Validation and performance of an invertebrate index of biotic integrity for Lakes Huron and Michigan fringing wetlands during a period of lake level decline

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Development of indicators of 'ecosystem health' for the Great Lakes was identified as a major need at the State-of-the-Lakes Ecosystem Conference in 1998, 2000, and 2002. Our goal was to develop an invertebrate-based index of biotic integrity that was robust to water level fluctuations and applied to broad classes of lacustrine wetlands across wave-exposure gradients. Our objectives were to evaluate the performance and test the robustness of our preliminary index (e.g., Burton et al., 1999) at a range of water levels, eliminate any problems with the index of biotic integrity, remove the preliminary status, test the index on similar wetlands of Lake Michigan, and establish stressor:ecological-response relationships. Twenty-two sites, both open- and protected-fringing lacustrine marshes of Lake Huron and Michigan were selected for study. Correspondence analysis and Mann-Whitney U tests were used to test the robustness of existing metrics and search for additional metrics. Wilcoxon Signed Rank tests were used to determine if metrics were responding to inter-annual water level fluctuation. Principal components analysis and Pearson correlations were used to establish stressor:ecological response relationships. Analyses confirmed the utility of most of the metrics suggested in our preliminary index, but we recommended several improvements. With improvements, the index was able to place all sites in a comparable order of disturbance that we placed them a priori based on adjacent landuse/landcover, limnological parameters and observed disturbances. The improved index worked very well from 1998 through 2001 despite the substantial decreases in lake level over this time-period. Analyses of 2001 data collected from similar fringing wetlands along the northern shore of Lake Michigan suggested that the index could also be used for fringing wetlands of northern Lake Michigan. We are confident that our index is ready for implementation as a tool for agencies to use in assessing wetland condition for Lakes Huron and Michigan fringing wetlands.

Keywords: coastal wetlands, Great Lakes, IBI, invertebrates

Introduction

Wetlands of the Great Lakes are subject to multiple anthropogenic disturbances. These disturbances are superimposed on systems that experience a wide variety of natural stress resulting primarily from a highly variable hydrologic regime (Burton et al., 1999, 2002; Keough et al., 1999). These wetlands are classified into geomorphological classes, reflecting their location in the landscape and exposure to waves, storm surges and lake level changes (Albert and Minc, 2001). Fringing wetlands form along bays and coves and leeward of islands or peninsulas. The location of the shoreline, with respect to long-shore current and wind fetch, determines the type of wetland found along the shoreline (Burton et al., 2002). The greater the effective fetch

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(e.g., Burton et al., this issue), the more the wetland is exposed to waves and storm surges until a threshold is reached where wetlands no longer persist. The separation of variation due to anthropogenic disturbance from variation due to natural stressors related to water level changes over long and short term periods is central to predicting community composition and in turn developing indices of biotic integrity (IBI) for these systems.

Development of indicators of 'ecosystem health' for the Great Lakes was recognized as a major need at the State-of-the-Lakes Ecosystem Conference (SOLEC) in 1998 in Buffalo, New York and progress in developing indicators was the emphasis of the SOLEC Conference in 2000 in Hamilton, Ontario and again in 2002 in Cleveland, Ohio. Among the indicators listed by the task force at SOLEC 98 were IBIs for coastal wetlands based on fish, plants and macroinvertebrates. These were also emphasized in the 2000 and 2002 conferences, but minimal progress in developing such indicators was reported at those conferences.

Wilcox et al. (2002) attempted to develop wetland IBIs for the upper Great Lakes using fish, macrophytes, and microinvertebrates. While they found attributes that showed promise, they concluded that natural water level changes were likely to alter communities and invalidate metrics. In an earlier paper, we developed a preliminary macroinvertebrate-based bioassessment procedure for coastal wetlands of Lake Huron (Burton et al., 1999). This system could be used across wide ranges of lake levels, since it included invertebrate metrics for as many as four deep- and shallow-water plant zones with a scoring system based on the number of inundated zones present.

While Great-Lakes wide studies of aquatic macrophytes indicate that similar geomorphic wetland types support distinctively different plant assemblages in geographically distinct ecoregions (Minc, 1997; Chow-Fraser and Albert, 1998; Minc and Albert, 1998; Albert and Minc, 2001), several plant zones are common to many of these systems. In our preliminary invertebrate-based IBI (Burton et al., 1999), we collected invertebrates from four plant zones characteristically inundated in fringing lacustrine wetlands of Lake Huron and northern Lake Michigan during high water years, and used invertebrate metrics from each of these zones in the IBI. By developing metrics for each wetland plant zone across a water level gradient from wet meadow to deep-water emergents, we assumed that we could compensate for absence of the higher elevation zones (e.g., wet meadow) during low lake level years by placing more emphasis on metrics from zones that remained inundated. As lake levels have fallen sharply since 1998, we have tested this assumption and report the results in this paper.

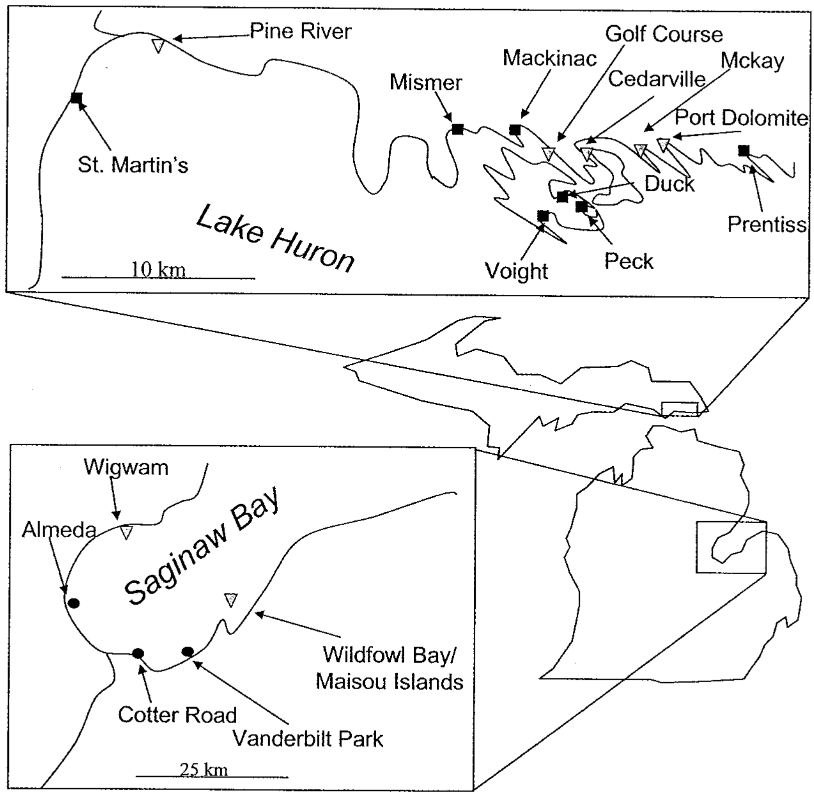
Our goal was to develop an IBI that is robust to water level fluctuations and applies to broad classes of lacustrine wetlands across natural wave exposure gradients. The broad class of wetlands we chose for the first stage of IBI development was fringing, lacustrine marshes (Burton et al., 1999). Fringing, lacustrine marshes are the most common type of wetlands of Lake Huron and the northern shore of Lake Michigan. They were included in three classes in the classification of Great Lakes wetlands by Albert and Minc (2001): Northern Great Lakes marshes, Northern rich fens, and Saginaw Bay lakeplain marshes. All of the wetland types included in our broader definition of fringing, lacutrine marshes are characterized by having a species of *Scirpus (*e.g., *Scirpus acutus, Scirpus americanus,* or *Scirpus validus* or combinations of two or more of these species) as the dominant plants in the two outer emergent zones (Burton et al., 1999) and by having wet meadow zones dominated by a combination of *Carex* spp. (*Carex stricta, Carex lasiocarpa,* and/or *Carex viridula*) and *Calamagrostis canadensis.* We initiated IBI development for this broad wetland class in Lake Huron (Burton et al., 1999) and have begun testing it in other lakes and wetland types. However, the data presented in this paper are only from open- and protected-embayment marshes (fringing) of Lake Huron, and northern Lake Michigan.

The objectives of this study were to: 1) evaluate the performance and test the robustness of our preliminary IBI (e.g., Burton et al., 1999) at reduced water levels when fewer plant zones per site were inundated; 2) identify and eliminate any problems and make improvements to the IBI where necessary; 3) remove the preliminary status from the Burton et al. (1999) IBI; 4) test the applicability of the IBI in similar wetlands of Lake Michigan; and 5) establish stressor: ecological-response relationships that could be used to manage high quality wetlands and restore degraded ones.

