

# **Rising Sea Level and The Effects on Vadose Zone Podzolized Carbon**

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## **Introduction**

Sea level rise is a major concern for the state of Florida and the southeastern United States. Sea level has been rising steadily for the past 12,000 years and getting faster within the last 100 years and this is caused by the melting of ice sheets and glaciers. By the year 2100 it is estimated that sea level will rise by approximately 55 cm (Allison et al. 2012) Using this data as a basis, sea level will continue to rise and lead to more saltwater intrusion, as well as cause areas that were previously saturated by freshwater to have greater saltwater concentrations than historical averages. The purpose of this study is to investigate how sea level rise and increased saltwater intrusion will affect podzolized carbon in spodic horizons within the coastal plains of Florida.

Podzolization is a process in which organic carbon in solution mixes with metals such as Iron (Fe) or Aluminum (Al) when the vadose zone water rises (Bacon et al., 2020). Once that vadose zone water table lowers, the organometallic compound super saturates and precipitates out of the soil leaving a distinct black or brown layer in the soil subsurface (Bacon et al., 2020).. Podzolization of carbon is the process that creates Spodic horizons. A spodosol is a classification of soil by the USDA NRCS that contains podzolized carbon (Schoeneberger et al. 2012). In soil science this podzolized carbon is commonly denoted as a Bh horizon and in this study will be referred to as such.

There is much research on how sea level rise may affect organic carbon especially in wetland ecosystems, there is little research done on the effects of podzolized carbon. In one study data suggests that sea level rise will actually increase the amount of sequestered carbon within coastal marshes (Herbert, Windham-Myers, and Kirwan 2021). This study looks at data of carbon

accumulation from 131 sites from around the U.S. The data that was collected was used as model to study how the significant loss of Marshes in Louisiana affected the carbon sequestering abilities of that ecosystem, and concluded that there is actually an increase in carbon sequestration (Herbert, Windham-Myers, and Kirwan 2021). However another study that was done in 2019 showed that there is significant carbon loss in Barataria Bay, Louisiana as the soil does not get sequestered and is actually eroded from rising sea level (Haywood et al. 2020). Another key factor besides carbon is the metals that form when the podzolization process occurs. There are studies that investigate how metals are able to mobilize through increased salinity. One study looked at how marine derived salts effected metal mobilization and it was determined that initially at 10-50% saltwater concentration, high concentrations of Al, Fe, Ni and Zn could mobilize (Wong et al. 2010). While there is some debate on the effects of sea level rise on organic carbon there are few studies done on how sea level rise will affect non-organic carbon storage in soils.

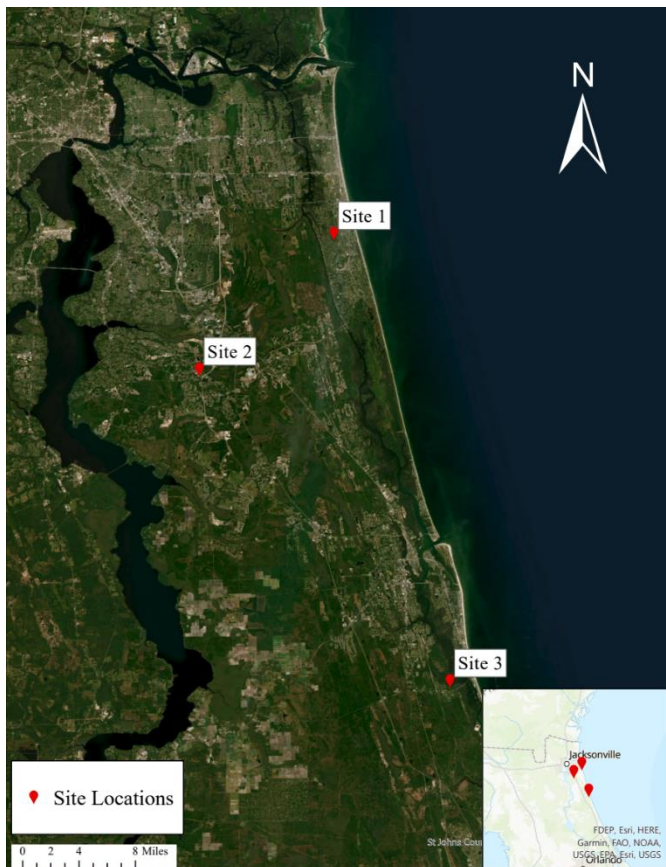
In the state of Florida approximately 3.6 million hectares or 27% of the land area of the state is classified as spodosol (Stone et al. 1993). Podzolized carbon is also a carbon sink as the organic material is held in the subsurface as stable podzolized carbon. Sea level rise has drastic effects on soil salinity (Corwin 2021) and will likely affect soil chemistry and there has been very little research on how increasing salinity levels may affect the stability of podzolized carbon. The amount of carbon that can be stored in the Bh horizon as much as  $10 \text{ kg m}^{-2}$  (Stone et al. 1993).

