Are New England salt marshes keeping up with rising sea levels: comparing sediment accumulation with estimates of net carbon storage based on Eddy flux tower measurements at the Plum Island Estuary?

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Abstract

As sea level increases there is a direct correlation to coastal erosion especially among marsh ecosystems. As a result there has been an increase in the destruction of coastal habitats and an increased risk in stronger storm surges. Understanding the resilience of a marsh’s ecosystem against sea level rise can lead to mitigation establishments and new policy developments. This study examined the resiliency of sea level rise on Plum Island estuary salt marsh. Sediment cores were extracted from the low marsh, high marsh, and a pond in order to answer the question is Plum Island estuary salt marsh sustainable against the rise in sea level? The results showed that Plum Island estuary salt marsh is currently keeping up with rising sea levels having an average sediment accumulation rate of 3.3 mm/yr and a carbon accumulation rate of 70 g/C/yr. Carbon accumulation rates from this study were compared to net carbon exchange calculated from annual eddy flux data. Data showed high carbon storage as compared to calculated carbon accumulation rates which showed only new carbon storage. Both the sediment data and the eddy flux data suggest that the marsh has been and is currently a sink to the atmosphere.

Introduction

Marshes along the east coast of the United States are believed to have developed post Wisconsin Glacier specifically after the Laurentide ice sheet over 10,000 years ago (Fagherazzi, 2013). As the sheet moved down the coast scraping, carrying, and depositing material it formed what is now the eastern coastline. Once the land was laid and the rivers were formed marshes begin to develop in places where the river, the ocean, and the land met (Valiela, 2006).

Marshes are one of earth’s most productive systems which can be attributed to inflows of sediment enriched nutrients from upland. As a result the rate of productivity increases, allowing nutrients to be filtered (Wiegret, 1988). Research estimates that 70% of the world marshes have been lost while the remaining is in danger of being lost due to rising sea levels (NOAA). However sea level rise does not directly destroy the marsh in fact research has shown that marsh plants enjoy being flooded and in the past have kept up with a rise in sea level by accreting sediments and migrating upland (Ocean, 2013). The problem that evolves from rising sea levels is that many marshes across the world have been dredged, harvested, built upon, or built around.
These manmade restrictions limit the ability of the marsh to freely readjust to deal with earth’s changing climate (Valiela, 2006). Usually marshes trap incoming inorganic enriched sediment use accretion mechanisms along with structural rearrangements to keep up with rising sea levels (Jones, 2013). As a result these plants and animals experience irregular high tides keeping the organisms under water for longer periods of time hindering their growth and production rates. The more restricted these systems are the less resilient the marsh becomes eventually going extinct (Montague, 1988).

Marshes are classified into low marsh, high marsh, and upland territories as a result of tidal gradients. Tidal gradients are developed by the rate and height at which the tide regularly inflows into the system (Rising Waters, 2013). Water flows into the marsh via tidal creeks which fill as the tide comes in; each segment of the marsh is greatly influenced by the way the tide flows inward. In the low marsh tides flow in twice daily which allows plants like Spartina alterniflora (tall/short) grow because they are more tolerable to the regular inflow of tides. Spartina alterniflora may grow into tall or short forms depending upon how close they are to the banks of the tidal creeks and accreting areas. These C4 plants can reach to 2 m in height and are very dense within the marsh. Spartina patens grow within the high marsh, farther past the shore and are only impacted by tides monthly (Sears, 1989). S. patens grow in dense packs across the high marsh and are usually less tolerable to tidal inflows. These plants in the past were harvested for bedding and fodder for farm animals one of the biggest anthropogenic disturbances to these systems due to the implementation of ditches within the wet areas of the marsh. The high marsh contains pond that have developed as a result of deposited organic debris and dead vegetation through microbial consumption, filling with water during high tide. The productivity of the marsh is extremely important in order to regulate how well the marsh is doing against climatic changes such as sea level rise (Pfifer, 1989).

