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DEVELOPMENT OF A PRELIMINARY INVERTEBRATE INDEX OF BIOTIC INTEGRITY FOR LAKE HURON COASTAL WETLANDS

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Abstract: The biota of aquatic systems are integrators of overall habitat quality, revealing both episodic as well as cumulative disturbance, and therefore are able to serve as natural monitors of the systems they inhabit. Invertebrate communities from three relatively pristine coastal wetlands located along the northern shore of Lake Huron were compared to those from three relatively impacted Saginaw Bay coastal wetlands in Lake Huron to identify components of the community that could ordinate wetlands according to anthropogenic disturbance. A total of 24 potential metrics were examined for each of four vegetation zones at the study sites. Of these, 14 successfully discriminated between sites and were used to generate a preliminary index of biotic integrity (IBI) for Lake Huron coastal wetlands. This IBI was then tested by assessing coastal wetlands, including five additional sites, based on invertebrate data collected the following year. The preliminary IBI seemed to provide an accurate depiction of the wetlands used to generate the IBI as well as the five additional wetlands. We do not recommend use of the presented IBI as the definitive assessment tool for Lake Huron coastal wetlands. Instead, we suggest that it be tested further on a series of wetlands with known degrees of anthropogenic disturbance.

Key Words: index of biotic integrity, coastal wetlands, aquatic invertebrates, Great Lakes, bioassessment

INTRODUCTION

Despite their importance, wetlands have been and continue to be lost at an alarming rate (Comer et al. 1995). Wetland losses are also compounded through impairment of function via hydrologic and atmospheric inputs of anthropogenic origin. Anthropogenic impacts on wetlands are difficult to detect and quantify, resulting in the interest of many federal, state, and local agencies in the development of procedures that can assess anthropogenic disturbance and wetland integrity. The traditional approach has relied on water chemistry. However, this approach has failed to account for human-induced habitat alteration, the introduction of exotic species (Schlosser 1990, Karr 1991), and episodic events such as spills and effluent discharge. Additionally, several researchers suggest that chemically defining the quality of a system in order to regulate human activities has not provided necessary protection of our natural resources (Karr and Dudley 1981, Benke 1990, Hughes and Noss 1992, Allan and Flecker 1993). Alternatively, the biota are integrators of overall habitat and water quality and, therefore, are natural monitors of the system revealing both episodic and cumulative disturbance (Plafkin et al. 1989, Barbour et al. 1995). An index of biotic integrity (IBI) may have advantages over traditional chemical analyses because it could be done rapidly and inexpensively with relatively inexperienced personnel while revealing more time-integrative information about the system. Although IBIs are thought to be qualitative tools, Fore et al. (1994) determined that a specific, fish-based IBI, used over time, could provide quantitative assessments for legal or regulatory purposes. Therefore, indices of biotic integrity will likely be valuable decision-making tools for governmental agencies, particularly during the process of issuing development permits. A wetland IBI would also prove beneficial for the rapid and inexpensive evaluation of mitigation projects.

Currently, fish and macroinvertebrates are being used as indicators of biotic integrity of wadeable streams across the United States (Plafkin et al. 1989, Barbour et al. 1992, Karr and Chu 1997). Minns et al. (1994) applied Karr's approach of using fish as indicators of stream biotic integrity (e.g., Karr 1981, Karr et al. 1986) to marshes of the Great Lakes' Areas of Concern. The modifications employed by Minns et al. (1994) seem to hold great promise for use in the Great Lakes, as the metrics were sensitive to integrative measures of ecosystem health, such as exotic fishes, water quality, physical habitat, and piscivore abundance.

The renewal of the Great Lakes Water Quality Agreement (GLWQA) in 1987 called for restoration and maintenance of the physical, chemical, and biological integrity of the water of the Great Lakes ecosystem. Development of indicators of "ecosystem health" for the Great Lakes was recognized as a major need and was the emphasis of the State-of-the-Lakes Ecosystem Conference held in 1998 (SOLEC 98) in Buffalo, New York, USA. One indicator listed by the taskforce on Great Lakes coastal wetlands at SOLEC 98 was an IBI based on macroinvertebrates. However, no such invertebrate-based IBI exists for coastal wetlands. In fact, only limited invertebrate data in coastal wetlands exist (Gathman et al. 1999).

We recognized this need and developed an IBI based on invertebrate data collected from Lake Huron coastal wetlands. While not yet completely tested across an array of reference and impacted coastal sites, these metrics seem to be robust and consistent enough to warrant further testing by others. The objective of this paper is to present our recommended metrics and methods for use in testing and adoption by management agencies. The focus of this project was to evaluate the usefulness of aquatic invertebrate communities as indicators of habitat quality.

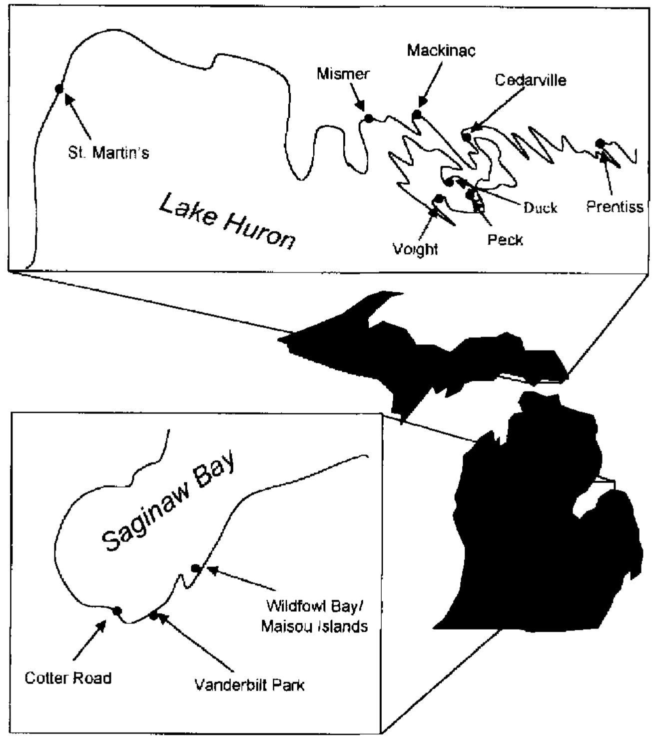

Figure 1. Map of Michigan showing the location of the three Saginaw Bay sites and the eight northern Lake Huron sites.

STUDY AREAS

Invertebrates were sampled from 11 wetlands along the Lake Huron shoreline in Michigan, USA. Three of these sites were in Saginaw Bay and the other eight were from northern Lake Huron near the eastern end of Michigan's upper peninsula (Figure 1).

