Sediment Accretion and Carbon Sequestration Rates in an intermittently tidal estuary on the Central California Coast

Lisa Stratton, Jennifer King, Ryan Clark
Outline

• **Sediment Accretion**, sea-level-rise and marsh extent
  • Context
  • Findings from Devereux Slough
  • North Campus Open Space Design and SLR adaptation

• **Carbon sequestration**
  • Findings from Devereux Slough
  • Context vis a vis tidal versus intermittently tidal systems
  • Restoration project sequestration: Emissions and potential sequestration
Current predictions: Impact of SLR on Tidal Saltmarsh extent (Thorne, et al)

• Under Moderate and High SLR predictions 83% of tidal wetlands would transition to unvegetated habitats by 2110 in 14 studied wetlands along the Pacific Coast.

• Primary predictive factors:
  
  *Current accretion rates*
  *Sediment supply*
  *Horizontal transgression space*
Devereux Slough, Santa Barbara, CA
Watershed size: 3.62 mi$^2$
Watershed elevation: 500ft
~ 50% Developed
Devereux Slough

51.5 acres

17% subtidal, flooded channel

60% mudflats, seasonally flooded

23% salt marsh

Intermittently tidal and variable in water depth and duration.
Sediment Cores taken to 45-47 cm and sliced into 2 cm segments for analysis
Dating sediment Cores

Cs137 isotope signal associated with nuclear bomb testing left a strong signal in sediment in 1963 and soil core studies use that as a dating mechanism.

How do you think this intermittently tidal system will perform relative to Fully Tidal Systems?

More or Less accretion?

Why?
Accretion Rate: Core 2
25 cm/2015-1963 (= 52 yrs)
= 0.48 cm/year

Accretion Rate: Core 5
15 cm/2015-1963 (= 52 yrs)
= 0.27 cm/year
More than 100 acres

Figure A-2 U.S. Coastal Survey Map, 1871/73. Adapted from Ferren and Thomas 1995.
Current road added on for reference.

1950's USGS Map NGV 29
1967: Large scale soil movement for golf course
How does land use history explain Sediment Accretion Rates at Core 2 and Core 5?
### Vertical accretion (cm year$^{-1}$)

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![Graph showing vertical accretion rates for different sites and conditions](image-url)
Rates are comparable to historic SLR rates averaging 0.3 cm/year but now rates are predicted to increase significantly.

Variation in rates reflects ability of system to accrete at higher rates with suitable sediment supply. Plants can capture and build on sediment fluxes to increase rate of accretion. How do we find max rates of accretion?

**Recent Sea Level Rise**

- Global SLR is accelerating:
  - 20th century = 2 mm/yr (e.g., Church et al., 2004)
  - 1993-present = 3 mm/yr (e.g., Merrifield and Merrifield, 2009)

Patrick Barnard, USGS
Although not linear increase
125cm/80 yrs = 1.54 cm/year
60 cm/80 years – 0.75 cm/year – nearly twice current accretion rates.
NCOS Restoration Project design considers medium to high sea level rise predictions from 2015 and provides accommodation for those potential impacts:
Loss of salt marsh in Devereux Slough – Lack of transgression space

Accommodation through creation of transgression space at multiple elevations.

Accommodation through long term conversion to a tidal system with larger tidal prism at 1.5 feet SLR.
Cross section C, West to East
Be adaptive to climate change and modeled sea level rise
Carbon Sequestration

Bulk Density (RA) by Depth

![Graph showing bulk density by depth for different cores.](image)

Carpinteria Salt Marsh Natural

![Graph showing running bulk density for natural conditions.](image)

Carpinteria Salt Marsh Restored

![Graph showing running bulk density for restored conditions.](image)
Data from Elemental analyzer.
$y = 0.8852x + 0.527$

$R^2 = 0.889$
This is based on converting LOI to SOC using the Craft equation:

\[ \text{Org C} = (0.4 \times \text{LOI}\%) + 0.0025 \times \text{LOI} \times \text{LOI} \]
Carbon Sequestration per meter squared per year Calculations based on Cs137; Callaway found Pb210 to be approximately 75% of those using Cs137 because over a longer time period (100 years).

