Mapping Coastal Great Lakes Wetlands and Adjacent Land use Through Hybrid Optical-Infrared and Radar Image Classification Techniques

Laura L. Bourgeau-Chavez, Kirk Scarbrough, Mary Ellen Miller, Zach Laubach, Sarah Endres, Elizabeth Banda, Michael Battaglia, Anthony Landon, Liza Jenkins, Richard Powell, Colin Brooks

June 6, 2012
Coastal Great Lakes

- Largest freshwater surface system on Earth
- Coastal Great Lakes border 8 states and Ontario Canada
- Range from temperate to boreal ecoregion
- Wetlands range from protected embayment to riverine, dune and swale, etc
Coastal Great Lakes

Needs:
• To protect existing wetlands and assess health and condition for management and planning

Problems:
• Pollution, invasive species and other environmental issues affect the entire Great Lakes basin, and do not know political boundaries
• An international comprehensive map depicting coastal Great Lakes wetlands does not exist

To comprehensively monitor and manage an ecosystem on the scale and complexity of the Great Lakes basin requires remote sensing integrated with field data and GIS
Great Lakes Coastal Wetland Mapping Project Overview

• **Project goal:** Develop repeatable mapping and monitoring techniques that allow for accurate delineation of Great Lakes coastal wetlands and adjacent land areas

• **Approach:**
  – Use techniques developed for landscape indicator protocol under the Great Lakes Coastal Wetlands Consortium Pilot Study (Bourgeau-Chavez *et al.* 2008)
  – Use fusion of moderate resolution (20-30 m) satellite remote sensing from optical and Synthetic Aperture RADAR (SAR) sensors
    • PALSAR L-band HH and HV polarization (20 m resolution)
    • Envisat C-band, HH and HV polarization (30 m resolution)
    • Landsat TM optical-IR (30 m) / thermal (120 m resampled to 30 m)
Multi-sensor L- and C-band radar composite depicts the biomass and flooding differences between the various emergent wetlands in this delta.
Why Sensor Fusion?

- **LANDSAT** can be used to identify a broad spectrum of land cover types
  - Radiant energy reflectance from vegetation varies depending on features at the cellular level (e.g., chlorophyll, leaf moisture), as well as variations in surface or background reflectance (e.g., soil type, water).

- **SAR** can differentiate wetland types based on:
  - Inundation/water level patterns
  - Vertical structure
  - Soil moisture
  - Biomass
GLCWC Pilot Study in 2004 Merged Landsat-SAR Land Cover Mapping

Results 94% map accuracy when compared to NWI, 70% compared to IFMAP

Fusion reduced confusion

Increased number of wetland classes delineated including the invasive species *Phragmites*
Great Lakes Coastal Wetland Mapping Project Overview

- **Development of Methods:**
  - **Wetland Field data collection** - Project builds from field data and PALSAR database created in 2010-11 to map invasive species *Phragmites australis*
  - **Air photo interpretation** (training and validation)
  - **Remote sensing**
    - Evaluated various methods for mapping wetlands using new technologies to compare to GLCWC pilot study methods (separate TM and SAR classifications - merged)

- **Preliminary Results:** Coastal maps of Lakes Huron and parts of Lake Michigan

- **Continued work:** Field data collection plan, work on woody wetlands
Field Data Integration and Air Photo Interpretation

Supervised Data Training + Validation Shapes

Key

- Measure
- Processing Step
- Predicted
- Error

Wetlands/Uplands

USGS.gov 2012

Image of woman in field and aerial view of wetlands and uplands
Wetland Field Training and Validation Data collected in 2010-11

- 1145 unique field site visits.
- 782 validation, 363 training
- Phragmites observed at 30% of sites.
- Only NWI "Palustrine Emergent" polygons used to generate random points for validation sites
- Need to target other wetland types (Forest & Shrubby) for additional field validation data
- Need to target Canada coastal areas, Michigan Natural Features Inventory (MSU) funded to collect new field data
Field Measurements Collected in ½ acre plots

- GPS locations
  - Center of ½ acre plots
- Photos with GPS tag – 4 cardinal directions (over 3000 photos in archive)
- Dominant covertype - Vegetative composition
- Wetland Ecosystem type
- Average Veg. height (3)
- Density of *Phrag* and *Typha* only
- *Phragmites* presence
- Recent changes/ herbicide/burn treatments
85% overall accuracy basinwide for Phragmites mapping. Mapped 87 PALSAR AOIs on US side of Great Lakes.
Mapping Area 10 km buffer on Coastal zone

