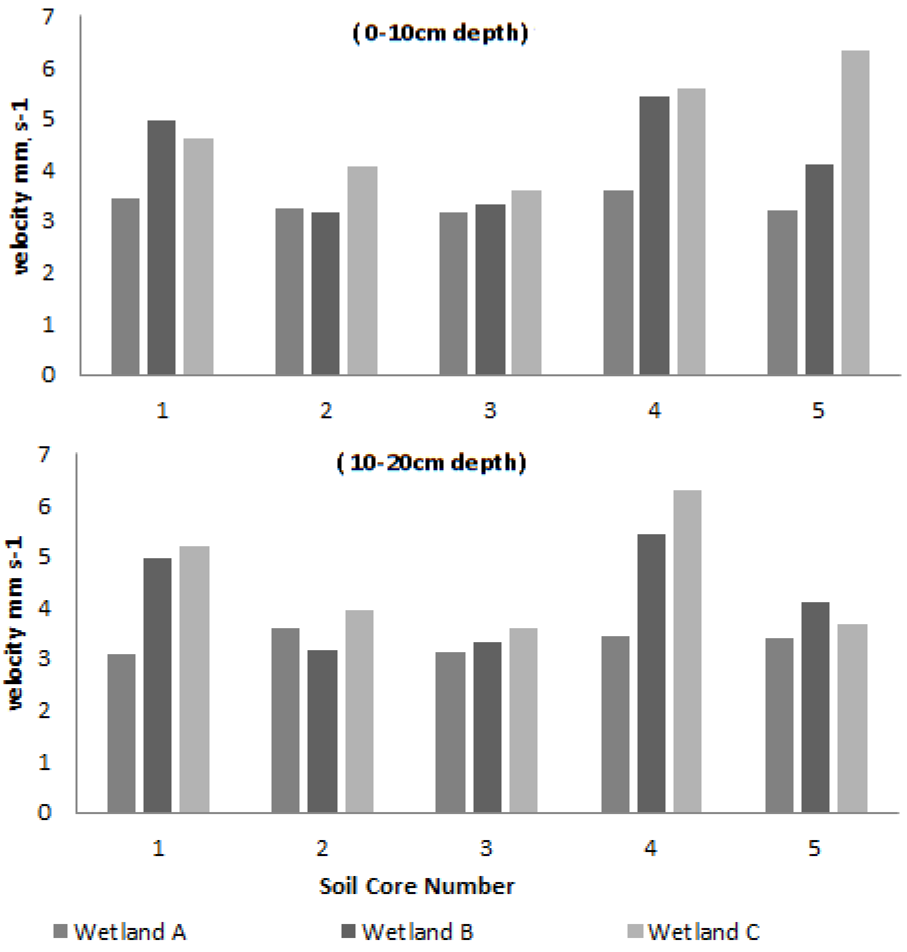


Figure 7. Top: Shear wave velocity measurement mm/s of each core sample by wetland at a depth of 0-10cm

Bottom: Shear wave velocity measurement mm/s of each core sample by wetland at a depth of 10-20cm

