Remote Sensing Metrics to Support Coastal Planning and Operations

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Coastal Geotools
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Outline

- National Coastal Mapping Program: background and products
- Coastal Engineering Index
- Parameter extraction to support:
  - Defining coastal regions,
  - Modeling critical species, and
  - Modeling landscape change
Goals

- Develop regional, repetitive, high-resolution, high-accuracy elevation and imagery data
- Build an understanding of how the coastal zone is changing
- Facilitate management of sediment and projects at a regional, or watershed scale

Marquette Harbor, MI, Lake Superior, 2011
National Coastal Mapping Progress

Products
- LAS format bathy/topo
- Aerial photos mosaics
- NAVD88 Zero contour
- 1-meter bathy/topo DEM
- 1-meter bathy/topo bare earth DEM
- Hyperspectral image mosaics
- Laser reflectance images
- Basic landcover classification
- Volume change metrics

Number of times surveyed since 2004

- ◯ One Time
- ✚ Two Times
- ✤ Three Times
- ▲ Four Times
- — Five Times
- ★ Six Times

FY15
Bathymetry and topography
Hyperspectral imagery

1 m pixel resolution, 48 spectral bands
375-1050 nm

Olowalu, Maui, HI 2013
Hyperspectral Imagery

Port Susan Bay, WA 2014
NCMP Schedule

CZMIL data coverage

- Tillamook Bay
- Nehalem Bay

2014-
- West Coast (Washington, Oregon, Puget Sound)

FY 2015 –
- Complete the West Coast (CA)
- Gulf
**Metrics/Parameters**

- **Elevation**
  - Change (elevation/volume)
  - Contour (change)
  - Shoal

- **Dune**
  - Elevation (crest/toe)
  - Continuity
  - Slope
  - Volume

- **Beach**
  - Width
  - Slope

- **Imagery**
  - Hyperspectral and Multi-Spectral Imagery

- **Land characterization**
  - Critical habitat (SAV, wetlands, dune vegetation, invasive/ITES)
  - Impervious surface
  - Landscape diversity

- **R&D/Value added products/tools**
  - Change Detection
  - Landscape change modeling
  - Volume/elevation/shoreline change
  - Structure assessment
  - Sediment Budgets
  - Monitoring Shore Protection
  - Defining Coastal Regions

- **Coastal Engineering Index**
- Coastal Resilience
- Critical Species Detection and Modeling
  - Sea turtle nesting habitat
  - Oysters*
  - Salmonid
  - * ECO-PCX model certification
Indices

Coastal vulnerability index (USGS)

Product mean:
\[ CVI_1 = \frac{(x_1 \cdot x_2 \cdot x_3 \cdot \ldots \cdot x_n)}{n} \]

Modified product mean:
\[ CVI_2 = \frac{x_1 \cdot x_2 \cdot (x_3 + x_4) \cdot x_5 \cdot \ldots \cdot (x_n + x_2)}{n - 2} \]

Average sum of squares:
\[ CVI_3 = \frac{x_1^2 + x_2^2 + x_3^2 + x_4^2 + \ldots + x_n^2}{n} \]

Modified product mean (2):
\[ CVI_4 = \frac{x_1 \cdot x_2 \cdot x_3 \cdot x_4 \cdot \ldots \cdot x_n}{5(n-4)} \]

Square root of product mean:
\[ CVI_5 = \sqrt{CVI_1} \]

Sum of products:
\[ CVI_6 = 4x_1 + 4x_2 + 2(x_3 + x_4) + 4x_5 + 2(x_6 + x_7) \]

State of the Coast (NOAA)
### Coastal Engineering Index

| Geomorphology       | Dune height  
|                     | Beach width   
|                     | Shoreline change |
|---------------------|---------------
| **Inlets**          | Ebb shoal volume change  
|                     | Structure dimensions relative to design  
|                     | Navigability |
| **Environment**     | Dune vegetation density  
|                     | Wetland density  
|                     | Submerged aquatic vegetation density |
| **Human use**       | Impervious surface density |

Parameters provide:

1) variability in scaling to either a region or project-level, and
2) data using remote sensing image and elevation products that do not require ground based sampling
Dunes

- Provide natural buffer from waves/runup to upland areas
- Volume of sediment available for beach recovery
- Included as part of beach nourishment projects

- Dune height – crest of the first dune
- Dune toe – slope change in dune

2010 Dune Height
2 m
Dune Vegetation Density

- Helps stabilize dunes and reduces erosion by trapping sand
- Provide habitat for critical species, including TE species

Dune Vegetation Density Area:
- Low: 0.75 km$^2$
- Medium: 0.28 km$^2$
- High: 0.12 km$^2$

- Extract vegetation within the dune field
Coastal engineering indices

CEI provides comparable combined indices for engineering, environmental, human use, and the inlets that provide a snap shot of coastal conditions.
Defining Coastal Regions

- Dynamic coastal areas can be challenging to define or delineate in a spatial context (boundaries can change often).
- In order to programmatically assess regional changes and find suitable project reference sites, a standard process would better enable utilization of available spatial data to delineate coastal regions.
- This study focused on synthesizing geomorphic and environmental parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Source</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dune Crest</td>
<td>USGS</td>
<td>2011</td>
</tr>
<tr>
<td>Beach Width</td>
<td>shoreline - NOAA; back line - FDEP CCCL</td>
<td>2014</td>
</tr>
<tr>
<td>Land Use Land Cover</td>
<td>USGS</td>
<td>2011</td>
</tr>
<tr>
<td>Ecological Systems</td>
<td>NatureServe</td>
<td>2003</td>
</tr>
</tbody>
</table>
Spatial Parameters

