Development of multimetric indices of biotic integrity for riverine and palustrine wetland plant communities along Southern Lake Michigan

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Abstract

Riverine and palustrine wetland plant communities were examined in order to propose a multimetric plant index of biotic integrity. The objectives were to determine the structural and functional attributes of these wetland plant communities, calibrate reference conditions in assessing aquatic plant communities, provide methods for further development and testing of the index, and present a case study. The index is based on a rapid assessment method using the information collected from a species list and cover estimates. Sampling was done using a modified relevé sampling approach with a modified Braun-Blanquet Cover Abundance Scale Method for estimating percent cover. More than 20 characteristics of aquatic plant communities were evaluated and 12 metrics in five categories were developed. Structural metrics focused on community composition, key indicator species such as number of *Carex* and *Potamogeton* species, and guild type. Functional metrics included sensitivity and tolerance measures; percent emergent, pioneer, and obligate wetland species; and the number of weed species as a substitute metric. Abundance was estimated based on evenness of average cover densities. Individual condition was suggested as a measure of the lowest extremes of biotic integrity. Palustrine study sites ranged across a disturbance gradient from 'least-impacted' to 'poor'; riverine study sites ranged from high quality to some of the most degraded riverine sites in the Great Lakes region. Ninety-five species of aquatic vascular plants were found in 42 families. The most common families were Cyperaceae (15 species), Polygonaceae (9 species), and Juncaceae (6 species). Fourteen submergent, four floating, two woody and 75 emergent aquatic plant taxa were found. Five species were on the endangered, threatened, or rare list for the State of Indiana. Sites receiving the highest index scores included several of the *a priori* least-impacted sites while the lowest scores were located near-field to a large industrial landfill. The index will need to be further validated and tested but shows potential as a rapid index of biotic integrity using aquatic plant assemblages.

Keywords: Metrics, structure and function, biological assessment, aquatic plant assemblage, Indiana Dunes National Lakeshore

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Introduction

Anthropogenic modifications of most global habitats have changed community structure and function prior to the characterization of biological communities (Grootjans and van Diggelen, 1995; Vitousek et al., 1997). Global environmental changes have altered the function of the biosphere, thus affecting species diversity and composition (Chapin et al., 1997; Bazzaz et al., 1998). In order to understand patterns of regional ecological conditions it has become necessary to establish expectations based on least-impacted areas (Hughes, 1995). These benchmarks of biological expectations provide best estimates of acceptable or desirable ecological conditions and should represent 'natural' conditions of a region (Davis and Simon, 1995).

Biological integrity is the ability of an aquatic ecosystem to support a balanced community of organisms comparable to that of natural habitats within a region (Karr and Dudley, 1981). Environmental indicators of ecological change are used as estimates of biological integrity and to assess community response to specific stressors (McKenzie et al., 1992; Stewart et al., 1999a). Although living systems provide interpretable indicators of environmental degradation (Yoder and Rankin, 1995; Karr, 1997), these indicators need calibration on a regional scale (Wiken, 1986; Omernik, 1995).

Biological patterns validating the biological integrity of wetland plant communities have generally not been analyzed. Numerous biological indicators, with the exception of aquatic plant assemblages, have been incorporated into multimetric indices for assessing the condition of water resource quality (McKenzie et al., 1992; Davis and Simon, 1995; Simon, 1998a). Hughes et al. (1987), as well as Matthews and Robison (1988) and Hughes et al. (1994), have evaluated stream fish community patterns. Biological assessment efforts using primary producers have focused on algal and periphyton communities (Bahls, 1993; Kentucky Division of Water, 1993; Oklahoma Conservation Commission, 1993; Rosen, 1995; Stewart, 1995).

