Eroding Wetland Soils in Coastal Louisiana's Barataria Bay Could Impact Future Climate and Sea Level Rise

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Abstract
Wetlands act as net carbon sinks due primarily to the coupled high levels of primary production and anaerobic conditions in the soils which preserve the organic matter. However, as coastal wetlands erode, organic matter (OM) that was once stored is now exposed to an aerobic water column where further decomposition can occur rapidly. This research project sought to quantify how much faster soil OM decomposition could occur in these aerobic conditions of the coastal bays and whether this increased decomposition rate is dependent upon depth in the soil profile. Soil cores collected from two salt marsh sites in Barataria Bay, LA were analyzed for soil physicochemical and microbial characteristics. Beta-glucosidase enzyme activity, potentially mineralizable nitrogen, soil oxygen demand, and aerobic/anaerobic carbon mineralization were measured as proxies for OM decomposition rates. Aerobic OM decomposition rates for subsurface soils were ~16x faster than the corresponding anaerobic rates, and aerobic decomposition was independent of depth. Therefore, the previously stored OM has the potential to decompose rapidly once eroded and deposited into the aerobic water column of the adjacent bay. Consequently, these eroding wetlands can become a substantial source of CO_2 to the atmosphere. This influx of CO_2 would act as a positive feedback loop to the atmosphere under influence of an ever increasing sea level rise. Research along the subsiding coastline of Louisiana also provides an opportunity to better predict and model future global changes to the coastal carbon cycle as well as providing a valuable opportunity to test wetland restoration and coastal erosion mitigation strategies since Barataria Bay is experiencing relative sea level rise rates that are predicted for world's stable coastlines in the next 50-100 years

1. INTRODUCTION

Coastal wetlands provide many different ecosystem services, including carbon sequestration. Vegetation in the wetlands fix carbon dioxide from the atmosphere and incorporate the carbon into plant biomass. This organic matter in the wetland soils is only partially decomposed and then stored due to the predominance of anaerobic conditions of the soil. Microbial communities adapted to use alternate electron acceptors besides oxygen to respire and breakdown organic matter for energy, such as NO_3^-, Mn^{4+}, Fe^{3+}, and SO_4^{2-} (Figure 1) (Reddy & DeLaune, 2008). These alternate electron acceptors have a lower redox potential than oxygen, so the breakdown of organic matter yields less energy for microbes, is less effective, and is much slower than if oxygen was available. For this reason, coastal wetlands are typically carbon sinks where carbon is stored in the soil for hundreds to thousands of years. In fact, it is estimated that wetlands store a disproportionate amount of carbon in their soil, holding ~20-30% of the Earth's pool of soil carbon while covering only ~5-8% of terrestrial land area (Mitsch & Gosselink, 2007).

However, Louisiana's coastal wetlands are facing high relative sea level rates due primarily to the Mississippi River Delta subsiding from rapid peat compaction and dewatering of mud sediments (Törnqvist et al., 2008). This subsidence combined with the lack of natural sediment input from the Mississippi River due to levees has caused Louisiana to have some of

the highest coastal erosion rates of the United States. Once eroded, the soils are being exposed to the aerobic water column of the surrounding bay. Since oxygen is now available for microbial respiration, further decomposition of the organic material in the soil occurs. This project seeks to quantify how much faster decomposition occurs in aerobic conditions compared to the typical decomposition in the anaerobic conditions of the soil. In addition, this project seeks to explore a possible dependence of organic matter decomposition with depth in the soil profile under anaerobic and aerobic conditions.

2. MATERIALS AND METHODS

2.1 Study Site

The sites chosen were *Spartina* dominated salt marshes in Bay Jimmy and Wilkinson Bay (~5km apart) in the northern area of Barataria Bay, Louisiana (Figure 2). Barataria Bay faces high coastal erosion rates due to multiple anthropogenic and natural factors, including channelization, subsidence of the delta, and global eustatic sea level rise. Barataria Bay has also been largely disconnected from freshwater and sediment inputs from the leveeing of the Mississippi River and the damming of Bayou Lafourche in 1904. Without these inputs, Barataria Bay is unable to maintain surface elevation with the high relative sea level rise, so these marshes are chronically flooded, drowned, and eroded.

2.2 Sampling Design and Methodology

Two 60 cm sediment cores were taken in September 2016 from an established study site in Bay Jimmy. These cores were taken back to LSU's Wetland Aquatic Biogeochemistry Lab (WABL) and cut into 5cm sections. They were weighed, placed in polyethylene containers, homogenized and stored at 4°C. In November 2016, a team collected three 20 cm cores at Wilkinson Bay site, one inland core at the Bay Jimmy site, and three estuarine cores off the marsh edge of the Bay Jimmy site. These cores were extruded in the field, cut into 10 cm sections, and put in Ziploc bags on ice. The samples were returned to the laboratory at LSU later that day, weighed, homogenized, and stored at 4°C.