The largest intact salt marsh on the east coast is Plum Island estuary Salt marsh, formed as a result of glacial retreat. Plum Island is a barrier estuary salt marsh that protects areas of Plum Island sound, Rowley river, Parker river, and Ipswich river. The marsh contains ponds, tidal creeks, and plants like Spartina alterniflora and Spartina patens. This marsh often experiences tides that are between eight and ten meters in height resulting in Depositions of organic materials. Like most marshes in the north east in the early 1700’s the marsh was harvested for Spartina patens and dredged for mosquito ditches for economic purposes (Gates,
Economically speaking marshes were one of the wealthiest places to be, the land provide easy access to water bodies and natural resources for trading. However, as a result of hydrologic engineering the flow of inorganic sediment into Plum Island has been reduced (Wiegret, 1988). With a reduction in inorganic sediment and an increasing rise in sea level it brings forth the question can New England Salt Marshes like Plum Island Salt Marsh keep up with the rise in sea level.

The goal of this research is to determine if New England salt marshes are keeping up with rising sea levels. The research compares depositional history and sediment accumulation with estimates of net carbon storage based on Eddy flux tower measurements at the Plum Island Estuary. My hypothesis is that the New England Plum Island estuary salt marsh has been a long term sink for carbon but that this may be decreasing with sea level rise, based on the comparative carbon eddy flux data. I used cesium 137 to identifying a time period from 1963 to 1964 in the sediments and lead to identify the time period 1978 to 1988.

**Materials and Methods**

*Section 3.1: Core preparation*

To examine the effects of tidal inundation a total of eight core sample were extracted from an elevation gradient along the low marsh, high marsh, and pond in Plum Island Salt Marsh. In the low marsh samples were taken from dense areas of *Spartina alterniflora* tall and *Spartina alterniflora* short. In the high marsh samples were taken within dense areas of *Spartina patens*. Replicates were also extracted approximately a meter away from the initial sites. All samples were taken within the footprint of the eddy flux tower to provide comparative CO$_2$ flux data to bulk carbon accretion in the sediments. Sediment cores were obtained by driving 3” x 20” PVC pipes into the ground. The cores were carefully removed from the sediment in order to reduce the risk of damaging the sediment integrity. After returning to the lab cores were divided in one centimeter sections for the first eight centimeters and two centimeter sections for the remainder of the core.

*Section 3.2: Bulk Density*

After sectioning, samples were analyzed for bulk density by measuring the wet weight, drying for at least 24 hours at 60°C, and then measuring the dry weight. After drying sediments were then subsampled for further analysis.
Section 3.3: Sediment Dating

A. Lead Analysis: Subsamples were taken from each section of every core, approximately .50 and .60 grams in weight and placed into 50 ml falcon tubes. Ten milliliters of 1.6M HNO₃ was added to every falcon tube and placed on a shaker table for approximately 12 hours. An additional four milliliters of 1.6 M HNO₃ was added to every falcon tube and placed on a shaker table for an additional two hours. Samples were then filtered using a Büchner filtration system and run on the Perkin Elmer 2380 AA spectrophotometer in order to calculate the approximate age of the sediment (Ng, A. and C. Patterson, 1982).

B. Cesium Analysis: After completing lead analysis and graphing the results subsamples of each core were extracted above and below the dominant lead peaks. It was important to record the height and weight of each sub sample. Each subsample was placed in a gamma counter that used the gamma ray spectrum to count the amount of cesium present in each sub sample.

Section 3.4: Bulk Carbon

A. Loss on Ignition (LOI) Analysis: Subsamples were taken from each section of every core, approximately two grams, and placed in small crucibles. Crucibles were taken from one replicate of every core and placed in a drying oven at 550 degrees Celsius for 2 hours to burn off all organic matter. Crucibles filled with sediments were pre and post weighed to determine the percentage of organic matter within each section.