Initial efforts to use wetland plants as biological indicators have been encouraging. Steinburg and Schiefele (1988) and Robach et al. (1996) successfully used wetland plant communities as indicators of trophic status. Species composition is known to change with the addition of organic pollution (Husák et al., 1989). Preliminary efforts by the United States Environmental Protection Agency have incorporated the percentage of aquatic macrophyte cover and dominance of exotic species into their tier I index for assessing lake integrity (USEPA, 1998). Despite the apparent responsiveness of plant communities to ecological change, no multimetric index of aquatic plant integrity exists (Stewart et al., 1999a). The presence of such an index would be useful, since current methods of wetland delineation do not evaluate wetland quality or biological integrity (U.S. Army Corps of Engineers, 1987) and generally are not rapid approaches.

In this paper, the rationale and proposed metrics are developed for an aquatic plant assessment index. The intention is not to validate these approaches, but to establish the foundation for further testing and development. Within the context of a case study, the objectives were to determine attributes of wetland plant communities, calibrate reference conditions by assessing aquatic plant communities, and provide an alternative, rapid method approach for development and testing of the index.

Methods and Materials

Study area

In order to develop an aquatic plant index of biotic integrity (PIBI), with similar rationale to that developed for fish communities (Karr, 1981; Karr et al., 1986; Simon, 1998b; Simon and Stewart, 1998), palustrine and riverine aquatic plant communities were examined along southern Lake Michigan. The Great Marsh and the Grand Calumet Lagoons are two wetland complexes along southern Lake Michigan (Fig. 1). Portions of both systems are included in the Indiana Dunes National Lakeshore, while a portion of the Great Marsh is included in the Indiana Dunes State Park. Based on a variety of chemical, physical, and non-plant biological indicators (Stewart and Butcher, 1997; Stewart et al., 1997; Gillespie et al., 1998; Simon, 1998b; Simon and Stewart, 1998, 1999; Stewart et al., 1999a,b,c) our sites are known to represent a wide range of habitat quality ranging from 'good' to 'very poor' quality riverine wetlands and from least-impacted palustrine sites to some of the most degraded sites in the Great Lakes region. While relatively few sites were used, previous experience with these sites and the ecological dose response curve hypothesis suggests that fewer sites can be used if they represent a broad range of biological exposures (Karr and Chu, 1999).