2.3 Soil Physicochemical Properties

Moisture content, percent organic matter, bulk density, total nitrogen, total carbon, total phosphorus, extractable nitrate (NO_3^-), ammonium (NH_4^+), and soluble reactive phosphorus (SRP) were measured in all samples. Moisture content of the soil was determined by weight before and after drying subsamples at 70°C until constant weight was achieved. Percent organic matter was determined by loss of ignition as a difference between the dry subsample weight and the ashed subsample weight after burning (Sparks, D.L. 1996). Bulk density of the sample was calculated as the total dry weight of the sample divided by the total wet volume of the 5 cm or 10 cm core section. Total carbon and total nitrogen values were determined on dried, ground subsamples of soil using a Costech 1040 CHNOS Elemental Combustion System with method detection limits of 0.005 g C kg^{-1} and 0.005 g N kg^{-1} (Costech Analytical Technologies, Inc. Valencia, California).

Total phosphorus values were determined by using the ashing method after Anderson (1976). Beakers with ~0.5g dried ground sample were weighed before and after being placed into a 550°C muffle furnace for 4 hours. Twenty mL of 6M HCL was added to each beaker, and beakers were placed on a 100-120°C hot plate until dry. Once dry, the hot plate was raised to high for 1-2 hours, and beakers were cooled to room temperature. 2.25mL of 6M HCl was then added to each beaker, and the samples were heated until near boiling and taken off of the plate. Samples were cooled, filtered through a Whatman #41 filter into 50mL volumetric flasks, and diluted to volume with deionized (DI) water. Total phosphorus was then analyzed for each diluted sample using a SEAL AQ2 Automated Discrete Analyzer (SEAL Analytical Inc, Mequon, Wisconsin) with a detection level 0.02 mg P L^{-1} (USEPA, 1993).

Extractable NO_3^-, NH_4^+, and SRP were determined by extraction using ~5g of wet, homogenized sample. Samples were placed in 40mL centrifuge tubes with 25mL of 2M KCl. Tubes were shaken for 30 minutes on a longitudinal shaker and then centrifuged in a Sorvall RC, 5C Plus centrifuge (Weaverville, NC) for 10 minutes at 4000 g at 10°C. The supernate was then vacuum filtered into 20mL scintillation vials through a 0.45µm membrane filter, acidified to pH <2 with H_2SO_4, and refrigerated at 4° C until further analysis. Samples were then analyzed for NO_3^-, NH_4^+, and SRP on a SEAL AQ2 Automated Discrete Analyzer (SEAL Analytical Inc, Mequon, Wisconsin) with a detection limit of 0.012 mg N L^{-1} and 0.002 mg P L^{-1}, respectively. These extractable nutrients help represent how many nutrients are available to life in the soil.

November 2016 samples were also analyzed for porewater pH and conductivity. Conductivity and pH were determined by following a procedure described in Folse et al. (2014). A subsample of ~20g of wet, homogenized soil was weighed out into plastic cups, and 20 mL of DI water was added. Each sample was then stirred with a glass rod for 1 minute, sat for 30 minutes, and then stirred again for another minute. Conductivity and pH of each cup was then measured twice with a Fischer Scientific accumet AB-30 conductivity meter and a Fischer Scientific accumet AR25 dual channel pH meter, respectively. Results of the two measurements were then averaged, and pore water conductivity was calculated as the average conductivity measured times the total volume of the cup divided by the volume of pore water in each sample.

2.4 Microbial Biomass Carbon

Microbial biomass carbon (MBC) was determined for November 2016 samples by using the chloroform-fumigation method after Brookes et al. (1985) with modifications by White and Reddy (2000). Approximately 5g of wet, homogenized sample were weighed out into 40 mL centrifuge tubes as non-fumigate samples, and a duplicate was weighed out as fumigate samples. Non-fumigate samples were extracted with 25mL of 0.5M K_2SO_4. Fumigate samples were fumigated with chloroform for 24 hours in a vacuum sealed glass desiccator and then extracted with 25mL of 0.5M K_2SO_4. All samples were shaken for 30 minutes on a longitudinal shaker and then centrifuged for 10 minutes at 4000 g at 10°C. The supernate was then vacuum filtered through a 0.45µm membrane filter, acidified with HCl, and refrigerated at 4° C until further analysis. Dissolved Organic Carbon (DOC) for each fumigate and non-fumigate were analyzed using a Shimadzu TOC-V CNS Analyzer. MBC was determined by the difference of DOC

between fumigates and non-fumigates. This difference is representative of the size of the microbial pool in the sample.

