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Assessing the Amount of Carbon Stored in Maine Salt Marshes

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Assessing the Amount of Carbon Stored in Maine Salt Marshes

A Senior Thesis

Presented to

The Faculty of the Department of Geology

Bates College

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

Ashley L. Kulesza

April 6, 2018

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Abstract

This project uses geochemical analyses of sediment cores from various sources and GIS to estimate the amount of carbon stored in Maine coast tidal marshes. Sedimentary carbon content values of Maine salt marsh sediments were compiled from dissertations, theses and previously published papers and mapped using GIS. Areas where few previous datasets exist were identified, and targeted for coring and carbon density analysis for this study. The goal was to have carbon density data from three to five sites from each of the four Maine coastal compartments, defined by (Kelley et al., 1987). Between one and five sediment cores were taken at each targeted marsh site. Cores were subsampled every 10 cm for bulk density and carbon content. The EA-C-IRMS in the Environmental Geochemistry Laboratory at Bates College was used to determine % carbon values. The average carbon density values from all 58 cores available from existing data sets, and generated data sets for each coastal compartments for the upper 1m are as follows: The Arcuate Embayment $0.040 \pm 0.01 \text{ gC/cm}^3$, the Island-Bay Complex $0.041 \pm 0.01 \text{ gC/cm}^3$, the Indented Shoreline $0.037 \pm 0.001 \text{ gC/cm}^3$ and the Cluffed Shoreline $0.031 \pm 0.001 \text{ gC/cm}^3$. The average carbon density values were determined for each coastal compartment and multiplied by the surface area of salt marsh to generate carbon stocks. Comparisons of carbon stocks among the different coastal compartments will be made, as will estimates for total carbon stored in Maine salt marshes. As well as different calculated surface areas to generate several whole state wide carbon stocks.

1 Introduction

Background and Importance

1.1. Tidal Salt Marshes

Salt marshes are coastal ecosystems that are flooded twice daily during high tide. Marsh size can have wide ranges of surface area based off morphology and age (Taylor et al., 2008). A higher global surface area of salt marshes estimate is 400,000 km² (McLeod et al., 2011). The coast of Maine has at least 79 km² of tidal saltmarsh area, significantly more than any other state in New England (Jacobson et al. 1987). This coastal surface area coverage makes up around 20% of Maine's total coastline, the complex bedrock geology of which provides coves and other protected intertidal areas in which saltmarshes have been able to form (Jacobson et al. 1987). Salt marshes are an important ecosystem to be considered for the state of Maine.

Tidal salt marsh ecosystems are found in two distinct locations: along the coast in protected embayments where lower energy system, are conducive for marsh development, and in estuaries that still have access to the tidal range flooding (Tiner, 2013). Salt marshes form at the boundary of the terrestrial landscapes and the coastline boundary. There needs to be a steady sediment supply and a low energy mostly flat protected region to support sediment accretion and marsh formation (Taylor et al., 2008). The complex bedrock geology of Maine's coast provides coves and other protected intertidal areas in which saltmarshes have been able to form (Jacobson et al., 1987). Salt marsh plants are able to colonize along the coast and survive in full or mostly saline conditions, approximately 36 ppt to freshwater at 0 ppt. These plants trap sediments to and accrete at a steady vertical rate above isostatic continental rebound of sea level change (Taylor et al., 2008).

Salt marshes are the most efficient at storing carbon compared to the other coastal ecosystems and even terrestrial ecosystems (Figure 1.1) (McLeod et al., 2011). Salt marshes exist all over the world, and are an important aspect of global climate mitigation efforts (Figure 1.2). Salt marshes are a benefit to climate because they sequester Carbon Dioxide (CO₂), a greenhouse gas, and bury and store it in its roots and soil (Johnson et al., 2016).

Figure 1.1 (McLeod et al., 2011) a bar graph comparing carbon burial rates across the different blue carbon ecosystems. The carbon values are mean long term storage rates. Error is due to maximum accumulation rates and a logarithmic y-axis.

Figure 1.2 (Nelleman et al., 2009) shows all the coastal salt marshes around the world. The bar graph on the left shows the loss of salt marshes in current times compared to the 1940's. There are salt marshes all over the world, the densest area being the east coast of the United States, which includes the Gulf of Maine.

1.1.2 Ecosystem Services

Salt marshes provide a plethora of ecosystem services (Gedan et al., 2009). An ecosystem service is defined as the positive benefits all tidal salt marshes produce, without human intervention or alteration. They occur through biotic and natural systems and processes that can simultaneously benefit humans and the climate (Gedan et al., 2011). Salt marshes have a wealth of these services that include but are not limited to protecting shoreline erosion by acting as a buffer from storms and flooding events, filtering out toxins and pollutants through the vegetation, and providing protected ecosystems for fragile or endangered wildlife as summarized in (Gedan et al., 2011; Johnson et al., 2016).

One of the most important ecosystem service is the ability salt marsh vegetation has to be able to pull CO₂ out of the atmosphere via photosynthesis and store it efficiently. Every green plant photosynthesizes and is able to use the CO₂ from the atmosphere, however the long term storage quantities of salt marsh capacity exceeds any other ecosystem (Nelleman et al., 2009). The consistent saturation of coastal salt marsh soils, referred to as peat, constrains atmospheric exchange which results in continuous build-up of carbon over time (Chmura et al. 2003). This carbon can be stored for millennia, which at the rate of carbon burial capacity of marshes can generate a large carbon sink.

1.1.3 Greenhouse Gases and Carbon Sequestration

Tidal salt marshes are controlled by local tidal ranges. Due to this daily flooding, the salt marsh peat is always fully saturated. This creates an anaerobic soil environment where decomposition and decay cannot occur due to the lack of oxygen. This environment is great for recording histories and sediments changed over time. This preservation allows an accurate record of carbon storage to be stored and examined through history based on vertical accretion.

The rate of degradation and destruction of global salt marshes is estimated to be 1-2% annual loss (Murdiyarso et al., 2015). It can go unnoticed that there is significant annual loss, which puts these ecosystems at risk of total destruction. This is worrisome based on the effectiveness of carbon storage, and the potential for climate mitigation. This is compared to green carbon terrestrial ecosystems, which have oxygenated soils that rapidly decomposes organics on land; this limits the carbon sequestration and storage capacity in these ecosystems (McLeod et al., 2011). Healthy salt marsh soils do not become saturated with carbon because sediments continuously accrete vertically as sea level rises. Through vertical accretion salt marshes are able to keep pace with gradual sea level rise and not get drowned out as an ecosystem.

Coastal Blue Carbon

1.2 Salt Marsh Blue Carbon

The current atmosphere has exceeded 400 parts per million (ppm) CO₂ content, the highest levels in 800,000 years. This recent increase in CO₂ has been traced to an increase in fossil fuel burning, often referred to as black and brown carbon (Nelleman et al., 2009; McLeod et al., 2011). There are very serious consequences to this increase in emissions, the Intergovernmental Panel on Climate Change (IPCC) estimates an 85% reduction of emissions by 2050 globally is needed to keep global atmospheric temperature increases to about 2 degrees Celsius (IPCC 2007; McLeod et al., 2011).

The term “blue carbon” was first used in a 2009 United Nations Environment Programme (UNEP) report “Marine Blue Carbon” (Nelleman et al. 2009). The term has been adapted to coastal blue carbon, and refers to productive vegetated coastal and marine ecosystems such as sea grasses, mangroves and tidal salt marshes. These ecosystems are able to sequester CO₂ from the atmosphere and store it in their root biomass and soil at a very efficient rate per square unit of area (Chmura et al., 2003). Compared to other carbon sinks, such as rainforests and forests often referred to as “green carbon”, Blue Carbon is more productive and efficient at long term massive carbon storage per square unit, even though the global area is one to two orders of magnitude smaller compared to green carbon (McLeod et al., 2011). Green carbon is able to store carbon for decades, compared to blue carbon that is able to store carbon for millennia (Nelleman et al., 2009).

There is much uncertainty around the amount of carbon sequestration that occurs in coastal blue carbon ecosystems due to the fact that these ecosystems are so variable (Nelleman et al., 2009). Long term carbon storage within salt marsh ecosystems have a calculated range of 18-1713 g C m⁻² (McLeod et al., 2011). Maximum carbon burial rates for an ecosystem can have a range of 3 to 10 times higher than the global mean value for that same ecosystems (Nelleman et al., 2009).

Many countries have utilized their carbon sink resources for economic gain and profit. There are systems in which these nations can globally trade emission credits. For example, emissions trading is a large component of the Kyoto Protocol created in 1997. This protocol was implemented to reduce global greenhouse emissions globally and to unite on climate protection of the planet. However, this protocols and other similar ones mainly focus on terrestrial ecosystems and green carbon (Johnson et al., 2016). Policies need to be developed and implemented around blue carbon to maximize the true benefits of their services. Accurate representation of true values and real understanding of how these ecosystems operate are why more blue carbon research and data is essential.

1.2.2 Maine Coast

The Maine coast has been divided into four compartments (Figure 1.3). These compartments differ in geomorphology, bedrock, wave energy, sediment supply and geomorphic salt marsh structure. The compartments going south to north are: the Arcuate Embayment, the Indented Shoreline, the Island-Bay Complex and the Cluffed Shoreline (Kelley et al., 1988).

Figure. 1.3 (Kelley et al., 1988) image showing the divided coast into compartment. Each compartment has their own identifying features and geomorphology relating to salt marshes.

The Arcuate Embayment is the southernmost compartment, and has a low energy coastal system favorable to marsh formation. This compartment stretches from the New Hampshire and Maine border to Portland. It is the shortest compartment extending only about 504km. The coastal terrain in this region is mostly flat rocky headlands with wide sandy beaches which has helped for marshes that are wide, crescent-shaped bays with sandy beaches and barrier islands. Due to all of these factors the marshes within this compartment are dominantly back-barrier marsh systems. This type of marsh morphology is slightly more common along the Maine coast (Kelley et al., 1988).

The Indented Shoreline stretches from Portland to Penobscot bay with a length of 1,636 km. This coastal compartment is dominated by high-grade metamorphic bedrock that has been carved by glaciers to form long, north-south oriented peninsulas with a few plutonic intrusions scattered and visible on the coast. This geology is conducive to a protected inlets and bays, all of these morphologic features are favorable to marsh formation and development. These inlets and

protected geologic features are fed by several rivers and exist in estuary systems. There is an abundance of fluvial major and minor marsh systems in this compartment. These sheltered inlets also support the formation of mud flats and back-barrier marsh systems; (Kelley et al., 1988).

The Island-Bay Complex stretches from the Penobscot Bay to Machias Bay and is 2,462km long. The geology in this region is very resistant rocks, mainly granitic plutons. Because the rock types are resistant to weathering the shoreline is rocky with several larger bays from the higher energy waves and energy hitting the coast. It is a high energy system with minimal protected areas thus, marsh formation is not favored. There are some smaller younger marshes on the northern end of the compartment, however the dominate ecosystems are mud flats and tidal zones (Kelley et al., 1988).

The Clifed Shoreline compartment extends from the Machias Bay to the Canadian Border and is the second shortest compartments with a length of only 681km long. The name is befitting this compartment; the bedrock is volcanic sheer cliff faces that meet the ocean. This high impact and energy shoreline does not support the formation or development of marshes. This region has sandy beaches and only a few small marsh systems. There are a few larger marsh systems at the northern end in a protected bay. However, muddy tidal flats and rocky coastal outcrops compose the majority of this compartment (Kelley et al., 1988).

1.3 Post Glacial Maine

The last glacial maximum covered the entire state of Maine in a wall of thick dense ice just 18,000 years ago. The Laurentide Ice Sheet extended as far south from the Hudson Bay as Long Island, New York. The ice began to retreat from this maximum extent about 15,000 calendar years ago. As the ice melted geologic markers and signals were left behind that allow us to follow the melt path in modern times. It took thousands of years after the retreat of the ice sheet for the ice carved landscape to rebound from the crustal depression left by the massive weight of the ice sheet.

During the time of higher sea level, the Presumpscot Formation was deposited. It is a unit found at the base of the cores collected from Maine coastal salt marshes. It has a blue-grey color and is mostly clay with some silt and occasional grains. This unit is thought to have been deposited by offshore marine environments that then formed in a costal environment after the last glacial maximum (Barnhardt et al., 1995; Kelley et al., 1988).

Isostatic rebound slowly stabilized, with slower sea level rise, this is when marsh vegetation was able to colonize and begin to trap coastal sediment and accrete juvenile marsh ecosystems (Figure 1.4). This occurred around 4,000 to 5,000 years ago along the coast of Maine (Kelley et al., 1988; Kelley et al., 2010). This is supported by a weathered surface of the Presumpscot Formation

often being the basal unit of many Maine salt marshes. The stabilization of the coastline post crustal rebound allowed for the accretion of salt marshes. Places where the glacial retreat carved protected embayments and had a sediment supply available, marshes were created. This creation now provides a several thousand year record of soil preserved overtime due to the saturated anoxic soil.

