Coastal Wetlands and Sea Level Rise: A Remote Sensing Perspective

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1.1 The projected range of global averaged sea-level rise re-plotted from the IPCC 2001 Third Assessment Report for the period 1990 to 2100.
Wetlands and Sea Level Rise (SLR)

- Wetlands valuable
  - Very productive (fisheries)
  - Wildlife habitat
  - Storm buffer
  - Pollution filter
- SLR will result in loss of 26%-69% wetlands
  - Inundation, erosion, saltwater intrusion
  - Gulf Coast will have greatest wetland loss
- Adaptation policies
  - Retreat, accommodate, protect
  - All costly to economy & society
Milford Neck Conservation Area

- 10,000 acres owned by
  - Delaware Division of Fish and Wildlife
  - Delaware Wildlands
  - The Nature Conservancy

- Complex dynamic landscape characterized by
  - Transgressing shoreline
  - Extensive tidal wetlands
  - Island hammocks
  - Upland forests

- Important habitat for
  - Migratory shore birds
  - Spawning horseshoe crabs
  - Beach – nesting birds
  - Waterfowl and wading birds
  - Forest interior dwelling birds
Milford Neck Conservation Area (cont)

- Narrow barrier beach was breached during winter of 1985-86.
- Breach allowed direct exchange of tidal flow between Delaware Bay and Greco’s Canal.
- Large areas of tidal marsh northwest of breach have become permanently inundated.
- Open water west of Greco’s canal has increased from 40 ha to 160 ha. (with loss of Sp. alterniflora marsh)
- Gravel sill at mouth of canal at breach regulates interior marsh hydrology.
- Phragmites expanding.
- Sediment erosion/accretion not yet clear.
Marsh Changes Due to SLR
Inundation by Saltwater

Tidal flat  →  open water
Low marsh  →  tidal flat
High marsh  →  low marsh
Upland forest  →  high marsh
Impact of Erosion Due to SLR

- Coverage by water $\rightarrow$ loss of vegetation
- Loss of vegetation $\rightarrow$ reduced sediment stability & entrapment
- Loss of stability $\rightarrow$ erosion of shoreline
- Storm surge $\rightarrow$ beach loss (1500 ft)
Impact of Hydrologic Changes

- Increased flow → channel widening and bank scouring (5.1-7.3 m; 9.1-16.2 m)
- Changed flow → sediment redistribution (lagoon: north accrete, south erode)
- Inundation → loss of vegetation, change of animal habitat
- Sill in canal → modified tidal flow (tidal range at breach= 4.6 ft mean, 5.5 ft spring)
- Salinity change → redistribution of Phragmites
Breach At Milford Neck
Winter 2002 Orthophoto
1 meter ground resolution distance
Milford Neck Canal Breach
18 September 1999
AISA Hyperspectral (1 m pixel size)

Both images at low tide.

Milford Neck Canal Breach
24 August 2001
Ikonos Merged Image (1-4 m pixel size)
Milford Neck Questions

1. Will the lagoon/mudflat system stabilize or return to salt marsh? (Sediment accretion monitoring stations and DEM)

2. What are present trends and rates of hydrologic and habitat change?

3. How much vegetation loss due to standing water and Snow Goose eat-outs?

4. Should management intervene in hydraulic regime by channel modification to delay or accelerate marsh development in a particular direction?
Remotely Sensed Environmental Indicators (Surrogates)

<table>
<thead>
<tr>
<th>Remotely Sensed</th>
<th>Derived_ *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Cover/Use/Buffers</td>
<td>Water Quality &amp; Wetland Health</td>
</tr>
<tr>
<td>Aboveground Biomass</td>
<td>Wetland Health</td>
</tr>
<tr>
<td>Drainage Network</td>
<td>Wetland Hydrology</td>
</tr>
<tr>
<td>Wetland Vegetation</td>
<td>Tidal Range</td>
</tr>
<tr>
<td>Water Color</td>
<td>Eutrophic State</td>
</tr>
<tr>
<td>Chlorophyll Conc.</td>
<td>Primary Production</td>
</tr>
<tr>
<td>Susp. Sediment Conc.</td>
<td>Light Attenuation</td>
</tr>
<tr>
<td>Fronts, Slicks, Plumes</td>
<td>Pollutant Dispersion</td>
</tr>
</tbody>
</table>