The Great Marsh is a remnant of the extensive wet-

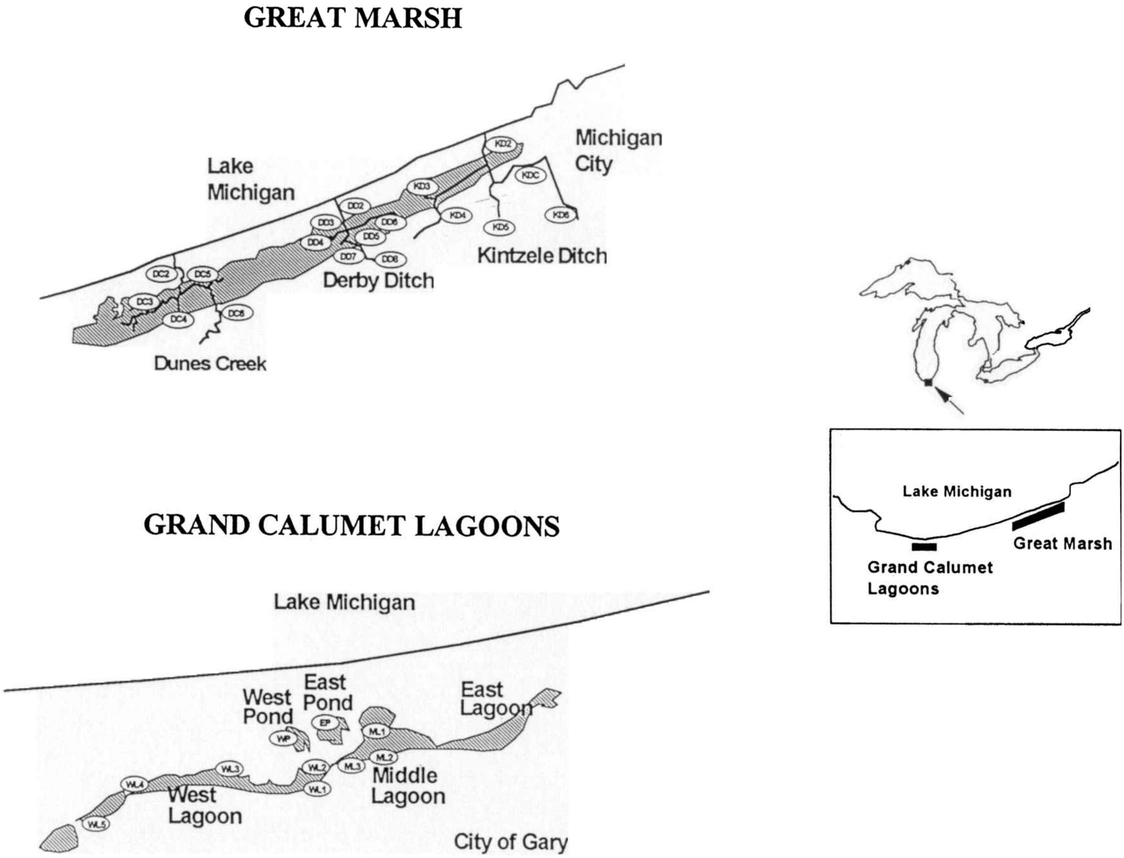

Figure 1 Map of Lake Michigan drainage wetlands in Northwest Indiana showing location of riverine (Great Marsh) and palustrine (Grand Calumet Lagoons) sites. Site codes are given that are referred to in the text.

lands that once existed in Northwest Indiana (Stewart et al., 1997). The Great Marsh is drained by three ditched streams that flow into Lake Michigan (Stewart et al., 1997, 1999c). Eighteen sites were sampled in the Great Marsh with five to seven sites per stream (Fig. 1). Land use in the watershed has been described by Hardy (1984) and Stewart et al. (1997). In summary, the Dunes Creek watershed consists of 66% public parks and wetlands, 19% agriculture and forests, and 15% urban, residential, and industrial use. Land use in the Derby Ditch watershed consists of 57% public parks and wetlands, 33% agricultural and forest, and 10% urban, residential, and industrial use. Kintzele Ditch land use consists of only 16% public parks and wetlands, 54% agriculture and forests, and 30% urban, residential, and industrial use.

The Grand Calumet Lagoons are palustrine wetlands that formed during the latter half of the 19th century by siltation damming of the former outlet of the Grand Calumet River to Lake Michigan (Fig. 1). This area is located in a Great Lakes Area of Concern, one of 43 areas in the Great Lakes watershed identified by the International Joint Commission as having severe environmental contamination (Holowaty et al., 1992). The 32.6 ha Grand Calumet Lagoons system drains a 3.5 km^2 watershed that is divided into three similarly-sized sections. Ten palustrine wetland sites were sampled from areas in the Middle and West Lagoons and two adjacent small ponds (Stewart et al., 1999b). The West Lagoon and West Pond are bordered by an industrial area that received steel slag, other industrial wastes, and has coal and coke storage areas and is known to have a range of disturbance regimes (Stewart and Butcher, 1997; Simon and Stewart, 1998; Stewart et al., 1999a).

Plant collection strategy, approach, and methods

Typical plant community census surveys require extensive effort to collect quantitative information using either a transect or quadrat approach (Cochran, 1977;

Greig-Smith, 1983; Moore and Chapman, 1986; Elzinga et al., 1998). Quadrats and transects are used for quantifying density, frequency, cover and biomass (Wiegert, 1962; Lucas and Seber, 1977). These approaches have several disadvantages including the time required to perform them, accuracy in large and dense areas, and problems associated with documenting the presence of rare species (Elzinga et al., 1998). This type of assessment does not serve the needs for rapid bioassessment. Qualitative techniques can be used for estimating numbers of species and individuals, estimating percentages of cover and stage class, evaluating signs of disease and disturbance, and association of site condition with habitat features (Elzinga et al., 1998). While a rapid assessment approach does not quantify the density and biomass of species, the rapidity and accuracy of estimating species diversity and relative abundance in a large area compensate for this loss of information. This allows biologists to make visits to multiple sites in the same amount of time. In addition, the development of a multimetric index of biotic integrity for aquatic plant assemblages is better than 'best professional judgement' and attempts to make more objective and repeatable the observations that measure quality.

