2004 Progress Report: Testing Indicators of Coastal Ecosystem Integrity Using Fish and Macroinvertebrates

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Center: Great Lakes Environmental Indicators Project
Center Director: Gerald J. Niemi
Title: Testing Indicators of Coastal Ecosystem Integrity Using Fish and Macroinvertebrates
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EPA Project Officer: Barbara Levinson
Project Period: January 10, 2001 to January 9, 2005 (Extended to January 9, 2006)
Project Period Covered by this Report: January 11, 2004 to January 9, 2005
RFA: Environmental Indicators in the Estuarine Environment Research Program (2002)
Research Category: Ecological Indicators/Assessment/Restoration

Description:

Objective: To evaluate and integrate indicators across multiple spatial scales, we will employ a multi-tiered sampling and modeling strategy, integrating data collected at regional scales via satellite imagery, local scales, and site scales via field sampling. These data will be used to identify indicators at each scale that reflect critical ecosystem process or state variables related to the integrity and sustainability of those ecosystems. We will test indicators representing fundamental driving variables and processes at multiple spatial scales, and integrate them into a system for identifying positive or negative trends in the condition of ecosystems in coastal regions of the Great Lakes. The goals of our project are to:

1. Evaluate the applicability of SOLEC-derived and complementary indicators in the context of the ecosystem types found in the Great Lakes coastal region;
2. Rigorously test the efficacy of a suite of indicators across the range of habitats within the Great Lakes coastal system;
3. Recommend indicators of specific ecological conditions keyed to assessment endpoints and stressors in the Great Lakes coastal region.

Progress Summary:
Most of 2004 has been spent in invertebrate sample processing, data entry, data quality checks, theoretical development, data analysis, and data presentation. All fish data processing is complete, and entries have been checked for data quality and accuracy. All 2002 invertebrate samples have been processed, and the data have been entered into the database and quality checked. All Chironomidae from benthic samples collected in 2002 have been mounted, and about 25% have been identified. Most of the invertebrate samples collected in 2003 have been processed and the data entered into the database. Remaining samples should be completely processed by May 2005. Most of the 2003 invertebrate data have yet to undergo a final quality check.

The fish data have been used in numerous presentations, and the results are being presented in 8 manuscripts. The invertebrate data have been used in several presentations, and 4 manuscripts are in preparation, most about invasive species. In total, fish and macroinvertebrate researchers have given 26 presentations this year, including 8 invited presentations and 6 presentations or seminars to special groups such as U.S. EPA or the general public. The other presentations were given at 11 scientific meetings. In total, the team is working on, or has completed, 15 manuscripts that use the data compiled to date.

The theoretical approaches that we have developed that stem from or relate to the overall philosophical considerations and study design of our project have attracted considerable attention from managing agencies at several levels of government in both Canada and the U.S.

The **Lake Erie Lakewide Area Management Plan** (LaMP) (as convened by the governments of Canada and the U.S. through the Great Lakes Water Quality Agreement) undertook a 4-year modeling and planning study to assess possible ecosystem states that could be attained by appropriate management practices. The results of a complex Fuzzy cognitive model (Hobbs et al. 2002. *Ecological Applications* 12:1548-1565) determined that the biota comprising the ecosystem could achieve various alternative states dependent upon the values of 6 independent multivariate axes of environmental condition. Four of these axes correspond closely to the GLEI pressure axes derived from GIS analysis of land use in second order watersheds. Accordingly, the Lake Erie LaMP has proposed to adopt these GLEI pressure axes as key elements of their environmental indicator program to assess the overall status of the lake. Plans are underway to crosswalk land use and stress data from Canadian databases so that they can be incorporated and scored within the GLEI stressor system and provide the first comprehensive land use indicator applicable to an entire Great Lake basin.

The **International Joint Commission** is an observer of LaMP activities. Accordingly, our research findings will be the topic of an invited presentation on 'incorporating physical, chemical, and biological integrity in support of the Great Lakes Water Quality Agreement' at a workshop on ecological integrity at the 2005 biennial meeting of the International Joint Commission. These findings, together with new collaborative work developing with members of the EPA-GNLPO sponsored Great Lakes Wetland Consortium will likely result in our leading a workshop on development of Great Lakes indicators at the 2006 binational **State of the Lakes Environmental Conference** (SOLEC).

