Remote Sensing of Wetland Change

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SYSTEM & TECHNIQUE EVALUATION

Working with NOAA/NERRS, USC, NOAA/CSC, DSU and Delaware DNREC, we have been evaluating estuarine habitat mapping and change detection techniques using imagery:

- aerial hyperspectral (AISA/CALMIT)
- aerial multispectral (digital camera)
- IKONOS multispectral (QuickBird)
- Landsat/TM multispectral

Tests were conducted on land cover, emergent wetlands and submerged vegetation at four NERRS sites:

- St. Jones River & Blackbird Creek, Delaware
- ACE Basin, South Carolina
- Grand Bay, Mississippi
- Padilla Bay, Washington
TYPICAL NERRS HABITAT QUESTIONS ADDRESSED BY REMOTE SENSING

1. What is the **extent** of emergent, intertidal & submerged habitat? (Baseline mapping of habitat spatial distribution and abundance)

2. How is the emergent, intertidal & submerged habitat changing? (Long term change monitoring)

3. How is the suburban sprawl and coastal **development** impacting reserves and their watersheds? (Watershed land cover mapping)

4. How have **invasive** plants impacted habitat? (Hyperspectral mapping of Phragmites)

5. How **diverse** is each NERRS site in terms of habitat types? (Hyperspectral discrimination of plant species)
1993 Delaware Bay Land Cover Classification

Land Use / Land Cover Categories
- Developed (Impervious)
- Disturbed/Transitional
- Bare (Non-agriculture)
- Herbaceous (Non-agriculture)
- Agriculture
- Forested
- Emergent Wetland Group 1
- Emergent Wetland Group 2
- Emergent Wetland Group 3
- Unconsolidated Shore
- Mudflat / Exposed Bottom
Change Detection Using Probabilities

Multidata Imagery

Image Preprocessing

Change Detection

Forbidden Changes

Probability Filtering

Allowed Changes

Change Mapping

Field Data

Accuracy Assessment

Ancillary Data
\[
\text{NDVI} = \frac{\rho_{\text{nir}} - \rho_{\text{red}}}{\rho_{\text{nir}} + \rho_{\text{red}}}
\]

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

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

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

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

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

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

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

6. Evaluate changes in flagged areas using high resolution imagery.
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)
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.
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
UPSTREAM WETLANDS

- influence the water quality of adjacent rivers by removing pollutants such as sediments, nutrients, and organics/inorganics
- increase detention time of flood waters, reducing flow velocity, erosion, and flood peaks downstream
- provide habitat for wildlife including waterfowl, mammals, and unique vegetation
- serve as spawning and nursery grounds for many estuarine and marine species of fish
- contribute detritus (decaying organic matter) to aquatic food chain
- prevent excessive water temperatures during summer which are lethal to invertebrates or fish
CONCLUSIONS

1. Multi-spectral sensors on satellites and aircraft can be used to map:
   - Land cover change (vegetated to impervious)
   - Buffer degradation (forest to developed)
   - Wetland loss (acreage)
   - Fragmentation (roads, drainage ditches)
   - Biomass change (gdw/sq m)
   - Coastline change/erosion
   - Hydrology (drainage network)
   - Invasive species (Phrag.)

2. Wetland species discrimination difficult even with hyperspectral imagery.
   Need ancillary data (visual air-photo analysis of texture and shapes).

3. Orthophotos from airborne digital cameras (ADS40) excellent for visual interpretation, not suitable for digital image analysis.

4. Use image segmentation, supervised/unsupervised classification, cluster busting.

5. Landsat TM is cost-effective for mapping large sites or entire watersheds.
   Use IKONOS only for small, critical areas or patchy freshwater wetlands.

6. Using biomass for change detection is effective if use Landsat to detect changed sites and examine only “flagged” areas with IKONOS.
Wetlands Legal Protection

• **Coastal** (salt, tidal) marshes are protected by Clean Water Act and state laws

• **Upstream** (freshwater) wetlands protected by CWA until 2001, when Supreme Court in **SWANCC** case excluded “isolated” wetlands from federal protection

• In 2006, Supreme Court in **Rapanos/Carabell** case ruled that:

  1) “Hydrology must show continuous surface connection to navigable waters or their seasonal tributaries” or
  2) “Hydrology must significantly affect chemical, physical or biological properties of downstream navigable waters” (need not physically abut navigable waters)
Figure 2a. Portion of standard NWI map showing wetland and riparian classifications along the Tongue River, Wyoming.