Depth to 1963 signal – e.g. 15 or 25 cm for Devereux cores (5 and 2)
Sum of total carbon (g/cm³) in that zone, divide by 52 years (2015 minus 1963) and multiply by 10000 to convert from cm² to m²

![Carbon Sequestration Chart]

- Intermittently tidal
- Tidal
- Brackish
$y = 1.5675e^{-0.055x}$

$R^2 = 0.8945$
Costs and Benefits of NCOS Project on Carbon Sequestration

A. Business as usual (e.g. without Project):
   a. Operations of 64 acre golf course;
   b. Loss of Devereux Slough 11 acres of salt marsh due to SLR and no transgression or adaptation option.

A. With Project:
   a. Emissions associated with Construction (-)
   b. Conservation of 11 acres of Devereux sequestration (+)
   c. Addition of 22 acres of restored salt marsh at NCOS (+)
   d. Elimination of emissions associated w/ golf course (+)
Carbon impact of North Campus Open Space Restoration Project

Business as Usual Conditions:

Carbon use associated with Golf Course Operations and Maintenance

<table>
<thead>
<tr>
<th>Course</th>
<th>Carbon contribution</th>
<th>Carbon sequestered</th>
<th>Net annual carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>1337.1 MT CO2e yr⁻¹</td>
<td>156.6 MT CO2e yr⁻¹</td>
<td>1180.5 MT CO2e yr⁻¹</td>
</tr>
<tr>
<td>Sunnyvale</td>
<td>415.5 MT CO2e yr⁻¹</td>
<td>129.6 MT CO2e yr⁻¹</td>
<td>285.9 MT CO2e yr⁻¹</td>
</tr>
<tr>
<td>P2</td>
<td>465.0 MT CO2e yr⁻¹</td>
<td>112.5 MT CO2e yr⁻¹</td>
<td>352.5 MT CO2e yr⁻¹</td>
</tr>
<tr>
<td>Average</td>
<td>739.2 MT CO2e yr⁻¹</td>
<td>132.9 MT CO2e yr⁻¹</td>
<td>606.3 MT CO2e yr⁻¹</td>
</tr>
</tbody>
</table>

Table 3. Total Annual Carbon Flux. Calculated carbon equivalent from spreadsheet model.

Golf course were on average 150 acres, emissions associated with electricity, water, fuel, fertilizer, average 4 MT C eq/year/acre. For Ocean Meadows (64 acres) that equals 258 MT/year total emissions.

Loss of 11 acres of salt marsh in Devereux Slough due to SLR

65 g C/m² over 11 acres (x 4046 m²/acre)/1,000,000 g/MT/year = 0.26 MT/acre/yr or: 2.89 MT total Devereux Slough.

Over 100 years that would represent 289 MT C eq sequestered.
WITH Project Carbon Emissions and sequestration potential
Total net CO$_2$-e emissions were 526.83 metric tons,

from grading 350,000 cy, site preparation and multimodal trail and bridge construction.

The American Carbon Registry (ACR) provides a tool to calculate net carbon dioxide equivalent (CO$_2$-e) emissions from fossil fuel combustion.
With Project Conditions at NCOS

A. With Project:
   a. Emissions associated with Construction (-) –
      + 526.83 metric tons = Total net CO\textsubscript{2}-e emissions

   b. Conservation of 11 acres Devereux sequestration (+)
      -289 MT C eq sequestered over 100 years

   c. Addition of 22 acres restored salt marsh NCOS (+)
      -578 MT C eq sequester over 100 years

   d. Elimination of emissions associated w/ golf course
      -258 MT C eq/year x 100 years
      ~ 25,800 MT/100 yrs

NET 26,141 MT C reduced emissions over 100 years.
Multiple Other Benefits of NCOS Project

Flood Reduction

Trails support walking and biking to work

Educational Benefits

Climate Change and SLR adaptation

Aquifer Recharge
Water Quality benefits – N-cycling, filtration

Endangered species habitat
Migratory bird habitat
Conservation of local genotypes and plant communities
Project made possible thanks to our PARTNERS!
Additional partners
Table 1: Carbon sequestration over the 52 years since the Cs Spike.

