Transpiration as a Hydrologic Driver of Ion and Mineral Accumulation on Tree Islands

Tree Islands GW– TP= 388 μg L⁻¹, Cl⁻ = 140 mg L⁻¹, Ca²⁺ = 176 mg L⁻¹

Marsh GW– TP= 11 μg L⁻¹, Cl⁻ = 55 mg L⁻¹, Ca²⁺ = 47 mg L⁻¹

Pamela L. Sullivan¹, Vic Engel², Mike S. Ross ¹&³, René M. Price¹&³

¹Southeast Environmental Research Center, Florida International University
²Southeast Ecological Science Center, United States Geological Survey
³Department of Earth and the Environment, Florida International University
Transpiration driven inputs of groundwater has been hypothesized to support the elevated ion and nutrient concentrations.

- **Groundwater Level on a Tree Island During Dry Season** (Ross et al. 2006)
- **Diurnal Water Table Fluctuations**
- **Enigmatic Carbonate Layer on the Head of an Island** (Schwadron et al. 2006, Churma et al. 2011)

(Wetzel et al. 2005)
Objective:
Determine if root water uptake by the overlying vegetation and tree island hydrodynamics controls potential mineral formation by affecting the distribution and concentration of ions in tree island groundwater.
Study Area:

- Located in Everglades National Park
- Teardrop in Shape
- Contains 3 differing plant communities

Satinleaf Tree Island

- Hammock
- Bayhead
- Bayhead Swamp

Soil Elevation:
- Marsh 1.29 m
- Hammock 2.20 m
- Bayhead 1.60 m
- Bayhead Swamp 1.45 m

(C) Satinleaf

(Ross et al. 2004 in Lago 2009)
## Monitoring Locations

<table>
<thead>
<tr>
<th>Satinleaf</th>
<th>Bayhead Swamp</th>
<th>Bayhead</th>
<th>Hammock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater and Surface Water Level Monitoring</td>
<td>GW Wells</td>
<td>SW Sampling</td>
<td>Marsh GW Sipper</td>
</tr>
<tr>
<td>Groundwater Surface Water Chemistry</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Monitored Trees</td>
<td>2007-2010 Sap Flow on 4 species (Hammock only)</td>
<td></td>
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</tr>
</tbody>
</table>

## Sampling Scheme

<table>
<thead>
<tr>
<th>Satinleaf</th>
<th>2007-2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 GW Wells</td>
<td></td>
</tr>
<tr>
<td>1 SW Site</td>
<td></td>
</tr>
<tr>
<td>30 min rate of collection</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>2008-2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 GW Wells</td>
</tr>
<tr>
<td>4 GW Sipper</td>
</tr>
<tr>
<td>2 Surface Sites</td>
</tr>
<tr>
<td>Analyzed for: Major ions, Oxygen and Hydrogen Isotopes, Nutrients</td>
</tr>
</tbody>
</table>

| 2007-2010 Relative Volumetric Soil Water Content (Hammock only) |
|---|---|

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<td>Analyzed for: Major ions, Oxygen and Hydrogen Isotopes, Nutrients</td>
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Methods:
Transpiration as a driver of ion accumulation and potential mineral formation

I. Groundwater Uptake

II. Inputs of Water (Water Levels and Chemistry)

III. Saturation State of Groundwater with Respect to Calcite and Aragonite

$R^2 = 0.30$

0%
20%
40%
60%
80%
100%

0.0
0.2
0.4
0.6
0.8

Average GW Uptake (d⁻¹ m⁻¹)

Average VSWC(θ, cm³ cm⁻³ d⁻¹ m⁻¹)

-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0

δ¹⁸O (‰)

Cl⁻¹ (mg l⁻¹)

Calcite precipitation

Calcite

Respiration

Aerobic Decay

Evapotranspiration

Calcite Dissolution

Log $\text{pCO}_2$ (bar)

1/6$C_6H_{12}O_6$ + O₂ $\rightarrow$ CO₂ + H₂O
1. Uptake of Groundwater by Overlying Trees