Saginaw Bay Study Sites

Maisou and Middle Grounds Islands are located in Wildfowl Bay of Saginaw Bay, approximately 1.5 km northeast of the Sumac Island public access, Huron County (T16/17N R9E). While adjacent land use and the Saginaw River undoubtedly impact the entire bay, these impacts are likely diluted at Wildfowl Bay due to its separation from the mainland and proximity to the outer bay. The island experiences little direct anthropogenic disturbance in the form of shoreline development pressure relative to the other two Saginaw Bay sites. Sparse *Scirpus pungens* Vahl zones around the perimeter of the shoreline dominated the outer wave exposed area of the southwest end of the island. We refer to this area as the outer *Scirpus* zone. Additionally, there are some rather large and distinct *Typha angustifolia* L. and *T. latifolia* L. complexes adjacent to the south end of the islands. In 1997, the protected interior of the island contained an extensive wet meadow dominated by *Carex* spp. and *Calamagrostis* spp. This zone was nearly devoid of water during 1998. Similarly, there were stands of *Scirpus* and *Typha* present on the lee side of the islands, which we referred to as protected due to the lack of substantial wave energy. Water depths within each plant community varied among site and year sampled. Depths rarely exceeded one meter and were as shallow as 10 cm. In general, the plant communities at each site typically fell along a depth gradient, with a typical transition from open water to shore. Outer *Scirpus* zones usually were associated with the open water portions of the marsh, and the wet meadow zones were typical of the upland portion of the marsh.

Vanderbilt Park is located approximately 2 km north of the Michigan Department of Natural Resources (MDNR) public access near Quanicassee Road, Tuscola County (T14N R6E). The site contains dense *Scirpus pungens* intermixed with a large *Typha angustifolia* complex on the north side. The *Scirpus* has been observed to extend greater than 500 m into the bay (Cardinale et al. 1997). The area nearest the pelagic zone experiences high wave action and is referred to as the outer *Scirpus* zone. The physical structure of the nearshore *Scirpus* zone dampens wave activity and hampers mixing, producing a chemically and physically different habitat in shallower areas (Cardinale et al. 1997, Cardinale et al. 1998). This area is referred to as the inner *Scirpus* zone. The plant community near the shoreline contained *Pontederia cordata* L. and a small, submerged macrophyte zone. There was no wet meadow area associated with this site. While all of the Saginaw Bay sites are impacted by the Saginaw River carrying byproducts of agriculture from the heavily farmed watershed, Vanderbilt Park may be considered the most impacted site at Saginaw Bay due to the close proximity of dwellings, the adjacent Quanicassee River, and large ditches draining intensely farmed fields of potatoes, beans, and sugar beets.

The Cotter Road site was located on Saginaw Bay, Bay County, (T14N R6E) and has been presumed to be more impacted than Wildfowl Bay but less impacted than Vanderbilt Park. However, because the amount of anthropogenic disturbance at Cotter Road closely resembles that of Vanderbilt Park with respect to the number of dwellings/development and agriculture in close proximity, we do not feel that we can say with any certainty that one is more impacted than the other. A narrow wet meadow containing *Carex* spp. and *Calamagrostis* spp. was present. Monodominant and mixed stands of *Scirpus* spp., *Pontederia cordata, Phragmites australis* (Cav.) Trin. ex Steud., and *Typha angustifolia,* and *T. latifolia* were also present throughout the marsh. The *Scirpus* zone at this site was protected by extensive *Typha* complexes near the open water. The outer *Scirpus* zone was too narrow and sparse to be sampled.

Northern Lake Huron Sites

All of the northern Lake Huron sites are located within the Les Cheneaux Island complex, except the St. Martin's Bay site, a large bay located west of the Les Cheneaux Islands (Figure 1). In general, these sites have typical wetland vegetation zonation, with wet meadow vegetation at higher elevations separated from deeper emergent marsh by *Typha*-dominated transitional communities. The emergent marshes are comprised of emergents such as *Scirpus acutus, Pontederia cordata,* and *Eleocharis* spp., interspersed with floating-leaved plants and patches of often-dense submersed plants. The outer, deeper regions of the emergent marshes are comprised primarily of wave-swept *Scirpus,* with sandier bottoms than inner regions. Exceptions to this general pattern are noted below. IBI development was based on data taken in 1997 from Mackinac, Mismer, and Duck Bays. We subsequently tested the IBI on data taken in 1998 from these same sites, plus Cedarville, Peck, Voight, Prentiss, and St. Martin's Bays (Figure 1).

The Mackinac Bay site is typical of the wetlands in the area. It is in an island-protected bay, has a low-gradient stream running through it and out into the open bay, and has the vegetation zonation described above. To the north, the embankment of a paved two-lane highway truncates the upper end of the wet meadow. The stream was diverted in the past to make way for an expansion of the embankment to accommodate a public viewing platform and small gravel parking lot. Several residences with private docks and boathouses line the shores of the bay to the south and east of the site. Boat traffic in the bay is relatively low, but the main dredged channel through the Les Cheneaux Islands crosses the southern end at the mouth of the bay.

The Mismer Bay site is more wave-swept than Mackinac Bay, having only partial protection from open-lake waves. The result is a sandier bottom and the lack of a *Typha* zone, although the wet meadow is well-established, nonetheless. Two residences, without docks, abut the site, and a dirt road borders the wet meadow to the east. Boat traffic is primarily limited to anglers.

Duck Bay is on the largest of the Les Cheneaux Islands. The bay is well-protected, but the wetland site has a very sparse submersed plant community, a relatively less dense and less diverse emergent marsh community, and a steeper slope to deep water than most other sites. The *Typha* zone is well-developed and dense. The wet meadow is not very expansive because of the relatively steep slope to the upland forest. There are no residences and only one private dock on the bay shore. Boat traffic is low.

Two bays share the large island with Duck Bay. Peck Bay and its wetland are very similar to the Duck Bay site but are located further south toward the open lake. Human impacts are apparently very low with only one residence on the opposite side of the bay from the wetland. Voight Bay differs from the others in that it is on the south side of the island with direct exposure to open-lake waves. The sampled area is partially protected by low sandbar islands, but the emergent marsh is somewhat sparsely vegetated and has a sandier bottom than most sites. The wetland site is well protected from wave action and receives very little human impact. There are no human developments on the bay shore, and boat traffic is presumably very low.