* Some of the derived properties require the use of ancillary data
Table 5.2 Coastal Wetland Species and Inundation Levels

<table>
<thead>
<tr>
<th>Low Marsh (Below MHT)</th>
<th>Intermediate Marsh (Across MHT)</th>
<th>High Marsh (Above MHT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spartina alterniflora</td>
<td>Spartina cynosuroides</td>
<td>Spartina patens</td>
</tr>
<tr>
<td>Salt water cord grass</td>
<td>Salt water cord grass</td>
<td>Salt hay</td>
</tr>
<tr>
<td>Pipe reed</td>
<td>pipe reed</td>
<td>salt meadow grass</td>
</tr>
<tr>
<td>many animals &amp; birds</td>
<td></td>
<td>drained marsh</td>
</tr>
<tr>
<td>muskrats, ducks, geese</td>
<td>Scirpus olneyi</td>
<td>Distichlis spicata</td>
</tr>
<tr>
<td>song sparrows, wrens</td>
<td>sedge</td>
<td>spike grass</td>
</tr>
<tr>
<td>clapper rail, etc.</td>
<td>less productive</td>
<td>salt hay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>drained marsh</td>
</tr>
<tr>
<td></td>
<td>Scirpus robustus</td>
<td>less productive</td>
</tr>
<tr>
<td></td>
<td>sedge</td>
<td></td>
</tr>
<tr>
<td></td>
<td>less productive</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phragmites australis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Useless</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crowds out other plants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grows near disturbed &amp; Sedimented areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Iva frutescens</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marsh elder</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Baccarhis halimifolia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sea myrtle</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hibiscus moschuetus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marsh hollybrook</td>
</tr>
</tbody>
</table>
Change Detection Approach

1. Wetlands are spatially complex & heterogeneous. Require high spatial & spectral resolution.

2. High resolution satellite data (IKONOS, QuickBird) lack spectral resolution and is expensive.

3. Airborne hyperspectral data is costly & requires experienced analysts.

4. Proposed approach:
   - use biomass as indicator
   - detect biomass changes with Landsat TM
   - study “flagged” areas with IKONOS.
\[ \text{NDVI} = \frac{\rho_{\text{nir}} - \rho_{\text{red}}}{\rho_{\text{nir}} + \rho_{\text{red}}} \]

\[ \text{NDII} = \frac{\rho_{\text{nir}} - \rho_{\text{mir}}}{\rho_{\text{nir}} + \rho_{\text{mir}}} \]

\[ \text{SAVI} = \frac{\rho_{\text{nir}} - \rho_{\text{red}}}{\rho_{\text{nir}} + \rho_{\text{red}} + L} \ (1 + L) \]

\[ \text{MSAVI} = \frac{2\rho_{\text{nir}} + 1 - \sqrt{(2\rho_{\text{nir}} + 1)^2 - 8(\rho_{\text{nir}} - \rho_{\text{red}})}}{2} \]
Figure 6. Demonstrations of soil background influences on the MSAVI, SAVI, WDVI and NDVI using MAC aircraft data.
Multiple Remote Sensing Features

- Spectral (hyperspectral band optimization)
- Spatial (texture, shape, context)
- Multitemporal (seasonal vegetation differences)
- Multisensor (MSS/Radar: forest vs forested wetland)

Incorporation of Ancillary Data

- Topography (vegetation altitude zonation)
- Soils (impact on vegetation)
- Road Density (urban lawns vs pastures)
- Other GIS data layers
Recent Advances in Remote Sensing

• High resolution satellite sensors (0.6 – 4 m)

• Hyperspectral imaging systems (200+ bands)
  (Hyperion, AVIRIS, AISA, CASI)

• Classification algorithms (neural networks, spectral mixture,
  texture, nearest neighbor, knowledge based, etc)

• Geographic Information Systems (GIS)

• Global Positioning System (GPS) (1-10 m)

• New platforms and field equipment (ocean gliders, UAV’s,
  robots, auticopters, helikites, etc)
END
Similar Classes Combined

