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Fish Habitat Use Within and Across Wetland Classes in Coastal Wetlands of the Five Great Lakes: Development of a Fish-based Index of Biotic Integrity

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ABSTRACT. *The relative importance of Great Lake, ecoregion, wetland type, and plant zonation in structuring fish community composition was determined for 61 Great Lakes coastal wetlands sampled in 2002. These wetlands, from all five Great Lakes, spanned nine ecoregions and four wetland types (open lacustrine, protected lacustrine, barrier-beach, and drowned river mouth). Fish were sampled with fyke nets, and physical and chemical parameters were determined for inundated plant zones in each wetland. Land use/cover was calculated for 1- and 20-km buffers from digitized imagery. Fish community composition within and among wetlands was compared using correspondence analyses, detrended correspondence analyses, and non-metric multidimensional scaling. Within-site plant zonation was the single most important variable structuring fish communities regardless of lake, ecoregion, or wetland type. Fish community composition correlated with chemical/physical and land use/cover variables. Fish community composition shifted with nutrients and adjacent agriculture within vegetation zone. Fish community composition was ordinated from* Scirpus, Eleocharis, *and* Zizania, *to* Nuphar/Nymphaea, *and* Pontederia/Sagittaria/Peltandra *to* Spargainium *to* Typha. *Once the underlying driver in fish community composition was determined to be plant zonation, data were stratified by vegetation type and an IBI was developed for coastal wetlands of the entire Great Lakes basin.*

INDEX WORDS: *Coastal wetlands, fish, IBI, fish community composition, Great Lakes, bioassessment, land use effect.*

INTRODUCTION

Great Lakes coastal wetlands provide critical habitat for more than 80 species of fish (Jude and Pappas 1992). More than 50 of these species are dependent upon wetlands while another 30+ migrate into and out of them during different periods in their life history (Jude and Pappas 1992, Wilcox 1995). An additional 30+ species of fish may be oc-

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casional visitors to coastal wetlands based on occurrence in adjacent habitats (Jude and Pappas 1992). Coastal wetlands also provide habitat for 20+ species of mammals, large numbers of amphibians and reptiles (Wilcox 1995, Weeber and Vallianatos 2000) and 80-90 bird species including 28 species of waterfowl (Prince *et al.* 1992, Prince and Flegel 1995, Weeber and Vallianatos 2000). We have identified more than 250 taxa of invertebrates which utilize coastal wetlands (Burton *et al.* 1999, 2002, 2004; Cardinale *et al.* 1997, 1998; Gathman *et al.* 1999; Kashian and Burton 2000, and unpublished data). Similar numbers have been reported by others (e.g., see reviews by Krieger 1992 and Gathman *et al.* 1999). The actual number of species may be 3–4 times greater, given the difficulty in identification of larval invertebrates. Coastal wetlands are occupied by many rare plants with over 40 species listed for Lake Huron alone (Wilcox 1995). Despite their importance as habitats for so many organisms, knowledge about the biota of these wetlands is limited.

As transitional systems between land and water, coastal wetlands are among the first habitats impacted by disturbances from adjacent uplands and/or pollutants from upstream. Activities and pollutants that degrade wetland habitat often also pose threats to other near shore and deep water habitats if allowed to continue unabated. Since many pollutants accumulate in them and adjacent changes in land use tend to impact them first, coastal wetlands can provide "early warning" of potential threats to the Great Lakes ecosystem. The governments of Canada and the U.S.A. recognized this potential and initiated a process to identify and/or develop indicators of "ecosystem health" for wetlands and other Great Lakes habitats at the State-of-the-Lakes Ecosystem Conference (SOLEC) held in Buffalo, New York in 1998. Progress was reviewed and potential indicators were identified by working group members at SOLEC 2000 in Hamilton, Ontario. Potential indicators listed by the wetlands indicators working group included indices of biotic integrity (IBIs) based on invertebrates, fish, and plants even though no broadly accepted protocol was available at the time for any of these biotic groups.

Recognition of the need for a biotic-based assessment system accelerated our on-going research on development of invertebrate-based IBIs for coastal wetlands and culminated in publication of an invertebrate-based IBI for coastal wetlands (Burton *et al.* 1999, Kashian and Burton 2000, Uzarski *et al.* 2004). We also expanded efforts to obtain data on fish populations in coastal wetlands, with the goal of developing fish-based IBIs for major classes of coastal wetlands described by Keough *et al.* (1999) and modified by Albert *et al.* (2003).

Great Lakes coastal wetlands occupy a relatively small percentage of the Great Lakes shoreline (e.g., about 11% of the shoreline of the U.S. side of Lake Huron—Prince and Flegel 1995). Conversion of wetlands over the last 100 years has reduced the area of Great Lakes coastal wetlands by more than 50% with losses greater than 95% in some areas such as Western Lake Erie (Krieger *et al.* 1992). Sustainable management of the remaining wetlands and efforts to restore the large number of wetlands that have been converted to other land uses are critical to the long-term viability of the Great Lakes ecosystem. An important tool needed for management and restoration of coastal wetlands is a system of assessment which will allow managers to monitor the health of these and adjacent coastal systems on a routine basis so that trends in wetland condition can be established and used to identify threats to these ecosystems. Our overall goal was to develop a system of indicators of biotic integrity for coastal wetlands based on fish, invertebrates, and plants. Our goal in this paper is to document and provide details of a fish-based IBI for wetlands of the Great Lakes.

Minns *et al.* (1994) developed a fish-based IBI for marshes of Great Lakes Areas of Concern which included metrics sensitive to impacts by exotic fishes, water quality changes, physical habitat alterations, and changes in piscivore abundance related to fishing pressure and stocking. This system has not been extended outside of the limited and often highly impacted Areas of Concern. The work of Brazner (1997), Brazner and Beals (1997), and Minns *et al.* (1994) demonstrated relationships between fish populations and wetland and/or nearshore habitats which suggest that development of a fish-based IBI for coastal wetlands is possible. Recently, Randall and Minns (2002) used an IBI to assess habitat productivity of near shore areas (including coastal wetlands) of Lakes Erie and Ontario and compared results to those obtained using their Habitat Productivity Index. Thoma (1999) developed a fish-based IBI for near shore waters of Lake Erie. Despite such promising results, Wilcox *et al.* (2002) concluded that development of wetland IBIs for the upper Great Lakes using macrophytes, fish, and microinvertebrates was impractical. Even though some of their metrics showed potential, they concluded that natural water level changes from those that existed during data collection were likely to alter communities enough to invalidate metrics in subsequent years. We overcame this problem for invertebrates in fringing coastal wetlands by developing a method based on sampling any or all of four plant zones depending on the number of zones inundated (Burton *et al.* 1999, Uzarski *et al.* 2004). The IBI scores for a particular year were calculated by summing scores from each of the zones that were inundated when sampling occurred. As water levels decreased and zones were no longer inundated, the IBI scores changed, but metrics for even a single inundated zone proved to be effective in establishing wetland condition for fringing wetlands of Lakes Huron and Michigan as water level decreased by more than 1-meter from 1997 through 2002 (Uzarski *et al.* 2004). Based on these results, we hypothesized that fish-based IBI metrics developed using samples from each inundated plant zone, rather than using composited samples to develop one set of metrics for the entire wetland, would provide the flexibility needed to make the IBI useful over a wide range of lake levels. This makes our approach different than efforts of others including sampling associated with the REMAP project of U.S. EPA where composite samples for the entire wetland are used.

Objectives

The primary objective of this study was to explore relationships of fish populations among Great Lakes, ecoregions, wetland types, and plant zones and relate these differences to water quality and adjacent land use/cover. Using what we learned from these analyses, our second goal was to develop a fish-based system of biotic indicators of wetland ecological health that could be employed in a monitoring program by federal, state, provincial, and local agencies to detect effects of anthropogenic disturbance on the biotic integrity of Great Lakes coastal wetlands.

