CONSEQUENCES OF THIN LAYER DEPOSITION FOR PIERMONT TIDAL MARSHES

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Abstract. Rising sea levels and stronger storm surges may expose tidal freshwater wetlands to expansion of open water areas; this phenomenon is best described as marshes drowning. Sea level rise rates outpace marsh vertical accretion, wave erosion accelerates edge retreat, or marsh collapse occurs within newly formed un-vegetated areas (VanZomeren 2018). Some marshes may have enough sediment supply that they will accrete vertically so will persist in their current condition (Sritrairat et al. 2012, Morris et al. 2016) but other marshes seem unlikely to keep pace. Traditionally, dredge materials are deposited in confined disposal facilities, used as fill material to build or restore wetlands (Berkowitz 2016). The application of this dredge sediment to the marshes surface has the potential to maintain marsh elevation despite accelerating future rates of potential sea level rise. We propose to evaluate the consequences of the application of this technique to the Piermont Tidal Marshes in term of soil nutrients. The results found supported the idea of using the material chosen for the experiment since the behavior of the variables tested was similar in both types of sediments. No significant difference was found between NO_3 and DEA amongst the treatments for the most part but there was a negative relationship showed in the graphs between NO_3 and DEA activity. The oxygen consumption was found to be similar in the marsh and the cap sediment and the organic matter content of the dredge sediment matches the marshes content.

INTRODUCTION

Sea level rise is the result of two primary biophysical factors. First, as the oceans absorb excess CO_2 from the atmosphere, it causes ocean temperatures to rise which expands the volume of water in the ocean. Second, as average global temperatures increase, arctic glaciers and ice caps melt, adding additional volume to ocean water levels (Sea Level Rise Affecting Marshes Model, 2019). This is one of the major elements of climate change that is highly likely to negatively affect Hudson River tidal marshes and other habitats. The medium to rapid projected rates of Sea Level Rise (SLR) will exceed current marsh vertical accretion in some portions of the estuary, leading either to loss of these habitats or conversion from one dominant vegetation type to another. Healthy marshes maintain elevation through vertical accretion and contain stable vegetated areas interspersed with shallow un-vegetated pannes or deeper, open water areas. This mosaic of vegetated and un-vegetated geomorphic features provides varied habitat types within the marsh, supporting a variety of threatened and endangered species (VanZomeren 2018). Wetlands perform a multitude of functions that make them invaluable ecosystems not only to the organisms they contain, but also to surrounding environments. Tidal freshwater wetlands are a unique environment because they are subject to ocean-generated, lunar tides. With high surface area, anoxic zones near the sediment surface, and abundant organic matter, tidal freshwater wetlands are an ideal environment for the removal of nitrate via denitrification. Median rates of denitrification in tidal freshwater wetlands are up to 40% higher than rates recorded for other intertidal and aquatic ecosystems. Denitrification in tidal freshwater wetlands is likely coupled to an influx of nitrate from flooding waters though can also be internally fueled in ecosystems with tightly coupled nitrogen cycles (Osborne 2015). All this information coincides with the fact that wetland soil provides an ideal environment for the transformation of nitrate to nitrogen gas due to the combination of low oxygen content and high organic carbon availability. Denitrification removes the bioavailable pool of nitrate from the system thereby improving the adjacent water quality (Berkowitz 2016). In the case of Piermont Tidal Marshes, site of our specific study, wetlands perform another important task that is reducing the effects of floodwaters and storm surges by moderating water velocity (Osborne 2015), which is very important for the Piermont Village that lies adjacent to the wetlands in defense of natural disasters like those. Piermont Marsh encompasses 1,017 acres and lies at the southern edge of the village of Piermont, four miles south of Nyack in Rockland County. The Piermont Marsh is on the western shore of the Tappan Zee. The site occupies two miles of shoreline south of the mile-long Piermont Pier and includes the mouth of Sparkill Creek and extensive tidal shallows. Piermont Marsh habitats include brackish tidal marsh, shallows and intertidal flats.