B. Isotope Analysis was conducted on four subsamples at an average depth of 2.5, 3.5, 15, and 27 cm. First all carbonate was removed from samples by combing approximately 5 ml of 10% HCL to the samples using a disposable pipet. Glass scint vials were than swirled by hand to mix the sediment and the HCL. Once samples were thoroughly mixed samples were than filtered through GF/F filters. Samples were than dried, grind, and sent to the isotope analysis lab where samples were analyzed for 13C.

C. CHN and lignin analysis were conducted together determine the amount of carbon at each section of every core. Five subsamples were taken from each core at an average depth of 0.5, 4.5, 9, 11, and 21 cm for both CHN and Lignin. CHN samples weighing approximately one gram were first slightly moisten with water, and then placed in a
covered desiccator filled with HCL for seven days in order to remove all the carbonate within the samples. Next samples were completely removed from the desiccator and placed in a drying oven overnight, then ground with a mortar and pestle and packed in small tins. Finally the samples were run through the CHN elemental analyzer to determine the amount of carbon present within each layer of the sediment.

D. Each of the twenty lignin subsamples weighing 400 mg were ground and dried at 50 degrees Celsius in a BD 20 tube. Next 3 ml of 0.8% sulfuric acid was added to each samples and placed in 30 degree Celsius water bath for one hour. Next 28 ml of DI water per ml acid used were added to each tube. Then samples were autoclaved for one hour at 120 degrees Celsius. Samples were than filtered using a Büchner filtration system and placed in a drying oven at 50 degree Celsius for 36 hours to dry. Once samples were completely dried their dry weights were recorded. Next samples were ashed and re-weighed to determine the amount of lignin within each layer of the sediment which was calculated by finding the difference between the ash and the dry weight (complete method for separation and analysis of carbon fractions of plant and soil materials).

Section 3.4: Accumulation Rates

A. Sediment accumulation rates for each core were calculated by multiplying the bulk density by 10,000, to scale to a meter squared, then by the thickness of each layer. We used the Cs profiles to determine the depth of the sediment accumulated over the last 50 years (according to the cesium/lead profiles) and summed to this depth.

B. Yearly carbon accumulation rates for each core were calculated by multiplying the total % carbon measured by CHN and $^{13}$C isotopes by the total sediment accumulation rate and divided by 50.

C. Eddy flux data was analyzed via work completed By Dr. Inke Forbirch and Dr. Anne Giblin within the Ecosystem Center at the Marine Biological Laboratory.

Results

Section 4.1: Bulk Density
Cores taken within the *Spartina alterniflora* tall cores were visually colorful the deeper along the core the more red the sediment became. Bulk density analysis showed a water content of 30% to 50% with a dry soil density between 0.2 g/cm$^3$ to 0.5 g/cm$^3$ (Figure 1 & 5). Cores taken within the *Spartina alterniflora* short cores not as colorful, but contained a very strong sulfide odor as depth increase (Figure 2 & 8). *Spartina patens* sediments were densely filled with roots at each cm interval. Bulk density analysis showed a water content of 10% to 30% with a dry soil density between 0.2 g/cm$^3$ to 0.5 g/cm$^3$ (Figure 3 & 7). Cores taken within the pond were saturated with water; cores contained a strong sulfur odor. Bulk density analysis showed a water content of 10% to 25% water with a soil density between 0.1 g/cm$^3$ to 0.2 g/cm$^3$ (Figure 4 & 9).

**Section 4.2: Sediment Dating**

A. Lead analysis showed huge variability for *Spartina alterniflora* tall, short, and *Spartina patens* showing peaks from (Figure 10-12). The ponds were the only core that showed a well-defined peak at approximately 10 to 12 cm (Figure 13). Hence only carbons was used to date the sediments

B. Cesium analysis showed well defined peaks throughout each core sample. *Spartina alterniflora* tall showed a rather broad peak have cesium all the way down the core starting at 10 to 12 cm (Figure 14). *Spartina alterniflora* short showed a strong peak at about 16 to 18 cm, while *Spartina patens* peaked at 14 to 16 (Figure 15 & 16). The ponds had several peaks with an abundance of variability, but the most defined was 10 to 12 cm (Figure 17).