- 239 PALSAR images of the United States
- 218 PALSAR images of the Canada coast
- 130 total Landsat scenes (US and Canada)
- Mapping by AOI defined by PALSAR extent (70x70 km)
- Circa 2008-2010 imagery – spring summer fall datasets
Classification Parameters

- Anderson level one classification across entire Great Lakes Basin
  - Focus on wetland identification

- Wetland Classification
  - NWI Classes
  - Where applicable *Phragmites* and *Typha*
Development of Methodology – Pilot Study Areas

• Methods Tested
  – Original GLCWC Pilot study methods (separate Landsat and SAR classifications)
  – Thresholding multiple bands/band combinations
  – Random Forests classification

• Landsat Processing
  – TOA vs. Ledaps atmospheric correction tested
Random Forests
Schematic Overview

Landsat TOA data:
Traverse City, MI

PALSAR HH/HV data

Random Forests

Supervised Data
80% training/20% validation

Field Data

Aerial Image Interp.

TM/PALSAR Stack of 31 bands

Key
Measure
Predicted
Processing Step
Error

Precision
Accuracy

USGS.gov
2012

Wetlands/
Uplands

Landsat TOA data: Traverse City, MI

PALSAR HH/HV data

Random Forests

Supervised Data
80% training/20% validation

Field Data

Aerial Image Interp.

Key
Measure
Predicted
Processing Step
Error

Precision
Accuracy

USGS.gov
2012

Wetlands/
Uplands
Random Forests – 500 Decision Trees

- Advantages:
  - Speed
  - Accuracy
  - Range of application

- Disadvantages
  - Heavily dependent on training data
  - Difficult to alter once classified
GLCWC PALSAR-Landsat Merge
Thresholding Technique
Preliminary Confusion Matrix: St. Clair

Overall Accuracy = 91%
Kappa Coefficient = 0.89

<table>
<thead>
<tr>
<th>Classified</th>
<th>Urban</th>
<th>Ag</th>
<th>Forest</th>
<th>Water</th>
<th>Wetland</th>
<th>Barren</th>
<th>Aqua Bed</th>
<th>Phrag</th>
<th>Typha</th>
<th>Scirpus</th>
<th>Shrub</th>
<th>Wet Scrub</th>
<th>Forest wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>15901</td>
<td>27</td>
<td>10</td>
<td>35</td>
<td>0</td>
<td>203</td>
<td>2</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>32</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Ag</td>
<td>202</td>
<td>18977</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>122</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>271</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Forest</td>
<td>0</td>
<td>0</td>
<td>20878</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>125</td>
<td>39</td>
<td>616</td>
</tr>
<tr>
<td>Water</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>14570</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wetland</td>
<td>4</td>
<td>36</td>
<td>1</td>
<td>2</td>
<td>1411</td>
<td>0</td>
<td>15</td>
<td>108</td>
<td>73</td>
<td>0</td>
<td>165</td>
<td>132</td>
<td>0</td>
</tr>
<tr>
<td>Barren</td>
<td>551</td>
<td>279</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>651</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Aqua_Bed</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>506</td>
<td>1</td>
<td>0</td>
<td>1386</td>
<td>17</td>
<td>192</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Phrag</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>1</td>
<td>93</td>
<td>0</td>
<td>28</td>
<td>1354</td>
<td>34</td>
<td>0</td>
<td>8</td>
<td>86</td>
<td>0</td>
</tr>
<tr>
<td>Typha</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>31</td>
<td>0</td>
<td>7</td>
<td>1</td>
<td>4000</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Scirpus</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>23</td>
<td>26</td>
<td>147</td>
<td>490</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Shrub</td>
<td>7</td>
<td>2</td>
<td>263</td>
<td>0</td>
<td>25</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2867</td>
<td>370</td>
<td>0</td>
</tr>
<tr>
<td>Wet_Scrub</td>
<td>0</td>
<td>0</td>
<td>220</td>
<td>0</td>
<td>91</td>
<td>0</td>
<td>2</td>
<td>67</td>
<td>6</td>
<td>0</td>
<td>365</td>
<td>832</td>
<td>0</td>
</tr>
<tr>
<td>Forest_wet</td>
<td>0</td>
<td>0</td>
<td>2717</td>
<td>0</td>
<td>91</td>
<td>0</td>
<td>2</td>
<td>67</td>
<td>6</td>
<td>0</td>
<td>365</td>
<td>832</td>
<td>0</td>
</tr>
<tr>
<td>Sum</td>
<td>16670</td>
<td>19321</td>
<td>24099</td>
<td>15124</td>
<td>1652</td>
<td>2810</td>
<td>304</td>
<td>577</td>
<td>228</td>
<td>10164</td>
<td>4547</td>
<td>638</td>
<td>42319</td>
</tr>
<tr>
<td>User Acc.</td>
<td>95%</td>
<td>98%</td>
<td>87%</td>
<td>96%</td>
<td>85%</td>
<td>67%</td>
<td>92%</td>
<td>85%</td>
<td>90%</td>
<td>99%</td>
<td>75%</td>
<td>56%</td>
<td>47%</td>
</tr>
<tr>
<td>Prod. Acc.</td>
<td>95%</td>
<td>98%</td>
<td>87%</td>
<td>96%</td>
<td>85%</td>
<td>67%</td>
<td>92%</td>
<td>85%</td>
<td>90%</td>
<td>99%</td>
<td>75%</td>
<td>56%</td>
<td>47%</td>
</tr>
</tbody>
</table>
Bands for Random Forest -> BIGSTACK

