Blue Carbon
Mitigating CO₂ Emissions through Coastal and Estuarine Ecosystem Conservation & Restoration

Stephen Crooks Ph.D.

Silvestrum Climate Associates

Baton Rouge
June 28th, 2016
Sustainable Management

Drivers
- Climate Change, SLR, food production, Urbanization, transport

Pressures
- Flooding
- Nutrient loading, Industrial, pollution, sewage, water needs

Impact
- Reduced welfare, biodiversity loss, Fisheries decline, water quality
- GHG emission, store

State
- Reduced habitat, eutrophication, species decline, sediment budget

Response
- Habitat protection, Emissions control, Levee realignment

Adaptive Management

Mitigation

Adaptation

Monitoring Modeling

Benefits analysis
- Scenario analysis

(Crooks and Turner, 1999 Advances in Ecological Research)
Goal of Ecosystem Management (Adaptation)

- **Degraded Estuary**
  - Decreasing Resilience Range
  - Time

- **Sustainable Estuary**
  - Shifting Resilience Range
  - Time

- **Restoring Estuary**
  - Increasing Resilience Range
  - Time
Goal of Carbon Management
Paris Agreement on Climate

• Signed by 195 nations. If fully implemented the Paris Agreement on Climate could signal the beginning of the end of the fossil fuel era. Challenges faced.

• Goals are to hold global temperatures below 2°C relative to pre-levels with an ambitious target of 1.5°C.

• Sea-level will continue to gradually rise under these warming scenarios though the potential of catastrophic change are reduced.

• Elements:
  • Financing and technical support to developing countries
  • Inclusion of forests and soils
  • Country commitments to action.
Connecting the dots on blue carbon ecosystems…

1. Components of an integrated multiuse landscape
2. Sustainable livelihoods and economies
3. Climate mitigation and adaptation
4. Natural Infrastructure and flood risk reduction
5. Ameliorating local ocean acidification

Qwuloont Wetland Restoration Project
Developing the Learning Curve

1. Recognize value of wetland management
2. Establish examples of good practice
3. Achieve multi-use functional landscape
4. Adaptation to climate change
5. Incorporate GHG fluxes and storage

Blue Carbon Interventions:
- Policy adjustment
- Management actions
- Carbon finance projects

Available at Silvestrum.com
• United Nations Framework Convention on Climate Change
  – Brief national climate change negotiators
  – Identify policy opportunities
  – Engage IPCC and SBSTA
  – Multi-national demonstration projects

• National Governments
  – Establish programs and science research
  – Recognize wetlands in national accounting
  – Agency awareness, action, funding

• Local Demonstration and Activities
  – Landscape level accounting
  – Establish carbon market opportunities
  – Look for synergistic conservation benefits
  – Demonstration projects and public awareness
Coastal (blue carbon) ecosystems in focus for climate change mitigation

Forest

Peatland

Mangroves

Tidal Marshes

Seagrass
Coastal Ecosystems: Long-Term Carbon Sequestration and Storage
The state of blue carbon science: a short review of achievements and gaps

- Twilley et al 1992
- Chmura et al 2003
- Duarte et al 2005

FISHERIES

SLR

BC

GI
Carbon fluxes and storage

Tidal wetlands

NPP

Respiration (R)

Degassing

Burial

Estuaries

River input

NPP, R

POC

DOC

DIC

Contiguous shelf

Air-water exchange

NPP, R

POC export

Resuspension

BPP

Sediments

Open Ocean

Advective exchange
Estimating Global "Blue Carbon" Emissions from Conversion and Degradation of Vegetated Coastal Ecosystems

Linwood Pendleton1, Daniel C. Donato2,5, Brian C. Murray1, Stephen Crooks3, W. Aaron Jenkins1, Samantha Sifleet4, Christopher Craft5, James W. Fourquarean6, J. Boone Kauffman7, Núria Marbà8, Patrick Megonigal9, Emily Pidgeon10, Dorothee Herr11, David Gordon1, Alexis Baldera12

Table 1. Estimates of carbon released by land-use change in coastal ecosystems globally and associated economic impact.