Transpiration = Water from the Unsaturated + Saturated Zones

\[ S = \frac{1}{2} \pi r^2 h \]

\[ y = 1.26x \]
\[ R^2 = 0.61 \]
\[ p\text{-value} < 0.01 \]

\[ E = \left( \sum_{j=1}^{3} \sum_{i=1}^{4} V_{avg,i,j} \rho_{i,j} \right) \frac{\rho_{stand}}{\rho_{mon}} \]

Diurnal Water Table Fluctuations

Groundwater Evapotranspiration (ET_{GW})

\[ ET_{GW} = \left[ (H_1 - L) + \frac{(H_2 - L)}{T_1} T_2 \right] 1000 S_y \]
I. Uptake of Groundwater by Overlying Trees

- Transpiration (E), Groundwater Evapotranspiration, Volumetric Soil Water Content (VSWC) at on the Hammock

\[
\text{Groundwater Uptake} = \frac{ET_{GW}}{E}
\]

Average Groundwater Uptake Compared to Volumetric Soil Water Content (VSWC) at on the Hammock

**Average VSWC (\(\theta, \text{cm}^3 \text{ cm}^{-3} \text{ d}^{-1} \text{ m}^{-1}\) )**

**Average GW Uptake (d^{-1}m^{-1})**
II. Inputs of Water: Water Levels

Average Monthly Groundwater Level Normalized to the Surface Water at Satinleaf

Graph showing the average monthly groundwater level normalized to surface water levels at Satinleaf. The graph includes data from multiple locations: Hammock, Bayhead, and Bayhead Swamp, with data points for each month from July 2007 to September 2010. The y-axis represents the average monthly groundwater level normalized to surface water level (cm), ranging from -7 to 3. The x-axis lists the months from July 2007 to September 2010.

Legend:
- Hammock
- Bayhead
- Bayhead Swamp

Data points are color-coded by location:
II. Inputs of Water: Water Chemistry

δ¹⁸O and Cl⁻ concentrations of groundwater indicated transpiration had a dominant influence on the tree island groundwater chemistry.

Ionic ratios of groundwater and surface water indicated all communities were recharge by marsh groundwater.
III. Calcium Carbonate CaCO$_3$ (e.g. calcite) and Saturation State

Precipitation and Dissolution

Calcite CaCO$_3$ ↔ Calcium Ions Ca$^{2+}$ + Carbonate Ions CO$_3^{2-}$

Precipitation ↔ Dissolution

Saturation State of Water

Ion Activity Product (IAP)

(Water Sample)

$SI = \log \left( \frac{IAP}{K_{sp}} \right)$

Calcite Equilibrium Constant ($K_{sp}$)

(Known Value)

$\frac{(aCa^{2+})(aCO_3^{2-})}{(aCaCO_3)} = 10^{-8.48}$

<table>
<thead>
<tr>
<th>IAP: $K_{sp}$</th>
<th>SI State</th>
<th>SI Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAP=$K_{sp}$</td>
<td>Equilibrium</td>
<td>0.00 ± .05</td>
</tr>
<tr>
<td>IAP&lt;$K_{sp}$</td>
<td>Undersaturated</td>
<td>&lt;-0.05</td>
</tr>
<tr>
<td>IAP&gt;$K_{sp}$</td>
<td>Supersaturated</td>
<td>&gt;0.05</td>
</tr>
</tbody>
</table>

Saturation State of Calcium Carbonates Influenced by:
- temperature
- concentration of CO$_2$
- common ion effect
- ionic strength of the water
- respiration, decay
- photosynthesis
III. Saturation State of Groundwater and Surface Water at Satinleaf

1. Calcium Compared to Chloride concentrations in Groundwater and Surface Water

2. Calcium Concentrations to Calcite Saturation in Groundwater and Surface Water

3. Partial Pressure of Carbon Dioxide (P$_{CO_2}$) and the Calcite Saturation in Groundwater and Surface Water
Conclusion:

Water level, transpiration, and hydrogeochemical data presented above generally support the hypothesis that root water uptake from phreatophytic vegetation drives groundwater fluxes toward the tree island from surrounding areas.

The supersaturated state of calcium carbonate minerals found in the tree island groundwater was a result of ion exclusion during root water uptake and indicated for the first time that transpiration-driven processes may potentially lead to mineral soil formation.
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