Geomorphometric Indicators of Tidal Marsh Condition in Plum Island Estuary

Vinton Valentine and Charles Hopkinson
The Ecosystems Center
Marine Biological Laboratory

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Intertidal Marshes as Critical Landscape Components

- Major source of organic matter fueling commercial and recreation fisheries
- Valuable habitat providing refuge for larval and juvenile organisms from predators
- Sink for high nutrient loads from human-dominated watersheds
- Buffer for urban and developed upland environments from catastrophic storms
- Aesthetically pleasing environment that affects real estate value and social systems
The Issues

- Natural forces and human activities in the coastal zone are contributing to the degradation and loss of critical tidal marsh habitat in estuaries
  - sea level rise
  - disruption of sediment supply
  - nutrient enrichment
  - altered hydrology and canaling
- The processes contributing to marsh degradation and loss are complex and include:
  - sedimentation
  - marsh plant production
  - peat accumulation and decomposition
  - erosion
  - ponding
  - marsh plant community shifts
Research Organization

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ACER
Atlantic Coast Environmental Indicators Consortium
Plum Island LTER
Chesapeake Bay
Neuse/Pamlico
North Inlet

remote sensing spectral data (AVIRIS)
geomorphology & pigments as indicators
seagrass indicators
ferry based monitoring (FerryMon)
monitoring/sampling stations
fish recruitment & biomass size spectra

climate changes
hurricanes

terrestrial/atmospheric pollutants
phytoplankton dynamics
zooplankton dynamics

river
marsh
estuary
Research Goals

- Develop a suite of geomorphic indicators of intertidal marsh condition and value that can be applied coastwide
- Seek indicators that:
  - measure the magnitude of marsh development relative to maximum potential development
  - identify whether the marsh is in a developmental or degradative phase
  - ascertain the value of marsh from the perspective of 1) storm buffering, 2) habitat, and 3) sink/source strength of atmospheric CO$_2$
  - offer landscape, as well as site, information when assigning priorities and developing strategies for wetland conservation and restoration efforts
Hypothetical Indicator Trajectories

Drainage Density Metric

Extent of Development

Degradation Trajectory

Developmental Trajectory

Storm Buffer Optimum - ⭐

Marsh: Water Area Metric

Developmental Trajectory

Degradation Trajectory

Habitat or CO₂ Sequestration Optimum - ⭐
Approach for This Study

• Selected regions in Plum Island Estuary marshes in northeastern Massachusetts, the site of an NSF Long-term Ecological Research (LTER) program, along gradients of salinity, sediment supply, vegetation community, and human impact

• Digitized tidal channels and mosquito ditches
  – Spring 2001 color orthophotography (MassGIS)
  – Wetlands cover data developed for the MA Department of Environmental Protection (DEP) Wetlands Conservancy Program (WCP) as starting point

• Generated distance from creek surface to use as a proxy for actual topographic surface

• Created basins from distance surface

• Generated centerline channel networks

• Calculated geomorphometric measures and related to selected regions
Study Locations

Plum Island Estuary

Upper Parker River
- Healthy marshes
- Flooded irregularly
- Low salinity
- Typha species and Spartina patens
- High productivity
- Few creeks
- Very few ponds
- Extensive ditch network

Shad Creek
- Degrading marshes
- Flooded regularly
- Moderate salinity
- High sedimentation rates
- Spartina alterniflora and S. patens
- Extensive creek network
- Extensive ponding
- Some ditches

Club Head Creek
- Degrading marshes
- Flooded regularly
- Moderate salinity
- Lower sedimentation rates
- Spartina patens with some S. alterniflora
- High productivity
- Broad creek network
- Large expanses of ponds
- Some ditches
Channel Networks

Upper Parker River

Shad Creek

Club Head Creek
Geomorphometric Measures

- Drainage Density:
  \[ D_d = \frac{\text{Total Channel Length}}{\text{Basin Area}} \]
- Constant of Channel Maintenance:
  \[ C = \frac{1}{D_d} \]
- Length of Overland Flow:
  \[ l_o = \frac{1}{2D_d} \]
- Sinuosity:
  \[ P = \frac{\text{Channel Segment Length}}{\text{Segment Straight Line Distance}} \]
- Fractal Dimensions for individual streams, channel network, and branching structure:
  \[ D_s = \text{negative slope of regression of log(box count) on log(grid resolution)} \text{ for fine scales} \]
  \[ D_{cn} = \text{negative slope of regression of log(box count) on log(grid resolution)} \text{ for broad scales} \]
  \[ D_b = \frac{D_{cn}}{D_s} \text{(related to log } R_b/\text{log } R_l) \] (after Helmlinger et al. 1993)
# Classical Measures

<table>
<thead>
<tr>
<th>Basin Name</th>
<th>Basin Area (ha)</th>
<th>Total Length (m)</th>
<th>(D_d) (m/ha)</th>
<th>(C) (sqm/m)</th>
<th>(I_o) (m)</th>
<th>(P) mean</th>
<th>(P) range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Parker</td>
<td>143.25</td>
<td>34,181.6</td>
<td>238.62</td>
<td>41.91</td>
<td>20.95</td>
<td>1.063</td>
<td>1.927</td>
</tr>
<tr>
<td>Shad</td>
<td>44.09</td>
<td>13,104.8</td>
<td>297.22</td>
<td>33.65</td>
<td>16.82</td>
<td>1.129</td>
<td>3.325</td>
</tr>
<tr>
<td>Club Head</td>
<td>72.85</td>
<td>18,560.1</td>
<td>254.77</td>
<td>39.25</td>
<td>19.63</td>
<td>1.103</td>
<td>3.536</td>
</tr>
</tbody>
</table>

![Maps of Upper Parker River, Shad Creek, and Club Head Creek](image_url)
Fractal Dimensions

<table>
<thead>
<tr>
<th>Basin Name</th>
<th>$D_s$</th>
<th>$D_{cn}$</th>
<th>$D_b$</th>
<th>Intersection (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Parker</td>
<td>1.016</td>
<td>1.577</td>
<td>1.552</td>
<td>22.54</td>
</tr>
<tr>
<td>Shad</td>
<td>1.012</td>
<td>1.609</td>
<td>1.590</td>
<td>20.46</td>
</tr>
<tr>
<td>Club Head</td>
<td>1.019</td>
<td>1.648</td>
<td>1.617</td>
<td>24.31</td>
</tr>
</tbody>
</table>
Summary

• While more data and work are needed, geomorphometric indicators hold promise in describing tidal marshes and their condition.

• Classical measures are applicable and provide foundation for assessing areas, establishing management priorities and targets, and monitoring status or restoration progress:
  – $D_d$ as indicator of landscape dissection and as surrogate for edge.
  – $C$ as integrator of water level and sedimentation changes.
  – $l_o$ as reflection of available nekton habitat.
  – $P$ as indicator of variable water velocity and varied edge habitat.

• Fractal dimension analysis seems to provide additional and multiple characteristics:
  – network pattern and distribution.
  – sinuosity.
  – channel support area.
  – underlying processes, scaling, and observation limits.
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Plans

- Calculate other measures:
  - number and mean length of terminal tributaries
  - mean area of terminal tributary basins
  - sinuosity of terminal tributaries for fractal comparison
  - edge length and edge density
  - number, density, and distribution of ponds and pannes
- Field checking and complete mapping
- Analyze entire Plum Island Estuary
- Run metrics on North Inlet, SC networks and compare
- Develop automated methods based on remote sensing to enable application of indicators to other systems in US coastal zone
- Interact with Massachusetts resource managers and USEPA/EMAP and AED personnel