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Global extent (Mha)</th>
<th>Current conversion rate (% yr⁻¹)</th>
<th>Near-surface carbon susceptible (top meter sediment+biomass, Mg CO₂ ha⁻¹)</th>
<th>Carbon emissions (Pg CO₂ yr⁻¹)</th>
<th>Economic cost (Billion US$ yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal Marsh</td>
<td>2.2–40 (5.1)</td>
<td>1.0–2.0 (1.5)</td>
<td>237–949 (593)</td>
<td>0.02–0.24 (0.06)</td>
<td>0.64–9.7 (2.6)</td>
</tr>
<tr>
<td>Mangroves</td>
<td>13.8–15.2 (14.5)</td>
<td>0.7–3.0 (1.9)</td>
<td>373–1492 (933)</td>
<td>0.09–0.45 (0.24)</td>
<td>3.6–18.5 (9.8)</td>
</tr>
<tr>
<td>Seagrass</td>
<td>17.7–60 (30)</td>
<td>0.4–2.6 (1.5)</td>
<td>131–522 (326)</td>
<td>0.05–0.33 (0.15)</td>
<td>1.9–13.7 (6.1)</td>
</tr>
<tr>
<td>Total</td>
<td>33.7–115.2 (48.9)</td>
<td></td>
<td></td>
<td>0.15–1.02 (0.45)</td>
<td>6.1–41.9 (18.5)</td>
</tr>
</tbody>
</table>

Compare to national emissions from all sources

Poland

Japan
# Tidal Wetland Net GHG Removal Potential

<table>
<thead>
<tr>
<th>Wetland Type</th>
<th>Carbon Sequestration Potential (tons CO(_2)e/acre/year)</th>
<th>Methane Production Potential (tons CO(_2)e/acre/year)</th>
<th>Net balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt Marsh (salinity &gt;18ppt)</td>
<td>High (0.74 – 3.71)</td>
<td>Low (&lt; 0.2)</td>
<td>High C sequestration</td>
</tr>
<tr>
<td>Mangrove</td>
<td>High (0.74 – 3.71)</td>
<td>Low – High</td>
<td>Depends on salinity</td>
</tr>
<tr>
<td>Brackish Tidal Marsh (salinity &lt;20 ppt)</td>
<td>High (0.74 – 6.68)</td>
<td>High (0.51 – 10.12)</td>
<td>Approx net balance[1]</td>
</tr>
<tr>
<td>Subsidence Reversal (managed FWTM)</td>
<td>Very High (8 - 25)</td>
<td>Very High (5 - 12)</td>
<td>Potential very high C sequestration[2]</td>
</tr>
<tr>
<td>Freshwater Tidal Marsh</td>
<td>Very High (2.02+)</td>
<td>Very high</td>
<td>Approx net balance</td>
</tr>
<tr>
<td>Estuarine Forest</td>
<td>High (1.49 – 3.71)</td>
<td>Low (&lt; 1.01)</td>
<td>High C sequestration</td>
</tr>
</tbody>
</table>

Crooks et al, 2009 Tidal Wetlands Offset Issues Paper.

\[1\] Too few studies to draw firm conclusions. CH\(_4\) emissions brackish wetlands may negate carbon sequestration within soils. Further research required.

\[2\] Too few studies to draw firm conclusions. CH\(_4\) emissions from freshwater tidal wetlands may partially or fully negate carbon sequestration within soils.
Methodological Guidance for Coastal Wetlands in the 2013 SUPPLEMENT TO THE 2006 IPCC GUIDELINES FOR NATIONAL GREENHOUSE GAS INVENTORIES: WETLANDS
1. Introduction
2. Drained Inland Organic Soils
3. Rewetted Organic Soils
4. Coastal Wetlands
5. Inland Wetland Mineral Soils
6. Constructed Wetlands for Wastewater Treatment
7. Cross-cutting Issues and Reporting

Adopted by IPCC Oct 2013, Published Feb 2014

http://www.ipcc-nggip.iges.or.jp/
U.S. Coastal Wetlands: Potential Emissions and Removal

• Drainage and excavation
• Human induced subsidence of wetlands (erosion)
  • (e.g. Mississippi Delta)
• Methane emissions from tidally disconnected /impounded waters
• Forestry Activities on Coastal Wetlands.
• Restoration of coastal wetlands and seagrasses
• Aquaculture (operations)
“Blue” Carbon Monitoring System