METHODS

Study Sites

Sixty-one sites spanning all five Great Lakes were selected for study. Five sites were located on Lake Superior, 18 on Lake Michigan, 13 on Lake Huron, 13 on Lake Erie, and 12 on Lake Ontario (Fig. 1). Each site was assigned designators based on lake (Superior, Michigan, Huron, Erie, or Ontario) ecoregion (E. Lake Superior, N. Lake Michigan, N.E. Lake Michigan, S.E. Lake Michigan, N. Lake Huron, Saginaw Bay Huron, Long Point Erie, N.W. Lake Ontario, and N.E. Lake Ontario), wetland type (open lacustrine, protected lacustrine, barrier-beach, and drowned river mouth), and vegetation type (*Sparganium* (bur-reed), *Scirpus* (bulrush) (inner and outer; e.g., Burton *et al.* 1999 and Uzarski *et al.* 2004), *Nuphar/Nymphaea* (lily), *Pontederia/Sagittaria/Peltandra* (pickerel weed/arrowhead/arrow arum), *Typha* (cattail), *Zizania* (wild rice), and *Eleocharis* (spike rush)) See Appendix A, available from the corresponding author's web site (http://www.gvsu.edu/wri/envbio/uzarski/index.htm), for specific site locations and classifications. Site selection was based on access and inundation. We sampled every site that we encountered if we were granted access and the site was inundated with enough water to set nets (approximately 25 cm).

Wetland Classification

Wetlands of the Great Lakes were classified into geomorphological classes that reflect location in the landscape and exposure to waves, storm surges, and lake level changes. Classes followed categories described by Albert *et al.* (2003) on behalf of the Great Lakes Wetland Consortium. Wetlands were categorized as *lacustrine* (fringing), *riverine*, or *barrier protected*. All 61 sites sampled fit into *open lacustrine*, *protected lacustrine*, *barrier-beach*, or *drowned river mouth* subcategories (Appendix A).

Chemical/Physical and Land Use/Cover Measurements

Basic chemical/physical parameters were sampled within each vegetation zone fished. Analytical procedures followed those recommended in Standard Methods for the Examination of Water and Wastewater (APHA 1992). These measurements included soluble reactive phosphorus, ammonium-N, nitrite/nitrate-N, dissolved oxygen, temperature, turbidity, specific conductance, pH, and total alkalinity at all sites. Additional measurements of chlorophyll a, sulfate, chloride, and redox potential were made at approximately half of the sites. Quality assurance/quality control procedures followed protocols recommended by U.S. EPA.

Land use/cover data were obtained from existing digitized maps. When land use/cover data from more than one year were available, on-site observations were used to determine the most accurate map. For example, we found that maps digitized

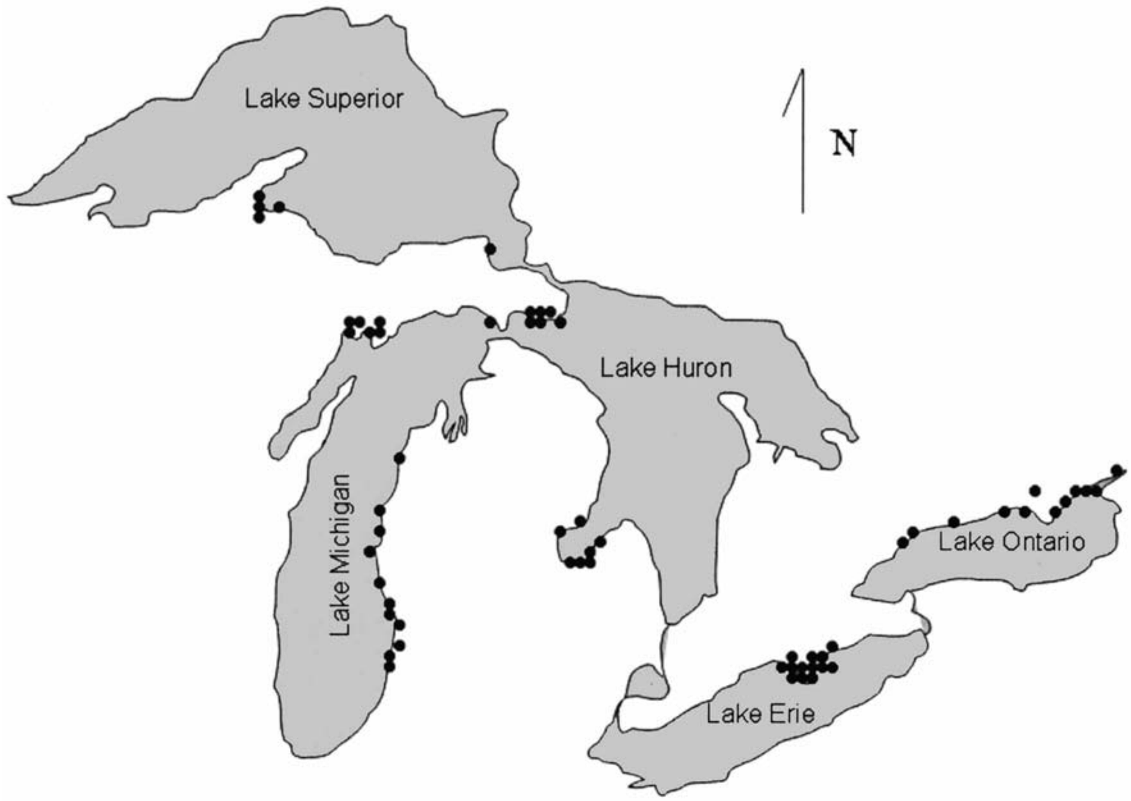

FIG. 1. Map of Great Lakes basin showing the locations of 61 coastal wetlands sampled during the summer of 2002.

from aerial photographs taken in 1978 (available from the Michigan Center for Geographic Information) were more accurate at coarse resolution for many of the Michigan sites than newer available versions. Coarse categories, including agriculture, urbanization, roads, idle lands, wetlands and forests, were calculated for 1-km buffers around all sites except drowned river mouths. Land use/cover was calculated for the entire watershed at drowned river mouth sites. These data were verified with on-site observations where possible. Additional 20-km buffers were calculated around approximately half of the sites; we were unable to acquire these data for all sites.

Fish Sampling

Fish sampling was conducted using a minimum of three replicate fyke nets with 4.8-mm mesh in each dominant vegetation zone for one net-night. Sampling was conducted during the summer of 2002 and corresponded to the maturity of the vegetation in each system. Only dominant plant zones that could be definitively assigned to a dominant (i.e., visually much more than 50% composition by one species) type (*Sparganium*, *Scirpus*, *Nuphar/Nymphaea*, *Pontederia/Sagittaria/Peltandra*, *Typha*, *Zizania*, or *Eleocharis*) were sampled to partition variation due to structure or habitat type. We rarely encountered vegetation zones without an obvious dominant. However, when we did, these were avoided. Two sizes of fyke nets were used, 0.5-m × 1-m openings and 1-m × 1-m openings. Smaller nets were set in water approximately 0.25 m deep to 0.50 m; larger nets were set in water depths greater than 0.50 m. Leads were 7.3 m in length and wings were 1.8 m. The depth of water in each plant zone dictated the net size used since the only difference between large and small nets was the height. Each net was randomly placed perpendicular to the vegetation zone of interest with leads extending into the vegetation itself. Therefore, fishes either occupying the vegetation or using the edge were likely to be caught. Wings were set at 45° angles to the lead and connected to the outer opening on each side of the net. Fishes were identified to species and enumerated. Catches per net per night were recorded. Ten to 20 specimens of each species were chosen randomly for measurement, but these data were not included in this paper; please contact authors regarding these data if they can be of use.

Statistical Analyses

Chemical/physical and land use/cover data were analyzed using principal components analysis (PCA). Percentages were transformed using an arcsine square root before inclusion in the PCA. All variables entered into the PCA represented a normal distribution. Correspondence analysis (CA), detrended correspondence analysis (DCA), and non-metric multidimensional scaling (NMDS) were used to analyze fish data. All three indirect gradient analyses were used because an "arch effect" can sometimes confuse the interpretation of CA. DCA and NMDS were used to determine if the arch was present. Fish data were not transformed. When CA, DCA, and NMDS all showed similar results, only CA was used to describe relative fish communities.

