Coastal Wetlands and Blue Carbon: Processes & Risks

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Relative sea level over the last 2100 years, reconstructed by [Kemp et al. (2011)](#) using analysis of microfossils in sediment from salt marshes in North Carolina.

Sea-Level Rise is Accelerating from A.C. Redfield (1972)

Slow rate of SLR for millennia led to progradation of coastal wetlands and massive accumulation of peat.

**North Carolina Sea Level**

- **Sea-Level Rise is Accelerating**
  - 1 and 2σ error bands

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**Figure 8.** Theoretical structure of salt marsh which is spreading over accumulating sediment on a sand flat and over the upland in the course of rising sea level. After Redfield and Rubin (1962).

From A.C. Redfield (1972)
Millennia of progradation of coastal wetlands has led to a massive accumulation of peat.
The plants are very most important

Turnover of roots and rhizomes adds carbon to the soil. About 10% of this material is lignin, and this is the fraction that is preserved.

Questions remain about its stability, the influence of rising temperature, and exposure to oxidizing compounds (O2 and NO3).
The Marsh Equilibrium Model (MEM)

Diagram A:
- Vascular Plant Primary Production or Standing Biomass
- $B_{max}$
- MSL
- Optimum
- MHHW
- $T_{amp}$

Diagram B:
- Vertical Accretion Rate
- Accretion by Organic Production
- Accretion by Mineral Deposition
- MHHW
Within their growth zone, they do not grow equally well.
Spartina stems trap sediment. The amount of sediment trapped is proportional to the biomass density.
AND they generate biovolume

1) \[ B_s = aD + bD^2 + c : \text{seasonal maximum standing biomass} \left( \frac{g}{m^2} \right) \]

2) \[ S_{\text{max}} = m \times 704 \times 0.5 \times (MHW - Z) : \text{sediment load} \left( g \text{ cm}^{-2} \text{ yr}^{-1} \right) \]

3) \[
\frac{dz}{dt} = \left[ \frac{S_{\text{max}}q\omega}{k_2} + \frac{k_r \varphi \tau B_s}{k_1} \right] = \\
\left[ \frac{qm \times 704 \times 0.5D^2}{k_2 (MHW - MLW)} + \frac{k_r \varphi \tau (aD + bD^2 + c)}{k_1} \right] : \text{vertical accretion rate} \left( \frac{cm}{yr} \right)
\]

4) \[ \text{LOI} = k_r \varphi \tau B_s / [k_r \varphi \tau B_s + S_{\text{max}}q\omega] : \text{soil organic matter concentration or LOI (g/g)} \]

Strategy: with known \( k_1, k_2, \varphi, \tau, q, \) and \( k_r \) (self-packing densities, RS ratio, turnover rate, trapping coefficient, and refractory fraction, substitute permutations of sediment concentration \( m \), maximum biomass, tidal amplitude \( \text{MHW} \), and solve for equilibrium depth \( D \) for different rates of sea-level rise \( \text{SLR} \), i.e. find \( D \) such that \( \frac{dZ}{dt} = \text{SLR} \).
Fertilized

High Marsh Controls

1.1 mm/yr

High Marsh Fertilized

4.7 mm/yr

Non-equilibrium response (temporary increase/decrease in root volume)

+ 1.1 cm  
- 2.1 cm

kr = 4.6%  q= 0.92
Correlation coefficients at different SLR. Note the insignificance of sediment except at extreme high SLR. Note the importance of productivity (B_{max}). Note the importance of tidal amplitude (elevation capital) at extreme SLR.

<table>
<thead>
<tr>
<th></th>
<th>SLR = 2 mm/yr</th>
<th></th>
<th>SLR = 10 mm/yr</th>
<th></th>
<th>SLR = 20 mm/yr</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>LOI</td>
<td>Carbon Sequestration Rate</td>
<td>LOI</td>
<td>Carbon Sequestration Rate</td>
<td>LOI</td>
<td>Carbon Sequestration Rate</td>
</tr>
<tr>
<td>Tidal Amplitude (T_{amp})</td>
<td>-0.08</td>
<td>-0.23</td>
<td>-0.07</td>
<td>0.32</td>
<td>0.49</td>
<td>0.55</td>
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<tr>
<td>Suspended Inorg. Sed. Conc. (SSC)</td>
<td>ns</td>
<td>ns</td>
<td>-0.05</td>
<td>0.15</td>
<td>0.40</td>
<td>0.45</td>
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<tr>
<td>Maximum Biomass (B_{max})</td>
<td>0.09</td>
<td>0.27</td>
<td>0.78</td>
<td>0.75</td>
<td>0.42</td>
<td>0.37</td>
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<tr>
<td>Means +/- 1SD</td>
<td>87.9±1.8</td>
<td>71.1±0.1</td>
<td>22.4±32.1</td>
<td>189.1±135.7</td>
<td>0.7±1.1</td>
<td>88.4±115.8</td>
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<tr>
<td></td>
<td>n=41943</td>
<td></td>
<td>n=36907</td>
<td></td>
<td>n=30545</td>
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</tbody>
</table>

From “Physical and biological regulation of carbon sequestration in tidal marshes”
James T Morris\textsuperscript{1} and John C. Callaway\textsuperscript{2}
Per unit weight biomass contributes 23x more volume than sediment. Organic matter accretion dominates vertical accretion.

Figure 5. Mean carbon sequestration rate as a function of the relative rate of sea-level rise and maximum biomass ($B_{\text{max}}$). Only feasible (non-zero equilibrium biomass) solutions were included.

C-sequestration increases with RSLR to an asymptotic level that is set by the level of productivity ($B_{\text{max}}$).

From “Physical and biological regulation of carbon sequestration in tidal marshes” James T Morris¹ and John C. Callaway²
The probability of survival declines dramatically as SLR rises. Only a very limited universe of marshes survives.

From “Physical and biological regulation of carbon sequestration in tidal marshes”
James T Morris¹ and John C. Callaway²
Relative sea level over the last 2100 years, reconstructed by Kemp et al. (2011) using analysis of microfossils in sediment from salt marshes in North Carolina.

Sea-Level Rise is Accelerating

Hypsometric Projections Based on Current LiDAR DEMS and Tides

<table>
<thead>
<tr>
<th>Intertidal Wetland Areas (km²) Current and Future</th>
<th>Current</th>
<th>Following a 1 m Rise in Sea Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Survival of Existing Marsh</td>
<td>100% Survival of Existing Marsh</td>
</tr>
<tr>
<td>Mississippi</td>
<td>117</td>
<td>46</td>
</tr>
<tr>
<td>FL Panhandle</td>
<td>116</td>
<td>173</td>
</tr>
</tbody>
</table>

Coastal wetlands are retreating
Marshes typically exist behind barrier islands that protect them from wave energy. When the barrier islands fail, the marshes behind them will fail.

North Inlet, SC: Tide range here is 1.7 m, and this marsh is not keeping up with sea level.
Due to SLR, the increase in volume of the tidal prism increases, causing edge erosion. What happens to this carbon?
Acknowledgements

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Thank you for your patience