Figure 2b. Digitized and color coded NWI map (wetland is blue; riparian is red) of the same area shown on the left.
<table>
<thead>
<tr>
<th>Satellite/Sensor</th>
<th>Spectral Range</th>
<th>Bands</th>
<th>GSD</th>
<th>Revisit Time</th>
<th>Swath Width</th>
<th>Application</th>
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</thead>
<tbody>
<tr>
<td>AVHRR NOAA 15/16</td>
<td>580-12500 nm</td>
<td>6</td>
<td>1.1 km</td>
<td>12 h</td>
<td>2400 km</td>
<td>SST; Turbidity; Circulation</td>
</tr>
<tr>
<td>SeaWiFS</td>
<td>402-885 nm</td>
<td>8</td>
<td>1.1 km</td>
<td>daily</td>
<td>2800 km</td>
<td>Ocean Color; Rel Products</td>
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<tr>
<td>MODIS Terra/Aqua</td>
<td>620-14385 nm</td>
<td>16 VNIR</td>
<td>variable</td>
<td>daily</td>
<td>2330 km</td>
<td>SST; Turbidity; Circulation</td>
</tr>
<tr>
<td></td>
<td>4 SWIR</td>
<td>250 m</td>
<td>daily</td>
<td>600 km</td>
<td></td>
<td>Ocean Color; Rel Products</td>
</tr>
<tr>
<td></td>
<td>16 TIR</td>
<td>1 km</td>
<td>-12 h</td>
<td></td>
<td></td>
<td>Ocean Color; Rel Products</td>
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<tr>
<td>MISR Terra (9 Camera angles)</td>
<td>425-886 nm</td>
<td>4</td>
<td>275 m</td>
<td>9 d</td>
<td>360 km</td>
<td>Ocean Color; Circulation</td>
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<tr>
<td>ASTER Terra</td>
<td>520-11650 nm</td>
<td>3 VNIR</td>
<td>15 m</td>
<td>16 d</td>
<td>60 km</td>
<td>Bathymetry, Vegetation; Land use, Change Dect.</td>
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<tr>
<td></td>
<td>6 SWIR</td>
<td>30 m</td>
<td></td>
<td></td>
<td></td>
<td>Circulation; Geomorphology</td>
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<tr>
<td></td>
<td>5 TIR</td>
<td>90 m</td>
<td></td>
<td></td>
<td></td>
<td>Digital Elevation Models</td>
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<tr>
<td>LANDSAT-7</td>
<td>450-2080 nm</td>
<td>6 VNIR</td>
<td>30 m</td>
<td>16 d</td>
<td>180 km</td>
<td>Bathymetry, Vegetation; Land use, Change Dect.</td>
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<tr>
<td></td>
<td>10420 nm</td>
<td>1 TIR</td>
<td>60 m</td>
<td></td>
<td></td>
<td>Circulation; Geomorphology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 Pan</td>
<td>15 m</td>
<td></td>
<td></td>
<td>Digital Elevation Models</td>
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<tr>
<td>SPOT 1-2-4-5</td>
<td>500-890 nm</td>
<td>3 MS</td>
<td>20 m</td>
<td>26 d</td>
<td>60 km</td>
<td>Bathymetry, Vegetation; Land use, Change Dect.</td>
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<tr>
<td></td>
<td></td>
<td>1 Pan</td>
<td>10 m</td>
<td>(daily)</td>
<td></td>
<td>Geomorphology; Circulation</td>
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<td>IKONOS</td>
<td>450-750 nm</td>
<td>4 MS</td>
<td>4 m</td>
<td>1-3 d</td>
<td>13 km</td>
<td>Bathymetry, Vegetation; Littoral Processes;</td>
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<tr>
<td></td>
<td></td>
<td>1 Pan</td>
<td>1 m</td>
<td></td>
<td></td>
<td>Digital Elevation models</td>
</tr>
<tr>
<td>Quick Bird 2</td>
<td>450-900 nm</td>
<td>4 MS</td>
<td>4 m</td>
<td>&lt;3 d</td>
<td>22 km</td>
<td>Bathymetry, Vegetation; Littoral Processes;</td>
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<tr>
<td></td>
<td></td>
<td>1 Pan</td>
<td>1 m</td>
<td></td>
<td></td>
<td>Digital. Elevation model</td>
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<td>Orbview 3</td>
<td>450-900 nm</td>
<td>4 MS</td>
<td>4 m</td>
<td>&lt;3 d</td>
<td>8 km</td>
<td>Bathymetry, Vegetation; Littoral Processes;</td>
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<tr>
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<td>1 Pan</td>
<td>1 m</td>
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<td>Digital. Elevation model</td>
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<td>Orbview 4</td>
<td>450-2500 nm</td>
<td>200 HS</td>
<td>8 m</td>
<td>&lt;3 d</td>
<td>5 km</td>
<td>Bathymetry, Vegetation; Littoral Processes;</td>
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<tr>
<td></td>
<td>450-900 nm</td>
<td>4 MS</td>
<td>4 m</td>
<td></td>
<td>8 km</td>
<td>Digital. Elevation model</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 Pan</td>
<td>1 m</td>
<td></td>
<td></td>
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<tr>
<td>ALI EO-1</td>
<td>400-2400 nm</td>
<td>9 MS</td>
<td>30 m</td>
<td>16 d</td>
<td>37 km</td>
<td>Bathymetry, Vegetation; Land use, Change Dect.</td>
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<tr>
<td></td>
<td></td>
<td>1 PAN</td>
<td>10 m</td>
<td></td>
<td></td>
<td>Geomorphology; Circulation</td>
</tr>
<tr>
<td>Hyperion EO-1</td>
<td>400-2400 nm</td>
<td>220</td>
<td>30 m</td>
<td>16 d</td>
<td>8 km</td>
<td>Bathymetry, Vegetation; Littoral Processes;</td>
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<tr>
<td>NEMO/COIS</td>
<td>400-2500 nm</td>
<td>210</td>
<td>30 m</td>
<td></td>
<td></td>
<td>Bathymetry, Vegetation; Littoral Processes;</td>
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<tr>
<td>MERIS ENVISAT-1</td>
<td>290-1040 nm</td>
<td>15</td>
<td>300 m</td>
<td>&lt;3 d</td>
<td>1150 km</td>
<td>Ocean Color; Circulation</td>
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<tr>
<td>ASAR ENVISAT-1</td>
<td>C-band 4 pol</td>
<td>2</td>
<td>30 m</td>
<td>&lt;3 d</td>
<td>50-100 km</td>
<td>Circulation, Waves</td>
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<tr>
<td>ASAR ERS-2 (SAR)</td>
<td>C-Band V pol</td>
<td>1</td>
<td>25 m</td>
<td>28 d</td>
<td>100 km</td>
<td>Circulation, Waves</td>
</tr>
<tr>
<td>RADARSAT-1 (SAR)</td>
<td>C-Band H pol</td>
<td>1</td>
<td>6-100 m</td>
<td>1-4</td>
<td>20-500 km</td>
<td>Circulation, Waves</td>
</tr>
<tr>
<td>RADARSAT-2 (SAR)</td>
<td>C-Band HV pol</td>
<td>1</td>
<td>3-100 m</td>
<td>3 20-500 km</td>
<td></td>
<td>Circulation Waves</td>
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</tbody>
</table>
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
END
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 are expensive.

