# Development of Environmental Indicators of Condition, Integrity, and Sustainability in the Great Lakes Basin (GLEI)

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**Natural Resources Research Institute**
**University of Minnesota Duluth**

# Acknowledgments


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 and R-828777

# Development of Environmental Indicators of Condition, Integrity, and Sustainability in the Great Lakes Basin (GLEI)

Principal Investigator:

Gerald Niemi – Natural Resources Research Institute & Department of Biology, University of Minnesota Duluth

Co-Principal Investigators: 27 individuals from 10 institutions

# Major Question/Objectives

"What environmental indicators can efficiently, economically, and effectively measure and monitor the condition and integrity of the Great Lakes coast?"

Objectives:

1. Identify environmental indicators that define the condition, integrity, and change of coastal margin ecosystems,
2. Rigorously test these indicators, and link stressors with environmental responses, and
3. Recommend a suite of hierarchically-structured indicators useful in the development of informed management strategies.

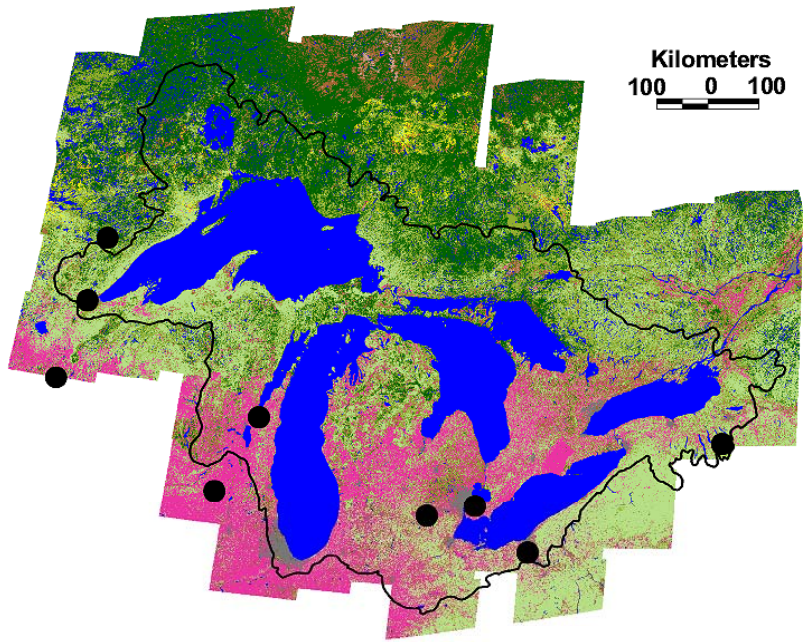
# Outline

- Approach & project overview
- Data base compilation
  - Experimental design – stress/response
  - Indicator development – examples but primarily linkages with stress/response, focusing on aquatic subcomponents.
- Brief summary of results
- Anticipated products

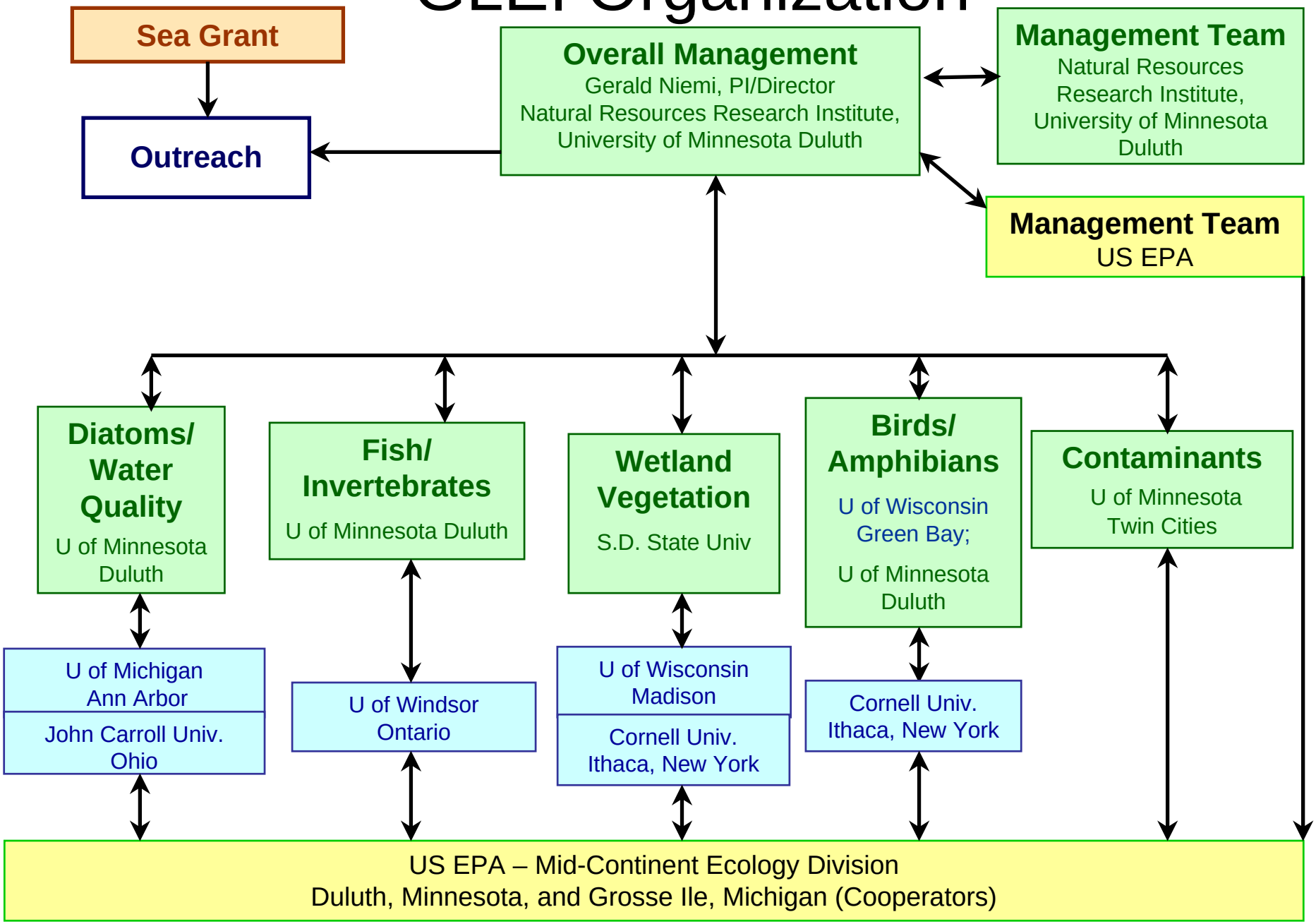
# Project Emphasis

- Develop indicators that assess condition and point to causes of impairment
  - Quantify stressor-response relationships for novel and existing indicators

- Indicators that are integrative across sub-components
  - Birds & Amphibians
  - Diatoms
  - Contaminants
  - Fish & Macroinvertebrates
  - Wetland Vegetation
  - Landscape - NASA



# GLEI Organization



# General Timetable

| | |
|---|---|
| Year 1<br>2001 | • Conduct pilot study,<br>• Select sites for intensive sampling. |
| Years 2-3<br>2002-2003 | • Complete intensive sampling to test hypotheses of linkages between pressure and state indicators. |
| Years 3-4<br>2003-2004 | • Evaluate cost-effectiveness of each indicator,<br>• Evaluate hypotheses relating pressure and state indicators,<br>• Recommend useful indicators to groups implementing monitoring programs. |

# Developing Environmental Indicators

**Goal:**

To obtain an unbiased sample of sites spanning the full gradient of condition that will allow us to develop indicators of ecological condition

**Problem:**

Massive coastal area with multiple stressors

- > 6,500 km of coastline
- > 750 wetlands

Sampling units are classified into distinct **Geomorphic Types**

**High energy shoreline**

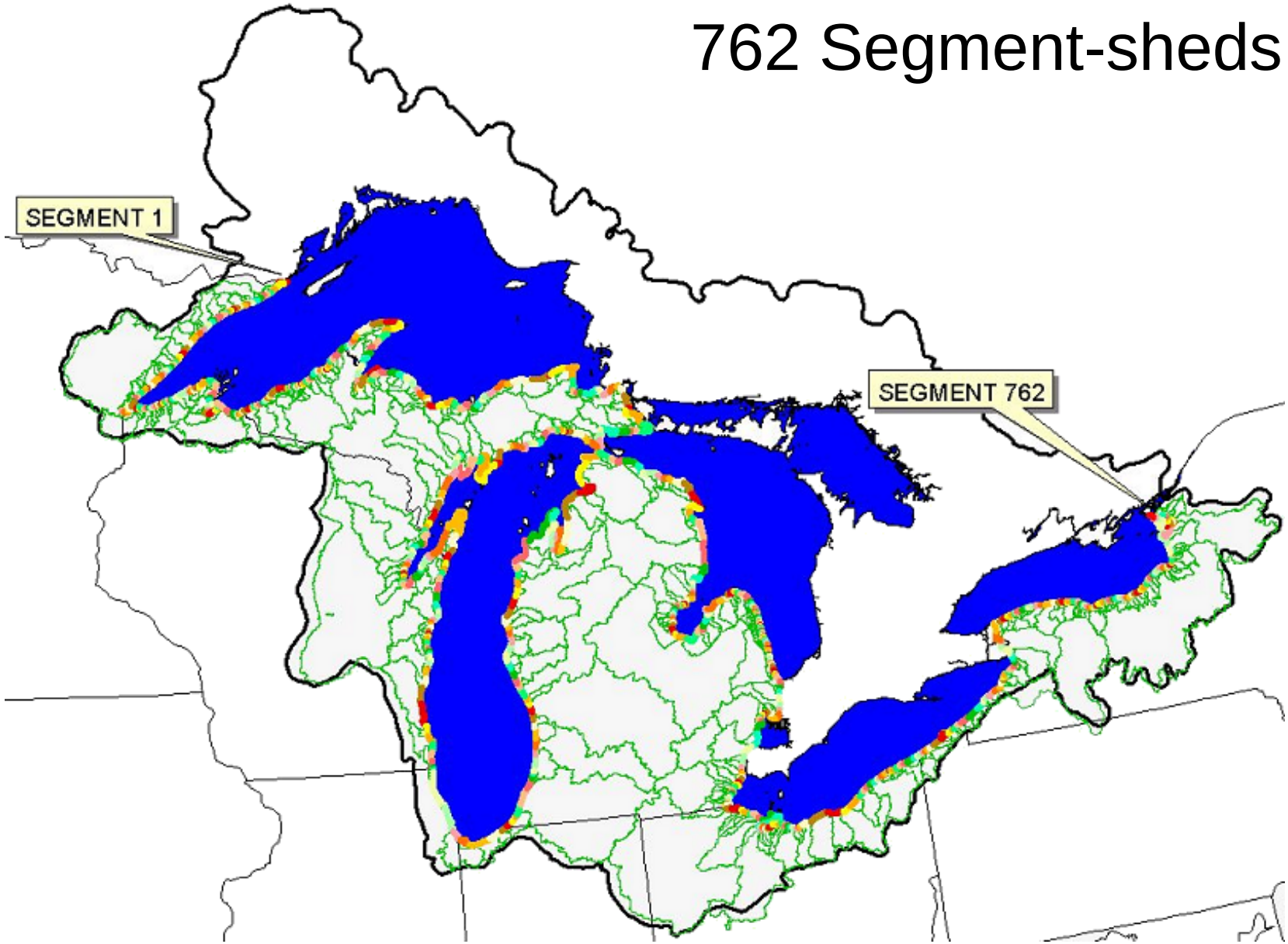
**Embayments**

**Lacustrine wetlands**

**River-influenced wetlands**

**Protected wetlands**

# 762 Segment-sheds



# Stress Data

- **Available to the public as GIS coverages**
- **Exist prior to sampling**
- **Require substantial processing effort**
- **Used to partially characterize stress regime for segment-sheds**

Envirofacts

USDA

National Atmospheric Deposition Program

United States Department of Agriculture
NRCS Natural Resources Conservation Service

National Land Cover Data

USGS science for a changing world

U.S. Census Bureau

TIGER

USGS science for a changing world

United States Census 2000

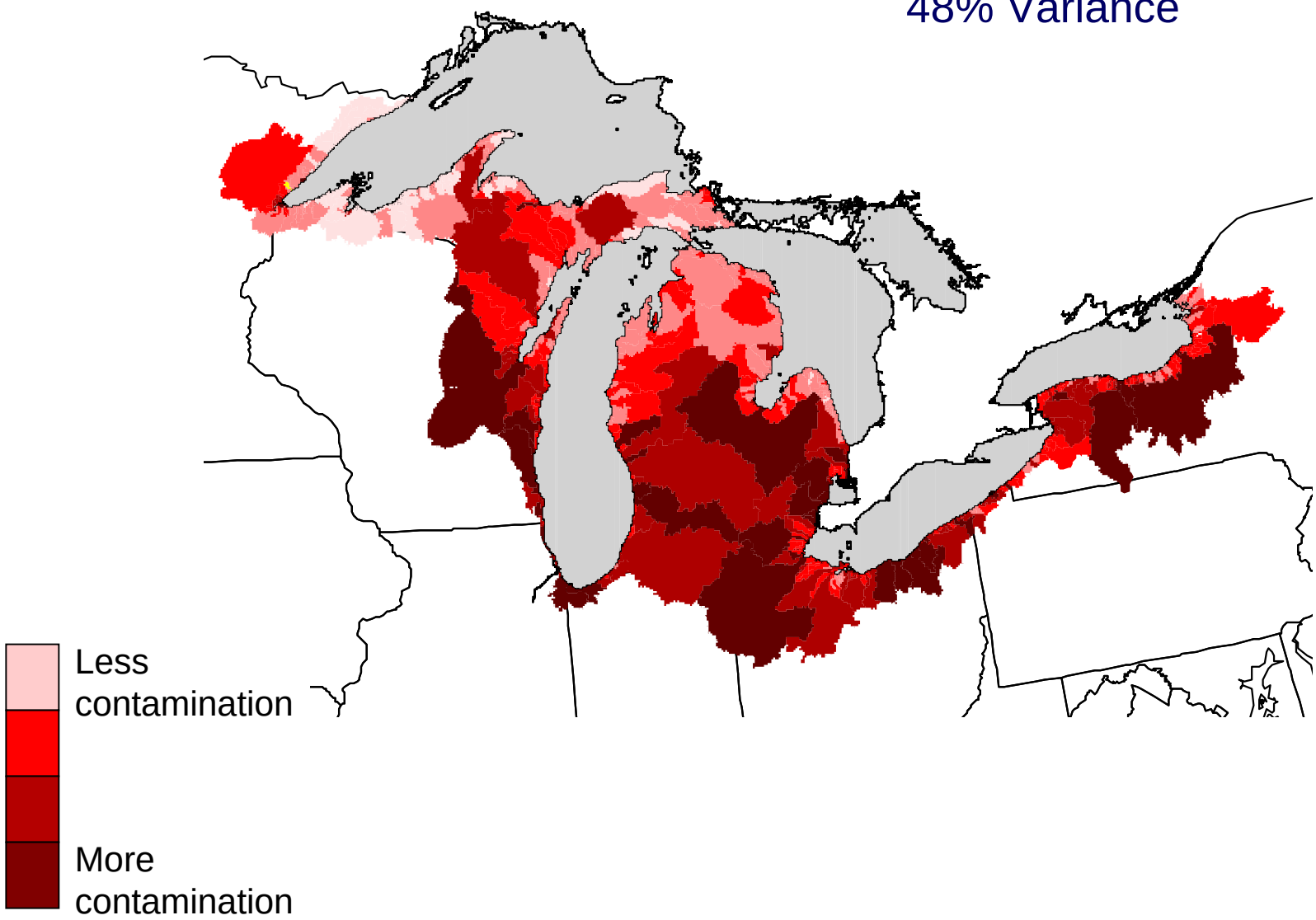
National Oceanic and Atmospheric Administration
Great Lakes Environmental Research Laboratory

# Stress Categories

| **7 Categories** | ***n* Variables** |
|---|---|
| Agricultural / Ag. Chemical | 21 |
| Atmospheric Deposition | 11 |
| Land Cover | 23 |
| Human Population / Development | 14 |
| Point and Non-point Pollution | 79 |
| Shoreline Protection | 6 |
| Soils | 53 |
| | 207 |

