Two Thousand Years of Salt Marsh Development, Carbon Stock, and Carbon Accumulation Rates in the Delaware Bay Tidal Salt Marshes

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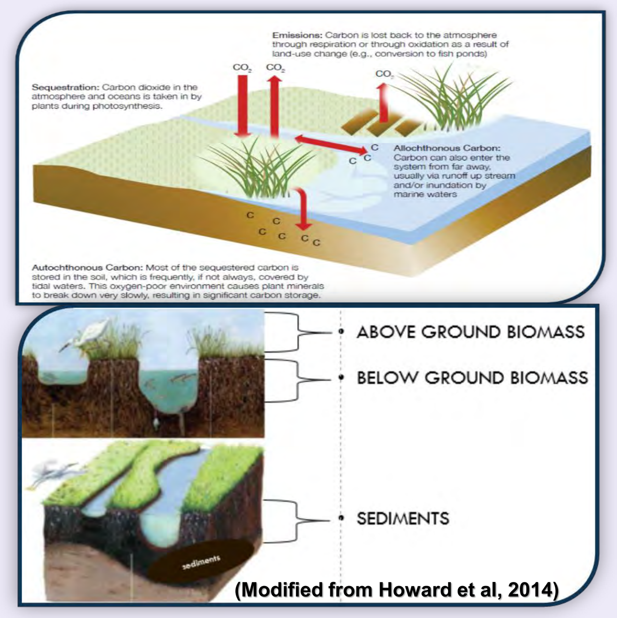
ABSTRACT

The Delaware Bay is the 2nd largest estuary in North America and has a tidal marsh area of ~ 830 km^2 (Reed et al. 2008; Titus et al. 2008). Salt marshes are reservoirs for blue carbon sequestration and storage, and when left undisturbed, can store carbon in the below ground sediments for thousands of years. When these systems are degraded – through erosion or land use changes - they become a potential source of carbon emissions. Delaware Bay salt marshes are being lost at a rate of an acre a day with an estimated net loss of 25% by 2100 (PDE, 2012).

Assessment of salt-marsh carbon pools and salt-marsh carbon accumulation rate (CAR) is usually focused on sediments from the surface to depths < 1 meter. The sediments accumulated at depths < 1 meter usually represent only ~ 100 years of salt marsh accumulation (Nikitina et al. 2014). There are no studies that estimate sediment carbon stock (SCS) and CAR at depth. Our study estimated SCS through the entire sediment sequence as well as short and long-term CAR. Our results show the variation in SCS to be positively related to depth and varying with depositional environment, whereas CAR is negatively related to depth of salt-marsh sediment. The carbon stock assessments that focus only on the top 1 meter of sediment sequence underestimate the total carbon stock by more than three-fold.

BACKGROUND



(Modified from Howard et al, 2014)

Blue carbon is defined as the carbon stored in marine and coastal ecosystems such as salt marshes, mangroves, and seagrasses. These ecosystems sequester carbon faster, and store it longer, than their terrestrial counterparts. Carbon is sequestered through the process of photosynthesis. Excess carbon becomes stored in the below ground sediments where decomposition rates are low due to the anoxic environment. Runoff and incoming tides bring an additional supply of sediment.

Three salt marsh carbon pools are recognized: above ground biomass, below ground biomass, and the sediments.

95%-99% of blue carbon resides in the depths of the organic-rich sediment beneath the salt-marsh system (Murray et al. 2011).

Our study attempted to estimate the carbon stock through the entire sequence of carbon sediment.

STUDY AREA

Two salt marshes were used in the study: Fortescue (150,000 m^2) and Sea Breeze (500,000 m^2). The sites are 9 km apart and located in New Jersey along the northeastern shore of the Delaware Bay. The salt marshes in this region have been developing under sea-level rise (SLR) for the last ~2,000 years (Nikitina et al. 2014).