It is important to determine how water table salinity in these areas can affect the stability of podzolized carbon and whether or not the carbon stored in these areas is more likely to be released as a result. It is generally accepted that the storage of carbon in podzolized carbon is very stable. The hypothesis of this study is that as salt water intrusion/ sea level rise occurs the stability of that carbon can break down and be released into the environment. This could potentially release

a major amount of carbon back into the system that was once extremely stable resulting in increasing levels of carbon dioxide in the atmosphere.

## Methods

The first step of the study was to determine locations that would have suitable soil collection. Three locations (See Map Below) were chosen and A, E and Bh horizons were



**Map 1.** Map of soil sampling sites in NE Florida

collected at each site. These three site locations were picked due to the location to the Atlantic Ocean, the presence of a spodic (Bh) horizon, and certain site characteristics. Site 1 is in a residential development with significant alterations to the soil while still retaining its spodic layer, site 2 is directly adjacent to residential development but is relatively untouched, and site 3 is in a managed pine flatwoods and is will closely resemble a natural system and nutrient inputs. The site locations show a gradient from natural to

heavily anthropogenically influenced. Even though the primary focus of the study involved examining Bh horizons it was determined that background information from the A and E may be useful. Soil samples were collected using a sharpshooter shovel and approximately ~3.78 liters of soil were collected for each soil horizon. Once the soil samples were collected, they were

sieved with a 40-mesh sieve to remove any large non-soil components. Once the soil was sieved it was kept wet and placed in a refrigerator until salt water extraction occurs. In order to create a scale of salinity treatments, salt water was collected directly from the Atlantic Ocean and diluted from 100% (35 PSU) to 50% (17 PSU) and 10% (3.5 PSU) with deionized water. The lower salinity concentrations would best represent how saltwater intrusion is a gradual process and create useful comparisons. De-ionized water was used as a control and would act as the 0% or pure freshwater. Three samples for each salt water concentration were put in a 50 ml Falcon® centrifuge tube with approximately ~ 5 grams of soil sample. In total 104 samples were prepared and put on a shaker table for 24 hours in order to maximize extraction. After 24 hours they were tested in the Whitney Laboratory for dissolved organic carbon (DOC) and total phosphorous (TP). The data that was collected shows the results for the A, E, and Bh layers at all three sites where samples were collected. For the purposes of this study the Bh horizon is the one that will be focused on. DOC samples were collected because that would best represent the breakdown of the stability of podzolized carbon. TP samples were also taken to see if there was any connection between DOC and TP as saltwater concentration increased.

## **Results**

Analysis results of each of three samples that were collected at each soil horizon and each salinity level are displayed in tables 1-6. The following Figures (1-6) are bar graphs that were created using the mean of the three samples collected at each soil horizon and salinity level derived from tables 1-6 respectively. In all of the tables the Sample ID's first number represents the site that the sample was collected from and then a corresponding soil horizon designation following the site number (i.e. 1A). Then there is a hyphen with which the letter corresponds to a separate sample going from A-C signifying that there are three samples collected from each soil