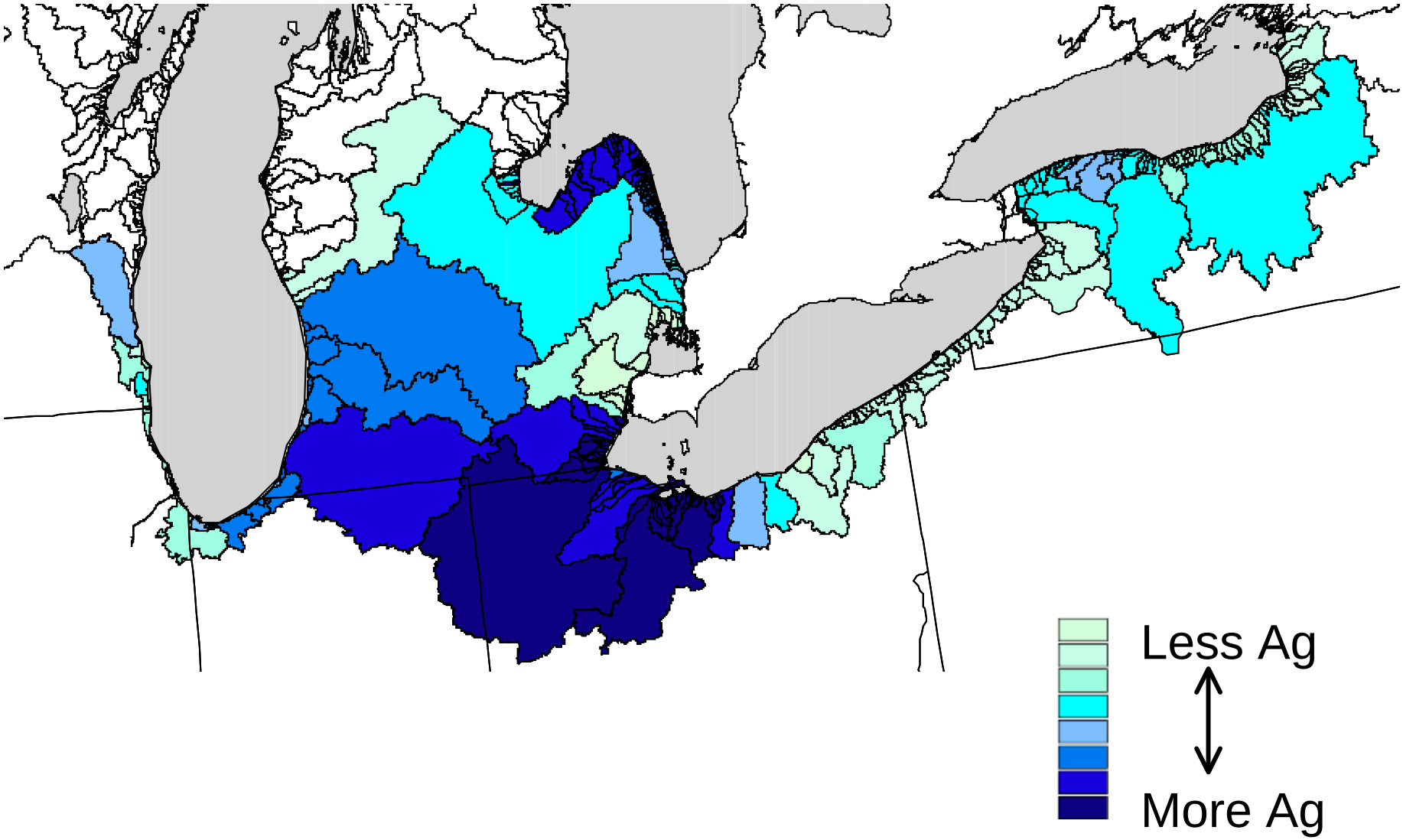
# Contaminants PC1

48% Variance



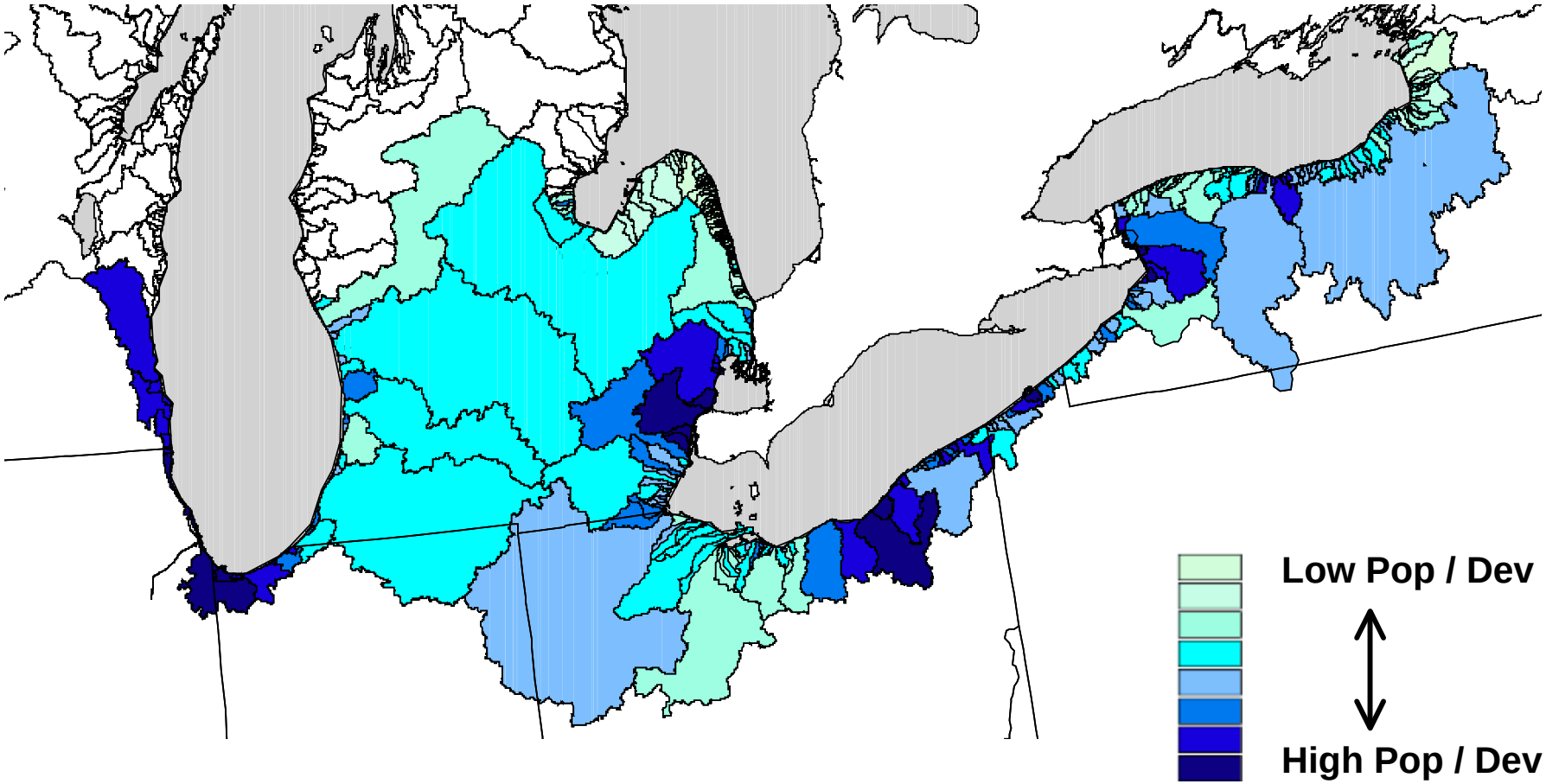
# Ag / Ag-Chem PC1

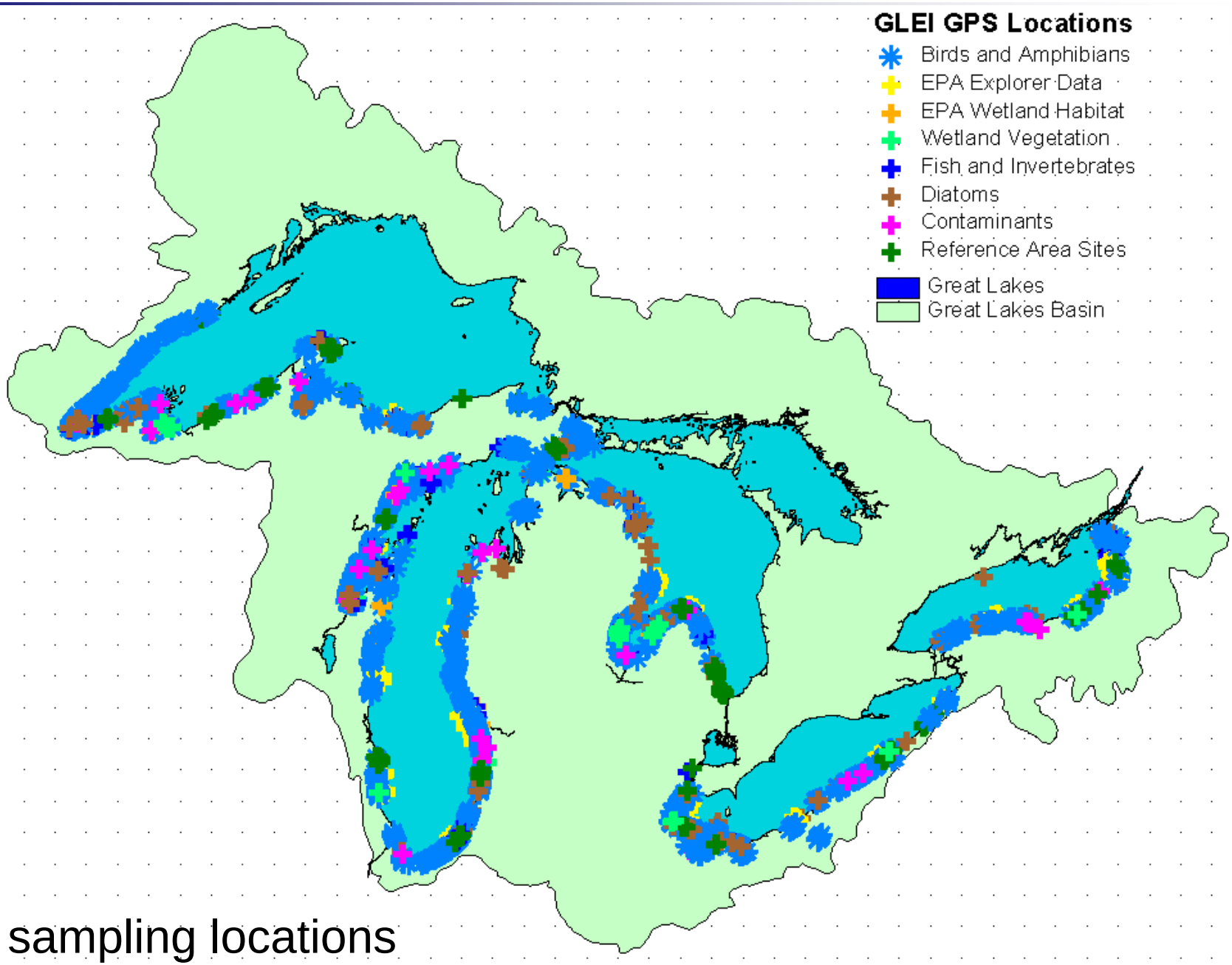
41 % variance



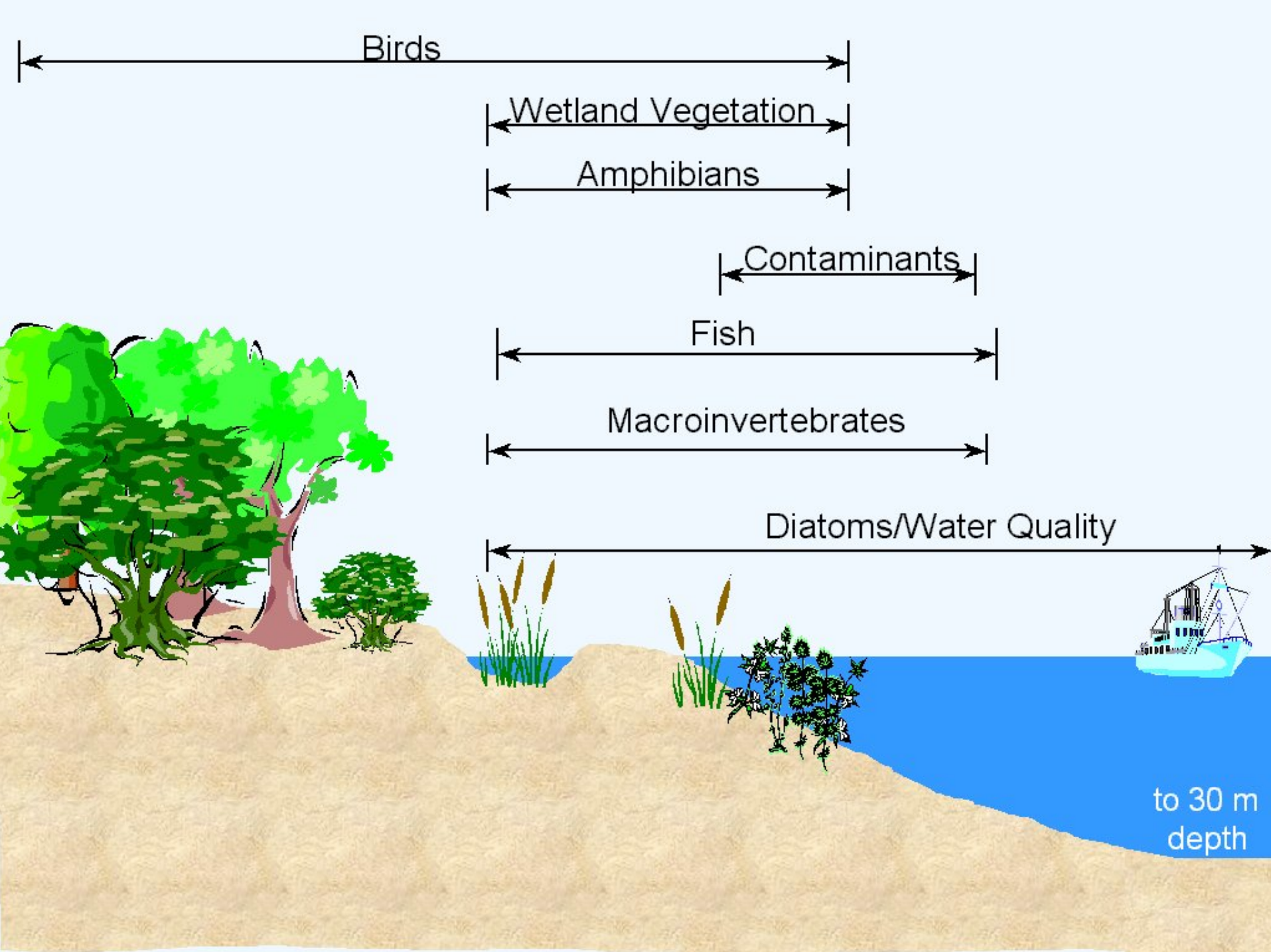
# Human Population / Development PC1

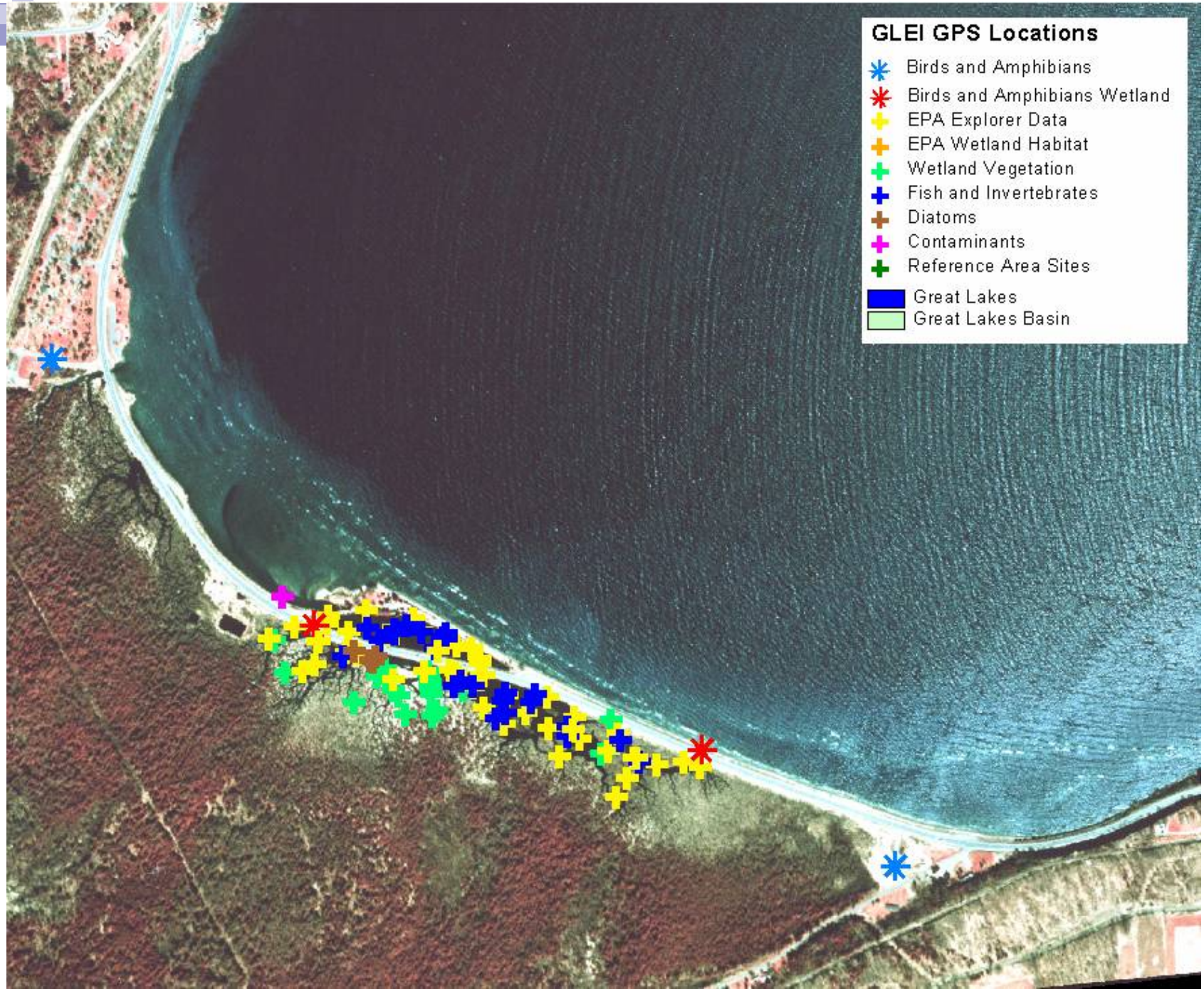
29 % variance






GLEI sampling locations

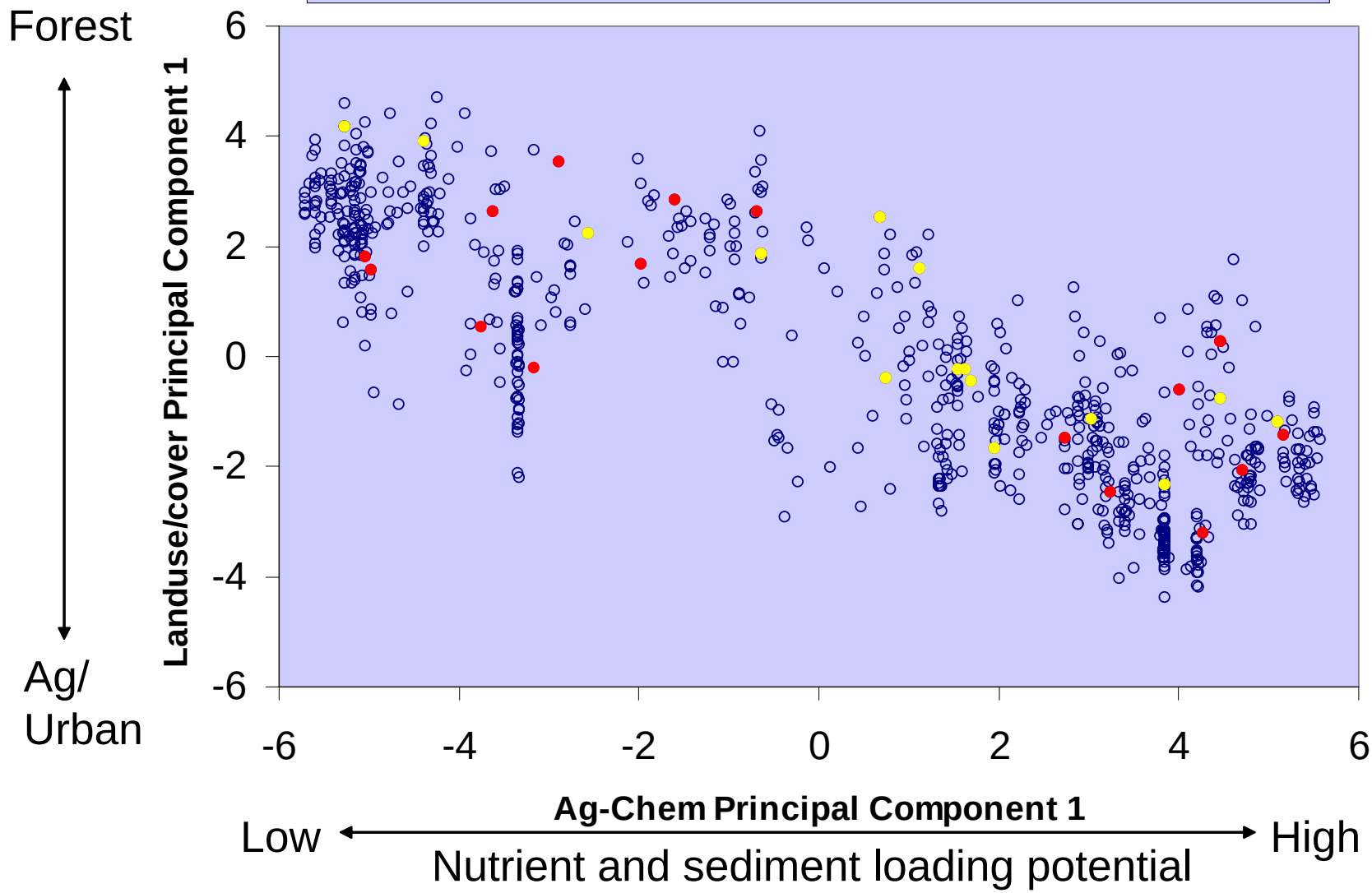

Birds
Wetland Vegetation
Amphibians
Contaminants
Fish
Macroinvertebrates
Diatoms/Water Quality
to 30 m depth


