Response of Tidal Freshwater Marsh Plant and Microbial Communities in the Delaware River Estuary to Sea-Level Rise and Salt-Water Intrusion

Nathaniel B. Weston
Department of Geography and the Environment, Villanova University

SWS/INTECOL

Salinization of freshwater wetlands: Implications for biogeochemistry, plant communities, and ecosystem dynamics

June 2012
Salinization of Tidal Freshwater Marshes

Changing Precipitation & Evapotranspiration

River

Rising Sea Level

Ocean
Salinization: Shift to Salt Marsh?

Watershed Inputs

Marsh Accretion

Inorganic Sediment

Primary Production

CO$_2$ + CH$_4$

CO$_2$ + CH$_4$

Organic Matter

Microbial Decomposition

CO$_2$ + CH$_4$
• How will tidal marshes respond to sea-level rise and altered flooding?

• How will tidal freshwater marshes (TFMs) respond to salt-water intrusion?

• How are microbial and plant responses coupled?

• What are implications for C cycling and marsh stability?
Tidal Freshwater Marshes

Salt Marshes
Average Maximum Daily Flooding (cm)

- 50 (-10)
- 60 (0)
- 70 (+10)
- 80 (+20)
- 90 (+30)
- 100 (+40)

• Plant Species Composition & Biomass
• Trace GHG (CH\textsubscript{4} & N\textsubscript{2}O) Flux
• Soil Biogeochemistry & Microbial Rates
End of Season Peak Biomass

Peak Biomass (g m$^{-2}$) vs. Average Daily Maximum Flooding Depth (cm)

- **Marsh Platform**
- **Zizania aquatica**
- **Spartina alterniflora**
- **Mixed Freshwater** (Bidens, Polygonum, Amaranthus, Acorus)
- **Peltandra virginica**
- **Nuphar lutea**
Plant Response to Salinization (Stow; Salinity 9.9)
Plant Response to Salinization (Salem; Salinity 2.2)

Average Daily Maximum Flooding Depth (cm)

End of Season Biomass (g m$^{-2}$)

- **Rancocas (TFM)**
- **Salem (Oligohaline)**
- **RAN-SAL 2010**
- **RAN-SAL 2011**

---

**Legend:**
- Blue diamonds: Rancocas (TFM)
- Red circles: Salem (Oligohaline)
- Orange triangles: RAN-SAL 2010
- Black squares: RAN-SAL 2011
## TFM Marsh Biomass Response to Sea-Level Rise and Salt-Water Intrusion

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooding Depth (cm)</td>
<td>-11.3</td>
<td>0.002</td>
</tr>
<tr>
<td>Conductivity (mS cm⁻¹)</td>
<td>-50.8</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Year</td>
<td>332.8</td>
<td>0.006</td>
</tr>
<tr>
<td>Intercept</td>
<td>1203.8</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>R²</th>
<th>F</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.49</td>
<td>18.1</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>
Stable Marsh

Unstable Marsh / Open Water

Relative Plant Biomass and Marsh Accretion

Average Daily Maximum Flooding Depth (cm)

Marsh Accretion

Sea Level Rise

Salt-tolerant Plant Colonization

TFM Plant Biomass

Marsh Platform

Salt-Marsh Plant Biomass

Marsh Accretion

20 30 40 50 60 70 80 90 100

20 30 40 50 60 70 80 90 100

Relative Plant Biomass and Marsh Accretion

Average Daily Maximum Flooding Depth (cm)
Microbial Response to Sea-Level Rise and Salinization

Primary Production → CO₂

Organic Matter → Microbial Respiration → CO₂ & CH₄

CO₂ & CH₄
Lab Experiment
CO₂ and CH₄ Flux

Weston, Vile, Neubauer & Velinsky (2011)
Biogeochemistry
Lab Experiment - Soil Organic Carbon

Weston, Vile, Neubauer & Velinsky (2011) Biogeochemistry
Sulfate Reduction - Salinity

\[ y = 0.0247x + 0.4523 \]

\[ R^2 = 0.5777 \]

\[ p < 0.001 \]
Sulfate Reduction – Plant Biomass

Salem (brackish marsh)

\[ y = -0.0075x + 10.475 \]
\[ R^2 = 0.0005 \]

Raccoon & Rancocas (freshwater marsh)

\[ y = -0.0029x + 0.4845 \]
\[ R^2 = 0.0161 \]