3. Airborne hyperspectral data are costly & require highly experienced analysts.

4. Proposed approach:
   • use biomass as indicator
   • detect biomass changes with Landsat TM
   • study only “flagged” areas with IKONOS.
Modified Soil Adjusted Vegetation Index

Choose MSAVI because:

1. Gives best fit to field data and minimum errors.

2. Minimizes influence of soil background variations.

3. Can be calculated directly from apparent reflectance values without a scene-dependent, subjective correction factor.

4. Is linear over wide range of biomass values.

\[
MSAVI = \frac{2\rho_{nir} + 1 - \sqrt{(2\rho_{nir} + 1)^2 - 8(\rho_{nir} - \rho_{red})}}{2}
\]
Figure 3.4.2. Advance of the invasive plant *Phragmites* into the wetlands of the Blackbird Creek watershed. *Phragmites* is shown in black. The figure at the left shows the watershed in 1979; at right is the watershed in 1993.
Figure 5. Reference diagram of mapped wetland and riparian areas. Wetlands are blue, riparian areas are beige, wetland-riparian areas are red.
Natural Habitat Integrity Indices

Natural Cover Index

Stream Corridor Integrity Index

Wetland and Other Waterbody Buffer Index

Wetland Extent Index

Standing Waterbody Extent Index

Dammed Stream Flowage Index

Channelized Stream Length Index

Wetland Disturbance Index

Index of Remotely-sensed Natural Habitat Integrity
Wetland Function Assessment

1. Surface water detention
2. Streamflow maintenance
3. Nutrient transformation
4. Sediment and other particulate retention
5. Coastal storm surge detention and shoreline stabilization
6. Inland shoreline stabilization
7. Fish and shellfish habitat
8. Waterfowl and waterbird habitat
9. Other wildlife habitat
10. Conservation of biodiversity
Potential Wetland Restoration Sites

Type 1 Sites

- Effectively drained former wetlands (farmed wetlands)
- Impoundments (former vegetated wetlands)

Type 2 Sites

- Tidally restricted wetlands
- Impounded wetlands and ponds (former vegetated wetlands)
- Ditched palustrine wetlands
- Excavated wetlands

Mapping Potential Restoration Sites

- Analyze hydric soils maps
- LC/LU data obtained by remote sensing
Wetlands Fragmentation

Wetlands that are divided into two or more units by roads, railroads, or other structures which likely disrupt the hydrology and create increased risk for wildlife crossing

• wetlands chopped up into multiple pieces by developments and associated roadways

• large wetlands crossed by major highways
In-Stream Habitat Quality Decline

Severe degradation occurred when:

• agricultural land use in watershed exceeds 50%
• urban land use in watershed exceeds 20%

* Ralph Tiner, et al. (2000)  
  “Watershed-based Wetland Characterization for Maryland’s Coastal Bay Watersheds”.
# 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>
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<td></td>
<td></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.
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.
Land Cover Changes at Milford Neck Wildlife Conservation Area (1954 – 1999 Sea Level Rise and Grecos Canal Breech)

- Agriculture
- Shrubs
  - Forest (Palustrine)
  - Sp. Patens
  - Sp. Alterniflora
- Unconsolidated Shore
- Open Water/Mudflats
- Sp. Patens
- Phragmites
- Shrubs
  - Sp. P.
Figure 2. Post-classification change detection.
Figure 4. Classification process of the image differencing change-detection technique.