- Geomorphic parameters were divided to reflect regional value ranges:
  - **Dune crest** divided into two categories: low (<2-m) and high (> 2-m) dunes
  - **Beach width** divided into two categories: narrow (< 100-m) and wide (> 100-m); based on regional requirements

<table>
<thead>
<tr>
<th>Dune Crest</th>
<th>Value Range</th>
<th>Value Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>&lt;2-m</td>
<td>C1</td>
</tr>
<tr>
<td>medium</td>
<td>&gt; 2-m</td>
<td>C2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Beach Width</th>
<th>Value Range</th>
<th>Value Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>narrow</td>
<td>&lt; 100-m</td>
<td>Wi1</td>
</tr>
<tr>
<td>Medium</td>
<td>&gt;100-m</td>
<td>Wi2</td>
</tr>
</tbody>
</table>

- Environmental parameters were also assigned codes for each unique class type
- When the underlying environmental components were similar, classes were combined into a representative value code
  - Ex: emergent/brackish/tidal wetlands were combined from both USGS and NatureServe datasets for a comprehensive emergent wetland class
Case Study: Southwest FL

- The input data layers were combined to form a hierarchical gradient ranging from broad coastal regions to detailed coastal regions.

**Broad coastal regions** – 1km bins grouped based on majority land use/cover only, resulting in 7 divisions.

**Intermediate coastal regions** – 1km bins grouped based on majority land use/cover and average beach width, resulting in 14 divisions.

**Detailed coastal regions** – 1km bins grouped based on majority land use/cover, average beach width, and dune crest ranges, resulting in 19 divisions.

- Group areas based on easily extractable parameters that are quantifiable.
- Flexible, hierarchical approach allows identification of areas based on broad, regional conditions vs project-relevant conditions providing a range of visualization options.
- Provides quick way to find areas that can be used as reference sites in a coastal context which may be useful for mitigation or design scenarios.
- Flexible nature of parameter partitioning and coding makes it simple to tailor methods to a particular area or management objective (i.e. if trying to manage for a particular coastal objective).
Demonstration of a Sea Turtle Nesting Habitat Model Using Remotely Sensed Data

- 700 miles of coastline designated as critical nesting habitat (CH) for loggerhead sea turtle (*Caretta caretta*) conservation

- The nesting habitat suitability model will:
  - provide an information tool to better evaluate management strategies
  - provide decision-support for USACE operations/planning activities

**GOAL:** Demonstrate relative suitability of selected sites within the CH zone for *C. caretta* by developing a spatially-explicit ecological model
Spatial Parameter Identification

- Mappable/spatial parameters identified through literature review
  - Morphological
  - Environmental
  - Anthropogenic
  - Habitat
- Parameter list refined based on feedback from subject matter experts
  - important for nesting habitat
  - correlates with the resolution of the spatial datasets
Project Value

- The C. caretta habitat suitability model will provide an information tool to better communicate management priorities, evaluate management strategies, and provide decision-support for USACE operations/planning activities.

- Map of relative suitability based on spatially derived parameters
  - Regional value ranges (transferable to other sites)
Ecological Modeling for Landscape Change Analysis

1) Identify changes to critical habitat using multi-temporal imagery and lidar data

2) Derive landscape metrics associated with landscape patterns

3) Integrate with ecological simulation to develop a better understanding of factors influencing change and a tool to assess project level impacts/benefits

<table>
<thead>
<tr>
<th>Metric</th>
<th>Process</th>
<th>Benefit</th>
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</thead>
<tbody>
<tr>
<td>Clumpiness</td>
<td>Biodiversity</td>
<td>↑↓</td>
</tr>
<tr>
<td>Cohesion</td>
<td>Connectivity</td>
<td>↑↓</td>
</tr>
<tr>
<td></td>
<td>historical_lidar</td>
<td>sparse_veg</td>
</tr>
<tr>
<td>----------------</td>
<td>------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Distance to ocean</td>
<td>O</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Lucas and Carter, 2013 (would need further adjustment); Geider et al 2014; Tissier et al 2013</td>
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<tr>
<td>Distance to sound</td>
<td>O</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Geider et al 2014</td>
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<tr>
<td>Distance to dune crest</td>
<td>O</td>
<td>I</td>
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<tr>
<td></td>
<td>Geider et al 2014</td>
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<tr>
<td>Distance to dune toe</td>
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<td>I</td>
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<tr>
<td>beach width</td>
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<tr>
<td>zero contour to dune toe</td>
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<td>I</td>
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<tr>
<td>dune field volume</td>
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<tr>
<td></td>
<td>Preistas and Fagherazzi 2010, implied</td>
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<tr>
<td>beach slope</td>
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<tr>
<td>barrier island width</td>
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<tr>
<td></td>
<td>Claudino-Sales et al 2008; background Houser and Hamilton, 2009; Smith et al 2008</td>
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<tr>
<td>elevation</td>
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<td></td>
<td>Lucas and Carter, 2013; Geider, 2014; Judd et al, 2008; Miller et al, 2010; Sellars and Jolls, 2007 (Amaranthus); Priestas and Fagherazzi, 2010</td>
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<tr>
<td>slope</td>
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<td>aspect</td>
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<td>foredune continuity (?)</td>
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<td>sparse density</td>
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<tr>
<td></td>
<td>Preistas and Fagherazzi 2010; Miller et al 2010</td>
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<tr>
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<tr>
<td>Effective surge depth</td>
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<td>Hayden et al 1995</td>
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<tr>
<td>Surge depth threshold</td>
<td>I</td>
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</tbody>
</table>

**Elevation**

Value

- High: 665308
- Low: -0.36588

**Distance to 0 Contour**

Value

- High: 665.093
- Low: 0
Thank You!

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