Quantification of Health and Productivity of Salt Marshes Using Satellite Data

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Salt Marsh
The Deepwater Horizon oil spill

- 20 April 2010
  - Continued flowing for three months

- Largest off-shore oil spill in U.S. history
  - Estimated 206 million gallons of crude oil

- First major U.S. oil spill to affect marsh/wetland habitat

http://gallery.usgs.gov/photos/05_05_2010_s84Aq10Ppk_05_05_2010_1
Impact on Salt Marsh Habitat

• Particularly damaging to marshland and marine habitat
  – Loss in green biomass (browning)
  – Reduction in photosynthetic activity
  – Impact from cleaning efforts
    • Burning
    • Flushing
    • Skimming
Objectives

• Estimate short term impact of the oil spill on salt marsh habitat by evaluating marsh biophysical characteristics

• Using remote sensing data, develop models and products that will facilitate monitoring restoration efforts of the coastal salt marsh habitat
Study Area

Louisiana Estuarine and Marine Salt Marshes

Area - 4554.7 sq. km

Vegetation:
- Spartina patens
- Spartina alterniflora
- Juncus roemerianus
- Distichlis spicata
- Salicornia virginica

☆ Sites
Field Data

- 69 locations; Aerial and Ground Survey

- Top of Canopy (TOC) hyper-spectral reflectance data (Ocean optics USB 4000 Spectroradiometer and ASD sensor)

- Vegetation Fraction (Olympus E-502 Digital Camera)

- Leaf Area Index (LAI Plant Canopy Analyzer 2000)

- Leaf level chlorophyll content (Minolta SPAD 502)

- Canopy level chlorophyll content calculating as $\text{Chl}_{\text{upper}} \times \text{LAI}$

- Above ground green biomass (gm/ft$^2$)
Field Methods

Dual Sensor Approach

\[ \rho = \frac{L}{E} \]

- \( L \): upwelling radiance
- \( E \): downwelling irradiance
- \( \rho \): remote sensing reflectance (sr\(^{-1}\))

Data acquisition

Sensor-Target: 16 ft
IFOV: 2.2 meter

~2m
Field Methods:
Canopy Chlorophyll

Leaf Area Index (LAI)

Leaf Level Chlorophyll

Canopy Chl = Leaf Level CHL * LAI
Leaf Area Index (Foliage area/Ground area)

The measurement of LAI is of fundamental importance in ecological research because LAI is a measure of plant growth; it directly affects the interception and absorption of light by the canopy and it influences the primary productivity of vegetation.
Vegetation Fraction (VF) = ratio of green vegetation area to ground area

Vegetation fraction is obtained as a ratio of the number of vegetation pixels to the total number of pixels in the image, expressed in percent

VF = 86%
VF = 42%
Field Methods

1. Canopy Height
   - Average of 5 measurements within a 1m radius of the scan center

2. Green Biomass
   - Destructive sampling of vegetation after reflectance acquisition
     - Samples were sorted, oven dried, and weighed
### Field Data

<table>
<thead>
<tr>
<th>N = 69</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>St. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass (g/ft²)</td>
<td>3.9</td>
<td>566.2</td>
<td>82.6</td>
<td>84.04</td>
</tr>
<tr>
<td>LAI</td>
<td>0.01</td>
<td>2.57</td>
<td>1.02</td>
<td>0.7</td>
</tr>
<tr>
<td>VF (%)</td>
<td>0.3</td>
<td>99</td>
<td>34</td>
<td>25.34</td>
</tr>
<tr>
<td>Canopy Chlorophyll (mg/m²)</td>
<td>0.4</td>
<td>1321</td>
<td>134.1</td>
<td>209.88</td>
</tr>
</tbody>
</table>

**Objective:** Measure *in-situ* canopy-level reflectance of dominant vegetation

- Develop spectral models to characterize selected biophysical parameters of each vegetation species individually
- Develop a single model to characterize biophysical parameters for the entire marsh regardless of speciation
Applied Vegetation Indices (VIs) for GBM estimation per species

