Climate Change Effects on Mangrove, Seagrass and Macroealgae Communities of the Coastal Everglades
Specific Future Climate Scenarios (2060)

I. +1.5 °C Temperature Increase
II. 1.5 Foot SLR Increase (9.5 mm y⁻¹)
III. +/- 10% Change in Precipitation
IV. 490 ppm CO₂
I) The Everglades Mangrove Community (Diverse Forest Structure, Geomorphology and Biogeochemistry)
Mangrove Community Distribution in Everglades

- 10K Island Coastal Mangrove Forests
- Southwest Coastal Mangrove Forests
- Interior Basin Mangrove Forests
- Northern Florida Bay Mangrove Forests
Major Drivers of Everglades Mangrove Communities

1) Sea Level Rise Rates
2) Hurricane (Disturbance/Recovery)
3) Salinity/Temp/CO$_2$
Measurements of Wetlands Keeping Pace with SLR

Rod-Surface Elevation Tables (RSET)

Wetland Surface Elevation Change

Shallow Subsidence/Expansion

Accretion Rates – Elevation Change = Shallow Subsidence/Expansion
Rod-Surface Elevation Tables (RSET)

Benchmark Rod

Metal Pin Holes

Courtesy K. McKee
Northern Florida Bay Mangroves (Taylor Creek Basin) – Coronado/Sklar

**Non-flooded Sites**

- Elevation Change: 1.5 mm yr\(^{-1}\)
- Vertical Accretion: 0.9 mm yr\(^{-1}\)
- Soil Expansion: 0.6 mm yr\(^{-1}\)

**Frequently Flooded Sites**

- Elevation Change: 2.5 mm yr\(^{-1}\)
- Vertical Accretion: 1.8 mm yr\(^{-1}\)
- Soil Expansion: 0.7 mm yr\(^{-1}\)

**Permanent Flooded**

- Elevation Change: 1.4 mm yr\(^{-1}\)
- Vertical Accretion: 3.3 mm yr\(^{-1}\)
- Shallow Subsidence: -1.9 mm yr\(^{-1}\)
Modified by Coronado from T. Smith et al. 2009*

Southwest Florida (Shark River Region) – Tom Smith

Shark River (SH3)

- Elevation Change: 0.87 mm yr\(^{-1}\)
- Vertical Accretion: 2.9 mm yr\(^{-1}\)
- Soil Subsidence: -2.0 mm yr\(^{-1}\)

Lostman River (LO3)

- Elevation Change: 2.4 mm yr\(^{-1}\)
- Vertical Accretion: 1.4 mm yr\(^{-1}\)
- Soil Expansion: 1.0 mm yr\(^{-1}\)
Mangrove Communities “state change” by Hurricanes

- Transport propagules inland (recruitment)
- Influx sediment, nutrients (accretion)
- Scour coastline (erosion/peat collapse)

Smith et al. 2009
Coastal Forests - Rapid Sediment Deposition
(10-80 mm pulsed event)

<table>
<thead>
<tr>
<th>Distance Upstream (km)</th>
<th>Sediment Deposition (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

Southwest Coastal Mangrove Forest

Efflux of Sediments and Compaction
(1 m tides along Gulf of Mexico)

Smith et al. 2009

Whelan et al. 2008
Long-Term Post Hurricane Sediment Elevation Change and Accretion Rates Southwest Florida (Shark River Region)

Shark River (SH3)

Lostman River (LO3)

Modified by Coronado from T. Smith et al. 2009
Loss of Forest and Belowground Structure

- Erosion of Surficial Peat – Delayed Tree Mortality
- Peat Oxidation
- Peat Collapse

Before

After

Little Shark Island-West Coast after Wilma 2005

Smith et al. 2009

Barr et al. 2012
Temperature, Salinity and Elevated CO₂ Effects Mangroves (Eddy Covariance 30 m Towers – Mouth of Shark River)

Barr et al. 2010
Rate of Mangrove Peat Accumulation—Caribbean

McKee et al. 2007

Scenario
2060
9.5 mm y$^{-1}$

3.5 mm/yr

Sea-level Curve for Western Atlantic

Depth (m MSL)

0 2000 4000 6000 8000 10000 12000

Age (Cal BP)

Belize (1)
△ Belize (2)
★ Bay Islands, Honduras (1)
■ Quintana Roo, Mexico (3)
○ Trinidad (4)
▼ Panama (1)

5.2 mm yr$^{-1}$
March of the Mangroves
(Latitudinal Shifts Community)

Courtesy K. McKee

Ross et al. 2000
Conclusions

- Using a 9.5 mm yr\(^{-1}\) scenario for sea level rise (SLR) coastal mangrove forests would be overwhelmed and not likely keep pace with SLR.