Indirect gradient analyses (CA, DCA, and NMDS) were used to determine if fish composition was mainly structured by Great Lake, ecoregion, wetland type, or plant zonation. This was determined by overlaying these variables as a third dimension onto the first two dimensions of the CA. If fish community composition was structured by one of these variables, fish community composition would in turn group the sites by either lake, ecoregion, wetland type, or plant zonation. Therefore, the first run of the CA contained all taxa represented by more than three individuals in the total dataset (15,000 + fish in total). Following each run of the analyses, sites were coded using Great Lake, ecoregion, wetland type, and plant zonation. Biplots were then visually inspected for groupings. Chemical/physical and land use/cover data were combined using PCA. Eigenvalues were then correlated with factor loadings from CA in an attempt to associate fish community structure with abiotic factors. If no groupings were observed and factor loadings did not correlate with eigenvalues, then taxa responsible for the most inertia in each dimension were identified. If these taxa were either very rare or had the tendency to school, they were likely to overwhelm the analysis and therefore were removed before the next iteration was performed. This process continued until a gradient (either Great Lake, ecoregion, wetland type, or plant zonation) could be identified. Once a gradient was identified, direct gradient analysis (canonical correspondence analysis) was performed to determine accordance between the two approaches (direct and indirect gradient analysis). The above statistical analyses were solely performed to determine the underlying forcing factors in establishing fish community composition in Great Lakes coastal wetlands. In turn, results of these analyses were used to determine proper stratification (either by Great Lake, ecoregion, wetland type, or plant zonation) for a fish-based IBI. Once the forcing factor was determined, the entire dataset, including those fishes removed from the CA, was stratified and analyzed under the confines of this stratification using Spearman or Pearson correlation to search for metrics. These data were correlated with disturbance gradients established *a priori* using land use and chemical/physical data. Statistical analyses were performed using Systat 8.0, SAS V8, and Canoco for Windows.

Establishing Disturbance Gradients

Disturbance gradients were established using land use/cover and chemical/physical data. They were established using both principal components (PCs) and calculating rank sums using all chemical/physical and land use/cover data (1-km and 20-km buffers). Turbidity, specific conductance, and chloride were ranked directly with the greater values indicating disturbance. Extreme values, either very high or very low, for nitrate-N, ammonium-N, and soluble reactive phosphorus concentrations, as well as percent saturation of dissolved oxygen, and pH were considered indicators of disturbance (reasoning for this assumption is explained in the discussion section). Therefore, absolute values of the difference from the median concentration were used to establish a rank order for each of these parameters. These data, as well as land use/cover data, were used to establish ranks. Ranks were then combined into a grand rank producing the final disturbance gradient.

Land use/cover data were analyzed at two scales for more than half of our sites and both were incorporated into the final disturbance gradient for this subset of sites. The larger scale (20-km buffers) was used to represent the impacts to the nearshore region or the water source of the wetland and was double weighted. These data were not available for all sites. A finer scale (1-km buffer) was used to relate impacts much more locally and received a single weighting. Metrics were correlated with this disturbance gradient as well as with PC1 of the chemical/physical, land use/cover PCA.

IBI Development

Community attributes were correlated with PCs and the rank-sum disturbance gradients using Pearson and Spearman correlations, respectively. When community attributes or specific taxa correlated with established disturbance gradients, they were deemed metrics. When attributes did not significantly correlate with the disturbance gradients but did show a dichotomy between pristine and impacted sites, Mann-Whitney U tests were performed and these too were maintained. Those attributes, including many from the literature that showed an empirical response to disturbance using one of the above methods, were deemed metrics. Natural breaks in metric values were then used as cut-offs for score categories.

RESULTS

Chemical/Physical and Land Use/Cover Measurements

Our chemical/physical and land use/cover data suggested a wide range of ambient conditions among our sites. However, we were not able to obtain a complete matrix for all of our parameters; some sites had missing values, especially the 20-km buffer. The 20-km buffer could only be calculated for 33 sites, and therefore, ranks and disturbance gradients could only be calculated with this variable for a subset of our sites. Chloride data were also only available from a subset of sites (Table 1a–c)).

Principal Components Analysis

Principal components analysis, including all of the chemical/physical and land use/cover data, produced results very similar to the last iteration of the CA. That is, the PCA was structured by vegetation zone especially in PC1. *Scirpus* sites were given low PC1 scores and *Typha* sites scored high with the remaining vegetation zones ordinated somewhere in between (Fig. 2). In combination, the two dimensions accounted for 37% of the variation in the dataset. In general, the PCA can be viewed as having three groupings, those that scored low in both PCs and those that scored high in PC1 and either low or high in PC2. Those sites that scored low in both PCs tended to have higher dissolved oxygen and pH as well as a high percentage of forest in the 1-km buffer surrounding the site. This grouping included nearly all *Scirpus* sites. The second grouping of the PCA included those sites with high PC1 scores and low PC2 scores. These sites tended to be composed of *Typha* and generally had high nutrients and a high percentage of adjacent land use in agriculture. Finally, the third grouping was also composed of mostly *Typha* sites scoring high in both PCs and was indicative of high run-off and percent urbanization. Nearly all remaining vegetation zones were placed between the first and second groupings discussed (Fig. 2). Consistent with biotic data in the CA, no patterns were visually detected when sites were coded by lake, ecoregion, or wetland type.

Correspondence Analysis

Rare or schooling taxa increased the variability in the data set and were often captured by chance alone. For example, schools of *Ameiurus melas* (black bullhead) and *Amia calva* (bowfin) were observed at nearly every site sampled, yet schools of these taxa were only caught at a few sites. When these taxa overwhelmed the first iteration of analyses, they had to be removed (see Table 2) and the entire process was repeated. Appendix B (available from the corresponding author's web site: http://www.gvsu.edu/wri/envbio/uzarski/index.htm) includes the mean catch per net for all species. After several iterations, the first pattern appeared (Fig. 3). Just as in the case of the PCA of the abiotic data, plant zone was the major driving factor of community composition, more so than even lake, ecoregion, or wetland type. Fish community composition was ordinated from *Scirpus, Eleocharis*, and *Zizania* to *Nuphar/Nymphaea,* and *Pontederia/Sagittaria/Peltandra* to *Sparganium* to *Typha.*

Correlation Between Abiotic and Biotic Data

Once the pattern appeared in the CA, a significant ($p = 0.001$) Pearson correlation was found between the first dimensions of the CA and the first PC (Fig. 4). The third dimensions (Great Lake, ecoregion, wetland type, and plant zone) were then applied to the correlation analysis just as they were in each PCA and CA. Once again, plant zone showed the only apparent relationship. The order of the plant zones in the correlation was identical to the CA and the PCA as well. The relationship seems to be better represented by a quadratic function, suggesting that a threshold in fish community composition is reached, but a linear correlation was applied and was significant. Direct gradient analysis (CCA) supported these results suggesting that the underlying gradient in the fish community data

TABLE 1A–C. Anthropogenic disturbance gradients of Inner and Outer **Scirpus** ***(1a),*** **Typha** ***(1b) and Lily (1c) zones in Great Lakes coastal wetlands using land use and water quality parameters sampled during the summer of 2002. Data represent ranks for each parameter; sum of the ranks was used to determine the disturbance gradient. Land use parameters included percent developed land (%Dev), percent agricultural land (%Ag), percent forested land^{-1} (%For^{-1}) and percent wetland/meadow^{-1} (%Wet Mead^{-1}) for both 1-km and 20-km buffers. Ranks for 20-km land use parameters were double weighted. Nitrate-N, pH and percent dissolved oxygen ranks were based on the absolute value of the measured value at a site minus the median of all sites. Principal components (PC) analysis was used to combine 13 chemical, physical and land use variables for*** **Typha** ***sites and the resulting PC1 scores represent increasing urbanization and agriculture.***