Figure 1.4 the most updated Gulf of Maine sea level curve taken from (Kelley et al., 2010). Shows what types of organisms and ecosystems were able to develop with the changing sea coast. Marsh peat formation began as far back in Maine as ~7ka.

1.4 Human Impact, Beyond Carbon

More than 40% of the world's population live on a coastal landscape. Due to this heavy human residency, there are human coastal alterations that occur; of these alterations salt marshes are heavily altered and impacted (Gendan et al., 2009; UNEP 2006).

Coastal blue carbon ecosystems are some of the most threatened ecosystems on earth, with an estimated 340,000 to 980,000 hectares being destroyed each year (Murray et al. 2011). These

alterations include exploitation of plant products within this ecosystems, the conversion to agricultural land, salt harvesting, converting land to urban development, and overall waste and pollution dumping (Gedan et al., 2009). New England states have lost an average of 37 percent of their salt marshes since 1777, these ecosystems are now gone permanently with modern developments in their place.

Many salt marshes around the Gulf of Maine have been filled in, drained, or diked, permanently changing wetlands to dry land (Taylor et al., 2008). Every marsh sampled for this study, just like the majority of the marshes in Maine, was altered in some way. The most common alteration found at these samples sites were dikes and dredges. Raised mounds of marsh that altered the natural stratigraphy, and or some sites had mechanical channels or pool created to alter water flow from the main stream. Samples were collected away from the human altered areas.

1.5 Purpose

Coastal blue carbon ecosystems have been minimally studied in the New England region specifically Maine. For this reason, salt marsh carbon storage rates are widely unknown for the state.

There are two main purposes of this thesis. 1) To study the carbon stored at depth at each site and attempt to formulate what is driving the storage rates; what are the leading factors that makes a higher storage capacity marsh, compared to a lower capacity storage marsh. This analysis will occur spatially across the entire coast of Maine and across the four coastal compartments defined in the Kelley et al., 1988 paper. 2) To generate the most accurate and current map of carbon density in the Maine salt marshes.

1.6 Study Area

Over 90% of the marshes in Maine have been altered (Taylor et al., 2008). All the sites sampled were as similar as possible (Figure 1.5). Cores were taken within or between human alterations, such as dikes or levees. Cores were collected in an attempt to represent the spatial diversity of each ecosystem. This system of collection allows for the potentiality of the true marsh carbon storage capacity to be captured in the core.

Figure 1.5 site map of all points where there is carbon data used in this study. The blue points are Wood, 1991, the green are Mansfield, 2009, the yellow points are Pickoff, 2013 and the pink are this study.

1.7 Significance

This study provides a condensed summary of all the data and work done on salt marshes for blue carbon. Multiple sites from all four coastal compartments were selected based on available data and access. These sites will provide the data necessary to generate an estimate of carbon stock capacity for each coastal compartment.

Each marsh ecosystem that has any data will be incorporated into generating an accurate state wide coastal carbon map. These maps can be used for municipal purposes. Coastal development is a huge source of salt marsh destruction, these maps can quantify the amount of carbon released per square unit of marsh altered or destroyed. Further application and development after this study is encouraged, there is more marshes to be cored and more avenues where this data can make a difference.

2 Methods

2.1 Previous Works

Margaret Pickoff wrote a thesis in 2013 at Bates College on “Maine’s Blue Carbon and estimated the amount stored in salt marshes”, for the southern two compartments on the coast. She calculated carbon density for her sampled marshes in addition to calculating carbon stocks for the two southern compartments where her sample sites were. This thesis provided the methodology and background for this study. This paper uses a similar methodology for selecting sites and how to process samples. This data is detailed and has carbon density values for each core at many known depth values. Her findings’ and carbon values were very similar as to those found in this study.

Mark Woods produced a master’s thesis in 1991 at University of Maine that has been heavily utilized in this study. Data from this paper includes sites all along the coast of Maine, these sites all have an average at depth carbon density value. He focused his studies on the morphological features and history of the salt marshes along the coast. Specifically, how sediment accumulated along the coast in different ways. Margot Mansfield produced also produced a dissertation in 2009 at the University of Maine that had a few a depth Loss on Ignition (%LOI) data values at depth. Two of these cores from two separate sites have been added to this study. Her thesis was focuses on the interface between salt marshes and fresh water wetlands. Thus her work does not directly aid this study, however her core data has been used to further this research.

2.2 Field Methods

Site Selection

Site were chosen based off lack of previous carbon data (Figure 2.1). Marshes were sampled based on accessibility. One to five cores were collected at each site. Cores were collected from the field May 2017 to November 2017. Seven marshes were sampled, which totaled 16 continuous cores, some were more than one 1m drive, for a total of 21 total meters of stratigraphy.

Figure 2.1 shows a combination of all other researchers' data and where there are clear holes where data is needed.

Each core was collected with spatial diversity to capture the wider marsh (see individual site maps). Human alteration features such as dug channels or raised dikes were evident on marshes such as Milbridge, Franklin, Adison, S. Thompson, and Harrington. These clear human altered areas were spatially avoided when sampling cores were collected away from dikes and dredged channels. Jasper Beach was a marsh with no visible human alterations. Scarborough Marsh was sampled in all the far corners of the large marsh.

This Study	Coastal Compartment	Secondary Location	Site	Coring Method	Lon Decimal Degrees	Lat Decimal Degrees	Depth (cm)
Kulesza	Island-Bay Complex	Machiasport, ME	Jasper Beach #1	Dutch Corer	-67.38571667	44.62825	60
Kulesza	Island-Bay Complex	Machiasport, ME	Jasper Beach #2	Dutch Corer	-67.38423333	44.62873333	100
Kulesza	Island-Bay Complex	Addison, ME	Addison	Dutch Corer	-67.7463	44.61826667	91
Kulesza	Island-Bay Complex	Franklin, ME	Franklin 1	Vibra Core	-68.26833333	44.52952778	84
Kulesza	Island-Bay Complex	Franklin, ME	Franklin 2	Dutch Corer	-68.2677778	44.52891667	91
Kulesza	Island-Bay Complex	Harrington, ME	Harrington 1	Dutch Corer	-67.80447	44.61728	100
Kulesza	Island-Bay Complex	Harrington, ME	Harrington 2	Dutch Corer	-67.80378	44.61853	100
Kulesza	Island-Bay Complex	Milbridge, ME	Milbridge 3	Dutch Corer	-67.855556	44.59108333	100
Kulesza	Island-Bay Complex	Milbridge, ME	Milbridge 4	Dutch Corer	-67.855556	44.59152778	98
Kulesza	Indented Shoreline	South Thompson, ME	Thompson 1	Dutch Corer	-69.14305556	44.07663889	116
Kulesza	Indented Shoreline	South Thompson, ME	Thompson 2	Dutch Corer	-69.14194444	44.07702778	103
Kulesza	Arcuate Embayment	Scarborough, ME	Woodside Dr	Dutch Corer	-70.32809	43.57404	101
Kulesza	Arcuate Embayment	Scarborough, ME	Ferry Rd	Dutch Corer	-70.3226	43.54818	181
Kulesza	Arcuate Embayment	Scarborough, ME	Rt 1	Dutch Corer	-70.37516667	43.57593333	127
Kulesza	Arcuate Embayment	Scarborough, ME	Clam Shack	Dutch Corer	-70.34285	43.5444	300
Kulesza	Arcuate Embayment	Scarborough, ME	Orchard Hill	Dutch Corer	-70.33994	43.55993	167

Table 2.1- Metadata on cores collected for this study. Locations identified by site names and GPS coordinates and the depths of each core. Color coded by compartment, orange for Island Bay complex, blue for Indented Shoreline and green for Arcuate Embayment. These colors remain the same for all tables.

Sediment Coring

Sediment cores were retrieved at each site using 1-meter-long and 2'' in diameter thick Eijkelkamp Gouge Auger, commonly called a Dutch corer at all sites but two (Table 1.). The hand held modified Vibracorer was used to retrieve two cores at the Franklin site. At the Route 1. site within Scarborough Marsh the 2 meter long 1' in diameter thin Dutch corer was used.

The Dutch coring method entailed manually pushing the corer into the marsh sediment from the surface until the core barrel was filled or until refusal. In some cases up to over 3m of sediment was recovered. At some sites refusal was not met, in these cases the number of extensions was the limiting factor. The device was rotated 360 degrees eight times, to ensure optimal chance of full recovery because of how the sediment compresses and solidifies. As the coring device was pulled out the sediment slowly with the same directional twist of which it was rotated eight times. Compaction of peat from the use of the Dutch corer method ranged between 0 and 5 cm. This range is considered negligible in this study, and was not factored into descriptions of core stratigraphy. Any noticeable error or compaction or missing stratigraphy log was noted and factored in.

Cores were carefully transferred from the core barrel to the halved PVC pipe via very careful knife leveraging and turning over. The other half of the PVC pipe was then used to cover the core with a hard surface, then cling wrap and duct-tape were used to secure and enclose the

core. Each core was labeled on the exterior with information such as collection date, collector, site name, depth and important top and bottom labels. These containers were kept horizontal to minimize compaction. Once transported to the lab, they were put into the refrigerator (4°C) and stored horizontally until ready to be analyzed.

2.3 Lab Methods

Sample Preparation

Each core was split down the middle to expose fresh faces using a putty knife cleaned between each cut to avoid cross contamination. Half of the core was preserved as the archived core, untouched and labeled back in the fridge. The other half was described and subsampled and labeled as the working core. The stratigraphy was described by color using the Munsell color identification chart, texture, grain size, type of roots and rhizomes, and root percentage density was immediately recorded. Detailed descriptions of the roots were included at each stratigraphic unit.

Each core was subsampled with a 2cc volume cookie cutter taken from the center of the core every 5cm or 10cm then at high close resolution wherever the stratigraphy changed or had clear boundaries. A boundary was a clear line or change of soil type or, a lens of inorganic material such as sand, or a visual change from one unit to another. Each subsample was cataloged and put in its own thoroughly labeled bag. The site name, the method of collection, the depth and the BCID number were all included on the label. Each subsample was weighed for a wet weight.

All samples were then put in the freezer for at least 24 hours then freeze-dried. Once the samples were dried, they were weighed again for a dry weight. Bulk density calculations are based off the dry weight of a known volume.

$$\text{Dry bulk density (g/cm}^3\text{)} = \text{Mass of dry soil (g)} / \text{Original volume sampled (cm}^3\text{)}$$

Each dry sample was homogenized using a mortar and pestle, or using the Shatterbox grinder for a consistent time of 2 minutes. At this time all samples were homogenized into a powder-like consistency. This technique ensures that all parts of the sediment, including peat, inorganics soil and such are represented in the sampled. This combined and uniform sample was then run through and read by the EA-IRMS. Care was taken to avoid cross contamination by washing grinding dishes in between each sample. In addition, fresh surfaces and cleaned brushes were used for each sample when transferring sample from dishes back to their respective containers.

EA-IRMS Analysis

A ThermoFinnigan Delta V Advantage stable isotope ratio mass spectrometer (IRMS) fixed to a Costech elemental analyzer (EA) via a Conflo III combustion interface in the Bates College Environmental Geochemistry Laboratory was used to run all samples. All samples were run to find isotopic carbon values and are calculated using delta notation (i.e., parts per thousand deviation from a standard) for each sample.

Each sample was individually weighed using a micro-balance to a weight range of 2.0 - 7.0mg for peat samples and 14-20mg for mineral rich sediments. These weighed samples were loaded into tin boat capsules in a sanitary environment using methanol washed metal scoops and tweezers. Each combust at 1300 degrees Celsius in the presence of excess O_2 , Cr_2O_3 , pellets and $\text{Cr}_3\text{O}_4/\text{Ag}$ to generate NO_x , H_2O and CO_2 gas. After this, the gasses were reduced to H_2O , N_2 and CO_2 by passing over Cu pellets at 500 degrees Celsius. To remove the water from the system the gases get pushed through the $\text{Mn}(\text{ClO}_4)_2$. From here, the gases go through a Gas Chromatography (GC) column to separate out the individual gasses. Then the gases enter the Conflo III (C) and then onto the IRMS through a combustion interface. This EA-IRMS analysis provided the values for % C which was what was examined in this study.