- Unconsolidated Shore
- Vegetated Unconsolidated Shore
- Spartina alterniflora (1) and (2)
- Salt Marsh Hay
- Phragmites and Canes
- High Tide Bush
- Shallow Water/Tidal Flat and Open Water
CLIMATE CHANGE

Predictions for 2100

Old T rise ( + 1.4°C to 5.8°C)
New T rise ( + 2°C to 6°C)
Sea level rise (+9 cm to 88 cm)

Indicators and Causes (Recent)

• Reduction of aerosols (control)
• Permafrost melting (albedo, CO₂, methane)
• Biomass feedback (soil & veg. CO₂ sources)
• Arctic ice shrinking (reducing albedo)
• Antarctic & Greenland ice (reducing albedo)
• Tropical cyclones more intense (warmer water)
• Ocean circulation changes (fresh water)
<table>
<thead>
<tr>
<th>Sponsor</th>
<th>Space Imaging</th>
<th>Digital Globe</th>
<th>Orbimage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial Resolution (m)</td>
<td>1.0</td>
<td>0.61</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>4.0</td>
<td>2.44</td>
<td>4.0</td>
</tr>
<tr>
<td>Spectral Range (nm)</td>
<td>Panchromatic</td>
<td>525 - 928</td>
<td>450 - 900</td>
</tr>
<tr>
<td></td>
<td>Blue</td>
<td>450 - 520</td>
<td>450 - 520</td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>510 - 600</td>
<td>520 - 600</td>
</tr>
<tr>
<td></td>
<td>Red</td>
<td>630 - 690</td>
<td>625 - 695</td>
</tr>
<tr>
<td></td>
<td>Near Infrared</td>
<td>760 - 850</td>
<td>760 - 900</td>
</tr>
<tr>
<td>Swath width (km)</td>
<td>11.3</td>
<td>16.5</td>
<td>8</td>
</tr>
<tr>
<td>Off nadir pointing</td>
<td>±26°</td>
<td>±30°</td>
<td>±45°</td>
</tr>
<tr>
<td>Revisit time (days)</td>
<td>2.3 - 3.4</td>
<td>1 - 3.5</td>
<td>1.5 - 3</td>
</tr>
<tr>
<td>Orbital Altitude (km)</td>
<td>681</td>
<td>450</td>
<td>470</td>
</tr>
</tbody>
</table>

Table 1: Satellite parameters and spectral bands (Space Imaging, 2003; Digital Globe 2003; Orbimage, 2003)
Environmental Factors

- Tidal range at breach (3-5 ft)
- Slope of land (shallow)
- Sediment supply (variable)
- Roads, canals, farmlands
Milford Neck Wildlife Conservation Area – Key Questions

1. Will the lagoon and mudflat areas relatively quickly infill and develop low marsh vegetation or will the extensive open water/mudflat persist or continue to expand?

2. Would it be possible/desirable by management to intervene in the hydraulic regime by channel modification to accelerate or delay the marsh development in a particular direction?
Tidal Wetland Land Cover Classes Mapped

1. Unconsolidated Shore
2. Spartina alterniflora (1)
3. Spartina alterniflora (2)
4. Salt Hay
5. Phragmites
6. Phragmites canes
7. High Tide Bush
8. Shallow Water/Tidal Flat
9. Open Water
10. Vegetated Unconsolidated Shore
11. Other
GENERAL SPECS AND DIMENSIONS
Main Rotor diameter: 72"
Height: 26"
Total length from tip of main blade to tip of tail blade: 86"
Payload capacity: 25lbs
Distance between tail and main shafts: 45"
Airframe construction of mostly 7075 and some 6061 aluminum.
Main and tail blade material: Carbon fiber

ENGINE
Number of cylinders: 2
Engine type: Two-stroke, air-cooled
Fuel mixture: Regular unleaded/oil mixture
Fuel capacity: 30 minutes
Horsepower: 5.75 hp
Operating RPM: 11,000

TRANSMISSIONS
Main trans.: Belt driven- HTD timing belts
Tail trans.: Belt driven- GT timing belt
The Relationship of Some Coastal Vegetative Species to the Mean High Tide Level