Linking soil and satellite data to reduce uncertainty in coastal wetland carbon burial: a policy-relevant, cross-disciplinary, national-scale approach

Lisamarie Windham-Myers

(18 Science PIs; October 2014-17)

Federal

USGS
Brian Bergamaschi
Kristin Byrd
Judith Drexler
Kevin Kroeger
John Takekawa
Isa Woo

NOAA-NERR
Matt Ferner

Smithsonian
Pat Megenigal
Don Weller
Lisa Schile

Postdoc: Meagan Gonneea

Non Federal

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U. Maryland/NOAA
U. San Francisco
Florida Intl. U.
Texas A&M U.
Independent

Jim Morris
Ariana Sutton-Grier
John Callaway
Tiffany Troxler
Rusty Feagin
Stephen Crooks

Postdoc: James Holmquist

NASA-JPL
Marc Simard
1. IPCC Tier 2: **National Scale** stock-based 30m resolution C flux maps (1996-2010) via NOAA’s C-CAP (with NWI) linked with regional SLR and SSURGO 0-1m soil data

2. IPCC Tier 3: **Sentinel Site** stock-based and process-based maps, with supporting
   - Field and remote sensing data availability
     - Within-site range of tidal wetland categories
       - Salinity, Elevation
       - Vegetation types
       - Landuse (degradation, restoration)
     - Between-site range of climate variables

3. Price of Precision **Error Analysis** (30m v 250m, Tier 1,2,3, Algorithms)
## Key Methodology Development Issues

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
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<tr>
<td>Real</td>
<td>Demonstrate that reductions have actually occurred</td>
</tr>
<tr>
<td>Additional</td>
<td>Ensure reductions result from activities that would not happen in the absence of a GHG market</td>
</tr>
</tbody>
</table>
| Permanent         | Mitigate risk of reversals
|                   | Verify reductions ex-post                                                   |
| Verified          | Provide for independent verification that emission reports are free of material misstatements |
| Owned unambiguously | Ownership of GHG reductions must be clear                                    |
| Not harmful       | Avoid negative externalities                                                |
| Practicality      | Minimize project implementation barriers                                    |
Lessons from Conservation and Restoration Planning

1. Have a clear and coherent planning approach
2. Plan conservation and restoration in the wider landscape context
3. Prioritize sites (not all are suitable)
4. Restore physical processes and ecosystem dynamics
5. Recognize the value of project design and engineering
6. Understand the restoration trajectory and ecological thresholds
7. Conserve and restore ecosystems sooner rather than later
8. Restoration of historic conditions is not always possible
9. Avoid transplantation of non-indigenous species
10. Be patient
Lessons learnt from carbon projects

1. Assume ownership of the project
2. Choose and demarcate the site(s) carefully
3. Choose the project standard and project delivery cycle
4. Access the market early
5. Link the project to other finance options
6. Check the costs and prepare for economies of scale
Lessons from community engagement

1. Invest in pre-project community capacity building
   • E.g. Field schools

2. Build capacity within government
   • National support
   • Subnational support

3. Meet in the middle
   • Train extensionists,
   • stakeholder communication

4. Establish livelihoods programs
Steps in Blue Carbon Project Planning

1. Define project concept and perform preliminary feasibility assessment.
2. Define target market and select a carbon standard
3. Establish effective community engagement
4. Design project activities
5. Assess permanence risk and develop mitigation strategy
6. Secure project development finance and structure agreements
7. Provide for legal due diligence and assess carbon rights
8. Provide for social and environmental impacts assessment
9. Maintain ongoing liaison with regulators.
10. Share and publish experience – build the learning curve
Example Project Activities

- **Conservation**
  - Protection of at risk wetlands
  - Improved water management on drained wetlands
  - Sediment recharge to coastal wetlands
  - Space for migrating wetlands

- **Restoration / creation**
  - Lowering of water levels on impounded wetlands
  - Raising soil surfaces with dredged material
  - Increasing sediment supply by removing dams
  - Restoring salinity conditions
  - Improving water quality
  - Revegetation
  - Combinations of the above
Historic

The Humber Estuary

405 km of levees
870 km² of drained wetlands

Loss of biomes and carbon stocks.