Aquatic macrophytes were surveyed twice in 1994 using a modified relevé sampling approach with a modification of the Braun-Blanquet Cover Abundance Scale Method of estimating percent cover (Mueller-Dombois and Ellenberg, 1974). Sampling was done by surveying the site up to a 100-m distance in the near-shore, offshore, and littoral zone of palustrine wetlands and within the floodplain and stream channel of riverine wetlands where facultative and obligate wetland species would be anticipated. The level of effort at a site ensured that the number of species found were in the upper limits of the species-area curve (Heck et al., 1975; de Caprariis et al., 1981; Smith et al., 1985). The sampling intent was to perform a representative qualitative survey, not an exhaustive census, and was targeted at biological diversity and relative abundance estimates. All species of aquatic plants were identified and an abundance rating (1-Observed, 2-Rare, 3-Rare/Common, 4-Common, 5-Very Common, 6- Abundant) was assigned to each species. Abundance categories were expanded from those used previously (Kershaw, 1964) and represent the number of individuals of a plant species at a site; 'observed' was assigned when only one individual of a species was found; 'rare' was assigned when a plant species was found two to four times at a site; 'rare/common' was assigned when the plant species was found more than four instances, but was never a common component of the community at a site; 'common' species were those that were easily located at a site; 'very common' species were slightly dominant at a site, comprising up to about 25% of the community at a site; and 'abundant' species were those that dominated a site, comprising from 25% to almost 100% of the plant community. Identifications were done in the field and unknowns were identified using appropriate floristic manuals (Fasset, 1957; Winterringer and Lopinot, 1977; Gleason and Cronquist, 1991; Swink and Wilhelm, 1994). Vouchered specimens were deposited at the Purdue University North Central herbarium. Details of this data set is available from the senior author

Metric development

To develop an index of biotic integrity for palustrine and riverine wetlands, we reviewed aquatic plant assemblage structure and function literature, published life history, and tolerance information (Swink and Wilhelm, 1994; Eggers and Reed, 1997) for species from the Great Marsh and the Grand Calumet Lagoons. More than 20 characteristics of aquatic plant communities were evaluated in selecting the 12 metrics among five main categories that were incorporated into separate multimetric indices for riverine and palustrine wetlands (Table 1). Structural metrics focused on community structure, key indicator species, and group membership such as the number of *Carex* or *Potamogeton* species. Functional metrics included sensitivity and tolerance measures; percent emergent, pioneer, and obligate wetland species; and the number of weed species as a substitute metric. Ratings in Reed (1988) were used to classify aquatic plant species based on a national wetland ranking of facultative (FAC), facultative wetland (FACW), or obligate wetland (OBL). Abundance was estimated based on the average of individual species cover densities. Individual condition incorporating presence of disease and deformed plants measured the lowest extremes of biotic integrity. We discuss the rationale for each metrics' group membership within the appropriate metric section. Scoring criteria for the PIBI follows Karr et al. (1986), which used three levels based on a trisection of the data. For a metric to score a '5' the attribute needs to be representative of the reference condition, a score of '3' shows deviation from the reference condition, and a score of '1' suggests the metric is significantly different from the reference condition.

Table 1 Calibrated plant index of biotic integrity (PIBI) for palustrine (P) and riverine (R) wetlands along southern Lake Michigan. Data beneath associated IBI scores (1, 3, 5) are based on a trisection of the information graphically presented in Figs. 3 and 4.