GLEI GPS Locations
Birds and Amphibians
Birds and Amphibians Wetland
EPA Explorer Data
EPA Wetland Habitat
Wetland Vegetation
Fish and Invertebrates
Diatoms
Contaminants
Reference Area Sites
Great Lakes
Great Lakes Basin

# Examples Stress/Response Linkages

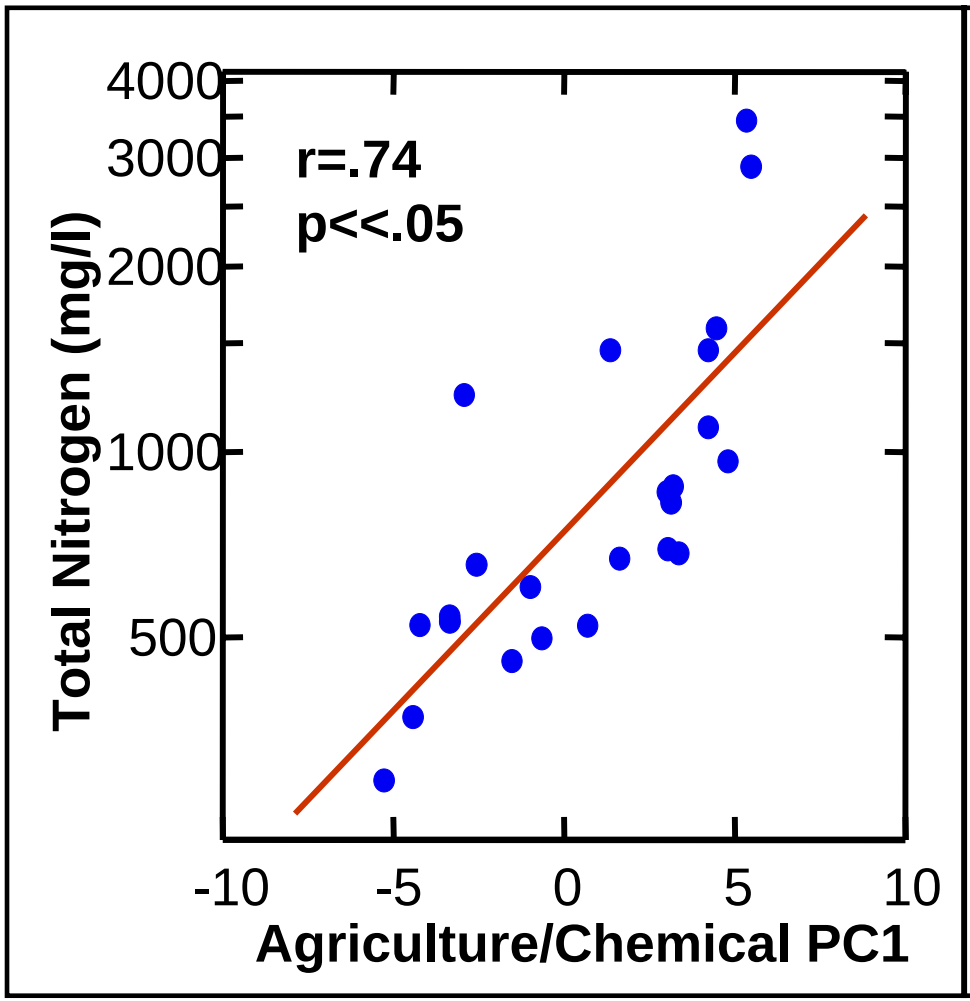
- Fish – exotic species and agricultural/chemical gradients
- Birds, macroinvertebrates, and plants – habitat and landscape change, particularly due to urban development and agriculture
- Diatoms – metal hotspots
- Chemical issues – detection of PAH toxicity and endocrine disruption

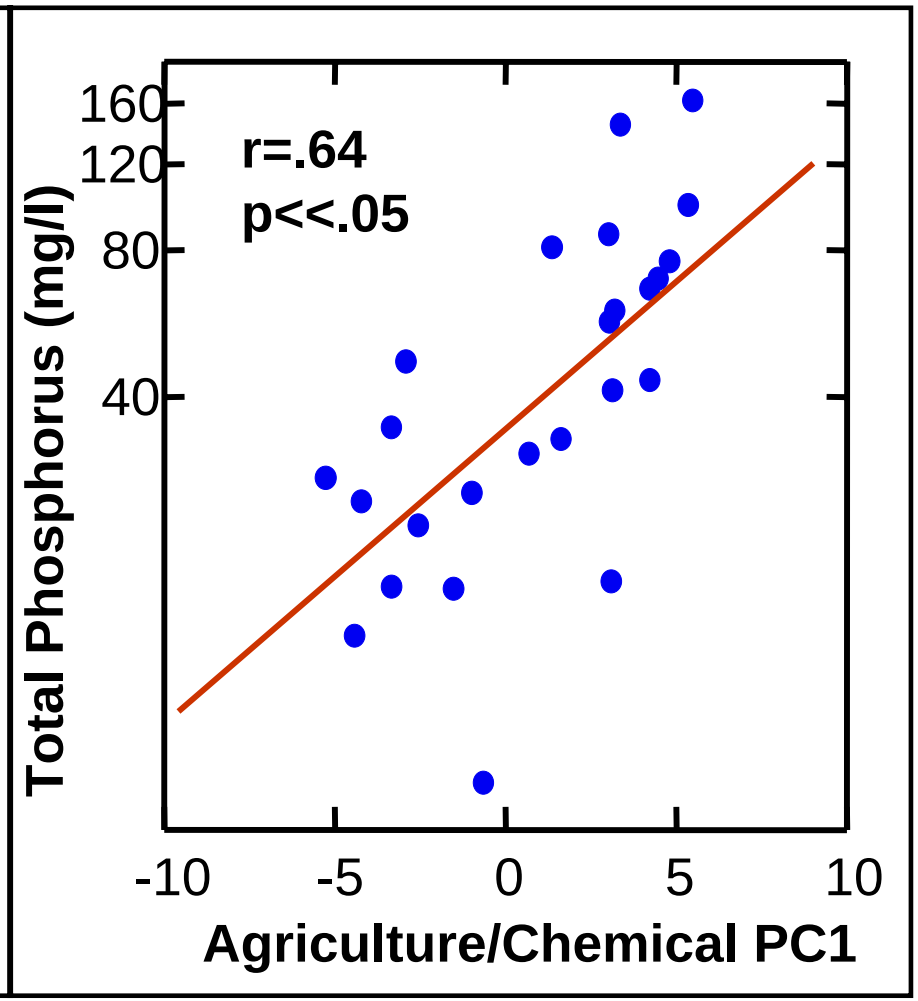
# Defining a coastal disturbance gradient



# Loading Metrics

**Agricultural Chemical PC1 vs. Nutrient Concentrations.**



# Fish and Macroinvertebrates

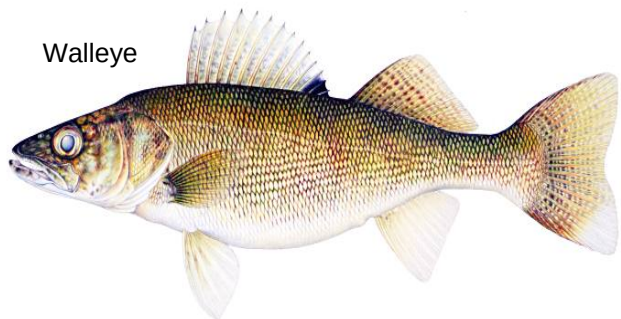
- Lucinda Johnson, Carl Richards & Tom Hrabik – University of Minnesota Duluth
- Jan Ciborowski – University of Windsor, Ontario
- John Brazner, Brian Hill, Jack Kelly, John Morrice, Jill Scharold, Michael Sierszen, Dan Tanner, Anett Trebitz & Peder Yurista – US EPA Mid-Continent Ecology Division

Fish and invertebrates reflect environmental conditions over longer time periods and larger areas than diatoms.

# Reference Condition and Classification Project

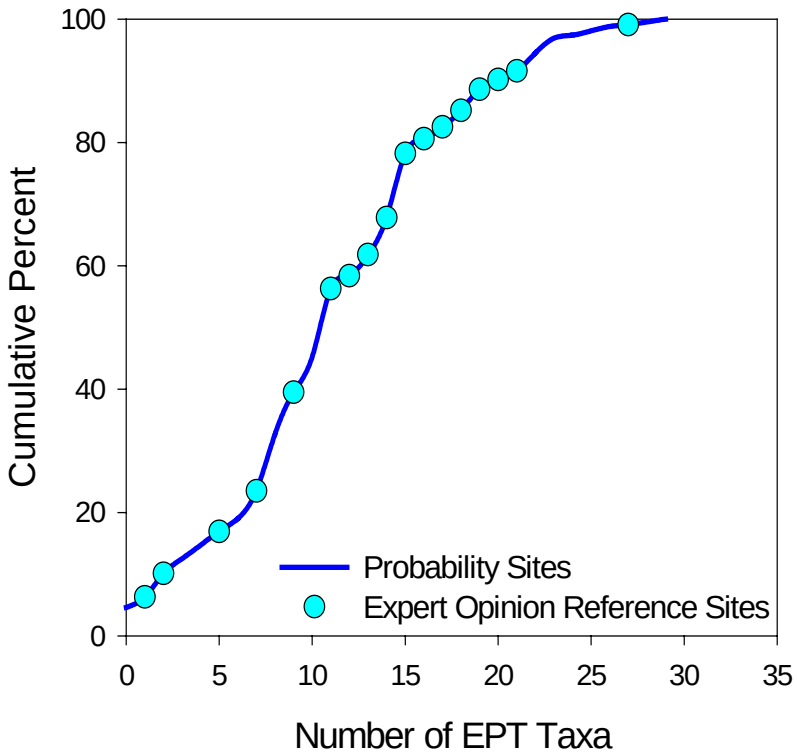

- Lucinda Johnson, George Host, Valerie Brady, Tom Hollenhorst, Dan Breneman

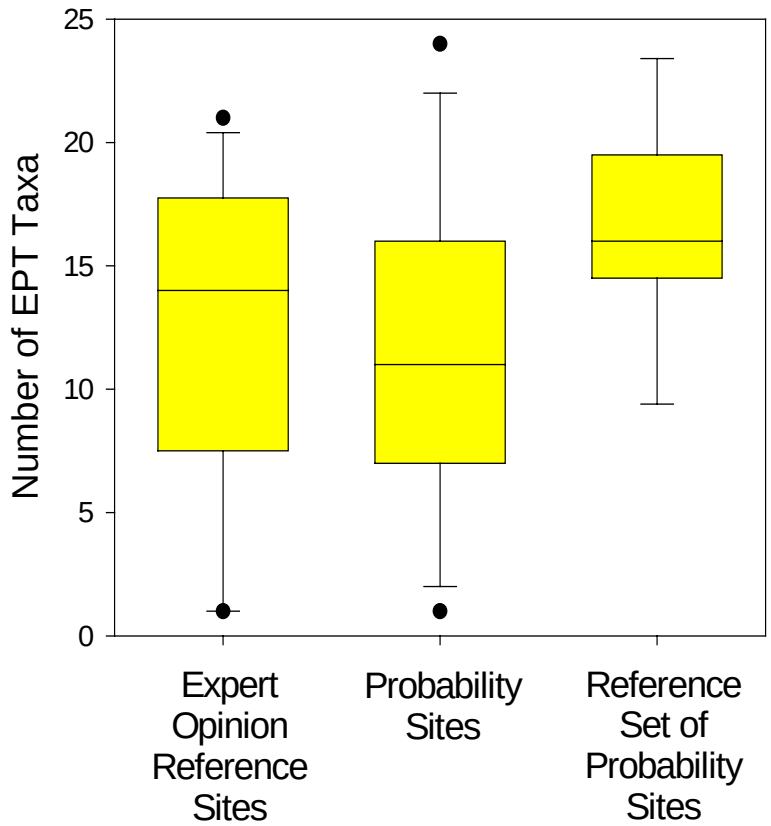
  Natural Resources Research Institute, University of Minnesota Duluth
- Jeff Schuldt - University of Wisconsin - Superior
- Jan Ciborowski, Joseph Gathman, Jeffrey Holland University of Windsor, Ontario
- Carl Richards - Minnesota Sea Grant

# Scientifically Sound Reference Conditions

## Expert opinion compared to probability




Mid Atlantic streams

Source: EMAP

# Reference Condition

…the condition that exists in ecosystems that are least impacted by anthropogenic stressors…

- "least disturbed"
- "represent natural biological community of region"
- "within the upper 20% of regional conditions"

This is only one of three different definitions for reference condition

# Inventory of Geomorphic Types

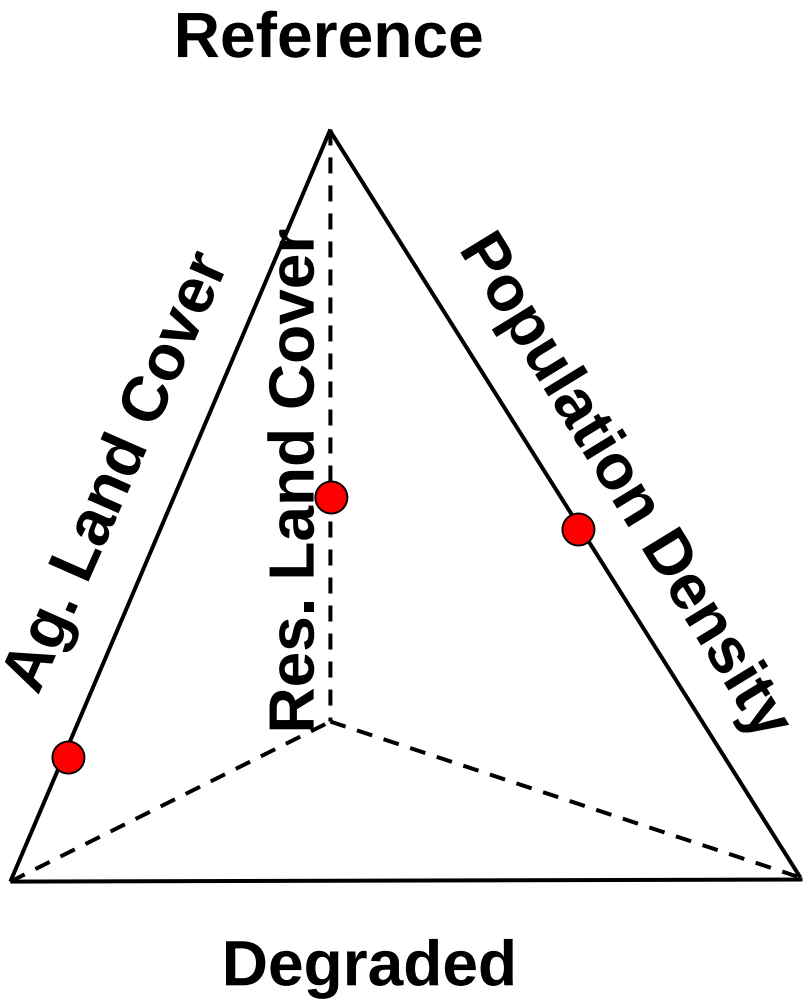
- National Wetland Inventory
- Herdendorf Inventory of Great Lakes Wetlands
- Digital Raster Graphics
- Digital Orthoquads
- Digital Elevation Maps (connectivity)

# Selection of Reference Sites

- Agricultural land cover (USGS-NLCD)
- Residential land cover (USGS-NLCD)
- Population density (US CENSUS)
- Road density (US CENSUS TIGER)
- NPDES and AOC (US EPA)
- Shoreline hardening (Army Corps)

*focus on quantifying anthropogenic impact

# Approach for defining Reference Condition




- Scale each stressor axis from 0-1 based on the maximum value within each ecosection
- Calculate maximum across each of 5 stressor axes
  - Max {Agriculture, Residential, Population, Roads, point sources}
- Reference = sites with low Anthropogenic Pressure metric scores