Cedarville Bay is generally considered to be the most human-impacted area in the Les Cheneaux Islands. The middle of the bay is occupied by a very large island, so the bay actually resembles a U-shaped channel, which receives very high boat traffic. The town of Cedarville, its marina, and its public boat launch occupy the northwestern shore of the bay, and many private residences, businesses, and docks (private and commercial) line the mainland and island shores. The main wetland surrounds the stream mouth, public launch, and several docks, but the emergent marsh is cut off from its historic wet meadow by a paved road and a lumber yard built on fill. The only remaining aquatic connection between the wet meadow and marsh is the stream, which runs through a culvert under the road and carries discharges from upstream sewage treatment lagoons twice each year. Possibly as a result of the discharge, the emergent marsh in this area has unusually dense growths of submersed plants and filamentous algae.

Prentiss Bay is distinct from most others in that a paved highway was built through the wetland, separating the wet meadow from the emergent marsh and supplanting the *Typha* zone. A single culvert connects the two remaining zones. Because of the proximity of the road to deeper water, anglers often put boats in near the culvert and fish at the edge of the deep marsh. The dense emergent zone is narrow, giving way to a deeper, sparser, and patchier emergent zone fairly near the road.

St. Martin's Bay differs from the typical vegetational and morphological pattern seen in the other sites. The wetland site is on an unprotected shoreline in this large bay. The site is characterized by two parallel sandbars, giving the protection necessary for wetland development. The inner sandbar is continuous and separates a wet meadow from the remainder of the site. The outer sandbar has a single inlet, which connects it to the open bay. The resulting wetland zone between the sandbars is a typical dense emergent zone, although the bottom is relatively sandy and submersed plants are sparse because of the exposure to bay waves. Because there is no direct wet meadow/emergent interface, *Typha* only occurs at the inner edge of the outer sandbar, at the protected transitions from aquatic to upland vegetation. Outside the outer sandbar lies a very sparse *Scirpus* patch.

METHODS

Macroinvertebrate Samples

Macroinvertebrate samples were collected with standard D-frame dip nets containing a 0.5-mm mesh. All major plant community zones were sampled at each site, including an emergent zone and a shallow, wet meadow zone. If certain depths contained more than one dominant plant community along the shoreline, each plant community type was sampled.

Dip net sampling entailed sweeps through the water column at the surface, middle of the water column, and above the sediment surface to ensure that an array of micro-habitats were included in the sample. Samples were placed in white enamel pans, and 150 invertebrates were collected by focusing on small areas of the pan and removing all of the specimens. Special consideration was made to ensure that smaller organisms were not missed, as there is a bias towards larger, more mobile individuals using this technique. Plant detritus was left in the pan and sorted through for a few additional minutes to ensure that sessile species were included in the sample. Three replicate samples were collected within each plant community zone in order to obtain a measure of variance associated with sampling.

Dip net samples were collected from June through August. Samples taken from ice-out through mid-July generally contain less diversity and a greater proportion of early instars of aquatic insects, making identification very difficult. Therefore, most of our results were based on samples taken in July and August. This time period also corresponds to fully developed plant communities that are characteristic of these wetland systems.

Invertebrate identification was performed in the laboratory. Specimens were sorted to lowest operational taxonomic unit; most were taken to genus or species. Taxonomic keys such as Thorp and Covich (1991) and Merritt and Cummins (1996), along with mainstream literature for species level, were used for identification. Accuracy was confirmed by expert taxonomists when possible.

IBI Development and Implementation

Data for individual plant zones were graphically analyzed by constructing box plots, which included the 10th, 25th, 50th, 75th, and 90th percentiles. These were used to detect differences among wetlands with respect to individual metrics. The variance of each metric was used to predict the robustness and the resolution that could be obtained using a given metric. The resolution obtained from a given metric was established by the amount of interquartile overlap of box plots between impacted and unimpacted sites (Barbour et al. 1996). We assigned sensitivity values of zero to three to each metric to provide an indication of metric quality. A metric received a sensitivity value of three only if nearly all of the northern Lake Huron sites were separated from all three Saginaw Bay sites with no major overlap. This comparison included two months of data from northern Lake Huron and only one month from

Table 1. List of coastal wetland study sites including a brief description of their major natural and anthropogenic impacts.

Site	Major Disturbance
Northern Lake Huron Sites	All sites have catchments that are primarily forested
St. Martin's Bay	National Forest, no dwellings, sediment from Pine River influences site.
Duck Bay	Forested catchment, some dwellings, on leeward side of Marquette Island
Peck Bay	Forested catchment, some dwellings, on more exposed side of Marquette Island
Voight Bay	Forested catchment, on most exposed side of Marquette Island
Mackinaw Bay	Forested catchment, highway across upper wet meadow zone, some dwellings
Mismer Bay	Forested catchment, highway across upper wet meadow zone, some dwellings
Prentiss Bay	Forested catchment, highway across upper wet meadow zone, some dwellings
Cedarville Bay	Lagoon discharge, urban runoff, marina traffic
Saginaw Bay Sites	All sites influenced by agricultural runoff from drains; urban and industrial runoff from Saginaw River
Wildfowl Bay	Outer Bay site, isolated islands, near intense agriculture and small town of Sebewaing
Vanderbilt Park	Inner Bay site, near mouth of Quanicassee River, which drains intensely farmed region
Cotter Road	Inner Bay site, near urban area of Bay City/Essexville and mouth of Saginaw River (Great Lakes' Area of Concern), which drains intensely farmed region

Saginaw Bay. To receive a value of three, both months of data from three sites, or at least five of these six box plots had to be separated from all of the Saginaw Bay box plots. We were only able to collect data during August at Saginaw Bay, but by adjusting our sensitivity values from two months of northern Lake Huron data, we felt that we would incorporate at least some temporal variance into our metrics. A metric received a sensitivity value of two if three to four of the northern Lake Huron plots had no major overlap with the Saginaw Bay plots. A metric received a value of one if one to two of the northern Lake Huron plots had no major overlap with the Saginaw Bay plots and received a value of zero if all plots had major overlap. Metrics with no overlap of the interquartile range were considered to have very high resolution, while those with considerable overlap were considered to have very low or no resolving power. Also, a metric that could distinguish between two sites with relatively similar exposure to anthropogenic disturbance was said to have high resolution. For example, a metric not only placing northern Lake Huron above Saginaw Bay, but also Wildfowl Bay above the other two Saginaw Bay sites, was considered to have very high resolving power.

We recommend using medians in place of means in the IBI because medians are more resistant to the overwhelming effects of outliers. Our goal is to typify the wetland or vegetation zone. If an area is sampled that is depleted or concentrated in the constituents of a metric, the area may be isolated from anthropogenic disturbance, receiving a dose of disturbance not typical of the entire wetland or vegetation zone, or may contain some "natural" chemical/physical component that is unique. Regardless of the cause, the area is not representative of the entire wetland/vegetation zone. The influence of these outliers can be dampened by using the median in place of mean as a measure of central tendency.

