Understanding an iconic landscape through comparative international long-term ecological research
Expanding the scope for US LTER research

- Leveraging international contacts developed through ILTER to expand the geographic, ecological and social scales for investigation
- Broadening the platform to address new, high impact research questions and contributing to general ecological theory to explain ecosystem pattern and process
- Expanded policy relevance
FCE collaborative research in the Caribbean and beyond

- Earlier initiatives motivated by understanding the ecology of FCE ecosystems because of commonalities (Rivera-Monroy et al. 2004) as well as a perceived uniqueness (Noe et al. 2001).

- Advancing hydrogeology and ecology of the Everglades and (karst) wetland systems in general.

- Leveraging these relationships, this work has expanded to new initiatives, research, and student opportunities while broadening the geographic scope to the Americas as well as several recent global assessments.
FCE collaborative research in the Caribbean and beyond

• Karst wetlands and the FCE

• The distribution of a few iconic features...
  ▪ Upside-down estuary
  ▪ Productivity paradox
  ▪ Endemism

• Iconic ecosystem sustainability
Karst Geology – a regulating feature

Carbonate wetlands:
- P-limited
- GW exchange
Karst Geology – a regulating feature

Carbonate wetlands:
- P-limited
- GW exchange

Karst Regions of the World

- FCE ILTER Studies
Central Question:

How do climate change and resource management decisions interact to influence freshwater availability, ecosystem dynamics and the value and utilization of ecosystem services by people in the coastal Everglades?
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How do climate change and resource management decisions interact to influence freshwater availability, ecosystem dynamics and the value and utilization of ecosystem services by people in the coastal Everglades?
The Everglades is an “Upside-Down” estuary: marine supply of P determines productivity.
The Everglades is an “Upside-Down” estuary: marine supply of P determines productivity.

Shark River Slough

Restoration
Freshwater Inputs
Low [P] High [N]

SLR
Marine Inputs
High [P] Low [N]

Ecosystem Productivity

Freshwater Oligohaline Marine

Tides and Storms
The Everglades is an “Upside-Down” estuary: marine supply of P determines productivity.

Restoration ↓ Freshwater Inputs
Low [P] High [N]

Shark River Slough
Taylor Slough

Tides and Storms

Dry Season GW

SLR ↓ Marine Inputs
High [P] Low [N]

Ecosystem Productivity

Freshwater Oligohaline Marine
Storms and tides provide marine P to the estuary

Water Total Phosphorus (µg l⁻¹)

SRS 4
SRS 5
SRS 6
Storms and tides provide marine P to the estuary

Hurricane Wilma

Water Total Phosphorus (µg L⁻¹)

- SRS 4
- SRS 5
- SRS 6

0.6 mg P cm⁻²

0.2 mg P cm⁻²
Marine P is also delivered underground through landward brackish water discharge.
Saltwater is intruding landward underground with SLR, bringing P to ecotone

- Notable GW influence on ecotone [P] in dry seasons and years

Saha et al. 2011
Koch et al. 2012
Are other karstic estuaries “upside-down?”

Partners:
• Ecosistemas Costeros de la Peninsula de Yucatan (ECOPEY) Mex-LTER
• Comisión Nacional de Áreas Naturales Protegidas (CONANP)
• Centro de Investigación y de Estudios Avanzados (CINVESTAV-Unidad Mérida)

Yucatan Peninsula

Celestún Estuary
Are other karstic estuaries “upside-down?”

In the Celestún estuary:
- Seawater is the dominant source of water (40-43%)
- Brackish and fresh groundwater account for 31-35% and 25-26% of water input.

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Stalker et al. 2013
Are other karstic estuaries “upside-down?”

Yucatan Peninsula

Sian Ka’an Biosphere Reserve

NASA WaterSCAPES
Science of Coupled Aquatic Processes in Ecosystems from Space
Are other karstic estuaries “upside-down?”

Yucatan Peninsula

Sian Ka’an Biosphere Reserve

**NASA WaterSCAPES**

Science of Coupled Aquatic Processes in Ecosystems from Space

<table>
<thead>
<tr>
<th>TP (µM)</th>
<th>Salinity (psu)</th>
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<tbody>
<tr>
<td>Playon</td>
<td>8</td>
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<tr>
<td>Inland Cenotes</td>
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<tr>
<td>Bahia de la Ascension</td>
<td>6</td>
</tr>
<tr>
<td>Rio Negro</td>
<td>5</td>
</tr>
<tr>
<td>Groundwater in tree island</td>
<td>4</td>
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<tr>
<td>Groundwater and pore water from mangrove zone</td>
<td>3</td>
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</tbody>
</table>

Lagomasino, Price et al. 2013
Marine P subsidizes mangrove forest production

Net Ecosystem Exchange (g C m\(^{-2}\) yr\(^{-1}\))

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Value</td>
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<td>750</td>
<td>2500</td>
<td>2500</td>
<td>2500</td>
<td>2500</td>
</tr>
</tbody>
</table>

Cold snap

Hurricane Wilma

Barr, Fuentes, Engel et al.
Carbon sequestration in subtropical mangrove forests

Barr et al. 2011
Carbon sequestration in subtropical mangrove forests

- Subtropical mangrove forests among most productive on planet
- Need to constrain lateral OC transport
- Need to consider global biogeochemical consequence to high areal loss rates