Attribute	Wetland	Scoring 1(worst)	3	5(best)
Species richness and composition				
1. Total number of species	P	<4	4-7	≥8
	R	Varies with surface area (Fig. 4a)		
2. Number of emergent species	P	≤2	3-6	≥7
Number of *Carex* species	R	Varies with surface area (Fig. 4b)		
3. Number of *Potamogeton* species	P	<1	1-2	≥3
Number of submergent species	R	≤1	2-3	≥4
4. Number of perennial species	P	≤4	5-10	≥11
	R	Varies with surface area (Fig. 4d)		
5. Number of weed species	P	≥2	1	0
	R	Varies with surface area (Fig. 4e)		
Species tolerance				
6. Number of sensitive species	P	≤1	2-3	≥4
	R	Varies with surface area (Fig. 4f)		
7. Number of tolerant species	P	≥4	2-3	≤1
	R	>4	3-4	≤2
Guild structure				
8. Percent emergent species	P and R	≥66%	>33-<66%	≤33%
9. Percent obligate wetland species	P	≤30%	>30-<60%	≥60%
	R	<25%	>25-50%	>50%
10. Number of pioneer or weed species	P	>10	>5-<10	<5
	R	>12	>6-<12	<6
Abundance				
11. Mean relative abundance	P	<1.4	>1.4-<2.8	>2.8
	R	>3	1.5-<3	<1.5
Individual condition				
12. Percent taxa with deformities or anomalies	P and R	Needs to be calibrated based on furter field observation		

Statistics

Patterns in species composition, group membership, and functional percentages were scaled against drainage area (riverine) or surface area (palustrine) to determine if a linear relationship existed. Scoring lines were drawn to trisect the data such that the maximum species richness line had 95% of the data beneath it (Barbour et al., 1995). Metric hypotheses were made *a priori* and qualitatively examined to determine if the patterns found fit these expectations.

Spearman correlations ($p<0.05$) were used to examine the relationship between wetland size and each metric (Conover, 1971). Bray-Curtis similarity was used in a cluster analysis (group average and Ward's method) to assess similarity between sites and species. The cluster analysis was confirmed by ordination using non-metric multidimensional scaling (MDS) to examine similarities among sites based on aquatic plant community composition (Clarke and Warwick, 1994; Carr, 1996).

Table 2 Mean, standard error, range, and statistical significance of aquatic plant community attributes from 28 wetlands used to calibrate an index of biotic integrity for riverine and palustrine wetlands along the southern shore of Lake Michigan.

	Riverine			Palustrine		
Attribute	Mean (± SE)	Range	r^2 (p-value)	Mean (± SE)	Range	r^2 (p-value)
Total number of species	18.4 (1.97)	9-33	0.42 (0.082)	11.1 (0.99)	6-17	-0.56 (0.090)
Number of emergent species	17.1 (1.81)	8-31	0.46 (0.056)	6.3 (0.70)	2-10	0.27 (0.445)
Number of *Carex* species	1.1 (0.38)	0-5	0.32 (0.193)	0.6 (0.22)	0-2	0.25 (0.493)
Number of *Potemogeton* species	0.3 (0.11)	0-1	-0.084 (0.741)	2.0 (0.52)	0-4	-0.93 (<0.001)
Number of submergent species	0.6 (0.19)	0-3	-0.27 (0.265)	4.0 (0.89)	0-7	-0.70 (0.025)
Number of perennial species	16.4 (1.74)	8-31	0.40 (0.096)	10.6 (0.90)	6-16	-0.56 (0.092)
Number of obligate wetland species	11.4 (1.57)	3-25	0.33 (0.185)	8.5 (1.01)	4-14	-0.737 (0.015)
Number of weed species	2.4 (0.35)	0-5	0.41 (0.095)	0.4 (0.22)	0-2	-0.08 (0.828)
Percent pioneer species	11.9 (0.98)	4.8-20	0.93 (0.713)	6.7 (2.0)	0-16.7	0.836 (0.828)
Number of sensitive species	2.5 (0.53)	0-8	0.15 (0.566)	1.5 (0.50)	0-5	-0.83 (0.003)
Number of tolerant species	4.1 (0.55)	1-9	0.47 (0.05)	2.7 (0.47)	0-5	0.52 (0.125)
Percent emergent species	93.1 (1.50)	81.5-100	0.13 (0.6)	61.4 (8.69)	20-100	0.69 (0.029)
Percent obligate wetland species	58.6 (3.01)	33.3-81	0.14 (0.586)	75.6 (3.96)	57.1-92.3	-0.59 (0.071)
Percent weed species	13.2 (1.89)	0-33.3	0.28 (0.255)	3.5 (1.97)	0-18.2	-0.079 (0.828)
Percent exotic species	8.5 (1.92)	0-30	0.22 (0.384)	7.6 (2.07)	0-20	-0.31 (0.384)
Percent taxa with DEL anomalies		Not measured			Not measured	
Relative abundance	3.13 (0.15)	1.6-4.5	-0.07 (0.782)	3.69 (0.19)	2.9-4.5	-0.82 (0.004)
PIBI	37.4 (1.58)	26-50	-0.08 (0.756)	40.0 (3.09)	26-54	-0.887 (0.001)