Ongoing emissions
Examples from San Francisco Estuary

300,000 acres lost

200,000 acres lost
**Pre-1880: Freshwater Tidal Marsh**

- Main Channel
- Anoxic Decay: CO₂, CH₄
- Vertical Accretion of Marsh Platform
- Water Table

**1900’s: Elevation Loss**

- Main Channel
- Microbial Oxidation: CO₂
- Wind Erosion, Burning
- Compaction

**2000’s: Increased Levee Maintenance**

- Main Channel
- Decreased Levee Stability
- Increased Pumping Costs
- Boil
- Lateral Deformation

**or Levee Failure**

**Figure 1**

Elevations and ROAs of Delta-Suisun Marsh Planning Area

**SOURCE:**
DWR 2007 LUDAR, ESA-PWA 2012
Emissions from One Drained Wetland: Sacramento-San Joaquin Delta

Area under agriculture: 180,000 ha

Rate of subsidence (in): 1 inch

2-3 million tCO$_2$/yr released from Delta

1 GtCO$_2$ release in c.150 years
4000 years of carbon emitted
Equiv. carbon held in 25% of California’s forests

Accommodation space: 3 billion m$^3$
Baseline emissions
Factor in Sea Level Rise into Project

Deposition

Transport

Erosion
Resilience to Sea Level Rise

SLR Scenario: NRC-III
Organic sedimentation rate: 1.0 mm/yr

SSC: 300 mg/L (very high)
SSC: 150 mg/L (high)
SSC: 50 mg/L (low)

Modeled with Marsh98
• 4749 ha of drained wetlands

• 29% of wetland loss in Puget Sound

• 1353 ha of restoration planned.
Figure 2 Snohomish Estuary nearshore restoration sites (Snohomish County, 2013).

Figure 8 Historic habitats of the Lower Snohomish Estuary based on River History Project (Geomorphological Research Group, Quaternary Research Center, 2005) and Haas and Collins (2001) and 2013 soil core and vegetation plot locations.
Snohomish Planning for Sea Level Rise

- Define future high water
  - 1 m
  - Location of future habitat/
  - Areas of future flood risk

- Basis for discussion
  - How to adapt to SLR
  - Land use decisions
    - Farming
    - Development
    - Conservation
    - Carbon management
Field and Laboratory Analysis

Soil carbon stock quantification:
- 3 Natural sites
- 5 Restoring sites
- 4 Restoration potential sites

Accretion rates:
- 5 sites
Restoration and carbon sequestration potential

Figure 18 Hypsometric analysis of entire project area (ha).
Table 11. Rates of sediment accretion, carbon accumulation, and mineral accumulation for five sites. Accretion rates were determined from the distribution of excess $^{210}$Pb activity with depth using one core from each site. Carbon and mineral accumulation rates were calculated from the accretion rates.

<table>
<thead>
<tr>
<th>Site</th>
<th>Site Name</th>
<th>Sediment accretion rate (cm yr$^{-1}$)</th>
<th>Carbon accumulation rate (g C m$^{-2}$ yr$^{-1}$)</th>
<th>Mineral accumulation rate (g m$^{-2}$ yr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QM</td>
<td>Quilceda Marsh</td>
<td>0.43</td>
<td>110.2</td>
<td>2134</td>
</tr>
<tr>
<td>HP</td>
<td>Heron Point</td>
<td>0.18</td>
<td>58.0</td>
<td>484</td>
</tr>
<tr>
<td>OI</td>
<td>Otter Island</td>
<td>0.58</td>
<td>173.1</td>
<td>2543</td>
</tr>
<tr>
<td>NE</td>
<td>North Ebey</td>
<td>1.61</td>
<td>352.1</td>
<td>7585</td>
</tr>
<tr>
<td>SP</td>
<td>Spencer Island</td>
<td>0.35</td>
<td>91.4</td>
<td>2148</td>
</tr>
</tbody>
</table>

Figure 19 Existing and approximate targeted restoration elevations by site as of 2013. Units are in meters (m), NAVD88.
Great Bulrush stems, roots and new shoots in autumn

Inflorescence with green rays, peduncles and brown spikelets c. 8 mm long with exserted styles