Investigators Lucinda Johnson and Jan Ciborowski have been actively involved with the **US EPA Office of Water** in applying concepts developed by the GLEI approach to multiple stressors to create national guidelines for assessing, quantifying, and integrating multiple stress effects in wadeable streams A document in preparation will ultimately provide guidance to the states and tribes on how to develop tiered aquatic life uses for assessing and reporting on the condition of all streams within their jurisdiction.

Results to Date:

Testing a Fish Index of Biotic Integrity for Great Lakes Coastal Wetlands
Fish community composition is often segregated along ecoregions, lakes or hydrogeomorphic types. However, attempts to develop an index of biotic integrity (IBI) for environmentally homogeneous sites at Great Lakes coastal margins have had only limited success. Of 14 measures of response to anthropogenic stress typically used to assess fish IBI in warmwater streams and at coastal margins (e.g. Minns et al. 1994, Simons et al. 2000), only 2 varied in the expected direction in wetlands of the lower Great Lakes, and 5 varied as expected in the upper Great Lakes (Bhagat et al. 2004).

Recently, Uzarski et al. (in press) used correspondence analysis to determine that the primary driver in coastal wetland fish community composition is emergent plant zonation, independent of ecological province. Consequently, they developed an IBI for sites dominated by (>50% cover) *Typha* (cattail) vegetation and a separate IBI for sites dominated by *Scirpus* (bulrush). We tested the IBIs developed by Uzarski et al. (in press) by applying their metrics to data collected at GLEI sites. We calculated Uzarski et al. IBI scores for 23 and 13 of the wetland sites with dominant *Typha* and *Scirpus* vegetation, respectively, that we had sampled in 2001-2003 using overnight sets of fyke nets. Our study design ensured that the sites fell across gradients of population density, road density, urban development, point source pollution, and agriculture measured using a GIS-based analysis of land use. Our analysis showed some striking patterns. Sites with low levels of disturbance (reference condition sites) had high IBI scores. The *Typha*-specific IBI was most highly negatively correlated with the GLEI human population/development gradient (r = -0.70, Table 1), whereas the *Scirpus*-specific IBI correlated most strongly with values of the agriculture and agricultural chemical stress (r = - 0.64) and point source pollutant (r= -0.57) stress gradients.

Table 1. Pearson product-moment correlation between GLEI-determined intensity of anthropogenic stress and value of IBI according to indices o f Uzarski et al. (2005). Bold-faced entries are statistically significant at p<0.01.

	IBI Index	
Stressor Class	*Typha*	*Scirpus*
Agriculture	0.02	**-0.64**
Land cover: forest	-0.38	0.15
Population/development	**-0.70**	-0.21
Point source discharge	-0.09	**-0.57**
Atmospheric deposition	**0.60**	0.04
Shoreline modification	-0.24	-0.13