- Rates of elevation change long-term are \(\sim 1-2.5\) mm yr\(^{-1}\) with reliance on belowground biomass and autochthonous processes to maintain elevation - highly vulnerable to SLR.

- Storm surges can deposit 10-80 mm along SW coast and \(\sim 5\) mm Florida Bay some of which is subsequently lost back to tide.

- Storms can also destabilize sediments with high forest mortality causing erosion (20-30 mm) and peat collapse with \(\sim 3\) yr lag phase.

- Reduced freshwater flows and marine transgression with SLR will move the mangrove community into marsh habitat.

- Mangrove community productivity is enhanced under polyhaline conditions (\(< 29\) ppt) and temperatures below 30°C.
Scientific Needs

• Regional measurements and estimates of SLR
• Higher resolution Elevation Maps in Mangrove zone
• Role physiochemical processes, forest type and pulsed events on Mangrove sediment elevation change
• Sediment “Erodibility” Index Maps – Nutrient Content
• Mangrove Island SET studies in Florida Bay
• Modelling scenarios integrating drivers of various time scales

Future Management Scientific Needs

• Develop models that can assist in determining if freshwater input into Florida Bay (as part of CERP) could slow down the inland expansion of mangrove into the Everglades?
• Will freshwater inputs increase above and belowground mangrove productivity and long-term elevation changes keep pace with SLR?
• Will rising CO₂ increase productivity at higher salinity levels and enhance above and below-ground productivity?
II. The Greater Everglades Seagrass and SAV Community
(Oligohaline to Marine Species: Ecotone to FL Reef Tract)
Marine SAV Community Distribution in Everglades
Why are Marine Macroalgae & Seagrasses Important?

- Habitat - Foundation
- Base Foodwebs
- Sediment Stabilization
- Sediment Generation Tropics
- Settlement Sites Corals
- Nutrient Cycling
- Competitors (Nuisance spp)
- Substrates - Epiphytes
Major Drivers of Greater Everglades Marine SAV Communities

1) Salinity
2) Nutrients
3) Light
4) Grazing/Competition (CO$_2$ Enrichment)
Modeled Increases Freshwater Flows

- Upper basins increased *Halodule (Ruppia)* over *Thalassia* (CERP Goal)
- Western basins insensitive up to 4xs flows because of mudbanks/basins
- Sea level rise dilute these modest effects

Herbert et al. 2011
Landscape Nutrient Flux with Sea Level Rise (Linkages between slr, water quality and light)
Large Scale Seagrass Mortality Events
Nutrient Pulses to Water Column Florida Bay

4 to 5 mmol P m$^{-2}$
1 m Depth
(4-5 $\mu$mol P L$^{-1}$)

280 Metric Ton P
(53% resorption)

Seagrass Recycling
(2,220 km$^2$)

Rosch and Koch (2009)
Landscape Nutrient Flux with Sea Level Rise (Linkages between slr, water quality and light)
Florida Bay Bank Elevation Changes - Critical GOM and Internal Circulation

- Currently Wide-Ranging Estimates Mudbank Accumulation Rates
- $^{210}\text{Pb}$ high rates 3 to 30 mm $y^{-1}$ (Median = 4.6 mm $y^{-1}$) (Holmes et al. 2001)
5 of 9 sites had increasing elevation (5-11 mm/y over 10 y period)

18 of 20 sites had decreasing elevation (-1 to -15 mm over 10 y period)

From Robert Halley, USGS
Direct Calcification-Dissolution Rates CaCO$_3$ on Banks

<table>
<thead>
<tr>
<th>Substrate type</th>
<th>Area (m$^2$)</th>
<th>$C_{net}$ (g CaCO$_3$ m$^{-2}$ yr$^{-1}$)</th>
<th>Sediment accumulation (cm 1000 yr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basins</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sparse seagrass</td>
<td>375,128,462</td>
<td>$-112.0$</td>
<td>$-9.6$</td>
</tr>
<tr>
<td>Intermediate seagrass</td>
<td>190,807,051</td>
<td>$-83.9$</td>
<td>$-7.2$</td>
</tr>
<tr>
<td>Hard bottom</td>
<td>439,668,144</td>
<td>$776.0$</td>
<td>$66.9$</td>
</tr>
<tr>
<td>Mud bottom</td>
<td>209,804,241</td>
<td>$-78.4$</td>
<td>$-6.8$</td>
</tr>
<tr>
<td>Dense seagrass</td>
<td>65,288,753</td>
<td>$235.0$</td>
<td>$20.2$</td>
</tr>
<tr>
<td>Mixed bottom</td>
<td>57,619,872</td>
<td>$126.0$</td>
<td>$10.8$</td>
</tr>
<tr>
<td>Open sand</td>
<td>59,182,515</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>Mud bank suite</td>
<td>309,493,603</td>
<td>$235.0$</td>
<td>$20.2$</td>
</tr>
</tbody>
</table>