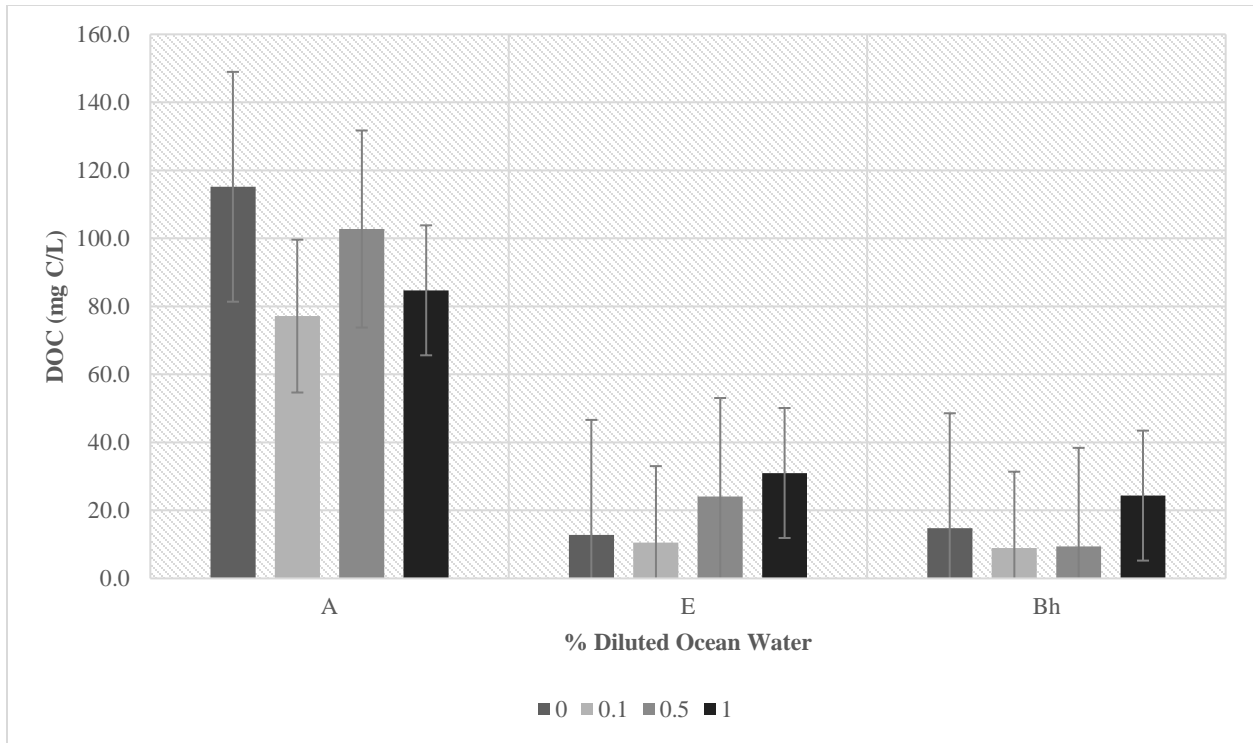
horizon (i.e. -A). The results for DOC show that the Bh layer at sites 1 and 2 have an overall increase of 64% from 14.8 mg C/L to 24.3 (Figure 1) 14.8 mg C/L and an increase of 46% from 4.1 mg C/L to 6.0 mg C/L (Figure 3) of DOC as salinity levels increase, however in site 3 there was a 94% decrease in DOC from 222.4 mg C/L to 11.6 mg C/L (Figure5) as salinity levels increased. For site 3 the levels of DOC in the control were significantly higher than the other sites and may have been caused by organic material contaminating the samples that were collected. The rest of the samples in the Bh horizon in site three show significantly decreased levels of DOC however those samples were closer to the levels that were detected at the other 2 sites. Although the data from sites 1 and 2 show an increase in DOC it is important to note that site 3 shows a decrease in DOC, and further sample collection would need to be done to see a clear pattern. The A horizons In site 1 and site 3 show a decrease in 26.7% DOC with site 1 going from 115.2 mg C/L to 84.7 mg C/L (Figure 1) and site 3 showing a decrease in 74.8% from 154.8 mg C/L to 39 mg C/L (Figure 5). Site 2 A horizon, however showed an increase in DOC by 8.8% from 89.3 mg C/L to 97.2 mg C/L. For the E horizons there was an increase of 142.2% from 12.8 mg C/L to 31.0 mg C/L (Figure 1) and in site 3 an increase of 42.1% increase from 12.1 mg C/L to 17.2 mg C/L(Figure 5). At the site 2 E horizon sample there was a decrease of 33.7% from 16.9 mg C/L to 11.2 mg C/L ( Figure 3).

The results for the Bh TP measurements were that TP decreased as salinity increased in site 1 by 34% from .143 mg P/L to .094 mg P/L (Figure 2) and site 3 by 63% from .226 mg P/L to .084 mg P/L (Figure 6). In site 2 there was very little to no TP detected throughout the Bh horizon (Figure 4) and no change occurred. For the A horizon there was an increase in TP as salinity increases in site 2 by 2410% from .010 mg P/L to .251 mg P/L (Figure 4), and in site 3 by 492% increase from .117 mg P/L to .693 mg P/L (Figure 6). In site 1 there was a decrease in

TP as salinity increases by 9% from 1.905 mg P/L to 1.732 mg P/L (Figure 2). For the samples collected at the E horizons all three sites show an increase in TP as salinity increases, at site 1 there is a 600% increase from .011 mg P/L to .077 mg P/L, at site 2 there was no TP detected at 0% salinity but at 100% salinity to .069 mg P/L, and for site 3 there was a 20800% increase from .003 mg P/L to .627 mg P/L. There are some major fluctuations in TP as salinity levels increase and further research must be done to determine how TP is affected in each horizon as salinity increases.

**Table 1:** Site 1 Dissolved Organic Carbon (DOC) is measured in milligrams of carbon per liter at increasing levels of salinity.

Sample ID	DOC (mg C/L)	% Salinity	Sample ID	DOC (mg C/L)	% Salinity
1A-A	145.6	0	1A-A	98.3	50
1A-B	90		1A-B	106.6	
1A-C	109.9		1A-C	103.3	
1E-A	12.8		1E-A	24.5	
1E-B	10.2		1E-B	23.7	
1E-C	15.4		1E-C	24.1	
1BH-A	17.7		1BH-A	11.6	
1BH-B	7.9		1BH-B	5.8	
1BH-C	18.6		1BH-C	10.9	
1A-A	106.8	10	1A-A	89.2	100
1A-B	77		1A-B	89.3	
1A-C	47.6		1A-C	75.7	
1E-A	14.5		1E-A	31.9	
1E-B	12.8		1E-B	29.9	
1E-C	4.3		1E-C	31.2	
1BH-A	5.5		1BH-A	23.5	
1BH-B	11.3		1BH-B	25.4	
1BH-C	9.9		1BH-C	24.2	