Table 1a.	20-km Land Use				1-km Land Use				Water Quality						
	% Dev	% Ag	% For^{-1}	Wet Mead^{-1}	% Dev	% Ag	% For^{-1}	Wet Mead^{-1}	Cond. (uS cm^{-1})	pH	Turb. (NTU)	No$_3$-N (mg L^{-1})	Cl^{-} (mgL^{-1})	% DO	
Inner *Scirpus*															
Mean ± SE:	2.9 ± 0.4	24.0 ± 6.7	63.0 ± 6.6	10.2 ± 1.0	16.1 ± 4.4	5.7 ± 3.0	42.4 ± 6.3	10.5 ± 2.3	292.2 ± 20.7	8.1 ± 0.1	8.5 ± 2.9	0.06 ± 0.03	11.7 ± 2.3	8.6 ± 0.6	
Range:	0.5–6.7	0.9–86.9	2.8–93.9	3.6–16.1	0.0–66.6	0.0–42.7	0.0–81.9	0.0–26.8	155.9–569.0	7.0–9.6	1.7–63.7	0.01–0.60	0.8–30.5	5.0–16.6	Rank Sum
Big Fish Dam	32	30	30	28	15	7	16	6	13	16	5		7	16	221
Rapid River	12	28	26	20	7	5	3	15	12	16	12		13	14	183
Lightfoot Bay	34	34	32	4	11	10	7	5	17	3	4		17	2	180
Garden Bay	30	18	10	30	12	1	6	11	9	14	7		9	17	174
Ogontz Bay	28	26	14	22	13	6	15	0	10	11	9		7	9	170
Sheppard Bay	22	22	28	14	6	10	13	7	8	5	14		10	11	170
Hill Island	18	24	24	18	4	10	12	4	16	12	11		12	5	170
Moscoe Channel	20	16	22	16	8	10	14	1	15	8	8		15	15	168
St. Ignace	6	32	16	34	2	10	9	13	11	9	2		6	7	157
Mackinac Bay	24	12	18	10	9	10	11	9	1	15	12		16	1	148
Hessel Bay	16	10	20	8	5	4	8	14	14	7	6		14	12	138
Cedarville	26	14	12	12	3	3	10	10	6	2	17		11	10	136
Escanaba	4	20	8	24	1	10	5	3	4	10	16		5	13	123
Pinconning	8	6	4	26	10	9	4	16	3	4	14		1	6	111
Wigwam Bay	10	8	6	32	14	8	0	12	5	1	3		3	4	106
Wildfowl Bay	14	4	2	6	15	10	1	2	7	6	1		4	7	79
Vanderbilt Park	2	2	0	2	15	2	2	8	2	13	9		2	3	62
Outer *Scirpus*															
Mean ± SE:	3.2 ± 0.5	25.1 ± 7.0	60.6 ± 6.8	11.1 ± 1.0	15.0 ± 4.6	6.3 ± 3.2	45.0 ± 6.2	11.2 ± 2.3	254.7 ± 18.0	8.5 ± 0.1	9.1 ± 1.7	0.04 ± 0.01	12.5 ± 2.8	105.3 ± 3.6	
Range:	0.6–6.7	2.7–86.9	2.8–77.6	3.6–16.1	0.0–66.6	0.0–42.7	0.0–81.9	0.0–26.8	101.2–366.0	7.8–9.5	2.3–25.3	0.01–0.12	2.9–35.1	78.8–124.1	Rank Sum
Big Fish Dam	32	30	30	22	14	8	15	4	11	6	4	14	9	9	208
Ogontz Bay	28	24	14	16	11	7	14	0	10	7	13	16	6	16	182
Sheppard Bay	24	20	28	8	5	11	12	6	13	11	8	15	13	6	180
Portage River	16	26	12	28	12	5	9	5	16	3	9	3	16	12	172
Garden Bay	30	16	10	24	10	1	5	10	9	15	14	4	8	11	167
Hill Island	20	22	24	12	3	11	11	3	15	11	15	2	12	2	163
St. Ignace	6	32	16	30	2	11	8	12	8	10	1	6	7	14	163
Moscoe Channel	22	14	22	10	7	11	13	1	14	15	10	1	14	7	161
Rapid River	14	28	26	14	6	6	2	14	2	4	12	7	10	1	146
Mackinac Bay	26	12	18	6	8	11	10	8	7	8	2	7	11	10	144
Hessel Bay	18	10	20	4	4	4	6	13	12	5	11	5	15	13	140
Escanaba	4	18	8	18	1	11	4	2	6	13	16	7	5	8	121
Wigwam Bay	12	8	6	26	13	9	0	11	5	1	6	7	4	4	112
Pinconning	10	6	4	20	9	10	3	15	4	2	4	7	1	5	100
Bradleyville	8	4	2	2	14	3	7	9	3	9	3	7	2	15	88
Vanderbilt Park	2	2	0	0	14	2	1	7	1	13	7	7	3	3	62

TABLE 1A–C. Continued.

Table 1b.	1-km Land Use				Water Quality				
	%Dev	%Ag	%For^{-1}	%Wet Mead^{-1}	Sp. Cond. (*u*S cm^{-1})	Turb. (NTU)	NO$_3$-N (mg L^{-1})	PC1 Score	
Mean ± SE:	18.2 ± 4.5	28.8 ± 5.5	21.2 ± 4.2	22.5 ± 4.8	369.0 ± 31.2	11.2 ± 2.5	0.30 ± 0.08	0.14 ± 0.33	Rank
Range:	0.0–84.2	0.0–88.1	0.0–94.0	0.0–99.1	206.0–957.5	1.3–69.1	0.01–1.63	–2.96–3.97	Sum
Bluff Marsh	28	23	6	28	30	30	19	28	192
Helmers Pond	29	23	15	25	25	28	19	27	191
Thoroughfare	27	23	1	30	28	23	19	29	180
Little Rice Bay	30	23	1	29	26	22	18	30	179
Long Point	10	23	14	27	19	25	18	26	162
Rapid River	8	19	16	22	23	24	18	21	151
Parrott Bay	15	16	21	26	15	27	8	17	145
Crown Marsh	4	23	1	24	29	21	17	25	144
Presqu’ile	9	18	27	17	18	29	9	12	139
Lincoln	21	13	25	19	13	9	12	19	131
Coletta Bay	5	23	7	23	19	19	15	22	133
Lee Brown Marsh	25	3	8	15	27	14	15	23	130
Muskegon	20	14	28	12	12	16	15	13	130
Pentwater	26	10	26	18	8	5	14	20	127
Port Rowan	7	11	18	5	22	26	14	24	127
Hill Island Canada	18	23	30	1	16	12	8	18	126
Pere Marquette	24	17	29	9	7	4	10	15	115
Allen Rd	16	8	20	4	10	15	12	16	101
Booth’s Harbor	19	5	19	1	9	20	12	10	95
South Bay	11	4	12	11	17	17	8	14	94
Robinson Cove	22	2	11	7	24	13	7	8	94
Bruce’s Bayou	12	12	24	14	5	2	8	11	88
Little Black Creek	3	22	22	13	1	10	9	2	82
Pigeon	17	9	23	10	4	11	1	7	82
Frenchman’s Bay	1	20	5	16	10	18	5	5	80
Hay Bay South	14	6	17	8	14	7	2	9	77
Port Britain	13	7	13	20	6	8	2	4	73
Bayfield Bay	23	1	9	6	21	3	1	6	70
Lynde Creek	6	15	10	21	2	1	1	1	57
Jones Road	2	21	4	1	3	5	1	3	40

Table 1c.	Watershed Land Use				Water Quality						
	%Dev	%Ag	%For^{-1}	%Wet Mead^{-1}	Sp. Cond. (*u*S cm^{-1})	Turb. (NTU)	NO$_3$-N (mg L^{-1})	NH$_4$-N (mg L^{-1})	SRP (mg L^{-1})	Cl$^-$ (mg L^{-1})	
Mean ± SE:	4.1± 0.8	24.5± 4.2	54.4± 5.4	13.0± 1.7	352.6± 32.8	13.4± 2.7	0.26± 0.12	0.058± 0.016	0.01± 0.00	12.9± 3.7	
Range:	1.0–9.4	0.1–50.1	34.8–87.3	7.3–28.9	160.0–553.9	3.0–35.5	0.01–1.48	0.03–0.217	0.01–0.02	0.7–47.1	Rank Sum
Taquamenon	12	12	12	7	12	11	9	12	7	11	105
Baraga	11	11	11	3	11	12	12	7	7	12	97
Arcadia River	10	6	3	12	8	5	3	9	7	10	73
Lincoln	6	5	4	11	9	7	4	10	7	9	72
Pere Marquette	8	9	10	1	6	6	9	11	4	8	72
Little Pigeon	1	10	9	10	10	1	5	5	6	6	63
Muskegon	5	8	7	5	2	10	9	6	3	4	59
Pentwater	9	2	5	9	3	8	8	3	3	7	57
White	7	7	8	4	5	4	7	2	3	5	52
Norris Creek	3	4	6	8	7	3	2	1	2	3	39
Bruces Bayou	2	3	2	6	4	2	5	4	2	2	32
Pigeon	4	1	1	2	1	9	1	8	1	1	29