Once all samples are run, and the carbon percentage data can be used to calculate our ideal unit of carbon density. This is the unit the final values will be presented in.

$$\text{Soil carbon density (gC/cm}^3\text{)} = \text{dry bulk density (g/cm}^3\text{)} * (\% \text{C}/100)$$

2.4 Standardizing Units of Carbon from Other Data Sets

A compilation of other data sets was created from dissertations and master theses from researchers at University of Maine, Orno. These dissertations and theses were examined for additional sites and existing data. A total of 42 cores were taken for existing data in all four coastal compartments. Woods had 26 cores with data from all four compartments, Mansfield had 6 cores from one compartment, the Island Bay Complex. Lastly, Pickoff had a total of 10 cores from two coastal compartments The Arcuate Embayment, and the Indented Shoreline. Data from all three of these other data sets can be seen in Table (2.2).

Collector	Site	Compartment	Longitude	Latitude
Wood	Scarborough- South	Arcuate Embayment	-70.3399	43.55993
Wood	Scarborough- Central	Arcuate Embayment	-70.3258	43.54967
Wood	Scarborough- North	Arcuate Embayment	-70.3117	43.55367
Wood	Gilsland	Island-Bay Complex	-70.2455	43.7075
Wood	Little Flying Pt. -S	Island-Bay Complex	-70.0463	43.83283
Wood	Little Flying Pt. -N	Island-Bay Complex	-70.0462	43.833
Wood	Upper Maquoit Bay	Island-Bay Complex	-70.0003	43.865
Wood	Wharton Point	Island-Bay Complex	-69.9917	43.86717
Wood	Stover Cove	Island-Bay Complex	-69.9995	43.76333
Wood	Cod Cove	Island-Bay Complex	-69.6408	44
Wood	Marsh River	Island-Bay Complex	-69.6075	44.02283
Wood	Deer Meadow Marsh	Island-Bay Complex	-69.583	44.02683
Wood	Salt Marsh Cove	Island-Bay Complex	-69.5922	43.94467
Wood	Salt Bay	Island-Bay Complex	-69.532	44.042
Wood	Hospital Cove	Island-Bay Complex	-69.5328	44.0275
Wood	Prentiss Island	Island-Bay Complex	-69.543	43.9995
Wood	Lowes Cove	Island-Bay Complex	-69.5753	43.93617
Wood	Hay Creek	Indented Shoreline	-67.6255	44.5395
Wood	Jasper Beach	Indented Shoreline	-67.3845	44.62583
Wood	Sanborn Cove	Indented Shoreline	-67.403	44.6825
Wood	Croker Point	Indented Shoreline	-67.3988	44.712
Wood	Machias River	Indented Shoreline	-67.4495	44.71717
Wood	Libby Cove	Indented Shoreline	-67.3853	44.69383
Wood	Cross Island	Cliffed Shoreline	-67.315	44.60633
Wood	Lubec	Cliffed Shoreline	-66.9903	44.823
Wood	Cobscook Bay	Cliffed Shoreline	-66.9867	44.81583
Mansfield	Grand Marsh (GM-23)	Island-Bay Complex	-67.1505	44.837
Mansfield	Grand Marsh (GM-37)	Island-Bay Complex	-68.0068	44.42241
Mansfield	Hay Creek (HC-9)	Island-Bay Complex	-67.627	44.53966
Mansfield	Hay Creek (HC-19)	Island-Bay Complex	-67.624	44.54221
Mansfield	Joanes Marsh (JM-DC-1)	Island-Bay Complex	-68.3499	44.41786
Mansfield	Hay Creek(JM-DC-11-C)	Island-Bay Complex	-67.627	44.53966
Pickoff	Eldridge Road	Arcuate Embayment	-69.8322	43.74308
Pickoff	Mile Rd	Arcuate Embayment	-69.8179	43.74378
Pickoff	Bourne 4	Indented Shoreline	-70.5877	43.27428
Pickoff	Furbish Rd	Indented Shoreline	-70.5751	43.29161

Table 2.2 All other data sets with respective longitude and latitudes, the compartments from where they were sample and who collected the cores. Of Pickoff's ten cores only one from each of her four marshes was selected for this table to represent the carbon content.

None of these previous data sets had values in %C or bulk density. The data was reported in % Ashed and %LOI. To convert these alternative reported data sets two imperial corrections were used. To convert from %LOI to bulk density the correction from Morris et al., (2016) was used. To

convert % LOI to % Carbon the other correction from Nelleman et al., (2009), the manual for Blue Carbon was used.

% Ashed to % LOI:

$$100 - \% \text{ Ashed value} = \% \text{ LOI}$$

% LOI to % Carbon:

$$0.0008 \times [\% \text{ LOI (gC/g sediment)}]^2 + 0.4763 \times \% \text{ LOI} = \% \text{ Carbon}$$

% LOI to Bulk Density:

$$1 / [(\text{LOI} / 0.085) + (1 - \% \text{ LOI}) / 1.99] = \text{Bulk Density}$$

For each calculation the constants are found in the published literature, as well as the accompany formula.

These newly calculated values were then combined with the data collected for this paper. For this study a total of 16 cores were collected; 9 cores from the Island Bay Complex, 2 from the Indented Shoreline and 5 cores from the Arcuate Embayment (Table 2.3).

This Study	Coastal Compartment	Secondary Location	Site	Coring Method	Lon Decimal Degrees	Lat Decimal Degrees	Depth (cm)
Kulesza	Island-Bay Complex	Machiasport, ME	Jasper Beach #1	Dutch Corer	-67.38571667	44.62825	60
Kulesza	Island-Bay Complex	Machiasport, ME	Jasper Beach #2	Dutch Corer	-67.38423333	44.62873333	100
Kulesza	Island-Bay Complex	Addison, ME	Addison	Dutch Corer	-67.7463	44.61826667	91
Kulesza	Island-Bay Complex	Franklin, ME	Franklin 1	Vibra Core	-68.26833333	44.52952778	84
Kulesza	Island-Bay Complex	Franklin, ME	Franklin 2	Dutch Corer	-68.2677778	44.52891667	91
Kulesza	Island-Bay Complex	Harrington, ME	Harrington 1	Dutch Corer	-67.80447	44.61728	100
Kulesza	Island-Bay Complex	Harrington, ME	Harrington 2	Dutch Corer	-67.80378	44.61853	100
Kulesza	Island-Bay Complex	Milbridge, ME	Milbridge 3	Dutch Corer	-67.855556	44.59108333	100
Kulesza	Island-Bay Complex	Milbridge, ME	Milbridge 4	Dutch Corer	-67.855556	44.59152778	98
Kulesza	Indented Shoreline ?	South Thompson, ME	Thompson 1	Dutch Corer	-69.14305556	44.07663889	116
Kulesza	Indented Shoreline ?	South Thompson, ME	Thompson 2	Dutch Corer	-69.14194444	44.07702778	103
Kulesza	Arcuate Embayment	Scarborough, ME	Woodside Dr	Dutch Corer	-70.32809	43.57404	101
Kulesza	Arcuate Embayment	Scarborough, ME	Ferry Rd	Dutch Corer	-70.3226	43.54818	181
Kulesza	Arcuate Embayment	Scarborough, ME	Rt 1	Dutch Corer	-70.37516667	43.57593333	127
Kulesza	Arcuate Embayment	Scarborough, ME	Clam Shack	Dutch Corer	-70.34285	43.5444	300
Kulesza	Arcuate Embayment	Scarborough, ME	Orchard Hill	Dutch Corer	-70.33994	43.55993	167

Table 2.3 Cores collected from this study showing the compartments, site name, GPS coordinates and depth of total core.

All values, from all researchers, were averaged for the upper one meter (Table 2.4). These upper 1 m values were then all used to calculate compartment wide carbon density averages and uncertainty, these can be seen in Table 2.5. Each core was taken as a singular value, thus no value was represented more heavily than others. The final units reported for carbon density are gC/cm^3 .

Site	Collector	Carbon Density Avg (Upper 1m)	Coastal Compartment	Compartment Avg (Upper 1m)	Uncertainty ±
Jasper Beach #1	Kulesza	0.0504	Island-Bay Complex	0.0414	0.0108
Jasper Beach #2	Kulesza	0.0559	Island-Bay Complex		
Addison	Kulesza	0.0291	Island-Bay Complex		
Franklin 1	Kulesza	0.0394	Island-Bay Complex		
Franklin 2	Kulesza	0.0374	Island-Bay Complex		
Harrington 1	Kulesza	0.0484	Island-Bay Complex		
Harrington 2	Kulesza	0.0306	Island-Bay Complex		
Milbridge 3	Kulesza	0.0414	Island-Bay Complex		
Milbridge 4	Kulesza	0.0398	Island-Bay Complex		
Thompson 1	Kulesza	0.0371	Indented Shoreline ?	0.0343	0.0014
Thompson 2	Kulesza	0.0314	Indented Shoreline ?		
Woodside Dr	Kulesza	0.0516	Arcuate Embayment	0.0403	0.0166
Ferry Rd	Kulesza	0.0306	Arcuate Embayment		
Rt 1	Kulesza	0.0275	Arcuate Embayment		
Clam Shack	Kulesza	0.0386	Arcuate Embayment		
Orchard Hill	Kulesza	0.0533	Arcuate Embayment		
Scarborough- South	Woods	0.0424		0.0438	0.0012
Scarborough- Central	Woods	0.0442			
Scarborough- North	Woods	0.0449			
Gil Island	Woods	0.0427	Island-Bay Complex	0.0433	0.0007
Little Flying Pt. -S	Woods	0.0439			
Little Flying Pt. -N	Woods	0.0421			
Upper Maquoit Bay	Woods	0.0428			
Wharton Point	Woods	0.0428			
Stover Cove	Woods	0.0432			
Cod Cove	Woods	0.0427			
Marsh River	Woods	0.0434			
Deer Meadow Marsh	Woods	0.0436			
Salt Marsh Cove	Woods	0.0437			
Salt Bay	Woods	0.0447			
Hospital Cove	Woods	0.0435			
Prentiss Island	Woods	0.0441			
Lowes Cove	Woods	0.0443	Indented Shoreline	0.0436	0.0011
Hay Creek	Woods	0.0426			
Jasper Beach	Woods	0.0453			
Sanborn Cove	Woods	0.0429			
Croker Point	Woods	0.0438			
Machias River	Woods	0.0428			
Libby Cove	Woods	0.0426	Cliffed Shoreline	0.0426	0.0002
Cross Island	Woods				
Lubec	Woods	0.0425			
Cobscook Bay	Woods	0.0435			
Grand Marsh (GM-23)	Mansfield	0.0229	Island-Bay Complex	0.0235	0.0007
Grand Marsh (GM-37)	Mansfield	0.0225			
Hay Creek (HC-9)	Mansfield	0.0237			
Hay Creek (HC-19)	Mansfield	0.0235			
Joanes Marsh (JM-DC-11-(	Mansfield	0.0244			
Hay Creek(JM-DC-11-09)	Mansfield	0.0241			
Eldridge Road	Pickoff	0.0550	Arcuate Embayment	0.0378	0.0062
Mile Rd	Pickoff	0.0393	Arcuate Embayment		
Bourne 4	Pickoff	0.0176	Arcuate Embayment		
Furbish Rd	Pickoff	0.0392	Arcuate Embayment		

Table 2.4 All data from all collectors shown based on calculated carbon densities. This table has the carbon density values (+/- standard deviation) for each core. Color coded by compartment, orange for Island Bay complex, blue for Indented Shoreline, green for Arcuate Embayment and purple for Cliffed Shoreline.

This paper, KULESZA		
Coastal Compartment	Compartment Avg (gC/cm3)	Uncertainty (gC/cm3)
Island-Bay Complex	0.0414	0.011
Indented Shoreline	0.0343	0.001
Arcuate Embayment	0.0403	0.017
Other DATA SETS		
Coastal Compartment	Compartment Avg (gC/cm3)	Uncertainty (gC/cm3)
Island-Bay Complex	0.0411	0.003
Indented Shoreline	0.0393	0.002
Arcuate Embayment	0.039	0.006
Cliffed Shoreline	0.0307	0.007
COMBINED DATA		
Coastal Compartment	Compartment Avg (gC/cm3)	Uncertainty (gC/cm3)
Island-Bay Complex	0.0412	0.006
Indented Shoreline	0.0368	0.001
Arcuate Embayment	0.0397	0.007
Cliffed Shoreline	0.0307	0.007

Table 2.5 Final carbon density values (+/- standard deviation) for Kulesza data only, then other data values only, then lastly the final carbon density values used boxed in red.

An ArcGIS map was generated to separate out the marshes within the entire state of Maine. The surface area of Maine saltmarshes from soil delineations generated from the USDA soil description data base, then produced on ArcGIS. An entire state surface area value was generated of 111.11 km² of salt marshes. By compartment the surface areas are Arcuate Embayment 54.31 km², Indented Shoreline 32.36 km², Island-Bay Complex 22.3 km² and the Cliffed Shoreline 2.14 km².

