Presented at
Great Rivers Reference Condition Workshop
January 10-11, Cincinnati, OH
Sponsored by
The U.S. Environmental Protection Agency and The Council of State Governments
Identifying Reference Sites in Great Lakes Coastal Areas

Lucinda Johnson, George Host, Jan Ciborowski, Valerie Brady, Dan Breneman, Jeff Schuldt, Carl Richards, Yakuta Bhagat
Acknowledgements

This research has been supported by a grant from the US Environmental Protection Agency's Science to Achieve Results (STAR) Estuarine and Great Lakes (EaGLe) Coastal Initiative through funding to the Great Lakes Environmental Indicators (GLEI) Project, US EPA Agreement EPA/R-8286750 & EPA/R-82877701.
Defining Reference Conditions

- Minimally disturbed- absence of anthropogenic disturbance;
- Least disturbed- best available given current condition;***
- Best attainable (theoretical)- equivalent to hypothetical least disturbed sites under BMP (Stoddard et al.)

*** working definition for the Reference Area project.
Selecting reference sites by committee
Expert opinion compared to a random sample

Mid Atlantic streams

Source: EMAP
Motivating issues:

- The appropriate spatial scales for regionalizing reference conditions are not well understood
  - Are the biota of Lake Superior reference wetlands similar to those of Lake Michigan? Erie?
  - Are riverine wetlands similar to protected wetlands?
- Over large geographic areas (e.g. the Great Lakes), quantifying anthropogenic stress is challenging
EPA/STAR Research Programs

Reference Condition
- Develop and apply an *a priori* classification system to Great Lakes coastal ecosystems
- Use spatial data to select reference sites
- Sample to define biological reference conditions
- Evaluate how biota respond to different levels of classification
  - Ecoregional
  - Hydrogeomorphic

Great Lakes Environmental Indicators
- Identify potential and useful environmental indicators
- Quantify relationships between stress and responses for diagnosis
- Recommend a suite of hierarchically-structured indicators that are useful for making informed management decisions

Sample ‘pristine’ sites
Sample across stress gradient
Hydrogeomorphic Classification of Coastal Ecosystems

- Open-coast Wetland
- Protected Wetland behind High Energy Shoreline
- Embayment
- Riverine Wetland
# Hydrogeomorphic Inventory for the Great Lakes

<table>
<thead>
<tr>
<th>Ecossection</th>
<th>High Energy Shoreline</th>
<th>Embayment</th>
<th>River Influenced Wetland</th>
<th>Protected Wetland</th>
<th>Coastal Marsh</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOL</td>
<td>1613 km</td>
<td>18</td>
<td>77</td>
<td>45</td>
<td>38</td>
</tr>
<tr>
<td>NGL</td>
<td>2687 km</td>
<td>34</td>
<td>53</td>
<td>95</td>
<td>188</td>
</tr>
<tr>
<td>NSU</td>
<td>389 km</td>
<td>0</td>
<td>16</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>SCG</td>
<td>592 km</td>
<td>2</td>
<td>12</td>
<td>6</td>
<td>33</td>
</tr>
<tr>
<td>SGL</td>
<td>520 km</td>
<td>0</td>
<td>2</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>SSU</td>
<td>920 km</td>
<td>10</td>
<td>39</td>
<td>29</td>
<td>27</td>
</tr>
</tbody>
</table>

- Sampled wetland systems (n > 30)
Anthropogenic stress model

How to identify wetlands with minimum anthropogenic pressure values across multiple stress axes

Reference

Degraded


Ciborowski et al., in prep.
Quantifying Anthropogenic Stress: Data

- Publicly available spatial data (raster/polygon)
  - Agricultural land cover
    - (USGS-NLCD – 30 m)
  - Residential land use
    - (USGS-NLCD – 30 m)
  - Population density
    - (2000 Census Block)
  - Road density
    - (TIGER)
- Point source data
  - NPDES permits (EPA)
  - Toxic Release Inventory (EPA)
  - Areas of Concern (AOC)
  - Mines and power plants

Population density (people/pixel)
Contributing areas

- **Watersheds**
  - River influenced wetlands
  - Protected wetlands
  - Coastal wetlands
- **“Moving Window” approach**
  - High energy shorelines
  - Embayments
Moving window analysis

Summarize stressor attributes (e.g. # Ag pixels) in a $1 \text{ km}^2$ window around each shoreline pixel.
Window Summary

Ag  125
Res  96
Pop  .306
AOC  5159
Axes of Evil

Select pixels with minimum stressor values across all axes
## Defining the Axes of Evil:
### Step 1: Standardize data by axis