<table>
<thead>
<tr>
<th>Vegetation Index</th>
<th>Application</th>
<th>Formula</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normalized Difference Vegetation Index (NDVI)</td>
<td>Biomass, Chl, VF</td>
<td>$\frac{NIR - Red}{NIR + Red}$</td>
<td>Rouse et al., 1974</td>
</tr>
<tr>
<td>Wide Dynamic Range Vegetation Index (WDRVI)</td>
<td>Chl, LAI, VF</td>
<td>$\frac{0.2NIR - Red}{0.2NIR + Red}$</td>
<td>Gitelson, 2004</td>
</tr>
<tr>
<td>Enhanced Vegetation Index (EVI)</td>
<td>Biomass, LAI</td>
<td>$\frac{2.5NIR - Red}{NIR + 6Red - 7.5Blue}$</td>
<td>Huete, 2002</td>
</tr>
<tr>
<td>Chlorophyll Index – Green (CI\textsubscript{green})</td>
<td>Chl, GPP, VF</td>
<td>$\left(\frac{NIR}{Green}\right) - 1$</td>
<td>Gitelson, 2006</td>
</tr>
<tr>
<td>Chlorophyll Index – Red Edge (CI\textsubscript{red edge})</td>
<td>Chl, GPP, VF</td>
<td>$\left(\frac{NIR}{Red Edge}\right) - 1$</td>
<td>Gitelson, 2006</td>
</tr>
</tbody>
</table>

Applied 15 VIs
- 5 models with 3 variants of each model using 760, 800, and 1100nm for NIR
Weighted Difference Biophysical Index (WDBI): best correlated when working with all species

\[ WDBI = \frac{0.2 \times \rho_{\text{NIR}} - \rho_{\text{green}}}{0.2 \times \rho_{\text{NIR}} + \rho_{\text{red}}} \]

Uses three characteristics of vegetation reflectance:

1) Visible wavelength with least absorption and most reflectance \((r_{\text{green}})\)
   - Does not saturate at high biophysical values

2) Visible wavelength with the highest absorption \((r_{\text{red}})\)
   - Representative of non-pigment scattering

3) Spectral region most sensitive to vegetation canopy structure \((r_{\text{NIR}})\)
Satellite Data

Multi-temporal LANDSAT TM 2009 - 2010

<table>
<thead>
<tr>
<th>Dates</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>May</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>June</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>July</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>August</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>September</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>October</td>
<td>13</td>
<td>9</td>
</tr>
</tbody>
</table>
Model Calibration

WDRVI = \( (\alpha \lambda_{\text{NIR}} - \lambda_{\text{Red}}) / (\alpha \lambda_{\text{NIR}} - \lambda_{\text{Red}}) \)

GBM = 298.943 \times \text{WDRVI (} \alpha = 0.05 \text{)} + 264.494

CHL = 251.955 \times \text{WDRVI (} \alpha = 0.1 \text{)} + 182.327
Model Validation

- CHL: 11.64%
- GBM: 6.92%
Results

Decrease in area (sq.km)

- CHL
- GBM

2009: 50
2010: 450
Results: Phenology

Fringing Marshes

Interior Marshes

Graphs showing the phenology of canopy chlorophyll and biomass over the months of April, May, June, July/Aug, and October for Fringing Marshes and Interior Marshes.
Temperature

- April
- May
- June
- July
- August
- September
- October

Precipitation

- April
- May
- June
- July
- August
- September
- October

Temperature (°F)

Precipitation (in)
Preliminary Results: MODIS
Preliminary Results: MODIS

2010 MODIS Derived LAI
Conclusion and Future Research

• This study successfully delineate the critical hotspots and the pattern of marsh stress and so that prioritization of restoration areas can be performed

• Tune models with more local data

• Apply the approach on the marsh degradation caused by other factors
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