Restoration strategies that mitigate marsh degradation while improving marsh structure and function are necessary, and have been implemented over several decades to stabilize, nourish, and enhance marsh ecosystems (Christine M. VanZomeren, 2018). Given the importance of wetland ecosystems, it is not surprising that recent studies like Christine M. VanZomeren et al., 2018 have focused efforts on wetland restoration techniques as a solution for all the problems that a projected increase of sea level rise represents. These studies have introduced a technique called Thin Layer Deposition (TLD). Thin layer placement restoration techniques involve the application of sediment; typically dredge from nearby navigation channels, to a depth, thickness, or elevation that ideally does not transform the ecological function of the receiving habitat, while improving environmental outcomes, infrastructure, and resiliency (VanZomeren 2018). The application of dredge sediments to the marsh surface has the potential to maintain marsh elevation despite current costal subsidence or accelerating future rates of sea level rise by supporting a stable platform for plant growth while maintaining natural patterns of hydrology and vegetation. Studies of the effects of placing dredged materials on marshes originated with recognition that marshes are adapted to respond to natural processes, such as storms, which deposit wrack and sediments on the marsh surfaces (Ray 2007). Amongst the aspects researches have focused on are response of plant community, invertebrates, soil organic matter accumulation and bulk density, and marsh resilience following a disturbance (Christine M. VanZomeren, 2018). It has been observed rapid vegetation recovery after 6 months of placement of dredge material, this observation has been recurrent after the application of 30 cm of dredge material or less (Christine M. VanZomeren, 2018). Soil microbial biomass has been seen more likely to decline in the buried soil.

Response of soil properties and the microbial pool to TLD remains poorly understood despite the recognized importance of soils in ecological restoration. Here we propose to focus on soil nutrients such as ammonium, nitrate, phosphate and oxygen. We expect the results of this research to be a starting point for future work to better understand these two important responses.

The questions we propose to investigate are:

1. Will a thin layer deposition (TLD) of low organic matter sediment (dredge) have a negative impact in the oxygen penetration and denitrification activity when applied in the Hudson River tidal marshes?
2. Is there a threshold in depth of addition where negative effects become apparent?
3. Does addition of organic matter to dredge material magnify effects of TLD?

The hypotheses stated and proposed are:

1. The application of TLD will increase the anaerobic conditions of the soil of the Piermont marshes thus reducing oxygen penetration.
2. An increment in the concentration of NH_4 is expected after the application of TLD.
3. The DEA is expected to decline at the cap and sediment layers of the Piermont marshes after TLD.

MATERIALS AND METHODS

The experimental set up was located at the green house of the Cary Institute. We attempted to simulate the TLD as performed in the field but in a minor scale using sediment samples. The Piermont marshes is considered the site of study because the sediment samples will be collected from there and brought to Cary Institute of Ecosystem Studies (Millbrook, NY). The sediment used were extracted directly from the Piermont marshes and the dredge sediment will be collected from Phillipstown Yacht Club, New York. The experiment consisted of bottom-capped 4 inches diameter cylinders used to collect a total of 25 marsh sediment cores of approximately 20 cm depth. The dredge sediment application was be done in layers or 5 cm, 15 cm, and 30 cm. A negative control with no dredge sediment added will be counted as one of the treatments as well. Another 5 cm cap treatment was set up, the dredge material in this case was mixed with organic matter that was collected along with the marsh sediment. There was a total of 5 treatments with 5 replicates each. The cores were placed in a tank connected to a water pumping system. This water pumping system was mimicking the tides that occur in the natural tidal marsh environment. The pumping system was set to automatically pump water in at 6 am, pump water out at noon, water in at 6 pm, and water out at 12 am. The height of the tank and the velocity at which water flows was provided to secure the water to overcome the height of the cylinders and make sure the water reaches the sediment. The cylinders had a hole through which water drained once the water started being pumped out the system. After 3 weeks the experiment was taken apart and marshes sediment (buried portion) and dredge sediment (cap portion) were collected to proceed analyzing the porewater nutrient.