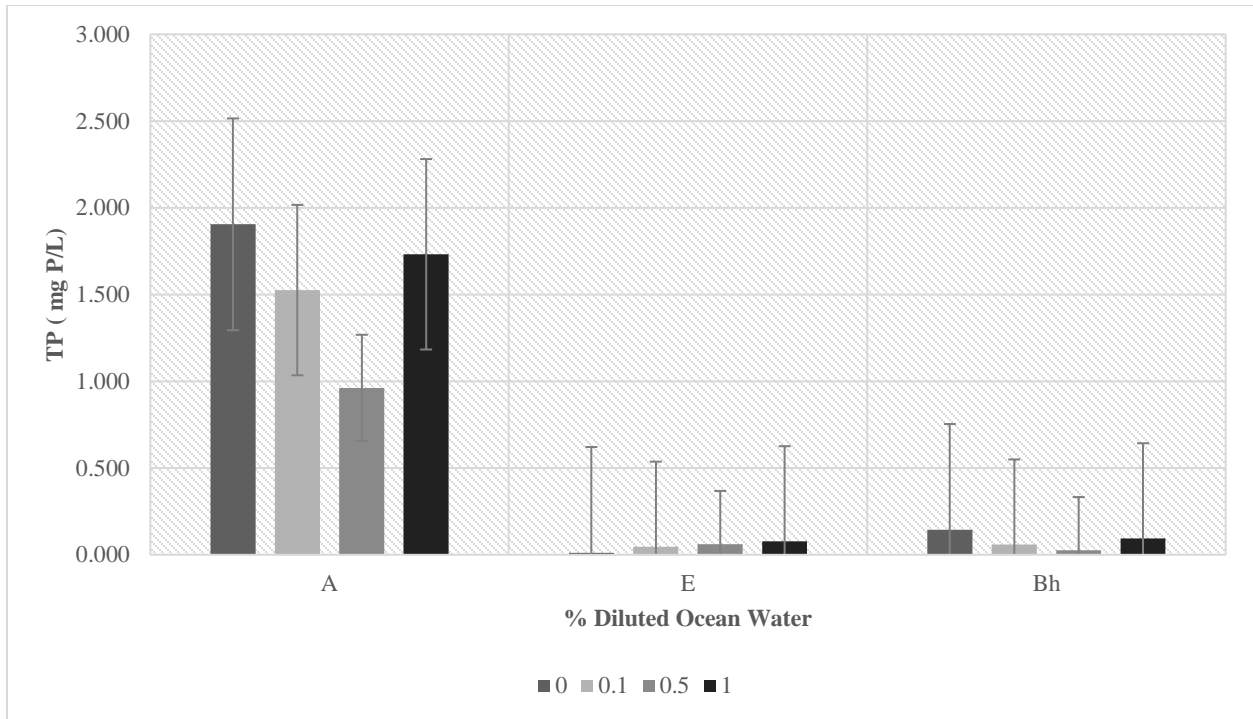


**Figure 1:** Site 1 Bar graph showing the A, E, and Bh soil samples of DOC at each salinity level a sample was made. The x axis shows the percent of salinity from pure saltwater to fresh water and on the y axis is the milligrams of carbon per liter. The three DOC samples that were taken for each horizon (Table 1) were averaged and was used to display on this graph.



**Table 2:** Site 1 total phosphorous (TP) measured in milligrams of phosphorous per liter. at increasing levels of salinity.