Scale each stressor axis from 0-1 based on the maximum value within that Type/Ecosection

<table>
<thead>
<tr>
<th>Window Summary</th>
<th>Scaled Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>0.352</td>
</tr>
<tr>
<td>Res</td>
<td>0.254</td>
</tr>
<tr>
<td>Pop</td>
<td>0.156</td>
</tr>
<tr>
<td>AOC</td>
<td>0.089</td>
</tr>
</tbody>
</table>
Defining the Axes of Evil:
Step 2: Select maximum across axes

Calculate maximum across each of 5 stressor axes

- Max\{Agriculture, Residential, Population, Roads, NPDES\}

<table>
<thead>
<tr>
<th>Stressor</th>
<th>Value</th>
<th>Scaled Value</th>
<th>Score for Pixel/Polygon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>125</td>
<td>0.352</td>
<td>0.352</td>
</tr>
<tr>
<td>Res</td>
<td>96</td>
<td>0.254</td>
<td></td>
</tr>
<tr>
<td>Point</td>
<td>5159</td>
<td>0.089</td>
<td></td>
</tr>
</tbody>
</table>

Assumption: biotic communities are limited by the “worst” stressor
Identifying reference wetlands
Step 3: Rank pixels by stressor type, select top 20%

Sort axes based on the ‘worst’ stressor

Northern Great Lakes Ecoregion

- Ag
- Res.
- NPDES
- Pop. Den.
- Rd. Den

MaxRel - Ranked Distribution
Distribution of sites by “Max-Rel” Score

Northern Great Lakes Wetlands

Erie Ontario Lowland Wetlands

MaxRel Cutoff – All Wetland Types

GLEI
Ref/GLEI
Reference
Distribution of sites by Max-Rel Score

US Side Great Lakes Basin

Ref Cutoff
659 Wetlands
0.080
Sum of Stressors- an alternate approach

- Max \{Agriculture, Residential, Population, Roads, Pt Sources\}
- Reference = lowest 20^{th} percentile Rel-Max scores

- \(\Sigma\) \{Agriculture, Residential, Population, Roads, Pt Sources\}
- References = lowest 20^{th} percentile Sum-Rel scores
### Max-Rel and Sum-Rel

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>4</td>
<td>1.19</td>
<td>0.20</td>
<td>0.40</td>
<td>0.34</td>
<td>0.40</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
<td>1.91</td>
<td>0.40</td>
<td>0.10</td>
<td>0.54</td>
<td>0.54</td>
</tr>
<tr>
<td>50</td>
<td>5</td>
<td>3.51</td>
<td>1.00</td>
<td>0.50</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>30</td>
<td>10</td>
<td>3.21</td>
<td>0.60</td>
<td>1.00</td>
<td>0.91</td>
<td>1.00</td>
</tr>
<tr>
<td>Max.</td>
<td></td>
<td>50</td>
<td>10</td>
<td>3.51</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>4</td>
<td>1.19</td>
<td>0.20</td>
<td>0.40</td>
<td>0.34</td>
<td>0.94</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
<td>1.91</td>
<td>0.40</td>
<td>0.10</td>
<td>0.54</td>
<td>1.04</td>
</tr>
<tr>
<td>50</td>
<td>5</td>
<td>3.51</td>
<td>1.00</td>
<td>0.50</td>
<td>1.00</td>
<td>2.50</td>
</tr>
<tr>
<td>30</td>
<td>10</td>
<td>3.21</td>
<td>0.60</td>
<td>1.00</td>
<td>0.91</td>
<td>2.51</td>
</tr>
<tr>
<td>Max.</td>
<td></td>
<td>50</td>
<td>10</td>
<td>3.51</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Distribution of Sites by Max-Rel and Sum-Rel
US Side Great Lakes Basin- 659 wetlands
Summary

- The ‘a priori’ approach based on spatial data effectively identifies reference areas.
- Reference cutoffs (defining what is ‘good’) vary greatly among ecoregions.
- Max-Rel and Sum-Rel behave similarly, especially at the reference end of the scale.
- Province and ecoregional stratifications account for biogeographic variability that could confound reference area interpretations (results not shown).
EPA/STAR Research Programs

Reference Condition
- Develop and apply an *a priori* classification system to Great Lakes coastal ecosystems
- Use spatial data to select reference sites
- Sample to define biological reference conditions
- Evaluate how biota respond to different levels of classification
  - Ecoregional
  - Hydrogeomorphic

Great Lakes Environmental Indicators
- Identify potential and useful environmental indicators
- Quantify relationships between stress and responses for diagnosis
- Recommend a suite of hierarchically-structured indicators that are useful for making informed management decisions