Oxygen Probes

Microelectrode measurements of in situ sediment dissolved oxygen (O_2) were conducted. Oxygen microelectrodes were calibrated using tap water saturated with oxygen (100% O_2 saturation) and then saturated with dinitrogen (0% O_2 saturation). Simultaneous measurements of dissolved oxygen were also taken in the water column with a conventional O_2 handheld meter. For each sediment profile, measurements were recorded at the sediment surface followed by a sequence of measurements at 1 mm vertical increments (based on changes in O_2) to a final depth of 2 cm into the sediment. (Robert I. Osborne, 2015)

Porewater nutrient

Sediment samples were placed into ---mL centrifuge tubes and centrifuged to extract the porewater. The samples were filtered. Porewater was collected and stored in acidified vials (HCL) until analysis (Mary Alldred, 2016).

Denitrification Enzyme Activity Assay

<u>Equipment and supplies:</u>

- Glass vials
- Gas bag with acetylene (C2H2) gas (8 ml per flask)
- 125 mL Erlenmeyer flasks with rough necks (VWR PN 89001-332)
- Rubber Cap
- needles, gas tight syringes
- Evacuation manifold with vacuum line, N_2 gas to flush, and small needles

- DEA media: In a 1 L volumetric flask add: 0.72 g KNO_3, 0.5 g glucose, 0.125 g Chloramphenicol, and bring to volume with DI water.
- Shaker table

Tasks before sampling:

- Make DEA media, store in fridge
- Acid wash and dry rough neck Erlenmeyer flasks
- Fill one gas bag with acetylene
- Evacuate vials
- Label vials duplicates for 30 min and 90 min sampling.

Approximately 5 g of sediment samples were placed in Erlenmeyer flasks and incubated with DEA media. The flasks were flushed with N_2 and evacuated 3 times to make sure no oxygen was present. Then the acetylene was injected to the flask and these were placed in the shaking table for 30 min before the first gas sampling was carried out. The samples collected at 30 and 90 minutes and stored in pre-evacuated glass vials. Gas samples were analyzed for N_2O using electron capture gas chromatography. This method provides an indication of the amount of denitrifying enzyme present in the soil and has been demonstrated to be a reliable measurement for comparing the potential for microbial communities to perform denitrification among experimental treatments or sites. While useful for detection of relative changes in denitrification among treatment plots, these denitrification potentials should not be interpreted as a measure of absolute denitrification rates. A subsample of each core was also used to determine sediment moisture content as the change in mass after drying at 70°C for a minimum of 24 hrs, total organic content as the loss after combustion at 450°C for 4 hrs.

RESULTS

Oxygen penetration

We performed the measurement of oxygen penetration in the cores layers by introducing a microprobe in the sediment and looking at the milimiter that it would take for oxygen to be depleted as the microprobe went through deeper layer within the core. The results for each replicate per treatments were found to be similar amongst the treatments. There was not found any significant differences differences amongst the treatments, the ANOVA results show a p value > 0.05. The oxygen penetration started to decline at approximately the same depth for the control treatment and the treatments with sediment cap added.

Porewater nutrients

The nutrients we analyzed from the extraction of the porewater of the sediment were NO_3 and NH_4. The results for NH_4 showed a trend of increase as the thickness of the cap material incremented from one treatment to another. The cap sediment was analyzed separated from the marsh sediment. The statistical results for the ANOVA prove significant differences for the NH_4 concentrations in pore water. The p value<0.05 shows that exists a big variation from control treatment to 30 cm cap treatment of increasing concentrations.

A DEA (Denitrification Enzyme Activity) assay was performed to evaluate N2O production rates, also in marsh sediment separately from cap sediment. This essay also was performed in each of the replicates and the average activity found was assigned to each treatment.

Lastly, we looked at the differences in organic matter content amongst the marsh sediment, the cap sediment, and the cap sediment with extra organic matter added to see what influence this variable could have in the results obtained. No difference amongst different types of sediments were found.

DISCUSSION

We performed an ANOVA test to statistically analyze the results and compare the mean values calculated for all the replicates of each treatment. The mean depth at which oxygen penetration decline showed in figure 3 was found not to be significantly different for each of the treatments 0cm cap, 5 cm cap and 5 cm + OM (organic matter) cap. The p value calculated was 0.25 as shown in Table 1. These results indicate that the cap material, foreign to the marsh, behaves like the marsh material in terms of oxygen penetration. The zone of oxygen depletion is not moving upwards after applying a layer on top of the cap material hence the access to oxygen would stay in a same range of depth down the soil for the invertebrate's population.