Note: Spearman correlation coefficients (r^2) reflects statistical significance between each metric and surface area.

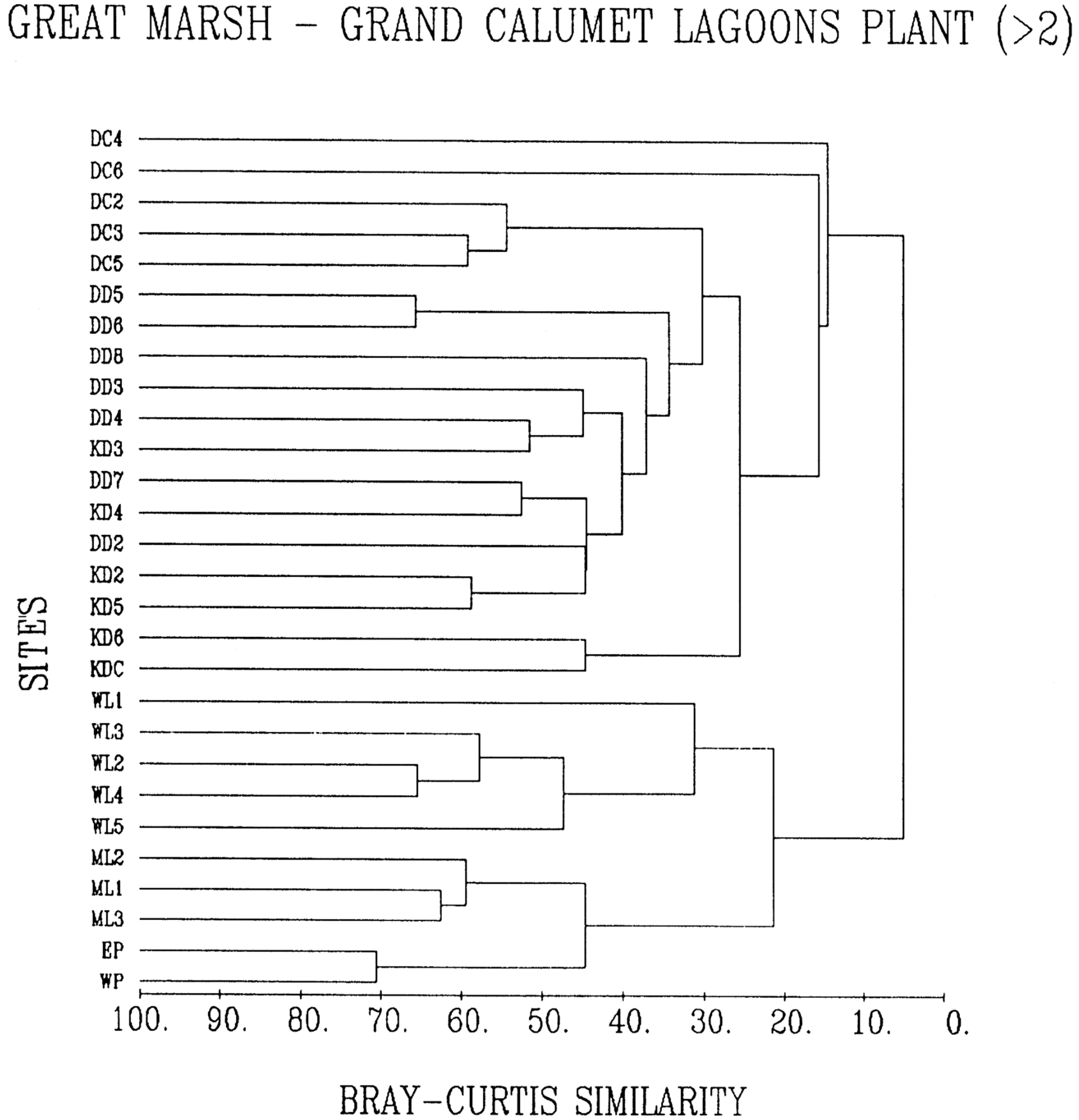

Figure 2 Cluster analysis of palustrine and riverine sites from Northwest Indiana using Bray-Curtis similarity. Only those taxa that were found in more than two samples were used in the analysis.

Results

Species composition and similarity

Ninety-five species of aquatic vascular plants were found in 42 families from riverine and palustrine wetlands (Stewart et al., 1997; Stewart et al., 1999b). The most common families represented were Cyperaceae (15 species), Polygonaceae (nine species), and Juncaceae (six species). Fourteen submergent, four floating, two woody, and 75 emergent aquatic plant species were found. Five species found were on the Heritage data base listing for the State of Indiana: *Juncus balticus var. littoralis* (rare), *Carex bebbii* (threatened), *Scirpus torreyi* (endangered), *Hydrocotyle americana* (endangered), and *Utricularia minor* (endangered) (Natural Heritage Data Center, 1994).

Riverine and palustrine wetlands formed two distinct clusters using Bray-Curtis similarity at a similarity coefficient of about 0.18 (Fig. 2). This divergent pattern between palustrine and riverine sites determined that separate PIBI indices should be developed (Table 1).

Table 3 Total PIBI scores, integrity classes, and a description of class attributes modified from Karr (1981).

Total PIBI Score	Integrity class	Class attributes
58-60	Excellent	Comparable to the best situation; all regionally expected species for the wetland habitat type present with regards to surface area, including the most sensitive forms, are present with a complete array of obligate wetland, emergent, submergent, and indicator taxa; balanced wetland function.