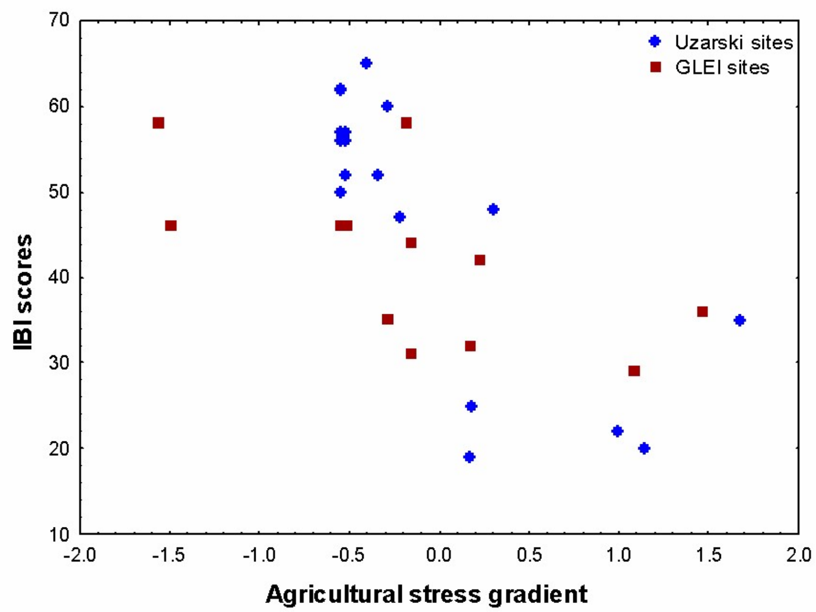

Figure 1. Relationship between *Scirpus* IBI score of Uzarski *et al*. (2005) determined for GLEI (red squares) and Uzarski (blue circles) sampling sites.

As a further check, we used the geographic coordinates of the wetlands sampled by Uzarski et al. to calculate their position and determined their stressor scores according to our stress axes. The combined plots of GLEI and GLWC data corresponded closely. The wetlands sampled by the GLEI project covered a broader range of stress than the GLWC sites, but the overall patterns of both data sets were remarkably consistent.

The most striking finding is that application of the combined data sets clearly indicate that the *Scirpus* and *Typha* IBIs responded to fundamentally different stressor gradients. The fish IBI developed for *Scirpus* changed only along an axis of agricultural development, with strong evidence of a threshold effect (Fig. 1). In contrast the IBI developed by Uzarski et al. for *Typha* zones was insensitive to agriculture but changed strongly in response to urban development (population density and point source discharges; Table 1 and Fig. 2).

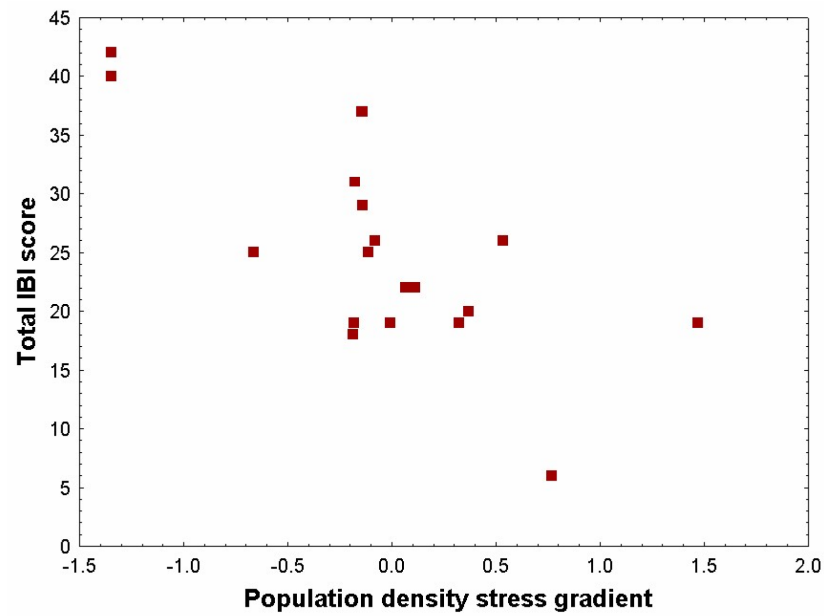

Figure 2. Relationship between *Typha* IBI score and Uzarski *et al*. (2005) determined for GLEI sampling sites.

The Uzarski IBI appears to be an effective indicator of some but not all classes of anthropogenic disturbance at Great Lakes coastal margins. However, stressor data such as those collected by the GLEI project are necessary to reveal that such indicators are stress-specific and to identify the classes of stress that regulate different indicator suites. This research is being prepared for submission to the *Canadian Journal of Fisheries and Aquatic Sciences.*

Quantifying the Scale of Fish Species Responses to Land Use in the Great Lakes
Species show a range of responses to environmental conditions, and the strength of those responses may vary with spatial scale. For example, a species may exhibit no response or a relatively consistent response to land cover across all scales. Alternatively, a species could respond weakly or strongly to a particular environmental cue at a particular spatial scale. A species that responds consistently across all spatial scales is an ideal candidate for an indicator. However, a more likely scenario is that the strength of responses will vary as the spatial scale changes. Species that exhibit either no response or a constant, unvarying response to varying land use extents at all scales would not be useful candidates as indicators of environmental conditions.