Seagrass ecosystems as a globally significant carbon stock
Seagrass ecosystems as a globally significant carbon stock

The amount of carbon stored per unit area of seagrass meadow is equivalent to forests.
Carbonate chemistry creates a productivity paradox

- Storms, tides and groundwater deliver marine P subsidy that stimulate high coastal productivity
Carbonate chemistry creates a productivity paradox

- Limestone and periphyton regulate water column P concentrations to oligotrophic levels (10 ppb)

- Storms, tides and groundwater deliver marine P subsidy that stimulate high coastal productivity
Productivity Paradox – an iconic Everglades feature

- Freshwater Everglades marshes are highly P-limited
- Benthic microbial biomass is several orders of magnitude higher than other aquatic ecosystems
Productivity Paradox – Iconic feature of karstic wetlands?

Karst periphyton studies

1. Everglades, Florida
2. New River, Belize
3. Sian Ka’an, Yucatan
4. Black River, Jamaica
5. Dorcas Bay, Ontario
6. Beatie Bay, Ontario

Karst wetland field team from FIU and UNAM at the Sian Ka’an Biosphere Reserve in Quintana Roo, Mexico
Productivity Paradox – Iconic feature of karstic wetlands?

**Biomass (g m\(^{-2}\))**

- Artificial Stream
- Effluent
- Marshes
- Lakes
- Ponds
- Rivers
- Salt Marshes
- Streams
- Everglades
- Caribbean
- Canada

**Phosphorus (µg g\(^{-1}\))**

- Data from Vymazal, 1995 and Goldsborough and Robinson, 1996
Productivity Paradox – Iconic feature of karstic wetlands?

- Benthic microbial biomass consistently high across karstic wetlands
- Inverse relationship to P availability is consistent
Microbial Species Endemism... or is everything everywhere?

- Cyanobacterial assemblage contains globally distributed stromatolitic taxa

- Initial investigations of Everglades diatom flora indicated 20% endemics and many new species
Microbial Species Endemism...or is everything everywhere?

Most abundant Everglades diatoms

α diversity

- Known only to Everglades
Microbial Species Endemism...or is everything everywhere?

Most abundant Everglades diatoms

α diversity

- Red: Known only to Everglades
- Orange: Found in Caribbean
- Yellow: Found in Alvars

Known only to Everglades
Found in Caribbean
Found in Alvars
Microbial Species Endemism...or is everything everywhere?

Most abundant Everglades diatoms

Diatom-based P inference models calibrated in Caribbean wetlands using Everglades assessment approach

- Cosmopolitan Weedy Taxa

La Hée & Gaiser 2011
Iconic ecosystem sustainability

• International studies reveal iconic features broadly characteristic of karst wetlands
  • Upside-down biogeochemistry
  • Paradoxical productivity patterns
  • Constrained biological assemblages

• ILTER studies have allowed robust understanding of drivers of long-term hydrological, ecological, and social change in these distinctive ecosystems, reducing uncertainties about long-term sustainability under different agents of change.
How do biophysical and social attributes facilitate or limit the ability to build the resilience of social ecological systems such that sustainability of water is ensured in the face of internally and externally driven changes?

- Preliminary analyses that stratified each of the sites by social and ecological indices revealed strong patterns in, for example, aridity and water use.
- Gradient approach was proposed for development as manuscript and proposal.
Vulnerability Assessment of Mangroves in the Americas

Marc Simard (Jet Propulsion Laboratory), Rinku Roy-Chowdhury (Indiana University & FCE), Temilola Fatoyinbo (Goddard Space Flight Center), Victor- H. Rivera-Monroy (Louisiana State University & FCE)

NASA Land Cover Land Use Change Program (Spring 2012-Winter 2015)

Goal: To develop spatially explicit models of mangrove forest vulnerability across North, Central and South America by integrating socioeconomic coarse datasets and local surveys with multi-sensor remote sensing of mangrove use and cover change.

- Leveraging existing collective databases, collaborations and expertise, two nested sets of sites were selected for extensive (17) and intensive (7) sampling, representing a wide range of socio-demographic, economic, policy and ecogeomorphic contexts found throughout the Americas.

- Intensive assessments will be conducted for calibration and validation of the regional-scale models, relating socioeconomic activity with local changes in mangrove forest use and cover.

<table>
<thead>
<tr>
<th>Intensive Sites</th>
<th>Planned dates for field campaigns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Celestun/Campeche</td>
<td>August 2012</td>
</tr>
<tr>
<td>Brazil (Caraguatuba region)</td>
<td>November 2012</td>
</tr>
<tr>
<td>Golfo de Morosquillo, Colombia</td>
<td>2013</td>
</tr>
<tr>
<td>Terraba Sierpe, Costa Rica</td>
<td>2013</td>
</tr>
<tr>
<td>Everglades National Park, USA</td>
<td>ongoing</td>
</tr>
<tr>
<td>Guayas, Ecuador</td>
<td>2013</td>
</tr>
<tr>
<td>Gulf of Fonseca, Honduras</td>
<td>2014</td>
</tr>
</tbody>
</table>
Leveraging expertise, data products and insight within US LTER and among international LTER Networks is contributing vital ecosystem research for addressing critical global policy issues, advance research and education beyond what could otherwise be accomplished and continue to engender globally-engaged US scientists.