**Section 4.3: Bulk Carbon**

A. Loss on Ignition (LOI) analysis conducted on *Spartina alterniflora* tall cores showed 25% organic matter (Figure 18). Analysis completed on *Spartina alterniflora* short cores showed 30% to 40% organic matter (Figure 19). Analysis completed on *Spartina patens* cores showed 20% to 40% organic matter while analysis completed on cores from the Pond showed 30% to 40% organic matter (Figure 20 & 21).
B. CHN analysis conducted on Spartina alterniflora tall cores showed 4% to 6% of Carbon content (Figure 22). Spartina alterniflora short cores showed 10% to 25% of Carbon content (Figure 23). Spartina patens cores showed 15% to 20% of Carbon content while cores taken in the pond showed 10% to 15% Carbon content (Figure 24 & 25).

C. \(^{13}\)C isotopes conducted on Spartina alterniflora tall had the lightest isotope values at -17.87.\(^{13}\)C isotopes conducted. Spartina alterniflora short had isotope values at -15.55, Spartina Patens had values at -15.63 and the pond had values at -14.02 (Figure 26).

D. Lignin analysis conducted on Spartina alterniflora tall cores showed 4% to 5% of carbon that comes from lignin and the Spartina alterniflora short cores showed 8% to 15% carbon that comes from lignin (Figure 27 & 28). Spartina patens showed 10% to 20% carbon that comes from lignin, while the ponds showed 10% to 12% carbon that comes from lignin (Figure 29 &30).

Section 4.4: Accumulation Rates

D. Yearly sediment accumulation rates for Spartina alterniflora tall was 5.4 mm/year. Spartina alterniflora short showed sediment accumulation rates at 3.4 mm per year and for Spartina patens at 3.0 mm per year. The pond had the lowest sediment accumulation rate at 2.2 mm per year (Figure 31).

E. Yearly carbon accumulation rates for Spartina alterniflora tall was 57.11 grams of carbon per year. Spartina alterniflora short showed carbon accumulation rates at 79.48 and 73.25 grams of carbon per year. Spartina patens showed carbon accumulation rates at 53.09 mm per year (Figure 32).

F. Eddy flux data showed that the amount of carbon going into the marsh was 180 grams of carbon per year (Figure 33).

Discussion

According to my data Plum Island Estuary Salt marsh is a long term sink of carbon from the atmosphere due to carbon storage within marsh sediments. Once samples were collected and analyzed, carbon data was taken from the eddy flux tower and interpreted along with the aging components to understand the resilience of the marsh through its accretion levels.
Bulk density analysis was consistent throughout the analysis of all sediment cores; the density of each core increased with depth while the water from each core decreased. The results obtained from this analysis are expected due to the compaction of sediment with depth. As the marsh accretes it brings with it more and more sediment making areas within the marsh denser than all the rest (Figures 1-9).

Lead analysis showed huge variability for *Spartina alterniflora* tall, short, and *Spartina patens*. The ponds were the only core that showed a well-defined peak. Lead analysis showed various amounts of noise within each core except for in the pond so it wasn’t a good resource to compare depositional rates to. Noise may be due to hunter’s use of lead coated shotgun bullets or past leaded gasoline boat fuel which had direct contact to the sediment rather than atmospheric contact (Figure 10-13).

Cesium analysis showed defined peaks with little variations throughout each core sample and was used to calculate depositional rates. The broad peak present in *Spartina alterniflora* tall may be due to the deposition of sediments which were previously buried due to erosion other places in the marsh. Trends in sediment extracted from the pond could be due to the structure and accretion mechanism within the pond (Figure 14-17).