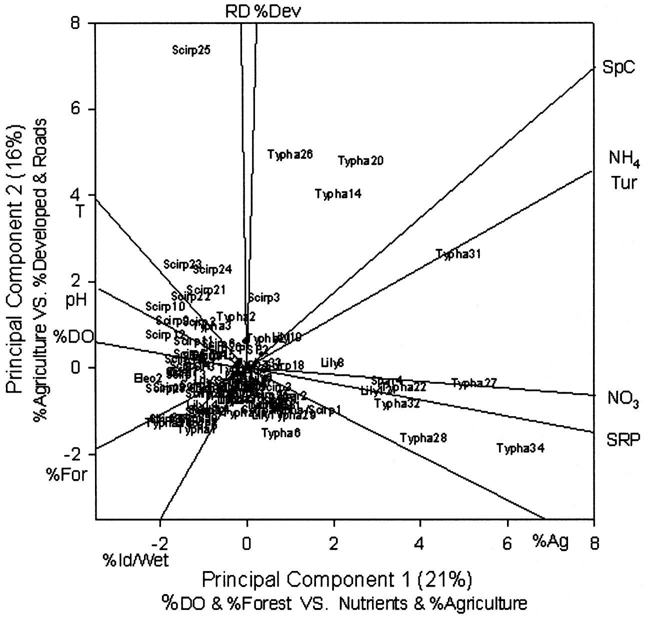

FIG. 2. Principal components analysis of 13 chemical/physical and land use (1-km buffer) parameters including specific conductance (SpC), ammonium-N (NH_4), turbidity (Tur), nitrate-N (NO_3), soluble reactive phosphorus (SRP), percent dissolved oxygen (%DO), pH, temperature (T), percent developed land (%Dev), percent agriculture (%Ag), percent idle lands and wetlands (%Id/Wet), percent forest (%For) and road density (RD) for 104 plant zones spanning all five Great Lakes sampled in 2002. Labels refer to vegetation type including **Typha** *(Typha),* **Scirpus** *(Scirp),* **Nuphar** *and* **Nymphaea** *(Lily),* **Zizania** *(Ziz),* **Sparganium** *(Spar),* **Pontederia/Sagittaria/Peltandra** *(PSP) and* **Eleocharis** *(Eleo) with numbers referring to site location codes (available from the corresponding author as an appendix).*

was established by the plant and/or abiotic data. This relationship suggested that not only were plants, fish communities, and the associated abiotic factors related, but also that they were somewhat predictable. Therefore, a fish-based IBI for the entire Great Lakes basin appeared to be feasible. From this point on, additional data analyses were performed after stratifying by plant zone.

Disturbance Gradient

The number of variables used to establish primary gradients varied with plant zone. For example, *Scirpus* was stratified into an outer wave-swept area and an inner protected area (e.g., Burton *et al.* 1999, Uzarski *et al.* 2004, Burton *et al.* 2004) and ranks of these data were averaged for the overall *Scirpus*-zone gradient. In the inner *Scirpus* zone, the median nitrate concentration was below our detection limit (0.01 mg l^{-1}) so nitrate could not be used in the gradient. Formulae used to calculate disturbance gradients for each plant zone can be found in Table 3 and the overall rank order of the sites can be found in Table 1a–c. The 20-km buffer proved important in showing that, for example, all Saginaw Bay sites tended to be more impacted than northern Lake Huron sites (large-scale differences in water quality), and the 1-km buffer was important in ordering sites within Saginaw Bay and the other regions.

Additional disturbance gradients were established using PCA for each plant zone. These were used to search for metrics that were not apparent from the primary gradients. Those variables that weighted the heaviest in PC1 of each analysis were identified and taken into consideration when searching for metrics. Those variables that weighted heaviest in PC1 for *Scirpus*, *Nuphar/Nymphaea*, and *Typha* were nitrate, chloride, and specific conductivity respectively.

IBI Development

Once it was revealed that plant zone was the major driving factor in establishing fish community composition, and the above analyses suggested that an IBI could be developed for all five Great Lakes, we stratified the entire dataset (including those taxa removed from iterations) and began to search for metrics. We were not assuming that the taxa that were eliminated in these iterations were not responding to vegetation, nutrients, and/or agriculture as the remaining taxa did. The taxa removed were simply masking gradients and community structure because they tended to school or were uncommon. Our sampling effort was not great enough to determine how schooling or rare taxa contribute to overall community composition because the tendency is to catch either large schools or rare taxa more by chance than by their true abundances with only three nets per plant zone.

Fish of 38, 39, and 30 taxa were identified in the *Scirpus*, *Typha,* and *Nuphar/Nymphaea-Pontederia/Sagittaria/Peltandra* zones, respectively. The *Nuphar/Nymphaea* and *Pontederia/Sagittaria/Peltandra* had to be combined post-hoc because sample size was simply too low for these communi-

TABLE 2. Fish species collected with fyke nets in coastal wetlands of the five Great Lakes in 2002. Fish species included in each iteration of the ordination analyses (42, 40, 34, 28 and 26-species analysis respectively) are indicated with "x". Functional feeding groups include: insectivore (INS), molluscivore (MOL), omnivore (OMN), piscivore (PISC), zoobenthivore (ZOB).