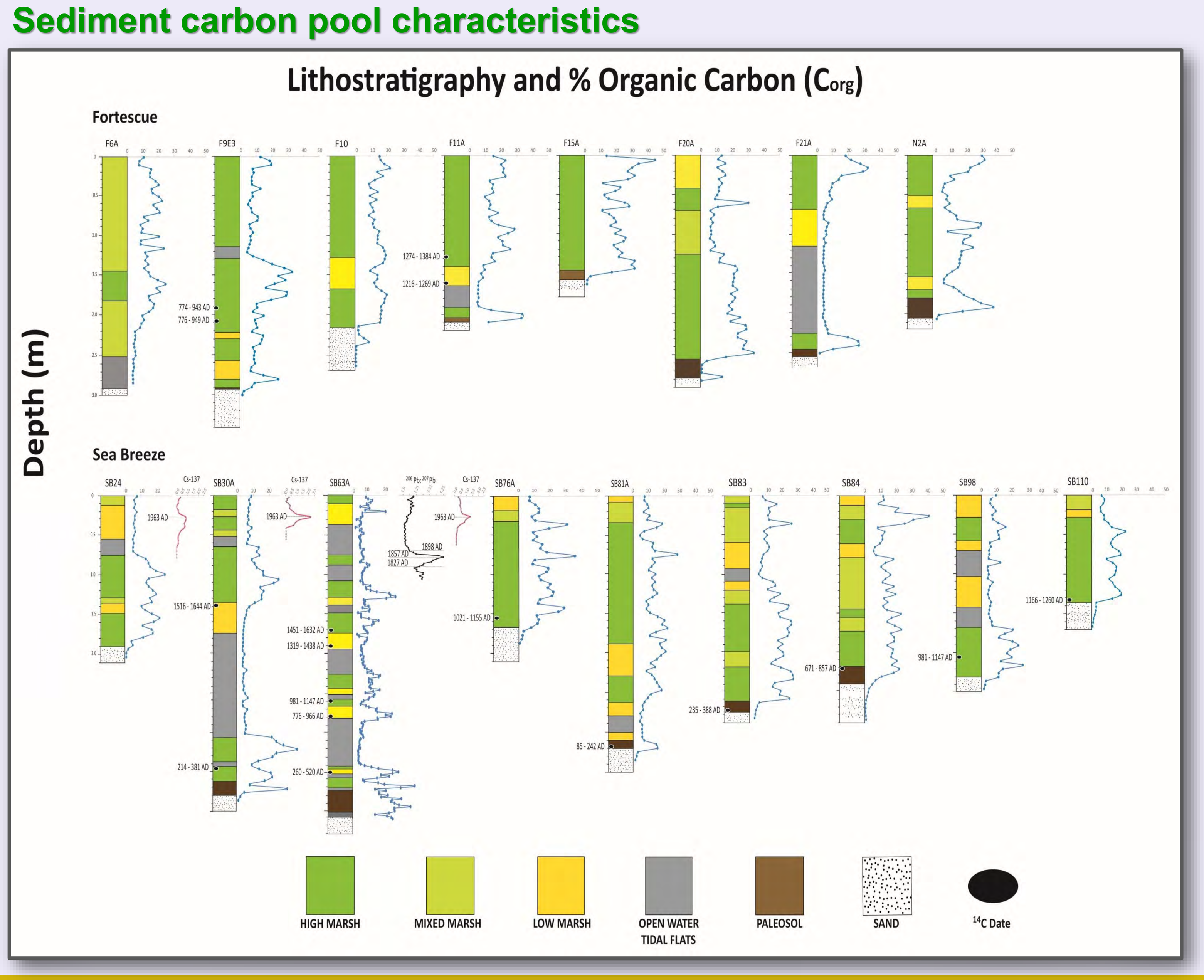
Both marshes share a similar tidal range of ~1.7 m (NOAA, 2016) and vegetation types. The type and distribution of salt marsh vegetation is a function of elevation within the tidal range and the duration of tidal inundation. Four depositional environments are recognized based on plant tolerance to salt inundation: tidal flats characterized by gray muds, low marsh vegetated by *Spartina alterniflora*, mixed marsh vegetated by stunted *Spartina alterniflora* and *Spartina patens, and* high marsh vegetated by *Spartina patens and Distichlis spicata*. Both marshes are dissected by tidal creeks and underlain by 1.4 to 4.0 m of tidal wetland sediments

METHODS

- 17 Sediment cores were recovered for sampling using a 5 cm wide and 0.5 m long Russian-type peat corer with 1 meter extensions. Core volume (V_{core}) =π(2.5 cm)²*50 cm = 981.7477 cm^3
- Depositional environments of salt-marsh sediments were established by comparing plant macro-fossils found in the core with roots, rhizomes, and plants stems in the modern environment.
- Cores sampled in 1 cm samples (V_{sample} =9.8175cm^3) at 5 cm increments, weighed (m_{wet}), oven dried at 121°C and reweighed (m_{dry121}), ignited in a muffle furnace at 550°C and reweighed (m_{dry550})
- Dry bulk density (DBD) (g/cm^3) and loss-on-ignition (LOI) (%) were measured for each sample.
- DBD = m_{dry121} - m_{dry550} /volume of sample (cm^3)
- % Organic Carbon (C_{org}) was calculated using the following equation: $\%C_{org} = 0.04 \times (LOI) + 0.0025 \times (LOI)^2$ (Craft et al. 1991).
- Sediment Carbon density (SCD) (gC/cm^3) = DBD x (%C_{org}/100)
- SCS (MgC/m^2) = Sum [Average SCD_{sample} x 5 cm] / 100; to a specified depth
- AMS radiocarbon dating of macrofossils, ^{137}Cs and ^{206}Pb:^{207}Pb concentrations used to establish sediment accumulation rates (SAR) as well as long and short term CAR (Nikitina et al. 2014).