Some multi-scale studies have found that fish metrics correlate most strongly to land cover when measured at levels below the catchment scale (e.g., Fitzpatrick et al. 2001, Stewart et al. 2001). The apparent inconsistent response to land cover could result from the fact that IBIs lump many different species, each of which exhibits a characteristic scale of response to a stressor. Furthermore, IBI development and testing is typically calibrated against land use data measured at a single spatial scale. If the (dominant) species in the community each respond at different spatial scales, this would weaken the overall relationship between the stressor and the IBI metric. It could also lead to different results between studies if the dominant species making up the IBI differ across studies. This problem could be avoided by identifying the characteristic scale of response of the individual species to the environmental gradients.

We used the Focus program of Holland et al. (2004; www.carleton.ca/lands-ecol/whatisle.html) to determine the spatial scale at which fish species responded most strongly to variation in the extent of three land cover types: urban, agriculture, and forest. Focus performs repeated linear regressions or determines correlations between predictor and response variables (here, land cover, and fish catch per unit effort abundance, respectively) using sets of spatially independent sites buffered at distances ranging from 0.5 km to 50 km. The strength of the correlation is assessed for each buffer width (hereafter referred to as spatial scale); a plot of response strength (correlation coefficient) versus spatial scale depicts how the relationship changes with spatial scale. The strength of the relationship between land cover and species abundance across spatial scales is measured using the Pearson product-moment correlation coefficient (r).