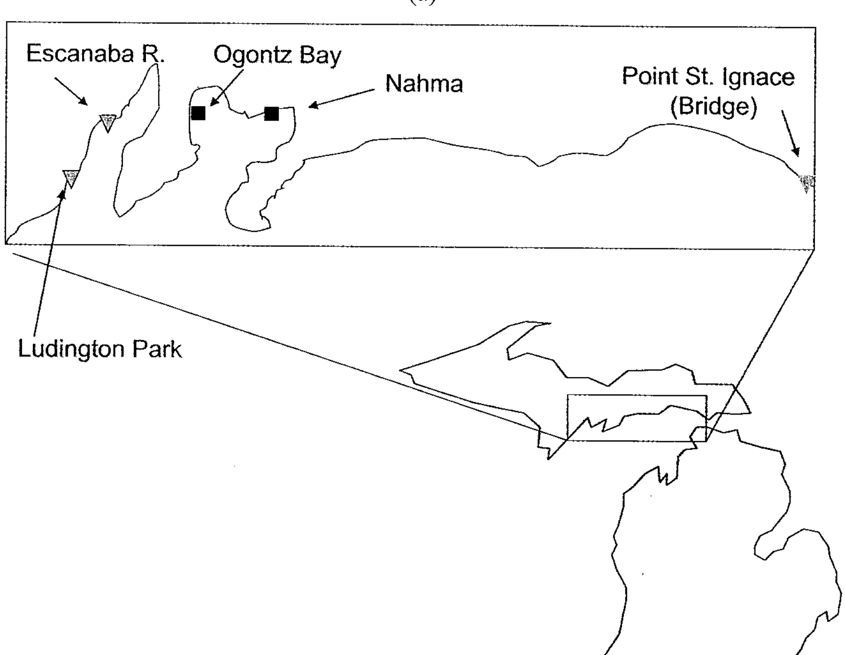
Methods and materials

Study sites

Both open- and protected-fringing lacustrine marshes of Lakes Huron and Michigan were selected for study (Figure 1). Site selection was based primarily on site access, inundation status, and degree of human disturbance to the marshes. Depths rarely exceeded one meter and were as shallow as 10 cm. The plant communities at each site changed along a depth gradient from



(a)



(b)

Figure 1. (a) Map of Michigan, USA including study sites located in Lake Huron (Low Disturbance Site ■; Intermediate Disturbance Site ▽; High Disturbance Site ●; (b) Map of Michigan, USA including study sites located in Northern Lake Michigan, Low Disturbance Site ■; Intermediate Disturbance Site ▽; High Disturbance Site ●).

open water to shore and typically included an outer *Scirpus* zone in deep, wave swept areas of the marsh, an inner *Scirpus* zone in deep areas subject to less wave impact, a transitional zone that sometimes included *Typha angustifolia* as a dominant, and a wet meadow zone. The wet meadow zones extended to upland ecosystems directly or graded into shrub and forested wetlands depending on topography of the site. Table 1 lists locations, dominant vegetation, and wave exposure classification (exposed or protected) for all sites included in this study. Major anthropogenic disturbances and a priori disturbance classification for each site are listed in Table 2.

Saginaw Bay study sites

Saginaw Bay sites were located along the eastern and western shores of Saginaw Bay (Figure 1a). The Saginaw River is likely the most important impact to Saginaw Bay sites as wetlands of the inner bay (Almeda, Cotter Rd. and Vanderbilt Park) have more degraded water quality than those of the outer bay (Wigwam and Wildfowl Bays). Vegetation at the Saginaw Bay sites generally followed the pattern of monodominant stands of *Scirpus* in the outer, exposed areas of the marshes grading into transitional communities often including *Typha, Phragmites australis*

Table 1. Saginaw Bay, northern Lake Huron, and northern Lake Michigan site location including the dominant vegetation types present, and exposure class. Exposure class is a representation of approximate fetch and exposure to waves and storm surges.

Site	Site Location		Dominant Vegetation†			Exposure Class
	°Lat.(N)	°Long.(W)	Wet Meadow	Inner *Scirpus*	Outer *Scirpus*	
Saginaw Bay						
Wildfowl Bay	43.801	83.462	*C., C.c., T.*††	*S.p., S.v., S.a.*	*S.p., S.v., S.a.*	Exposed/ Protected
Wigwam Bay	43.963	83.856	*J.*	*S.p.*	*S.p.*	Exposed
Vanderbilt Park	43.600	83.661		*S.p.*	*S.p.*	Exposed
Almeda	43.801	83.923		*S.p., E.*	*S.p., E.*	Exposed
Cotter Road	43.652	83.865	*C.s., C.c., S.p.*			Exposed
Northern Lake Huron						
Duck Bay	45.966	84.389	*C.s., C.l ,T.***	*S.a.*	*S.a.*	Protected
Peck Bay	45.946	84.358	*C.s., C.l.*	*S.a.*	*S.a.*	Protected
Voight Bay	45.941	84.412	*C.s., C.l.*	*S.a.*	*S.a.*	Exposed
Mackinac Bay	46.001	84.409	*C.s., C.l.*	*S.a.*	*S.a.*	Protected
Mismer Bay	46.007	84.462	*C.s., C.l.*	*S.a.*	*S.a.*	Protected
Prentiss Bay	45.988	84.226	*C.s., C.l.*	*S.a., T.*	*S.a.*	Protected
St. Martin's Bay	46.020	84.513		*S.a.*	*S.a.*	Exposed
Pine River	46.038	84.622			*S.a.*	Exposed
Golf Course	45.983	84.383		*S.a.*	*S.a.*	Exposed
Port Dolomite	45.985	84.252		*S.a.*†††	*S.a.*	Exposed
Cedarville Bay	45.996	84.362		*S.a.**		Protected
Northern Lake Michigan						
Ogontz	45.832	86.781		*S.a.*	*S.a.*	Exposed
Nahma	45.852	86.631		*S.a.*	*S.a.*	Exposed
Pt. St. Ignace 'Bridge'	45.845	84.739		*S.a.*	*S.a.*	Exposed
Escanaba	45.817	87.052	*T.***	*S.a.*	*S.a.*	Exposed
Ludington Park	45.738	87.056		*S.a.*		Protected

†*S.p.*-*Scirpus* pungens Vahl, *S.v* = *S. validus*, *S.a.* = *S. acutus*, *C.* = *Carex spp.*, *C.s.* = *C. stricta*, *C.l.* = *C. lasiocarpus*, *C.c.* = *Calamagrostis canadensis*, *E.* = *Eleocharis spp.*, *J.* = *Juncus*, *T.* = *Typha sp.*

††The wet meadow at Wildfowl Bay was nearly dry in 1998 and was dry in subsequent years.

†††The Port Dolomite site has seeps that are likely from settling ponds from the dolomite mining operation. *Cladophora* was observed growing around these seeps.

*The Cedarville site had dense filamentous green algae, *Elodea canadensis*, and *Myriophyllum spicatum*.

**The *Typha stands* at the Duck Bay and Escanaba sites were scattered within the wet meadow.

Table 2. Saginaw Bay, northern Lake Huron, and northern Lake Michigan sites noting known major disturbances and a priori disturbance classification.

Site	Major Disturbances	*a priori* Disturbance Classification
Northern Lake Huron		
Duck Bay	No dwellings, one private dock	Low Impact
Peck Bay	Adjacent dwellings (limited)	Low Impact
Voight Bay	Adjacent dwellings (limited)	Low Impact
Mackinac Bay	Adjacent dwellings (limited), highway	Low Impact
Mismer Bay	Adjacent dwellings (limited), highway	Low Impact
Prentiss Bay	Adjacent dwellings (limited), highway	Low Impact
St. Martin's Bay	Sediment from the Pine River (limited)	Low Impact
Pine River	Substantial sediment from Pine R.	Intermediate Impact
Golf Course	Adjacent golf course	Intermediate Impact
Port Dolomite	Dolomite [(Ca, Mg) CO_3] mining	Intermediate Impact
Cedarville Bay	Sewage effluent, urban runoff, marine traffic	Intermediate Impact
Northern Lake Michigan		
Ogontz	Some adjacent dwellings, boat launch	Low Impact
Nahma	Nearby golf course, dwellings, road	Low Impact
Pt. St. Ignace 'Bridge'	Highway, bridge, urban area	Intermediate Impact
Escanaba	Nearby urban/industrial areas	Intermediate Impact
Ludington Park	Nearby urban/industrial areas	Intermediate Impact
Saginaw Bay		
Wildfowl Bay	State wildlife management area, some agriculture	Intermediate Impact
Wigwam Bay	Sparse shoreline development, some agriculture	Intermediate Impact
Vanderbilt Park	Quanicassee R. (agriculture), adjacent dwellings	Intense Impact
Almeda	Adjacent dwellings, agriculture	Intense Impact
Cotter Road	Agriculture, adjacent dwellings, Saginaw R.	Intense Impact

(Cav.) and *Pontederia cordata.* The Wildfowl Bay, Vanderbilt Park and Cotter Rd. sites had wet meadow zones that graded into terrestrial habitats (Table 1).

Northern Lake Huron sites

The northern Lake Huron sites were located in the Les Cheneaux Island complex along the southeastern end of Michigan's upper peninsula and along St. Martin's Bay, a large bay located west of the Les Cheneaux Islands (Figure 1a). Wetlands in this region had primarily forested catchments. Major impacts in the region included adjacent dwellings and boathouses and a two-lane highway running adjacent to or bisecting the wet meadows of the Mackinaw, Mismer and Prentiss Bays. The Cedarville Bay site was the only Northern Lake Huron site with substantial adjacent urbanization. Cedarville Bay was considered to be the most human-impacted area in the Les Cheneaux Islands (Kashian and Burton, 2000). The middle of the bay was occupied by a very large island with large numbers of residences, summer homes and docks on it. The town of Cedarville, its marina, and public boat launch occupied the northwestern shore of the bay, and many private residences, businesses, and docks (private and commercial) lined the mainland near the marsh.

The Golf Course site was located along a heavily used boat channel adjacent to a golf course. The Port Dolomite (Bush Bay) site was adjacent to a dolomite mining operation (Figure 1a). A small stream draining settling ponds from the adjacent dolomite mining operation entered the Bush Bay wetland via a culvert. Several dwellings were adjacent to the marsh, and boat traffic was common.