1. Layer (Band 1 TOA ref (0.485) Spring:Landsat 5.dat)
2. Layer (Band 2 TOA ref (0.560) Spring:Landsat 5.dat)
3. Layer (Band 3 TOA ref (0.660) Spring:Landsat 5.dat)
4. Layer (Band 4 TOA ref (0.830) Spring:Landsat 5.dat)
5. Layer (Band 5 TOA ref (1.650) Spring:Landsat 5.dat)
6. Layer (Band 7 TOA ref (2.220) Spring:Landsat 5.dat)
7. Layer (NDVI Spring:Landsat 5.dat)
8. Layer (Band 6 (11.45) TOA temp (C) Spring:Landsat 5.dat)
9. Layer (YYJJJ YY-year JJJ -Julian day Spring:Landsat 5.dat)
10. Layer (Band 1 TOA ref (0.485) Summer:Landsat 5.dat)
11. Layer (Band 2 TOA ref (0.560) Summer:Landsat 5.dat)
12. Layer (Band 3 TOA ref (0.660) Summer:Landsat 5.dat)
13. Layer (Band 4 TOA ref (0.830) Summer:Landsat 5.dat)
14. Layer (Band 5 TOA ref (1.650) Summer:Landsat 5.dat)
15. Layer (Band 7 TOA ref (2.220) Summer:Landsat 5.dat)
16. Layer (NDVI Band 6 (11.45) Summer:Landsat 5.dat)
17. Layer (TOA temp (C) Summer:Landsat 5.dat)
18. Layer (YYJJJ YY-year JJJ -Julian day Summer:Landsat 5.dat)
19. Layer (Band 1 TOA ref (0.485) Fall:Landsat 5.dat)
20. Layer (Band 2 TOA ref (0.560) Fall:Landsat 5.dat)
21. Layer (Band 3 TOA ref (0.660) Fall:Landsat 5.dat)
22. Layer (Band 4 TOA ref (0.830) Fall:Landsat 5.dat)
23. Layer (Band 5 TOA ref (1.650) Fall:Landsat 5.dat)
24. Layer (Band 7 TOA ref (2.220) Fall:Landsat 5.dat)
25. Layer (NDVI Fall:Landsat 5.dat)
26. Layer (Band 6 (11.45) TOA temp (C) Fall:Landsat 5.dat)
27. Layer (YYJJJ YY-year JJJ -Julian day Fall:Landsat 5.dat)
28. Layer (Band 1:palsar_layerstack_georef_subset_median1.dat)
29. Layer (Band 2:palsar_layerstack_georef_subset_median1.dat)
30. Layer (Band 3:palsar_layerstack_georef_subset_median1.dat)
31. Layer (Band 4:palsar_layerstack_georef_subset_median1.dat)
32. Layer (Band 5:palsar_layerstack_georef_subset_median1.dat)
33. Layer (Band 6:palsar_layerstack_georef_subset_median1.dat)
Duncan Bay Preliminary Results

<table>
<thead>
<tr>
<th>AOI</th>
<th>Overall Accuracy</th>
<th>Kappa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harsens Island</td>
<td>94%</td>
<td>0.92</td>
</tr>
<tr>
<td>Duncan Bay</td>
<td>92%</td>
<td>0.90</td>
</tr>
<tr>
<td>Manistique</td>
<td>90%</td>
<td>0.88</td>
</tr>
</tbody>
</table>
LULC Map

Traverse City, MI Classified RF Image
### Accuracy:

**Confusion Matrix of Traverse City**

**Overall Accuracy** = 97%

**Kappa Coefficient** = 0.95

<table>
<thead>
<tr>
<th>Classified</th>
<th>Urban</th>
<th>Ag</th>
<th>Forest</th>
<th>Water</th>
<th>Wetland</th>
<th>Barren</th>
<th>Aquatic Bed</th>
<th>Typha</th>
<th>Scirpus</th>
<th>Shrub</th>
<th>Wet shrub</th>
<th>Wet forest</th>
<th>Urban grass</th>
<th>Urban road</th>
<th>Sum</th>
<th>Commission Acc.</th>
<th>User Acc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>686</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>26</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>114</td>
<td>853</td>
<td>20%</td>
</tr>
<tr>
<td>Ag</td>
<td>27</td>
<td>14940</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>2</td>
<td>8</td>
<td>1</td>
<td>33</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>150</td>
<td>15225</td>
<td>2%</td>
</tr>
<tr>
<td>Forest</td>
<td>1</td>
<td>1</td>
<td>51590</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>18</td>
<td>0</td>
<td>59</td>
<td>8</td>
<td>13</td>
<td>13</td>
<td>51690</td>
<td>0%</td>
</tr>
<tr>
<td>Water</td>
<td>0</td>
<td>0</td>
<td>96353</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>96354</td>
<td>0%</td>
</tr>
<tr>
<td>Wetland</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>957</td>
<td>0</td>
<td>3</td>
<td>6</td>
<td>0</td>
<td>6</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>983</td>
<td>3%</td>
</tr>
<tr>
<td>Barren</td>
<td>0</td>
<td>200</td>
<td>0</td>
<td>25</td>
<td>0</td>
<td>1713</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1954</td>
<td>12%</td>
</tr>
<tr>
<td>Aqua_Bed</td>
<td>0</td>
<td>0</td>
<td>42</td>
<td>2</td>
<td>2</td>
<td>594</td>
<td>10</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>653</td>
<td>9%</td>
</tr>
<tr>
<td>Typha</td>
<td>0</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>831</td>
<td>0</td>
<td>63</td>
<td>192</td>
<td>4</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>16</td>
<td>0</td>
<td>16</td>
<td>1143</td>
<td>83%</td>
</tr>
<tr>
<td>Scirpus</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>52</td>
<td>4%</td>
</tr>
<tr>
<td>Shrub</td>
<td>24</td>
<td>573</td>
<td>56</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>0</td>
<td>3391</td>
<td>4</td>
<td>15</td>
<td>40</td>
<td>0</td>
<td>40</td>
<td>4114</td>
<td>18%</td>
</tr>
<tr>
<td>Wet shrub</td>
<td>0</td>
<td>0</td>
<td>134</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>31</td>
<td>10</td>
<td>0</td>
<td>317</td>
<td>1116</td>
<td>31</td>
<td>0</td>
<td>13</td>
<td>1660</td>
<td>33%</td>
</tr>
<tr>
<td>Wet forest</td>
<td>0</td>
<td>0</td>
<td>1150</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>48</td>
<td>961</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2162</td>
<td>56%</td>
</tr>
<tr>
<td>Urban grass</td>
<td>0</td>
<td>289</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>283</td>
<td>51</td>
<td>0</td>
<td>51</td>
<td>623</td>
<td>55%</td>
</tr>
<tr>
<td>Urban road</td>
<td>7</td>
<td>0</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1295</td>
<td>0</td>
<td>1318</td>
<td>2%</td>
</tr>
</tbody>
</table>

| Sum        | 745   | 16043 | 52947 | 96420 | 1798   | 1768   | 698        | 232   | 58 | 3776 | 1206 | 1051 | 456 | 1586 | 178784 |
| Omission   | 8%    | 7%    | 3%    | 0%    | 47%    | 3%    | 15%        | 17%   | 14% | 10%  | 7%   | 9%   | 38% | 18%  |         |
| Prod. Acc. | 92%   | 93%   | 97%   | 100%  | 53%    | 97%   | 85%        | 83%   | 86% | 90%  | 93%  | 91%  | 62% | 82%  |         |
Preliminary Mapping Status

- Priority
  - Lake Huron
  - Lake Michigan
  - Lake Erie
  - Lake Ontario
  - Lake Superior

- Need more field data on Canadian side of Lake Huron
Random Forests allows a semi-automated method that provides consistent results among various image interpreters.

Problem types: forested and shrubby wetlands
- Developed methods to map forested wetlands with PALSAR, through thresholding
  - Collect field validation data/ training
  - Leaf off air photos to aid in delineation

Field verify preliminary maps and adjust training data as necessary.

Continue work on Lakes Michigan and Huron.
Current Distribution of Available Field Data for Lake Huron

2010-2011 Data Field Data Collect Coverage
Areas of Most Concern: *Informed* Site Selection