Establishing relationships between plant zones and greenhouse gases

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Outline: Relating plant zones to GHGs

I. Overview of salt marsh zonation
   A. Plant impacts on GHG fluxes
   B. Potential roles of plants for Blue C accounting

II. Comparison of GHG fluxes across plant zones at Sage Lot Pond

III. Applications for the results
   A. Scaling up
   B. Modeling
Section #1

OVERVIEW OF SALT MARSH ZONATION
Salt marsh zonation reflects an ecological interplay


Figure 3. Distinct zones characterize a New England salt marsh, for animals as well as plants. On the coastal side of the low marsh, shown in cross section, thick beds of ribbed mussels are attached to the roots of cordgrass. The mussels decrease in abundance as one moves inland, and the marsh soil becomes dotted with small holes, the burrows of fiddler crabs. These too, however, are largely limited to the low marsh. Even the cordgrass of the low marsh is divided into two zones: The cordgrass closer to the sea is tall and the cordgrass farther from the sea is short because soil there is composed of compacted peat produced by the decay of the grass. The high-marsh zones of salt-meadow hay and black rush are primarily monocultures, but disturbed areas support small populations of spikegrass and slender glasswort.
Environments differ between marsh zones

<table>
<thead>
<tr>
<th>Zone</th>
<th>Avg. salinity (psu) +/- stand. Error</th>
<th>Avg. moisture (%) +/- stand. error</th>
<th>Avg. redox (mV) +/- stand. error</th>
<th>H₂S (mM) +/- stand. error</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>33.2 +/- 1.3</td>
<td>55.6 +/- 2.7</td>
<td>207 +/- 24.0</td>
<td>565.3 +/- 284</td>
</tr>
<tr>
<td>Low</td>
<td>27.9 +/- 1.4</td>
<td>62.9 +/- 0.8</td>
<td>102 +/- 55.0</td>
<td>2437.9 +/- 490</td>
</tr>
</tbody>
</table>

Photo: Irv Mendelssohn
http://life.bio.sunysb.edu/marinebio/spartina.html
Dominant plant species

High marsh
• *Distichlis spicata*
• *Juncus gerardii*

Low marsh
• *Spartina alterniflora*
Contrasting morphologies of high marsh plants


Left:
Distichlis spicata
(spike grass)

Right: Juncus gerardii
(black rush)

Figure 4. Plant morphology affects competitive ability. Spikegrass stems are separated by lengths of belowground runners (left). This makes for a less densely growing plant, but one well adapted for colonizing new areas. Black rush (right) has turf morphology—dense groups of stems arising from a belowground mat of roots and rhizomes. Turf grasses do not rapidly invade new areas, but turf morphology is competitively superior to runner morphology over time.
Physiological adaptations to different marsh zones

Oxygen transport by roots

![Graph showing oxygen transport by roots across different marsh zones.](image)

**Fig. 2** Rates of internal oxygen transport ($\mu$mol g$^{-1}$ h$^{-1}$) for the species in the study, grouped by ecological functional type. Oxygen transport rates were found by comparing oxygen consumption around root tissue when plants were exposed to air and when shoots were cut off and sealed with paraffin oil, thereby stopping the flow of oxygen. Shown is the least squares mean of 3–15 plants ± s.e. Letters indicate significant differences between species at $p = 0.05$. Species abbreviations are as follows: alt algorithms, ang S. anglica, den S. densiflora, fol S. foliosa, hybrid S. alterniflora × S. foliosa F1 hybrid, spar S. spartinae, pat S. patens, dist Distichlis spicata, pec S. pectinata, rice Oryza sativa, com Zea mays, and oat Avena sativa

Oxidative stress in leaves

![Graph showing oxidative stress in leaves across different marsh zones.](image)

**Fig. 7** The effect of decreasing soil $\Psi$ on leaf ascorbate peroxidase (APX) activities. Bars indicate ± S.E. $(n = 3–15)$. Species are grouped by ecological functional type; treatments are arranged by decreasing $\Psi$ and are labeled as in Fig. 2.
Waterlogging impacts plant diversity and composition