A comparison of the organic matter content amongst the different sediments was carried out. An ANOVA test was also performed to compared mean organic matter content and the results are shown in Table 2. No significant difference was found looking at a p value of 0.63. This result has the same implication as the result obtained for oxygen penetration. A similarity in the organic matter content of the different sediments suggests the cap sediment as a good candidate to be used in TLD. If this was the case, and the dredge material from the cap was to be used in a bigger scale in the marshes, the ecosystem and the soil environment were not be disturbed since the same amount of organic matter was going to be available for life to succeed and thrive.

The results of NH_4 concentration showed significant differences amongst the treatments with $p<<0.05$ in both, marsh and cap sediments, as we can see in tables 3 and 4. As cap thickness increased from 0 cm to 30 cm, the NH_4 stayed trapped beneath the layers of sediment which increased the NH_4 concentrations. Extrapolating these results to the field, we could expect good consequences after the application of a medium thickness cap of soil, the NH_4 pool of the soil will increase and more NH_4 will be available for plants uptake and NO_3 formation, less NH_4 will escape the soil via volatilization.

The results for DEA and NO_3 can be analyzed together since we expect a correlation between NO_3 concentrations and N2O production using NO_3 in the soil. Starting by the cap sediment, we did not find any significant difference amongst the treatments for NO_3 concentrations and DEA activity as shown in tables 6 and 7 with p values > 0.05. We expected to find less nitrate in treatment with high DEA and that is the trend that figures 5 and 6 show, for treatments that show high DEA we find little NO_3 concentration, but we did not find any correlation between these variables and thickness of the cap. We did find significant differences amongst the treatments for the NO_3 concentrations in the marsh sediment, but no trend was found in figure 5 that associate these differences to the thickness of the cap. The p value of 0.0009 can be seen in Table 5.

CONCLUSION

We conclude that the performance of this experiment provide scientist with a background information of what to expect after the application of a thin layer deposition in Piermont Marshes as a strategy for conservation. The biogeochemical characteristics of the soil will not be change drastically if this material used for the experiment is chosen to be applied in the field. The oxygen consumption was found to be similar in the marsh and the cap sediment and the organic matter content of the dredge sediment matches the marshes content, this two results support the idea of using this material for the application in the field to not disturb the marsh ecosystem. Also, NH_4 was kept trapped when thickness of the cap increased and scaping via volatilization declined making bigger the NH_4 pool in the soil for plants uptake if these results are extrapolated to the field, this will imply more NH4 for NO_3 formation as well. No significant difference was found between NO_3 and DEA amongst the treatments for the most part but there was a negative relationship showed in the graphs between NO_3 and DEA activity. There was no evidence to link changes in DEA activity or NO_3 to thickness of the cap since statistical analysis proved no significant differences.

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APPENDIX

TABLE 1. Results for the ANOVA performed to evaluate the differences amongst treatments for oxygen penetration.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.533333	2	3.266667	1.555556	0.250789	3.885294
Within Groups	25.2	12	2.1			
Total	31.73333	14				

TABLE 2. ANOVA test to evaluate organic matter content.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.061684	2	0.030842	0.481723	0.629165	3.885294
Within Groups	0.76829	12	0.064024			
Total	0.829973	14				

TABLE 3. ANOVA test to evaluate NH4 concentrations in porewater of the marsh sediment.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	366.7092	4	91.67731	10.88224	7.51E-05	2.866081
Within Groups	168.4898	20	8.424488			
Total	535.199	24				

TABLE 4. ANOVA test to evaluate NH4 concentrations in porewater of the cap sediment.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	798.7935	3	266.2645	11.04966	0.000355	3.238872
Within Groups	385.5534	16	24.09709			
Total	1184.347	19				

TABLE 5. ANOVA test to evaluate NO3 concentrations in porewater of the marsh sediment.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.25322	4	0.313305	7.186866	0.000932	2.866081
Within Groups	0.871882	20	0.043594			
Total	2.125102	24				

TABLE 6. ANOVA test to evaluate NO_3 concentrations in porewater of the cap sediment.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.01492	3	0.004973	0.664218	0.586085	3.238872
Within Groups	0.1198	16	0.007488			
Total	0.13472	19				