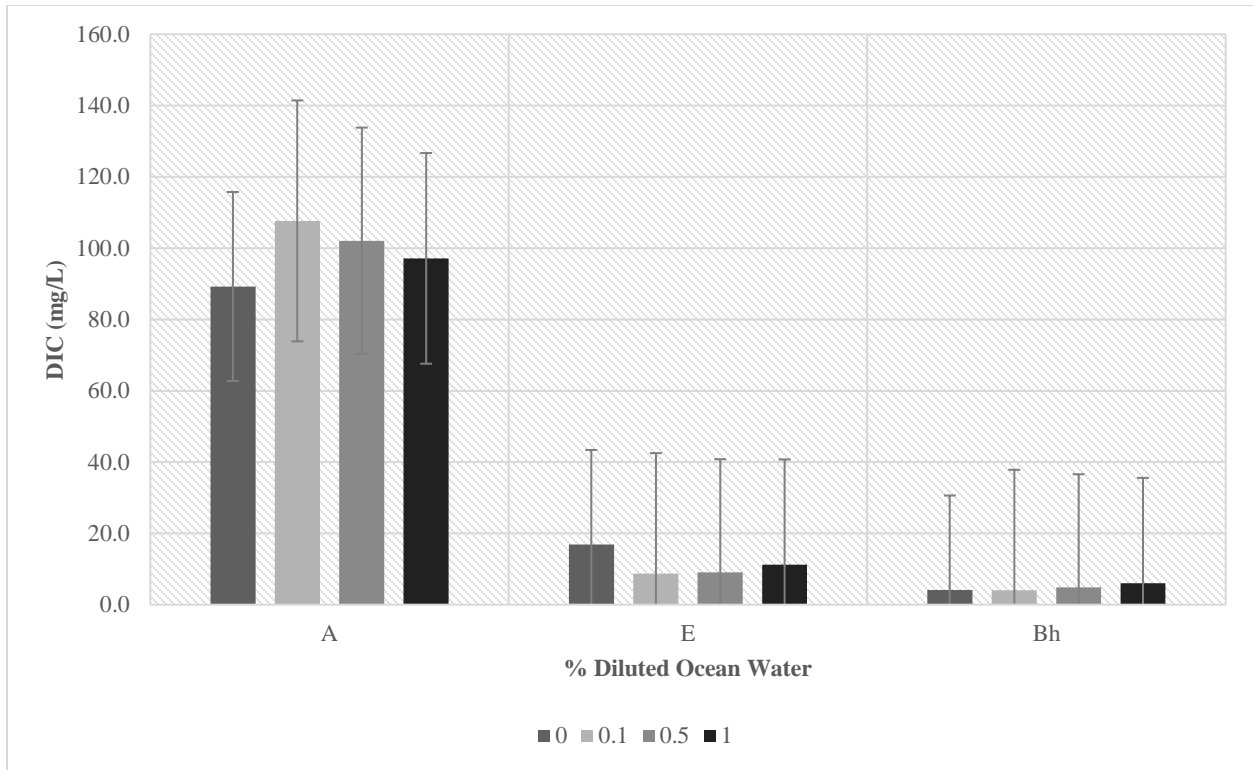
<u>Sample ID</u>	<u>TP (mg P/L)</u>	<u>% Salinity</u>	<u>Sample ID</u>	<u>TP (mg P/L)</u>	<u>% Salinity</u>
1A-A	3.027	0	1A-A	0.168	50
1A-B	0.101		1A-B	1.225	
1A-C	2.586		1A-C	1.493	
1E-A	0.033		1E-A	0.071	
1E-B	0		1E-B	0.061	
1E-C	0		1E-C	0.054	
1BH-A	0		1BH-A	0.008	
1BH-B	0.187		1BH-B	0.046	
1BH-C	0.243		1BH-C	0.026	
1A-A	2.591	10	1A-A	1.178	100
1A-B	0.482		1A-B	2.73	
1A-C	1.504		1A-C	1.289	
1E-A	0.063		1E-A	0	
1E-B	0.037		1E-B	0.16	
1E-C	0.038		1E-C	0.072	
1BH-A	0.028		1BH-A	0.098	
1BH-B	0.056		1BH-B	0.091	
1BH-C	0.092		1BH-C	0.094	



**Figure 2:** Site 1 Bar graph showing the A, E, and Bh soil samples of TP at each salinity level a sample was made. The x axis shows the percent of salinity from pure saltwater to fresh water and on the y axis is the milligrams of phosphorous per liter. The three TP samples that were taken for each horizon (Table 2) were averaged and was used to display on this graph.

**Table 3:** Site 2 Dissolved Organic Carbon (DOC) is measured in milligrams of carbon per liter at increasing levels of salinity.

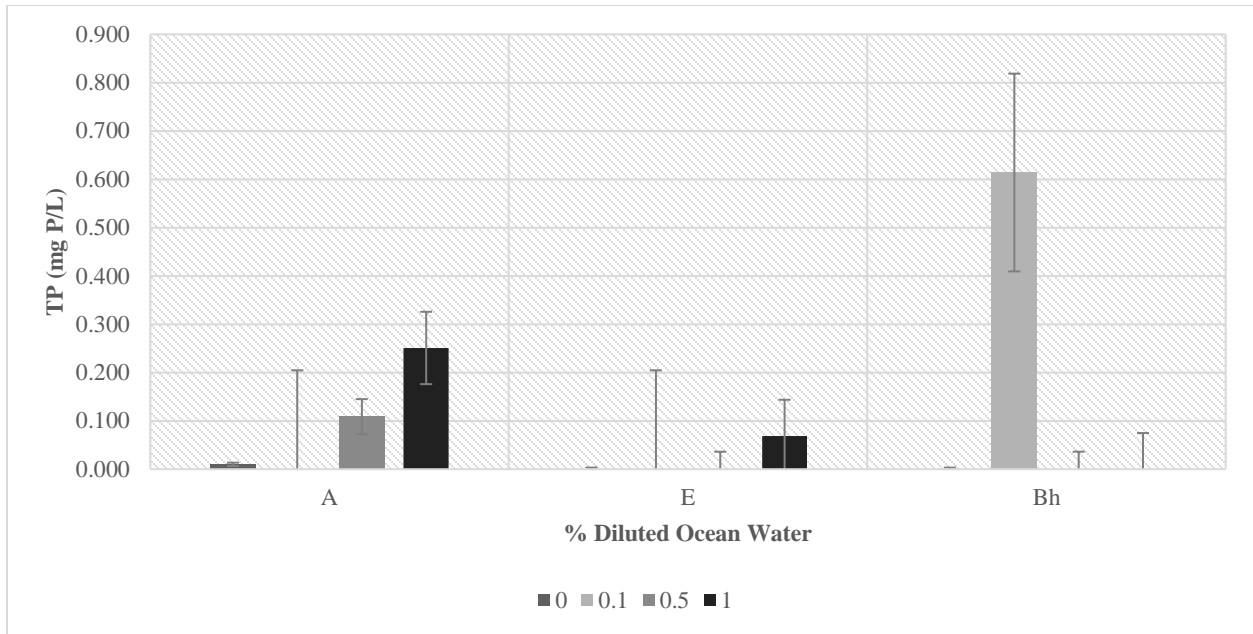
Sample ID	DOC (mg C/L)	% Salinity	Sample ID	DOC (mg C/L)	% Salinity
2A-A	37.2	0	2A-A	95.6	50
2A-B	99.2		2A-B	102.7	
2A-C	131.4		2A-C	108	
2E-A	15.6		2E-A	8.4	
2E-B	16.8		2E-B	8.9	
2E-C	18.3		2E-C	9.9	
2BH-A	4.2		2BH-A	4.6	
2BH-B	3.5		2BH-B	4.6	
2BH-C	4.6		2BH-C	5.4	
Sample ID	DOC (mg C/L)	10	2A-A	107.5	100
2A-A	85.3		2A-B	92.9	
2A-B	111.7		2A-C	91.1	
2A-C	126		2E-A	11.2	
2E-A	9.2		2E-B	11.9	
2E-B	8.7		2E-C	10.6	
2E-C	8.3		2BH-A	6.6	
2BH-A	4.7		2BH-B	6.1	
2BH-B	3.8		2BH-C	5.4	