Host, et al., *accepted*

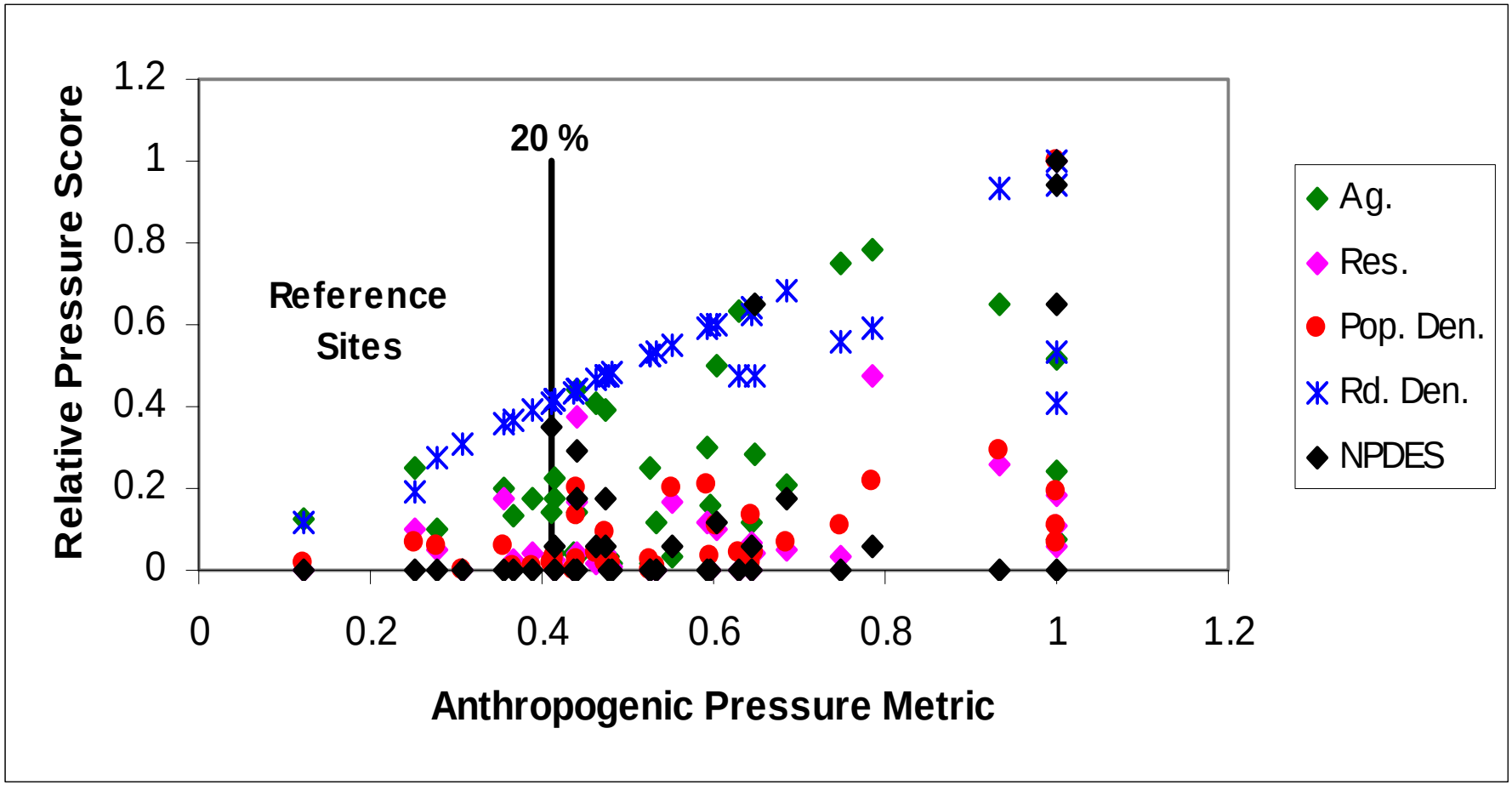
J. Schuldt 2003

# Anthropogenic Pressure Metric

| | Ag. | Res. | Pop. Den. | Scaled Ag. | Scaled Res. | Scaled Pop. Den | AP Metric |
|---|---|---|---|---|---|---|---|
| | 10 | 4 | 1.19 | 0.20 | 0.40 | 0.34 | 0.40 |
| | 20 | 1 | 1.91 | 0.40 | 0.10 | 0.54 | 0.54 |
| | 50 | 5 | 3.51 | 1.00 | 0.50 | 1.00 | 1.00 |
| | 30 | 10 | 3.21 | 0.60 | 1.00 | 0.91 | 1.00 |
| | | | | | | | |
| Max. | 50 | 10 | 3.51 | | | | |

# River Influenced Wetlands

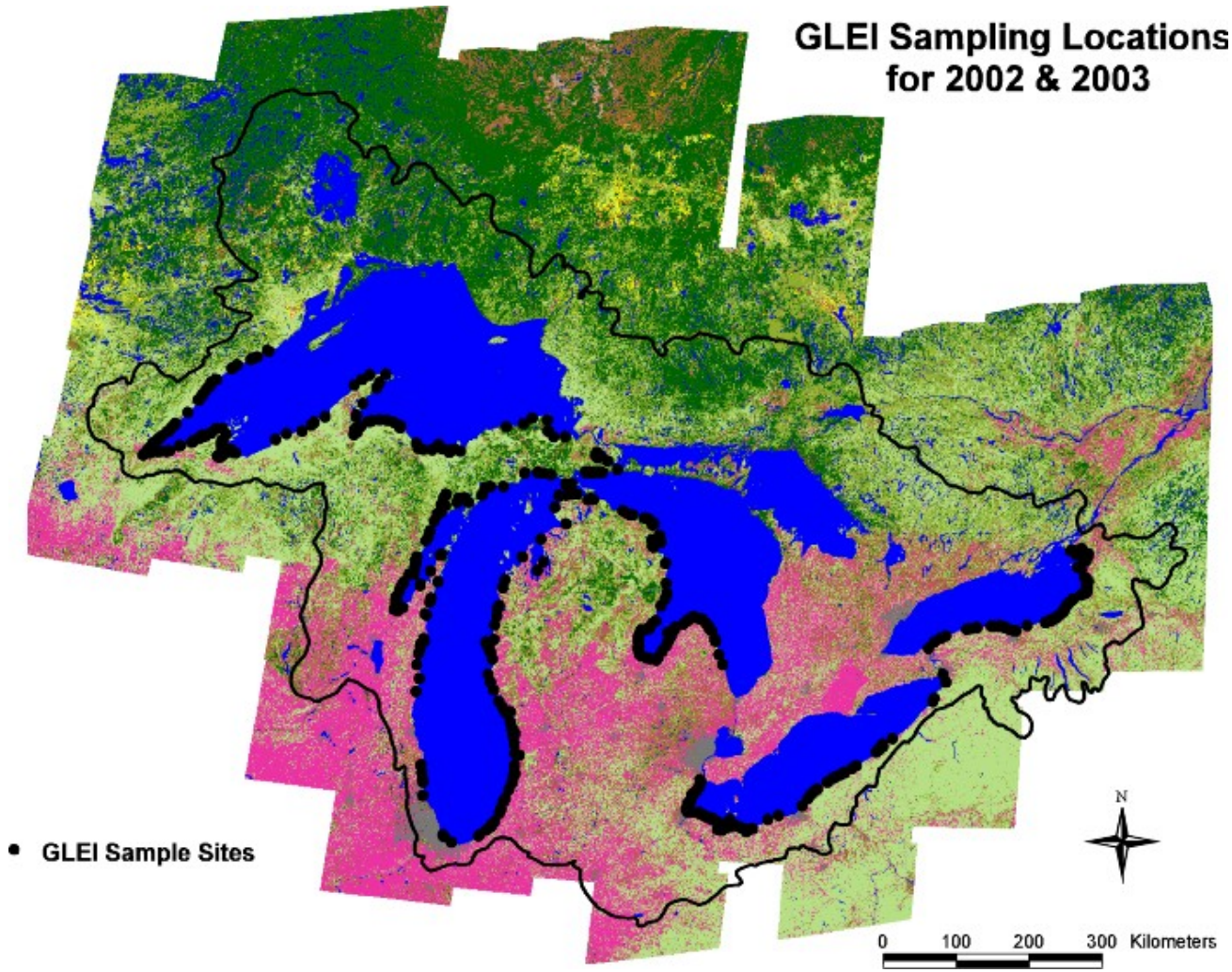
## Southern Superior Uplands Ecosection




J. Schuldt 2003

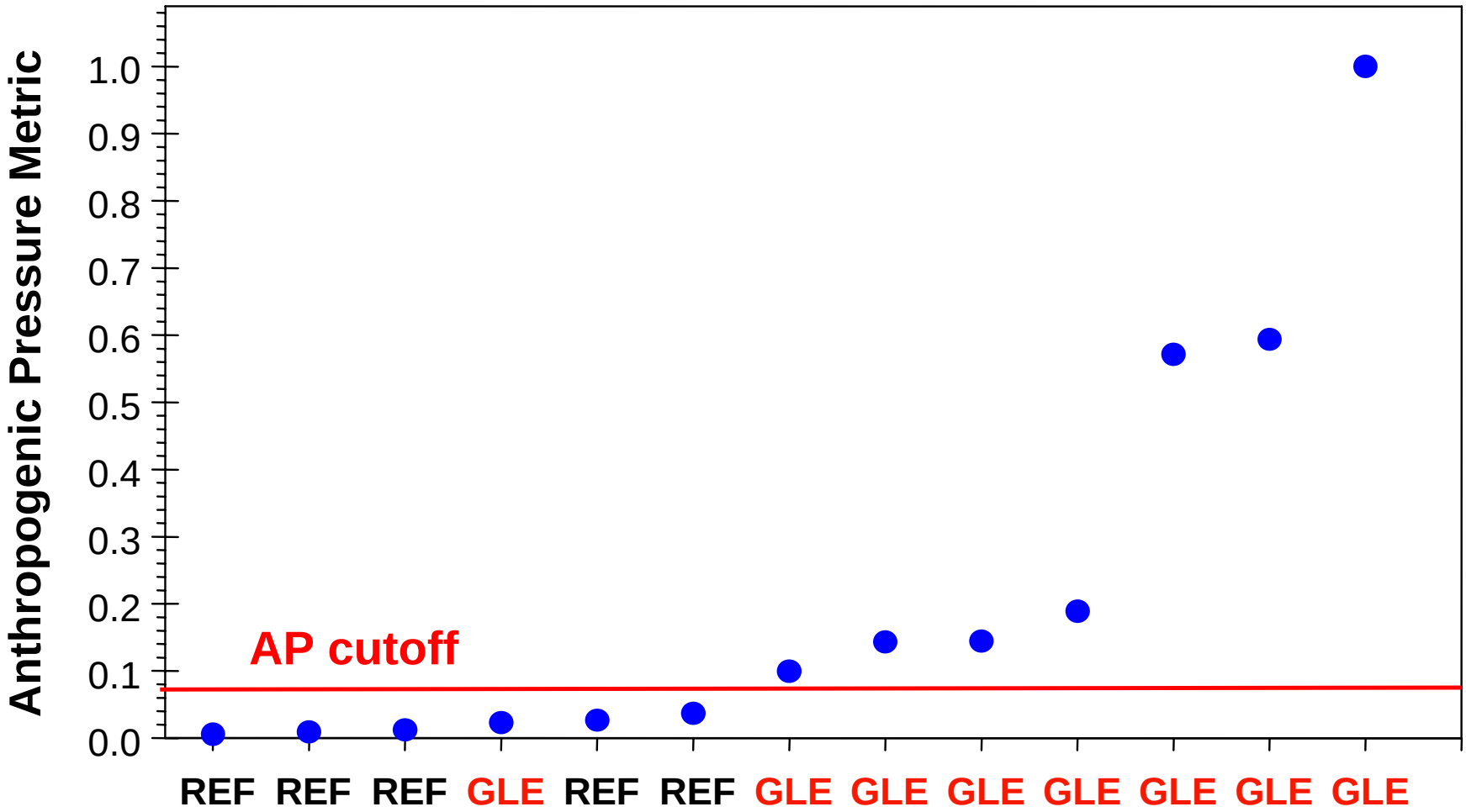
# Great Lakes Environmental Indicators (GLEI)

## Sites chosen to represent entire anthropogenic pressure gradient



# Reference / Degraded Ecosystem Comparisons

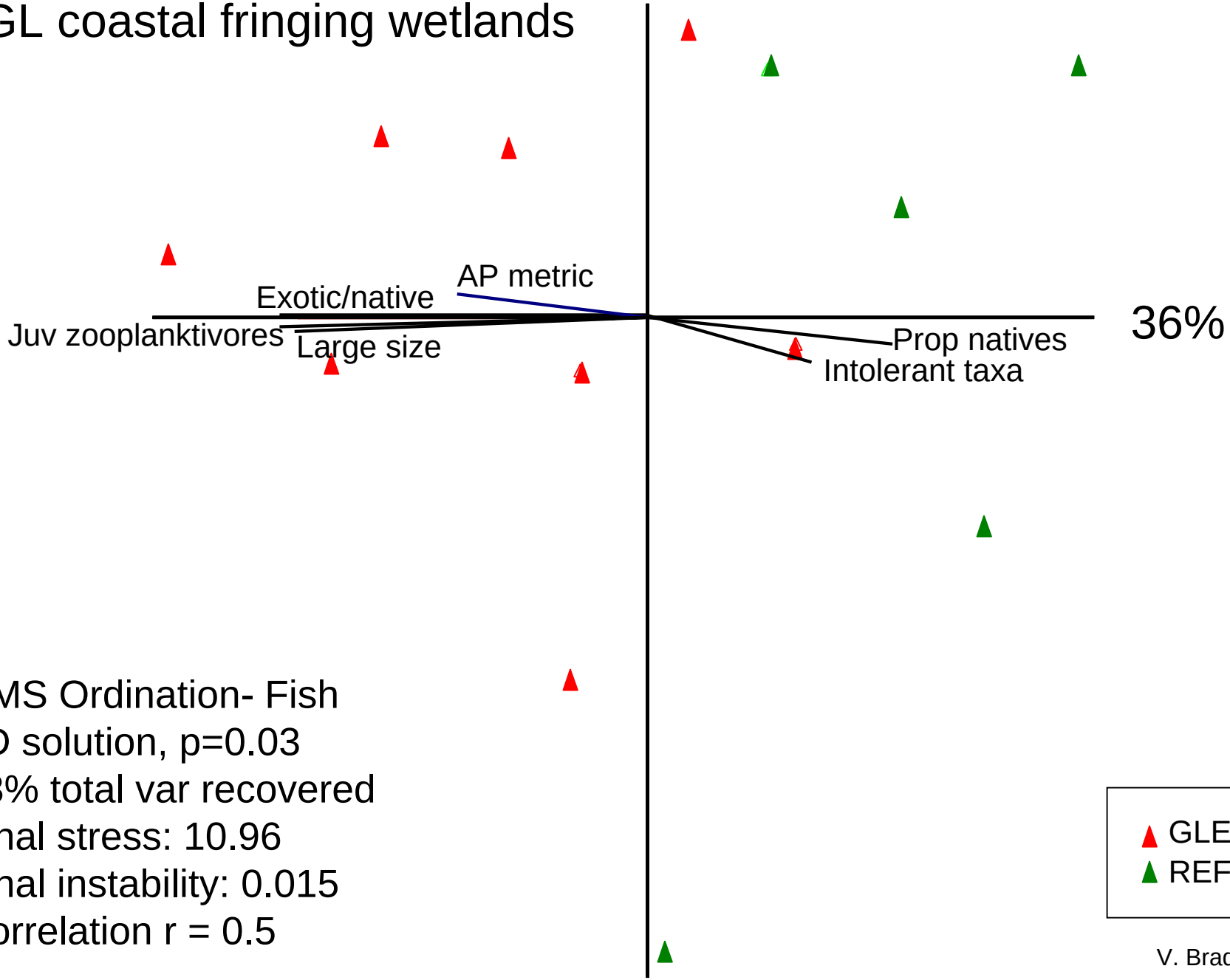
## NGL coastal fringing (lacustrine) wetlands




V. Brady 2004

# Fish communities:

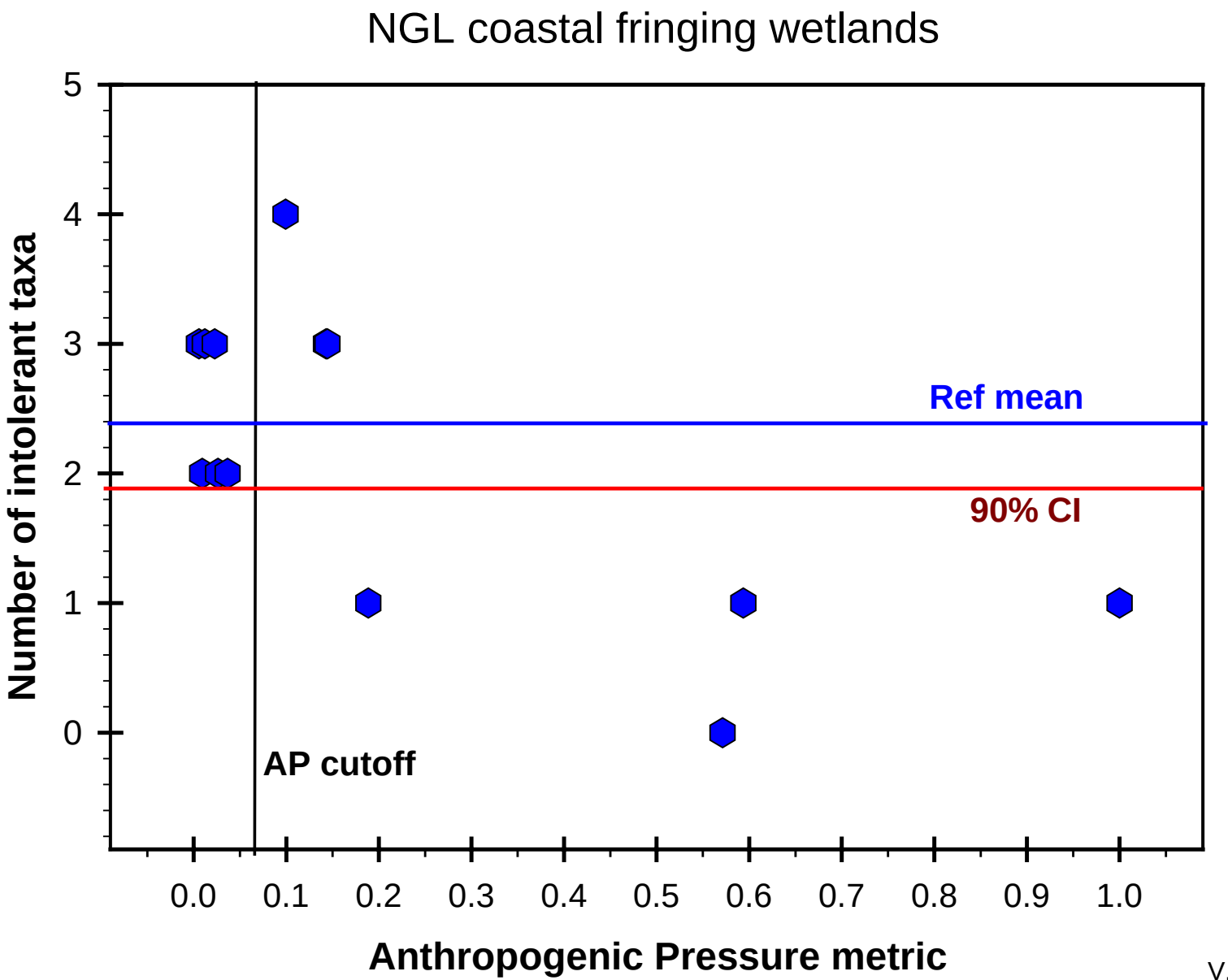
# NGL coastal fringing wetlands




NMS Ordination- Fish
2D solution, p=0.03
53% total var recovered
Final stress: 10.96
Final instability: 0.015
Correlation r = 0.5