Net Calcification Banks and Basins FL Bay Declined higher Salinity and Temp

Yates and Halley (2006)
Temperature and Photosynthesis

Adapted from Hopkins and Hünter 2004

X CO₂ Marine Plants

~31-32°C

Florida Bay Seasonal Highs
Monthly Mean

33.5°C 2060 Scenario

136.0°C 2100 Scenario

0 10 20 30 40 50

Temperature (°C)

T min

T max

T opt

0 10 20 30 40 50

Reaction Rate
Thalassia-Growth

Leaf Elongation Rates (mm day$^{-1}$)

Salinity Level - PSU

- 40°C
- 36°C
- 32°C
- 28°C

Temperature Treatment

# Days at Temperature Treatment

$R^2 = 0.99$

Koch et al.
Elevated Temperature and Thermal Limits (Australian Seagrasses)

Halodule (tropical)

Collier et al. 2011
Sargassum-Temperature Threshold

Koch and Anderson in prep.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>0 days</th>
<th>6-7 days</th>
<th>12-13 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>28°C</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
</tr>
<tr>
<td>30°C</td>
<td><img src="image4" alt="Image" /></td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
</tr>
<tr>
<td>32°C</td>
<td><img src="image7" alt="Image" /></td>
<td><img src="image8" alt="Image" /></td>
<td><img src="image9" alt="Image" /></td>
</tr>
<tr>
<td>34°C</td>
<td><img src="image10" alt="Image" /></td>
<td><img src="image11" alt="Image" /></td>
<td><img src="image12" alt="Image" /></td>
</tr>
</tbody>
</table>
Thermal Limits Keystone Florida Keys Species

- Coral
  - Anderson 2006
  - Temperature: 26°C, 28°C, 30°C, 32°C

- Macroalgae
  - Zieman 1970
  - Temperature: 34°C, 36°C

- Seagrasses
  - Koch et al. 2007
  - Temperature: 36°C

- Temperature °C:
  - 2060 Scenario: 33.5°C
  - 2100 Scenario: 36°C
Oxygen (mg L\(^{-1}\)) = \text{min}*(-0.0191)+12.065

\(R^2 = 0.996; p < 0.01\)

19.1 mg O\(_2\) consumed m\(^{-2}\) min

July 28, 2009 to Aug 17, 2009

Oxygen (mg L\(^{-1}\)) = \text{min}*(-0.00627)+10.27

\(R^2 = 0.989; p < 0.01\)

6.2 mg O\(_2\) consumed m\(^{-2}\) min

Feb 2, 2010 to Feb 22, 2010

Temp 30\(^\circ\)C
Salinity 40 psu

Temp 20\(^\circ\)C
Salinity 33 psu

Koch et al.
# Oxygen Concentrations (mg/L) at 100% O₂ Saturation as Function Salinity and Temperature

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>9.62</td>
<td>9.32</td>
<td>9.02</td>
<td>8.74</td>
<td>8.47</td>
<td>8.20</td>
<td>7.94</td>
</tr>
<tr>
<td>15</td>
<td>8.65</td>
<td>8.39</td>
<td>8.14</td>
<td>7.89</td>
<td>7.65</td>
<td>7.42</td>
<td>7.20</td>
</tr>
<tr>
<td>20</td>
<td>7.85</td>
<td>7.62</td>
<td>7.40</td>
<td>7.18</td>
<td>6.97</td>
<td>6.77</td>
<td>6.57</td>
</tr>
<tr>
<td>30</td>
<td>6.59</td>
<td>6.41</td>
<td>6.24</td>
<td>6.07</td>
<td>5.90</td>
<td>5.74</td>
<td>5.59</td>
</tr>
<tr>
<td>35</td>
<td>6.08</td>
<td>5.92</td>
<td>5.77</td>
<td>5.62</td>
<td>5.47</td>
<td>5.33</td>
<td>5.19</td>
</tr>
<tr>
<td>40</td>
<td>5.64</td>
<td>5.49</td>
<td>5.35</td>
<td>5.22</td>
<td>5.08</td>
<td>4.95</td>
<td>4.83</td>
</tr>
</tbody>
</table>
CO$_2$ Enrichment
Seawater
“Ocean Acidification”
Inorganic Carbon Speciation – Carbonate Equilibria