**Figure 3:** Site 2 Bar graph showing the A, E, and Bh soil samples of DOC at each salinity level a sample was made. The x axis shows the percent of salinity from pure saltwater to fresh water and on the y axis is the milligrams of carbon per liter. The three DOC samples that were taken for each horizon (Table 3) were averaged and was used to display on this graph

**Table 4:** Site 2 Total Phosphorous (TP) measured in milligrams of phosphorous per liter. at increasing levels of salinity.

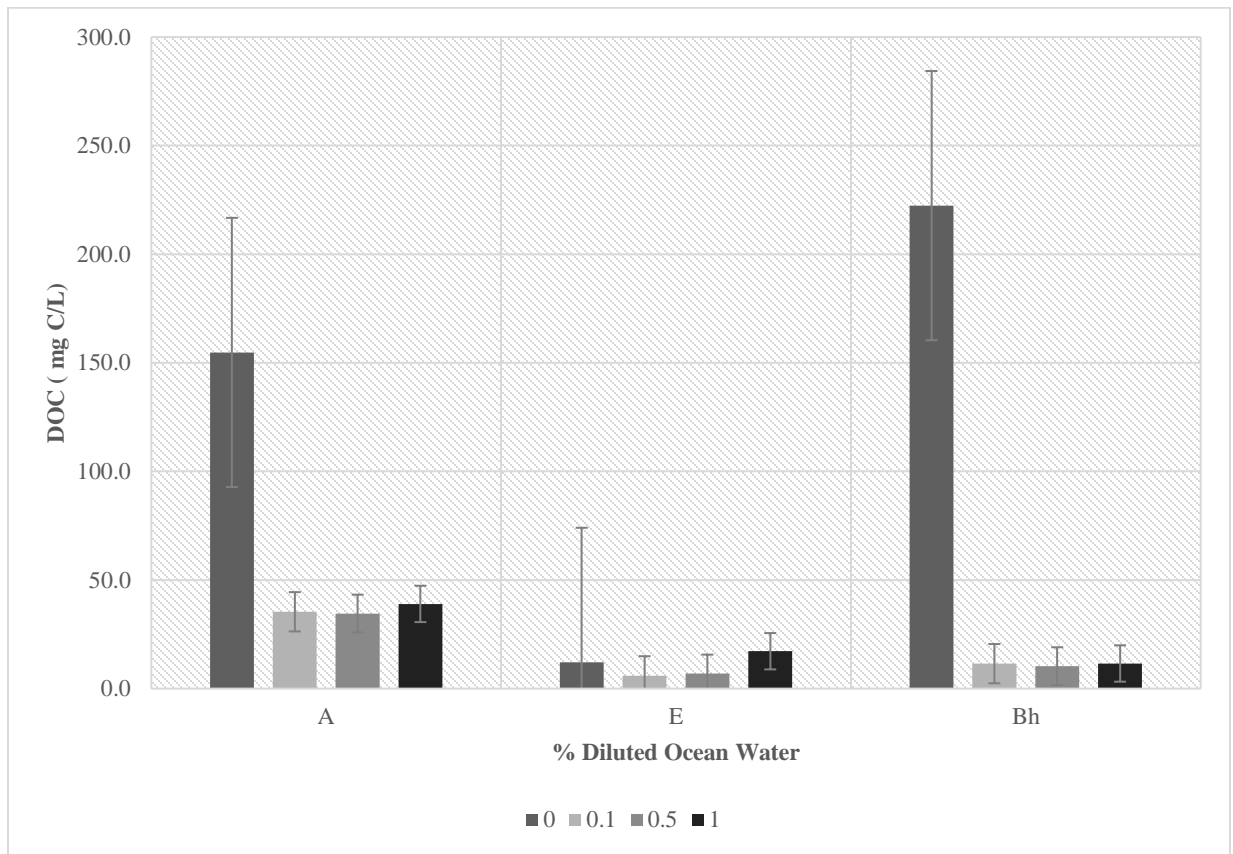
<u>Sample ID</u>	<u>TP (mg P/L)</u>	<u>% Salinity</u>	<u>Sample ID</u>	<u>TP (mg P/L)</u>	<u>% Salinity</u>
2A-A	0	0	2A-A	0.022	50
2A-B	0		2A-B	0.304	
2A-C	0.03		2A-C	0	
2E-A	0		2E-A	0	
2E-B	0		2E-B	0	
2E-C	0		2E-C	0	
2BH-A	0		2BH-A	0	
2BH-B	0		2BH-B	0	
2BH-C	0		2BH-C	0	
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2A-A	0	10	2A-A	0.732	100
2A-B	0		2A-B	0	
2A-C	0		2A-C	0.021	
2E-A	0		2E-A	0.207	
2E-B	0		2E-B	0	
2E-C	0		2E-C	0	
2BH-A	1.84		2BH-A	0	
2BH-B	0.002		2BH-B	0	
2Bh-C	0		2BH-C	0	