2.5 Potentially Mineralizable Nitrogen (PMN) Rates

All samples were analyzed for PMN rates. Potentially mineralizable nitrogen rates represent the rate of nitrogen mineralization under anaerobic conditions and were used in this study as a measurement of organic matter decomposition/ microbial respiration under anaerobic conditions. Rates were determined by a method described in White and Reddy (2000). Approximatley10g of wet, homogenized sample was weighed out in triplicate in serum bottles labeled A, B, and C. All bottles were capped with rubber stoppers and sealed with aluminum crimp caps. The bottles were then evacuated for 1 minute and purged with N_2 gas for 5 minutes to create anaerobic conditions. A 12.5 solution of Instant Ocean was used to mimic the site water in Barataria Bay, and the solution was purged with N_2 gas for 30 minutes. Each bottle was injected with 10 mL of this Instant Ocean solution to create a slurry for incubation. Bottles were placed in a Jeio Tech Lab Companion IS-971R refrigerated and incubated shaker at 135 rpm at 40°C. "A" Samples were incubated for 2 days, "B" samples for 5, and "C" samples for 10. After the designated incubation period for the bottle, samples were removed from the incubator, injected with 25mL of 2M KCl, shaken for 30 minutes, transferred to centrifuge tubes, and centrifuged for 10 minutes at 4000 g at 10°C. The supernate was then vacuum filtered through a 0.45µm membrane filter, acidified pH<2 with K_2SO_4, and refrigerated at 4° C until further analysis. NH_4 concentrations for each sample were measured by a SEAL AQ2 Automated Discrete Analyzer (SEAL Analytical Inc, Mequon, Wisconsin; USEPA, 1993). Extractable NH_4 was used as a 0 day measurement, and NH_4 concentrations for 0, 2, 5, and 10 days were plotted. A least squares regression line was then fit, and the slope of the line was the PMN rate for the sample.

2.6 β-glucosidase Enzyme Activity

β-glucosidase enzyme activity is a measure of organic matter decomposition by determining the activity of the microbial extracellular enzyme, β-glucosidase, as it hydrolyzes glucosidic bonds found in carbohydrates in the soil. β-glucosidase enzyme activity was used in this study as a measurement of aerobic organic matter decomposition. Eight samples from the Wilkinson Bay site were analyzed within 24 hours of sample collection. Before samples were analyzed, a quench curve was run to determine any potential soil color interference in the samples. A 4-Methylumbelliferyl β-D-glucopyranoside (MUF) substrate was used because of the increased fluorescence produced when β-glucosidase enzymes cleave glucosidic bonds of the carbohydrates found in the soil. (Sinsabaugh et al., 1997). One g of wet, homogenized sample was placed in a 160mL serum bottle with 99mL of DI water, and shaken for 1 hour to create a homogenized slurry. A soil slurry of 150µL was pipetted into a 96-well microplate with an 8-channel automated pipette and 110µL of 0.05M MUF solution was added to each well in the microplate. Immediately after addition of substrate, the microplate was analyzed on a Bio Tek FLx800 Microplate Fluorometer (Winooski, VT) for fluorescence for a time zero reading. Subsequent readings for fluorescence were taken after 2, 6, 12, 17, 23, and 24 hours after MUF

addition in order to determine a linear rate of substrate hydrolysis. Enzyme activity for each sample was calculated as average nanomoles of MUF fluorescence released per gram of dry soil weight per hour (Prenger and Reddy, 2004).

2.7 Soil Oxygen Demand (SOD)

Cores collected in November 2016 were analyzed for SOD, which is a measure of the oxygen demand in wetland soils from microbes and reduced chemical species in the soil. The SOD was determined using the method found in Reddy et al. (2013). One to two grams of wet, homogenized soil was weighed out into 250mL BOD glass bottles. Bottles were then filled with chilled, fully oxygenated 12.5ppt Instant Ocean solution, reweighed, wrapped in aluminum foil, placed in a dark room, and stirred on a stir plate. After 15 minutes, dissolved oxygen (DO) readings were collected as a time zero measurement, and then the bottles were sealed with a glass stopper. Another DO reading was taken 18-19 hours later, and the SOD rate was calculated as the difference of mg of DO $g^{-1}d^{-1}$

2.8 Anaerobic and Aerobic Carbon Mineralization

Three depths from duplicate inland cores in Bay Jimmy were analyzed for aerobic and anaerobic carbon mineralization rates. Anaerobic carbon mineralization rates were determined by following a procedure described by Land et al. (2011). Five g of wet, homogenized sample was weighed into 160 mL serum bottles, sealed with a rubber stoppers and aluminum crimps, evacuated for 1 minute, purged with N_2 for 5 minutes, and over pressurized with N_2 for ~10 seconds. Each bottle was then injected with 10 mL of N_2 purged 12.5 Instant Ocean solution. Samples were placed in a Jeio Tech Lab Companion IS-971R refrigerated and incubated shaker at 135 rpm at 40°C. One mL gas samples were taken daily from each bottle and analyzed for CO_2 using a SRI 8610C Gas Chromatograph with a Hayesep D 3m column. Anaerobic C mineralization rates were then calculated as mg C-CO2 per kg of dry soil per hour.