2.4 GIS Modeling to Generate Salt Marsh Surface Area Map

An ArcGIS map was generated to separate out and isolate the marshes within the entire state of Maine. The surface area of Maine saltmarshes from soil delineations generated from the USDA soil description data base, then produced on ArcGIS. An entire state surface area value was generated of 111.11 km² of salt marshes.

GPS coordinates from each core collected was plotted into ArcMap GIS (Figure 2.3).

Cores collected from other publishers and researchers were also plotted on this map (Figure 2.2). From here spatially each ecosystem was analyzed for spatial diversity and differences.

The surface area of Maine saltmarshes was created from soil delineations generated from the USDA soil description data base, and soils layers from downloaded from Matt Duvall, Bates College. The USDA was an existing data bases on soil descriptions for the entire state of Maine. All layers were used to represent the entirety of marsh coverage for the state of Maine. The soils from the USDA layers that were pulled out to represent the salt marsh surface was: Tm, Su and Go. Only marsh soils were used to generate a map of the entire marsh coverage along the coast of Maine. These soil types were polygons in ArcGIS, these polygons were then generated into one layer to create a state wide salt marsh only layer. The values were all normalized to the area of Maine in square meters. This map was used for the carbon stock calculations, as the modern surface area value.

To calculate Carbon Stocks per marsh, per compartment and for the entire coast an appropriate carbon density value for the area and the actual marsh surface area is needed.

$$\text{Carbon Stock (Mg C)} = (\text{carbon density gC/cm}^3) * (100\text{cm}) * (\text{surface area km}^2) * (100,000)^2 * (1/1,000,000)$$

All carbon stock values were computed for the upper 1m or 100cm of the marsh across all surface areas. All carbon stock values were also reported in Mega tons of carbon.

2.5 Sites

Figure 2.2 are all the sites collected for this study. The following figures are the site maps for each individual marsh. The pink circles are the GPS coordinates of where the respective cores were collected. These sites provide a visual aid for the following results and interpretations.

Figure 2.2 Site map of all sites collected by Kulesza et al., for this study.

Site map for Jasper Beach, Island-bay complex compartment. Most northern site

Site map for Addison Island-bay complex compartment

Site map for Harrington Island-bay complex compartment

Site map for Milbridge, Island-bay complex compartment.

Site map for Franklin, Island-bay complex compartment

Site map for S. Thompson, Island-bay complex compartment

Site map for Scarborough, Arcuate Embayment compartment.

3 Results

3.1 Stratigraphy, Geochemistry and Carbon Density

The state map with marsh soils and site locations can be found in Figure 3.1. The stratigraphic core symbology used for the detailed descriptions of each of the cores collected in this study can be found in Figure 3.2. A description of the marsh, the stratigraphy and geochemistry from north to south are laid out for each marsh within each of the four coastal compartments follow. All stratigraphy logs are in Appendix A, and all geochemistry plots are in Appendix B. From north to south the sites are as follows: Jasper Beach, Pleasant River Marsh, Harrington Marsh, Millbridge Marsh, Franklin Marsh, South Thomason Marsh, and Scarborough Marsh. These marshes were mostly named after the towns they were in or close to for this study.

Figure 3.1 Site map collected by Kulesza, et al. Sites shown in pink circles, marsh surface area along coast of ME shown in dark grey. Jasper Beach is the most northern site and Scarborough Marsh is most southern site.

Symbol Legend of Core Stratigraphic Units and Microfossils

Organic rich peat, contains visible THIN rhizomes, either within or dominating matrix
Organic rich peat , contains visible THICK rhizomes, rarely present as dominant within matrix
Sandy micaceous peat unit, organics are visible
Silty to clayey matrix, with few organics visible or present
Very fine-grained (clay) unit, may contain some organics
Rock fragment or pebble within the unit
Sand-silt dominate horizon or lens wih few to no visible organics

Figure 3.2 Symbol Legend of all units shown and described all stratigraphic units used.

3.1.1 Island Bay Complex

Jasper Beach, Machiasport, ME

Two cores were collected from Jasper Beach Marsh, with no compaction during the coring process (Appendix A.1 and Appendix A.2). These cores were collected using different diameter Dutch-Corers. The thick diameter was unable to penetrate deeply and only recovered 62 cm. The skinny diameter Dutch Corer was able to retrieve a full meter.

Core #1 is dominated by a dark hair-like fibrous peat units with lenses of silt and clay and coarser clay at the top half of the core and a larger clast rock at the top as well (Figure 3.2). The % carbon varies between 5 and 40%, bulk density varies between 0.2 and 0.8 g/cm³, and carbon density between 0.02 gC/cm³ and 0.08 gC/cm³ (Appendix B.1).

Core #2 is dominated by thin dark brown peat with hair-like fibrous roots. The % carbon varies between 8 and 20%, bulk density between 0.250 and 0.650 g/cm³, and carbon density between 0.04 gC/cm³ and 0.06 gC/cm³ (Appendix B.2). Jasper Beach marsh is a small marsh with a surface area less than 1.0 x 10⁶ m² it is the smallest marsh sampled for this study.

Pleasant River Marsh, Addison, ME

One core was collected for Pleasant River Marsh, commonly called Addison Marsh in this study. Using the thick diameter Dutch corer a 95 cm drive was recovered with little to no compaction during the coring process.

The stratigraphy switches between thin root peat then to a siltier unit then back to the thin root peat unit then into the blue Presumpscott formation (Appendix A.3). The % carbon varies between 2 and 14%, bulk density between 0.40 and 0.12 g/cm³, and carbon density between 0.02 gC/cm³ and 0.04 gC/cm³ (Appendix B.3). The averaged carbon storage for the 95cm depth of this core is 0.03+/-0.01 gC/cm³. Addison site has a surface area of 2.4 x 10⁶ m².

Harrington Marsh, Harrington, ME

Harrington marsh had two cores collected. Due to the cores not being continuous, they were plotted separately. Both these cores have a majority of thin root dark brown peat at the top of the stratigraphy log (Appendix A.4 and A.5). This remains the overall unit throughout the core, with one switch to a different thick root peat unit different depths, followed by a smaller more inorganic unit before returning to thin root peat for core #1.

For core #1, the % carbon varies between 5 and 40%, bulk density between 0.2 and 0.8 g/cm³, and carbon density between 0.02 gC/cm³ and 0.09 gC/cm³. The upper 1m average carbon density is 0.05 +/- 0.01 gC/cm³ (Appendix B.4).

For core #2 the switch occurs as the basal unit, thus no return to thin root peat. The % carbon varies between 2 and 9%, bulk density between 0.40 and 0.85 g/cm³, and carbon density between 0.02 gC/cm³ and 0.04 gC/cm³. The upper 1m average carbon density is 0.03 +/- 0.01 gC/cm³ (Appendix B.5). Harrington Marsh is a surprisingly small marsh that is represented by these two cores with a surface area of 1.6 x10⁶ m². This marsh is approximately half the size of its northern adjacent marsh, Addison.

Millbridge Marsh, Millbridge, ME

Millbridge Marsh is represented by two cores Millbridge #3 and #4. Both cores have the thick straw like root peat at the top of each stratigraphy column (Appendix A.6 and A.7). The stratigraphy switches to the more dominate thin root peat for the remainder of the stratigraphy, expect in Millbridge #4 where the last unit is a silty unit.

For core #3 the % carbon varies between 4 and 12%, bulk density between 0.35 and 0.85 g/cm³, and carbon density between 0.03 gC/cm³ and 0.06 gC/cm³. The upper 1m average carbon density is 0.04 +/- 0.01 gC/cm³ (Appendix B.6).

For core #4 the % carbon varies between 5 and 30%, bulk density between 0.2 and 0.7 g/cm³, and carbon density between 0.02 gC/cm³ and 0.09 gC/cm³. The upper 1m average carbon density is 0.04 +/- 0.02 gC/cm³ (Appendix B.7). Millbridge Marsh is to the south of Harrington Marsh, and has a surface area of 2.7 x10⁵ m². This marsh is much smaller, than its neighbor marsh to the north, Harrington Marsh.

Franklin Marsh, Franklin, ME

Franklin Marsh is represented by cores #1 and #2. These cores were recovered using the Vibra-corer, this method has a higher compaction rate. For core #1 there was about 12 cm compaction. For core #2, there was closer to 20 cm compaction rate. This is the highest compaction rate out of all the cores collected for this study. This method was only used at this site.

Both cores have the thick root peat at the top of each stratigraphy column. These two stratigraphy logs are very different from each other, both start in different peat units. One similarity is that they both end in a very silty, potentially Presumpscott unit at the very end of the core (Appendix A. 8 and A.9).

For core #1, carbon varies between 1 and 30%, bulk density between 0.15 and 1.2 g/cm³, and carbon density between 0.01 gC/cm³ and 0.06 gC/cm³. The upper 1m average carbon density is 0.04 +/-0.02 gC/cm³ (Appendix B.8).

For core #2, carbon varies between 0.5 and 22%, bulk density between 0.2 and 1.3 g/cm³, and carbon density between 0.02 gC/cm³ and 0.05 gC/cm³. The upper 1m average carbon density is 0.04 +/- 0.01 gC/cm³ (Appendix B.9). Franklin Marsh has a surface area of 3.5 x10⁵ m², larger than Harrington and Addison. It is the largest marsh in this compartment.

3.1.2 Indented-Shoreline Compartment

South Thomason Marsh, South Thomason, ME

South Thomason has two cores collected, core #1 and core #2. Both of these cores begin with the thick root peat at the top core, they both switch to the thin root peat unit before ending in a silty clay unit. All these changes occur at different depths, however follow the same pattern of units (Appendix A.10 and A.11).

For core #1, the % carbon varies between 4 and 16%, bulk density between 0.20 and 0.65 g/cm³, and carbon density between 0.03 gC/cm³ and 0.06 gC/cm³. The upper 1m average carbon density is 0.04 +/-0.01 gC/cm³ (Appendix B.10).

For core #2 the % carbon varies between 2 and 14%, bulk density between 0.20 and 0.75 g/cm³, and carbon density between 0.02 gC/cm³ and 0.06 gC/cm³. The upper 1m average carbon density is 0.03 +/-0.01 gC/cm³ (Appendix B.11). South Thomason is the only site collected from the Indented-Shoreline Compartment with a total surface area of 2.3 x10⁶ m².

3.1.3 Arcuate Embayment Compartment

Scarborough Marsh, Scarborough, ME

Scarborough Marsh is the largest marsh in Maine, and needed more than two cores to capture all of its surface area, a total of five cores were collected. The surface area of this marsh is 1.9 x10⁷ m². Stratigraphy varied greatly across all cores.

The most northern site was Route 1, with no compaction during the coring process only lost 0.5cm. The peat was dominantly thin hair-like root dark brown peat, with a more inorganic rich last few units (Appendix A.12). The % carbon varies between 0 and 40%, bulk density between

0.10 and 0.80 g/cm³, and carbon density between 0.01 gC/cm³ and 0.05 gC/cm³. The upper 1m average carbon density is 0.03 +/-0.01 gC/cm³ (Appendix B.12).

The next southern core from the north is Woodside Rd (Appendix A.12 and A.13), this core is continuous and has a combined depth of 200 cm. The stratigraphy is very diverse, switching between the two different root thicknesses of peat. The last 150cm are very inorganic rich units. The % carbon varies between 2 and 18%, bulk density between 0.20 and 1.0 g/cm³, and carbon density between 0.01 gC/cm³ and 0.08 gC/cm³. The upper 1m average carbon density is 0.05 +/- 0.03 gC/cm³ (Appendix B. 13).

The middle core, which also happens to be almost exactly spatially in the middle of the marsh is Orchard Hill (Appendix A.14 and B.15), which is also a continuous core with a total depth of 170 cm. This core stratigraphy is dominated by the thin hair-like root dark brown peat. The base unit is inorganic rich. The % carbon varies between 7 and 48%, bulk density between 0.15 and 0.45 g/cm³, and carbon density between 0.03 gC/cm³ and 0.12 gC/cm³. The upper 1m average carbon density is 0.05 +/- 0.03 gC/cm³ (Appendix B.14).

The second most southern site Ferry Rd (Appendix A.16 and A.17), it is a continuous core with a total depth of 200 cm depth. There is a missing section of stratigraphy from 100-112, which was just assumed to be the same continuous unit due to the stratigraphy matching above and below. About 4 cm were also lost at the bottom of the drive. The stratigraphy is mostly thin hair-like root dark brown peat that the top then switches to thicker roots at around 60 cm. After this unit the majority of the core is comprised of inorganic units. The % carbon varies between 1 and 28%, bulk density between 0.15 and 1.1 g/cm³, and carbon density between 0.01 gC/cm³ and 0.05 gC/cm³. The upper 1m average carbon density is 0.03 +/- 0.01 gC/cm³ (Appendix B.15).