<table>
<thead>
<tr>
<th>High Marsh (Generally above MHT)</th>
<th>Intermediate Marsh (Across MHT)</th>
<th>Low Marsh (Below MHT)</th>
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<tr>
<td>Spartina patens</td>
<td>Spartina cynosuroides</td>
<td>Spartina alterniflora</td>
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<tr>
<td>Baccarhitis halimifolia</td>
<td>Scirpus olneyi</td>
<td>Amaranthis cannabina</td>
</tr>
<tr>
<td>Phragmites australis</td>
<td>Scirpus robustus</td>
<td>Peltandra virginica</td>
</tr>
<tr>
<td>Distichlis spicata</td>
<td>Scirpus americanus</td>
<td>Pontederia cordata</td>
</tr>
<tr>
<td>Iva frutescens</td>
<td>Typha augustifolia</td>
<td>Nuphar advena</td>
</tr>
<tr>
<td></td>
<td>Typha latifolia</td>
<td>Zizania aquatica</td>
</tr>
</tbody>
</table>
Land Cover Changes at Milford Neck Wildlife Conservation Area (1954 – 1999 Sea Level Rise and Grecos Canal Breech)

Agriculture

Shrubs

Forest (Palustrine)

Sp. Patens

Phragmites

Sp. Alterniflora

Unconsolidated Shore

Open Water/Mudflats

Shrubs  Sp. P.
Land Cover Changes at Milford Neck Wildlife Conservation Area (1938 – 1954 Grid Ditching)

- Open Water Mudflats
  - Sp. Alterniflora
    - Sp. Patens
      - Shrubs
        - Agriculture
      - Phragmites
        - Forest
Tidal Wetland Habitat Problems

1. Grid – ditching for mosquito control (90% of northeast since 1930’s)
2. Pollutant run-off from watershed.
3. Phragmites expansion
4. Snow geese eat-outs
5. Wetland fragmentation (roads, ditches, etc)

Possible Solutions

1. Open Marsh Water Management (OMWM) creates open water habitats (ponds) for fish that eat mosquito larvae.
2. Create vegetated buffers (grass, forest) to filter and reduce run-off.
3. Control phragmites with herbicides, burning or hydrology (salinity).
4. Confine goose herbivory to discrete areas of wildlife refuge impoundments.
5. Avoid constructing new roads, ditches etc. in wetland habitats and link wetland habitats by creating wetland corridors.
<table>
<thead>
<tr>
<th>STRESSOR CHECKLIST</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Hydrologic modification</td>
</tr>
<tr>
<td>• Sedimentation</td>
</tr>
<tr>
<td>• Dissolved oxygen</td>
</tr>
<tr>
<td>• Contaminant toxicity</td>
</tr>
<tr>
<td>• Vegetation alteration</td>
</tr>
<tr>
<td>• Eutrophication</td>
</tr>
<tr>
<td>• Acidification</td>
</tr>
<tr>
<td>• Turbidity</td>
</tr>
<tr>
<td>• Thermal alteration</td>
</tr>
<tr>
<td>• Salinity</td>
</tr>
</tbody>
</table>
Change Detection Problems

1. Interannual variation (dry vs. wet year)
2. Seasonal variation (leaf-off vs. leaf-on)
3. Atmospheric (scattering and absorption)
4. Tidal variation (within 1 ft. of LMT)
5. Clouds and shadows
6. Solar irradiance, angle, azimuth
7. Spatial misregistration
8. Resolution differences
9. Sensor radiometric drift
1. The average biomass of a healthy wetland may vary greatly between years, but the relative spatial distribution of biomass will remain essentially constant.

2. Compute mean and standard deviation (SD) of MSAVI for each sub-basin.

3. Compute MSAVI deviation from sub-basin mean (Z-score) for each pixel where

\[
Z = \frac{MSAVI - \overline{X}_{MSAVI}}{(SD)_{MSAVI}}
\]

4. Compute difference \(Z_{before} \) – \(Z_{after}\) for each pixel.

5. Select threshold for significant change (e.g. 2 SD).

6. Evaluate changes in flagged areas using high resolution imagery.
Advantages of Biomass Change Detection Approach

1. Corrects for natural variations between scenes in a time series. (e.g. interannual, seasonal, atmospheric, etc.)

2. Requires no absolute calibration of biomass values, since detect only relative biomass changes.

3. Corrects for soil reflectance variations without the need for local correction factors (MSAVI).

4. Is linear over wide range of biomass values (MSAVI).

5. Requires high resolution data only for changed sites identified by medium resolution imagery.
Impact of Land Use on Water Quality

Map
• Land Cover (forest, agriculture, urban, etc.)
• Land Use (row crops, pastures, low/high density residential, industrial, etc.)
• Land Use Practice (till/no-till corn, disturbed/non-disturbed soil, etc.)
• Topography & Geology (slopes, soils, drainage network, etc.)