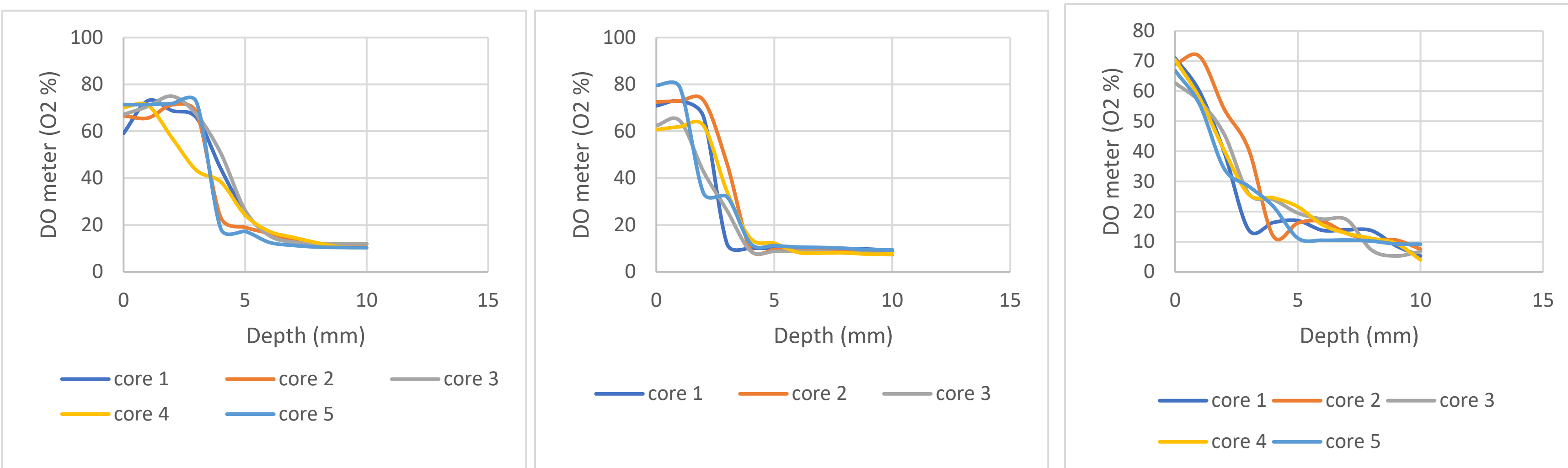
TABLE 7. ANOVA test to evaluate DEA activity of marsh sediment.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.7682	4	0.442	1.1124	0.3783	2.8661
Within Groups	7.9475	20	0.3974			
Total	9.7157	24				

TABLE 8. ANOVA test to evaluate DEA activity of cap sediment.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.2111	3	0.737	2.7374	0.0778	3.2389
Within Groups	4.3079	16	0.2692			
Total	6.519	19				

FIGURE 1. Map of Piermont Marsh and Piermont Village. Retrieved from: https://dailyvoice.com/new-york/mountpleasant/news/kayakers-pulled-to-safety-along-hudson-river/717263/



A. B. C.

FIGURE 2. A. Oxygen profile for control treatment, no cap sediment added. B. Oxygen profile for treatment with 5 cm cap added. C. Oxygen profile for treatment with 5 cm cap added and extra organic matter (OM).