Peck and Voight Bays were located on Marquette Island (Figure 1a). Human impacts were low with only one residence located along the channel that leaded into the wetland. Voight Bay was on the windward side of the island with direct exposure to open-lake waves from Lake Huron (Figure 1). There were no human developments near the marsh. Boat traffic in both bays was limited, since neither were near main boat channels.

The Pine River site was located on the east side of St. Martins Bay (Figure 1). Only a narrow band of *Scirpus* approximately 100 m wide was present at this site. The Pine River entered the bay approximately 1 km west of the site. The river drained an agricultural region with red clay soils and was always quite turbid. The turbidity plume was usually pushed by prevailing winds along the shore into and past the sampled marsh. High turbidity levels at the site reflected this.

Northern Lake Michigan sites

Fringing wetlands similar to those sampled in Lake Huron were also common along the northern shore of Lake Michigan. We sampled a subset of these sites in 2001 to test whether the Lake Huron IBI would work for these wetlands (Figure 1b).

The Point St. Ignace (Mackinac Bridge) marsh was located immediately northwest of the Mackinac Bridge in Lake Michigan near the mouth of the Straits of Mackinac (Figure 1b). The Nahma and Ogontz marshes were located on Big Bay de Noc (Figure 1b). There were less than five dwellings adjacent to the Ogontz Bay marsh, and most of the adjacent riparian zone was forested. The Nahma site was near a golf course and adjacent to several dwellings. The Escanaba/Highway 2 site was located in Little Bay de Noc near an urban area along U.S. Highway 2 approximately 2 km north of the Escanaba River. The Ludington Park wetland was located approximately 10 km south of the Escanaba Highway 2 site in Ludington Park located in downtown Escanaba.

Chemical and physical measurements

Basic chemical/physical parameters were sampled from each plant zone each time biological samples were taken. Analytical procedures followed procedures recommended in Standard Methods for the Examination of Water and Wastewater (APHA, 1998). These measurements included soluble reactive phosphorus (SRP), nitrate-N, nitrite-N, ammonium-N, turbidity, alkalinity, temperature, dissolved oxygen (DO), chlorophyll *a*, oxidation-reduction (redox) potential, and specific conductance. Quality assurance/quality control procedures followed protocols recommended by APHA (1998).

Determination of anthropogenic disturbance

Wetlands that experienced a wide range of anthropogenic stressors were chosen for study. The extent of disturbance was determined using surrounding land use data in conjunction with limnological data and site-specific observations such as evidence of dredging, point-source pollution, and discharge into the wetland from drainage ditches or streams. If streams entered the wetland, land use from the stream catchment was considered when determining anthropogenic disturbance. Each site was placed into a very coarse disturbance category were breaks in the data occurred. For example, those sites that we considered to be 'intermediately impacted' had much less anthropogenic influence than those considered to have 'intense impact' and much more anthropogenic influence than those labeled as 'low impact.'

Land use data were obtained from existing digitized maps, topographic maps, and personal observations; the primary data source was the Michigan Resource Information System (MIRIS, 1978) Land Cover Maps based on 1978 aerial photography. These data included: percent urban and agricultural area, number of adjacent dwellings, percent impervious surface, total length of adjacent roads, and the number of connecting drainage ditches. The MIRIS data were the most recent data available to us. Visual observations of these data and current land use suggested that land use had not changed substantially for most of the wetlands included in our study.

Macroinvertebrates sampling

Macroinvertebrate samples were collected with standard 0.5 mm mesh, D-frame dip nets from late July through August. July–August is when emergent plant communities achieve maximum annual biomass and larger and easier to identify, late instars of most aquatic insects are present in the marsh.

Dip net sampling consisted of sweeps at the surface, mid depth and just above the sediments, incorporating all microhabitat at a given location. Nets were emptied into white pans and 150 invertebrates were collected by attempting to pick all specimens from one area of the pan before moving on to the next. Special efforts were made to ensure that smaller and sessile organisms were not ignored. Beginning in 1999, we modified this procedure to limit the amount of picking-time required at each site and to semi-quantify our samples. Individual replicates were picked for one-half-person-hour, organisms were tallied, and picking continued to the next multiple of 50. Therefore, each replicate sample contained either 50, 100, or 150 organisms. This procedure made it easier to compare samples on a catch per unit effort basis. The number of organisms remaining in the pan was nearly always exhausted to the point where finding just a few more organisms required a substantial effort. Three replicate dip net samples were collected in each plant zone to obtain a measure of variance associated with sampling.

Specimens were sorted to lowest operational taxonomic unit, usually genus or species for most insects, crustaceans and gastropods. Difficult to identify insect taxa such as Chironomidae were identified to tribe or family, and some other invertebrate groups including Oligochaetes, Hirudinea, Turbellaria, Hydracarina, and Sphaeridae were identified to family level or, in a few cases, to order. Taxonomic keys such as Thorp and Covich (1991), Merritt and Cummins (1996), and mainstream literature were used for identification. Accuracy was confirmed by expert taxonomists whenever possible.

Metric development and testing

Burton et al. (1999) developed metrics for their published IBI by initially analyzing data graphically by constructing box plots including the 10th, 25th, 50th, 75th, and 90th percentiles as recommended by Barbour et al. (1996). When attributes from Burton et al. (1999) showed an empirical and predictable change across a gradient of human disturbances, Mann-Whitney U tests were performed on these to test for significant differences between those sites designated a priori as being either impacted or reference sites. Burton et al. (1999) used 1997 data to develop IBI metrics for Lake Huron wetlands and tested these metrics by calculating IBI scores using data collected in 1998.

We expanded on Burton et al. (1999) analyses in this paper using our 1998 data (from Burton et al. (1999) and newly collected data from 1999 through 2001 to test the performance of the IBI during this period of rapid decline in lake levels. We initially calculated IBI scores using the 1999 through 2001 data compared the results to our gradient of disturbance established a priori. Additional analyses were then employed using the larger data set to search for any new metrics that could improve the IBI. Instead of the graphical approach used previously, we used correspondence analyses (CA) (SAS version 8, SAS Institute Inc., Cary, NC, USA) of invertebrate community composition to determine if sites would ordinate according to predetermined gradients of anthropogenic disturbance. Correspondence analyses were performed individually on Inner and Outer *Scirpus* zone data. Taxa represented by less than 20 total individuals (from all replicates from all sites combined) per zone in any one year were eliminated from the analysis. This resulted in approximately 40 taxa being used in each analysis. Unknown taxa were also included in the analysis to ensure that those taxa that could not be identified to a finer resolution were not either responsible for ecoregional differences or potential indicators of disturbance. Total taxa collected was also included. A separate CA was conducted for each plant zone for each year for 1998, 1999, and 2000. The 1999 data were most complete and were used to identify key taxa. These key taxa were then analyzed for each of the three years from 1998 through 2000. When reference sites separated from impacted site, groups of individual taxa containing the most inertia responsible for the separation were deemed potential metrics. Mann-Whitney U tests (SYSTAT version 5.0, Evanston, Illinois) were then used to determine if density of each of these taxa at reference sites were significantly different from its density at impacted sites. This allowed us to confirm the utility of our initial metrics and identify additional ones.

As in Burton et al. (1999), we used medians in place of means as measures of central tendency for measuring assemblages of invertebrates. Invertebrate parameters are highly variable, and medians are more resistant to effects of outliers. Therefore, we used medians to dampen the influence of outliers.

Testing and validation of the IBI

We continued to collect data from a subset of the original sites of Burton et al. (1999), providing us with our best indication of temporal variability. We calculated IBI scores by site (all plant zones present) as well as by individual plant zones (simulating a situation where only one plant zone had been inundated) and compared these scores within and among years. This exercise was used to determine which, if any, individual plant zones were most subject to inter-annual variability and to identify problematic plant zones that could give conflicting results if sampled alone.

Testing metrics robustness from inter-annual variation

We used Wilcoxon Signed Rank tests (SYSTAT version 5.0, Evanston, Illinois) on individual metrics through time to search for metrics that may have been responding to water level fluctuations. Significance was set at $p < 0.05$. Analyses were only done on two Inner *Scirpus* data sets, since these two data sets were the only ones available that were large and complete enough to permit this type of analysis. The analysis comparing 1998 to 1999 metrics included data from Duck, Mackinac, Prentiss, Mismer, St. Martin's, and

Cedarville (n = 6). The second analysis was done using data from 1997 through 2000, but only included Duck, Mackinac, and Mismer (n = 3), since these were the only wetlands sampled every year over this four-year period.

Test of the applicability of the IBI in similar wetlands of Lake Michigan

We sampled five similar fringing wetland sites in Lake Michigan (Figure 1b). We applied the IBI with improvements to those data to see if the IBI would place the Lake Michigan sites in the correct sequence along a disturbance gradient that had been identified a priori with land use data and other observation following the procedures detailed below. This was in attempt to provide evidence that the Lake Huron IBI could be extended to similar fringing wetlands in Lake Michigan. As a reference, we sampled many of our Lake Huron sites during this time-period as well.

Establishing stressor—ecological response relationships

Principal Components Analysis (PCA) using SAS version 8 (SAS Institute Inc., Cary, NC, USA) was used to establish Principal Components (PCs) based on chemical/physical parameters as well as surrounding (1 km buffer) land use/cover data (MIRIS, 1978). Principal components analysis was performed on the correlation matrix using untransformed SRP, NH_4, NO_3, SO_4, Cl, turbidity, chlorophyll a, alkalinity, DO, redox, and specific conductance data while additional analyses were done using percent adjacent agriculture, urbanization, shrub-range land, swamps, and the total length of roads within a 1 km buffer. Pearson Correlations (SYSTAT version 5.0, Evanston, Illinois) between individual metrics and PCs were used to establish stressor-ecological response relationships. The PCs were then decomposed to explore relative contributions of individual stressors. These analyses were performed on 1999 and 2001 Inner and Outer *Scirpus* data sets because they were the most complete.

