Valuing Aquatic Ecosystem Services from Reductions in Nutrient Loadings

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Background and Motivation

• Nutrient pollution is among top 5 sources of designated use impairments…
  – States charged with selecting nutrient concentration criteria
  – EPA is encouraging *quantitative* (numeric) ambient criteria
    → How to set? Use costs and benefits?
  – Many states require assessment of costs/benefits for criteria selection
    → How to measure?
    → Apparent and concentrated costs, subtle and diffuse benefits

• EPA solicited proposals to help states with benefits measurement
Project Objectives

• Develop an integrated modeling approach to evaluate the benefits of protecting aquatic ecosystems services by reducing nutrient pollution in lakes:
  – Develop models for mapping measured water quality (e.g. TN, TP) to a lake eutrophication index
    • Use expert elicitation and data from North Carolina lakes and reservoirs
  – Develop models for mapping changes in the lake eutrophication index to dollar-measured benefits
    • Communicate lake ecosystem attributes and services associated with eutrophication levels
    • Elicit values for changes in the levels and spatial distribution of lake eutrophication
  – Transfer knowledge on the framework and its application via a training workshop
    • Apply model results to estimate benefits for lakes in Ecoregion IX
Study Area: EPA Nutrient Ecoregion IX for Lakes and Reservoirs

Aggregate Nutrient Ecoregion 9
Southeastern Temperate Forested Plains and Hills
Overview of Research

Measured water quality data ➔ Modeled link to water narrative description ➔ Survey of general public ➔ Value for general water quality improvement ➔ Workshop on developing values for policy analysis

Survey of recreational lake users ➔ RP study of recreational lake users ➔ Value for improved recreational use
Nutrient Inputs to Estuary

Primary Symptoms of Eutrophication

Secondary Symptoms of Eutrophication

Impacts on Ecosystem Endpoints

Nitrogen Loadings from Direct and Indirect Deposition

Chlorophyll a (Phytoplankton) Blooms

Macroalgal Blooms

Low Dissolved Oxygen (DO) (Hypoxia/Anoxia)

Nuisance/Toxic/Harmful Algal Blooms (HABs)

Low Water Clarity and Light Availability

Loss of Submerged Aquatic Vegetation (SAV)

Increases in Fish Kills

Declines in Aesthetic (Visual, Odor) Quality

Declines in Fish/Shalfish Abundance

Declines in Shoreline Quality
**Expert Elicitation:** 14 water quality experts were presented with the same 100 rows of water chemistry data, each representing a different lake in North Carolina.

- **Example row:**

<table>
<thead>
<tr>
<th>Photic Total Nitrogen</th>
<th>Photic Total Inorganic Nitrogen</th>
<th>Photic Total Phosphorus</th>
<th>Photic Chlorophyll a</th>
<th>Surface Dissolved Oxygen</th>
<th>Secchi Depth</th>
<th>Photic Turbidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.46 mg/l</td>
<td>0.02 mg/l</td>
<td>0.03 mg/l</td>
<td>38 μg/l</td>
<td>6.3 mg/l</td>
<td>1.3 m</td>
<td>3.9 NTU</td>
</tr>
</tbody>
</table>

- **Elicitation Task:** Imagine 100 different lakes with the characteristics specified by the given data row. Of the 100 lakes, how many of the lakes would you expect to fall into each of the following five categories of eutrophication?
## Lake Eutrophication Categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Water clarity</th>
<th>Color</th>
<th>Algae</th>
<th>Nutrient levels</th>
<th>Oxygen</th>
<th>Odor</th>
<th>Aquatic life</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Excellent</td>
<td>None</td>
<td>Very little</td>
<td>Very low</td>
<td>Very high</td>
<td>No</td>
<td>Very healthy, abundant</td>
</tr>
<tr>
<td>2</td>
<td>Good</td>
<td>Little</td>
<td>Little</td>
<td>Low</td>
<td>High</td>
<td>Little</td>
<td>Healthy, abundant</td>
</tr>
<tr>
<td>3</td>
<td>Fair</td>
<td>Some</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Little</td>
<td>Somewhat healthy, abundant</td>
</tr>
<tr>
<td>4</td>
<td>Poor</td>
<td>Noticeable</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Noticeable</td>
<td>Unhealthy, scarce</td>
</tr>
<tr>
<td>5</td>
<td>Poor</td>
<td>Considerable</td>
<td>Very high</td>
<td>Very high</td>
<td>Low to no</td>
<td>Strong offensive</td>
<td>Unhealthy, scarce or none present</td>
</tr>
</tbody>
</table>
Ordered Logit Analysis of Expert Responses

- **Dependent Variable**: Category with highest selected probability mass by expert is assigned a 1 (others 0)
  - \( N = 1400 = 14 \times 100 \)