Loss on Ignition (LOI) analysis showed the organic matter found % organic matter within each section of each core. *Spartina alterniflora* tall had very low % organic matter which could have been the result of tidal deposition of organic material. *Spartina alterniflora* short, *Spartina patens*, and ponds cores all showed high presence of % organic matter which means that most of the sediment was once living at some point in time (Figure 18-21).

CHN analyses were combined with $^{13}$C isotopes to establish a bulk carbon estimate for each core. CHN analysis gave a total estimate of carbon for each section of each core. *Spartina alterniflora* tall had less carbon within the sediment which could be attributed to the tidal mineral deposition. *Spartina alterniflora* short, *Spartina patens*, and ponds all had consistent amounts of total % carbon found (Figures 22-25).

Total % carbon shows the amount of Carbon that has come into this area and stayed. According to the data *Spartina alterniflora* tall has the lowest amount of % carbon between 4
and 6% which is expected. The sediments under *Spartina alterniflora* are directly tidal influenced having regular deposits of minerals, as compared to the other 3 who stayed between 10% and 20% carbon due to low tidal influence.

$^{13}$C isotopes showed that the majority of the carbons taken into the system are attributed to C$_4$ plants that are native to the marsh. The small percentage of outside carbon could be attributed to algal or terrestrial influences as a result of direct influences from tidal inundation (Figure 26).

Lignin analysis conducted on the cores showed high percentage of lignin content credible to the amount of % Carbon. Lignin represented the amount of organic material present that had yet to be broken down due to its chemical makeup. *Spartina alterniflora* tall had the lowest amount of lignin which can be attributed to tidal influences while all other cores had similar % lignin content (Figures 27-30).

Calculated yearly sediment accumulation rates were compared to the average rate of sea level rise for Boston, 2.3 mm per year which showed that sedimentation rates within this marsh were higher in all but the ponds. This shows that the marsh is keeping up with sea level rise through accretion (Figure 31).

Calculation of carbon accumulations rates found in the sediments account for approximately 60% of eddy flux data calculations. This means that the rate of carbon accumulation is either greater now than the average for the past 50 years According to the data the marsh is consistently storing carbon and therefore can be deemed as a sink to the atmosphere (Figure 32). Alternatively, the eddy flux data may overestimate net carbon storage because it does not take into account the organic and inorganic carbon that is being lost through tidal flow (Figure 33).

**Section 6: Acknowledgements**

This project would not have been possible without my mentor Dr. Anne Giblin, Dr. Inke Forbirch, Alice Carter, Dr. Ken Foreman, Rich Mchorney, Fiona Jevon, Sarah Nalven, Dr. Marshall Otter, and All of the SES/MBL/Ecosystem Center staff.
Section 7: References

“Complete method for separation and analysis of carbon fractions of plant and soil materials”


IPCC Fourth Assessment Report, Summary for Policymakers, p. 5


**Graphs and Figures**

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Section 8.1 Bulk Density

Figure 1

Figure 2

Figure 3

Figure 4
Section 8.2: % Water
Section 8.3: Core aging

A: Lead Peaks
B: Cesium Peaks

**Spartina alterniflora tall**

![Graph of Cesium Peaks for Spartina alterniflora tall](image)

**Spartina alterniflora short**

![Graph of Cesium Peaks for Spartina alterniflora short](image)

**Spartina patens**

![Graph of Cesium Peaks for Spartina patens](image)

**Pond**

![Graph of Cesium Peaks for Pond](image)
Section 8.4: Bulk Carbon
A: Loss on Ignition
B: Total % Carbon

![Graphs showing the % Total Carbon for different species](image)
Figure 8.5 Carbon Isotope

![Bar chart showing carbon isotope data for different species and a pond.]

Figure 26
Figure 8.6 % Carbon that is Lignin
Section 8.6 Accumulation rates

Figure 31
Carbon Fluxes

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<thead>
<tr>
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<tr>
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<td>S. patens</td>
<td>60</td>
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<td>Pond</td>
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Figure 32
Figure 33