Results

Testing and validation of the preliminary IBI

We calculated IBI scores using the preliminary IBI (Burton et al., 1999). The IBI ranked the majority of wetlands in order of anthropogenic disturbance, with only zero to four sites placed out of order in any given year. We evaluated the metrics for each of the four plant zones individually to determine the efficacy of an IBI based on only a single zone. The inner and outer *Scirpus* and wet meadow zone metrics worked well when present. Metrics based on the inner *Scirpus* zone proved to be almost as effective as were metrics based on summing values from all inundated zones present, and would be the single zone to use if only one zone is to be sampled. The *Typha* zone was rarely sampled, due to lack of inundation or absence at a site, and IBI metrics for this zone did not consistently rank sites by degree of disturbance. In the preliminary IBI, we proposed four diversity and richness metrics based on combined data from all zones present. These combined zone metrics proved to be ineffective in ranking sites along a disturbance gradient. Based on these results, we recommend dropping the *Typha* zone metrics from the IBI and calculating the four diversity and richness metrics for each zone rather than calculating them using combined data for all zones.

Correspondence analyses

Correspondence analyses were performed on data from the Inner *Scirpus* zone collected from 1998 through 2000 and for the Outer *Scirpus* zone from 1999 through 2000 (the 1998 outer *Scirpus* data were excluded because data were only collected from two sites). The CAs were used to identify either ecoregional, disturbance, or other underlying gradients. After completion of preliminary CAs, it was apparent that ecoregional differences were driving the ordinations. Therefore, we initially used 1999 data to identify those taxa responsible for the ordination of the sites according to ecoregion. The 1999 data set was the most balanced with respect to number of sites sampled from each ecoregion (Saginaw Bay and northern Lake Huron sites are in two different ecoregions). Correspondence analyses ordinated 1999 Inner and Outer *Scirpus* zone site data by ecoregion (northern Lake Huron sites clustered separately from Saginaw Bay sites). We identified and removed taxa responsible for the most inertia separating the sites by ecoregion (Table 3) and ran the correspondence analysis again (Figure 2a). With taxa responsible for ecoregional differences removed (Table 3), the sites ordinated by disturbance (Figure 2b). The taxa showing ecoregional differences in 1999 were also removed from data from other years before running correspondence analyses, and sites for each year ordinated based on degree of disturbance after these taxa had been removed. In 2000, due to low water, we only obtained data from Northern Lake Huron. When the taxa identified as having

Table 3. Taxa from the Inner and Outer *Scirpus* zone that contributed to the most inertia responsible for ordinating the sites based on ecoregion in correspondence analyses.

Taxa from the Inner Scirpus Zone Responsible for Ecoregional Inertia				Taxa from the Outer Scirpus Zone Responsible for Ecoregional Inertia			
Class	Order	Family	Genus	Class	Order	Family	Genus
Crustacea	Decapoda			Crustacea	Amphipoda	Gammarid	*Gammarus*
Bivalvia	Veneroida	Dreisseniidae	*Dreissena*	Crustacea	Amphipoda	Crangonctidae	*Crangonyx*
Gastropoda	Lymnophila	Lymnaeidae	*Fossaria*	Gastopoda	Lymnophila	Lymnaeidae	*Fossaria*
Gastropoda	Lymnophila	Lymnaeidae	*Pseudosuccinea*	Insecta	Tricoptera	Leptoceridae	*Mystacides*
Gastropoda	Lymnophila	Physidae	*Physa gyrina*	Insecta	Tricoptera	Leptoceridae	*Nectopsyche*
Gastropoda	Mesogastropoda	Hydrobiidae	*Amnicola*	Insecta	Hemiptera	Corixidae	*Sigara*
Insecta	Diptera	Ceratopogonidae	*Atrichopogon*	Insecta	Hemiptera	Corixidae	*Trichorixa*
Insecta	Odonata	Libellulidae	*Libellula*	Tubificidae			
Insecta	Odonata	Coenagrionidae	*Enallagma*				
Insecta	Hemiptera	Corixidae	*Trichocorixa*				
Insecta	Coleoptera	Halipidae	*Halipus*				
Insecta	Coleoptera	Gyrinidae	*Gyrinus*				
Insecta	Trichoptera	Leptoceridae	*Oecetis*				

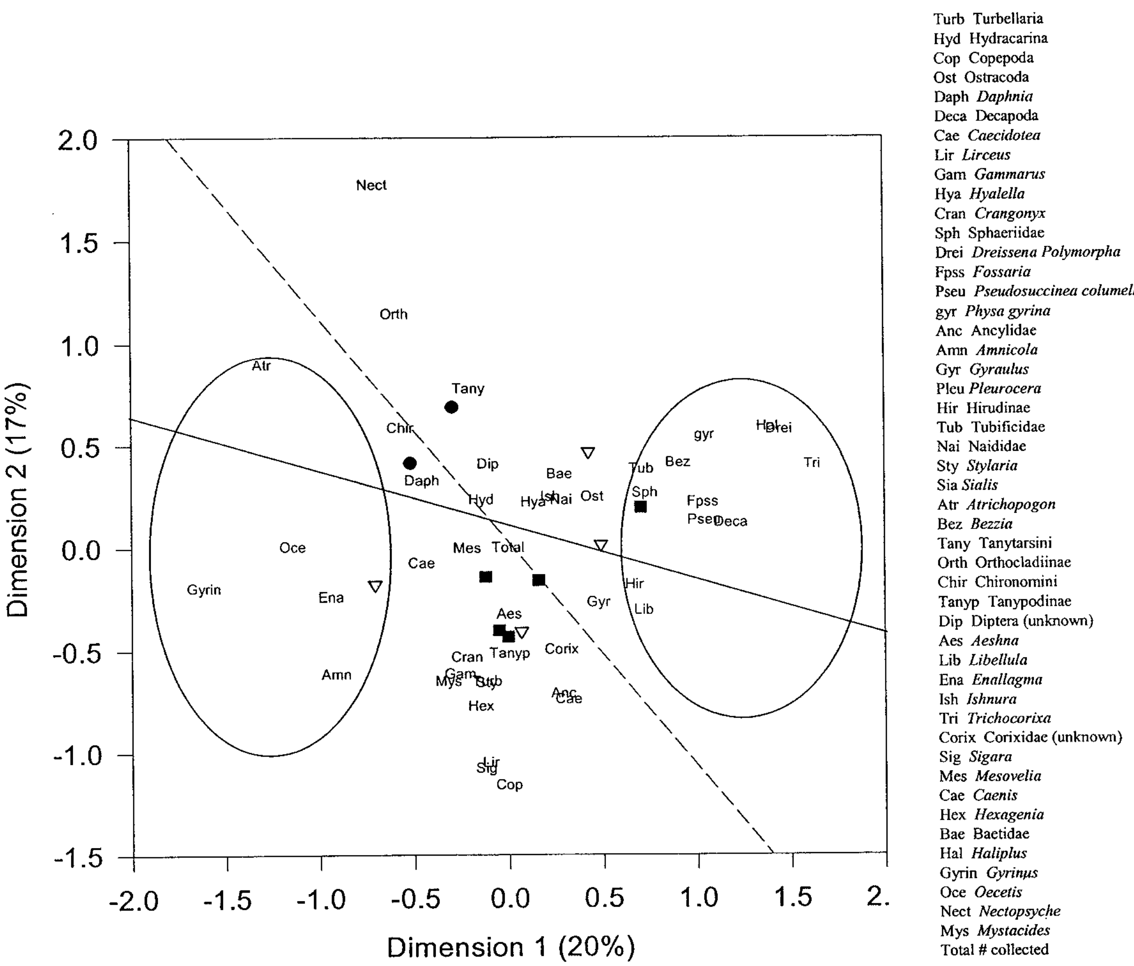
ecoregional differences in 1999 (Table 3) were removed from the 2000 analysis, ordination based on anthropogenic disturbances was much improved even though no Saginaw Bay sites were included in the data set.

We used the CAs not only to search for additional metrics, but also to determine if any of our previous metrics may have included responses to ecoregion instead of disturbance. In the Inner *Scirpus* zone, few taxa removed due to ecoregional differences were major contributors to metrics. The caddis fly, *Oecetis*, was included in the Ephemeroptera plus Trichoptera taxa richness metric. *Oecetis* was more often found at Saginaw Bay, but was quite rare even in those sites decreasing its influence on the metric. Thus, its removal from the analyses did not have a significant effect on the metric. The Odonate *Enallagma* was generally common at all sites, but tended to be at higher densities in Saginaw Bay sites. Conversely, *Libellula* was more common in Northern Lake Huron than it was in Saginaw Bay marshes. Differences in these two taxa may have offset each other in the Odonata taxa richness metric and in Odonata relative abundance metric, since these metrics worked well with or without these two genera included in the data set. The snail *Amnicola* tended to be more common in northern Lake Huron, and occurred in only one site in Saginaw Bay. Three other snails, *Fossaria spp.*, *Pseudosuccinea columella*, and *Physa gyrina* were all more common in Northern Lake Huron than in Saginaw Bay, contributing to separation by ecoregion. However, these taxa also separated sites based on disturbance within each ecoregion. Even though we removed these taxa from the CA so that they would not pull ecoregions apart in the analysis, we still believe these taxa are likely to be valuable metrics for an IBI. Ecoregional differences in individual taxa did affect the Gastropoda or Crustacea plus Mollusca metrics enough to warrant removing either metric from the IBI. *Dreissena* was much more common in Saginaw Bay than in Northern Lake Huron and may have counter-balanced differences in some gastropod taxa in the Crustacea plus Mollusca metrics. Decapods were rarely collected, but were more common in Northern Lake Huron than in Saginaw Bay. This may reflect differences in habitat between the two ecoregions rather than differences in anthropogenic disturbance. The Northern Lake Huron sites tended to have more cobble, pebble and boulder sized rocks and more submersed plants than did the Saginaw Bay sites. Decapods were relatively rare in samples from both ecoregions, and differences between the two regions did not affect the Crustacea plus Mollusca metric.