The most southern sample from Scarborough Marsh is the Clam Shack core, which is the longest core collected at 300cm depth (Appendix A.18, A.19 and A.20). This core, because of its length has many different units including micaceous units. The upper 1m is dominated mainly by thin hair-like roots in dark brown or grey peat. There are two thin sand lenses. The % carbon for the upper 1m varies between 1 and 20%, bulk density between 0.15 and 0.90 g/cm³, and carbon density between 0.03 gC/cm³ and 0.05 gC/cm³. The upper 1m average carbon density is 0.04 +/- 0.01 gC/cm³ (Appendix B.16).

3.2 Previous Works

Margaret Pickoff wrote a thesis in 2013 at Bates College on Maine's Blue Carbon and estimated the amount stored in salt marshes for the southern two compartments on the coast. She

calculated carbon density for her sampled marshes in addition to calculating carbon stocks for the two southern compartments where her sample sites were. This thesis provided the methodology and background for this study. This paper uses a similar methodology for selecting sites and how to process samples.

Pickoff's findings and methodologies for lab and field work is what dictated the structure for this study. This previous work made this current study possible. These data is from this thesis has been included in this paper to add to the volume of sites and known values. This data is detailed and has carbon density values for each core at many known depth values.

Mark Woods produced a master's thesis in 1991 at University of Maine. His many sites and down core stratigraphy and Loss on Ignition (%LOI) values are heavily utilized in this study. His data is the only data from the Cluffed Shoreline. Margot Mansfield also produced a thesis iat the University of Maine in 2009 that had a few a cores in the Island-Bay complex coastal compartment. Her down core %LOI data values were used in this study.

This study is a summarization and expansion from all of these works, and other works published on Maine salt marshes and coastal blue carbon. This study would not be possible without these previous researcher's work and data. This paper adds to these bodies of work and to the wider field of coastal blue carbon climate mitigation.

3.3 Area Calculation

An ArcGIS map was generated to separate out the marshes within the entire state of Maine (Figure 3.3). The surface area of Maine saltmarshes from soil delineations generated from the USDA soil description data base, then produced on ArcGIS. An entire state surface area value was generated of 111.11 km² of salt marshes. By compartment the surface areas are Arcuate Embayment 54.31 km², Indented Shoreline 32.36 km², Island-Bay Complex 22.3 km² and the Cluffed Shoreline 2.14 km². These coastal compartment surface area values match previously published literature for all coastal compartments except the Arcuate Embayment.

Figure 3.3 A map of just all the Maine salt marshes, generated in ArcGIS using USDA soil data.

3.4 Carbon Stocks

Due to the difference in area calculations in this study compared to other literature such as (Jacobson et al., 1987), two different carbon stock calculations were done. One calculation using the calculated values from this study, and another using the values from Jacobson et al., (1987). The final averaged carbon density values for the upper 1m from all data available including other data sets and from this paper were used in the final carbon stock calculations for both surface areas. All carbon stocks will be reported in Mega tons (Mt) of carbon for the upper 1m.

Using the surface areas from (Jacobson et al., 1987), with calculated surface area for each coastal compartment defined by (Kelley et al., 1988), each compartment areas sum up to 79.8

km². Using this conservative surface area the total carbon stock in Maine is **3.04 x 10⁶ +/- 0.10 x 10⁶ Mt C.**

Using the surface areas calculated for this paper, calculated for each coastal compartment and for a state sum of 111.11 km². Using this much larger surface area the carbon stock will increase. The entire Maine carbon stock is **4.33 x 10⁶ +/- 0.15 x 10⁶ Mt C.**

4 Discussion

4.1 Stratigraphy and Carbon Geochemistry: Spatial Carbon Densities

A large sample size of marshes was sampled, and included for this study. 16 cores were collected for this study, 42 cores were included from other researchers, making 58 cores the total number of cores included in this study. Each marsh has its own unique morphology and development through time. This paper focuses on the cores collected specifically for this study, and all the implications and discoveries for carbon storage, and carbon storage capacity. The total 58 cores were used for carbon density values for the entire coast, to generate final carbon stocks.

Carbon densities over the upper one meter vary due to a variety of factors. Such as the location of the core on the marsh, the core stratigraphy and peat type, the human alterations within the marsh and lastly the scale of the marsh.

Anthropogenic alterations can also influence modern carbon storage, as well as future carbon storage capacities. These impacts can include sea level rise, and surface area degradation as well as future carbon sequestration after tampering with the stratigraphy has occur. Soil composition, growth and productivity of above biomass will effect and limit belowground biomass, which will limit carbon storage capacity (McLeod et al., 2011).

4.1.1 Island Bay Complex

Jasper Beach Marsh, Machiasport, ME

The Jasper Beach core #2 is the shortest collected core at 60 cm depth, out of all cores collected. There is a sand unit then shift back to thin root peat in Jasper Beach #1, which does not exist in Jasper Beach #2 (Appendix A.1 & A.2).

The sand layer occurs and ends at a 60cm depth, meaning that if it existed it should have been visible in core #2. However, there is no sand layer, which suggests that there is a different sediment supply for each core. Visibly the spatial difference of where the cores exist in the marsh could account for the sandy unit formation (Figure 4.1). The area where #2 was collected farther back in the marsh. However, #1 was collected in the center of the marsh closest to the inlet of tidal water. This is an area that would receive more sediment transport and a potentially

large storm or barrier breach could have formed the sandy unit in #1 that is not seen in #2. This increased sediment flow could also account for the deeper core collected, compared to #2. The increased tidal flooding and sand deposition for core #1 shows the different sediment dynamics within the marsh. This sand unit also limits carbon storage, resulting in a lower carbon density of $0.0504 \pm 0.007 \text{ gC/cm}^3$ (Appendix B.1).

The carbon density values differ for each core. Core #1 is a full one meter with a value of $0.0504 \pm 0.007 \text{ gC/cm}^3$ and the only available upper 62 cm average for core #2 is $0.0559 \pm 0.015 \text{ gC/cm}^3$. Even with the stratigraphic differences, and the depth average differences the values are within the uncertainty range of each other. This shows that the carbon storage is similar for the upper one meter across the sampled area of the marsh.

Figure 4.1. The two core logs and average ($\pm$ standard deviation) carbon density in the upper 1m for the Jasper Beach Marsh. For Jasper Beach #2 the carbon density average is only the upper 62 cm because that was all that was recovered.

Pleasant River Marsh, Addison, ME

At Addison Marsh, only one core was collected in a single drive yielding a 91cm core (Appendix A.3). The carbon density average for this core is $0.029 \pm 0.009 \text{ gC/cm}^3$, this value is on the lower side (Figure 4.2). This can be explained by the large unit of inorganic matter from the silty clay Presumpscott formation. Clay does not hold carbon very efficiently, resulting in a lower overall carbon density value.

Without another core to compare it to, there are limited inferences we can generate spatially across the marsh. However, this marsh like most marshes in Maine was heavily diked and altered for agricultural practices. This was evident by the many raised dikes on the marsh and the Presumpscott formation creating these dikes. From glacial history, we know the Presumpscott should be the basal unit; proving that there must be some large disturbance in the peat and marsh system to have created these systems. This heavy human impact disrupted the peat, releasing previously stored carbon and damaging the potential for future carbon. This altered carbon storage capacity was found as high as 25% less effective at carbon storage in other blue carbon ecosystems, and it has been predicted to be the same for salt marshes (Duarte et al., 2005). This marsh had large dikes scattered all over the marsh. The marsh has a history of being used for agriculture, thus the stratigraphy was heavily impacted by humans. The stratigraphy and carbon storage values are altered and potentially much lower than what they could have been without human alterations (Duarte et al., 2005; McLeod et al., 2011).

Figure 4.2 One core represents all of Pleasant River Marsh in Addison, ME and the corresponding stratigraphy log and upper 1m carbon density value (+/- standard deviation). The core is comprised of Presumpscott formation for the bottom half of the core. The carbon density average is only the upper 95 cm because that was all that was recovered.

Harrington Marsh, Harrington, ME

Each collected core from this one marsh has varying stratigraphy, which signifies that there is a shift in sediment supply or channel migration. There is also a large difference in carbon density storage $0.048 \pm 0.010 \text{ gC/cm}^3$ for core #1 compared to $0.030 \pm 0.005 \text{ gC/cm}^3$ for core #2. Unlike at Jasper Beach Marsh the uncertainty range between the two cores do not overlap, thus differences between the two is substantial (Figure 4.3).

Both top units of each core (Appendix A.4 & A.5) begins with the thin root peat, which signifies high marsh vegetation. However, this is the only similar stratigraphy between the two cores. #1 shifts to the thick root peat for one unit, then a silty unit before shifting back to the thin root, this trend is not seen in #2. This shift between vegetation types could be described by a migrating main stream channel, or just an irregular patch of vegetation that has been captured in this core. #2 core at the very base shifts to a siltier inorganic rich unit. This basal unit could be a tidal or marine unit that lacks vegetation.

The difference in carbon storage does not seem to be purely based on peat type. Both cores have both mainly the thick peat type. Core #2 is not a full 1m core, and the end is a more inorganic unit. This could explain the large carbon density difference. Another contributing factor could be that core #2 is much more inland, up a smaller tributary channel marsh area. Whereas core #1 was collected adjacent to the main stem of the tidal stream (Figure 4.3).

Figure 4.3 Two cores from site Harrington Marsh, and the corresponding stratigraphy logs and upper 1m carbon density values ($\pm$ standard deviation). For Harrington #2 the average is only upper 84cm, because that was all that was recovered.

Millbridge Marsh, Millbridge, ME

The trend stated for Harrington Marsh holds true for Millbridge as well, lower carbon density values inland compared to closer to the stream channel and the middle of the marsh. For core #3, the carbon density value is $0.0414 \pm 0.007 \text{ gC/cm}^3$ and $0.0398 \pm 0.017 \text{ gC/cm}^3$ for core #4 (Figure 4.4). These values are within the uncertainty of each other, which makes the values less significant to if they were outside of the range. There are also significant stratigraphic differences between the two cores.

Both cores (Appendix A.6 & A.7) have the top unit of the tick root peat, then for Millbridge #3 there is a shift to thin roots at 46 cm depth, compared to Millbridge #4 where the shift to thin root peat occurs much quicker at 7cm depth. The shift of peat type for Millbridge #3 is reflected in carbon % dropping from high content to low, supporting the claim that low organic matter, or high inorganic matter holds less carbon (Appendix B.4). For Millbridge #4, there is a sharp peak to the highest carbon density value at a depth 50 cm at a high resolution zone, however the peat itself was overall uniform thin root peat (Appendix B.5).

Figure 4.4 The two core sites for the Millbridge Marsh site and the corresponding stratigraphy logs and upper 1m carbon density values (+/- standard deviation). For Millbridge #4 the average is only upper 98cm, because that was all that was recovered.

Franklin Marsh, Franklin, ME

The stratigraphy between the two cores do not share any similarities (Figure 4.5) and (Appendix A.8 & A.9). The upper 1m average carbon density values are $0.040 \pm 0.02 \text{ gC/cm}^3$ for Franklin core #1 and $0.037 \pm 0.01 \text{ gC/cm}^3$ for Franklin core #2 (Appendix B.8 & B.9).

Core #1, has the higher carbon density value however is still within the uncertainty range, even though core #2 is more central on the marsh. However, there is a substantial patch of terrestrial trees very close to core #2, this irregularity could account for this lower value. This patch could be just enough of a terrestrial influence to lower the carbon storage for this area of the marsh (Figure 4.5).

Figure 4.5 The two core sites for the Franklin site and the corresponding stratigraphy logs and upper 1m carbon density values ($\pm$ standard deviation). Both of these cores were recovered using the Vibra-Core method, thus the cores are shorter than one meter deep. The upper 1m average was only 91 cm for core #2 and 84 cm for core #1, because that is all that was recovered.

4.1.2 Indented-Shoreline Compartment

South Thomason Marsh, South Thomason, ME

The only site collected for this paper in the Indented-Shoreline Compartment, this site has two deep one drive cores collected. The stratigraphy between the two cores are very similar, starting units are thick root peat for the top of each core. There is a shift to thin root peat as the second unit for both, however S. Thomason #1 has a longer stratigraphy of the thin root peat than

S. Thomason #2 (Appendix A.10 & A.11). From the thin root peat there is a shift to more silty clay unit, this unit continues until the end of the core.

This marsh was also altered by humans, there were mostly dug channels scattered around the marsh. Cores were taken far away from any visible human alteration, however these impacts must be considered in this analysis (Figure 4.6).