V. Brady 2004

# Reference / Degraded Ecosystem Comparisons



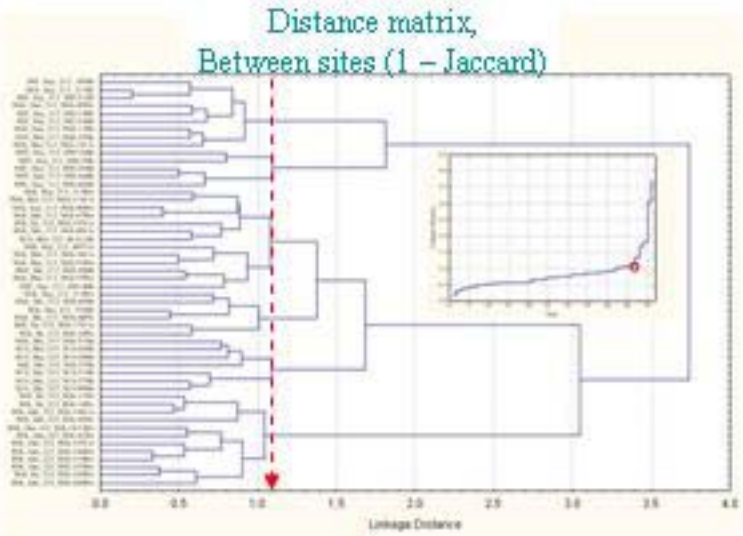

V. Brady 2004

# Evaluating Reference Condition sites based on fish assemblages

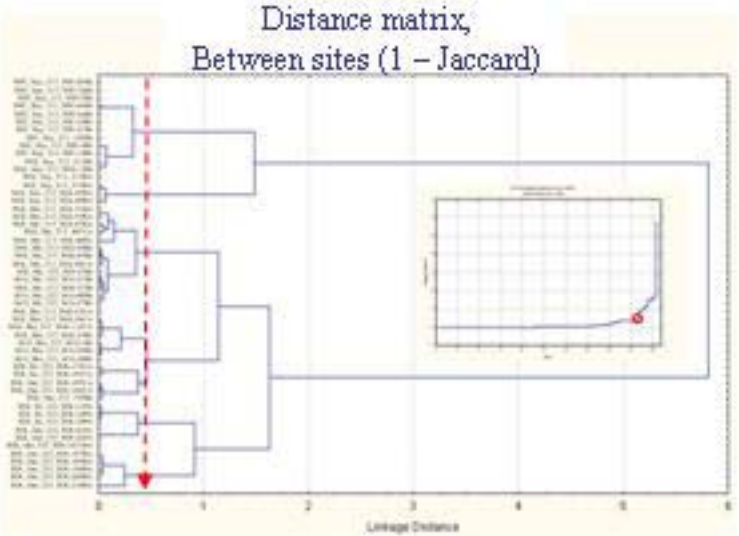
Species occurrence

Species range

Distance matrix, Between sites (1 – Jaccard)



Distance matrix, Between sites (1 – Jaccard)

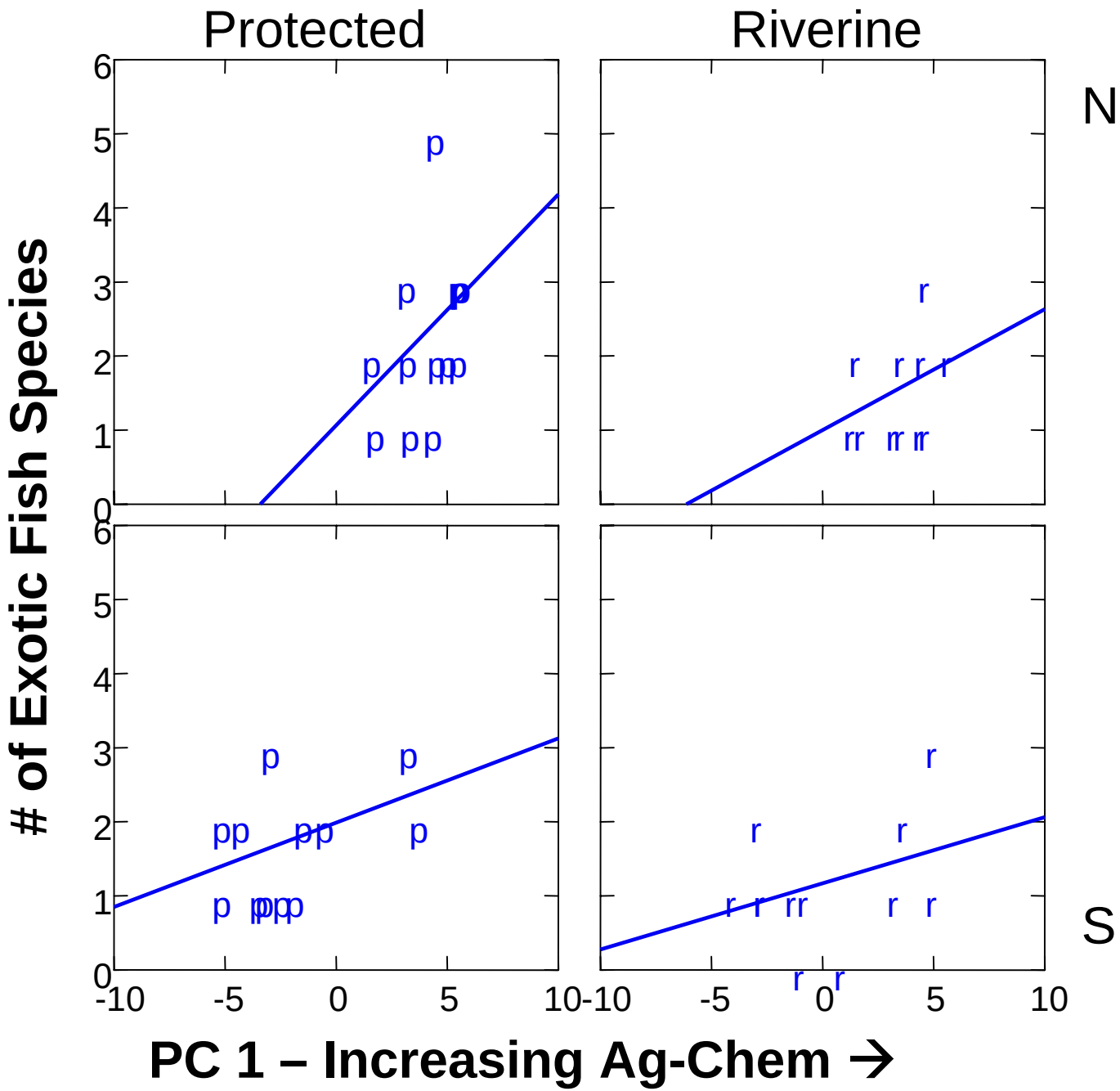


Mantel test

r = 0.1479

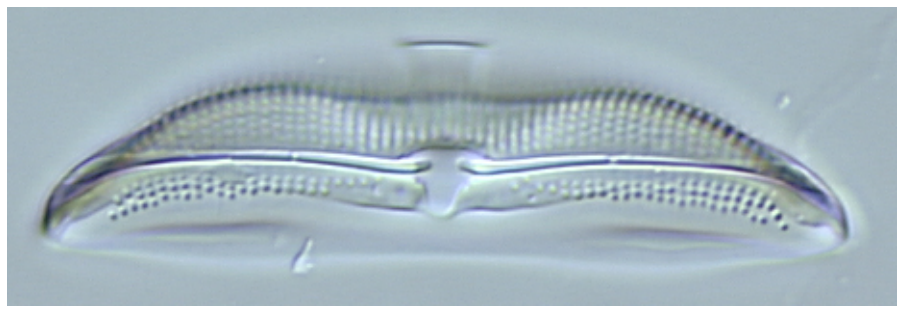
p = 0.0012

# Other fish indicators



# Diatom / Water Quality

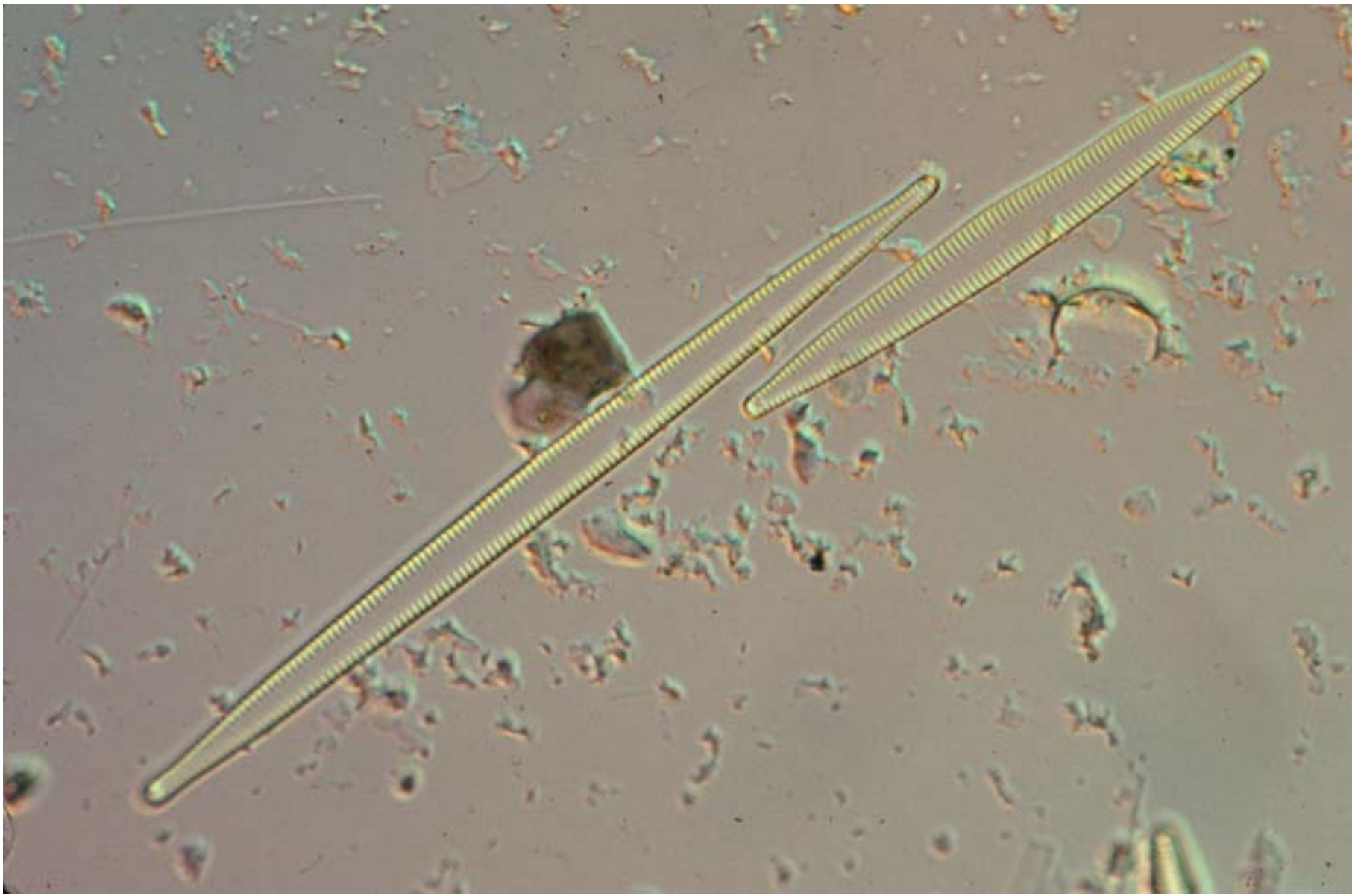
- Euan Reavie & Richard Axler – Natural Resources Research Institute, University of Minnesota Duluth
- Jeffrey Johansen & Gerald Sgro – John Carroll University, Cleveland
- Eugene Stoermer – University of Michigan
- Russell Kreis, Jo Thompson, Jack Kelly, & John Morrice – US EPA Mid-Continent Ecology Division



# Identification of “atypical” *Tabularia spp.* diatoms from Lake Erie

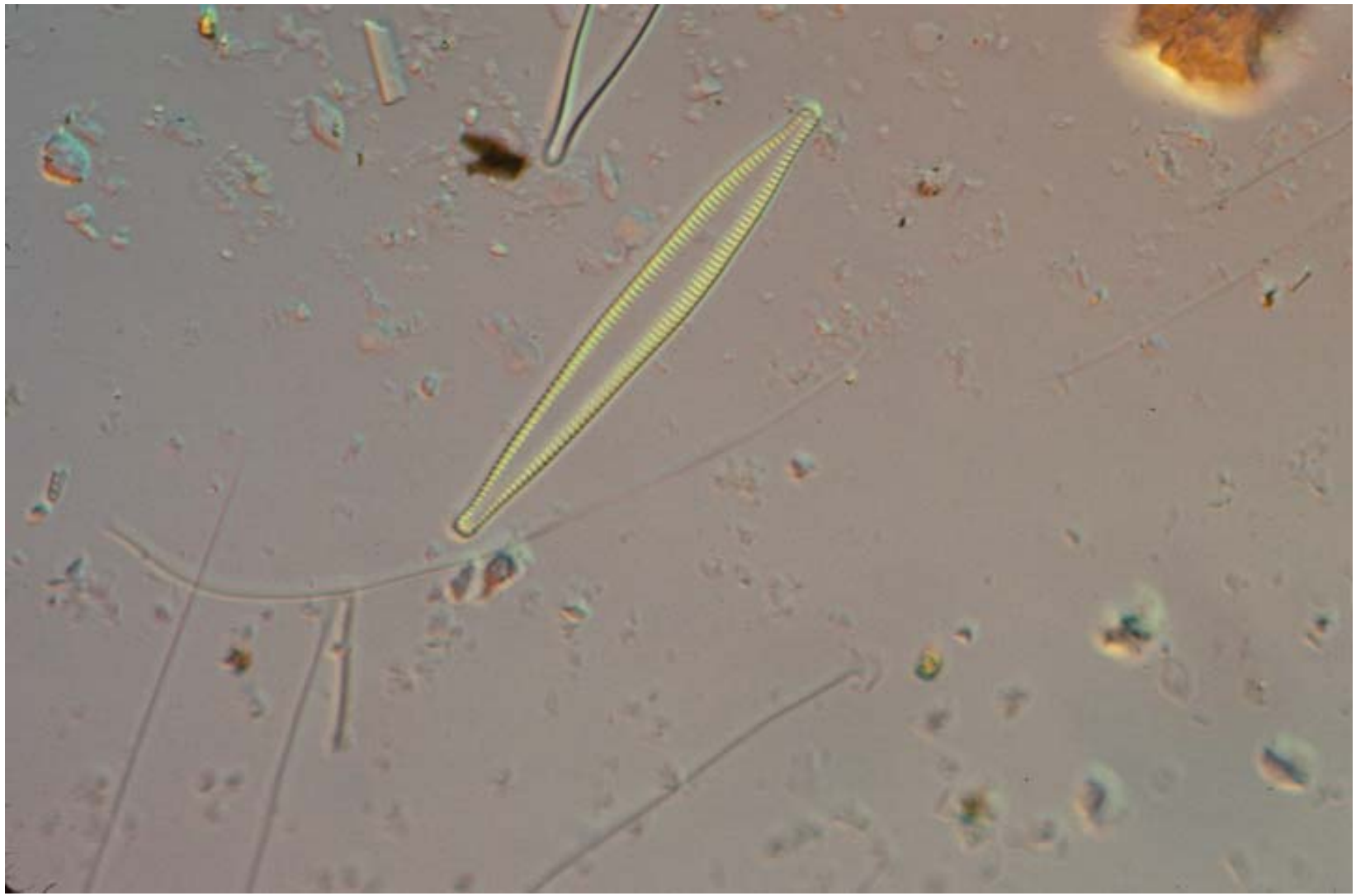
- Three new morphological forms of *Tabularia* found in high abundance near Cleveland – associated with heavy metal hotspots
- Cuyahoga River (“River on Fire”) – identification of environmental legacy problems
- These morphological forms can be used as an indicator of metal problems
- Identified by E. Stoermer, U of Michigan

# *Tabularia* “good” Specimens



# “Skinny” Bent Ends

# “Fat Asymmetric”



# “Blunt Mangled”

# GLEI Surrogate Water Quality Indicators

- Transparency tubes and turbidity are widely used, inexpensive measures of suspended sediments and clarity
- Often well correlated with TP, TN and other pollutants including Hg, fecal coliforms, …
- Other “field friendly” surrogate parameters being tested are color (DOC), EC25 ($Cl^-$, TDS), fluorescence (algal chlorophyll and DOC)
- First comprehensive look at submergent zone water clarity in all five Great Lakes

# Development of Environmental Indicators Using Remote Sensing Technology


- Gerald Niemi, and Peter Wolter - Natural Resources Research Institute, University of Minnesota Duluth
- Carol Johnston - South Dakota State University

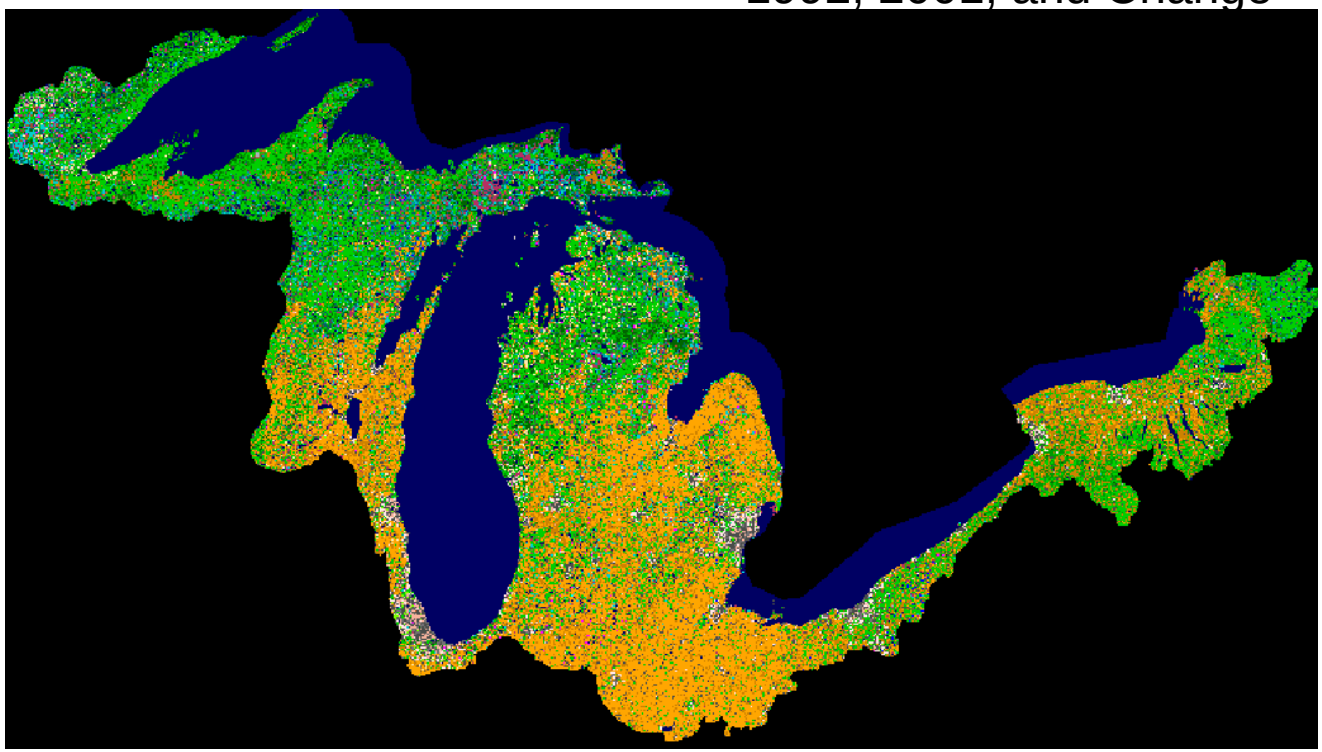

Overall goal: Produce a basin-wide suite of land cover and land cover change variables to better frame potential landscape pressures on coastal areas.