Aerobic carbon mineralization rates were determined by following a procedure described by D'Angelo and Reddy (2000). Approximately 7g of wet, homogenized sample was weighed out into 600 mL glass media bottles whose caps were fitted with rubber stoppers for easy gas sampling. Bottles were then injected with 120mL of room air to pressurize the bottles, and 20mL of 12.5 Instant Ocean solution was injected into each bottle. Samples were then placed in a Jeio Tech Lab Companion IS-971R refrigerated and incubated shaker at 135 rpm at 40°C. One mL gas samples were taken daily from each bottle and analyzed for CO_2 using a SRI 8610C Gas Chromatograph with a Hayesep D 3m column. Every 2 days, bottles were reaerated by opening the bottle cap, using an air pump to re-aerate the headspace of the bottle, re-capping the bottle, and pressurizing with injecting 120 cm^3 of room air. Anaerobic C mineralization rates were then calculated as mg C-CO_2 kg^{-1} of dry soil hr^{-1} after subtracting the room air ppm of CO_2 for samples the day after reaeration.

2.9 Statistical Analysis

A correlation matrix was generated for all physicochemical, microbial, and organic matter decomposition properties for inland cores from the Bay Jimmy site. Data for the two inland September 2016 cores cut in 5cm sections were averaged so that they reflected 0-10, 10-

20, 20-30, 30-40, and 40-50 cm sections to compare to the inland November 2016 core. Pairs of 5 cm sections were also homogenized to reflect these depths for SOD and the carbon mineralization studies. For a Pearson's correlation two-tailed test and a significance level of 0.05, significant r values were determined as >0.553 for n=15, >0.707 for n=10, and >0.950 for n=6.

A two sample t-test assuming equal variances was conducted to compare anaerobic and aerobic carbon mineralization rates. Another two sample t-test assuming equal variances was also conducted to compare β-glucosidase values at -5cm and -15cm depths. A p-value <0.05 was considered significant.

3. RESULTS AND DISCUSSION

3.1 Soil Physicochemical Properties

The average values and samples standard deviations of physical and chemical properties of the three inland cores taken from the Bay Jimmy site (2 from September 2016 and 1 from November 2016) are shown in Table 1. Note that SOD, Anaerobic C Mineralization, and Aerobic C Mineralization values are averages for 2 inland cores as soil from the third core was exhausted before these experiments could be conducted. Also, after extraction, there were no detectable amounts of extractable NO_3^-or SRP in the cores. For the November 2016 inland core, the pH was 7.13 ± 0.36 and pore water conductivity was 15.29 ± 2.46 mS cm-1. There was a significant correlation of depth and percent organic matter (0.598), total carbon (0.66), and total nitrogen (0.59). These values decrease with increasing depth (Table 2).

3.2 Microbial Characteristics

The November 2016 inland core was used to determine MBC. The r^2 coefficient of determination for that core's MBC and depth was 0.924, such that the microbial pool decreased as depth increased similar to other studies (White and Reddy, 2000).

3.3 Organic Matter Decomposition Studies

I. Anaerobic Studies

There was a significant correlation with PMN and depth (r=0.77), such that anaerobic organic matter decomposition rates decreased as depth increased (Figure 3). This was expected due to the decreasing efficiency of alternate electron acceptors further down the soil profile of hydric soils. The anaerobic C mineralization study had a similar trend with depth (r=0.833) as PMN; however, due to small sample size of this study, this correlation was lower than the 0.950 r value needed to be significant.

II. Aerobic Studies

There was not a significant correlation of SOD and depth (r=0.347). For the β-glucosidase enzyme activity at -5cm and -15cm, the p-value from the two-sample, two-tailed t-test was not significant at p=0.61. (Figure 4). In addition, there was not a significant correlation of the aerobic C mineralization rates and depth (r=-0.079). Therefore, what these three aerobic studies suggest is that the rate of organic matter decomposition under aerobic conditions is independent of soil depth.

III. Comparison of Anaerobic and Aerobic Decomposition Rates

There was a significant difference between the anaerobic and aerobic C mineralization rates measured (p-value <0.001). On average, aerobic rates were 12.07 ± 8.21 times faster than anaerobic rates, and aerobic rates for subsurface samples were 16.36 ± 6.21 times faster than anaerobic rates (Figure 5). This result suggests that there is a large potential for organic matter to breakdown further in the aerobic conditions of the surrounding water column once eroded.

4. FUTURE WORK

For this project, greater depth and site replication is needed for the anaerobic and aerobic studies to determine if there is any significance with depth for Barataria Bay, LA. In addition, measuring amounts of soil carbon at varying distances from the marsh edge would be helpful to the understanding of how much of this organic material is actually being decomposed compared to reburial once the vegetation is gone. In the coming year, I hope to explore this question as well as continue this project with more depth measurements and samples from different sites.

Coastal Louisiana is facing relative sea level rise at rates today that are predicted for the world's stable coastlines in the next 50-100 years. Therefore, this high relative sea level rise and subsequent erosion can be seen as a potential model for what is to come as well as an opportunity to test and develop restoration and mitigation strategies that other communities could implement in the future. Understanding all the implications of wetland erosion, including influx of atmospheric carbon dioxide, loss of storm protection and ecological habitats, and increased risk of eutrophication and hypoxia, needs to be examined now so that society is prepared to adapt with these changes with these challenges elsewhere in the future.