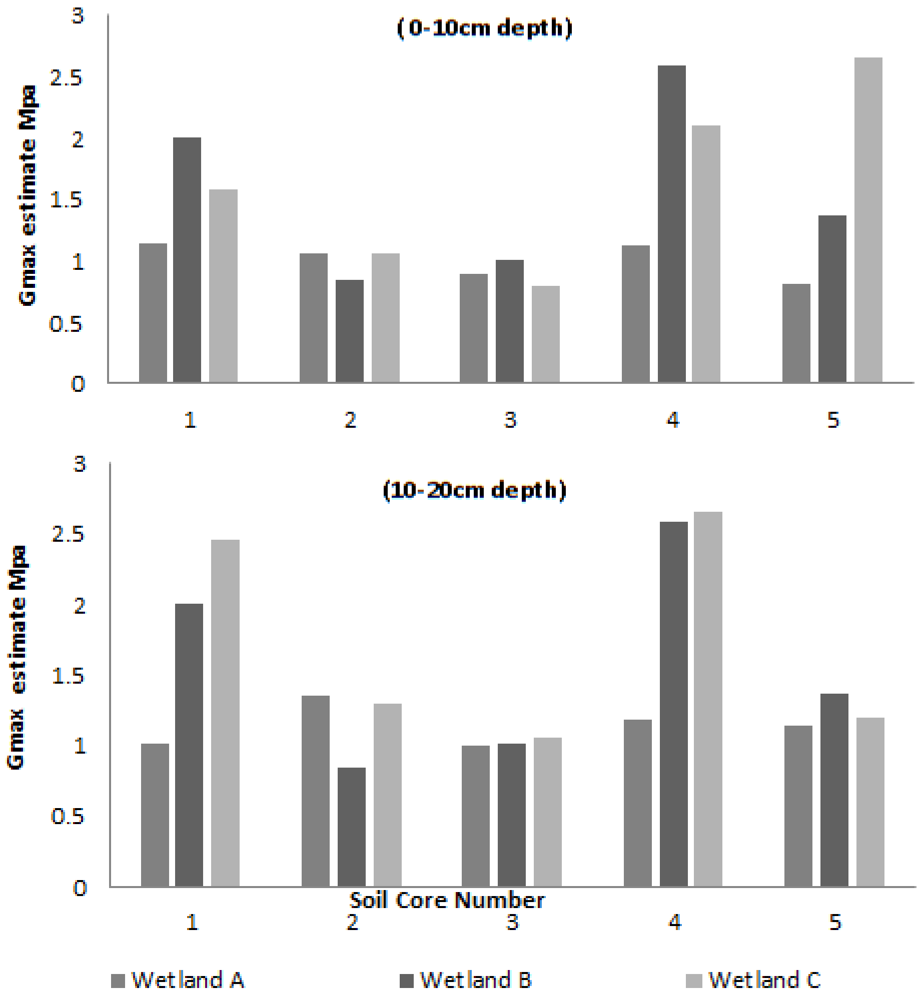


Figure 8. Top: Gmax estimates by core sample in each wetland at a depth of 0-10cm

Bottom: Gmax estimates by core sample in each wetland at a depth of 10-20cm

Table 2. T Tests comparing Gmax, velocity and density between wetlands by depth

Two tailed T Tests

Wetlands	Gmax	velocity	Density

0-10cm	WC vs. WB	NS	NS	*
	WC vs. WA	NS	*	**
	WB vs. WA	NS	NS	NS
10-20cm	WC vs. WB	NS	NS	*
	WC vs. WA	NS	NS	*
	WB vs. WA	NS	NS	NS
0-20cm	WC vs. WB	NS	NS	**
	WC vs. WA	*	**	***
	WB vs. WA	*	NS	NS

A p value of 0.05 or less is flagged with one star (*) 0.01 or less is flagged with two stars (**) less than 0.001 is flagged with three stars (***) and if not significant then p value is marked (NS)

Table 3. Average values and confidence interval for each wetland by depth for density, shear wave velocity and estimated Gmax

measurement	Depth	wetland	average	confidence interval
Density gcm-3	0-10cm	A	0.90	0.10
	0-10cm	B	0.85	0.06
	0-10cm	C	0.70	0.90
	10-20cm	A	1.02	0.03
	10-20cm	B	1.07	0.15
	10-20cm	C	0.82	0.12
	0-20cm	A	0.96	0.06
	0-20cm	B	0.96	0.10
	0-20cm	C	0.76	0.07
velocity m/s	0-10cm	A	3.33	0.23
	0-10cm	B	4.19	1.23
	0-10cm	C	4.60	1.21
	10-20cm	A	3.33	0.26
	10-20cm	B	3.64	0.80

	10-20cm	C	4.54	1.46
	0-20cm	A	3.33	0.13
	0-20cm	B	3.92	0.60
	0-20cm	C	4.57	0.74
Gmax Mpa	0-10cm	A	1.01	0.19
	0-10cm	B	1.56	0.90
	0-10cm	C	1.54	0.75
	10-20cm	A	1.14	0.18
	10-20cm	B	1.42	0.55
	10-20cm	C	1.73	0.94
	0-20cm	A	1.07	0.11
	0-20cm	B	1.49	0.41
	0-20cm	C	1.63	0.47