Figure 4.6 The two core sites for the South Thomason marsh and the corresponding stratigraphy logs and upper 1m carbon density values (+/- standard deviation). The upper 1m average was for core s #1 and #2, even though a greater depth was recovered.

4.1.3 Arcuate Embayment Compartment

Scarborough Marsh, Scarborough, ME

As the largest marsh in Maine, this marsh has five, all deeper than 100 cm cores collected across the surface of this ecosystem. The cores were collected from diverse areas of the marsh (Map 3.8).

This marsh was also effected by human innovation and need to cultivate and control the land. There are long dug out channels scattered throughout the marsh. The cores collected from

this site were not close to these alterations, but must be considered in stratigraphy and geochemical analysis.

One trend that all the cores share, is that there is a sandy unit at some depth for each core. Consistently at this point, this is where the carbon content dips, due to it being more mineral rich and less organic rich. This sand layer has been a source of in depth study by Barker, (2018), however other than this one layer of sand the stratigraphy varies greatly across all five cores. Thus we cannot infer anything about tidal channel movements or development of the marsh. The only narrative to be generated is related to where carbon is stored (Figure 4.7).

Figure 4.7 The five core sites for Scarborough Marsh, the most cores collected per marsh, and the corresponding stratigraphy logs and upper 1m carbon density values (+/- standard deviation). Only the upper 1m were used in carbon density average calculations, even though all cores are deeper than 1m.

4.2 Spatial Variability in Carbon Storage

It appears that there is more variation of spatial carbon storage in Harrington Marsh and Scarborough Marsh compared to Jasper Beach Marsh, Addison Marsh, Millbridge Marsh, Franklin Marsh and South Thomason Marsh. It is important to note that Scarborough Marsh was

sampled over a much greater distance than any of the other marshes. These data reflect the true variability in carbon storage across each individual marsh ecosystem.

The fact that four of the marshes out of the seven sampled have identical, or within the uncertainty range, carbon densities suggest that the sites sampled may not be reflective of the true variability in their respective marshes. I recommend for future work, a transect of cores should be taken as a method of collection within a marsh. This way would capture the spatial differences within the marsh in a more methodological way. Harrington Marsh is also an apparent anomaly in this study and warrants further investigation and coring.

In reality, this study shows that carbon density values, or carbon storage in a marsh is not clear cut or easily predictable. There are several factors that could easily effect carbon storage spatially such as terrestrial or watershed influences. Salt marshes are low in elevation, thus when there is a storm or any time of sediment movement it comes into the marsh. This influx through the river and overrun could account for a diluted carbon signal more inland. There could also be differences in carbon storage based on sediment supply, how frequently an area gets sediment which tends to be inorganic that doesn't store carbon well. Proximity to the ocean can also lower carbon storage due to over wash of sediment from large storms. These deposits also decrease and limit carbon storage. This follows the same logic as the sediment supply theory. Similar logic can be used for proximity to the stream channel on a lesser scale. Increased volume of water during tidal flooding would introduce inorganic sediment into the marsh system. There are all systematic, yet naturally occurring, factors that would alter carbon storage in spatially diverse regions of the marsh.

Using the salt marshes with more than one core sampled, we can observe carbon storage within the marsh and the spatial differences of carbon storage. Scarborough Marsh has five cores, which is the highest amount of cores collected. Through this marsh we can observe spatial differences within one ecosystem. Figure (4.6) shows each core on the marsh of Scarborough Marsh, with the corresponding carbon density averages for the upper one meter. These five cores even within one marsh have a wide range of carbon densities from $0.027 \pm 0.012 \text{ gC/cm}^3$ to $0.053 \pm 0.025 \text{ gC/cm}^3$. This is important when sampling marshes, recognizing that wherever you sample there will be spatial difference of carbon storage within that marsh.

Carbon density values are similar across all researchers, the calculated values for each compartment are very similar. For the total combined total of 58 cores included in this study, the values all are within the range of expected values. It also shows that there is a reproducibility aspect of carbon density values across the entire coast.

4.3 Stratigraphy, Carbon Storage

There were some noticeable differences in carbon storage across the various types of stratigraphy. One obvious difference was within inorganic content such as sand or clay, the carbon storage or carbon density dropped significantly in these units. This strongly shows that inorganic content does not store carbon as well as peat does.

4.3.1 Peat Differences

Differences in peat were apparent throughout the study. In some cases, stratigraphy was dominated by thin root peat, in other cases, the sediments were dominated by thick root peat. Significant differences in carbon densities were found for peat having thin wispy hair like roots compared to peat defined by having thicker straw-like hollow dense roots. A T-test was conducted to find if the difference was significant, and the p-values result was 4.83×10^{-5} , which is less than 0.05 making the result significant. The thin root peat has a carbon density capacity of $0.044 \pm 0.001 \text{ gC/cm}^3$ compared to the thick root peat which has a carbon density capacity of $0.034 \pm 0.001 \text{ gC cm}^3$. In the 16 cores collected for this study, the majority of the peat was thin root peat with 114 observations included in this t-test, the thick root has only 39 observations.

This finding is significant because this shows that not all peat layers have equal carbon content. When coring in different vegetation types, carbon storage will vary. The root type does not definitively say something about vegetation type. Thus, concretely only carbon storage can be assumed when a core is collected and observed at depth. If the core is dominated by thin root peat, more carbon will be stored compared to a core dominated by thick root peat.

Theoretically these peat storage differences could be tied to the hydrology of the marsh. How water moves from the main channel flooding twice daily through the peat. The higher marsh vegetation and peat might be saturated to the ideal point for carbon storage. Compared to closer to the stream channel or low marsh peat and vegetation where there is total saturation. This saturation level might prevent continuous carbon storage compared to less saturation or flooding. In addition, because the stream channel migrates, the low vegetation or low marsh area might be eroded away over time, thus carbon is released and not being stored and lost in the stratigraphic record. There is more movement in this region, thus less sequestration and reliable storage.

4.5 Depth Estimates, Go Deeper

When comparing carbon densities across literatures there are conflicting ideas on how to accurately calculate carbon storage. Chmura et al. (2003) used 50cm to capture carbon storage, which is the deepest value published at this time. These values for the upper 50 cm were reported as $0.039 \pm 0.003 \text{ g cm}^{-3}$ for carbon density storage in the north east region. Most published values only use the top 10 cm or 50 cm of peat to represent carbon density values (Chmura et al., 2003; Tanner et al., 2007). The Blue Carbon Manual recommends the deeper the core the better the results (Howard et al., 2014).

From this recommendation, this study uses the top 100 cm, or upper 1 m was used to quantify carbon density for the state of Maine for an accurate representation. These values can be seen in (Table 3). , including other researchers. When comparing values using these same cores but only the upper 50 cm averages there is a large discrepancy (Table 4.1). The values for the upper 50 cm differ by 0.0006, -0.0025 and 0.0045, respectively for the three compartment with data for this paper. This difference is covered within the uncertainty of each compartment. Thus, the difference for these values are not significant. However, the best value comparatively will be greater and more accurate when using the complete 1m value method.

This paper, KULESZA					
Coastal Compartment	Compartment Avg (gC/cm3)	Uncertainty (gC/cm3)		Upper 50cm Compartment Avg (gC/cm3)	Upper 50cm Uncertainty (gC/cm3)
Island-Bay Complex	0.0414	0.011	Island-Bay Complex	0.0408	0.007439
Indented Shoreline	0.0343	0.001	Indented Shoreline	0.0368	0.003907
Arcuate Embayment	0.0403	0.017	Arcuate Embayment	0.0358	0.007425

Table 4.1 Comparing upper 50cm carbon density values with full 1m values for data collected for this paper. The full 1m values on the left, and the 50 cm values on the right.

4.5 Mapping Surface Area Comparisons

There are few published salt marsh surface areas for the entire state of Maine and by coastal compartment. The most recently published surface area that also includes costal compartment surface areas defined by Kelley et al. (1988) is Jacobson et al. (1987). The total

calculated Maine surface area was 79 km², and defined by compartment was Arcuate Embayment with 26.4 km², The Indented Shoreline with 27.4 km², the Island-Bay Complex with 20.6 km², and Clifed Shoreline with 4.5 km². When using these surface areas, and the final carbon densities from this paper we can calculate a carbon stock value per compartment and for the entire state (Table 4.2).

If there are large differences in surface areas there will be different carbon stocks. Since the same carbon density values are being used per compartment the only altered factor is the surface area. The greater the surface area the greater the stock. Between the two carbon stock calculations the difference, or range is 1.2×10^6 Mg C. This is a large range. However, with restoration efforts and awareness to blue carbon and the carbon storage capacity this range can be lowered. More research and more accurate mapping techniques can be implemented to correct this large range.

Jacobson et al.	Compartment	Surface Area (km ²)	Avg, All Data	C stock in upper 1m	Carbon Stock (Mg)
	Arcuate Embayment	26.4	0.007	1.848E+11	184800
	Indented Shoreline	27.4	0.002	5.480E+10	54800
	Island-Bay Complex	20.6	0.006	1.236E+11	123600
	Clifed Shoreline	4.5	0.007	3.150E+10	31500
	Sum	78.9			3.04E+06
	std dev				1.00E+05
Kulesza, This study					
	Arcuate Embayment	54.31	0.0397	2.156E+12	2.16E+06
	Indented Shoreline	32.36	0.0368	1.191E+12	1.19E+06
	Island-Bay Complex	22.3	0.0412	9.197E+11	9.20E+05
	Clifed Shoreline	2.14	0.0307	6.561E+10	6.56E+04
	Sum of State	111.11			4.33E+06
Standard Dev.	Arcuate Embayment	54.31	0.007	3.802E+11	3.80E+05
	Indented Shoreline	32.36	0.002	6.472E+10	6.47E+04
	Island-Bay Complex	22.3	0.006	1.338E+11	1.34E+05
	Clifed Shoreline	2.14	0.007	1.498E+10	1.50E+04
	Sum of State	111.11			1.48E+05

Table 4.2 Has both surface areas from (Jacobson et al., 1987) and Kulesza, this study. The separate carbon stocks were calculated and the (+/-standard deviation). The avg. all column shows the best value average for the upper 1 m carbon density value from all data combined. The final bolded number in reported carbon stock values in Mega Tons Carbon (Mg C).

These values then compare to the surface areas generated through ArcGIS for this study. The total surface area found is 111.11 km², and broken down by compartment are Arcuate Embayment with 54.31 km², The Indented Shoreline with 32.36 km², the Island-Bay Complex with 22.30 km², and Cluffed Shoreline with 2.14 km² (Figure 4.8). These surface area values were calculated by separating out salt marsh classified polygons from existing data sets generated by the United States Department of Agriculture (USDA). The layers classified across the state varied based on layer, however the classifications identified were Tm, Go, and Su. These terms are classified by the USDA as: Tm stands for Tidal Marsh, Go stands for Gouldsboro silt loam, and Sm stands for Sulfihemists and Sulfaquents, frequently flooded. This is how the surface area of the marsh was separated out from non-marsh area.

Figure 4.8 The marsh map generated in ArcGIS with the surface areas per coastal compartment generated for this paper. Pink are Kulesza sites.

A possible error associated with the GIS model of calculation, would be polygon overlap. However, virtually examining all layers imported visually by hand, overlap did not appear to be an issue. Using the map and definitions from Kelley et al. (1988), boundaries were delineated. When comparing the map generated for this study, against the map from Jacobson et al. (1987) with compartment salt marsh surface area values there were two noticeable differences. Jacobson et al. (1987) define the Arcuate Embayment below Portland, excluding the large Scarborough Marsh area. There is also a cut off of the very edge of Maine, and the salt marshes that run along the river, however, are still within the state of Maine. This could account for the large discrepancy of surface areas between the two data sets. Scarborough Marsh is close to 20 km² alone.

Another source of error could be the soil types included in these USDA layers. For example if they are including fresh water marshes in addition to salt water marshes, this will yield higher surface area results than just the salt marshes.

For the Cluffed Shoreline coastal compartment the map also seems to be cut off even before the Canadian border. However, the Jacobson et al. (1987) compartment boarder seems to extend into the Island-Bay complex passed the defined boundary, the boundary is closer to Jonesport where it should be delineated in Machias Bay as stated by Kelley et al. (1988). This would explain the overestimated surface area reported.

There is also an associated error in the soil delineations from the USDA. All sites have the individual marsh surface area mapped using this ArcGIS method (Figure 4.9). The Jasper Beach Marsh the most northern site is the smallest surface area site, this entire marsh does not show up on the USDA mapped area, however the beach they mapped as marsh (Figure 4.10). Thus this error needs to be taken into account for the calculation.

Figure 4.9 Shows sites Scarborough Marsh, South Thomason Marsh and Franklin Marsh surface area mapped using ArcGIS.