Stow (saltmarsh)

\[ y = -0.0931x + 30.219 \]
\[ R^2 = 0.0379 \]
Sulfate Reduction – Flooding Depth

Raccoon & Rancocas (freshwater marsh)

\[ y = 0.0258x - 1.6136 \]

\[ R^2 = 0.1735 \]

Salem (brackish marsh)

\[ y = -0.4548x + 44.358 \]

\[ R^2 = 0.3284 \]

\[ p = 0.05 \]

Stow (saltmarsh)

\[ y = -0.5286x + 68.66 \]

\[ R^2 = 0.3238 \]

\[ p = 0.05 \]
Methanogenesis - Salinity

\[ y = -0.0008x + 1.8609 \]

\[ R^2 = 0.0143 \]

Acetoclastic Methanogenesis (mmol m\(^{-2}\) d\(^{-1}\))

Chloride Inventory (µmol cm\(^{-2}\))

Adjacent  TFM Transplant

Salem

Rancocas & Raccoon

Rancocas & Raccoon
Methanogenesis – Plant Biomass

Raccoon & Rancocas (freshwater marsh)

\[ y = -0.0006x + 1.5611 \]
\[ R^2 = 8E-05 \]

Salem (brackish marsh)

\[ y = -0.0339x + 3.2718 \]
\[ R^2 = 0.1189 \]

Stow (saltmarsh)

\[ y = -0.0244x + 1.8148 \]
\[ R^2 = 0.1844 \]
Methanogenesis – Flooding Depth

Raccoon & Rancocas (freshwater marsh)

\[ y = 0.0845x - 4.8622 \]
\[ R^2 = 0.218 \]
\[ p = 0.06 \]

Salem (brackish marsh)

\[ y = 0.1061x - 6.1073 \]
\[ R^2 = 0.1957 \]

Stow (saltmarsh)

\[ y = 0.0402x - 2.0955 \]
\[ R^2 = 0.132 \]
Short-Term Methane Flux (Months)

TFM Site

\[ y = 0.0165x - 0.5324 \]
\[ R^2 = 0.59 \]
\[ p < 0.001 \]

Salt-Marsh Site

TFM Transplant
\[ y = 0.0237x - 1.5963 \]
\[ R^2 = 0.6103 \]
\[ p < 0.001 \]

Adjacent Salt-Marsh
# Methane Flux – 2 years

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity (mS cm(^{-1}))</td>
<td>-0.04</td>
<td>0.016</td>
</tr>
<tr>
<td>Date (days)</td>
<td>-0.62</td>
<td>0.001</td>
</tr>
<tr>
<td>Flooding Depth (cm)</td>
<td>0.01</td>
<td>0.082</td>
</tr>
<tr>
<td>Intercept</td>
<td>68.4</td>
<td>0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>R(^2)</th>
<th>F</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.03</td>
<td>5.3</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Sea-Level Rise</td>
<td>Salt-Water Intrusion</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>----------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Sulfate Reduction</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td>Methanogenesis</td>
<td>↑</td>
<td>↑ then ↓</td>
</tr>
<tr>
<td>Organic Matter Decomposition</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td>Plant Biomass and</td>
<td>↓ or ↑*</td>
<td>↓ **</td>
</tr>
<tr>
<td>Organic Matter Production</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic Matter Sequestration</td>
<td>↓ or ↑*</td>
<td>↓ **</td>
</tr>
<tr>
<td>Marsh Stability</td>
<td>↓ or – *</td>
<td>↓ **</td>
</tr>
</tbody>
</table>

*Depends on rate of SLR  **Unless/until salt-marsh develops
*Eric Au
*Sarah Celone
*Patrick Costello
*Amanda Foskett
*Margaret Garcia
Olivia Gibb
Anthony Geneva
Paul Kiry
Chris McLaughlin
Avni Malhotra
*Neil Mehta
*Justin Meschter
Stephen Mowbray
Scott Neubauer

*Michael Patson
*Melanie Pingoy
*Tatjana Prša
James Quinn
*Daniel Russo
*Mariozza Santini
Kimberli Scott
Roger Thomas
*Cindy Troy
*John Ufferfilge
David Velinsky
Melanie Vile
*Justin Walsh
*Paul Weibel

(* - Undergraduate Student)

National Science Foundation
Environmental Protection Agency, STAR Program
Villanova University