Particle Size Analysis

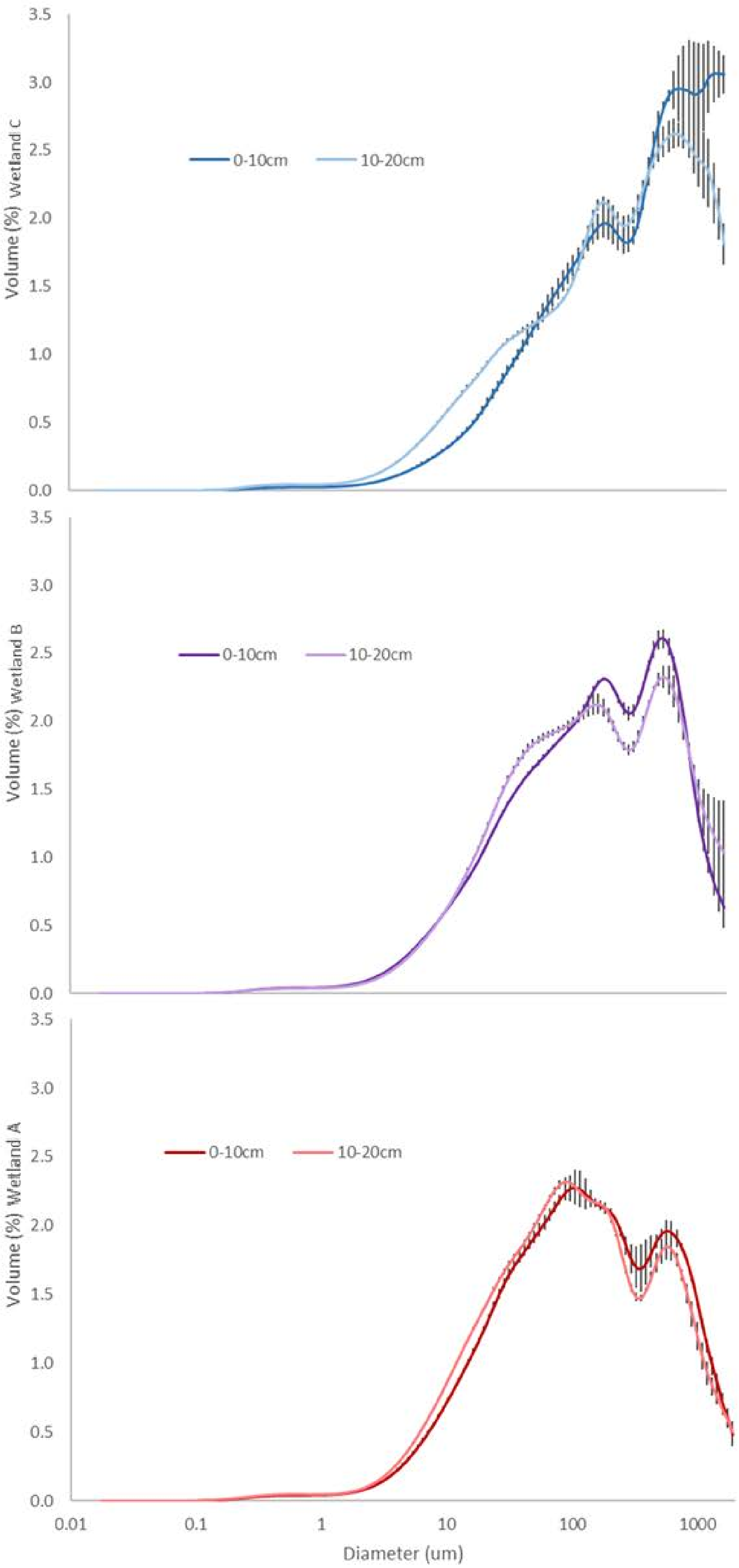
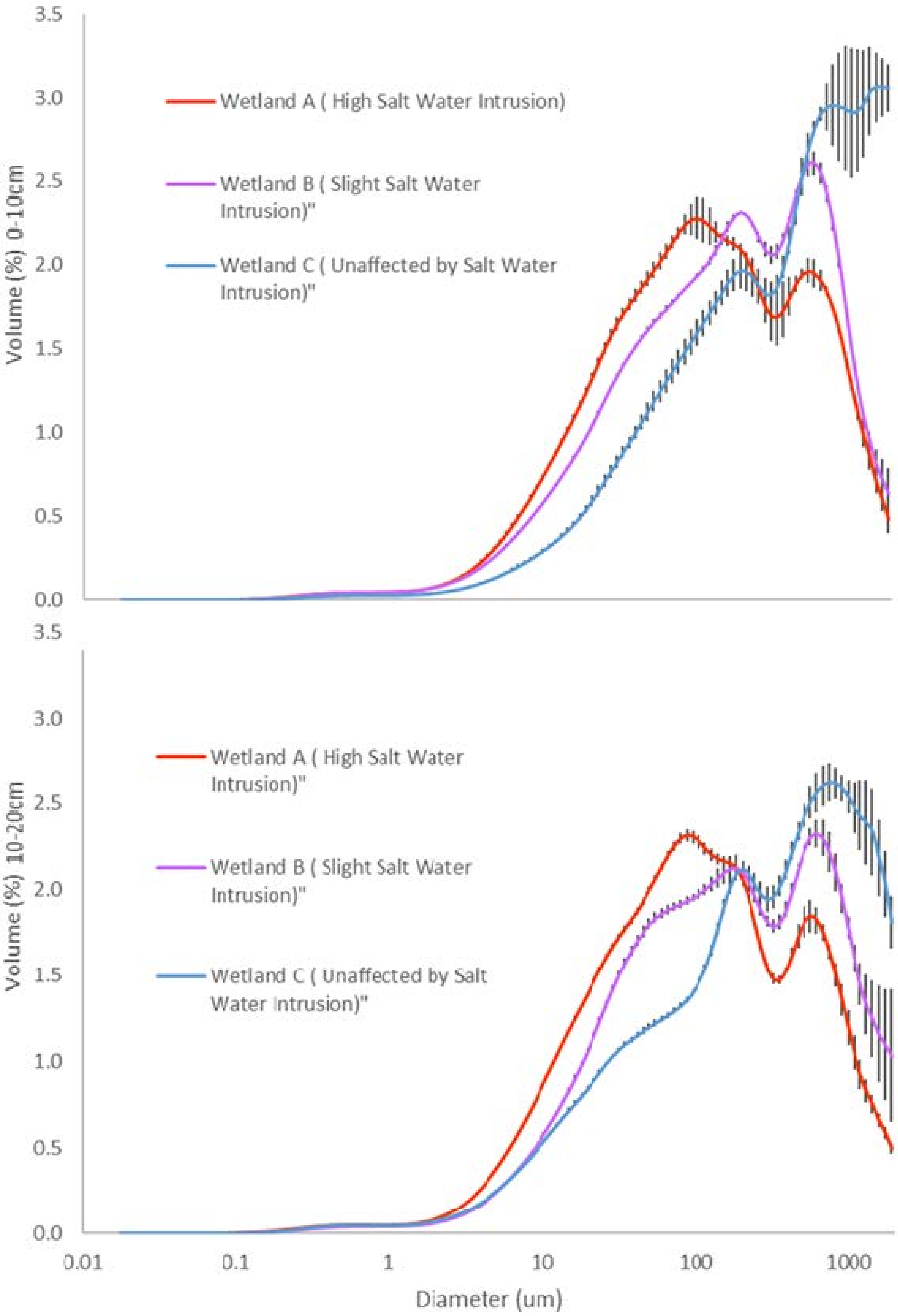