					Iteration of Ordination Analyses				
Species Name	Family Name	Common Name	Code	FFG	42-Sp	40-Sp	34-Sp	28-Sp	26-Sp
Labidesthes sicculus	Atherinidae	Brook silversides	BRS	INS	x	x	x	x	x
Catostomus commersoni	Catostomidae	White sucker	WHS	OMN	x	x	x	x	x
Ambloplites rupestris	Centrarchidae	Rock bass	ROB	PISC	x	x	x	x	x
Lepomis cyanellus	Centrarchidae	Green sunfish	GRS	INS	x	x	x	x	x
Lepomis gibbosus	Centrarchidae	Pumpkinseed	PUS	INS	x	x	x	x	x
Lepomis macrochirus	Centrarchidae	Bluegill	BLG	INS/PISC	x	x	x	x	x
Lepomis microlophus	Centrarchidae	Redear sunfish	RES	INS	x	x	x	x	x
Micropterus dolomieu	Centrarchidae	Smallmouth bass	SMB	PISC	x	x	x	x	x
Micropterus salmoides	Centrarchidae	Largemouth bass	LMB	PISC	x	x	x	x	x
Pomoxis nigromaculatus	Centrarchidae	Black crappie	BLC	INS/PISC	x	x	x	x	x
Cyprinella spiloptera	Cyprinidae	Spotfin shiner	SFS	ZOB	x	x	x	x	x
Cyprinus carpio	Cyprinidae	Common carp	COC	OMN	x	x	x	x	x
Notemigonus crysoleucas	Cyprinidae	Golden shiner	GOS	OMN	x	x	x	x	x
Notropis anogenus	Cyprinidae	Pugnose shiner	PNS	INS	x	x	x	x	x
Notropis heterodon	Cyprinidae	Blackchin shiner	BCS	OMN	x	x	x	x	x
Notropis hudsonius	Cyprinidae	Spottail shiner	STS	INS	x	x	x	x	x
Pimephales notatus	Cyprinidae	Bluntnose minnow	BNM	OMN	x	x	x	x	x
Pimephales promelas	Cyprinidae	Fathead minnow	FHM	OMN	x	x	x	x	x
Esox lucius	Esocidae	Northern pike	NOP	PISC	x	x	x	x	x
Fundulus diaphanus	Fundulidae	Banded killifish	BKF	INS	x	x	x	x	x
Ameiurus nebulosus	Ictaluridae	Brown bullhead	BRB	INS	x	x	x	x	x
Noturus gyrinus	Ictaluridae	Tadpole madtom	TPM	INS	x	x	x	x	x
Lepisosteus osseus	Lepisosteidae	Longnose gar	LNG	PISC	x	x	x	x	x
Perca flavescens	Percidae	Yellow perch	YEP	INS/PISC	x	x	x	x	x
Aplodinotus grunniens	Sciaenidae	Freshwater drum	FWD	INS/MOL	x	x	x	x	x
Umbra limi	Umbridae	Central mudminnow	CMM	INS	x	x	x	x	x
Amia calva	Amiidae	Bowfin	BOW	PISC	x				
Carpiodes cyprinus	Catostomidae	Quillback	QUB	OMN					
Moxostoma carinatum	Catostomidae	River redhorse	RIR	INS/MOL	x	x	x		
Moxostoma duquesnei	Catostomidae	Black redhorse	BRH	INS					
Pomoxis annularis	Centrarchidae	White crappie	WHC	INS/PISC	x	x	x		
Alosa pseudoharengus	Clupeidae	Alewife	ALE	OMN	x	x	x	x	
Dorosoma cepedianum	Clupeidae	Gizzard shad	GIZ	OMN	x	x			
Luxilus cornutus	Cyprinidae	Common shiner	COS	INS	x	x			
Macrhybopsis storeriana	Cyprinidae	Silver chub	SIC	INS					
Nocomis biguttatus	Cyprinidae	Hornyhead chub	HHC	INS					
Notropis atherinoides	Cyprinidae	Emerald shiner	EMS	INS	x	x			
Notropis heterolepis	Cyprinidae	Blacknose shiner	BNS	INS	x	x			
Semotilus atromaculatus	Cyprinidae	Creek chub	CRC	INS					
Esox americanus vermiculatus	Esocidae	Grass pickerel	GRP	PISC	x	x	x		
Lota lota	Gadidae	Burbot	BUR	PISC					
Gasterosteus aculeatus	Gasterosteidae	Threespine stickleback	TSS	INS					
Pungitius pungitius	Gasterosteidae	Ninespine stickleback	NSS	INS	x	x			
Neogobius melanostomus	Gobiidae	Round goby	ROG	OMN	x	x	x		
Ameiurus melas	Ictaluridae	Black bullhead	BLB	INS	x				
Ameiurus natalis	Ictaluridae	Yellow bullhead	YEB	INS/PISC					
Ictalurus punctatus	Ictaluridae	Channel catfish	CHC	INS/PISC	x	x			
Morone americana	Moronidae	White perch	WHP	PISC	x	x	x		
Etheostoma exile	Percidae	Iowa darter	IOD	INS					
Etheostoma nigrum	Percidae	Johnny darter	JOD	INS	x	x	x	x	
Percina caprodes	Percidae	Logperch	LOP	INS					

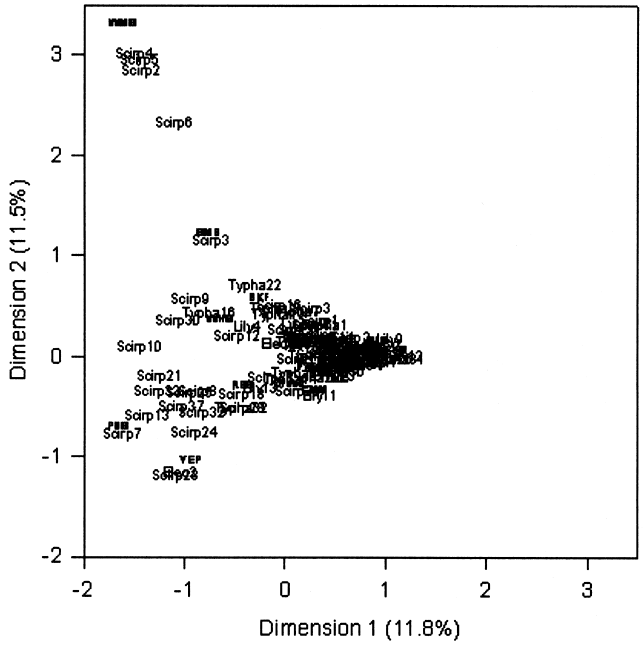

FIG. 3. Correspondence analysis of 26 fish species in 104 plant zones in coastal wetlands of the five Great Lakes sampled in 2002. Site labels refer to vegetation type including: **Typha** *(Typha),* **Scirpus** *(Scirp),* **Nuphar** *and* **Nymphaea** *(Lily),* **Zizania** *(Ziz),* **Sparganium** *(Spar),* **Pontederia/Sagittaria/Peltandra** *(PSP) and* **Eleocharis** *(Eleo) with numbers referring to site location codes (available from the corresponding author as an appendix). Fish codes are defined in Table 2.*

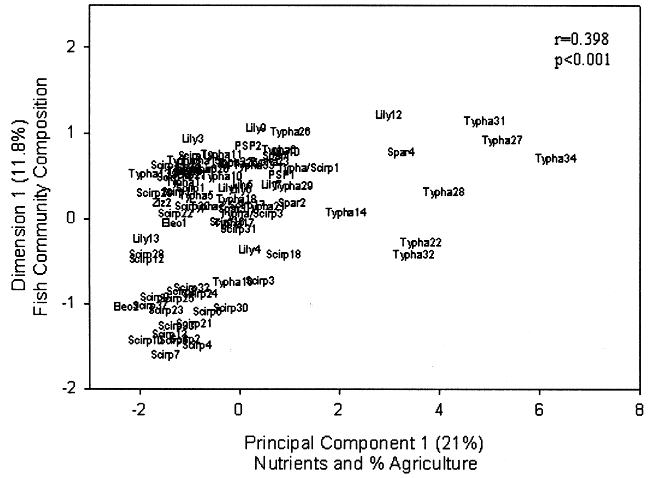

FIG. 4. Correlation between abiotic factors (combined in principle components analysis), and fish communities (represented by correspondence analysis), for 104 vegetation zones sampled during the summer of 2002. Labels refer to vegetation type including: **Typha** *(Typha),* **Scirpus** *(Scirp),* **Nuphar** *and* **Nymphaea** *(Lily),* **Zizania** *(Ziz),* **Sparganium** *(Spar),* **Pontederia/Sagittaria/Peltandra** *(PSP) and* **Eleocharis** *(Eleo) with numbers referring to site location codes (available from the corresponding author as an appendix).*

ties and the CA showed very similar fish communities in these two vegetation zones. Community attributes and indicator species were evaluated based on their ability to order sites according to anthropogenic disturbance. Additionally, 41 published metrics were also evaluated (Wilcox *et al.* 2002, Minns *et al.* 1994, and Simon 1998). Correlation and graphical interpretation yielded 14, 11, and 2 metrics for *Scirpus, Typha,* and *Nuphar/Nymphaea-Pontederia/Sagittaria/Peltandra,* respectively. Metric scores were established by searching for natural breaks in the metric values.

Fish data are inherently variable. In an attempt to remove some of this variability from the IBI, we eliminated data for plant zones when fewer fishes than a mean of at least 10 per net per plant zone had been caught before applying the IBI. Of the 22 *Scirpus*, 29 *Typha*, and 12 *Nuphar/Nymphaea- Pontederia/Sagittaria/Peltandra* sites fished, 5, 11, and 8, respectively, were excluded because of insufficient catches. We did not feel that these catches accurately reflected a "typical catch" for these sites (we recommend that if the user feels that he/she collected an atypical sample for a given site, the site is fished for an additional night). After removing sites with insufficient data, metric scores correlated with disturbance rankings at r = 0.891 for *Scirpus* and r = 0.824 for *Typha* (Fig. 5). Table 4 contains the final set of IBI metrics for *Scirpus* and *Typha* zones. No significant correlation was found between the disturbance ranking for the *Nuphar/Nymphaea* or *Pontederia/Sagittaria/Peltandra* sites and their respective candidate IBI metric scores. Therefore, no metrics could be developed for *Nuphar/Nymphaea* or *Pontederia/Sagittaria/Peltandra* either separately or together.