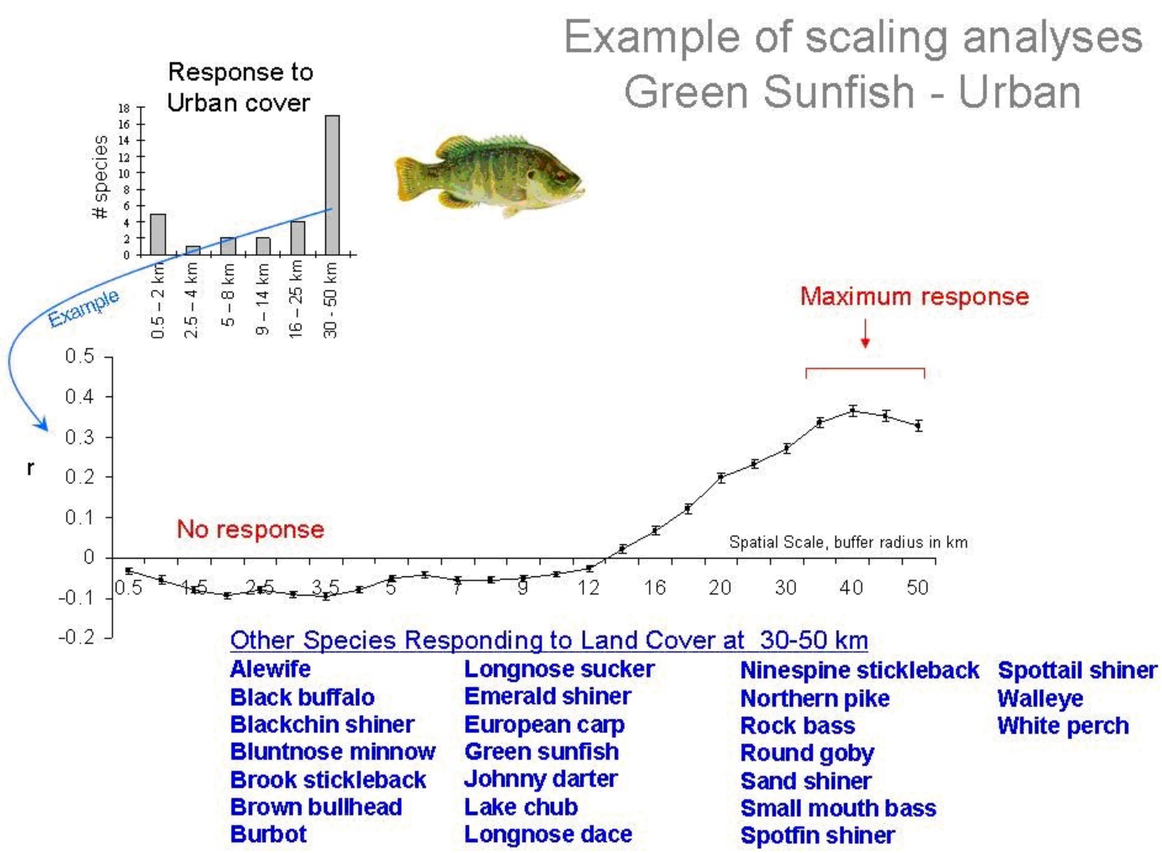

Figure 3. Scale of responses to land use for the green sunfish. Maximum responses were observed at large spatial scales (30 - 50 km radius). Many fish species respond to land use at these large spatial scales.

We found that most of the correlations above a threshold value of r=0.25 reached their maximum at the larger spatial scales (Figure 3). Three of the four species that responded most strongly (black buffalo, blackchin shiner, and tadpole madtom) showed strong positive correlations to amount of forest cover at 50 km, and relatively strong negative correlations with amount of agricultural land cover at the larger spatial scales. Fewer species showed maximum responses at smaller spatial scales (Table 2).

Table 2: Scale and direction (positive/negative) of maximum responses to land use (URB = urban; AGR = agriculture; FOR = forest) for fish species in the Great Lakes. Species were filtered to remove exotics and species with confined geographic ranges. (From Holland *et al*., in preparation.)

Fish Species	Scale Max URB		Scale Max AGR		Scale Max FOR	
Black Buffalo, Ictiobus cypinellus (Rafinesque)	50	-	50	-	50	+
Blackchin Shiner, Notropis heterodon (Cope)			45	-	50	+
Bowfin, Amia calva L.					40	+
Brook Stickleback, Culaea inconstans (Kirtland)					35	+
Brown Bullhead, Ameriurus punctatus (Lesueur)			40	-	35	+
Burbot, Lota lota (L.)			40	-	10	+
Eastern Longnose sucker, Catostomus catostomus (Forster)			40	-	12	+
Emerald Shiner, Notropis atherinoides Rafinesque			45	-		
Golden Shiner, Notemigonus crysoleucas (Mitchill)					50	+
Johnny Darter, Etheostoma nigrum Rafinesque			50	-	40	+
Lake Chub, Couesius plumbeus (Agassiz)			30	-	5	+
Northern Pike, Esox lucius L.					50	+
Northern Rock Bass, Ambloplites rupestris (Rafinesque)	50	-				
Sand Shiner, Notropis stramineus (Cope)	50	-	25	-		
Tadpole Madtom, Noturus gyrinus (Mitchill)					50	+
White Sucker, Catostomus commersonii (Lacepede)	20	-	35	-		

Wetland Invertebrate Indicator Development

Using data from 52 of 83 sampled wetlands, we found that the northern vs. southern areas of the Great Lakes have significantly different wetland invertebrate assemblages. We are in the process of determining how much of this difference is due to latitudinal (species range) variation, and how much is due to the differences in the amount of anthropogenic stress between the northern (less stressed) and southern (more stressed) Great Lakes. In addition, we have found that invertebrate assemblages in riverine wetlands are significantly different from those in protected and open coastal wetlands. While this is not an unexpected result because of the different habitats available among the wetland types, it means that we will have to ensure that invertebrate indicators developed for wetlands work in all types of Great Lakes wetlands. Ordination analysis of riverine wetlands in the northern Great Lakes indicated that invertebrate assemblage differences were most strongly correlated with differences in population density and amount of agriculture in the segment shed. Potential metrics derived from this ordination include proportion clingers and proportion scrapers as indicators of less impacted sites.

We hypothesize that many of the effects on aquatic invertebrates are indirect, with habitat being the intermediary between anthropogenic stress on the wetland and the effects that we are seeing in the invertebrates. For example, in northern open coastal wetlands there is a negative correlation between the proportion of row crop agriculture in the segment shed and the density of floating aquatic plants (Fig. 4a). In turn, the density of floating aquatic plants is correlated with invertebrate taxa richness, with fewer invertebrate types found in wetlands with less floating plants (Fig. 4b).