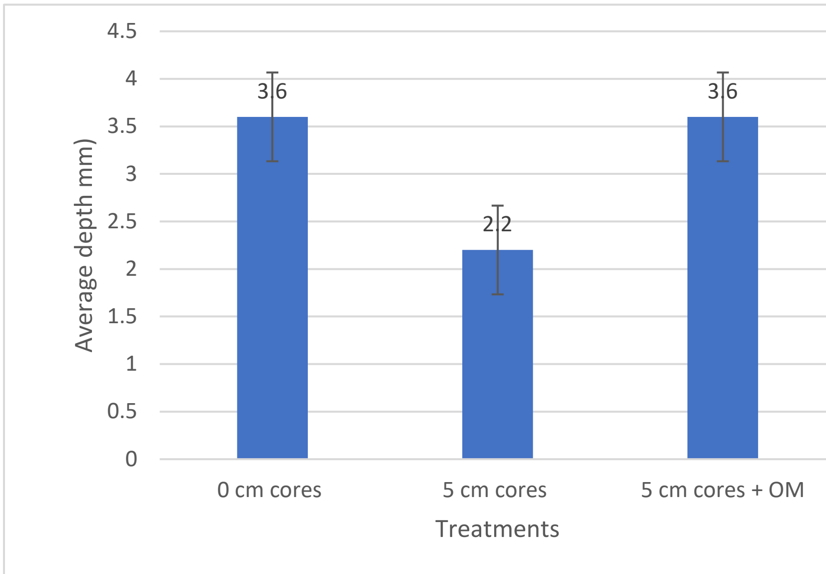


FIGURE 3. Average depth at which the oxygen penetration showed a steep decline inside the core for each treatment.

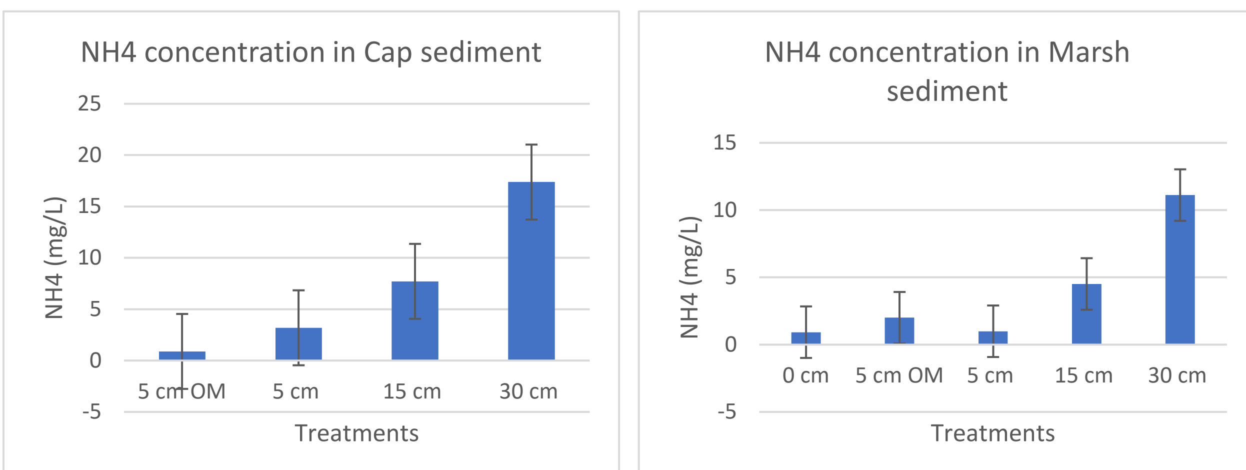
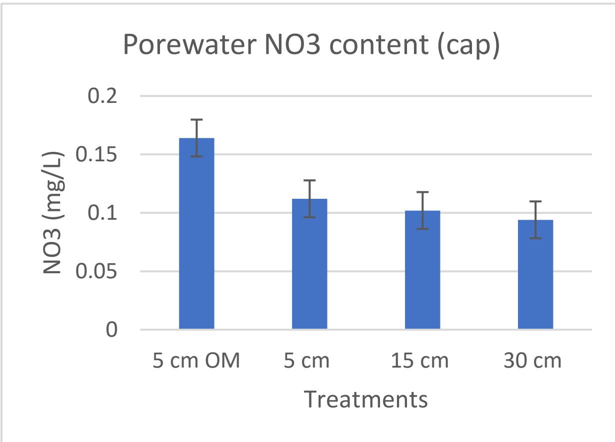


FIGURE 4. The graph to the right corresponds to the NH4 concentration in porewater of marsh sediment. The graph to the left corresponds to the NH4 concentration in cap sediment.