During the development of the IBI, we assumed that Saginaw Bay sites were more disturbed than northern Lake Huron sites and that Wildfowl Bay is less disturbed than the other two Saginaw Bay sites (Table 1). This assumption was based in part on adjacent land use, including dwelling density, and limited limnological data. Saginaw Bay is considered to be one of the five "areas of concern" responsible for increasing eutrophication rates in Lake Huron (Hartig et al. 1993). However, Wildfowl Bay experiences little direct anthropogenic disturbance relative to the other two Saginaw Bay sites and is the outermost site, suggesting that pollution entering the bay from the mainland is likely diluted by Lake Huron water. Monthly mean chemical/physical data from 1991 through 1993 support these observations (Nalepa et al. 1996).

Most of the initial metrics used in this analysis were adopted from established wadeable stream IBIs (e.g., Plafkin et al. 1989, Kerans and Karr 1994) and modified when necessary (Kashian 1998). Modifications were due to inherent differences between lotic and lentic habitats and biota. Community diversity indices were also examined to assess their potential as useful metrics. The Shannon index (H′) was calculated as follows:

$$H' = -\sum p_i \log_{10} p_i$$

where p_i is the proportion of individuals found in the i^{th} species. An increase in H′ reflects an increase in the diversity of the community. Conversely, Simpson's index (D) decreases as the diversity of a community increases and was calculated using the following equation:

$$D = \sum (n_i(n_i - 1))/(N(N - 1))$$

where n_i is the number of individuals in the i^{th} species and N is the total number of individuals in the sample. Evenness (J′), which also increases with an increase in community diversity, was calculated as:

$$J' = H'/\log_{10} S$$

where S is the total number of taxa in a sample.

We recommend that individual metrics be established based on reference sites in the same ecoregion with relatively little anthropogenic disturbance (Hughes et al. 1981), and wetland type should remain consistent within that ecoregion (Simon 1998). In this study, the northern Lake Huron sites were used as coastal wetland reference sites, however, these sites were not located in the same ecoregion as the impacted sites (Albert 1994). There are only an estimated 24,767 ha of coastal wetlands remaining along Lake Huron (Herdendorf et al. 1981), and this estimate is quite high because it includes all wetlands within 304.8 m of the shore. A coastal wetland IBI for Lake Huron that could only be used within an ecoregion is impractical; most likely, all of the coastal wetlands located in each ecoregion would have to be studied to develop each individual IBI. Therefore, our objective was to pursue metrics robust enough to cross ecoregions of Lake Huron.

We returned to the field for a second year (1998) with the intention of exploring the robustness of our preliminary IBI by repeating the previous year's sampling at a water level 0.37 m lower than 1997 and sampling five additional northern Lake Huron sites, including Cedarville Bay, a site more disturbed than the other northern Lake Huron sites (Kashian 1998). We used our IBI to calculate sites scores from the 1998 data.

RESULTS AND DISCUSSION

In general, the wet meadow zones of all of the sites in 1997 were comprised largely of Mollusca, Crustacea, and Diptera, with respect to their relative abundances. Gastropoda and Chironomidae often dominated Mollusca and Diptera respectively. However, only Mollusca and Crustacea showed potential for metrics in our preliminary IBI (Table 2). Odonata were rather rare compared to all the other groups in the wet meadow zones of each site but seemed to provide useful metrics. Crustacea, and more specifically Amphipoda, were relatively more abundant than other groups in the *Typha* zones at most sites. However, Chironomidae were also quite abundant. The relative abundance of Ephemeroptera was comparatively high during June at the northern Lake Huron sites, but this was not the case in August. Crustacea seemed to be useful in an IBI at the taxonomic resolution of both Crustacea and Amphipoda, while Chironomidae and Ephemeroptera did not. The relative abundance of Odonata found in the *Typha* zone was much greater than it was in the wet meadow zone at the northern Lake Huron sites but this was not the case at Saginaw Bay. Odonata also seemed to be useful in the *Typha* zone. No single group of macroinvertebrates seemed to dominate the inner *Scirpus* zone in 1997. Crustacea, especially Amphipoda, were slightly more abundant than the other groups. Ephemeroptera played a relatively larger role in the inner *Scirpus* than any other vegetation zone. All three groups seemed to be useful in separating the sites according to anthropogenic disturbance. Crustacea, with Amphipoda being the major contributor, overwhelmingly dominated the outer *Scirpus* zones of all of the sites except Vanderbilt Park. The outer *Scirpus* zone of Vanderbilt Park was dominated by Chironomidae. While Crustacea did seem to be useful, Chironomidae did not separate the sites according to anthropogenic disturbance.

IBI Development

Twenty-four potential metrics were calculated for each of four plant zones at every site (Table 3). Criteria for retaining metrics were based largely on separation among sites and plant zones across the disturbance range. Of the 24 attributes, eight gave contradictory results, increasing with disturbance in some plant zones, while decreasing in others. This difference among plant zones observed during the development of the IBI will likely prove important in determining how robust a given attribute will be at other sites dur-

Table 2. Median and range (*in parentheses*) of the recommended metrics for each site. The preliminary IBI was based on these data. Northern Lake Huron medians represent samples collected in August while Saginaw Bay medians represent samples collected in July.