In most cases, a genus or species associated with one ecoregion was replaced by a closely related genus or species in the other, and therefore had little effect on the diversity and richness metrics or metrics at coarser taxonomic resolution. Three insects taxa were removed from the CAs, the family, Ceratopogonidae, a ceratopogonid genus, *Atrichopogon,* and the genus *Trichocorixa (*Corixidae). *Atrichopogon* was collected only at Saginaw Bay. *Trichocorixa* was only found at two sites in Northern Lake Huron and not at all in Saginaw Bay.

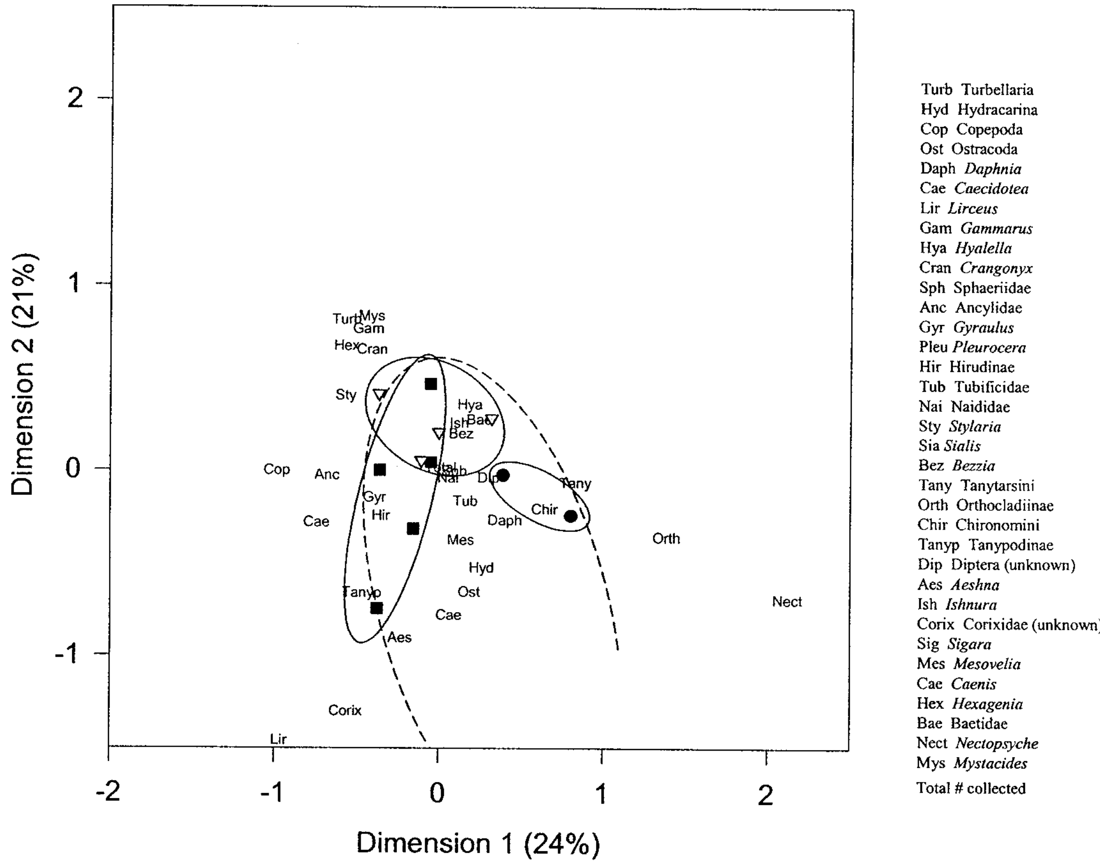
In the Outer *Scirpus* zone, two amphipods, *Crangonyx* and *Gammarus*, were more common in Saginaw Bay than in northern Lake Huron sites. Neither was used in metrics other than richness and diversity in the Outer *Scirpus*. As was the case in the Inner *Scirpus* zone, in the Outer *Scirpus* zone, the gastropod, *Fossaria*, and the Hemipteran, *Trichorixa*, were much more common in Northern Lake Huron. They were not good indicators in either ecoregion. Tubificids were common at sites in both ecoregions; however, two sites in Saginaw Bay had an over abundance of Tubificidae, one was a very impacted site, and the other was one of the least impacted in that ecoregion. Two Tricoptera were removed, *Mystacides* and *Nectopsyche*. *Mystacides* was more common in northern Lake Huron, while *Nectopsyche* was more common in Saginaw Bay. The Corixid, *Sigara*, was only found at one site in northern Lake Huron and was not found in Saginaw Bay in 1999.

Correspondence analyses of the data from 1999–2000 identified the same metrics that were proposed in the preliminary IBI based on 1997 and 1998 data



(a)

Figure 2. (a) Correspondence analysis including 1999 taxa collected from the Inner *Scirpus* zone of Lake Huron Sites. The solid line represents an estimated ecoregion gradient with Saginaw Bay sites toward the left side of the gradient and Northern Lake Huron sites on the right. The dashed line represents an estimated disturbance gradient with the most disturbed sites towards the top and the least disturbed sites near the bottom. Circles are drawn around those taxa responsible for the most inertia separating the data based on ecoregion; (b) Second run of a correspondence analysis including 1999 taxa collected from the Inner *Scirpus* zone of Lake Huron sites. Circled taxa from Figure 2a were removed from this analysis. The dashed line represents an estimated disturbance gradient. The ecoregion gradient no longer exists. Circles are drawn around sites with different levels of disturbance (symbols for Low Disturbance, Intermediate Disturbance, and High Disturbance Sites as in Figure 1). *(Continued)*



(b)

Figure 2. Continued

(Burton et al., 1999), thus providing support for the importance of the preliminary metrics. Two new metrics for Inner *Scirpus* were suggested by the CA results: (1) relative abundance of Isopoda (%) which decreased with disturbance, and (2) relative abundance of Amphipoda (%) which increased with intermediate disturbance.

Calculating IBI scores with new metrics and category score

Using results from calculation of preliminary IBI scores and the CAs, we dropped *Typha* zone metrics from the IBI, calculated the four richness and diversity metrics by plant zone, and adopted two new metrics for the Inner *Scirpus* zone. When the IBI scores were calculated with these changes included, the IBI worked nearly perfectly from 1997 through 2001 (Table 4). Even without these changes, however, the preliminary IBI metrics suggested by Burton et al. (1999) performed reasonably well. We should note that some sites sampled multiple years did sometimes change disturbance category from year to year. We cannot attribute this change to natural variation such as water levels. We detected no significant differences in metrics using Wilcoxon signed rank tests meaning that the inter-year metric variability did not change in a consistent direction as would be expected if annual water level changes were the driving forces for the observed differences. We do have to consider the temporal extent and recovery time of different types of disturbances. For example, a boat traveling through the wetland itself is certainly considered anthropogenic disturbance, but its impacts are likely not felt nearly as long as an almost continuous supply of agricultural runoff. If sampling was conducted shortly after one of these ‘short-term’ disturbances, the system was in fact disturbed to the degree detected at that time, but may have recovered within days or weeks. Therefore, we should not expect a given site to maintain a consistent level of perturbation.

Table 4. IBI placement of Lake Huron sites from 1997 through 2000. For each year, sites are listed in order of IBI ranking from least impacted to most impacted with an 'X' placed indicating which plant zones were sampled (WM = Wet Meadow; OS = Outer *Scirpus*; IS = Inner *Scirpus*) and into which overall category each site was placed.

Site	WM	OS	IS	Ex. Degraded	Degraded	Mod. Degraded	Mod. Impacted	Mild. Impacted	Reference
1997									
Mackinac	X	X	X						X
Duck	X	X	X					X	
Mismer	X	X	X					X	
Wildfowl	X	X	X			X			
Cotter Road	X					X			
Vanderbilt		X	X			X			
1998									
Peck			X						X
Duck			X						X
Mismer			X					X	
Mackinac			X					X	
St. Martins			X					X	
Prentiss			X					X	
Voight	X	X	X				X		
Cedarville			X				X		
Wildfowl	X	X	X				X		
1999									
Duck Bay		X	X						X
Mismer		X	X					X	
Mackinac		X	X					X	
Port Dolomite		X	X					X	
Prentiss		X	X					X	
St. Martins		X	X				X		
Wigwam		X	X				X		
Golf Course		X	X				X		
Wildfowl		X					X		
Vanderbilt		X	X				X		
Almeda		X	X				X		
Cedarville			X			X			
2000									
Mismer		X	X					X	
Duck		X	X					X	
Mackinac		X	X				X		
Pine River		X					X		
Cedarville			X				X		

Use of one-half person-hour count

Most often, 150 organisms were collected. Occasionally 50 or 100 organisms were collected from the Outer Scirpus zone. While the timed count did not prove useful as a semi-quantitative metric, it did not negatively affect the IBI. We recommend its use, particularly for the Outer Scirpus zone where invertebrates are sparser than they are in the Inner Scirpus or wet meadow zones making collection of 150 individuals too time consuming for wide spread use.