Photo: Olivier Prichard
Plant-microbe interactions mediate C and N cycling

Belowground

- **Nitrification**
  - \( \text{NH}_4^+ \rightarrow \text{NO}_2^- \rightarrow \text{NO}_3^- \)

- **Denitrification**
  - \( \text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{N}_2 \)

- **Methanogenesis**
  - \( \text{CH}_3\text{COOH} \rightarrow \text{CH}_4 \)

Aboveground

- **Methanogenesis**
  - \( \text{N}_2 \rightarrow \text{CH}_4 \)

- **Denitrification**
  - \( \text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{N}_2 \)

- **Nitrification**
  - \( \text{NH}_3 \rightarrow \text{NO}_2^- \rightarrow \text{NO}_3^- \)

- **Gas transport**
  - \( \text{N}_2 \rightarrow \text{CH}_4 \)

Organic C
Zonation shifts in response to disturbance

Bertness M D et al. PNAS 2002;99:1395-1398
Vulnerability of Northeastern US Marshes

• High relative rates of sea level rise:
  – Avg. 3.8 mm/y
  – Global <1 mm/y

• Low sediment supply (Weston 2014, Meade 1982)

• Limited transgression opportunity

Figure: “Hotspot of accelerated sea level rise” Sallenger et al. 2012. Nature Climate Change
What is the fate of Blue C? Uncertain futures for coastal marshes

Venice Lagoon, Italy

Plum Island, MA

Jamestown, RI
How can zonation studies serve Blue Carbon efforts?

• Are plants simple proxies?
• Does stratification improve C accounting?
• Mechanistic understanding of changes: die back, invasion, sea level rise
Section #2

COMPARING GHGS ACROSS PLANT ZONES- SAGE LOT POND
Objectives: To characterize GHG fluxes across major zones

2012-2013
1. High and low marsh zones
   - Light and dark, diel cycles
   - Growing season for both zones
   - Monthly in low marsh zone

2013-2014 (summer)
2. Unvegetated ponds

3. Invasive Phragmites upland border
   - See Rose Martin poster
Sage Lot Pond-field sites

Pond Site A

Pond Site B

Vegetation Assemblages
- phragmites
- high marsh high
- marsh border
- low marsh
- scirpus
- panne
- high marsh low
Environmental Data (2012-2013)

**Plant properties**
- community composition (% cover)
- biomass
- density
- height
- leaf area

**Soil properties**
- sediment moisture, salinity, temperature
- oxidation-reduction potential, pH
- soil organic content
- sulfide, nitrate, ammonium
- water level (depth relative to marsh surface)

**Climatic properties**
- precipitation, air temperature
- wind
-- photosynthetically active radiation (PAR)
CO₂ uptake is significantly greater in the low marsh than the high marsh and the fluxes vary over time.
Methane emissions do not significantly differ between low and high marsh zones.
Temporal patterns for CO$_2$ in low marsh

![Graph showing day and night CO$_2$ levels with error bars.](image-url)
Temporal patterns for CH4 in low marsh

Day CH4

Night CH4

mmol CH4 m$^{-2}$ h$^{-1}$

CO₂ fluxes in ponds, high marsh & Phragmites

- Ponds
- High marsh
- Phragmites

5-27-14
6-24-14
8-21-14

mmol CO₂ m⁻² s⁻¹
Methane fluxes in ponds, high marsh & Phragmites zones

![Bar chart showing methane fluxes in different zones and dates]

- **Ponds**
- **High marsh**
- **Phragmites**

**Dates and Flux Values:**
- 5-27-14: [Value] mmol CH₄ m⁻² h⁻¹
- 6-24-14: [Value] mmol CH₄ m⁻² h⁻¹
- 8-21-14: [Value] mmol CH₄ m⁻² h⁻¹
Zonation patterns for Net GHG Fluxes in Sage Lot (Waquoit Bay) (mg CO$_2$eq. m$^{-2}$ h$^{-1}$)
• Are plants simple proxies? 
Not quite.
• Does stratification improve C accounting?
Yes, CO$_2$ fluxes vary significantly between marsh zones.
  (Highest CO$_2$ uptake in low marsh and Phragmites zones)