	Northern Lake Huron Sites			Saginaw Bay Sites		
Metric	Duck Bay	Mackinaw Bay	Mismer Bay	Wildfowl Bay	Vanderbilt Park	Cotter Road
Wet Meadow zone:						
No. of Crustacea + Mollusca genera	4 (3–6)	9 (9–11)	8 (6–8)	9 (7–9)	4 (3–4)	7 (5–8)
No. of Odonata genera	1 (0–2)	4 (3–5)	3 (3–5)	0 (0–1)	1 (1–1)	0 (0–0)
Total no. of genera	15 (13–16)	26 (23–26)	21 (20–24)	18 (15–21)	12 (12–17)	18 (13–21)
% Gastropoda	21.1 (20.7–27.3)	29.0 (24.4–47.7)	30.3 (24.0–35.7)	36.1 (36.0–55.1)	1.7 (1.3–3.4)	22.6 (7.8–23.4)
% Odonata	0.6 (0.0–3.3)	7.1 (5.7–10.9)	18.5 (12.1–22.8)	0.0 (0.0–0.6)	0.7 (0.6–1.7)	0.0 (0.0–0.0)
% Sphaeriidae	2.7 (1.8–6.7)	8.3 (3.6–8.3)	0.0 (0.0–1.5)	0.0 (0.0–0.0)	1.9 (0.0–10.0)	0.0 (0.0–0.0)
Typha zone:						
No. of Crustacea + Mollusca genera	8 (7–10)	6 (–7)	7 (4–7)	7 (4–8)	7 (5–7)	4.5 (2–5)
No. of Odonata genera	3 (1–3)	6 (6–7)	4 (3–7)	1 (0–1)	0 (0–0)	1 (0–1)
Total no. of genera	19 (18–21)	27 (24–28)	23 (21–27)	17 (12–21)	17 (17–19)	16 (11–19)
% Amphipoda	23.3 (19.6–26.7)	10.4 (4.7–11.0)	11.4 (9.0–12.8)	21.8 (0.0–53.4)	53.9 (50.6–63.5)	36.2 (8.5–73.3)
% Gastropoda	10.7 (10.1–11.6)	4.7 (4.6–13.4)	11.4 (7.8–22.6)	10.0 (4.2–17.8)	5.9 (3.0–7.2)	0.6 (0.0–1.9)
% Odonata	18.0 (11.6–21.6)	24.0 (12.8–26.7)	22.8 (9.0–25.5)	0.6 (0.0–2.4)	0.0 (0.0–0.0)	2.6 (0.0–9.1)
% Sphaeriidae	0.0 (0.0–1.7)	0.0 (0.0–0.7)	0.0 (0.0–0.0)	0.0 (0.0–0.0)	0.0 (0.0–0.0)	0.0 (0.0–0.0)
Inner *Scripus* zone:						
No. of Crustacea + Mollusca genera	10 (7–11)	8 (7–8)	7 (7–7)	4 (3–8)	5 (3–7)	4 (3–6)
No. of Ephemeroptera + Trichoptera genera	3 (2–5)	4 (4–4)	5 (4–5)	2 (1–6)	2 (1–3)	3 (1–3)
No. of Odonata genera	3 (2–4)	4 (2–4)	3 (2–5)	1 (0–3)	1 (0–3)	1.5 (0–3)
Total no. of genera	25 (23–26)	24 (23–27)	23 (21–28)	17 (13–23)	15 (13–20)	18.5 (16–20)
% Crustacea + Mollusca	53.4 (53.3–54.2)	32 (30.4–49.7)	32.7 (27.3–36.6)	26 (8.4–39.3)	20.1 (9.7–37.4)	13.9 (5.4–24.9)
% Gastropoda	7.3 (2.0–11.3)	8.5 (7.5–20.6)	9.3 (8.0–14.5)	1.9 (0.0–13.5)	2.3 (1.2–9.6)	1.2 (0.0–4.1)
% Odonata	9 (5.6–12.0)	18 (15.2–24.2)	11 (8.0–17.1)	1.3 (0.0–3.7)	0.9 (0.0–3.2)	1.2 (0.0–3.6)
% Sphaeriidae	0.6 (0–0.7)	0 (0–1.3)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Outer *Scirpus* zone†:						
No. of Crustacea + Mollusca genera	11 (8–11)	6 (5–7)	4 (3–6)	4 (4–5)	3 (3–5)	
No. of Odonata genera	2 (2–4)	2 (2–2)	1 (0–2)	0 (0–0)	0 (0–0)	
Total no. of genera	25 (19–26)	18.5 (18–19)	16 (13–16)	14 (13–17)	12 (11–18)	
Total no. of families	15 (15–19)	15 (14–16)	11 (9–12)	12 (11–12)	10 (9–14)	
% Crustacea + Mollusca	50.0 (43.2–55.3)	41.1 (39.4–42.8)	39.0 (15.7–41.2)	60.4 (51.3–61.7)	11.5 (11.5–12.8)	
% Gastropoda	7.5 (4.0–14.0)	2.8 (2.5–3.1)	0.6 (0.0–3.3)	3.7 (1.3–4.2)	1.8 (0.7–4.1)	
% Odonata	3.5 (2.1–4.0)	10.5 (7.6–13.5)	1.1 (0.0–1.3)	0.0 (0.0–0.0)	0.0 (0.0–0.0)	
% Sphaeriidae	0.7 (0.0–2.1)	0.5 (0.0–1.04)	0.0 (0.0–0.0)	0.0 (0.0–0.0)	0.0 (0.0–0.0)	
All Vegetation zones:						
Total no. of taxa	21 (13–26)	27 (20–30)	22 (13–28)	17 (12–23)	15 (11–20)	18 (11–21)
Evenness	0.78 (0.60–0.87)	0.85 (0.81–0.90)	0.79 (0.57–0.87)	0.69 (0.56–0.79)	0.70 (0.56–0.79)	0.73 (0.44–0.85)
Shannon diversity index	1.08 (0.67–1.13)	1.20 (1.05–1.31)	1.09 (0.64–1.18)	0.84 (0.60–1.03)	0.82 (0.67–0.99)	0.92 (0.51–1.08)
Simpson index	0.12 (0.09–0.32)	0.08 (0.06–0.14)	0.12 (0.08–0.34)	0.21 (0.14–0.40)	0.22 (0.14–0.34)	0.18 (0.10–0.54)

† Data not available from outer *Scirpus* vegetation zone at Cotter Road site.

Table 3. Summary of metrics analyzed using 1997 invertebrate data from northern Lake Huron (Duck Bay, Mackinaw Bay, Mismer Bay) and Saginaw Bay (Wildfowl Bay, Vanderbilt Park, Cotter Road) coastal wetlands. Sensitivity values of zero through 3 were assigned to each metric in each plant zone. A value of zero indicates no separation between sites and a value of 3 indicates that nearly all of the northern Lake Huron sites were separated from all three of the Saginaw Bay sites with box plots showing no major overlap. A metric received a sensitivity value of two if three to four of the northern Lake Huron plots had no major overlap with the Saginaw Bay plots, and a value of one if one to two of the northern Lake Huron plots had no major overlap with the Saginaw Bay plots.