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>ESTIMATE</th>
<th>STD. ERROR</th>
<th>Z-RATIO</th>
<th>P-VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Nitrogen</td>
<td>0.436</td>
<td>0.301</td>
<td>1.450</td>
<td>0.147</td>
</tr>
<tr>
<td>Total Inorganic Nitrogen</td>
<td>0.873</td>
<td>0.494</td>
<td>1.770</td>
<td>0.078</td>
</tr>
<tr>
<td>Total Phosphorous</td>
<td>9.792</td>
<td>2.463</td>
<td>3.980</td>
<td>0.000</td>
</tr>
<tr>
<td>Chlorophyll</td>
<td>0.076</td>
<td>0.012</td>
<td>6.530</td>
<td>0.000</td>
</tr>
<tr>
<td>Surface Dissolved Oxygen</td>
<td>-0.004</td>
<td>0.050</td>
<td>-0.080</td>
<td>0.933</td>
</tr>
<tr>
<td>Secchi Depth</td>
<td>-0.730</td>
<td>0.139</td>
<td>-5.240</td>
<td>0.000</td>
</tr>
<tr>
<td>Turbidity</td>
<td>0.017</td>
<td>0.009</td>
<td>1.960</td>
<td>0.050</td>
</tr>
<tr>
<td>Cut 2</td>
<td>-1.112</td>
<td>0.764</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut 3</td>
<td>0.535</td>
<td>0.546</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut 4</td>
<td>3.044</td>
<td>0.394</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut 5</td>
<td>6.264</td>
<td>0.561</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Mapping Eutrophication Index to Monetary Values

• **Stated Preference (SP) Surveys**
  – Communicate lake attributes/ecosystem services associated with each eutrophication category
  – Describe scenarios involving tradeoffs between lake eutrophication conditions and some form of “payment” (i.e., choice-based conjoint scenarios)
    • Lake site choice for recreational users
    • Lake improvement policy choice for general public

• **Revealed Preference (RP) Analysis**
  – Use data on actual lake recreation site choices to measure tradeoffs

• **Combined RP-SP Analysis**
Stated Preference Surveys

• Knowledge Networks Internet Panel
  – Sample 1: N=700 from NC, SC, and VA
  – Sample 2: N=500 from KY, TN, GA, AL, MS

• Lake site choice for recreational users
  – Tradeoff lake water quality (eutrophication index),
    travel distance, and other lake characteristics
    (e.g., facilities)

• Lake improvement policy choice for general public
  – Tradeoff increase in % of lakes in better
    eutrophication categories against household
    payments
### Communicate Lake Attributes and Ecosystem Services for Eutrophication Categories

<table>
<thead>
<tr>
<th></th>
<th><strong>POOR</strong></th>
<th><strong>GOOD</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COLOR</strong></td>
<td><img src="image" alt="Brownish Green blooms" /> (mid-size areas, lasting about 1 month, occur 5 times a year)</td>
<td><img src="image" alt="Good Color" /> (can see 1-2 feet deep)</td>
</tr>
<tr>
<td><strong>CLARITY</strong></td>
<td>Can see 1-2 feet deep</td>
<td>Can see 5-8 feet deep</td>
</tr>
<tr>
<td><strong>ODOR</strong></td>
<td>Noticeable unpleasant odor, lasting about 1 week, occurs 3-4 times a year</td>
<td>Faint unpleasant odor, lasting about 1 day, occurs at most 2 times a year</td>
</tr>
<tr>
<td><strong>FISH</strong></td>
<td>A few mostly small and rough fish present</td>
<td>Moderately large and diverse population of fish.</td>
</tr>
<tr>
<td><strong>ALGAE</strong></td>
<td><strong>blooms</strong>: mid-size areas, lasting about 1 month, occur 5 times a year</td>
<td><strong>blooms</strong>: Small area occurs less than 2 times a year</td>
</tr>
<tr>
<td></td>
<td><strong>mats</strong>: large clusters are present for almost half the year</td>
<td><strong>mats</strong>: small clusters in a few parts of the lake occur at most 2 times a year</td>
</tr>
</tbody>
</table>

**EXAMPLE:**

- **COLOR**: Brownish Green blooms (mid-size areas, lasting about 1 month, occur 5 times a year)
- **CLARITY**: Can see 1-2 feet deep
- **ODOR**: Noticeable unpleasant odor, lasting about 1 week, occurs 3-4 times a year
- **FISH**: A few mostly small and rough fish present
- **ALGAE**: **blooms**: mid-size areas, lasting about 1 month, occur 5 times a year}
Revealed Preference Analysis

- Use data from the National Survey of Recreation and the Environment (NSRE) to estimate a simple lake recreation “random utility” site choice model

\[ U_{ji} = \alpha_j + \delta p_{ji} + \varepsilon_{ji} , \quad j = 1, \ldots, J , \]

- \( \alpha_j \) represents a site-specific constant
- \( p_{ij} \) represents travel cost by individual \( i \) to site \( j \)
- \( \varepsilon_{ji} \) represents random unobserved component
Combined RP and SP Model

- Combine results of RP model with the recreation site choice SP model to estimate parameters of a full random utility model (RUM)

\[ U_{ji} = \sum_{l=1}^{L} \beta_l e_{lj} + \delta p_{ji} + \xi_j + \varepsilon_{ji}, \quad j = 1, \ldots, J, \]

- \( e_j \) represents eutrophication index at site \( j \)
- \( \xi_j \) represents all non-eutrophication characteristics at site \( j \)

- Use full RUM to estimate recreation benefits of changes in eutrophication at specific lakes
Even further down the road...

- Use combined model results to develop benefit estimation tool for analysis of nutrient reduction policies
  - Output from our project is a framework for non-experts to conduct benefits estimate for policy purposes

- Conduct training workshop for state-level water quality managers
  - Planned for end of project ≈ Spring 2010
  - Target audience is people who need to do benefits assessment for proposed water quality criteria