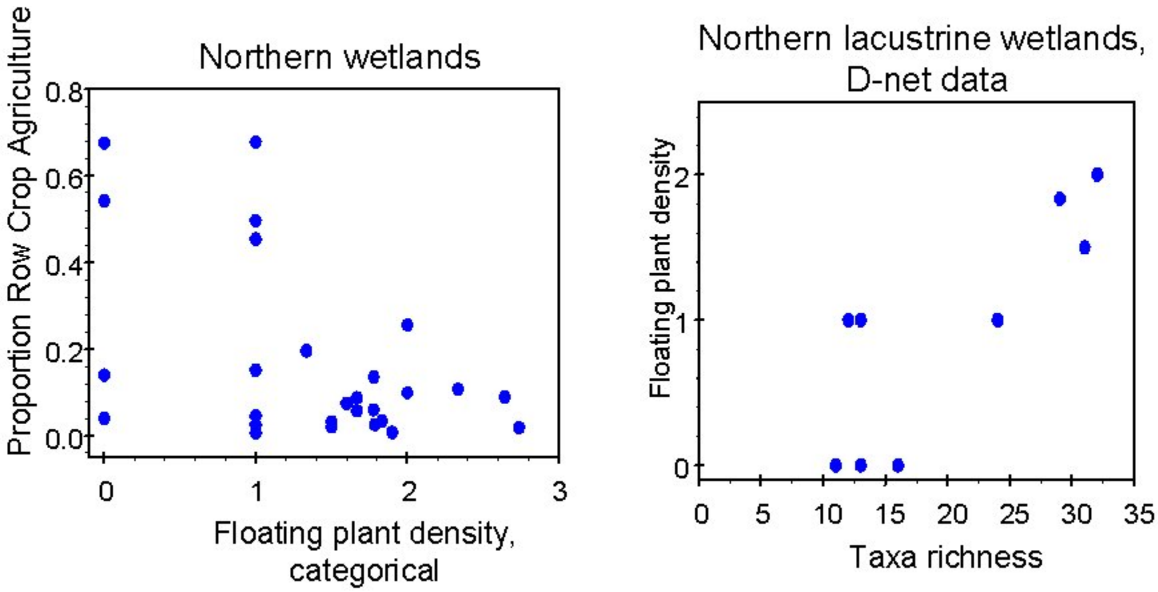

Figure 4. A. There is a negative correlation between the proportion of row crop agriculture in the segment sheds of northern Great Lakes coastal wetlands and the density of floating aquatic plants in the wetlands. B. Density of floating aquatic plants is positively correlated with wetland invertebrate taxa richness in northern Great Lakes lacustrine wetlands.

Future Activities:
This year we will be completing the invertebrate sample processing, data entry, and data quality checks. Data analysis for indicator development, manuscript writing, and presentation of results to other researchers and indicator clients will be the work focus for 2005. We expect that the indicator development frameworks that we have proposed will receive increasing acceptance and use by agencies and by the academic community, leading to a rethinking of the relationships between human activity and associated environmental changes and ultimately more responsive policy-making and planning processes.

Publications and Presentations:

Type	Citation
Journal	Bhagat, Y., J.J.H.Ciborowski, L.B. Johnson, V. Brady, D. Breneman, J. Schuldt, T. Hrabik, C. Richards, D. Uzarski, T. Burton. Testing a fish index of biotic integrity for Great Lakes coastal wetlands: stratification by plant zones. In preparation for submission to *Canadian Journal of Fisheries and Aquatic Sciences*, summer 2005.
Journal	Brady, V., J. Ciborowski, J. Holland, N. Danz, L. Johnson, D. Breneman, J. Gathman, T. Hrabik, J. Schuldt. Optimizing fishing time: One vs. two night fyke net sets in Great Lakes coastal systems. In preparation for submission to *Transactions of the American Fisheries Society*, May 2005.
Journal	Brazner, J.C., N.P. Danz, G.J. Niemi, J.M. Hanowski, C.A. Johnston, L.B. Johnson. Evaluating geographic and geomorphic influences on indicators of Great Lakes coastal wetland condition across multiple taxonomic groups. In preparation for submission to *Ecological Applications*, April 2005.
Journal	Breneman, D.B., T. Hrabik, J. Schuldt, L.B. Johnson. Effects of landscape-scale stressors on size class distribution of Great Lakes nearshore fish communities. In preparation for submission to *Canadian Journal of Fisheries and Aquatic Sciences*, August 2005.