Volume (%) Wetland C
0-10cm
10-20cm
Volume (%) Wetland B
0-10cm
10-20cm
Volume (%) Wetland A
0-10cm
10-20cm
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.01
0.1
1
10
100
1000
Diameter (um)

Figure 9. Top: The average particle distribution of Wetland C, the least affected by salt-water intrusion at 0-10cm and 10-20cm with standard deviation bars

Middle: The average particle distribution of Wetland B at 0-10cm and 10-20cm with standard deviation bars. The standard deviation bars are bigger in the large particle sizes ~1000um compared to the standard deviation bars ~90um suggesting that there is a lot of variation in the larger particle sizes.

Bottom: The average particle distribution of Wetland A, the most salt water affected, at 0-10cm and 10-20cm with standard deviation bars


3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Volume (%) 0-10cm
Wetland A (High Salt Water Intrusion)
Wetland B (Slight Salt Water Intrusion)"
Wetland C (Unaffected by Salt Water Intrusion)"
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Volume (%) 10-20cm
Wetland A (High Salt Water Intrusion)"
Wetland B (Slight Salt Water Intrusion)"
Wetland C (Unaffected by Salt Water Intrusion)"
0.01
0.1
1
10
100
1000
Diameter (um)

949

Figure 10. Top: The average particle distribution of all three wetland from at 0-10cm with standard deviation bars

Bottom: The average particle distribution of all three wetland from at 10-20cm with standard deviation bars