IBI response to water levels

We used Wilcoxon Signed Rank tests on individual metrics. There were no significant differences at

Table 5. A summary of p values for each metric in Wilcoxon Signed Ranks Tests using Inner *Scirpus* metrics from 1998 and 1999 ($n = 6$) corresponding to a 46 cm decrease in water levels over this period. Nearly identical results were obtained using data from 1997 through 2000 ($n = 3$). A significant difference ($p < 0.05$) would indicate that metric values were changing with time and water level fluctuation.

Wilcoxon Signed Ranks Tests
Inner *Scirpus* Metrics: 1998 vs. 1999
(Water Level was 46 cm Lower in 1999 than in 1998)

Metric (Inner *Scirpus*)	p
Odonata Richness	0.083
% Odonata	0.310
Crustacea + Mollusca Richness	0.999
Genera Richness	0.157
% Gastropoda	0.180
% Sphaeriidae	0.317
Ephem + Trichop Richness	0.157
% Isopoda	0.317
Evenness	0.414
Shannon Diversity	0.999
Simpson Index	0.564

Duck, Mackinac, Prentiss, Mismer, St. Martin's, and Cedarville ($n = 6$).
Similar results for 97–00 using Duck, Mackinac, Mismer ($n = 3$).

the $p < 0.05$ level in Metrics over time with changing water levels for either the 1998 vs. 1999 ($n = 6$) or 1997 through 2000 ($n = 3$) analyses (Table 5). However, with more power of detection, Odonata genera richness ($p = 0.08$) may have decreased with water level decline between 1998 and 1999.

Relating stressor to ecological response

We used Pearson correlation matrices to search for relationships between chemical/physical and land-use/land-cover PCs and our metrics. We ran 302 total correlations and identified 53 significant ones (15 significant correlations would be predicted by chance alone at $p = 0.05$). We did not use a Bonferroni correction because n was low, ranging from 7 to 12. Therefore, these results should be viewed as suggesting hypotheses rather than being conclusive. These analyses suggest several possible relationships (Figure 3). Several examples of suggested relationships are also presented in Figure 4a, b, c. Wetlands with high percentages of adjacent land use in agriculture tended to have relatively higher pH, temperature, turbidity, alkalinity, $DO_{(daytime)}$, redox $potential_{(daytime)}$ and sulfate compared to wetlands with high percentages of land use in forests. If urbanization and roads were adjacent, the wetland tended to have higher chloride, nitrate, and ammonium concentrations and higher specific conductance values. If the adjacent land cover was predominantly swamps, alkalinity and specific conductance tended to be higher while $DO_{(daytimc)}$, sulfate, redox $potential_{(daytime)}$, turbidity and soluble reactive phosphorous tended to be lower in the wetland. Adjacent shrub land correlated with low turbidity in the wetland. Adjacent agricultural land use and/or urbanization and roads or wetland chemical conditions that correlated with these adjacent land use/land cover parameters correlated with reduced % Sphaeriidae, % Crustacea + Mollusca, % Gastropoda, Shannon Diversity, Evenness, and % Odonata and increased Simpson Diversity. Adjacent shrub lands or decreased turbidity was also associated with lower % Sphaeriidae, % Crustacea + Mollusca, and % Gastropoda. Adjacent swamps, or the correlated chemical/physical conditions, tended to be correlated with increased Shannon Diversity, Evenness, and % Odonata. Adjacent agricultural land use or wetland chemical conditions that correlated with agriculture reduced Crustacea + Mollusca richness, Odonata richness, and total genera richness. Adjacent swamps or the related chemical/physical parameters correlated with increased Ephemeroptera + Trichoptera richness, increased total genera richness, and decreased Simpson Diversity. Adjacent agriculture correlated with decreased % Isopoda while adjacent swamps correlated with increased % Isopoda. Finally, as urbanization and roads increased adjacent to wetlands % Amphipoda in the wetland tended to decrease.

Discussion

Performance of the IBI with new metrics and category scores

Calculating the preliminary IBI (Burton et al., 1999) using data collected from 22 sites during 1997 through 2001 and using correspondence analyses to search for disturbance related metrics confirmed the utility of most of the metrics suggested previously. Several improvements suggested by these calculations include: 1) adding two new metrics to the Inner Scirpus zone, 2) removing the *Typha* zone from the IBI, and 3) calculating the four diversity metrics for each individual plant zone. With these improvements, the IBI was able to place all 22 sites in the same order that we placed them in based on adjacent land use/cover, limnological parameters and other observed disturbances. The improved IBI worked very well from 1998 through 2001

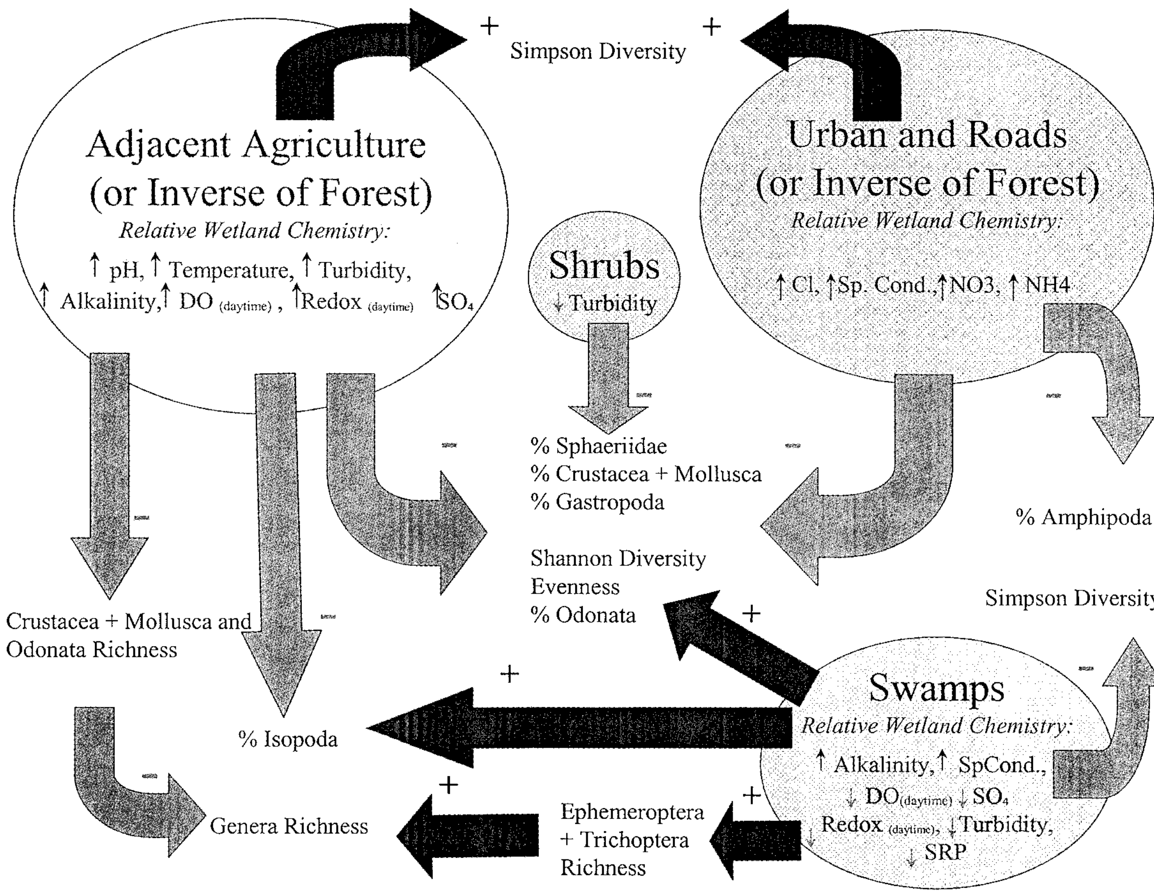
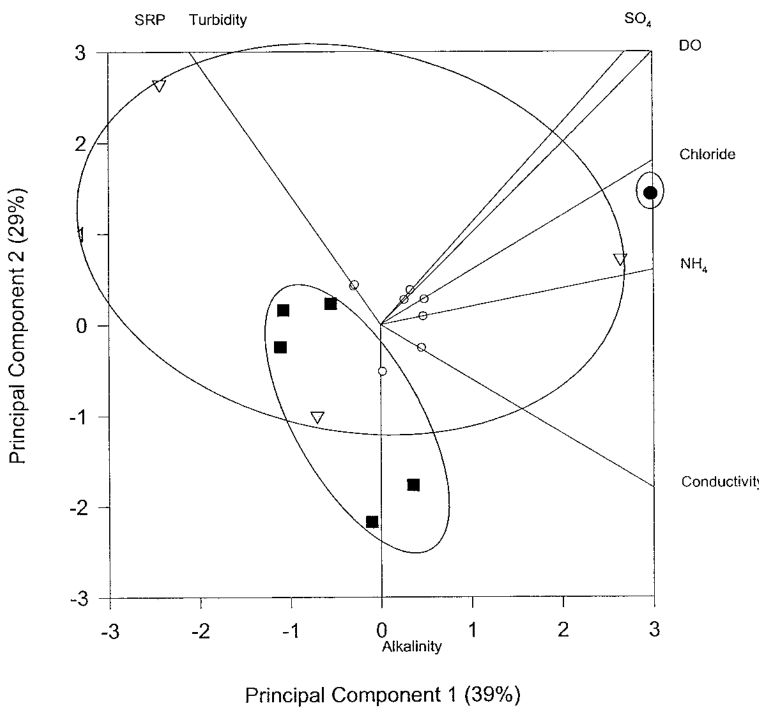


Figure 3. Conceptual drawing established using chemical/physical principal components, land use principal components, and biotic metrics in a Pearson correlation matrix.