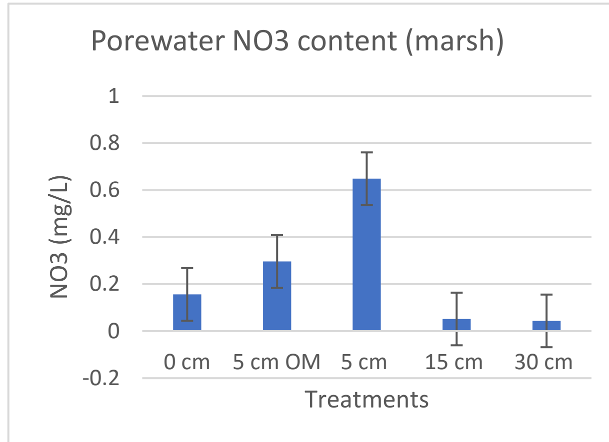
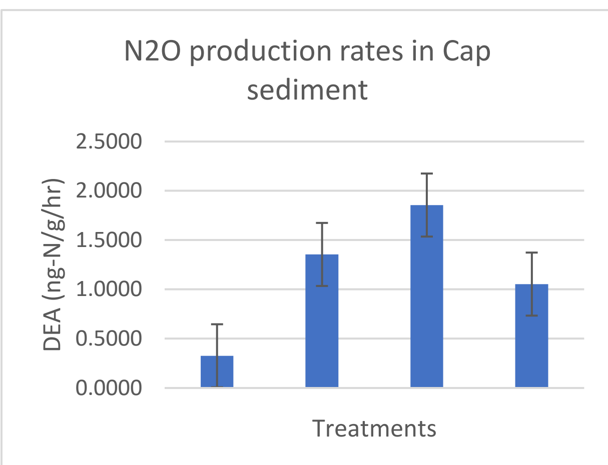


FIGURE 5. Nitrate concentration for different treatments. Graph to the right represents nitrate concentration in marshes sediment. Graph to the left represent nitrate concentration in cap sediment.



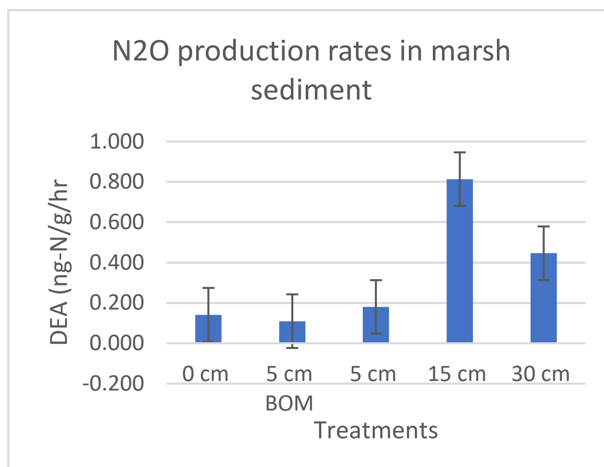


FIGURE 6. Denitrification activity in cap sediment, showed to the left and in marsh sediment, showed to the right.

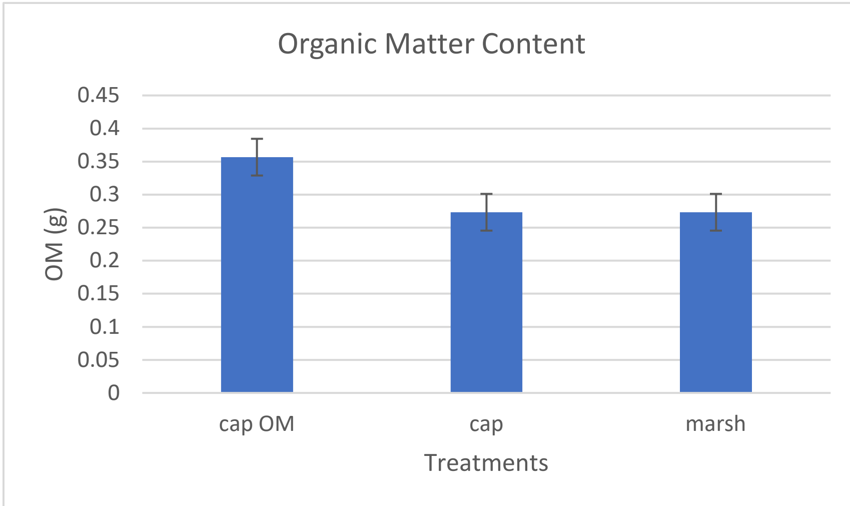


FIGURE 7. Organic matter content found in the marsh sediment, cap sediment, and cap with extra organic matter.