Context: Research Questions

• **GLEAM 1**
  1. What are the cumulative effects of important stressors affecting the GL and how do they vary across the basin?
  2. What is the relationship between stressors and benefits?

• **GLEAM 2**
  1. How concordant are GLEI and GLEAM stressor maps with one another and with lake condition indicators?
  2. How important are interactions among stressors in determining cumulative stress?
  3. How can we make stressor and benefit mapping useful to managers and other end users?
Context: Broader Implications

• Living in a multi-stressor world (Bails et al. 2005)
  – Need to find balance between identifying top priorities and recognizing that dozens of stressors may be important

• Stressors, both individual and cumulative, vary a lot from place to place
  – Need to appreciate that individual locations may experience a particular suite of challenges

• Integrating benefits into planning
  – While protecting and restoring the GL is the rationale for virtually all management activity, not all locations provide the same benefits
Project Outputs - Completed

Allan et al. 2013, PNAS

Allan et al. 2015, Frontiers in Ecology & the Environment

Smith et al. 2015, Ecol. Appl.
Outputs: GLEI-GLEAM Concordance

• How concordant are GLEI and GLEAM stressor maps with one another and with lake condition indicators?

Integrated composite stress maps for the Great Lakes basin.

Composite stress scores were derived from five land variables of GLEI project and 34 lake stressors of GLEAM project. Stress scores were normalized for entire basin.

Further progress is described by L. Johnson
Outputs: Stressor Interactions

- How important are interactions among stressors in determining cumulative stress?

- From expert knowledge, eutrophication and climate change likely drive several important interactions

<table>
<thead>
<tr>
<th>Stressor pair</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change impacts x P loading</td>
<td>Synergy</td>
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<tr>
<td>Coastal dev. x N &amp; P loading</td>
<td>Synergy</td>
</tr>
<tr>
<td>P loading x invasive mussels</td>
<td>Synergy</td>
</tr>
<tr>
<td>P loading x hypoxia</td>
<td>Synergy</td>
</tr>
<tr>
<td>Climate warming water temperature x hypoxia</td>
<td>Synergy</td>
</tr>
<tr>
<td>Tributary dams x sediment loading</td>
<td>Antag.</td>
</tr>
<tr>
<td>Coastal dev. x changing water levels</td>
<td>Either</td>
</tr>
</tbody>
</table>
Outputs: Stressor Interactions

- How important are interactions among stressors in determining cumulative stress?
- From literature review, antagonisms appear to be at least as common as synergies.
Outputs: Lake Erie Prioritization

• How can we make stressor and services mapping useful to managers?
### Outputs: Erie Stressor Layers

**Stressors**

<table>
<thead>
<tr>
<th>Stressors</th>
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</tr>
</thead>
<tbody>
<tr>
<td>AOCs</td>
<td>Mining</td>
</tr>
<tr>
<td>Ballast Water</td>
<td>Mussels</td>
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<tr>
<td>Biomagnifying Metals</td>
<td>N loading</td>
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<tr>
<td>Boating</td>
<td>Native Stocking</td>
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<tr>
<td>Charter Fishing</td>
<td>Non-Biomagnifying Metals</td>
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<tr>
<td>Coastal development</td>
<td>Non-Native Stocking</td>
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<tr>
<td>Commercial Fishing</td>
<td>Organics</td>
</tr>
<tr>
<td>CSOs</td>
<td>P loading</td>
</tr>
<tr>
<td>Dams</td>
<td>Ports</td>
</tr>
<tr>
<td>GLEI Watershed Ag/Dev</td>
<td>Power Plants</td>
</tr>
<tr>
<td>HABs</td>
<td>Recreation</td>
</tr>
<tr>
<td>Hardening</td>
<td>Roads</td>
</tr>
<tr>
<td>Hypoxia</td>
<td>SAVs</td>
</tr>
<tr>
<td>Ice Cover</td>
<td>Sediment Loading</td>
</tr>
<tr>
<td>Invasive Fish</td>
<td>Shipping</td>
</tr>
<tr>
<td>Invasive Plants</td>
<td>Shoreline Extensions</td>
</tr>
<tr>
<td>Lamprey</td>
<td>Water Level</td>
</tr>
<tr>
<td>Light</td>
<td>Water Temperature</td>
</tr>
</tbody>
</table>

![Map showing cumulative stress levels](image-url)
Outputs: St. Clair-Detroit River System Stressor Layers

SCDRs Layers

- AOCs
- Ballast Water
- Charter Fishing
- Coastal Development
- CSOs
- Dams
- Industrial Ports
- Light
- GLEI Ag/Dev
- Phosphorus Loading
- Phragmites
- Pipelines
- Power Plants
- Recreational Fishing
- Round Goby
- Sediment Loading
- Shipping
- Shoreline Hardening

Shoreline hardening degree of protection:
- Red: 70 - 100% protected
- Yellow: 40 - 70% protected
- Cyan: 15 - 40% protected
- Blue: < 15% protected
Outputs: Erie Ecosystem Services

Services
- Birding
- Beaches
- Commercial Fishing
- Marinas
- Parks
- Sport Fishing (Charter)
- Sport Fishing (Non-Charter)
- TNC Coastal Terrestrial Biodiversity
- TNC Coastal Wetlands Biodiversity
- Water Withdrawals
Outputs: Priorities