DISCUSSION

Principal Components Analysis

Uzarski *et al.* (2004) used a similar approach to examine invertebrate responses to human influences. They also used multivariate analyses to doc-

TABLE 3. Parameters used to establish anthropogenic disturbance gradients for four vegetation zones in coastal wetlands of the five Great Lakes using land use/cover and water quality data collected in 2002. Disturbance gradients were determined using the sum of the ranks of the parameters identified with "x" for each vegetation type. Principal component 1 represents increasing urbanization and agriculture from a principal components analysis combining 13 chemical/physical and land use/cover variables for **Typha** *sites.*

	Vegetation Zones			
Parameters	Outer *Scirpus*	Inner *Scirpus*	*Typha*	Lily
Land Use—20-km or watershed				
% Developed	x	x		x
% Agriculture	x	x		x
% Forest^{-1}	x	x		x
% Wetland & Meadow^{-1}	x	x		x
Land Use—1-km				
% Developed	x	x	x	
% Agriculture	x	x	x	
% Forest^{-1}	x	x	x	
% Wetland & Meadow^{-1}	x	x	x	
Water Quality				
Specific conductance	x	x	x	x
|pH - median pH|	x	x		
Turbidity	x	x	x	x
NO_3-N			x	x
|NO_3-N—median NO_3-N|	x			
NH_4-N				x
SRP-P				x
Cl	x	x		x
% DO—median % DO|	x	x		
PC1			x	

ument relationships between chemical/physical and land use/cover variables and related these to invertebrate attributes. Both King and Brazner (1999) and Uzarski *et al.* (2004) stressed that relationships between adjacent land use/cover and the chemical/physical conditions within the wetland are strictly correlative and cannot be used to infer causation. For example, Uzarski *et al.* (2004) data seemed to suggest that urban areas contribute more nitrate-N and ammonium-N to wetlands than do agricultural areas, since water in wetlands with adjacent urban land use tended to contain more nitrate-N and ammonium-N than did water in wetlands with adjacent agricultural land use. They explained that increased inorganic nitrogen in the urban wetlands might not be processed as efficiently as it is in agricultural wetlands. Therefore, no conclusion about quantity of input from the adjacent area was warranted (Jude *et al.* 2005). They simply tended to find relatively higher nitrate-N and ammonium-N concentrations in wetlands near urban areas where there was relatively higher runoff from the upland and lower productivity in the wetland itself. It does not necessarily suggest that a given land use/cover taken alone would create the associated chemical/physical conditions in the wetland. Our PCA suggested that agriculture was associated with higher nutrients in wetlands. However, this relationship was driven by seven of the 61 sites having extremely high nutrient concentrations as well as adjacent agriculture. Many sites with a high percentage of land use in agriculture actually had non-detectable dissolved nutrients in the water column. This may have been because these systems tend to have higher productivity and efficiently store excess nutrients in biomass. If sites with extremely high nutrients were removed from the analyses, results would have shown: 1) that agricultural sites either had very high or very low nutrient concentrations as was found for invertebrate populations (Uzarski *et al.* 2004), and 2) that relatively pristine sites had moderate nutrient concentrations.

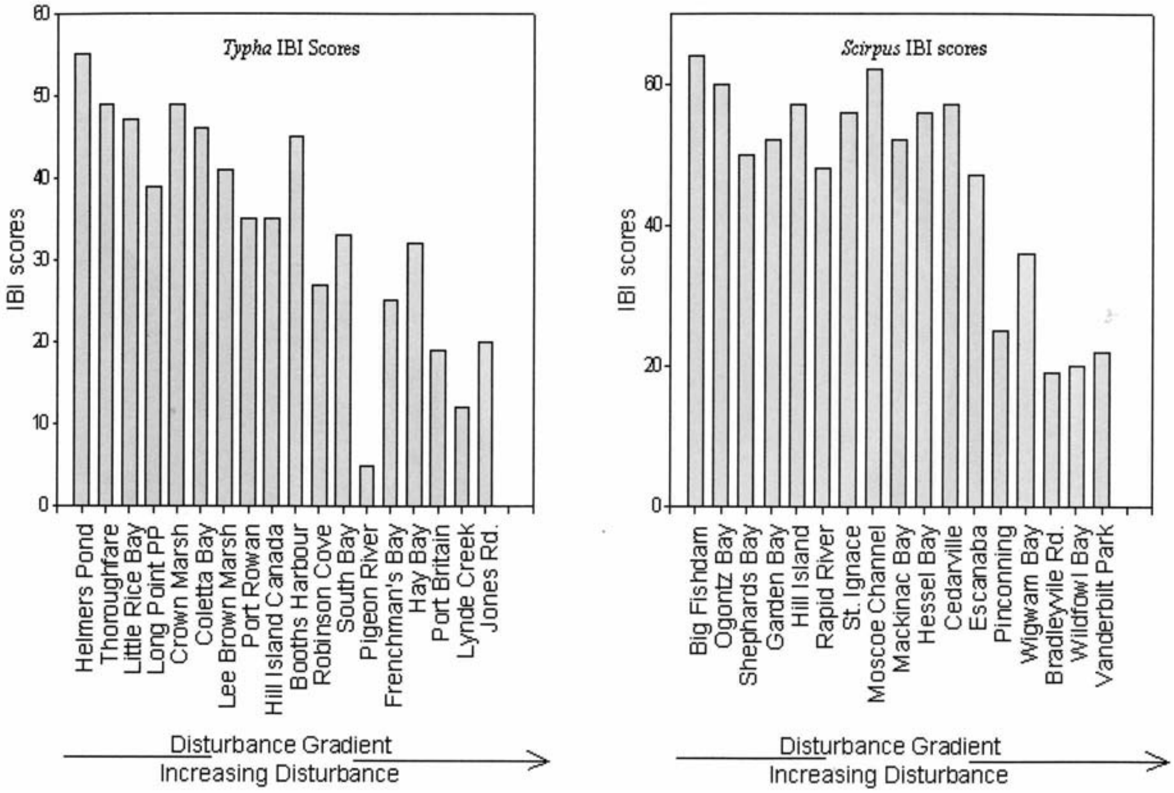

FIG. 5. Sum of IBI metric scores for* Scirpus *and* Typha *sites based on fish collected with fyke nets in 61 Great Lakes coastal wetlands in 2002. Sites are ordered by increasing disturbance. See Table 4 for IBI metrics.

Uzarski *et al.* (2004) sampled many of the same sites included in these analyses. They found an association between nutrients and urbanization because their (and our) most pristine sites had a relatively high concentration of cabins adjacent to the systems producing a relatively high "urbanization" component to the 1-km buffers around the sites. However, by using an additional buffer of 20-km it became apparent that most of the watershed was intact forest. These sites rarely had either non-detectable or very high nutrient concentrations (unpublished data from 1996 through 2003). This is likely the reason for a long struggle with using chemical/physical and land use/cover variables to detect moderate disturbance in biotic populations in wetlands. We believe that an approach similar to our method of establishing disturbance gradients may be a valuable tool for detection.

Correspondence Analysis

Rare or schooling fish taxa increased the variability in the data set and were often captured by chance alone. For example, schools of black bullhead and bowfin were observed at nearly every site sampled yet schools of these taxa were only caught at a few sites. When these taxa overwhelmed the first iteration of analyses, they had to be removed and the entire process was repeated. These data were not discarded from the study, but only from the exploratory analysis. There has been much debate in the literature regarding how to handle rare taxa. Studies involving fishes meet similar challenges when dealing with taxa that tend to school. The tendency is to occasionally capture rare taxa and to either catch many or no schooling taxa. When determining the importance in community composition of such taxa, studies will have to involve an enormous amount of sampling effort and this will likely be at the expense of the number of sites that can be visited. Our analysis suggests that, at least for the cosmopolitan taxa of the Great Lakes, plant zone or habitat structure was the major driving factor in shaping the community and we have no reason to believe that the same is not true for those rare or schooling taxa. However, our sampling effort was not great enough to establish such a relationship.

TABLE 4. Preliminary fish-based index of biotic integrity metrics for Great Lakes coastal wetlands derived from data collected in 2002. Scoring is to be conducted from mean values per net-night in* Scirpus *and* Typha *zones when a mean of at least 10 fish are captured per net per vegetation zone. If less than 10 are captured or a sample is suspected to be atypical, an additional net-night is recommended.