5. CONCLUSION

While wetlands act as global carbon sinks that hold partially decomposed organic matter for hundreds to thousands of years, there is the potential for this stored carbon to be exhumed during coastal erosion. I found that these soils could potentially be a large source of atmospheric carbon as they are eroded and placed in an aerobic water column. On average, the aerobic decomposition rate of subsurface soil samples occurred ~16x faster than anaerobic decomposition and was independent of depth. With further decomposition, this release of CO_2 would act as a positive feedback loop, increasing atmospheric CO_2 and potential for warming, thermal expansion, sea level rise, and increased future coastal erosion. Therefore protection of these coastal wetlands carbon stocks and the understanding of the implications of coastal erosion are very important for the future of coastal and non-coastal communities.

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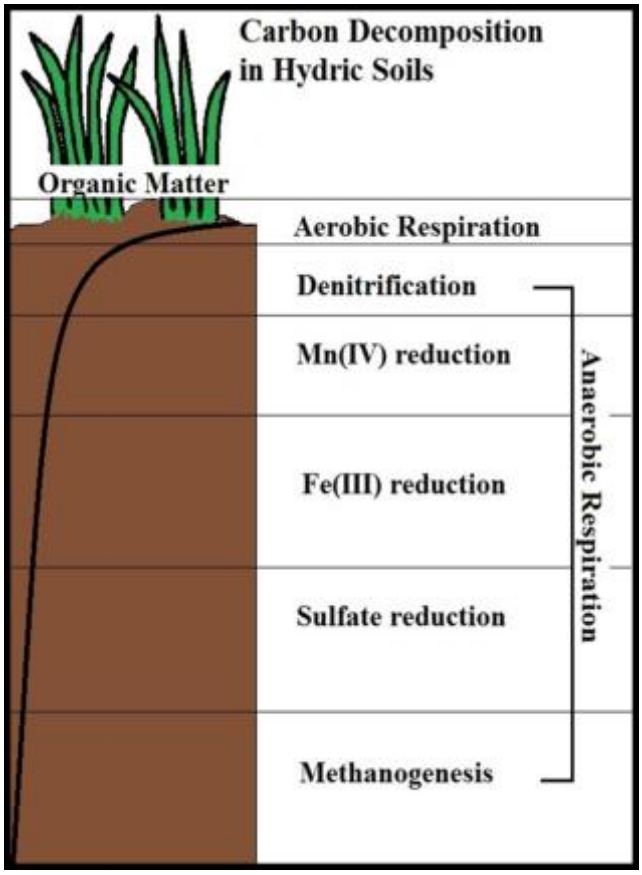

Figure 1: A conceptual diagram of the redox processes occurring in the soil profile and the amount of organic matter found in these soils in relation to depth and decomposition process.