Cross-section of rhizome 7 mm thick with roots and new white shoot 5 cm tall

Lower stem 12 mm wide with leaf blade shorter than sheath

Young stamens x10; each c. 2 mm long

Fertile scale x15; dorsal side

awn
papilla
scale
midvein

style
spikelet
peduncle
ray

blades
sheath
shoot
roots
stem
shoot
rhizome cross-section
roots

EPA PWA
Key Results – Existing Projects

1. *Planned* restoration of 1,353 ha would yield 1,176,000 tons CO$_2$ sequestration at current sea level

2. Planned restoration would yield additional 1,377,000 tons CO$_2$ sequestration to future sea level

3. Total CO$_2$ sequestration of 2,553,000 tons

4. This is equivalent to the emissions from 500,000 cars in one year, or 5,000 cars/year for 100 years
Snohomish Estuary
Opportunities and Constraints

• **Opportunities**
  – High restoration potential (topo, sediment, vegetation)
  – Whole landscape restoration opportunities
  – High resilient to sea level rise (veg, floodplain, sediment)
  – Grouping project instances under single large project.
  – Community aware (local, state, federal)
  – Regional replication

• **Constraints**
  – Quantification of methane in baseline and project.
Concluding thoughts

- Base carbon projects on good practice for restoration and conservation
- Embed mitigation planning in a climate adaptation context
- Look to account across whole landscape to improve system wide resilience.
- Account for all greenhouse gases
- Include coastal forest and seasonal floodplains in GHG management
- Areas with high sediment availability will be the most resilient to sea level rise
- Methane reductions by reconnecting impaired drainage areas offer zero permanence risk.
## Coastal Land Cover (Ha)

<table>
<thead>
<tr>
<th>COASTAL LAND COVER BY CATEGORY - ALL SOILS</th>
<th>California</th>
<th>Conterminous US</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CCAP Class</strong></td>
<td>Total Area</td>
<td>Organic Soil</td>
</tr>
<tr>
<td>High Intensity Developed</td>
<td>2,573</td>
<td>66</td>
</tr>
<tr>
<td>Medium Intensity Developed</td>
<td>8,281</td>
<td>316</td>
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<td>Low Intensity Developed</td>
<td>6,761</td>
<td>568</td>
</tr>
<tr>
<td>Developed Open Space</td>
<td>2,579</td>
<td>271</td>
</tr>
<tr>
<td>Cultivated</td>
<td>101,433</td>
<td>50,269</td>
</tr>
<tr>
<td>Pasture/Hay</td>
<td>15,469</td>
<td>8,072</td>
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<tr>
<td>Grassland</td>
<td>25,948</td>
<td>11,142</td>
</tr>
<tr>
<td>Deciduous Forest</td>
<td>27</td>
<td>-</td>
</tr>
<tr>
<td>Evergreen Forest</td>
<td>227</td>
<td>18</td>
</tr>
<tr>
<td>Mixed Forest</td>
<td>63</td>
<td>4</td>
</tr>
<tr>
<td>Scrub/Shrub</td>
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<td>80</td>
</tr>
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</tr>
<tr>
<td>Bare Land</td>
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<td>161</td>
</tr>
<tr>
<td>Palustrine Aquatic Bed</td>
<td>-</td>
<td>-</td>
</tr>
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<td>-</td>
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<td><strong>Total</strong></td>
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</tr>
</tbody>
</table>

Does not include upland transition areas
Emission / removals from California’s coastal lands

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Area (Ha)</th>
<th>Emission tC / Ha/ yr</th>
<th>Total tC / yr</th>
<th>Total tCO2 / yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impaired Drainage</td>
<td>10,000</td>
<td>1.11</td>
<td>11,100</td>
<td>40,703</td>
</tr>
<tr>
<td>Salt marsh restoration</td>
<td>40,000</td>
<td>-0.91</td>
<td>-36,400</td>
<td>-133,479</td>
</tr>
<tr>
<td>Drained organic soil</td>
<td>69,483</td>
<td>7.9</td>
<td>584,916</td>
<td>2,146,641</td>
</tr>
<tr>
<td>seagrass</td>
<td>?</td>
<td>-0.43</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Natural saltmarsh</td>
<td>42,246</td>
<td>-0.91</td>
<td>-38,444</td>
<td>-140.974</td>
</tr>
</tbody>
</table>

Notes: Negative value reflects sequestration. Emissions factors derived from IPCC default values.