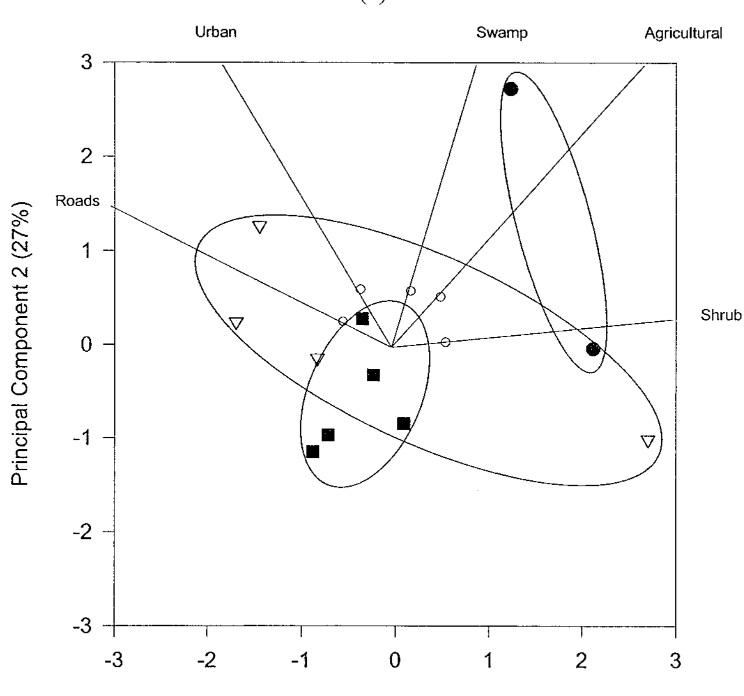
despite the rather substantial decreases in lake level over this time period. Analyses of 2001 data collected from similar fringing wetlands along the northern shore of Lake Michigan suggested that the Lake Huron IBI could also be used for fringing wetlands of northern Lake Michigan (Table 6).

One of the two new metrics suggested for use in the Inner *Scirpus* zone (relative abundance (%) of Amphipoda) does not increase or decrease with disturbance the way most of the metrics do. Instead, highest values for this metric occur at intermediate levels of disturbance. Conversely, the other metric, relative abundance Isopoda (%), decreased with disturbance. One possible explanation is that Isopoda and Amphipoda compete for resources when disturbance is low with isopods being the superior competitor. As isopod abundance decreases with increases in disturbance, amphipods, which appear to be less sensitive to disturbance, are subject to less competition and increase in abundance at intermediate levels of disturbance. As levels of disturbance continue to increase, the threshold for impacting amphipods is exceeded and amphipod relative abundance also decreases. Specifically, the relative abundance of isopods tended to decrease with increasing adjacent Agriculture and/or where wetland water chemistry included relatively higher pH, temperature, turbidity, alkalinity, $DO_{(daytime)}$, redox $potential_{(daytime)}$ and sulfate. Amphipods tended to decrease with increasing adjacent urbanization and roads and/or as chloride, nitrate, ammonium, and specific conductance values increased. Amphipods were much more common than isopods where sites experienced an intermediate amount of disturbance regardless of type of disturbance or ecoregion.

Due to low water, *Typha* zones were often not inundated during the period of rapid decline in lake levels from 1998 through 2001. Samples were collected from only two sites in 1998 and 1999, so our ability to test

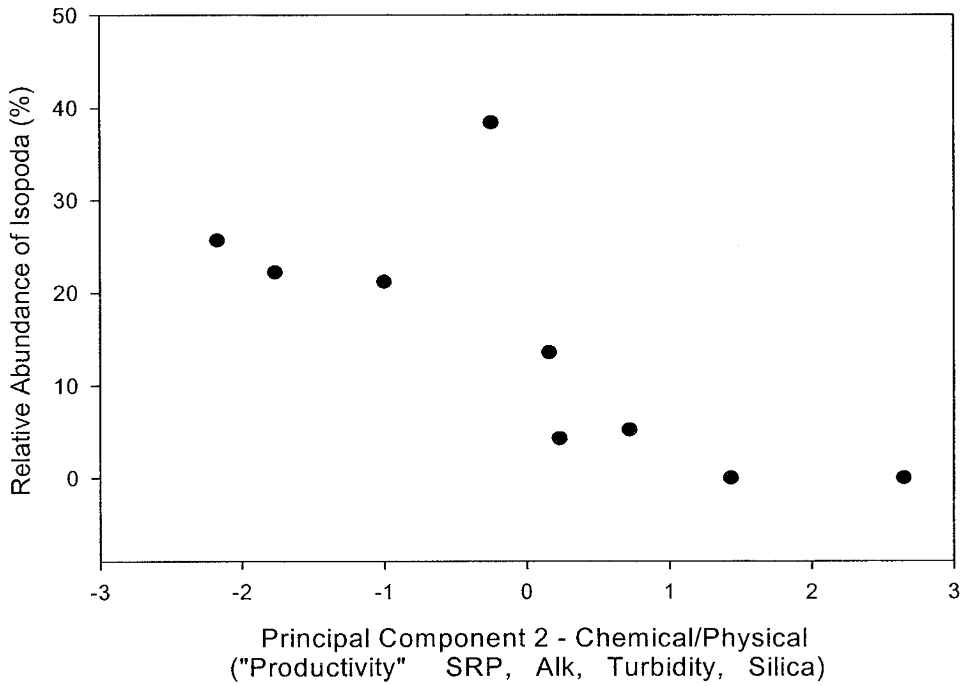


(a)



(b)

Figure 4. (a) Principal components analysis using 1999 Inner *Scirpus* chemical/physical variables. Circles are drawn around sites with different levels of disturbance. Small circles located on vectors near the origin represent actual eigenvectors; (b) Principal components analysis of 1999 Inner *Scirpus* sites using land use/land cover variables. Circles are drawn around sites with different levels of disturbance. Small circles located on vectors near the origin represent actual eigenvectors; (c) Pearson correlation ($r = -0.734$; $p = 0.024$; $n = 9$) between the relative abundance of isopods and chemical/physical principal component two. Symbols for Low Disturbance, Intermediate Disturbance, and High Disturbance Sites as in Figure 1. *(Continued)*



(c)

Figure 4. Continued

metrics for this zone was limited by sample size. Even so, the *Typha* zone metrics never ordinated the sites according to disturbance, and we recommend dropping the zone from the IBI. A possible reason for the failure of the *Typha* zone metrics to separate sites is that this zone tends to occur in very different areas of the wetlands in the two ecoregions included in this study. *Typha* zones in the more pristine northern Lake Huron sites were located in a transitional zone between wet meadow and Inner *Scirpus*. This was not the case for the more impacted Saginaw Bay sites. Monodominant stands of *Typha* were found in areas exposed to direct

Table 6. IBI placement of Lake Huron and Michigan sites from 2001. Each year includes IBI ranking from least impacted to most impacted with an X placed indicating which plant zones were sampled (WM = Wet Meadow; OS = Outer *Scirpus*; IS = Inner *Scirpus*) and into which overall category each site was placed.

Site	WM	OS	IS	Ex. Degraded	Degraded	Mod. Degraded	Mod. Impacted	Mild. Impacted	Reference
2001									
Mackinac		X	X					X	
Duck		X	X				X		
Nahma		X	X				X		
Ogontz		X	X				X		
Escanaba		X	X				X		
Bridge		X	X				X		
Cedarville			X				X		
Port Dolomite			X				X		
McKay			X			X			
Pine River		X				X			
Ludington Park		X				X			

wave action in Saginaw Bay as well as in protected wetlands behind islands or in the middle of *Scirpus pungens* stands. Exposure to waves can play a large role in determining invertebrate community composition regardless of the extent of anthropogenic disturbance (Burton et al., 2002). We did not have enough data from the *Typha* zone to separate variance due to anthropogenic disturbance from that of wave exposure. It may be that *Typha* zone metrics would prove useful if location of the zone in relation to wave action were taken into account as it was in metrics for the two *Scirpus* zones.

We recommend calculating the four richness and diversity metrics by plant zone instead of combining all of the plant zones present (e.g., Burton et al., 1999) to calculate these metrics. Since the number of plant zones inundated varies by wetland and year, a combined calculation means that diversity is being calculated from a variable number of habitats for any given wetland or year. Since wetlands with the most structural diversity would be a function of the number of plant zones included in the calculation, and since habitat diversity would likely be related to invertebrate diversity, the combined calculation should be dropped. By incorporating the metrics into each individual plant zone and adjusting category scores appropriately, we remove variation due to inequitable number of vegetation zones sampled.

With improvements incorporated (Table 7), we recommend dropping the 'preliminary' status from the initial IBI (Burton et al., 1999). Our data proved that this system could work well even during periods of rapid lake level decline as long as any of the three plant zones used in the improved IBI was present. The improvements and increased resolution also allowed us to introduce some new status categories. With these changes in place, we are confident that our IBI is ready for implementation as a tool for management and conservation agencies to use in assessing wetland condition for Lake Huron and Lake Michigan fringing, coastal wetlands.