Journal	Ciborowski, J.J.H., J. Schuldt, L.B. Johnson, G. Host, C. Richards, T. Hollenhorst. Reference conditions, degraded areas, stressors, and impaired beneficial uses: conceptual integration of approaches to evaluating human-related environmental pressures. In preparation for submission to *Ecological Applications,* summer 2005
Journal	Danz, N.P., R.R. Regal, G.J. Niemi, V.J. Brady, T. Hollenhorst, L.B. Johnson, G.E. Host, J.M. Hanowski, C.A. Johnston, T. Brown, J. Kingston, J.R. Kelly. 2005. Environmentally stratified sampling design for the development of Great Lakes environmental indicators. *Environmental Monitoring and Assessment* 102:41-65.
Journal	Danz, N.P., G.J. Niemi, R.R. Regal, V.J. Brady, L.B. Johnson, T. Hollenhorst et al. Human disturbance gradients in the U.S. Great Lakes. In preparation.
Journal	Foley, C., D. Breneman, J.J.H. Ciborowski, J.P. Gathman, V.J. Brady, L.B. Johnson., C. Richards. The associations between larval Odonata and habitat structure as indicators of anthropogenic stress in great lakes coastal margin wetlands. In preparation for submission to *Freshwater Biology*, summer 2005.
Journal	Grigorovich, I.A., E.L. Mils, C. Richards, D. Breneman, J.J.H. Ciborowski. 2005. European valve snail *Valvata piscinalis* (Miller) in the Laurentian Great Lakes basin. *Journal of Great Lakes Research* 31:135-143.
Journal	Grigorovich, I.A., M. Kang, J.J.H. Ciborowski. Establishment of the invasive amphipod *Gammarus tigrinus* Sexton in Saginaw Bay, Lake Huron. *Journal of Great Lakes Research*. Accepted with minor revisions.
Journal	Hrabik, T.R., D.B. Breneman, L.B. Johnson, J. Schuldt, C. Richards, J. Ciborowski, V. Brady, Y. Bhagat. Variability in the trophic structure and diversity of fish assemblages in Great Lakes wetlands: the influence of anthropogenic stressors and land use information. In preparation for submission to *Journal of Great Lakes Research* or *Canadian Journal of Fisheries and Aquatic Sciences*.
Journal	Holland, J., J.J.H. Ciborowski, L.B. Johnson, T. Hollenhorst. The spatial scale of fish indicator responses in Great Lakes coastal regions. In preparation for submission to *Canadian Journal of Fisheries and Aquatic Sciences*, June 2005.
Journal	Johnson, L.B., T. Hollenhorst, G. Host, and C. Richards. Scale effects in mapping riparian zones. In preparation for submission to *Landscape Ecology*.
Journal	Johnson, L.B., J.A. Schuldt, V. Brady, D. Breneman, G.E. Host, C. Richards. Comparison of fish communities in reference and non-reference coastal Great Lakes wetlands. In preparation for submission to *Canadian Journal of Fisheries and Aquatic Sciences*, August 2005.
Journal	Kang, M., J.J.H. Ciborowski, L.B. Johnson, T. Hrabik, C. Richards, J. Schuldt. The relationship between anthropogenic disturbance and the distribution of a nonindigenous species, *Echinogammarus ischnus* Stebbing, 1898 (Amphipoda: Gammaridae), at Great Lakes coastal margins. In revision for submission to *Oecologia*, June 2005.
Presentation	Ciborowski, J.J.H., L.B. Johnson, G.E. Host, T. Hollenhorst, J. Schuldt, C. Richards. 2004. Identifying reference areas at Great Lakes coastal margins. Invited seminar web cast to members of the human disturbance gradient development team from EPA, TetraTech, Inc., and others. June 2004.
Presentation	Johnson, L.B., G.J. Niemi, et al. Development of environmental indicators of condition, integrity, and sustainability in the Great Lakes basin. Liquid Science Seminar Series (for the general public), Duluth, MN and Grand Portage, MN, January 2004.
Presentation	Johnson, L.B., J.J.H. Ciborowski, G.E. Host, T. Hollenhorst, J. Schuldt, C. Richards.2004. Protocols for selecting classification and reference conditions: a