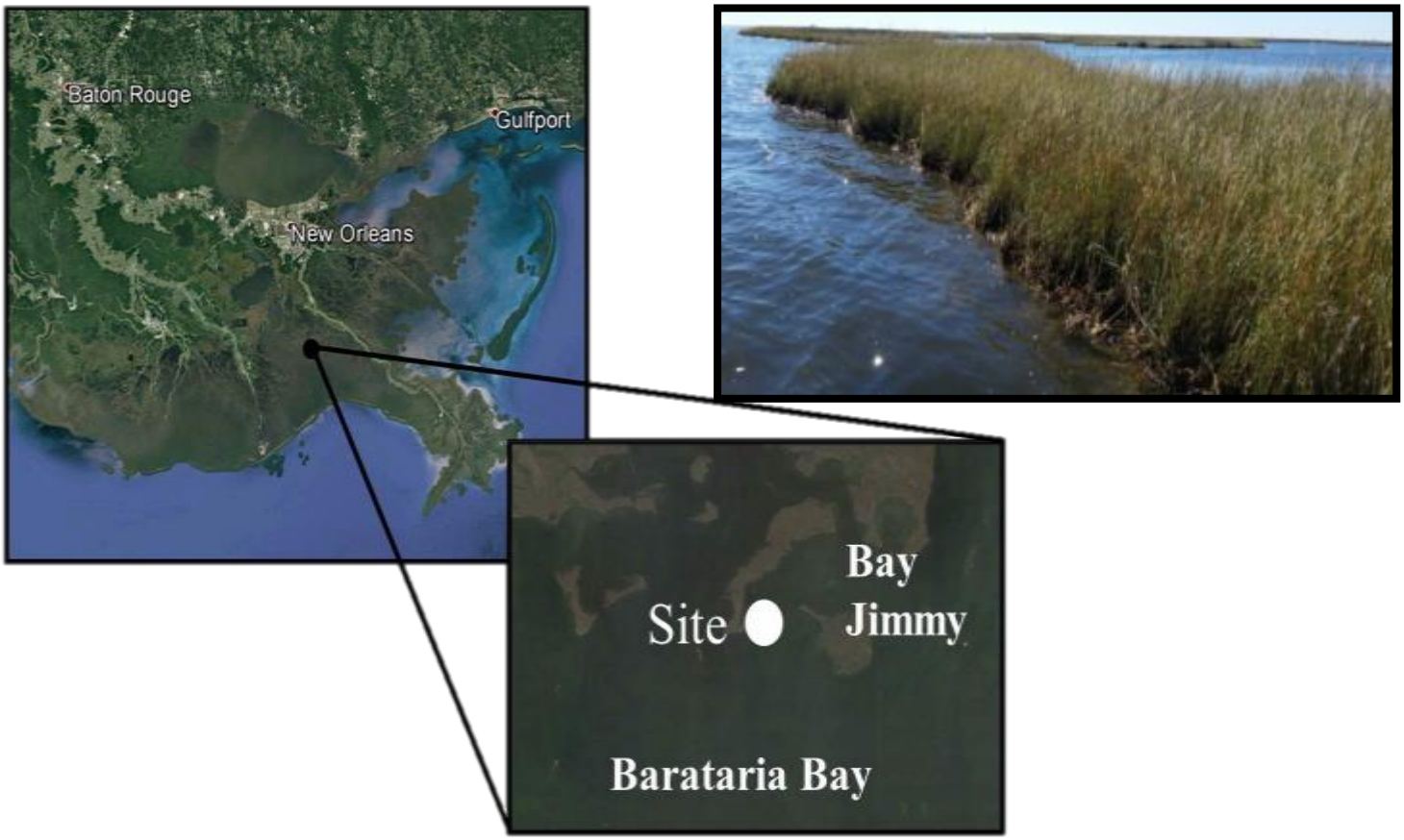

Figure 2: The map on the left shows the relative location of the Bay Jimmy site, and the picture on the right is a picture of the marsh site from the November 2016 core collection.

Table 1: The average values (±1 standard deviation) for physicochemical properties of wetland cores

Property	**Value**
Moisture Content, %	71.31 ± 6.72
Percent Organic Matter, %	19.72 ± 5.72
Bulk Density, g cm^{-3}	0.24 ± 0.11
Total Carbon, g C kg^{-1}	91.33 ± 29.75
Total Nitrogen, g N kg^{-1}	4.99 ± 1.44
Total Phosphorus, mg P kg^{-1}	522.01 ± 34.46
Extractable NH_4^+, mg N kg^{-1}	12.75 ± 13.39

Table 2: Correlation matrix of Pearson Correlation r values for Bay Jimmy wetland cores. Significance was determined at a 0.05 level, and significant r values are bolded in the table. *Note depth was recorded as a negative value; therefore, positive r values indicate decreasing values with increasing depth.

	Depth	*LOI*	*Soil Moisture*	*Bulk Density*	*TP*	*TC*	*TN*	*NH4*	*PMN*	*SOD*	*Anaerobic C*
LOI	**0.598**										
Soil Moisture	0.508	**0.936**									
Bulk Density	-0.307	-0.312	-0.438								
TP	0.109	0.324	0.277	-0.229							
TC	**0.664**	**0.983**	**0.890**	-0.338	0.339						
TN	**0.586**	**0.964**	**0.942**	-0.311	0.234	**0.944**					
NH4	0.125	0.042	0.011	-0.042	**0.555**	0.092	0.119				
PMN	**0.774**	**0.642**	0.487	-0.147	0.332	**0.672**	**0.601**	0.425			
SOD	0.347	0.559	0.668	-0.052	0.040	0.528	0.671	0.330	0.126		
Anaerobic C	0.833	0.716	0.463	-0.075	0.155	0.771	0.517	-0.633	0.814	-0.041	
Aerobic C	-0.079	0.088	0.375	-0.314	-0.069	0.029	0.313	0.835	-0.375	0.736	-0.603