<table>
<thead>
<tr>
<th>Gas Exchange</th>
<th>$pCO_2$ in μatm</th>
<th>Pre-industrial</th>
<th>Present</th>
<th>Yr 2100</th>
<th>Change pre-industrial to Yr 2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air CO₂ (g)</td>
<td>280</td>
<td>394</td>
<td>1,000</td>
<td>257%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[277]</td>
<td>[392]</td>
<td>[1,087]</td>
<td>[292%]</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Seawater</th>
<th>Carbon Speciation μmol kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ (aq) + H₂O</td>
<td>H₂CO₃ Carbonic Acid</td>
</tr>
<tr>
<td></td>
<td>8</td>
</tr>
<tr>
<td>H₂CO₃</td>
<td>H⁺ + HCO₃⁻ Bicarbonate</td>
</tr>
<tr>
<td></td>
<td>1650</td>
</tr>
<tr>
<td>HCO₃⁻</td>
<td>H⁺ + CO₃²⁻ Carbonate</td>
</tr>
<tr>
<td></td>
<td>264</td>
</tr>
<tr>
<td>DIC</td>
<td>1922</td>
</tr>
</tbody>
</table>

| pH(sw) | 8.16 | 8.04 | 7.66 | (-6%) |
| Ω(calcite) | 6.36 | 5.18 | 2.49 | (-61%) |
| Ω(agg) | 4.19 | 3.41 | 1.64 | (-61%) |
Seagrasses and Marine Macroalgae Utilize HCO$_3^-$ and CO$_2$
Are They Saturated with Ci?

Photosynthesis (mg O$_2$ g$^{-1}$ dry wt h$^{-1}$)

- Not DIC Saturated
- Higher P elevated CO$_2$
- Can utilize HCO$_3^-$

DIC Ocean ~2.4 mM

Thalassia testudinum
(Seagrass – Angiosperm)

Durako 1993
Elevated $p$CO$_2$ x Temperature Winter Experiment

**Sargassum fluitans**

- High CO$_2$ x Temp
- High Temp
- High CO$_2$

**Halimeda incrassata**

- High CO$_2$ x Temp
- High Temp
- High CO$_2$

Koch et al.
Field CO$_2$ Vent Studies

Hall-Spencer et al. (2008)
Carbonate Dynamics
Estuarine Systems
Driven by Metabolic Processes

\[ \sim 490 \text{ ppm } \rho\text{CO}_2 \text{ Contour} \]

- - - > \( > 490 \text{ ppm } \rho\text{CO}_2 \)
- - - > \( < 490 \text{ ppm } \rho\text{CO}_2 \)

Millero et al. (2001)
Conclusions

• Increased freshwater flows not likely balance increased salinities with a 9.5 mm y\(^{-1}\) SLR scenario unless higher precipitation occurs and banks overtop increasing basin exchange

• Higher salinity and P and lower light promote *Halodule* and Phytoplankton over *Thalassia*, using NW lakes as a model

• Major losses of *Thalassia* in the Bay will elevate water column P and recycling, promoting Phytoplankton blooms

• Sustained 1.5\(^\circ\)C increase (33.5\(^\circ\)C, 2060) modest physiological effects on macro-autotrophs, but 4\(^\circ\)C (36\(^\circ\)C, 2100) significant impacts

• Elevated temperatures (+salinity) increase ecosystem respiration, sulfide production and lower saturation of dissolved O\(_2\) in the Bay

• CO\(_2\) dynamics in productive coastal systems primarily driven by ecosystem metabolism: > heterotrophy:autotrophy promote fleshy over calcifying algae and sediment dissolution (compounded over long term by ocean acidification)
Scientific Needs

• Regional measurements and estimates of SLR
• Bank and basin water quality and vegetation monitoring in support FATHOM model – validation and tracking system metabolic shifts
• Better quantification of changes in bank elevation and movements
• Sensitivity of dissolution basin/bank carbonate sediments (temp, salinity, light and $pCO_2$) and linkage with seagrass metabolism
• Temperature x light x CO$_2$ interactions marine benthic autotrophs

Future Management Scientific Needs

• Integrate regional hydrodynamic models to landscape and ecosystem models of mangrove-seagrass-reef tract system capture synergistic responses from various climate change scenarios (SLR, precip, tidal, hydrodynamic, temp changes)
• Include major drivers of seagrasses, phytoplankton and carbonate sediment processes in new models developed to test scenarios of climate change impacts (light, nutrients, temperature, metabolism)
Questions?