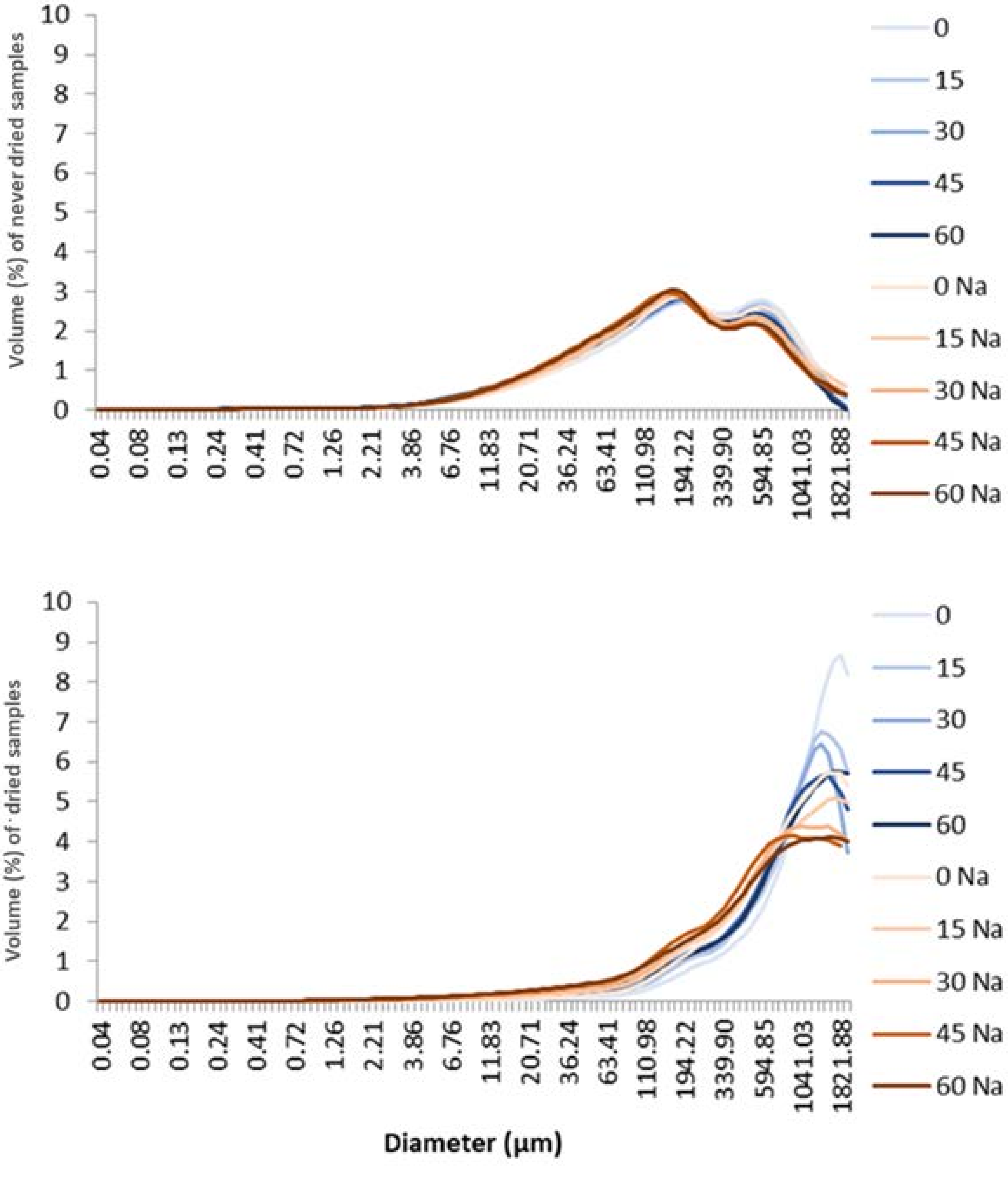


Figure 11.Top:Particle size distribution with time by water treatment of wetland C soil 0-10in, with samples kept field moist

Bottom: Particle size distribution with time by water treatment of wetland C soil 0-10in, with dried samples

Table 4. The pH of each soil solution by depth and treatment after one day

Wetland	Depth cm	Treatment	pH
C	0-10	Di	6.17
C	0-10	Na	6.43
B	0-10	Di	6.01
B	0-10	Na	6.39
A	0-10	Di	6.76
A	0-10	Na	6.47
C	10-20	Di	5.88
C	10-20	Na	6.4
B	10-20	Di	5.53
B	10-20	Na	6.43
A	10-20	Di	6.73
A	10-20	Na	6.47

Di are treatments with only Deionized water added and Na stands for treatments with Sodium Hexametaphosphate added