**Figure 4:** Site 2 Bar graph showing the A, E, and Bh soil samples of TP at each salinity level a sample was made. The x axis shows the percent of salinity from pure saltwater to fresh water and on the y axis is the milligrams of phosphorous per liter. The three TP samples that were taken for each horizon (Table 4) were averaged and the average was used to display on this graph.

**Table 5:** Site 3 Dissolved Organic Carbon (DOC) is measured in milligrams of carbon per liter at increasing levels of salinity.

Sample ID	DOC (mg C/L)	% Salinity	Sample ID	DOC (mg C/L)	% Salinity
3A-A	186.6	0	3A-A	34.3	50
3A-B	137.7		3A-B	33.6	
3A-C	140		3A-C	35.9	
3E-A	12.6		3E-A	6.4	
3E-B	12.9		3E-B	6	
3E-C	10.7		3E-C	8.4	
3BH-A	215.8		3BH-A	12	
3BH-B	233.6		3BH-B	7.9	
3BH-C	217.8		3BH-C	11.2	
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3A-A	37.2	10	3A-A	38.1	100
3A-B	33.8		3A-B	40.2	
3A-C	35.1		3A-C	38.7	
3E-A	6.1		3E-A	18.6	
3E-B	5		3E-B	17	
3E-C	6.5		3E-C	16.1	
3BH-A	11.5		3BH-A	12.1	
3BH-B	11.7		3BH-B	11.3	
3BH-C	11.3		3BH-C	11.2	