Sample ‘pristine’ sites
Sample across stress gradient
Summarizing land use within a watershed
Reference and GLEI sites

Reference sites (Ref. Condition project) 20%

Test sites (GLEI project)

Min  Stress Gradient  Max

********

******************************************************************************
WORST 20%
150 Sites Sampled
Including 50 Reference Sites

Fish & Invertebrate Study Sites
- Cw
- Em
- He
- Pw
- Rw
- Pilot Study Areas

Great Lakes
Great Lakes Basin
Fish & Macroinvertebrate community sampling

<table>
<thead>
<tr>
<th>Emergent</th>
<th>Submergent</th>
<th>Coastal Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3-0.5 m</td>
<td>0.5-1.0 m</td>
<td>5.0 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.0 m</td>
</tr>
</tbody>
</table>

Fyke Net Arrays

D-frame; cores

Ponar
Environmental Variables

Physicochemical -
• Temperature
• pH
• Dissolved Oxygen
• Conductivity
• ORP

Habitat –
• Shoreline
• Landuse
• Vegetation (density/cover)

Water Clarity -
• Secchi depth
• Turbidity tube depth

Sediment -
• Particle size
• Organics %
• Depth of fines
Hierarchical Partitioning – Independent Effects

Proportion of Explained Variance

- Wetland type
- Lake
- Ecoprovince
- Stressor Index

From: Brazner, et al., in review
Indicator Development

- Development indicators of stress for Great Lakes coastal margins using multivariate techniques and fish assemblages.
Approach

Cluster Analysis:
Identify reference sites with similar species composition

Identify set of environmental variables that best separate clusters of reference sites (DFA)

Use DFA model to determine the clustering for test sites

Ordinate clusters of sites along stressor axes

Test site within reference cluster

Reference

Test site outside of reference cluster

Non-reference
DFA Model - Variables

- EOL  p < 0.05
- SSU  p < 0.001
- NGL  p < 0.001
- SCG  p < 0.05
- Latitude p < 0.001
  - Julian Day p < 0.05
  - Protected wetland p < 0.05
  - Mean EM cover p < 0.01
DFA – Classification of Reference sites

<table>
<thead>
<tr>
<th>Group</th>
<th>Percent Correct</th>
<th>Ecorregion</th>
<th>Latitude</th>
<th>Julian Day</th>
<th>Pw</th>
<th>Em cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>100</td>
<td>SCG/SGL</td>
<td>Low</td>
<td>Early</td>
<td>No</td>
<td>Low</td>
</tr>
<tr>
<td>Group 2</td>
<td>100</td>
<td>NGL/SSU</td>
<td>Low-High</td>
<td>Mid</td>
<td>No</td>
<td>Low</td>
</tr>
<tr>
<td>Group 3</td>
<td>80.0</td>
<td>NGL/SSU</td>
<td>High</td>
<td>Mid</td>
<td>No</td>
<td>Low</td>
</tr>
<tr>
<td>Group 4</td>
<td>100</td>
<td>NSU</td>
<td>High</td>
<td>Late</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Group 5</td>
<td>100</td>
<td>EOL</td>
<td>Low</td>
<td>Mid</td>
<td>Yes</td>
<td>High</td>
</tr>
<tr>
<td>Total</td>
<td>91.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Ordinations

- Bray-Curtis Ordination
  - Subjective endpoint selection

- PCA of stressor axes
  - Population pressure
  - Agricultural pressure
Cluster 2 Ordination - Population Pressure

Fish Species Ordination Score

-2 -1 0 1 2 3

0.0
0.1
0.2
0.3
0.4
0.5
0.6

GLEI sites
Reference sites

r = 0.47

Alewife
Round goby
Bluegill sunfish
Yellow bullhead
Brown bullhead

Blacknose shiner
Sand shiner
Smallmouth bass

Population Pressure
Ordination of Sites Along Bray-Curtis Axes 1 and 2 - Group 2

- GLEI sites
- Reference sites

Bray-Curtis Population Axis vs. Bray-Curtis Agriculture Axis

Non-reference
Reference
Summary

- **Cluster Analysis** - clear separation of sites
- **DFA model**
  - good classification of sites
  - 8 main variables (48 total)
- **Ordinations**
  - Separate indicator assemblages at reference and non-reference sites.
  - Establish criteria for identifying condition at test sites.
Acknowledgements

Research supported by a grant from the US EPA’s Science to Achieve Results (STAR) Estuarine and Great Lakes (EaGLE) Coastal Initiative through funding to the Great Lakes Environmental Indicators (GLEI) and Reference Area Projects