• Mechanistic understanding of changes:
  Die back and sea level rise will decrease CO2 uptake,
  Invasion by Phragmites may maintain or increase it!
Section #3
APPLICATIONS FOR DATA ON GHGS AND PLANT ZONES
Estimated % of overall carbon uptake rates (g C per hour)
Estimated % of overall carbon uptake rates (g C per hour)
Modeling CO\textsubscript{2} sequestration from plant variables

\textbf{Dr. Omar Abdul- Aziz, K. S. Ishtiaqu}

\[ F_{CO2} = [SD]^{0.19} [AGB]^{0.27} [BGB]^{0.58} \]

- Biomass and plant related variables explained 77\% of the \( F_{CO2} \).
- BGB is the most dominant and significant driver in the regression.
- SD and AGB had low and moderate dominance on \( F_{CO2}\).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficients</th>
<th>p-value</th>
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<tbody>
<tr>
<td>Stem density (SD)</td>
<td>-0.19</td>
<td>0.32</td>
</tr>
<tr>
<td>AGB</td>
<td>-0.27</td>
<td>0.20</td>
</tr>
<tr>
<td>BGB</td>
<td>0.58</td>
<td>0.02</td>
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</table>

\( R^2 = 0.77 \)

\( r = 0.88 \)

\( R^2 = \) Coefficient of determination; \( r = \) correlation between observed and predicted \( FC_2 \)
Future directions for research

• Predicting longer-term feedbacks with SLR
  – What are irreversible thresholds?
  – Which factors influence marsh resilience?
  – What is the fate of carbon?

• Marsh restoration: Predict impact of converting fresh/brackish Phragmites marsh to native saline marsh
  – Multiple factors change:
  – What is strongest driver? On what time scale?
Acknowledgements

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                Conetta

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               Earl Davey (EPA), Art Gold (URI)
Comparisons to similar studies: **Sage Lot is a conservative reference**

<table>
<thead>
<tr>
<th></th>
<th>Spartina alterniflora</th>
<th>Spartina patens/High marsh</th>
<th>Phragmites australis</th>
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</thead>
<tbody>
<tr>
<td><strong>CH4 (mmol m⁻² h⁻¹)</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>SAGE LOT</td>
<td>0.1 to 12 (3)</td>
<td>-4 to 45 (6)</td>
<td>-20 to 47 (-8)</td>
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<tr>
<td>Narragansett Bay</td>
<td>5 to 620 (150)</td>
<td>2 to 40 (10)</td>
<td>see Martin poster</td>
</tr>
<tr>
<td></td>
<td>4 to 44 (17)</td>
<td>2 to 13 (5)</td>
<td></td>
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<tr>
<td>Moseman-Valtierra Plum Island estuary</td>
<td>n/a</td>
<td>3 to 91 (30)</td>
<td>n/a</td>
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<tr>
<td>Emery and Fulweiler Plum Island estuary</td>
<td>0 to 50 *</td>
<td>n/a</td>
<td>0 to 50</td>
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<td><strong>CO2 (mmol m⁻² s⁻¹)</strong></td>
<td></td>
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<td></td>
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<tr>
<td>SAGE LOT</td>
<td>-13 to 1 (3)</td>
<td>-4 to 4 (0.3)</td>
<td>-20 to 7 (-8)</td>
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<tr>
<td>Narragansett Bay</td>
<td>-31 to -1 (-12)</td>
<td>-17 to 6.0 (-3)</td>
<td>See Martin poster</td>
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<td></td>
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<td>3 to 6 (4.3)</td>
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<td>-14 to 2</td>
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