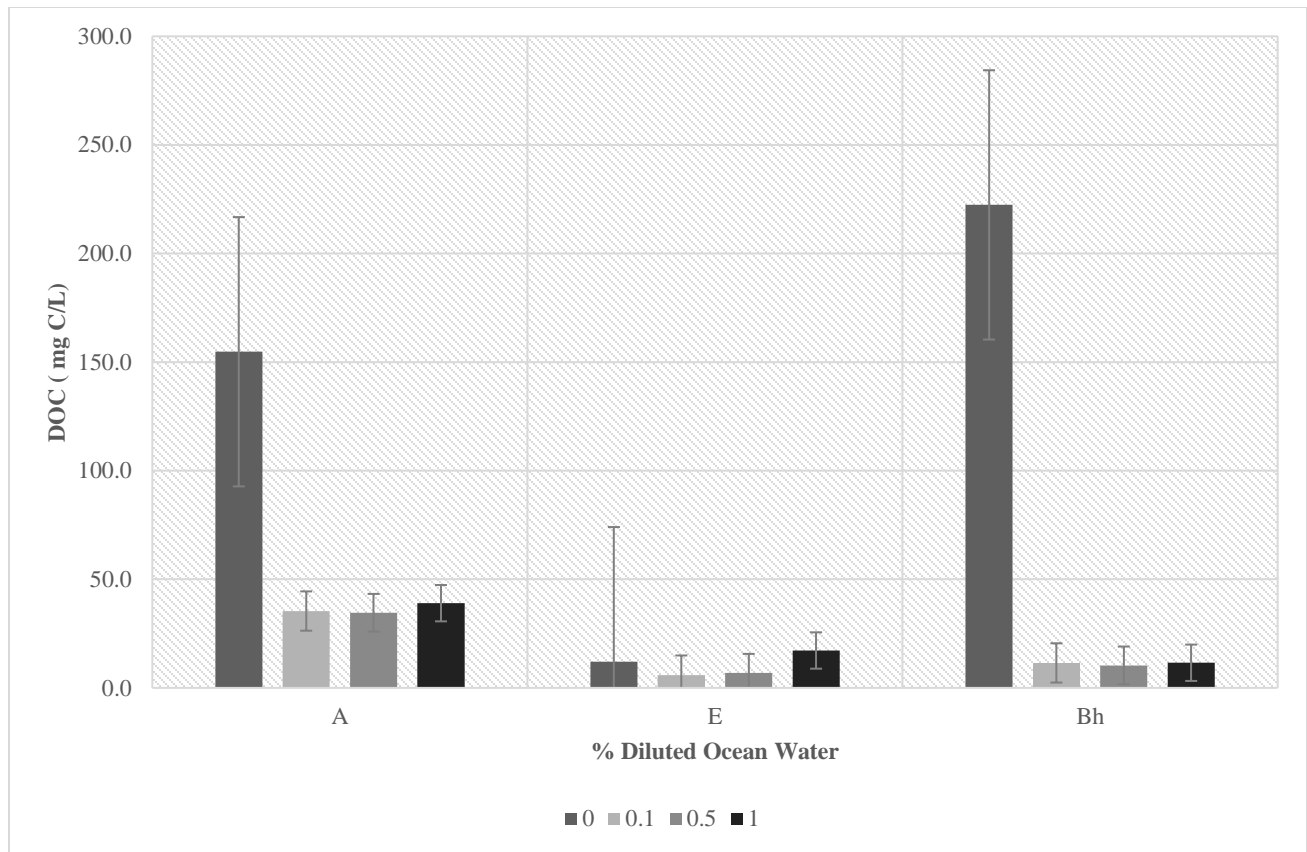


**Figure 5:** Site 3 Bar graph showing the A, E, and Bh soil samples of DOC at each salinity level a sample was made. The x axis shows the percent of salinity from pure saltwater to fresh water and on the y axis is the milligrams of carbon per liter. The three DOC samples that were taken for each horizon (Table 5) were averaged and the average was used to display on this graph.

**Table 6:** Site 3 Total Phosphorous (TP) measured in milligrams of phosphorous per liter. at increasing levels of salinity.

<u>Sample ID</u>	<u>TP (mg P/L)</u>	<u>% Salinity</u>	<u>Sample ID</u>	<u>TP (mg P/L)</u>	<u>% Salinity</u>
3A-A	0.099	0	3A-A	0.212	50
3A-B	0		3A-B	0.645	
3A-C	0.251		3A-C	0.002	
3E-A	0.007		3E-A	0	
3E-B	0.002		3E-B	0	
3E-C	0		3E-C	0	
3BH-A	0.45		3BH-A	0	
3BH-B	0.228		3BH-B	2.089	
3BH-C	0		3BH-C	0	
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3A-A	0.084	10	3A-A	0.706	100
3A-B	0.269		3A-B	0.714	
3A-C	0.028		3A-C	0.659	
3E-A	0		3E-A	1.607	
3E-B	0		3E-B	0.273	
3E-C	0		3E-C	0	
3BH-A	0		3BH-A	0.004	
3BH-B	0.01		3BH-B	0.248	
3BH-C	0		3BH-C	0	





**Figure 6:** Site 2 Bar graph showing the A, E, and Bh soil samples of TP at each salinity level a sample was made. The x axis shows the percent of salinity from pure saltwater to fresh water and on the y axis is the milligrams of phosphorous per liter. The three TP samples that were taken for each horizon (Table 6) were averaged and the average was used to display on this graph.

## Discussion

There is some evidence to suggest that increasing levels of salinity in the water table leads to an increase in DOC levels. This data suggests that as sea level rise occurs, and as saltwater intrusion increases it has some effect on the amount of carbon that is held in the Bh layer. For TP is a significant decrease in TP levels as salinity increased (figs 2 and 6). There were some outliers in the data as in figure 5 there was a significant decrease of 94% DOC in the Bh layer as salinity levels increased, however this may be due to some organic carbon contamination and further sampling would need to be done to see if there is a trend.

we see an approximate increase of ~40%-60% of carbon being released as DOC with increasing saltwater (Figs 1 and 3). It has been shown in previous studies that increasing salinity levels may actually show a decrease in DOC (Ardón, Helton, and Bernhardt 2016; Chambers et al. 2014; Krauss and Whitbeck 2012). It is important to note that again these studies were not focused on Podzolized carbon and focused on organic carbon, and in (Chambers et al. 2014) shows that there is an increase in DOC in soil pore water, which corroborates the data that was collected. While the data suggest that there may be an increase in DOC there is a study that it may not have an effect on CO<sub>2</sub> emissions into the atmosphere (Krauss and Whitbeck 2012; Liu et al. 2017). There are multiple studies that show that increased salinity levels do not affect the emissions of CO<sub>2</sub> since this process is mainly controlled by microbial processes (Krauss and Whitbeck 2012; Liu et al. 2017). Further research should be done to conclude if this is repeatable in different spodosols. It is also important to see if there is a time factor that plays a part in the process. There will also need to be further research to explore how once that carbon is released in the water table whether that exits the soil or reforms as podzolized carbon if the water table recedes. The data that was collected can suggest that stable podzolized carbon can be affected by saltwater intrusion and sea level rise showing that maybe it is not as stable while inundated with salt water.

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