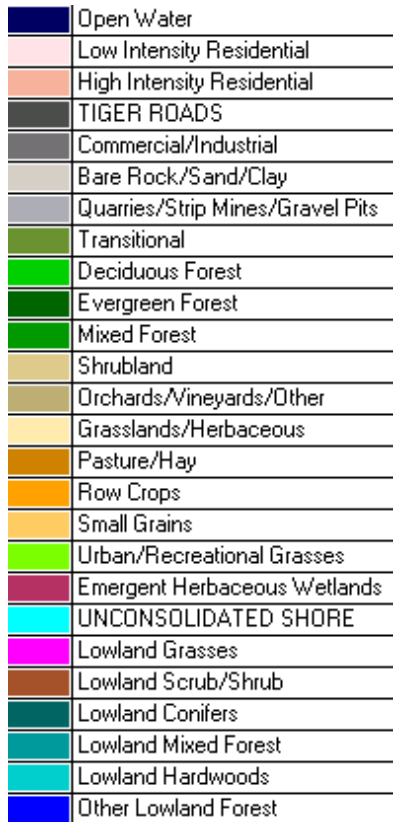
# Land Cover and Change

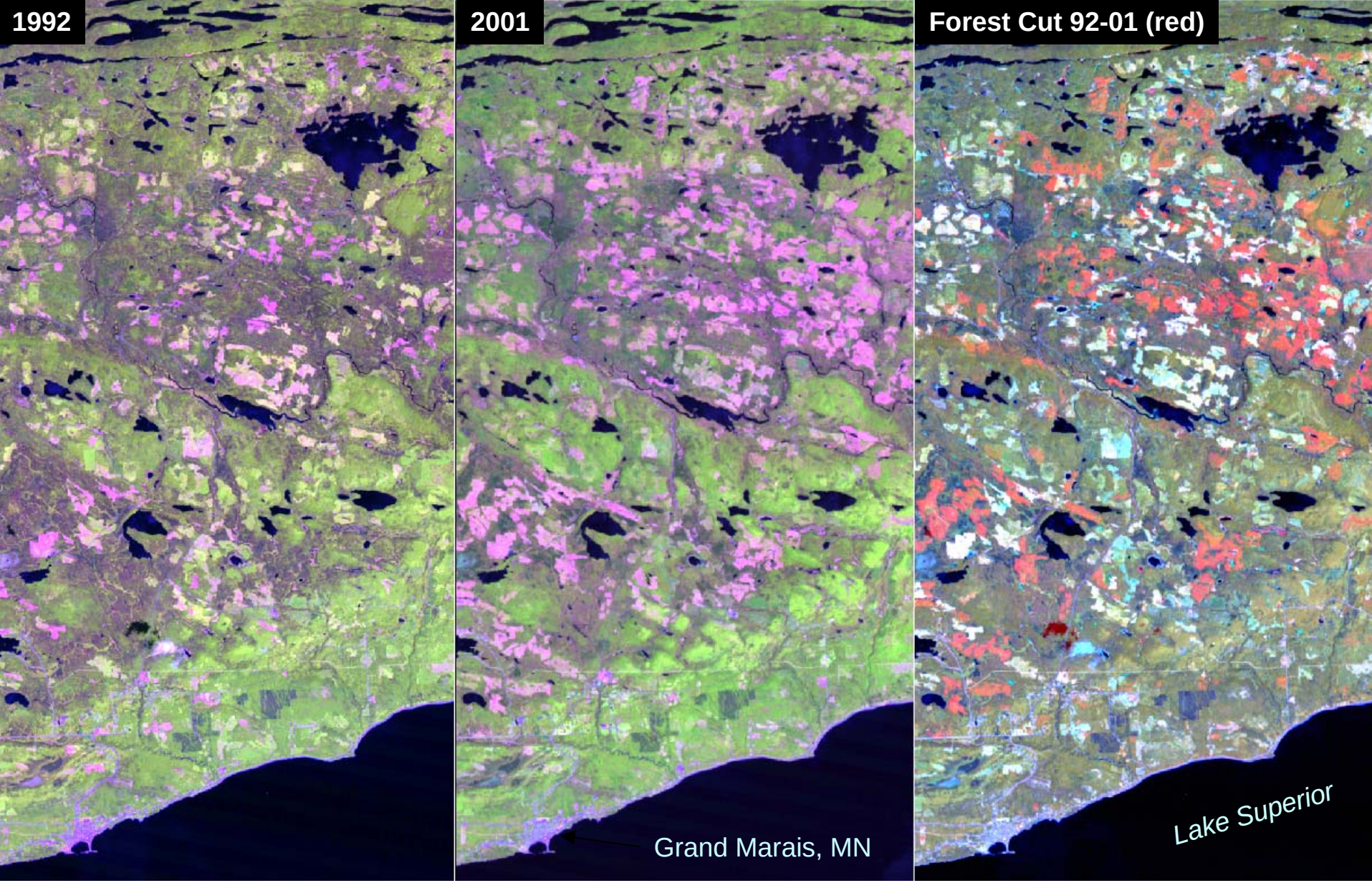
Landsat-based Land cover classifications from 1992 and 2001 for the U.S. portion of the Great Lakes basin. Indicator development will concentrate on:

- wetland area and vegetation type (e.g., Tyhpa, Phragmites, and Phalaris)
- development pressure and forest harvesting
- specific agricultural crops (e.g., corn, soybeans, and sugar beats)

1992, 2001, and Change

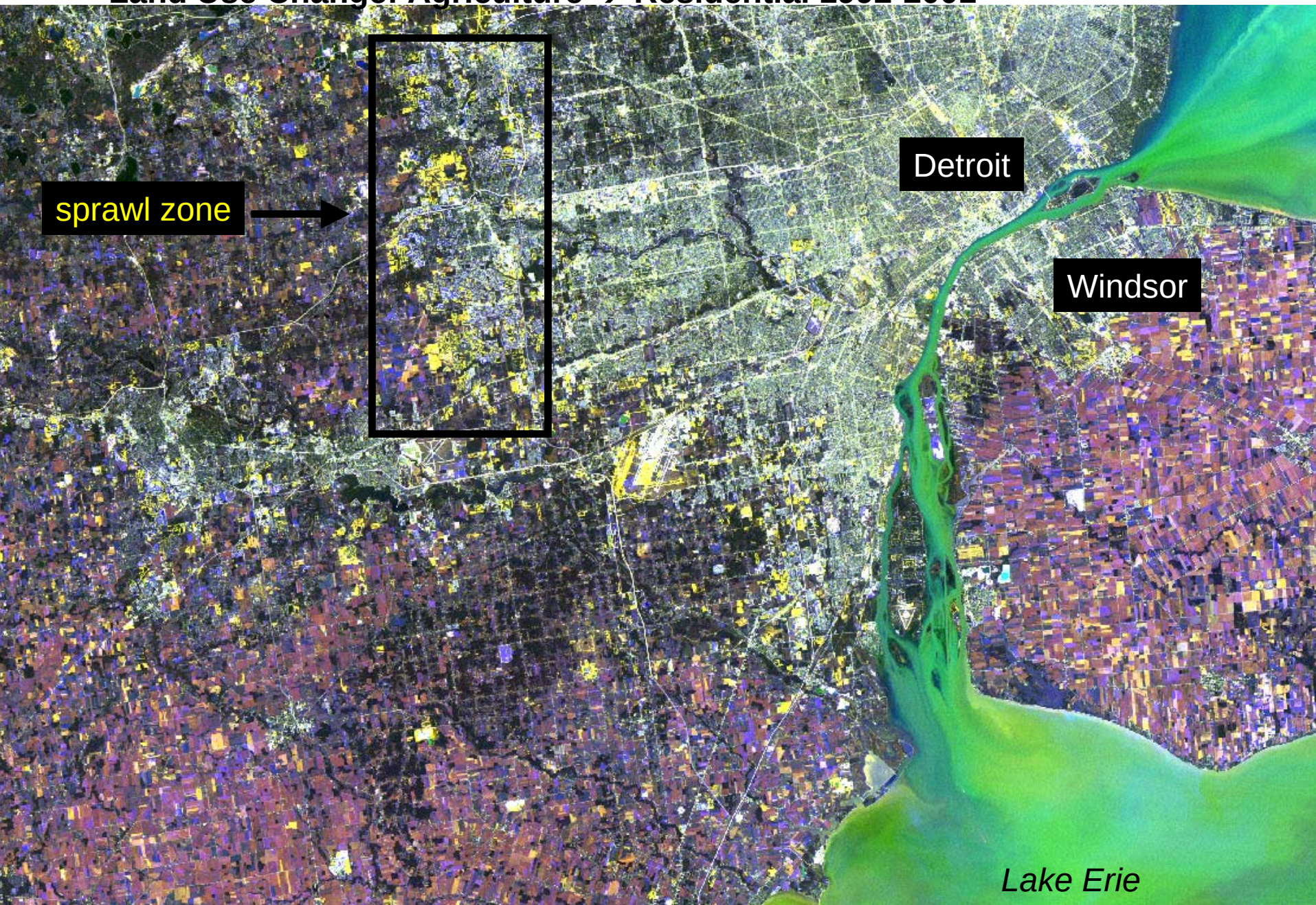


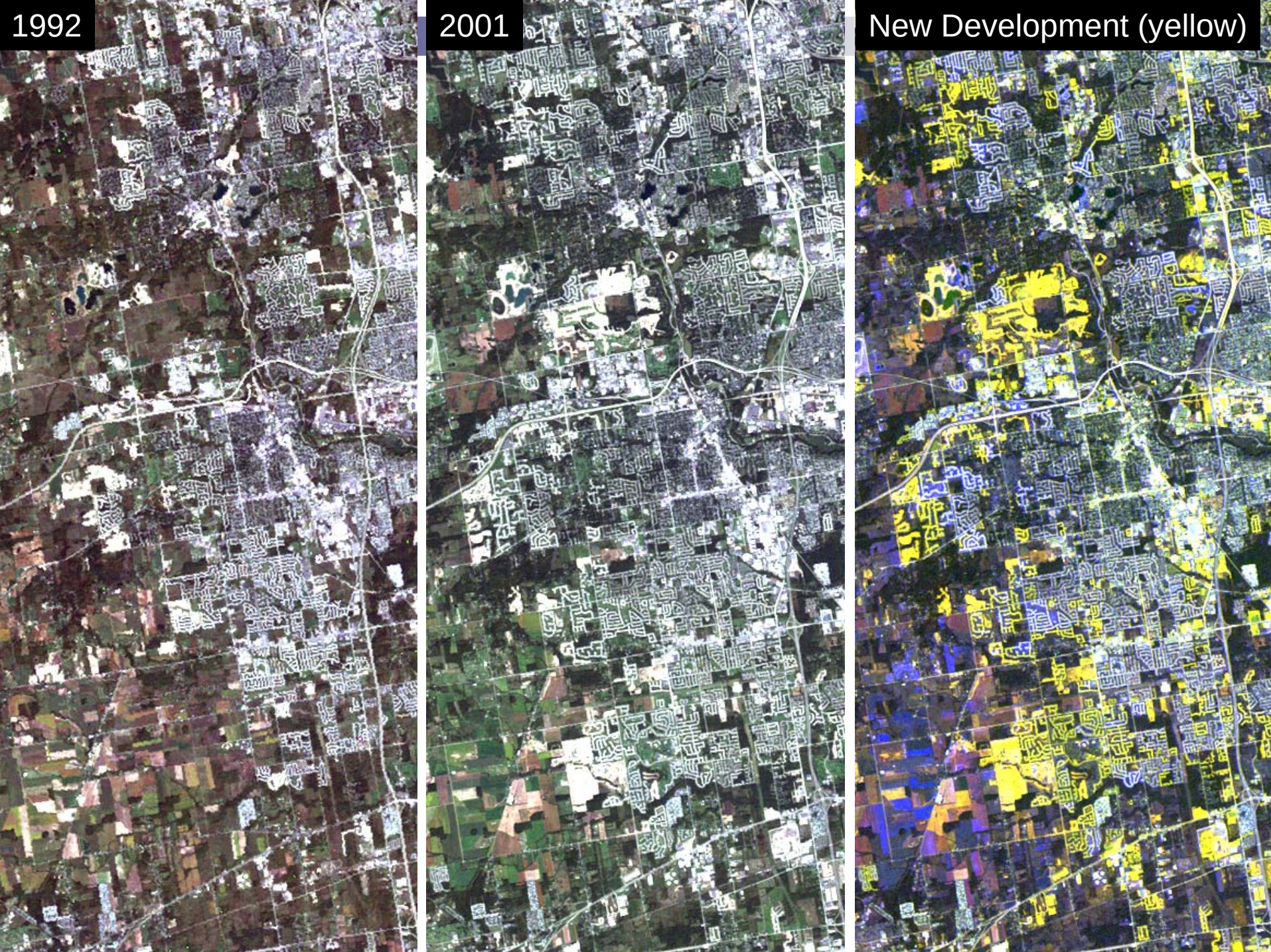





Forest harvesting places pressure on coastal areas in terms of increased water runoff, siltation, and thermal pollution.

# Land Use Change: Agriculture → Residential 1992-2001




1992
2001
New Development (yellow)

# Shoreline Morphology

Lakes Michigan and Huron are experiencing near record-low water levels.

Fluctuations in water level impose natural hydrologic disturbances on coastal areas.



Probability of wetland inundation and siltation will be the focal point of indicator development using a 30 m interferometric DEM of exposed lake bed.

## SAV

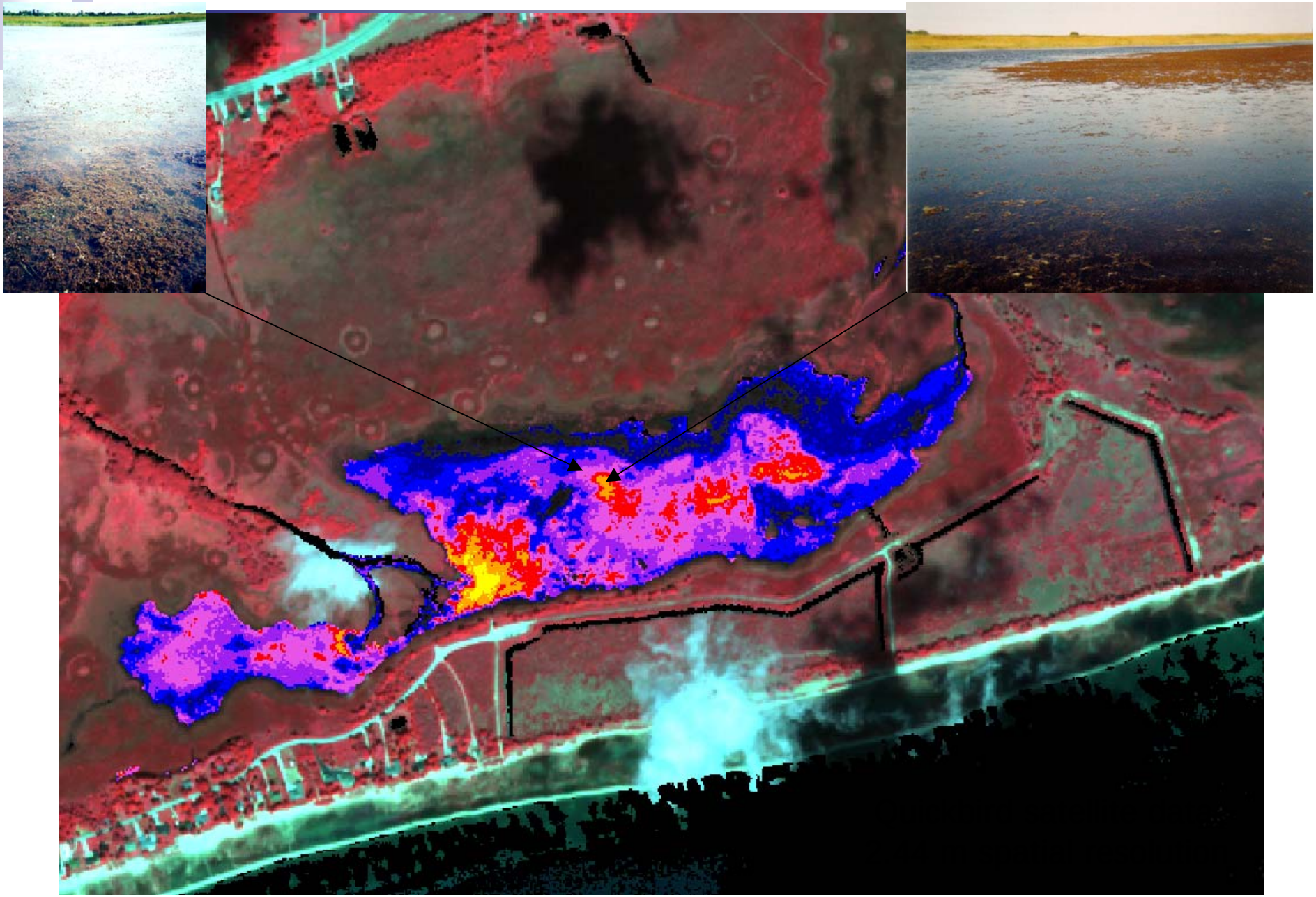
Because of its sensitivity to certain types of human activity, SAV can be viewed as a "canary" of coastal habitats and can be used as a sensitive index of the impact of human activities.

thermal effluents
toxic agents
dredging
industrial discharges
cultural eutrophication
oil spills
commercial fishing
turbidity

} Have all been associated with reductions in SAV

Remote detection of SAV from space has been a goal of marine research since the launch of Landsat-1 in 1972. Recent improvements in commercial satellites have renewed interest in these research goals, which are now being extended to fresh water systems.