Measure
• Precipitation (seasonal, annual, daily)
• Water Discharge Rates (seasonal, storms, etc.)
• Water Quality (nutrients, particulates, bacterial, herbicide, heavy metals, etc.)

Model
• Calculate average seasonal area-yield loadings from each land use category for each water quality parameter.
• Predict future water quality as land use changes.
SLR impacts on wetlands

- Inundation by saltwater (drowning!)
  - Tidal flat $\leftrightarrow$ open water
  - Low marsh $\leftrightarrow$ tidal flat
  - High marsh $\leftrightarrow$ low marsh
  - Upland forest $\leftrightarrow$ high marsh

Kana et al 1991
Interacting factors

- **Slope of land**
  - Steeper = more loss

- **Sediment supply**
  - Less = more loss

- **Human developments**

- **Tidal range**
  - Smaller range = more loss
  - Faster rise = more loss

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**Figure 2:** Four modes of wetland response to rising sea level are defined by extremes in landscape slope and sediment supply: (a) High marsh encroaches on terrestrial forest by migrating overland; tidal creeks and lagoon margins prograde toward the estuary because sediment is abundant. (b) Similar to (a) except that marsh-ward erosion occurs because sediment supply is low. (c) Similar to (a) but steep slope stalls overland migration. (d) Similar to (c) but erosion occurs. (From Branson et al. 1995)
Sediment accretion is the key!

- Accretion rate $\geq$ sea level rise rate = migration
- Accretion rate $<$ sea level rise rate = drowning
Wetland loss with sea level rise

- By 2100, best estimate 29 –69% total

<table>
<thead>
<tr>
<th>Sea level rise</th>
<th>Square miles lost</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 m</td>
<td>4,000</td>
<td>30%</td>
</tr>
<tr>
<td>1 m</td>
<td>6,441</td>
<td>49%</td>
</tr>
<tr>
<td>2 m</td>
<td>7,423</td>
<td>56%</td>
</tr>
<tr>
<td>3 m</td>
<td>13,145</td>
<td>100%</td>
</tr>
</tbody>
</table>
So what can we do?

Three options

• **Retreat** - no protection of land
• **Accommodation** - limited protection of developed areas with planned retreat
  – Flood shelters
  – Raise buildings
  – Switch to aquaculture or different crop
• **Protection** – permanent protection for all developed areas
  – Soft or hard structures
Environmental implications

• **Retreat** – some loss (26% - 66% loss)
  – Ecosystems grow inland where accretion rate > sea level rise

• **Accommodation** – same result (29-69% loss)

• **Protection** – wetlands squeezed between structures and sea (50% - 82% loss)
  – Less loss with soft vs. hard structures
Economic implications

- **Retreat** – landowners bear all the costs
- **Accommodation**
  - Landowners lose property value
  - Eventual buy-out
  - Rolling easements
  - Lease land from buyer
- **Protection** – government pays all
Louisiana today

- Subsiding at 4 - 8.8 mm/yr as land settles
- Decreased sedimentation rate
  - Sediment impounded upstream
  - Spring flood contained
  - Distributaries dammed
- Increased saltwater intrusion
  - Channelization & dredging
- ~34 mi² / yr

From: www.lacoast.gov/watermarks/2005-08/1wetlandsDisappear/index.htm
Summary

• Wetlands valuable
  – Wildlife habitat
  – Fishery resource
  – Recreation & housing areas
  – Buffer zone

• Sea level rise will result in loss of 26-69% wetlands
  – Inundation, erosion, saltwater intrusion
  – Gulf Coast will experience greatest wetland loss

• Adaptation policies
  – Retreat, accommodation, protection
  – All costly to economy, environment, & society

Photos from: shiftingbaselines.org/blog/images/mangrove.jpg & www.dickinson.edu/departments/envst/lucewebpage