Figure 4.10 Shows sites Millbridge Marsh, Harrington Marsh, Addison Marsh and Jasper Beach Marsh surface area mapped using ArcGIS. Jasper beach error in surface area visible.

4.6 Carbon Stocks

All 58 cores collected for this study and from other researchers are included in carbon stock calculations. The all data carbon density values were used per compartment. Spatially each compartment has at least two researcher's data per compartment; except for Cluffed Shoreline which is only has data from Woods (Figure 4.10).

Figure 4.10 The marsh map generated in ArcGIS, and the spatial distribution of data along the coast. All 58 sites included on this map from this study.

Using the coastal compartment surface area values calculated from this carbon stocks per compartment and for the entire state can be calculated (Table 4.2). The entire carbon stock in Maine, reported in mega tons of carbon are $4.33 \times 10^6 \pm 0.15 \times 10^6 \text{ Mt C}$. This value can then be compared to the carbon stock calculated using the Jacobson et al (1987) surface areas. The carbon stock for this surface area is $3.04 \times 10^6 \pm 0.10 \times 10^6 \text{ Mt C}$.

4.7 Significance

This study shows that there are spatial differences of carbon storage, within ecosystems. There are peat carbon storage differences, surface of the individual marsh carbon storage capacity differences and there are state wide coastal compartment differences in carbon storage. All these factors need to be considered when sampling salt marshes. A recommended methodology would be to sample along a transect of the marsh. This study also generated values for an entire state wide carbon stock for the upper 1m. This study is important because it shows that deeper cores can be taken for a more complete picture of salt marsh carbon storage in Maine.

All these factors are important when attempting to accurately quantify carbon storage in any region. This study also provides a framework for deeper cores to be taken and more carbon to be accounted for. Most studies need to account for more than just the upper 10 cm or 50 cm, going to 1 m or even deeper is the best way to capture the full carbon storage capacity.

4.8 Suggestions for Further Study

Using the current surface areas, and the known degradation and salt marsh annual rate loss to project potential carbon storage values, and then if destruction of these ecosystems continue how much carbon will be emitted and not sequestered. Carbon projections, if we restored v. if we destroyed land.

This could occur through restoring culverted marshes. Restoring tidal flow to areas of the landscape that was restricted previously would restore the capacity to store carbon. Additionally this could be used as a methodology to prevent roads or buildings to be built on or restrict natural marsh ecosystem services. Being able to quantify how much carbon would be released in this square footage or average, then extending that to prevention of storage over a certain time frame.

Additionally, providing this data to towns and policy makers. This data could be used to progress protection and restoration of Maine salt marshes. Restoration would provide an even larger surface area for carbon storage. Could be a way to provide a city with a carbon sink source, or way to show city wide progression in climate mitigation efforts by protecting these ecosystems.

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Appendix A:

Stratigraphy

Jasper Beach Core #1

Stratigraphy	Unit Description	Munsell Color Description
0 (cm)	<ul style="list-style-type: none"> -Dark brown peat -Visible sand grains -Long hairlike roots -Not a dense root system -Angular pebble at 6cm depth 	4/1 5YR Dark Grey
25	<ul style="list-style-type: none"> -Dark brown peat layer -Hairlike roots -No grains, silty clay matrix 	3/1 7.5 YR Very Dark Grey
32.5	<ul style="list-style-type: none"> -Grey silty peat matrix -Hairlike roots, no grains 	4/1 10YR Dark Grey
36	<ul style="list-style-type: none"> -Dark brown peat -Hairlike roots -Roots are dense and compact 	3/1 10YR Very Dark Grey
59	<ul style="list-style-type: none"> -Sandy peat -Hairlike roots dense and compact 	
61	<ul style="list-style-type: none"> -Peat layer from above (0-25cm) continued 	4/1 5YR Dark Grey
72	<ul style="list-style-type: none"> -Fades into dark brown/black peat -Compact hairlike roots, but not dense -Sand grains visibly mixed in 	2/1 10YR Black
101		

Appendix A.1 Detailed full stratigraphy of Jasper Beach #1, stratigraphy includes unit descriptions and Munsell color descriptions.

Jasper Beach Core #2

Stratigraphy	Unit Description	Munsell Color Description
0 (cm)	-Dark peat -Hairlike dense roots	2.5/2 7.5 YR Very Dark Brown
3	-Light brown reddish peat -Hairlike roots -Root system thins towards base	4/2 7.5 YR Brown
12	-Faded into a darker brown peat -No clear boundry -Same density and type of roots	3/1 7.5 YR Very Dark Grey
23	-Dark brown peat -Silty clay matrix -Black small rounded rocks scatterd at base of unit	2.5/2 5 YR Dark Reddish Brown
62		

Appendix A.2 Detailed full stratigraphy of Jasper Beach #2, stratigraphy includes unit descriptions and Munsell color descriptions.

Addison Core

Appendix A.3 Detailed full stratigraphy of Addison, stratigraphy includes unit descriptions and Munsell color descriptions.

Harrington 1

Stratigraphy	Unit Description	Munsell Color Description
0 (cm)	<ul style="list-style-type: none"> -Thin straw like roots, light yellow -Brown peat, no grains -Very dense roots, live roots at top -Fading boundry at base 	3/2 7.5YR Dark Brown
20	<ul style="list-style-type: none"> -Thin straw like roots from above unit, more hair like roots introduced -Grey color, silty peat no grains 	3/2 10YR Very Dark Greyish Brown
38	<ul style="list-style-type: none"> -Clear boundry bwtween units -Light brown, no grains larger silt grains -Less hair like roots, only type of roots 	3/2 7.5YR Dark Brown
49	<ul style="list-style-type: none"> -Clear boundry -Dark borwn, silty, no grains -Thin waspy hair like roots not dense 	2.5/2 7.5YR Very Dark Brown
67	<ul style="list-style-type: none"> -Fading boundry -Lighter brown unit than above -Yellow hair like roots -Silty peat, no grains 	3/2 7.5YR Dark Brown
84	<ul style="list-style-type: none"> -Dark dark brown, almost black -Less hair like root percentage -Silty peat, no grains 	2/1 10YR Black
100		

Appendix A.4 Detailed full stratigraphy of Harrington #1, stratigraphy includes unit descriptions and Munsell color descriptions.

Harrington 2

Stratigraphy	Unit Description	Munsell Color Description
0 cm	<ul style="list-style-type: none"> -Thin roots at top, fades into straw like roots at base -Light brown peat -Silty, no grains 	3/2 7.5 YR Dark Brown
23	<ul style="list-style-type: none"> -Dense roots at top -Roots thin out towards base of unit -Silty grey peat, no grains 	3/2 7.5 YR Dark Brown
48	<ul style="list-style-type: none"> -Slightly darker redox condition bands -Bands look close to black -Bands at 48cm and 56cm depth 	
58		
64	<ul style="list-style-type: none"> -More clay unit -Gets more silty towards base of unit -Same color through unit 	4/1 10YR Dark Grey
84 cm		

Appendix A. 5 Detailed full stratigraphy of Harrington #2, stratigraphy includes unit descriptions and Munsell color descriptions.

Millbridge 3

Stratigraphy	Unit Description	Munsell Color Description
0 (cm)	-Thicker hollow roots, very dense root system, strawlike	3/1 7.5 YR Very Dark Grey
15	-Silty peat, no grains. Lighter brown with fading boundry	3/2 7.5 YR Very Dark Greyish brown
42	-Light brown/grey peat -Dense hollow strawlike roots at top -Fades into thin waspy roots at base of unit	
48	-Clear boundry -Thin waspy roots -Brown silty peat, no grains	3/2 2.5 Y Very Dark Greyish Brown
77	-Less root percentage and density -Thin waspy roots only -Very fine, silty with no grains	3/1 2.5 Y Very Dark Grey
83	-Different coloration due to redox	
100	-Different coloration due to redox	

Appendix A.6 Detailed full stratigraphy of Millbridge #3, stratigraphy includes unit descriptions and Munsell color descriptions.

Millbridge 4

Stratigraphy	Unit Description	Munsell Color Description
0 (cm)		
7	<ul style="list-style-type: none"> -Dense roots, thick yellow strawlike -Brown peat, very saturated -No grains, smooth silty with smaller wispy roots at base 	3/2 7.5YR Dark Brown
26	<ul style="list-style-type: none"> -More grey peat, with no clear boundry -Less dense roots, low percentage -Thin hairlike waspy yellow roots -Very silty, no grains 	4/1 10YR Dark Grey
45	<ul style="list-style-type: none"> -Less dense roots than above unit -Dark grey peat -Clay texture, very sicky -No grains 	3/1 10YR Very Dark Brown
90	<ul style="list-style-type: none"> -Clear boundry with above unit -Dark brown peat, crumbly -Low percentage of thin waspy roots, scattered -No grains -Not clay like, larger sed size 	2.5/1 5YR Black
98	<ul style="list-style-type: none"> -Fades into this unit -Dark brown, darkest of all units -No grains -Scattered very low percentage of waspy roots 	2/1 10YR Black

Appendix A.7 Detailed full stratigraphy of Millbridge #4, stratigraphy includes unit descriptions and Munsell color descriptions.

Franklin 1

Stratigraphy	Unit Description	Munsell Color Description
0 (cm)	0-9cm -Very dense roots -Strawlike, yellow roots -Dark red brown peat, no grains	3/3 5YR Dark Reddish Brown
9	9-13cm -Darker brown than above -Thin hair like roots, no grains	2.5/1 10YR Black
13	13-20cm-Grey color -Thin hair like roots dominate with some scattered straw like roots -Silty, no grains	4/1 10YR Dark Grey
20	20-30cm -Dark brown, fades into light grey -Less root percentage, hairlike thin roots only	2.5/1 5YR Black
30		
	-Lighter red brown with dark brown bands, silty peat -Less root percentage -Hair like waspy roots only -Silty, no grains -Dominate brown peat	2.5/2 7.5YR Very Dark Brown
59		
	-Black, almost no roots, a few hairlike roots only -Silty, no grains	2.5/1 7.5YR Black
66		
	-Dense grey clay -No roots -Dried out -Blue tint	4/1 2.5YR Dark Grey
84		

Appendix A.8 Detailed full stratigraphy of Franklin #1, stratigraphy includes unit descriptions and Munsell color descriptions.

Franklin 2

Stratigraphy	Unit Description	Munsell Color Description
0 (cm)	<ul style="list-style-type: none"> -Thin hairlike roots, some strawlike at the top -No clear boundry, brown peat -No grains -Large root at 17cm depth -Dark brown, same roots as above -No grains, not silty but fine -Same color as above unit -Dark brown -Less root percentage, no grains 	3/3 7.5YR Dark Brown
24		2.5/1 7.5YR Black
29		3/3 7.5YR Dark Brown
36		4/1 10YR DarkGrey
42	<ul style="list-style-type: none"> -Clear dark borders around this unit -Light band -Very silty clay, no roots -This unit returns to peat -Has a lot of bands that switch between darker black and reddish brown widths ~3cm -Reddish brown dominate -Hairlike roots, no grains -Black unit, darkest of whole core -Low percentage of roots -Only hairlike roots, no grains -Marine clay, more blue than clay above. No grains, no roots 	3/2 10YR Very Dark Grey Brown
83		2/1 10YR Black
89		4/1 2.5YR Dark Grey
91		

Appendix A.9 Detailed full stratigraphy of Franklin #2, stratigraphy includes unit descriptions and Munsell color descriptions.

S. Thomason 1

0 (cm)	Stratigraphy	Unit Description	Munsell Color Description
	<ul style="list-style-type: none"> -Thick straw roots at top -Dark brown peat -Hairlike roots through out -No grain, not silty, mostly roots 	3/1 7.5YR Very Dark Grey
16		<ul style="list-style-type: none"> -Hairlike roots 	2/2.5 7.5YR
20		<ul style="list-style-type: none"> -Grey, no grains less root percent 	Very Dark brown
	<ul style="list-style-type: none"> -Dark brown -Thin hair like roots -Less root percentage 	2.5/1 7.5YR Black
30		<ul style="list-style-type: none"> -Dark brown -Hair like roots, less percentage -Slight redox in middle 	2.5/2 7.5YR Very Dark Brown
38		<ul style="list-style-type: none"> -Clear boundry with above unit -Black, no grains, silty -Less percent hair like roots 	2.5/1 7.5YR Black
48		<ul style="list-style-type: none"> -Grey, silty no grains -Hair like roots -Low percentage of roots 	3/2 10YR Very Dark Grey Brown
57		<ul style="list-style-type: none"> -Dark brown -Hairlike roots, low percentage -Thicker straw like roots scattered -Slightly different redox, more black at base 	3/1 10YR Very Dark Grey
111			

Appendix A.10 Detailed full stratigraphy of South Thomason#1, stratigraphy includes unit descriptions and Munsell color descriptions.