	Sensitivity Values* Vegetation Zone†					Direction with Disturbance** Vegetation Zone†				
Potential Metrics††	OS	IS	TY	WM	ALL	OS	IS	TY	WM	ALL
Richness Measures:										
No. of Crustacea + Mollusca genera	1	2	2	**2**	2	D	D	D	D	D
No. of Ephemeroptera + Trichoptera genera	0	**2**	0	0	0	N	D	N	N	N
No. of Ephemeroptera genera	0	**1**	0	0	0	N	D	N	N	N
No. of Odonata genera	3	2	3	2	3	D	D	D	D	D
No. of Trichoptera genera	1	1	0	0	0	I	D	N	N	N
Total no. of taxa	2	3	3	1	2	D	D	D	D	D
Total no. of genera	1	2	2	1	2	D	D	D	D	D
Total no. of families	2	2	0	0	1	D	D	N	N	D
Relative Abundances:										
% Amphipoda	0	0	1	0	0	N	N	I	N	N
% Chironomidae	**2**	**2**	1	2	0	I	I	D	D	N
% Crustacea + Mollusca	**3**	2	0	0	0	D	D	N	N	N
% Ephemeroptera	1	**2**	1	2	0	D	I	D	D	N
% Gastropoda	1	2	**2**	**1**	**3**	D	D	D	D	D
% Isopoda	2	3	0	3	0	D	D	N	I	N
% Odonata	3	2	3	3	2	D	D	D	D	D
% Sphaeriidae	1	2	1	1	2	D	D	D	D	D
% Tanytarsini	**3**	1	0	2	0	I	I	N	D	N
% Trichoptera	**3**	1	1	1	0	I	D	I	D	N
% Diptera	**2**	**1**	**1**	1	0	I	I	D	N	N
% Crustacea (not including microcrustaceans)	0	1	0	3	0	N	D	N	I	N
Diversity Indices:										
Evenness (J')	2	2	2	2	2	D	D	D	D	D
Shannon index (H')	2	3	3	2	2	D	D	D	D	D
Simpson index (D)	2	2	2	2	2	I	I	I	I	I

* Bold numbers indicate separation of Vanderbilt Park and Cotter Road sites from northern Lake Huron (NLH) sites but not Wildfowl Bay (WFB) from NLH sites.
** Assuming disturbance is greater at Saginaw Bay sites than at NLH sites and that WFB is less impacted than Vanderbilt Park and Cotter Road. N = No effect of impact, I = Increase in metric, D = Decrease in metric.
† OS = Outer *Scirpus*, IS = Inner *Scirpus*/Pickerelweed, TY = *Typha*, WM = Wet meadow, ALL = All sampling stations combined.
†† Recommended metrics italicized.

ing its use. For example, if an attribute increases with impact in the outer *Scirpus* zone but decreases with impact in the inner *Scirpus* zone, the likelihood of overlap increases and the chance of losing resolution and/or incorrectly assessing a wetland also increases. Therefore, the *number* and *relative abundance of Trichoptera genera, relative abundance of Chironomidae, relative abundance of Ephemeroptera, relative abundance of Isopoda, relative abundance of Tanytarsini, relative abundance of Diptera,* and *relative abundance of Crustacea* attributes were the first to be eliminated from the original list of 24 metrics, although each may prove useful if sampling were restricted to a single zone (Kashian 1998). Metrics including Trichoptera and Chironomidae have been shown to be very valuable in stream ecosystems, but our data suggest that metrics including these organisms will be of little use in Lake Huron coastal wetlands if all plant zones are sampled within each wetland.

Of the remaining 15 attributes, several ordinated sites according to anthropogenic disturbance only in certain vegetation zones while showing little or no discrimination between sites in other zones. The *number of Ephemeroptera plus Trichoptera genera* only ordinated the sites in the inner *Scirpus* zone. This metric separated Saginaw Bay from northern Lake Huron and

Wildfowl Bay from the other two sites; however, there were no detectable differences in the three remaining zones. The *total number of families* decreased with impact, separating Wildfowl Bay from Vanderbilt Park, but did not seem useful anywhere but in the outer *Scirpus*. These were the only two Saginaw Bay sites compared because the Cotter Road site had no outer *Scirpus* zone. The *relative abundance of Amphipoda* increased with impact in the *Typha*-dominated zones, while no differences were detected in the other zones. Wildfowl Bay was separated from the other two Saginaw Bay sites. The *relative abundance of Crustacea plus Mollusca* seemed to be a powerful metric, decreasing with disturbance in both the outer and inner *Scirpus* zones and separating Wildfowl Bay from the other two Saginaw Bay sites. All of the previously mentioned measures except *total number of families* also seemed to be useful in separating an impacted and relatively unimpacted site in northern Lake Huron in 1996 (Kashian 1998). Based on the performance of these metrics, all four seem to have potential value in a multi-metric IBI but will be moderately weighted because they only appear to work in particular plant zones.

The following metrics provide the most insight into the relative amount of anthropogenic disturbance; thus, these metrics will carry the most weight in a multi-metric IBI. The *number* and *relative abundance of Odonata genera* seem to be two of the most useful metrics, providing excellent separation between Saginaw Bay and northern Lake Huron across all of the plant zones. However, these metrics did not separate Wildfowl Bay from the other two Saginaw Bay sites, suggesting either that the resolution of the metric is not necessarily very fine, or that these differences are due to ecoregion differences. Importantly, Odonata always decreased with impact. Kashian (1998) also found that Odonata separated an impacted site from a relatively unimpacted site in northern Lake Huron. The *number of Crustacea plus Mollusca genera* also functioned adequately across vegetation types, sometimes separating Wildfowl Bay from the other two Saginaw Bay sites. Our data suggest that the *total number of genera* seems to be useful in any vegetation zone; however, either the resolution obtained with this metric is not high, as Wildfowl Bay could not be differentiated from the other two Saginaw Bay sites, or we detected differences due to changes in latitude. The *relative abundance of Gastropoda* separated the sites well across vegetation zones but seemed to work best in the inner *Scirpus* and *Typha* zones. The same was true of the *relative abundance of Sphaeriidae*; however, it worked best in the inner *Scirpus* zone of northern Lake Huron sites. Other metrics such as *total taxa richness, Evenness, Shannon index,* and *Simpson index* worked well across vegetation types, but these metrics should be used with caution as they can be greatly affected by the amount of taxonomic resolution acquired. Therefore, if an index of this type is to be used, the lowest taxonomic unit will have to be defined in the metric. We recommend using the average of the four vegetation zones. An example of a testable IBI developed from these data can be found in Table 4.

Preliminary Testing of IBI

In 1998, our preliminary IBI seemed to provide an accurate depiction of the sites used to generate our IBI, as well as the five additional sites, even though water levels had changed considerably (Table 5). Mackinaw and Wildfowl Bays were the only two sites that contained data sets from all four plant zones. Both sites were classified as Mildly Impacted, with Mackinac at the high end and Wildfowl Bay at the low end of the range, the same designation that we designed our IBI to assign using the 1997 data. We only had data for the inner *Scirpus* zone of Duck and Mismer Bays, the other two sites sampled both in 1997 and 1998. During IBI development, we designated both of these sites to score at approximately the Mildly Impacted and Reference Site margin. While the power of the IBI is reduced as the number of plant zones are reduced, both Duck and Mismer bays still scored near the middle and low ends of the Reference conditions range, respectively.