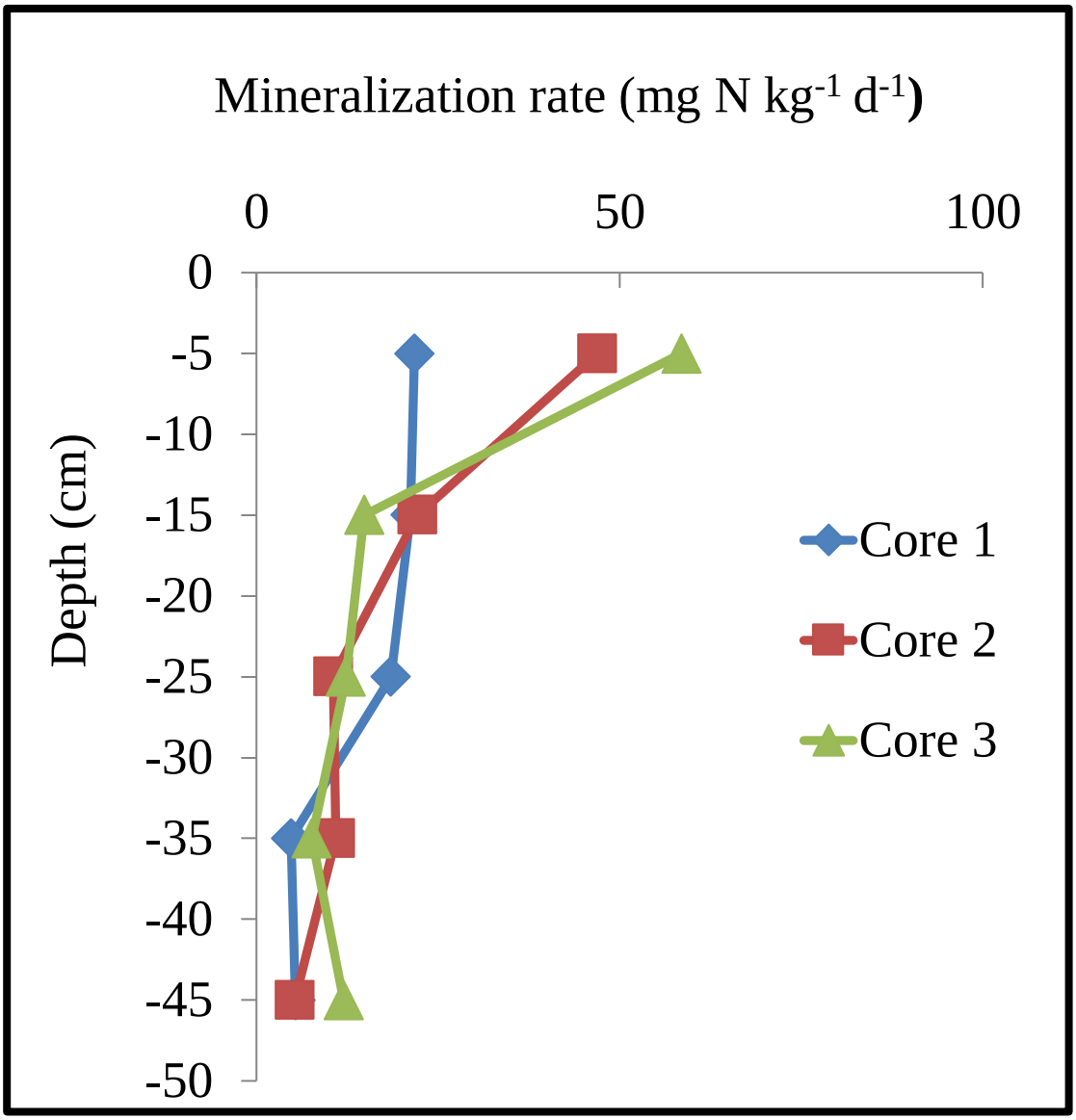

Figure 3: Potentially Mineralizable Nitrogen rates seen in 3 cores compared to the depth of each sample.