Other EaGLe centers are looking at *in-situ* spectral measures of seagrass health. Eventually, scaling up to satellite-based measures will follow. Being able to detect SAV from space reliably and with greater spatial detail than in the past is a first step in this process.



Mapping SAV near Escanaba, Michigan using change detection techniques

Erie Marsh, Michigan

***Phragmites sp.***

***Nelumbo lutea***

Identifying invading vegetative species

***Lythrum salicaria***

# More information …

- Vegetation Indicators
- Bird/ amphibian Indicators
- Contaminents:
  - Endocrine Disruptors
  - Photoactivated PAH’s

# Conclusions

- Successfully implemented a large-scale sampling program for the Great Lakes coastal region
- Multiple stress gradients identified
- Field data have verified many of these important gradients (e.g., nutrients, exotic spp., and chemical contamination),
- Very non-trivial exercise in multivariate statistics and geographic information systems

# Conclusions continued

- Many stress/response relationships have already been identified
  - Exotic species (fish and plants) with agricultural/chemical gradient
  - Birds, amphibians, and macroinvertebrates with habitat change and landscape fragmentation
  - Diatoms with metal hotspots and water quality
  - Field detection of PAHs and endocrine disruption
  - And many more to come…

# Conclusions continued

- NASA component has been very successful
  - Remote sensing – land use change detection
  - Digital elevation modeling – water level fluctuations
  - Remote sensing of submerged aquatic vegetation
- Data base coordination effort among EaGLes

What's New - GLEI Pub - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Back Forward Stop Refresh Home Search Favorites Media History Mail Print Edit

Address http://glei.nrri.umn.edu/default/new.htm Go Links

Google Search Web Search Site PageRank 0 blocked AutoFill Options

GLEI

Back to Home

A multi agency project funded by US EPA's **STAR Program**

## What's New

**last updated Oct 1, 2003**

### EPA STAR Grantee Honored for Work in the Great Lakes

An EPA Science to Achieve Results (STAR) grantee has been named the first recipient of the International Joint Commission (IJC) Biennial Award for Great Lakes Science. Dr. Jan Ciborowski, a professor at the University of Windsor in Ontario, Canada, was honored for his role in the U.S.-Canadian effort to restore and maintain the chemical, physical, and biological integrity of the Great Lakes.

Dr. Ciborowski was particularly cited for his work in the restoration of Lake Erie, where he is helping policymakers on both sides of the border make critical decisions regarding cleanup of the lake. The IJC assists the United States and Canada in implementing the Great Lakes Water Quality Agreement.

"This is truly a collaborative award", said Dr. Ciborowski. "It reflects an effort involving many people to restore and protect the magnificent international resources of these lakes."


GLEI
Home
FAQs
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What's New
Outreach
Intranet
A multi agency project funded by US EPA's STAR Program
Toxins
Birds
Plants
Frogs
Bugs
Fish
Algae
Water
Welcome to the Great Lakes Environmental Indicators Project Website
Visit our website
http://glei.nrri.umn.edu
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# Plants as Environmental Indicators in Great Lakes Coastal Wetlands


- Carol Johnston & Ken Iverson - South Dakota State University
- Michael Bourdaghs & Terry Brown - Natural Resources Research Institute, University of Minnesota Duluth
- Christin Frieswyk & Joy Zedler - University of Wisconsin - Madison
- Barbara Bedford & Lynn Vaccaro - Cornell University
- Mary Moffett & Jack Kelly - US EPA Mid-Continent Ecology Division


***Phragmites australis***

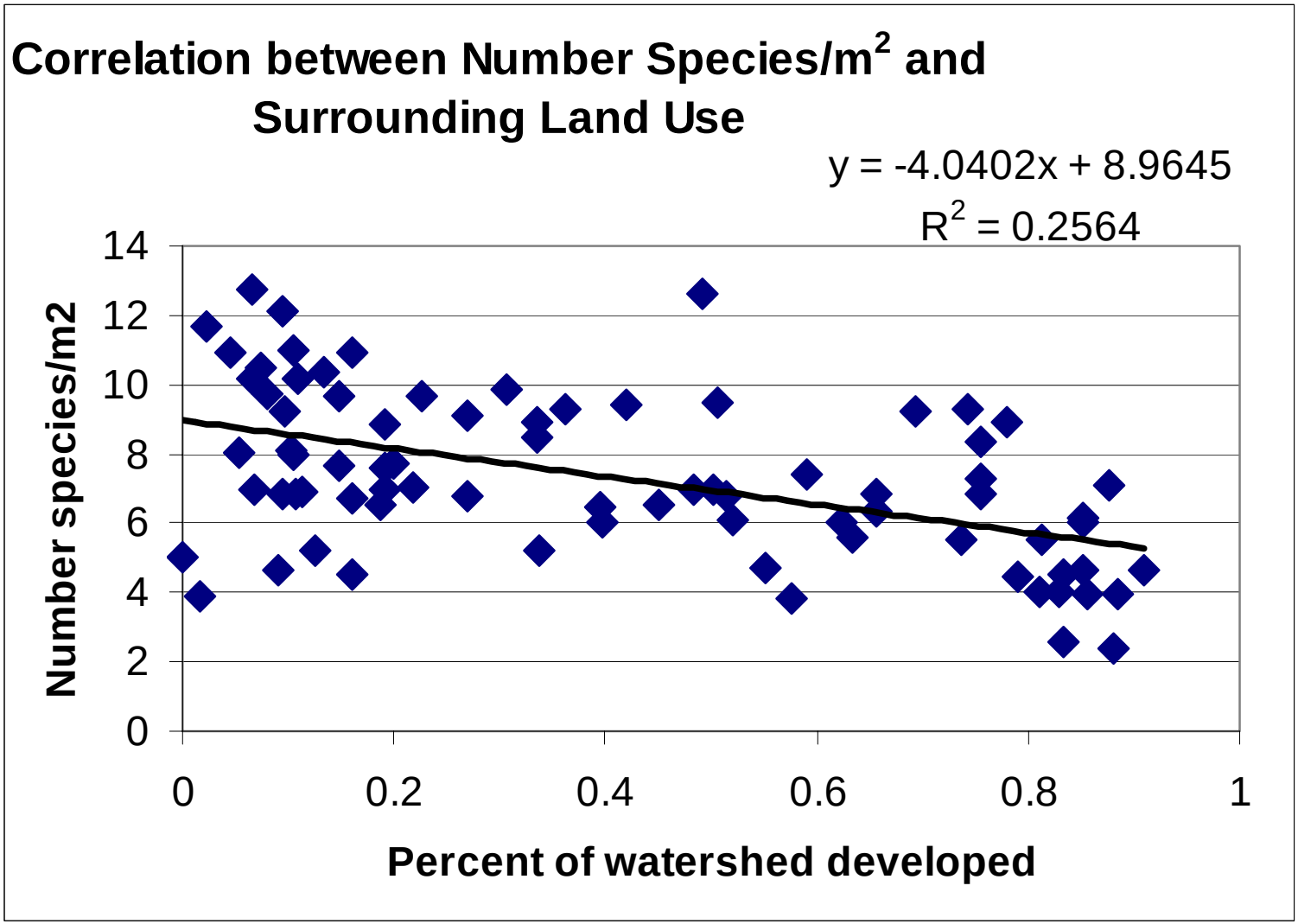
*Phalaris arundinacea*

*Typha x glauca*

*Lythrum salicaria*

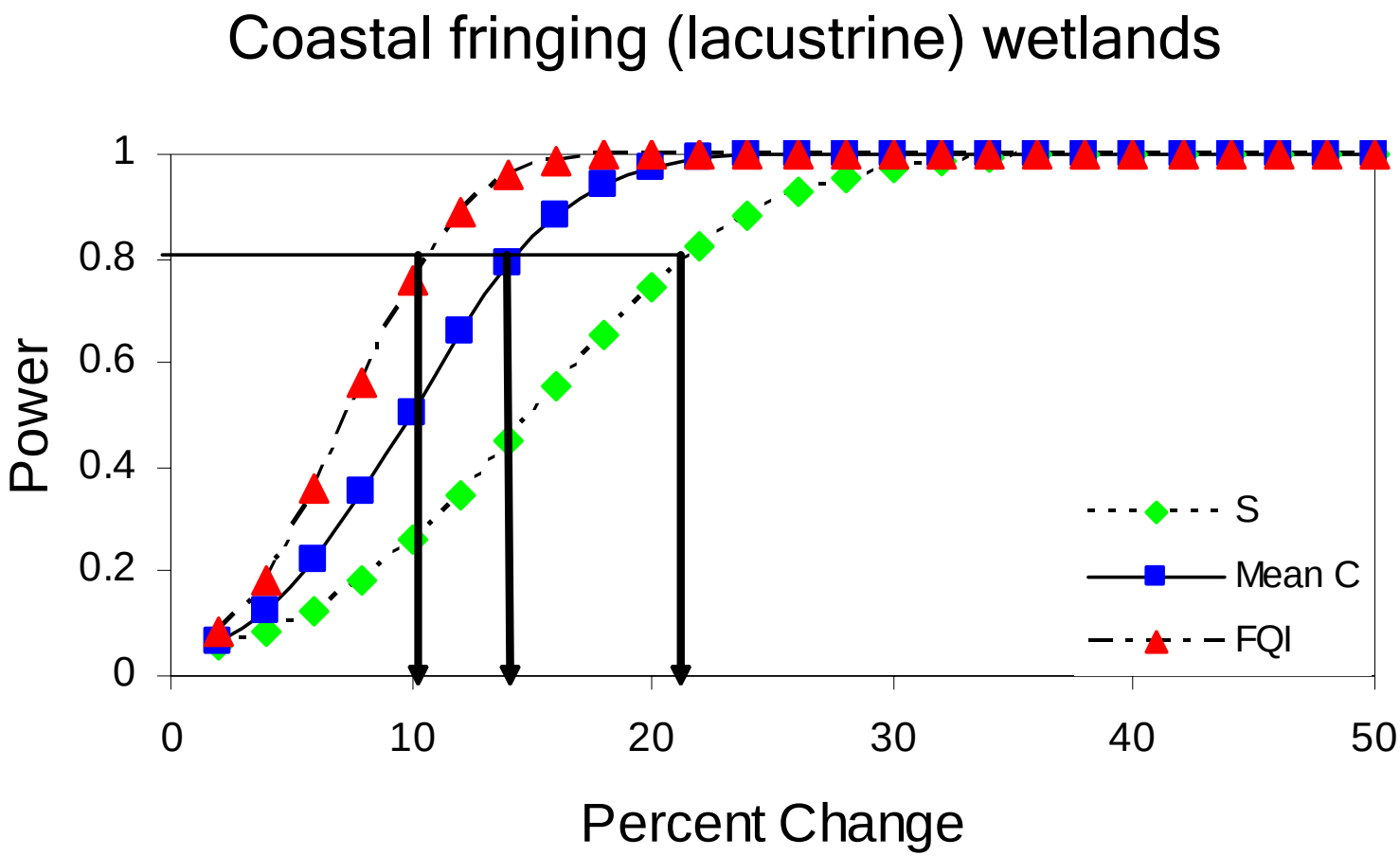
**SOLEC 4513: Presence, Abundance & Expansion of Invasive Plants**

# Surrounding land use correlated with species richness




**Source: Lynn Vaccaro**

# Indicator Testing – Power Curves




**S = species richness; C = Coefficient of Conservatism; FQI = Floristic Quality Index**

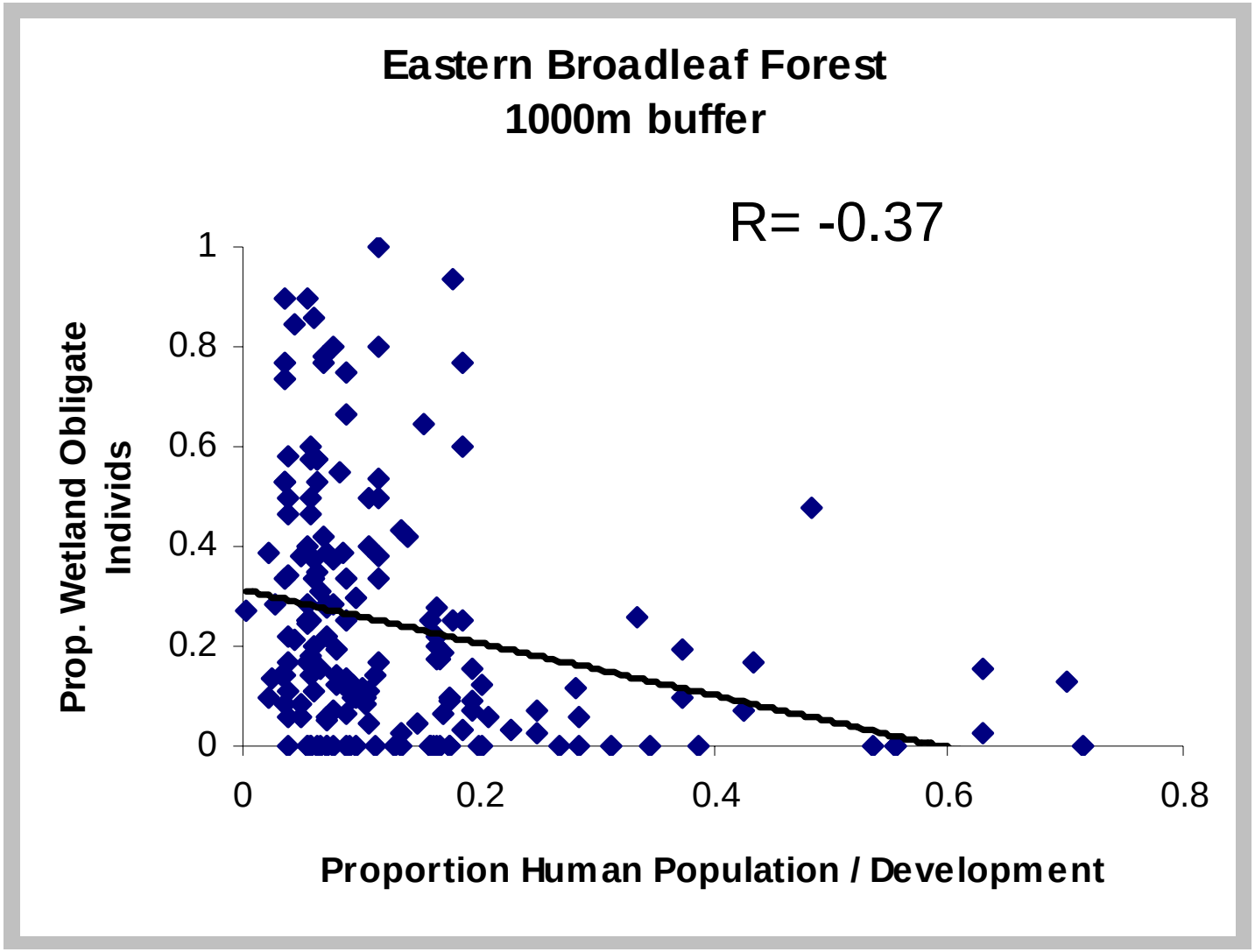
# Birds and Amphibians

- Bob Howe - U of Wisconsin, Green Bay
- JoAnn Hanowski - NRRI, University of MN
- Charles Smith - Cornell University

- Amphibians use both aquatic and terrestrial habitats therefore are good indicators of both habitats.