RESULTS

Sediment carbon pool characteristics



- 6 lithologic units are recognized representing 4 different depositional salt-marsh environments, and 2 pre-salt marsh environments:

  - Peat/high marsh
  - Peat and organic-rich mud /mixed marsh
  - Organic-rich mud/low marsh
  - Mud/open water/tidal flats
  - Paleosol
  - Pre-Holocene sand

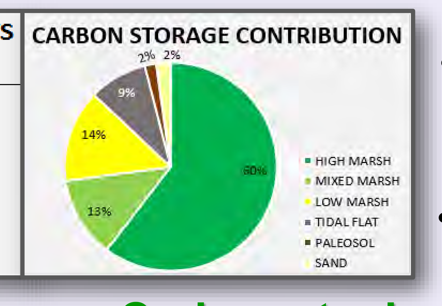
- The average thickness of the sediments in Fortescue is 2.4 m.
- The average thickness of sediments in Sea Breeze is 2.75 m.
- %C_{org} varies through the sediment sequence ranging from 0.6 % to 44.6 %.

Depositional Environments

CARBON COMPONENT IN DEPOSITIONAL ENVIRONMENTS

Depositional Environment	Mean %C_{org} Fortescue	Sea Breeze	Combined
High Marsh	17.3	15.3	16.3
Mixed Marsh	12.4	11.8	12.0
Low Marsh	10.0	8.1	8.9
Open Water/Tidal Flat	4.6	6.3	5.8
Paleosol	14.0	10.1	11.9
Sand	2.0	2.3	2.3

CARBON STORAGE CONTRIBUTION



- % C_{org} vary with sediment type ranging from 4.6 % C_{org} in the tidal flat sediments to 17.3 %C_{org} in the high-marsh sediments.
- High marsh sediments were found to contribute 60% of the total carbon storage.

Carbon stock

STUDY AREA MEAN SEDIMENT CARBON STOCK AND CARBON STORAGE

SITE	STUDY AREA (m^2)	MEAN DEPTH (m)	CARBON STOCK in 1 m depth (MgC/m^2)	CARBON STOCK in mean depth (MgC/m^2)	CARBON STORAGE In study area (MgC)
Fortescue	150,000	2.4	0.038	0.096	14,360
Sea Breeze	500,000	2.75	0.036	0.104	52,234
Combined	650,000	2.58	0.037	0.102	66,093

COMPARISON OF MEAN SEDIMENT CARBON STOCK IN TOP 1 METER (Mgc/m^2)

FLORIDA	N. CAROLINA	N.E. CANADA	NEW ENGLAND	GULF OF MEXICO	DELAWARE BAY (this study)
0.0278	0.0316	0.0345	0.0366	0.0518	0.0367

COMPARISON OF MEAN SEDIMENT CARBON STOCK TO 3 METER DEPTH (Mgc/m^2)

N. AMERICA	DELAWARE BAY (this study)
No Data	0.1146

- Mean (SCS) (to 1 m depth)
  - Fortescue is 0.038 MgC/m^2.
  - Sea Breeze is 0.036 MgC/m^2.
- SCS increases with depth from a mean of 0.037 MgC/m^2 in top 1 m to 0.102 MgC/m^2 in top 2.6 m.
- The total organic carbon storage:
  Fortescue study area is ~14,360 MgC.
  Sea Breeze study area is ~ 52,234 MgC.
- Carbon stock in the top 1 m is comparable to recent NE regional studies.
- Carbon stock varies along the US Atlantic and Gulf of Mexico coasts.
- No studies account for carbon stock through the entire sediment sequence.

Carbon accumulation rates

COMPARISON OF MEAN SHORT-TERM CAR RATE (~ TOP 1 METER) (gC/m2/yr)

NW FLORIDA	ASSAWOMAN BAY	NW ATLANTIC	DELAWARE BAY (Tucker, 2015 unpublished)	DELAWARE BAY (this study)
130	154	134	172.4	191.78

COMPARISON OF MEAN LONG-TERM CAR (1-3 METERS) (gC/m2/yr)

N. AMERICA	DELAWARE BAY (this study)	DELAWARE BAY (Tucker, 2015 unpublished)
No Data	71.15	72.8

- Short-term CAR shows regional variation.
- Our results are comparable with Tucker 2015 study in the Delaware Bay.

DISCUSSION

- Traditionally, carbon stocks are assessed to a depth of 1 meter.
- We have calculated carbon stock through the entire sediment sequence.
- We have documented variation in sediment, % organic carbon, and carbon accumulation rates through time due to changes in depositional environments. Estimates of carbon accumulation ranged from 0.0367 MgC/m^2 at a depth of 1 meter, to 0.1146 MgC/m^2 at a depth of 3 meters.
- The results show that the Delaware Bay salt marshes sequester significant amounts of carbon and suggest that carbon stock assessments that focus only on the top 1 meter of sediment sequence underestimate the total carbon stock by more than three-fold.
- We therefore propose that in order to increase the accuracy of carbon stock assessments, future studies should account for the entire salt-marsh sediment sequence.

CONCLUSION

- The study area is 650,000 m^2 and has stored ~ 66,093 MgC
- SCS varies through the sediment sequence with depositional environment.
- SCS increases with depth; CAR decreases with depth.
- % C_{org} varies with depositional environments.
- Accurate estimates of carbon stock need to take into account the entire history of salt-marsh development.
- When salt marshes erode due to SLR and storms or are degraded through land use changes, carbon emissions could be greater than predicted if the carbon stored at depth has not been taken into account.

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