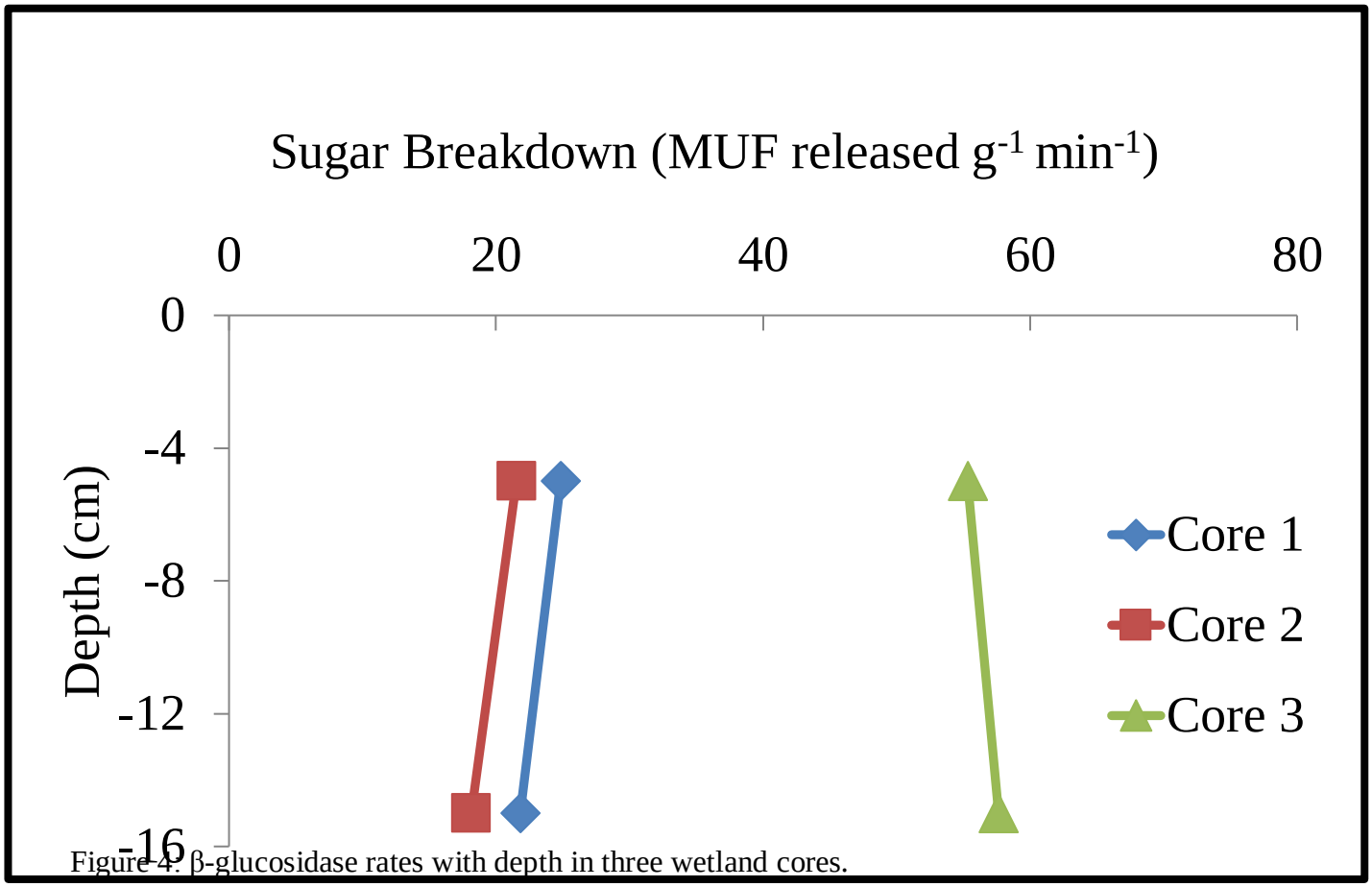

Figure 4. β-glucosidase rates with depth in three wetland cores.

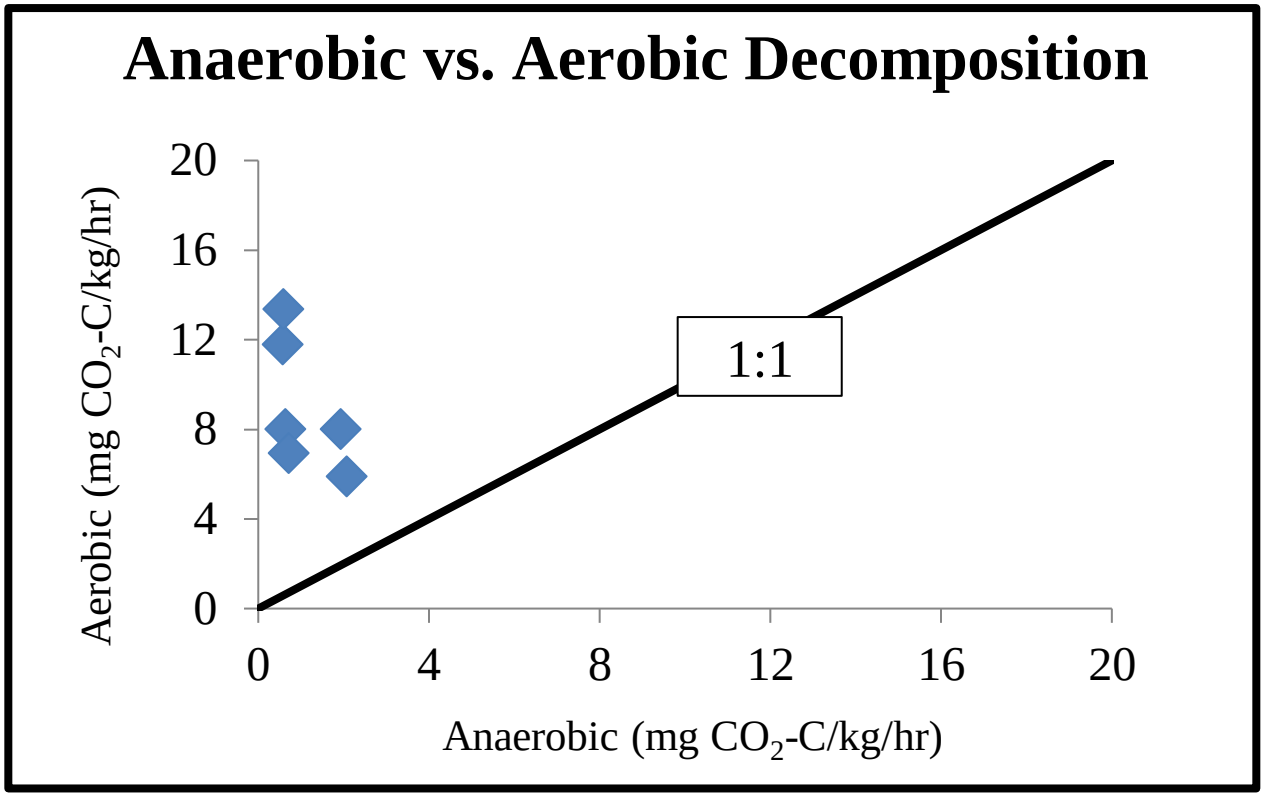

Figure 5: Anaerobic vs. aerobic C mineralization rates. Also shown is a 1:1 line for comparison. Aerobic rates were on average ~12x faster than their corresponding anaerobic rates.