Metric				
Scirpus Zone:				
1. Mean catch per net-night:	< 10 score = 0	10–30 score = 3	> 30 score = 5	
2. Total richness:	< 5 score = 0	5 to < 10 score = 3	10 to 14 score = 5	> 14 score = 7
3. Percent non-native richness:	> 12% score = 0	7 to 12% score = 3	< 7% score = 5	
4. Percent omnivore abundance:	> 70% score = 0	50 to 70% score = 3	< 50% score = 5	
5. Percent piscivore richness:	< 15% score = 0	15 to 25% score = 3	> 25% score = 5	
6. Percent insectivore abundance:	< 20% score = 0	20–30% score = 3	> 30% score = 5	
7. Percent insectivorous Cyprinidae abundance:	< 1% score = 0	1–2% score = 3	> 2% score = 5	
8. Percent carnivore (insectivore+piscivore+zooplanktivore) richness:	< 60% score = 0	60–70% score = 3	> 70% score = 5	
9. White sucker (*Catostomus commersoni*) mean abundance per net-night:	0 score = 0	> 0 to 0.4 score = 3	> 0.4 score = 5	
10. Black bullhead (*Ictalurus melas*) mean catch per net-night:	0 score = 0	> 0 to 3 score = 3	> 3 score = 5	
11. Rock bass (*Ambloplites rupestris*) mean catch per net-night:	0 score = 0	> 0 to 4 score = 3	> 4 score = 5	
12. Alewife (*Alosa psuedoharengus*) mean catch per net-night:	> 11 score = 0	1 to 11 score = 3	< 1 score = 5	
13. Smallmouth bass (*Micropterus dolomieu*) mean catch per net-night:	0 score = 0	> 0 to 5 score = 3	> 5 score = 5	
14. Pugnose shiner (*Notropis anogenus*) mean catch per net-night:	0 score = 0	> 0 to 5 score = 3	> 5 score = 5	
Typha Zone:				
1. Percent insectivore catch:	< 40% Score = 0	40 to 80% score = 3	> 80% score = 5	
2. Insectivorous Cyprinidae richness:	0 to 1 Score = 0	> 1 to 3 score = 3	> 3 score = 5	
3. Percent Centrarchidae abundance:	0–30 score = 0	> 30 to 60 score = 3	> 60 to 80 score 5	> 80 score = 7
4. Centrarchidae richness:	0 to 1 score = 0	> 1 to 3 score = 3	> 3 score = 5	
5. Mean Shannon Diversity Index:	< 0.2 score = 0	0.2 to 0.7 score = 3	> 0.7 score = 5	
6. Mean evenness:	< 0.2 score = 0	0.2 to 0.6 score = 3	> 0.6 score = 5	
7. Longnose gar (*Lepisosteus osseus*) catch per net-night:	0 score = 0	> 0 to 0.5 score = 3	> 0.5 to 2 score = 5	> 2 score = 7
8. Largemouth bass (*Micropterus salmoides*) abundance per net-night:	0 to 2 score = 0	> 2 to 30 score = 3	> 30 score = 5	
9. Rock Bass (*Ambloplites rupestris*) catch per net-night:	0 to 1 score = 0	> 1 to 5 score = 3	> 5 score = 5	
10. Bluegill (*Lepomis macrochirus*) abundance per net-night:	0 to 3 score = 0	> 3 to 20 score = 3	> 20 to 30 score = 5	> 30 score = 7
11. *Lepomis* catch per net-night:	0 to 5 score = 0	> 5 to 20 score = 3	> 20 to 50 = 5	> 50 score = 7

Correlation between Abiotic and Biotic Data

Plant zones were ordered consistently in PC1 and CA1 suggesting that nutrients and the percent adjacent land use in agriculture were important in determining the plant zone found in the wetland. Fish community composition shifted with, and even within, plant zone with increasing nutrients and agriculture. However, it is also important to note that both the plant and abiotic data may also be correlated with parameters that we did not measure. These parameters include, but are not limited to, fetch and/or pelagic mixing and the accumulation of organic sediment. The order of the vegetation seems to represent an organic sediment gradient from *Scirpus* with the least amount to *Typha* with the most. Numerous studies have shown that macroinvertebrate communities also differ among plant zones (Burton *et al.* 1999, Burton *et al.* 2002, Burton *et al.* 2004, Uzarski *et al.* 2004). Fish community composition may be following a similar pattern based on food availability.

Disturbance Gradient

Turbidity, specific conductance, and chloride were ranked directly, with greater values indicating disturbance. Extreme values, either very high or very low, for nitrate-N, ammonium-N, and soluble reactive phosphorus concentrations, as well as percent saturation of dissolved oxygen and pH were considered indicators of disturbance. With respect to inorganic dissolved nutrients, we tended to find moderate concentrations at relatively pristine sites. Impacted sites often have either non-detectable values, because these systems are very productive and the nutrients are tied-up in organic matter and sediments, or nutrient concentrations that are so high that the communities do not assimilate them as quickly as they enter the system. Also, in a system experiencing cultural eutrophication, dissolved oxygen may be as high as 180% saturated during the day when we sample. In this case, percent saturation likely plummets at night when only respiration is taking place in the absence of photosynthesis. Likewise, a system with organic pollutants may have very low percent saturation (e.g., 50%) of dissolved oxygen due to decomposition of excess organic matter in the absence of photosynthesis. This can be caused by siltation, cloud cover, coverage of duckweed (*Lemna* or *Spirodela* spp.), and/or turbidity. Our pH measurements follow this relationship to some degree; a very high daytime pH may be indicative of extreme productivity, while very low daytime pH may be indicative of organic pollution.

Land use/cover data were analyzed at two scales and both were incorporated into the final disturbance gradient for a subset of our sites. The larger scale (20-km buffers) was used to represent the impacts to the nearshore region or the water source of the wetland and was double weighted. A finer scale (1-km buffer) was used to relate impacts much more locally and received a single weighting. The need for two scales was realized because the Saginaw Bay region represents the majority of agriculture in Michigan yet many areas around the bay have a relatively large forested area adjacent to the wetlands. This forested area undoubtedly intercepts excess nutrients that would have entered the wetland from the agricultural areas directly. However, impacts to the systems are coming through drainage ditches acting as conduits of pollution into the bay. These ditches, as well as the Saginaw River, often have extremely high nutrient loads, sometimes in excess of 40 mg L^{-1} nitrate-N (personal observation). When we determined land use for a 1-km buffer, land use for several of these sites was ~ 80% forested, yet when we determined land use for 20-km buffers, the same sites were ~ 80% agriculture. We felt it was appropriate to double weight the 20-km land-use buffer in the disturbance gradient because it better reflected the overall impacts of the adjacent landscape on the general water quality of the nearshore area. The nearshore water in turn inundated fringing wetlands.

IBI Development

Others have suggested that the IBI approach would not work for coastal wetlands because natural water level fluctuations of the Great Lakes would likely alter communities and invalidate metrics (Wilcox *et al.* 2002). By sampling only defined and inundated vegetation zones, Burton *et al.* (1999) and Uzarski *et al.* (2004) were able to remove enough variation associated with water level fluctuation to maintain metric consistency from year to year, even though annual average lake levels increased to above average and then fell 1.08 m to near historic lows over the several-year period included in those studies. Since our analyses were stratified by plant zone, it seems unlikely that changes in water levels will invalidate the IBI. As plant communities shift in location or change all together, fish communities associated with specific zones should seek preferred structure. In some years, a few wetlands may dry out completely. During these times, a fish-based IBI could only be applied to wetlands with at least one inundated plant zone present but could still be used to assess overall water quality changes in a given Great Lake or region of one of the Great Lakes using data from such wetlands.

Unfortunately, we were only able to develop metrics for two plant zones. While at least one of these zones can likely be found in most Great Lakes coastal wetlands, some will certainly lack both. In that case, this IBI will not apply. However, by maximizing the number of available protocols, we are increasing the likelihood that one will be applicable. Furthermore, using several IBIs utilizing different organisms at a given site should prove most robust and we recommend doing so whenever possible.

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