S. Thomason 2

Stratigraphy	Unit Description	Munsell Color Description
0 (cm)
<ul style="list-style-type: none"> -Thick straw like roots at top -Last 5cm of unit has thin hair like roots -Very dense roots -No grains 	<p>3/1 10YR Very Dark Grey</p>
21
<ul style="list-style-type: none"> -Fades to grey at base -Hair like roots, no straw like roots -No grains, thick peat 	<p>2/2 10YR Very Dark Brown</p>
31
<ul style="list-style-type: none"> -Very dark grey, with a blue tint -Very low root percentage -Few hairlike roots, silty clay -No grains -Slight redox shifts to grey in this unit 	<p>3/1 2.5YR Very Dark Grey</p>
50
<ul style="list-style-type: none"> -Low percentage of hairlike roots -Dark brown, some thicker brown roots -No grains, not silty but smooth -Slight bands of dark brown/red grey brown 	<p>3/2 2.5YR Very Dark Greyish Brown</p>
88
<ul style="list-style-type: none"> -Dark brown silty peat -Low percentage of hairlike roots -Very silty, no grains 	<p>3/1 10YR Very Dark Grey</p>
103		

Appendix A.11 Detailed full stratigraphy of South Thomason #2, stratigraphy includes unit descriptions and Munsell color descriptions.

Route 1 Core

Stratigraphy	Unit Description	Munsell Color Description
0 (cm)	0-7cm -Brown yellow hairlike long roots -Silty clay matrix, no sand	3/1 2.5 YR Dark Reddish Brown
7	7-16cm -Woody thick strawlike roots -Clay silty matrix -Roots not very dense	3/1 5 YR Very Dark Grey
16	16-27cm -Brown yellow hairlike long roots -Silty clay matrix -Lighter brown than unit 7-16cm	2.5/2 7.5 YR Very Dark Brown
27	-Brown yellow hairlike roots -Silty clay peat matrix -Band of black, change in redox at 47-45cm -Dark black brown peat -No sand grains	3/1 2.5 YR Dark Reddish Brown
57	-Clay silty matrix -Darker peat color than unit above -No sand grains visible -Roots?	2.5/1 5 YR Black
85	85-92cm -Sandy layer with visible grains -Mica flecks visible -Some hairlike roots scattered at a low percentage	
92	92-99cm -Darker black peat than 57-85 -Silty clay matrix -Minimal hairlike roots	2.5/1 5 YR Black
99	-Grain heavy sandy clay -Fining upwards, coarsest at base -Dark dense brown fibrous roots with a mix of shorter hairlike roots	2.5/2 5 YR Dark Reddish Brown
127		

Appendix A.12 Detailed full stratigraphy of Route 1 in Scarborough Marsh, stratigraphy includes unit descriptions and Munsell color descriptions.

Woodside Rd Core #1

Appendix A.13 Detailed full stratigraphy of Woodside Rd #1 in Scarborough Marsh, stratigraphy includes unit descriptions and Munsell color descriptions.

Woodside Rd. Core #2

Stratigraphy	Unit Description	Munsell Color Description
101cm	<ul style="list-style-type: none"> -Thin waspy yellow hairlike roots -Not compact root system -Silty clay matrix, no sand grains -Very dark grey peat 	3/1 7.5 YR Very Dark Brown
123	<ul style="list-style-type: none"> -Very dark grey peat, more brown than unit above -No visible roots -Clay silty matrix 	3/1 10 YR Very Dark Grey
163	<ul style="list-style-type: none"> -Very dark grey silty peat -Small mica flecks -No Roots -Very silty fine grained, sticky texture 	3/1 5 Y Black
180	<ul style="list-style-type: none"> -Dark brown clay peat -No grains felt -No roots 	3/2 7.5 YR Very Dark Brown
189	<ul style="list-style-type: none"> -Black clay compact peat -Some sand grains visible -Very dense unit 	2/1 10 YR Black
194	<ul style="list-style-type: none"> -Very dark brown silty peat -Dense compact -Sand grains visible -No roots 	2/2 10 YR Very Dark Brown
202		

Appendix A.14 Detailed full stratigraphy of Woodside Rd #2 in Scarborough Marsh, stratigraphy includes unit descriptions and Munsell color descriptions.

Orchard Hill Drive #1

Appendix A.15 Detailed full stratigraphy of Orchard Hill Dr #1 in Scarborough Marsh, stratigraphy includes unit descriptions and Munsell color descriptions.

Orchard Hill Drive #2

Stratigraphy	Unit Description	Munsell Color Description
107 cm	<ul style="list-style-type: none"> -Fine clay-silt matrix -No roots or rhizomes -Possible contamination from horizon below (135-174 cm) 	7.5 YR 2.5/1 Black
117	<ul style="list-style-type: none"> -Dense yellow strawlike roots mixed in w/ high concentraion of hairlike roots (1-4 cm) -Similar to horizon 80-107 cm -Clay-silt matrix 	7.5 YR 2.5/2 Very Dark Brown
135	<ul style="list-style-type: none"> -Fine clay-silt matrix -Little to no organics -If present, roots are hairlike -Fines down to a clay matrix from at 155 cm 	7.5 YR 2.5/1 Black
174		

Appendix A.16 Detailed full stratigraphy of Orchard Hill Dr #2 in Scarborough Marsh, stratigraphy includes unit descriptions and Munsell color descriptions.

Ferry Rd. Core #1

Stratigraphy	Unit Description	Munsell Color Description
0 (cm)	<ul style="list-style-type: none"> -Peat has some slight different oxidation bands in this unit -Yellow thin hairlike roots -Roots are dense in top 0-15cm then get less dense until end of unit -Very dark grey brown peat -Can see sandy clay matrix -Quarts and mica grains visible 	3/1 10 YR Very Dark Grey
36.5	<ul style="list-style-type: none"> -Very sandy layer -Has some thin roots at top of unit -Two dominate sand layer, but sand throughout unit -Dark brown peat between sand layers 	3/3 10 YR Dark Brown
42.5	<ul style="list-style-type: none"> -Thin hairlike dense roots -Some sand grains in clay matrix -Dark yellow brown peat 	3/4 10 YR Dark Yellowish Brown
49	<ul style="list-style-type: none"> -Thick strawlike roots -Compact dense roots -Clay matrix -Very dark greyish peat 	3/2 2.5 Y Very Dark Greyish Brown
79	<ul style="list-style-type: none"> -Top 10cm has sand grains visble -Thin hairlike roots -At the base is minimal to no sand -Silty clay matrix -Lower in unit the roots are more compact and dense 	2.5/10 Y Greenish Black
100		

Appendix A.17 Detailed full stratigraphy of Ferry Rd #1in Scarborough Marsh, stratigraphy includes unit descriptions and Munsell color descriptions.

Ferry Rd. Core #2

Appendix A.18 Detailed full stratigraphy of Ferry Rd #2 in Scarborough Marsh, stratigraphy includes unit descriptions and Munsell color descriptions.

Clam Shack Core #1

0 (cm)	Stratigraphy	Unit Description	Munsell Color Description
	<ul style="list-style-type: none"> -Thin yellow long hairlike roots -Silty clay peat matrix -No sand visible -Dark brown grey peat 	3/1 5 YR Very Dark Grey
10		<ul style="list-style-type: none"> -Top 10-18cm yellow brown strawlike woody long roots -Dense percentage of root coverage -Silty clay matrix, some small sand grains -Darker than 0-10cm unit 	3/1 7.5 YR Very Dark Grey
31		<ul style="list-style-type: none"> -Small >1cm lense of sand 	
33		<ul style="list-style-type: none"> -Small >1cm lense of sand
	<ul style="list-style-type: none"> -Thin long brown red hairlike roots -Clay silty peat clay matrix -Peat fades darker with greater depth 	2/1 10 YR Black
59		<ul style="list-style-type: none"> -Reddish brown long hairlike roots -Higher percentage of roots at depth 59-75cm -Clay dark brown peat matrix 	2/2 10 YR Very Dark Brown
100			

Appendix A.19 Detailed full stratigraphy of Clam Shack #1in Scarborough Marsh, stratigraphy includes unit descriptions and Munsell color descriptions.

Clam Shack Core #2

Stratigraphy	Unit Description	Munsell Color Description
100 cm	-Thin yellow reddish long hairlike roots -No sand grains visible -Clay peat matrix	2.5/1 5 YR Black
110	-Low percentage of roots -Yellow reddish long hairlike roots -Clay sand matrix	2/2 10 YR Very Dark Brown
142	-Thin lense of sand (matches core #1 58-100cm) -Sandy clay dark brown peat -Mica flecks visible -Minimal to no roots	3/2 7.5 YR Very Dark Brown
149	-Thin sandy layer -Visible mica flakes	3/2 7.5 YR Very Dark Brown
163	-Very low percentage of roots -No roots present at base of unit -Sandy clay dark brown peat	
172	-Thin sandy layer -Visible mica flecks -High percentage of roots at top of unit -Brown wisp long hairlike roots -Dark brown black peat -Clay peat matrix	2/1 10YR Black
200		

Appendix A.20 Detailed full stratigraphy of Clam Shack #2 in Scarborough Marsh, stratigraphy includes unit descriptions and Munsell color descriptions.

Clam Shack Core #3

Appendix A.21 Detailed full stratigraphy of Clam Shack #3 in Scarborough Marsh, stratigraphy includes unit descriptions and Munsell color descriptions.

Appendix B:

Geochemistry

Appendix B.1 Jasper Beach Core #1 data plotted depth down core on the y axis with Carbon %, Bulk Density g/cm^3 and then Carbon Density gC/cm^3 .

Appendix B.2 Jasper Beach Core #2 data plotted depth down core on the y axis with Carbon %, Bulk Density g/cm^3 and then Carbon Density gC/cm^3 .

Figure B.3 Addison core data plotted depth down core on the y axis with Carbon %, Bulk Density g/cm³ and then Carbon Density gC/cm³.

Harrington #1: Harrington Marsh, Harrington, ME

Appendix B.4 Harrington Core #1 data plotted depth down core on the y axis with Carbon %, Bulk Density g/cm³ and then Carbon Density gC/cm³.

Harrington #2: Harrington Marsh, Harrington, ME

Appendix B.5 Harrington Core #2 data plotted depth down core on the y axis with Carbon %, Bulk Density g/cm³ and then Carbon Density gC/cm³.

Appendix B. 6 Millbridge Core #3 data plotted depth down core on the y axis with Carbon %, Bulk Density g/cm³ and then Carbon Density gC/cm³.

Millbridge #4 : Millbridge Marsh, Millbridge, ME

Appendix B.7 Millbridge Core #4 data plotted depth down core on the y axis with Carbon %, Bulk Density g/cm³ and then Carbon Density gC/cm³.

Franklin #1, Franklin Marsh, Franklin, ME

Appendix B.8 Franklin Core #1 data plotted depth down core on the y axis with Carbon %, Bulk Density g/cm³ and then Carbon Density gC/cm³.

Franklin #2, Franklin Marsh, Franklin, ME

Appendix B.9 Franklin Core #2 data plotted depth down core on the y axis with Carbon %, Bulk Density g/cm³ and then Carbon Density gC/cm³.

Appendix B. 10 South Thomason Core #1 data plotted depth down core on the y axis with Carbon %, Bulk Density g/cm³ and then Carbon Density gC/cm³.

South Thomaston #2: South Thomaston, ME

Appendix B. 11 South Thomaston Core #2 data plotted depth down core on the y axis with Carbon %, Bulk Density g/cm³ and then Carbon Density gC/cm³.

Appendix B. 12 Route 1 core in Scarborough Marsh data plotted depth down core on the y axis with Carbon %, Bulk Density g/cm³ and then Carbon Density gC/cm³.

Woodside Road Core; Scarborough Marsh; Scarborough, Maine

Appendix B. 13 Woodside Rd. Core, in Scarborough Marsh data plotted depth down core on the y axis with Carbon %, Bulk Density g/cm³ and then Carbon Density gC/cm³.

Orchard Hill Core; Scarborough Marsh; Scarborough, Maine

Appendix B. 14 Orchard Hill core, in Scarborough Marsh data plotted depth down core on the y axis with Carbon %, Bulk Density g/cm³ and then Carbon Density gC/cm³.

Appendix B. 15 Ferry Rd core, in Scarborough Marsh data plotted depth down core on the y axis with Carbon %, Bulk Density g/cm³ and then Carbon Density gC/cm³.

Clam Shack Core; Scarborough Marsh; Scarborough, Maine

Appendix B. 16 Clam Shack core, in Scarborough Marsh data plotted depth down core on the y axis with Carbon %, Bulk Density g/cm³ and then Carbon Density gC/cm³.