48-52	Good	Species richness showing some decline, especially because of the loss of the most sensitive forms; some indicator species, life styles, and guild function may be less than optimal; function metrics show some signs of stress.
40-44	Fair	Additional loss of integrity is a result of loss of sensitive forms, fewer species, and skewed function structure; number of perennial taxa starting to decline.
28-34	Poor	Dominated by weeds, tolerant species, and pioneer species; fewer obligate wetland species, declining numbers of life styles, indicator species, and species richness; diseased plants may be present.
12-22	Very poor	Low mean relative abundance, mostly tolerant and pioneer forms; exotic species common, diseased plants present (DEL).
0	No plants	Repeated sampling finds no plants.

Riverine sites from the Great Marsh formed a cluster that lacked further watershed discrimination based on stream membership. The palustrine sites had two distinct clusters; the West Lagoon sites formed a cluster, while the Middle Lagoon and pond sites formed a second group. An ordination by non-metric, multi-dimensional scaling (MDS) showed three distinct groups that closely followed the cluster analysis, thus no figure is shown. Along with the three main groups, the West Lagoon sites formed a group in apparent order of increasing disturbance.

In addition to cluster analysis, we examined patterns in the number of species, Shannon-Wiener diversity, and evenness. The number of species and Shannon-Wiener diversity were lowest at two of the degraded palustrine sites and at a riverine wetland with poor habitat. Evenness did not show any relationship with either number of species or Shannon-Wiener diversity. Details are available from the senior author.