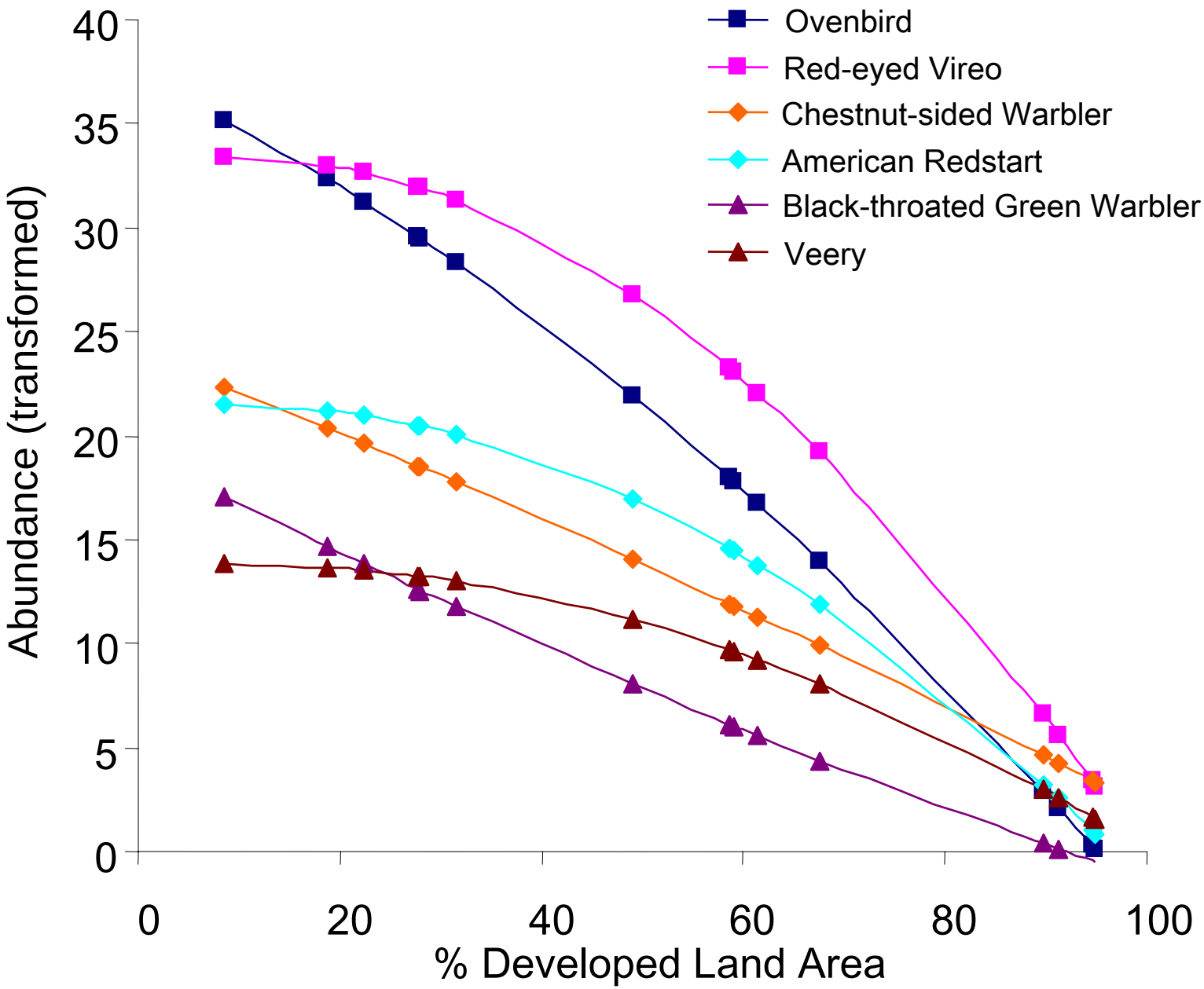
- Birds have long been used as environmental indicators

# Wetland obligate birds

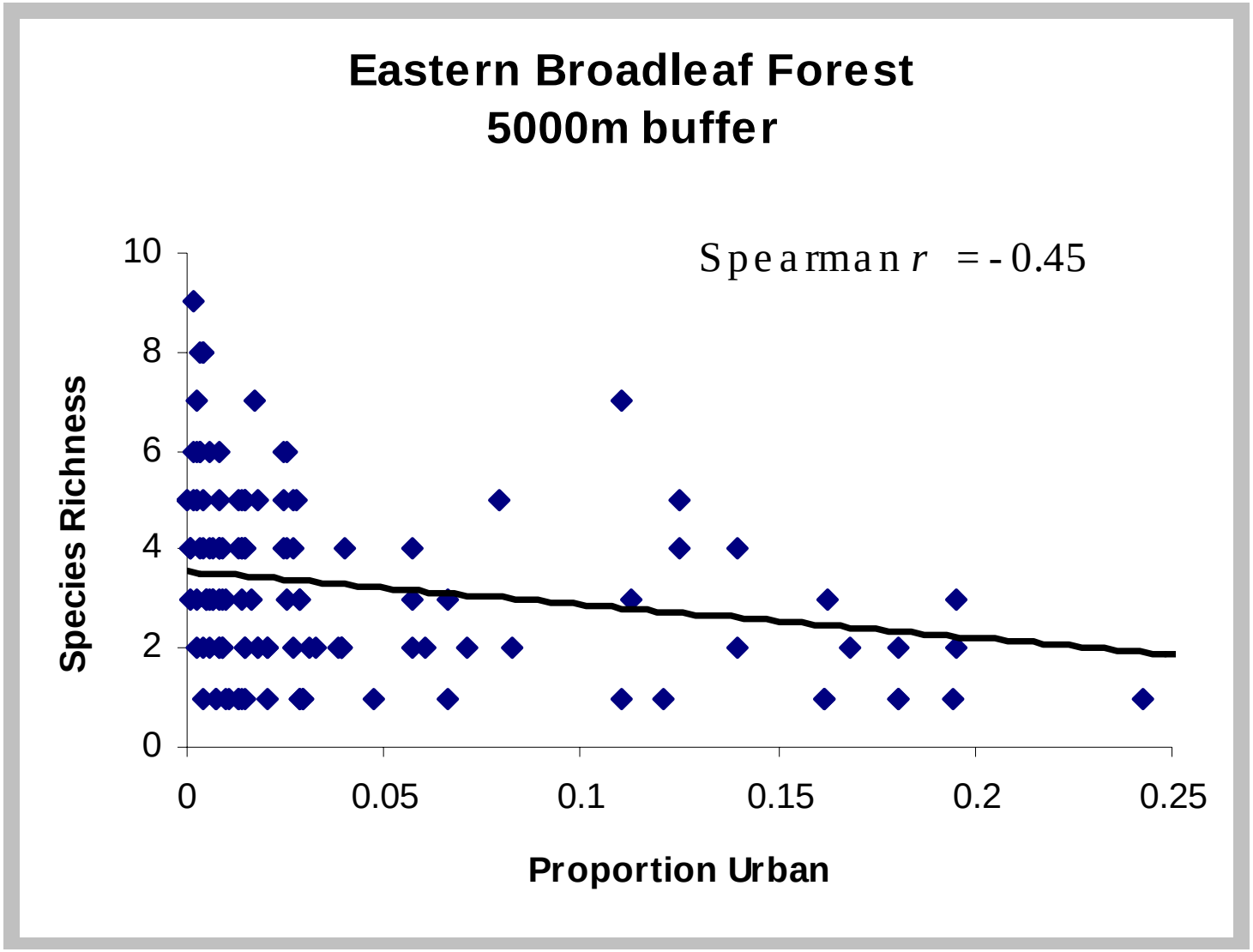



Very similar results for each buffer in each Province

# Forest Associated Neotropical Migrants

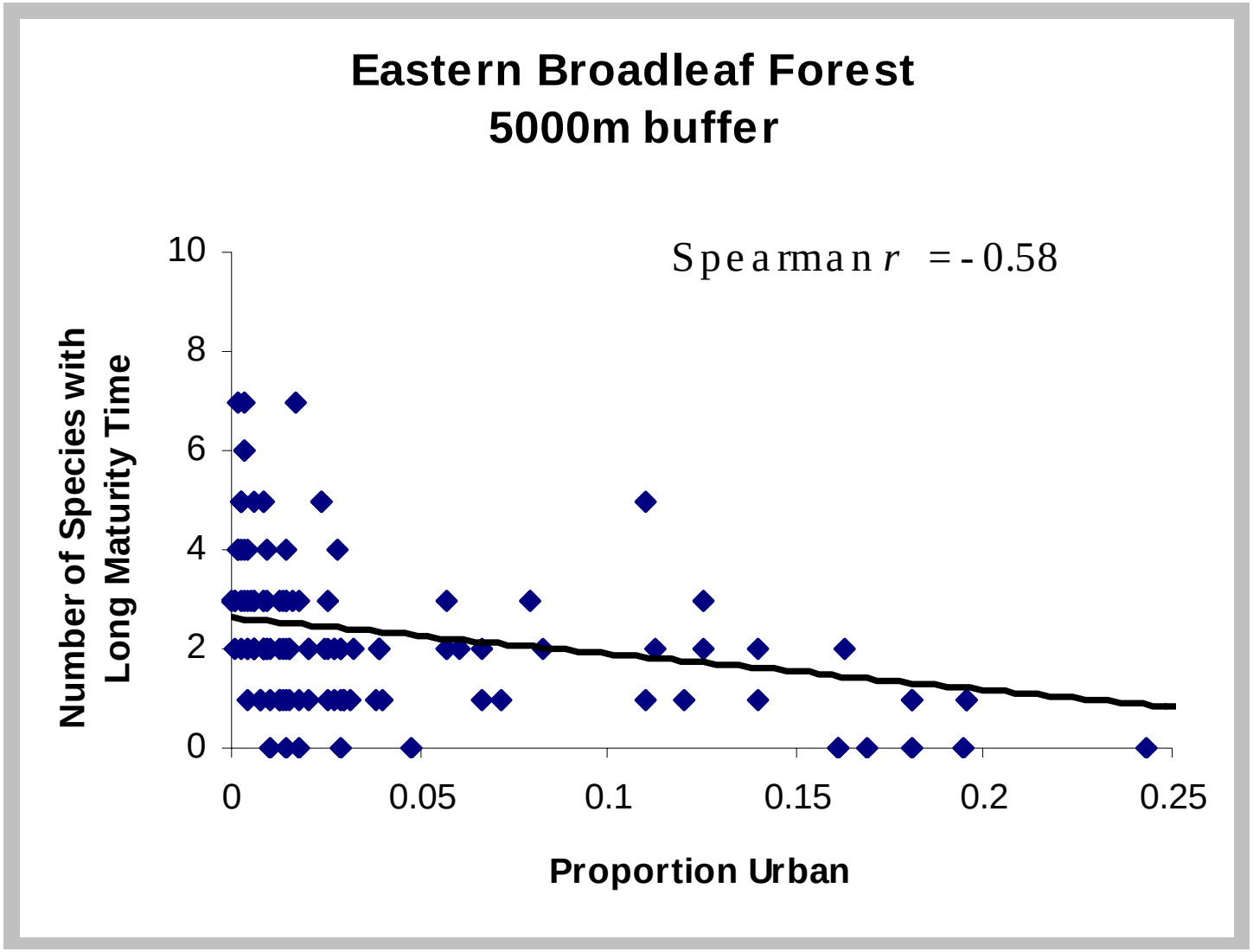


# Amphibian Species Richness




Higher correlation in the eastern broadleaf province

# Amphibian Metrics




Higher correlation in the eastern broadleaf province

# Contaminant Indicators

- Deb Swackhamer, Matt Simcik, Randy Lehr, Andy Adams – University of Minnesota Twin Cities

- Gary Ankley, Dave Mount, Steve Diamond, Russ Erickson, Phil Cook, Lawrence Burkhard – US EPA Mid-Continent Ecology Division

- Much is known about traditional contaminants such as PCBs and heavy metals

- This research concentrates on contaminants which pose an increasing threat: UV-activated PAHs and environmental estrogens.

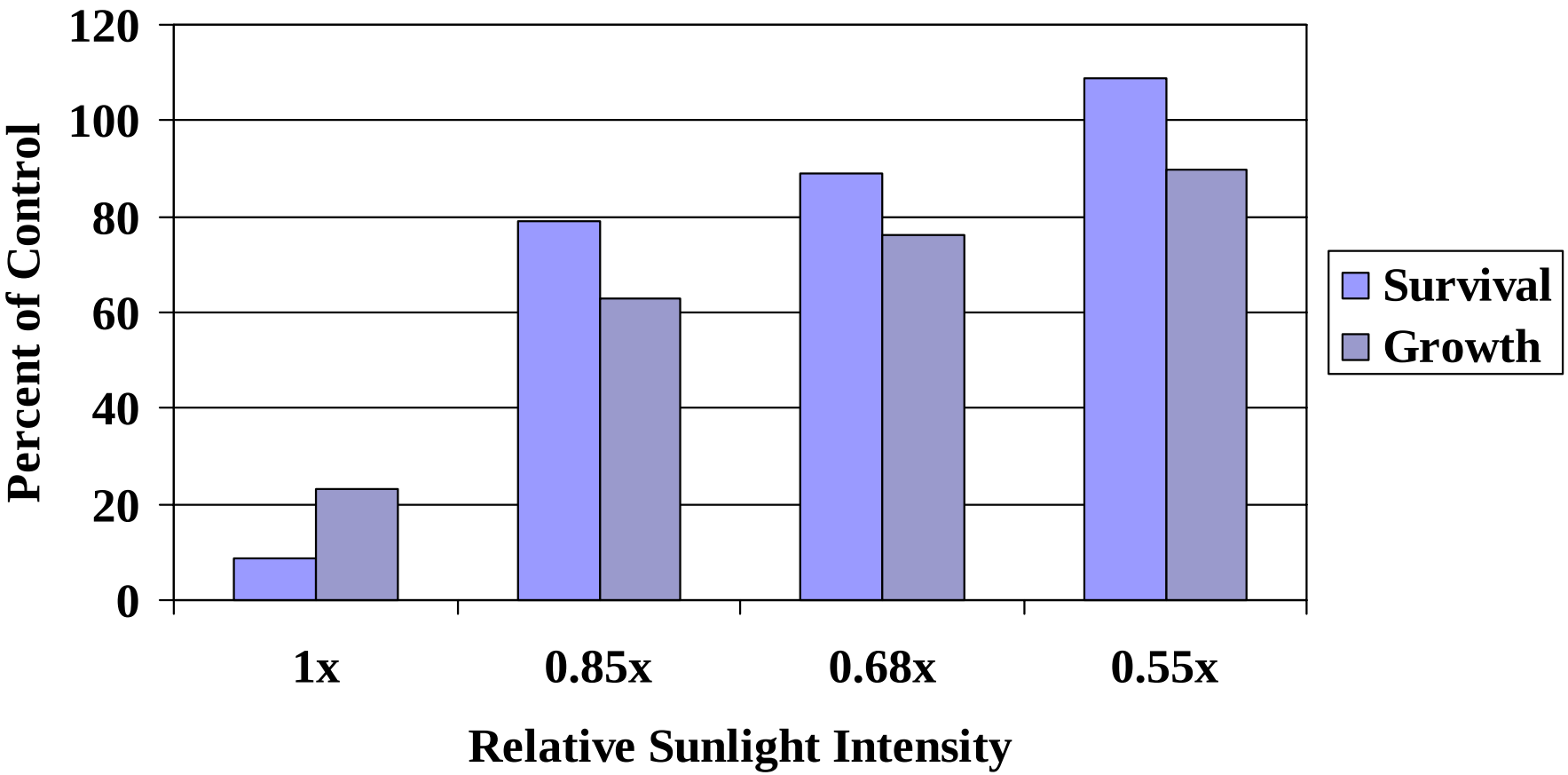
# *Hypothesis:*

*Specific PAHs are indicators of potential loss of vulnerable species within coastal fish communities*

## Resulting Indicator:

Specific PAH compounds in sediments

# Response of Larval Fish Under Field UV/PAH



# *Hypothesis:*

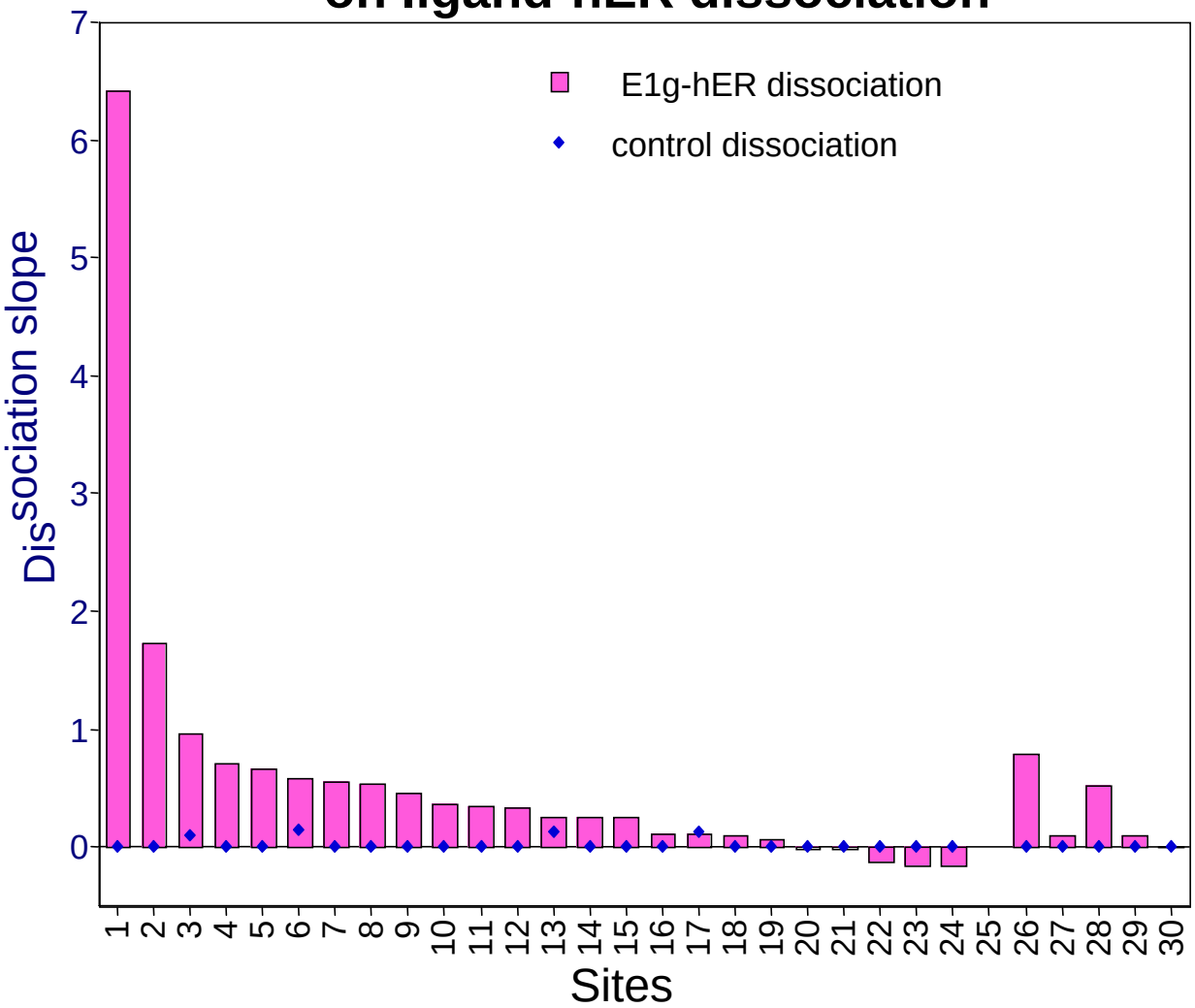
*Specific chemicals are indicators of endocrine disruption in fish via the estrogen receptor*

Resulting Indicator

Suite of Estrogenic chemicals in water and/or sediment

# Estrogenic ligand-mimicking activity in Great Lakes

## Effect of Water Samples from the Great Lakes Watershed on ligand-hER dissociation




1. Waste stream WLSSD
2. Erie: Maumee
3. Waste stream WLSSD 1:10
4. Superior: Dul. Har. Bong Bridge
5. Superior: Dul. Har. Bong Bridge
6. Superior Duluth Harbod, WLSSD 50'
7. Erie: Grand River
8. Superior: Ashland
9. Erie: Ashtabula
10. Superior: Ashland
11. Superior: Ashland
12. Erie: Pte. Mouilee
13. Waste stream WLSSD 1:100
14. Ontario: Braddock
15. Erie: Grand River
16. Michigan: Two Rivers
17. Waste stream WLSSD 1:100
18. Michigan: Onconto
19. Ontario: Buck Pond
20. Michigan: Petes Lake
21. Erie: Pte. Mouilee
22. Michigan: Pigeon Lake
23. Michigan: Suanico
24. Ontario: Long Pond
25. Huron: Saginaw
26. estradiol 1e-6 M
27. estradiol 1e-8 M
28. 4-OH-tamoxifen 1e-6
29. genestein 1e-6
30. Tween 20