	comparison of methods. Invited seminar at the Great Lakes National Program Office, U.S. EPA, Chicago, IL. May 2004.
Presentation	Johnson, L.B., J.J.H. Ciborowski, V. Brady, T. Hollenhorst, J. Schuldt, G. Host, C. Richards, T.M. Hrabik. 2004. Development of environmental indicators of condition, integrity, and sustainability in the Great Lakes basin. Invited seminar at EPA Region 5, STAR Science Colloquium. Chicago, IL. July 2004.
Presentation	Johnson, L.B., J.J.H. Ciborowski, V. Brady, T. Hollenhorst, J. Schuldt, G. Host, J. Holland, J.P. Gathman, C. Richards, T.M. Hrabik. Developing indicators of coastal ecosystem condition. Seminar for the Office of Wetlands, Oceans, and Watersheds, U.S. EPA. December 2004.
Presentation	Johnson, L.B., J.J.H. Ciborowski, V. Brady, T. Hollenhorst, J. Schuldt, G. Host, J. Holland, J.P. Gathman, C. Richards, T.M. Hrabik. Development of environmental indicators and identification of reference conditions in the coastal regions of the U.S. Great Lakes basin. U.S. EPA/State/Tribal Surface Water Monitoring and Standards conference. February 2005.
Review Panel	External review of the SOLEC indicators. Detroit, MI, January 2004. Attended by Jan Ciborowski and Lucinda Johnson.
Workshop	Human disturbance gradient, Tiered Aquatic Life Workshop, Washington DC, March 2005. Attended by Jan Ciborowski and Lucinda Johnson.

In addition to the presentations listed above, 20 presentations were given at 11 scientific meetings, 8 of which were invited. GLEI fish and invertebrate researchers also gave 5 departmental seminars.

Training the Next Generation of Researchers:

Postdoctoral Fellows and Research Activities

Gathman, J. 2004. Great Lakes Environmental indicators - multivariate analysis of zoobenthic distribution at Great Lakes coastal margins

Holland, J. 2004. Great Lakes Environmental indicators - role of scale in indicator sensitivity

Kirkpatrick, A. 2004-2005. Great Lakes Environmental Indicators - database organization, coordination and management

Graduate Student Research

Bhagat, Y. 2005. Fish community responses to anthropogenic stress at Great Lakes shorelines: multimetric vs. multivariate approaches. MSc thesis, University of Windsor.

Kang, M. In progress. The influence of entry sequence on invasion success and the importance of scale for biotic resistance to biological invasion. PhD thesis, University of Windsor.

Graduate Student Participants

Y. Bhagat, J. Baillargeon, R. Eedy, C. Foley, K. Jedlinski, M. Kang, T. Mabee, D. Sasaki, P. Short

Undergraduate Thesis Students

Foley, C. 2004. The associations between larval Odonata and habitat structure as indicators of anthropogenic stress in great lakes coastal margin wetlands. Hon BSc thesis, University of Windsor.

Undergraduate Interns 2004

University of Minnesota Duluth

N. Cardot, T. Winter

University of Windsor

M. Barkley, Z. Charara, J. Duncan, L. Evon, K. Fawdry, F. Hall, S. Mazael, P. Mbaga, R. Mbaga, M. Mehdi, D. Ryzebol, L. Walker

Supplemental Keywords: *Great Lakes, coastal wetlands, environmental indicators*, *community, fish, macroinvertebrate, high energy shorelines, embayment*

Relevant Web Sites: http://glei.nrri.umn.edu