Deviation from protocol

Our protocol was developed for sampling macroinvertebrates, and field crews were told to pick only macroinvertebrates. However, it was common to have microinvertebrates such as Copepoda and Cladocera in samples. These microinvertebrates were identified and included in the IBI database. Inclusion of such animals by our sampling crews suggests that this might occur when others use the IBI. To ensure that the IBI was robust to this common error, we used those data in calculations of metrics such as percent Crustacea plus Mollusca and the total richness and diversity metrics. Inclusion of the microinveretbrates had little effect on the IBI.

Use of one-half person-hour count

Use of the timed count did not improve the IBI, but as well did not have an negative impact. The timed count reduced time in the field. Without it, two or three individuals could spend up to four hours collecting three replicate samples from the Outer *Scirpus* zone alone.

IBI response to water levels

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, we removed 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 our sampling effort. Except for Odonata genera richness, there were no significant differences in metric scores among years even though water levels declined. With more power of detection, Odonata genera richness ($p = 0.08$) may have decreased with water level decline. The Odonate metric played a crucial role in detecting anthropogenic disturbance within years, and the IBI was robust enough to accommodate among-year variation. Thus, we included this metric in the final IBI.

Relating stressor to ecological response

It is important not only to detect anthropogenic disturbance, but also to identify which disturbance or suite of disturbances is likely to be causing most of the observed changes in IBI metrics. Once specific disturbances are identified, managers can use this information to decide on best management options. Biota usually respond to a suite of correlated ambient conditions. Multivariate analyses were used to combine parameters for more power of detection. Once relationships were established, we decomposed combined parameters to the original parameters. Such relationships are strictly correlative, cannot be used to infer causation, and must be used with caution. It is difficult to determine the impact of adjacent land use or land cover on a given

Table 7. An index of biotic integrity (IBI) for Lakes Huron and Michigan fringing coastal wetlands. All values were based on the median of at least three replicates taken from each zone.

Metric	Score 0	Score 1	Score 3	Score 5	Score 7
Wet Meadow Zone: dominated by *Carex* and *Calamagrostis*					
Odonata taxa richness (Genera):		0 score = 1	>0 to 3 score = 3	>3 score = 5	
Relative abundance Odonata (%):		0 to <1 score = 1	>1 to 5 score = 3	>5 score = 5	
Crustacea plus Mollusca taxa richness (Genera):		<2 score = 1	2 to 6 score = 3	>6 score = 5	
Total Genera richness:		<10 score = 1	10 to 18 score = 3	>18 score = 5	
Relative abundance Gastropoda (%):		0 to 1 score = 1	>1 to 25 score = 3	>25 score = 5	
Relative abundance Sphaeriidae (%):		0 score = 1	>0 to 3 score = 3	>3 score = 5	
Evenness:		0 to 0.4 score = 1	>0.4 to 0.7 score = 3	>0.7 score = 5	
Shannon diversity index:		0 to 0.4 score = 1	>0.4 to 0.9 score = 3	>0.9 score = 5	
Simpson index:		>0.3 score = 1	>0.15 to 0.3 score = 3	0 to 0.15 score = 5	
Inner Scirpus Zone: Often dense Scirpus mixed with *Pontedaria* and submergents, protected from wave action					
Odonata taxa richness (Genera):		0 score= 1	>0 to <1 score = 3	1 to 2 score = 5	>2 score = 7
Relative abundance Odonata (%):		0 score = 1	>0 to <2 score = 3	2 to 7 score = 5	>7 score = 7
Crustacea plus Mollusca taxa richness (Genera):		0 to 2 score = 1	>2 to 4 score = 3	>4 to 6 score = 5	>6 score = 7
Total Genera richness:		<10 score = 1	10 to 14 score = 3	>14 to 18 score = 5	>18 score = 7
Relative abundance Gastropoda (%):		0 score = 1	>0 to 2 score = 3	>2 to 4 score = 5	>4 score = 7
Relative abundance Sphaeriidae (%):		0 score = 1	>0 to 0.05 score = 3	>0.05 score = 5	
Ephemeroptera plus Trichoptera taxa richness (Genera)		0 score = 1	>0 to 3 score = 3	>3 score = 5	
Relative abundance Crustacea plus Mollusca (%):		<8 score = 1	8 to 30 score = 3	>30 score = 5	
Relative abundance Isopoda (%):	0 score = 0	0 to 1 score = 1	>1 to 10 score = 3	>10 to 20 score = 5	>20 score = 7
Evenness:		0 to 0.4 score = 1	>0.4 to 0.7 score = 3	>0.7 score = 5	
Shannon diversity index:		0 to 0.4 score = 1	>0.4 to 0.9 score = 3	>0.9 score = 5	
Simpson index:		>0.3 score = 1	>0.15 to 0.3 score = 3	0 to 0.15 score = 5	

(Continued on next page)

Table 7. An index of biotic integrity (IBI) for Lakes Huron and Michigan fringing coastal wetlands. All values were based on the median of at least three replicates taken from each zone. *(Continued)*

Metric	Score 0	Score 1	Score 3	Score 5	Score 7
Relative abundance Amphipoda (%):					
If 40 to 60— and total score from inner Scirpus Zone (metrics 1 through 12) is greater than 41, then subtract 5;					
If 40 to 60— and total score from inner Scirpus Zone (metrics 1 through 12) is less than 41, then add 5.					
Outer Scirpus Zone : Sometimes relatively sparse, usually monodominant stands, subject to direct wave action.					
Odonata taxa richness (Genera):		0	>0 to <1	1 to 2	>2
		score = 1	score = 3	score = 5	score = 7
Relative abundance Odonata (%):		0	>0 to <1	1 to 2	>2
		score = 1	score = 3	score = 5	score = 7
Crustacea plus Mollusca		0 to 2	>2 to 4	>4 to 5	>5
taxa richness (Genera):		score = 1	score = 3	score = 5	score = 7
Total Genera richness:		<8	8 to 13	>13 to 17	>17
		score = 1	score = 3	score = 5	score = 7
Relative abundance Gastropoda (%):		0	>0 to 3	>3 to 5	>5
		score = 1	score = 3	score = 5	score = 7
Relative abundance Sphaeriidae (%):		0	>0 to 0.05	>0.05	
		score = 1	score = 3	score = 5	
Total number of families:		0 to 7	>7 to 12	>12	
		score = 1	score = 3	score = 5	
Relative abundance Crustacea		<8	8 to 30	>30	
plus Mollusca (%):		score = 1	score = 3	score = 5	
Evenness:		0 to 0.4	>0.4 to 0.7	>0.7	
		score = 1	score = 3	score = 5	
Shannon diversity index:		0 to 0.4	>0.4 to 0.9	>0.9	
		score = 1	score = 3	score = 5	
Simpson index:		>0.3	>0.15 to 0.3	0 to 0.15	
		score = 1	score = 3	score = 5	

When all vegetation zones were present, wetlands were scored as follows: A total score of 31 to 53 (0 to 15% of possible score) = 'Extremely Degraded', or 'in comparison to other Lake Huron wetlands, this wetland is amongst the most impacted'; a total score of >53 to 76 (>15 to 30% of possible score) = 'Degraded' or 'the wetland shows obvious signs of anthropogenic disturbance'; A total score of >76 to 106 (>30 to 50% of possible score) = 'Moderately Degraded' or 'the wetland shows many obvious signs indicative of anthropogenic disturbance'; A total score of >106 to 136 (>50 to 70% of possible score) = 'Moderately Impacted' or 'the wetland shows few, but obvious, signs of anthropogenic disturbance'; A total score of >136 to 159 (>70% to 85% of possible score) = 'Mildly Impacted' or 'the wetland is beginning to show signs indicative of anthropogenic disturbance'; A total score of > 159 to 182 (>85 to 100% of possible score) = 'Reference Conditions' or 'the wetland is amongst the most pristine of Lake Huron'. When a subset of vegetation zones were present, wetland category scores were adjusted as follows: Wet Meadow Only = 9 to 14; >14 to 19; >19 to 27; >27 to 34; >34 to 39; >39 to 45; Inner *Scirpus* only = 11 to 19; >19 to 29; >29 to 41; >41 to 53; >53 to 62; >62 to 72; Outer *Scirpus* only = 11 to 18; >18 to 26; >26 to 37; >37 to 48; >48 to 56; >56 to 65; Wet Meadow and Inner *Scirpus* = 20 to 33; >33 to 47; >47 to 66; >66 to 84; >84 to 99; >99 to 113; Wet Meadow and Outer *Scirpus* = 20 to 32; >32 to 46; >46 to 64; >64 to 82; >82 to 96; >96 to 110; Inner and Outer *Scirpus* = 22 to 38; >38 to 55; >55 to 79; >79 to 102; >102 to 119; >119 to 137.

fringing wetland. For example, Figure 3 seems to suggest that urban areas contribute more NO_3 and NH_4 to wetlands than do agricultural areas, since water in wetlands with adjacent urban land use contains more NO_3 and NH_4 than does water in wetlands with adjacent agricultural land use. An alternative explanation would be that increased inorganic N in the urban wetlands might not be processed as efficiently as it is in agricultural wetlands, so no conclusion about quantity of input from the adjacent area is warranted. We simply tended to find relatively higher NO_3 and NH_4 concentrations near urban areas where there was high run-off and lower productivity in the wetland. The conceptual drawing (Figure 3) shows the relationships between the metrics and the appropriate land use and/or the chemical/physical parameters that correlate with that land use. It does not necessarily suggest that a given land use/land cover taken alone will create the associated chemical/physical conditions in the wetland. It does, however, provide some insight into what potentially might be causing the degradation. Confirmation of the causative agent would then need to be established using a more experimental approach.

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