Identify dominant stressors by lake sub-region

Identify locations where stress and services are greatest

Identify locations where fewest stressors dominate stress
Outputs and Engagement: Management Priorities for Lake Erie

• Combine insights from analysis of multiple stressors and services, their variation across sub-regions of Lake Erie, and their spatial coincidence

• Input from experienced managers
  – Informal: feedback of steering committee
  – Formal: quantitative survey of ecosystem objectives
### Survey goals:
1. Prioritization of objectives (~parallel GLWQA objectives)
2. Identification of stressors that compromise objectives
3. Estimation of reversibility of stressors
4. Evaluator confidence self-score

<table>
<thead>
<tr>
<th>Tier 1 Objectives</th>
<th>Tier 2 Objectives</th>
<th>Examples</th>
<th>Importance of Objective/ES</th>
<th>Stressors</th>
<th>Importance of stressor to this objective/valve</th>
<th>Reversability</th>
<th>Confidence in Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Healthy Fish Communities</td>
<td>Sport and Commercial Fishing</td>
<td>Habitat fragmentation in watershed, P-loads, rivers, sediment loads, rivers, harmful algalblooms, hypoxia, cladophora, native fish stocking, non-native fish stocking, invasive fish (round goby), sea lamprey, toxics and ADCs, commercial fishing, recreational/fishing, other (write-in), other (write-in)</td>
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<tr>
<td>2. High Quality Water</td>
<td>Drinking Water, Beach Use</td>
<td>Harmful algalblooms, hypoxia, nutrient loading, sediment, chemicals of mutual concern in water, other toxins, other (write-in), other (write-in)</td>
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<tr>
<td>3. High Quality Habitat</td>
<td>Wetlands, Terrestrial Systems, Habitat Connectivity</td>
<td>Invasive phragmites, coastal development, shoreline hardening, river mouth activity, other (write-in), other (write-in)</td>
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<tr>
<td>4. Recreation/Aesthetic Use</td>
<td>Beaches, Boating, Birding, Camping</td>
<td>Harmful algalblooms, cladophora, land use in watershed, P-loads, rivers, sediment loads, rivers, water levels, litter/plastics, other (write-in), other (write-in)</td>
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<tr>
<td>5. Economic/Industrial Uses (Shipping, Power Plants)</td>
<td>Transportation, Energy Economies</td>
<td>Water levels, invasive species fouling, other (write-in), other (write-in)</td>
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<tr>
<td>6. Reduction of Excess Nutrients</td>
<td>HABs, Hypoxia, Beach Fouling, WQ Degradation</td>
<td>harmful algal blooms</td>
<td>cladophora</td>
<td>land use in watershed</td>
<td>P-loads, rivers</td>
<td>sediment loads, rivers</td>
<td>other (write-in)</td>
</tr>
<tr>
<td>7. Prevention/Control of Invasive Species</td>
<td>Biodiversity, Fouling, Food Web Integrity</td>
<td>sea lamprey</td>
<td>round goby</td>
<td>dreissenid mussels</td>
<td>invasive phragmites/other macrophytes</td>
<td>asian carp</td>
<td>alewines</td>
</tr>
<tr>
<td>8. Prevention/Reduction in Toxic Chemicals/ Delistment of AOCs</td>
<td>Public Health, Fish Consumption, Ecosystem Health</td>
<td>AOCs</td>
<td>PCBs</td>
<td>copper</td>
<td>mercury</td>
<td>chemicals of mutual concern in water</td>
<td>PBTs</td>
</tr>
<tr>
<td>9. Improved Groundwater Condition</td>
<td>Drinking Water, Public Health, Ecosystem Health</td>
<td>land use in watershed</td>
<td>other (write-in)</td>
<td>other (write-in)</td>
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<tr>
<td>10. Climate Change Impacts</td>
<td>Shoreline Exposure/Inundation, Ecosystem Effects, Infrastructure Risk</td>
<td>changing water levels</td>
<td>reduced ice cover</td>
<td>land use in watershed</td>
<td>other (write-in)</td>
<td>other (write-in)</td>
<td>other (write-in)</td>
</tr>
</tbody>
</table>
End User Engagement

• **Collaboration**
  – TNC (Lake Erie Biodiversity Conservation Strategy), GLAHF, GLEI
  – Engaging with lake managers and scientists from NGOs, governmental and educational institutions in the stressor interactions and Lake Erie projects.
  – Participating in Lake Erie LAMP calls and meetings

• **Data sharing**
  – Secured permission from original data providers to share rescaled GLEAM1 layers with other research groups
  – Filled 13 requests in past year for GLEAM data layers (Great Lakes Futures Project, USGS, TNC, University of Minnesota, and students at UM, University of Guelph and University of Waterloo).

• **Education and outreach**
  – Filled 6 requests for information in past year from students, nonprofits, government agencies, and concerned citizens
  – Website improvements (ongoing; fixing issues with interactive map, updating Drupal, adding content)
With the help of many!

• Financial support from the Erb Family Foundation and the UM Water Center

• Stressor Interactions Working Group, Lake Erie Steering Committee, GLEI colleagues

• Data providers
  – Dozens of staff from GLERL, USGS, Environment Canada, OMNR, USFWS, TNC, GLFC, MDNRE, IFR, GLEI, NFHAP, others.
  – Academic scientists from USA & Canada

http://www.greatlakesmapping.org