Peck, Voight, Prentiss, St. Martin's, and Cedarville bays were sampled in 1998 and were not used for IBI development. We established *a priori*, using the same criteria as for the other sites, that all but Cedarville should be designated near the Mildly Impacted/Reference Site cut off. This was true for all but Voight Bay; it scored near the middle of the Mildly Impacted category, a bit lower than we had anticipated. We felt that the Cedarville site would be a good test of ecoregion robustness since it had a relatively large amount of anthropogenic disturbance, likely even greater than Wildfowl Bay, our least impacted Saginaw Bay site. Cedarville Bay was placed below Wildfowl Bay in the Moderately Degraded category. If Cedarville Bay would have scored higher than Wildfowl Bay, our test would have been inconclusive. We would not have known if the observed results were due to disturbance or ecoregional differences.

The 1998 data provided an opportunity not only to begin testing our IBI but also to revisit metrics that provided inconclusive results in 1997. Metrics involving Ephemeroptera and Trichoptera in plant zones other than inner *Scirpus* showed more potential in 1998 than they did in 1997. The relative abundance of Chironomidae in the outer *Scirpus* zone showed promise,

Table 4. Preliminary index of biotic integrity for Lake Huron coastal wetlands. The worksheet includes a description of vegetation zones to be sampled and the metrics following that description should be applied only to that zone. The worksheet should be filled in by checking the appropriate value accompanying each metric. After tallying each individual score, the overall score should be compared to the category scores. All values should be based on the median of at least three replicates taken from each zone.

Wet Meadow Zone: dominated by *Carex* and *Calamagrostis*.

1. Odonata taxa richness (Genera):		
0 score = **1**	>0 to 3 score = **3**	>3 score = **5**
2. Relative abundance Odonata (%):		
0 to <1 score = **1**	>1 to 5 score = **3**	>5 score = **5**
3. Crustacea plus Mollusca taxa richness (Genera):		
<2 score = **1**	2 to 6 score = **3**	>6 score = **5**
4. Total Genera richness:		
<10 score = **1**	10 to 18 score = **3**	>18 score = **5**
5. Relative abundance Gastropoda (%):		
0 to 1 score = **1**	>1 to 25 score = **3**	>25 score = **5**
6. Relative abundance Sphaeriidae (%):		
0 score = **1**	>0 to 3 score = **3**	>3 score = **5**

Typha Zone: Monodominant island or stand of *Typha*, may or may not be subject to wave action.

1. Odonata taxa richness (Genera):			
0 score = **1**	>0 to <1 score = **3**	1 to 2 score = **5**	>2 score = **7**
2. Relative abundance Odonata (%):			
0 score = **1**	>0 to <2 score = **3**	2 to 10 score = **5**	>10 score = **7**
3. Crustacea plus Mollusca taxa richness (Genera):			
<2 score = **1**	2 to 4 score = **3**	>4 to 6 score = **5**	>6 score = **7**
4. Total Genera richness:			
<10 score = **1**	10 to 15 score = **3**	>15 to 20 score = **5**	>20 score = **7**
5. Relative abundance Gastropoda (%):			
0 to 1 score = **1**	>1 to 5 score = **3**	>5 to 8 score = **5**	>8 score = **7**
6. Relative abundance Sphaeriidae (%):			
0 score = **1**	>0 to 0.5 score = **3**	>0.5 score = **5**	
7. Relative abundance Amphipoda (%):			
>60 score = **1**	>15 to 60 score = **3**	0 to 15 score = **5**	

Inner Scirpus Zone: Often dense *Scirpus* mixed with *Pontederia* and submergents, protected from wave action.

1. Odonata taxa richness (Genera):			
0 score = **1**	>0 to <1 score = **3**	1 to 2 score = **5**	>2 score = **7**
2. Relative abundance Odonata (%):			
0 score = **1**	>0 to <2 score = **3**	2 to 7 score = **5**	>7 score = **7**
3. Crustacea plus Mollusca taxa richness (Genera):			
0 to 2 score = **1**	>2 to 4 score = **3**	>4 to 6 score = **5**	>6 score = **7**
4. Total Genera richness:			
<10 score = **1**	10 to 14 score = **3**	>14 to 18 score = **5**	>18 score = **7**
5. Relative abundance Gastropoda (%):			
0 score = **1**	>0 to 2 score = **3**	>2 to 4 score = **5**	>4 score = **7**
6. Relative abundance Sphaeriidae (%):			
0 score = **1**	>0 to 0.05 score = **3**	>0.05 score = **5**	

Table 4. Continued.

7. Ephemeroptera plus Trichoptera taxa richness (Genera):			
0 score = **1**	>0 to 3 score = **3**	>3 score = **5**	
8. Relative abundance Crustacea plus Mollusca (%):			
<8 score = **1**	8 to 30 score = **3**	>30 score = **5**	
Outer Scirpus Zone: Sometimes relatively sparse, usually monodominant stands, subject to direct wave action.			
1. Odonata taxa richness (Genera):			
0 score = **1**	>0 to <1 score = **3**	1 to 2 score = **5**	>2 score = **7**
2. Relative abundance Odonata (%):			
0 score = **1**	>0 to <1 score = **3**	1 to 2 score = **5**	>2 score = **7**
3. Crustacea plus Mollusca taxa richness (Genera):			
0 to 2 score = **1**	>2 to 4 score = **3**	>4 to 5 score = **5**	>5 score = **7**
4. Total Genera richness:			
<8 score = **1**	8 to 13 score = **3**	>13 to 17 score = **5**	>17 score = **7**
5. Relative abundance Gastropoda (%):			
0 score = **1**	>0 to 3 score = **3**	>3 to 5 score = **5**	>5 score = **7**
6. Relative abundance Sphaeriidae (%):			
0 score = **1**	>0 to 0.05 score = **3**	>0.05 score = **5**	
7. Total number of families:			
0 to 7 score = **1**	>7 to 12 score = **3**	>12 score = **5**	
8. Relative abundance Crustacea plus Mollusca (%):			
<8 score = **1**	8 to 30 score = **3**	>30 score = **5**	
Average of All Vegetation Zones Present			
1. Total taxa richness:			
0 to 5 score = **1**	>5 to 20 score = **3**	>20 score = **5**	
2. Evenness:			
0 to 0.4 score = **1**	>0.4 to 0.7 score = **3**	>0.7 score = **5**	
3. Shannon diversity index:			
0 to 0.4 score = **1**	>0.4 to 0.9 score = **3**	>0.9 score = **5**	
4. Simpson index:			
> 0.3 score = **1**	>0.15 to 0.3 score = **3**	0 to 0.15 score = **5**	

Category Scores:

All Vegetation Zones Present
33 to 57 (0 to 15% of possible score)
Degraded: *In comparison to other Lake Huron wetlands, this wetland is amongst the most impacted.*

>57 to 114 (>15 to 50% of possible score)
Moderately Degraded: *The wetland shows obvious signs of anthropogenic disturbance.*

>114 to 171 (>50 to 85% of possible score)
Mildly Impacted: *The wetland is beginning to show signs of anthropogenic disturbance.*

>171 to 195 (>85 to 100% of possible score)
Reference Conditions: *The wetland is amongst the most pristine of Lake Huron.*

Adjusted Category Scores:

Wet Meadow Only
10 to 16; >16 to 30; >30 to 44; >44 to 50

Wet Meadow and *Typha*
17 to 32; >32 to 69; >69 to 88; >88 to 120

Table 4. Continued.