<table>
<thead>
<tr>
<th></th>
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<th>Core 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical accumulation (cm/year)</td>
<td>0.48</td>
<td>0.488</td>
<td>0.488</td>
<td>0.488</td>
<td>0.28</td>
</tr>
<tr>
<td>Mineral accum g/m2/year</td>
<td>2331.920834</td>
<td>2344.326193</td>
<td>2331.690954</td>
<td>2324.369527</td>
<td>1396.195443</td>
</tr>
<tr>
<td>Organic accum g/m2/year</td>
<td>168.0791658</td>
<td>155.6738067</td>
<td>168.3090459</td>
<td>175.6304729</td>
<td>142.2660957</td>
</tr>
<tr>
<td>Carbon Sequestration gC/m2/year</td>
<td>71.18250931</td>
<td>65.80556081</td>
<td>74.04747146</td>
<td>75.72623847</td>
<td>64.58598</td>
</tr>
<tr>
<td>in g/cm²/year</td>
<td>0.233192083</td>
<td>0.234432619</td>
<td>0.233169095</td>
<td>0.232436953</td>
<td>0.139619544</td>
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<tr>
<td>Organic accum g/cm²/yr</td>
<td>0.016807917</td>
<td>0.015567381</td>
<td>0.016830905</td>
<td>0.017563047</td>
<td>0.01422661</td>
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Table 2. Bulk density and % organic matter average over top 20 and 10 cm depth (Elgin did 10 and Callaway 20)

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<tr>
<td>Org Matter BD top 20 (g/cm³)</td>
<td>1.0957916670</td>
<td>0.9583986770</td>
<td>0.8488323930</td>
<td>0.9473277490</td>
<td>0.527309498</td>
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<tr>
<td>% Org top 20</td>
<td>8.7963102599</td>
<td>4.6091434214</td>
<td>5.481677112</td>
<td>5.125501320</td>
<td>4.0282513</td>
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<tr>
<td>Top 10 cm</td>
<td>12.8255003214</td>
<td>5.556720425</td>
<td>8.226703520</td>
<td>0.716343324</td>
<td>6.2188939</td>
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**Vertical accretion (cm year$^{-1}$)**

**Carbon sequestration (g m$^{-2}$ year$^{-1}$)**

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<tr>
<td></td>
<td>Org Matter Density (g/cm³)</td>
<td>OM Density top 10cm</td>
<td>OM Density top 20cm</td>
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<tr>
<td></td>
<td></td>
<td>0.09308892</td>
<td>0.07934077</td>
<td>0.08650621</td>
<td>0.08498345</td>
<td>0.09403809</td>
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<td></td>
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<td>0.07618834</td>
<td>0.06623908</td>
<td>0.06405996</td>
<td>0.07398317</td>
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<td>0.90691108</td>
<td>0.92065923</td>
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<td>0.92381166</td>
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<td>0.93594004</td>
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Avg Rates of Vertical accretion, mineral accumulation and carbon accum based on 137 Cs over 52 years for 25 cm in cores 1-4 and 15cm in core 5

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<td>(based on Craft equation data)</td>
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<td>estimated C sequestration per year over 22 acres in NCOS</td>
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<tr>
<td>89,030 m2/22 acres</td>
<td>6337378.8</td>
<td>5858669.08</td>
<td>6592446.38</td>
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<td>5750089.8</td>
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<tr>
<td>metric tons/year (divide by 1,000,000)</td>
<td>6.3373788</td>
<td>5.85866908</td>
<td>6.59244638</td>
<td>6.74190701</td>
<td>5.7500898</td>
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<tr>
<td>X 100 years = tons C per 100 years</td>
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(based on Craft equation data)

Estimated C sequestration per year over 22 acres in NCOS

89,030 m²/22 acres

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Metric tons/year (divide by 1,000,000)

6.3373788  5.85866908  6.59244638  6.74190701  5.7500898

X 100 years = tons C per 100 years

633.73788  585.866908  659.244638  674.190701  575.00898
Habitat and Trail Map shows proposed wetland and upland habitats and average water levels within the proposed sub-tidal and marsh plain elevations. Ensuing images show photos of a variety of proposed habitats.
Total net CO$_2$-e emissions were 526.83 metric tons, 490.37 metric tons (93%) of which were from grading and site preparation from April 14, 2017 to October 6, 2017, and 36.46 metric tons (7%) of which were from multimodal trail and bridge construction from November 27, 2017 to June 21, 2018.

The American Carbon Registry (ACR) provides a tool to calculate net carbon dioxide equivalent (CO$_2$-e) emissions from fossil fuel combustion.