Wet Meadow, *Typha,* and Inner or Outer *Scirpus*
25 to 48; >48 to 103; >103 to 157; >157 to 180
Wet Meadow, Inner and Outer *Scirpus*
26 to 45; >45 to 88; >88 to 131; >131 to 150
Wet Meadow and Inner or Outer *Scirpus*
18 to 30; >30 to 59; >59 to 88; >88 to 100
Typha only
11 to 19; >19 to 38; >38 to 57; >57 to 65
Typha and Inner or Outer *Scirpus*
19 to 33; >33 to 67; >67 to 101; >101 to 115
Typha, Inner and Outer *Scirpus*
27 to 48; >48 to 96; >96 to 144; >144 to 165
Inner or Outer *Scirpus* only
12 to 21; >21 to 41; >41 to 61; >61 to 70
Inner and Outer *Scirpus*
20 to 35; >35 to 70; >70 to 105; >105 to 120

as did the relative abundance of Amphipoda in the inner *Scirpus*. In the future, we would like to evaluate the effectiveness of other potential metrics, such as the relative abundance of Tubificidae and the Chironomid genus *Chironomus*.

CONCLUSIONS

Our design was not rigorous enough to recommend that our preliminary IBI be used to evaluate the integrity of Lake Huron coastal wetlands. Instead, we recommend testing this IBI on a series of Lake Huron wetlands with known degrees of anthropogenic disturbance. Since development is in its infancy, we feel that spatial boundaries should remain within the confines of the Michigan shoreline from northern to southern Lake Huron and pertain only to comparable habitat types as described for each metric. These boundaries should be maintained until the robustness of the IBI can be determined.

Lake levels throughout the study did change significantly from 1997 to 1998 but remained well within the historic norm. We believe that sampling by vegetation type will alleviate problems associated with water-level fluctuation from year to year; however, the wet meadow zone is most susceptible to the influence

Table 5. Assessments of coastal wetlands in 1998 using the preliminary IBI created using 1997 invertebrate data (see Table 3). Plant zone(s) sampled and category that the IBI placed each site in is included. The data collected in 1998 was used to reassess some sites used in the development of the preliminary IBI and to assess new sites.

Site	Vegetation Zones Included	Percentage of Total Possible Score	Category (relative position within category)
Northern Lake Huron			
Cedarville Bay	Inner *Scirpus*	41	Moderately Degraded (high)
Duck Bay*	Inner *Scirpus*	93	Reference Conditions (middle)
Mackinaw Bay*	All	79	Mildly Impacted (high)
Mismer Bay*	Inner *Scirpus*	86	Reference Conditions (low)
Peck Bay	Inner *Scirpus*	93	Reference Conditions (middle)
Prentiss Bay	Inner *Scirpus*	83	Mildly Impacted (high)
St. Martin's Bay	Inner *Scirpus*	83	Mildly Impacted (high)
Voight Bay	Wet Meadow Inner *Scirpus* Outer *Scirpus*	69	Mildly Impacted (middle)
Saginaw Bay			
Wild Fowl Bay*	All	65	Mildly Impacted (low)

* Previous year's data from these sites used to generate IBI.

of changing water levels, so samples taken from the wet meadow were given a lower overall weighting in the IBI. Preliminary data (Burton et al. unpublished) suggest that rising water levels can cause reduced community diversity within plant zones and greater community homogeneity across zones. Of course, very low water levels can completely drain the higher elevation zones, thus "re-setting" the system before the next rise.

We do not anticipate that these changes would hinder comparisons of sites within Lake Huron because all such sites should experience the same multi-year hydrologic changes. However, because our candidate metrics were selected using data from a relatively high-water year, it is crucial that, before being used, they be tested in the same sites after water levels have fallen and again after water has risen to roughly average levels. It is also important that these multi-year changes be considered in any study intended to monitor wetland biotic integrity over time. Given these concerns, our 1998 sampling was focused on the inner *Scirpus* zone, which remains flooded most years, is consistently found in all sites, and has shown more stability in community composition than other zones (Gathman, unpublished data).

Our multimetric IBI incorporates four defined plant zones, with specific metrics associated with each zone. The user should keep in mind that as the number of plant zones present at a coastal wetland of interest decreases, the overall power of the IBI also decreases. Our invertebrate IBI will not discriminate between natural and anthropogenic reasons for the presence or absence of particular plant zones; that question is more easily addressed using an IBI based on vegetation itself. Instead, our IBI uses the plant zones only to define habitat type. Our IBI should be used in conjunction with an IBI based on plants whenever possible.

We included a group of metrics that are used by combining the data from all of the plant zones present. This portion will be most powerful when all of the four defined plant zones are present but should be used regardless. This particular section is also given a relatively low weighting because these metrics are highly dependent on taxonomic resolution, and therefore, results will be dependent on taxonomic expertise.

Simon (1998) pointed out that the estimated loss of over 80% of Great Lakes coastal wetlands has resulted in a limited number of reference sites. We believe that the sites that we selected for study are some of the best remaining for their respective ecoregions, and our study lacked sites closer to the degraded end of the continuum. Sites containing more anthropogenic disturbance should have been and will be included in the future. Inclusion of such sites will allow us to make the IBI a much more robust tool for bioassessment.

We use results from the northern Lake Huron sites as an approximation for conditions between reference and mildly impacted because it is this collective data set that defines the "reference condition" category and is based on least impacted conditions (Simon and Emery 1995). No single wetland will reflect outstanding scores for all metrics because pristine sites no longer exist (Simon and Emery 1995). Therefore, there is a very small range for an exceptional wetland to be scored as "reference conditions." The same is true for the "degraded" category; a wetland would have to be exceptionally impacted to fall into this classification.

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