Structural attributes of aquatic macrophyte communities

The number of species is the most widely used diversity index (Smith et al., 1985; Davis and Simon, 1995). The reference condition hypothesis was that the number of aquatic macrophyte species would increase with biological integrity. The number of species ranged from seven at several of the palustrine sites to more than 30 at several of the riverine sites (Table 2). The reference condition expectation for number of species did not show a surface-area relationship (Table 2) for palustrine sites (Fig. 3a) or riverine sites (Fig. 4a). The two largest palustrine sites (WL3 and WL5) had the lowest num-

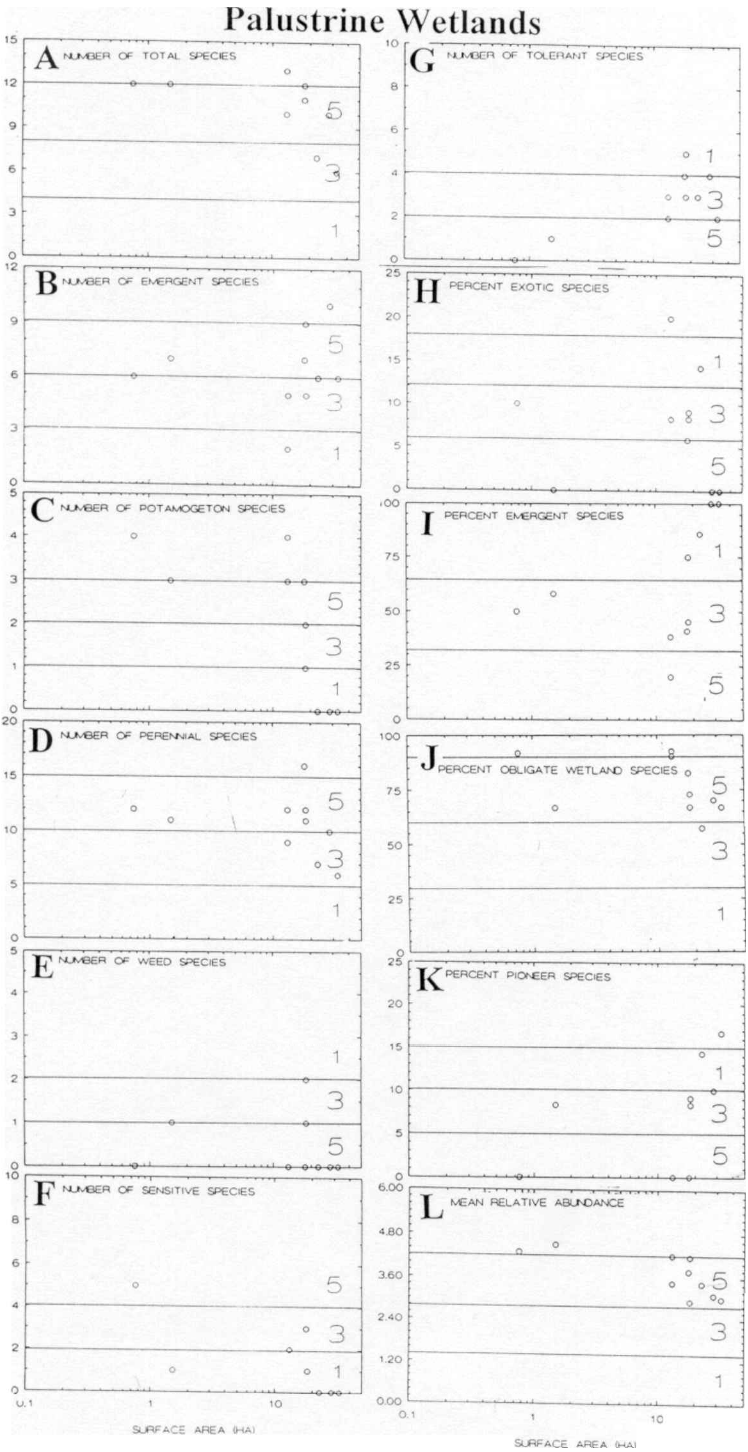

Figure 3 Attributes of aquatic plant communities plotted against surface area used in assessment of biotic integrity from palustrine sites. A = number of species, B = number of emergent species, C = number of *Potemogeton* species, D = number of perennial species, E = number of weed species, F = number of sensitive species, G = number of tolerant species, H = percent exotic species, I = percent emergent species, J = percent obligate wetland species, K = percent pioneer species, and L = average relative abundance based on mean species cover.

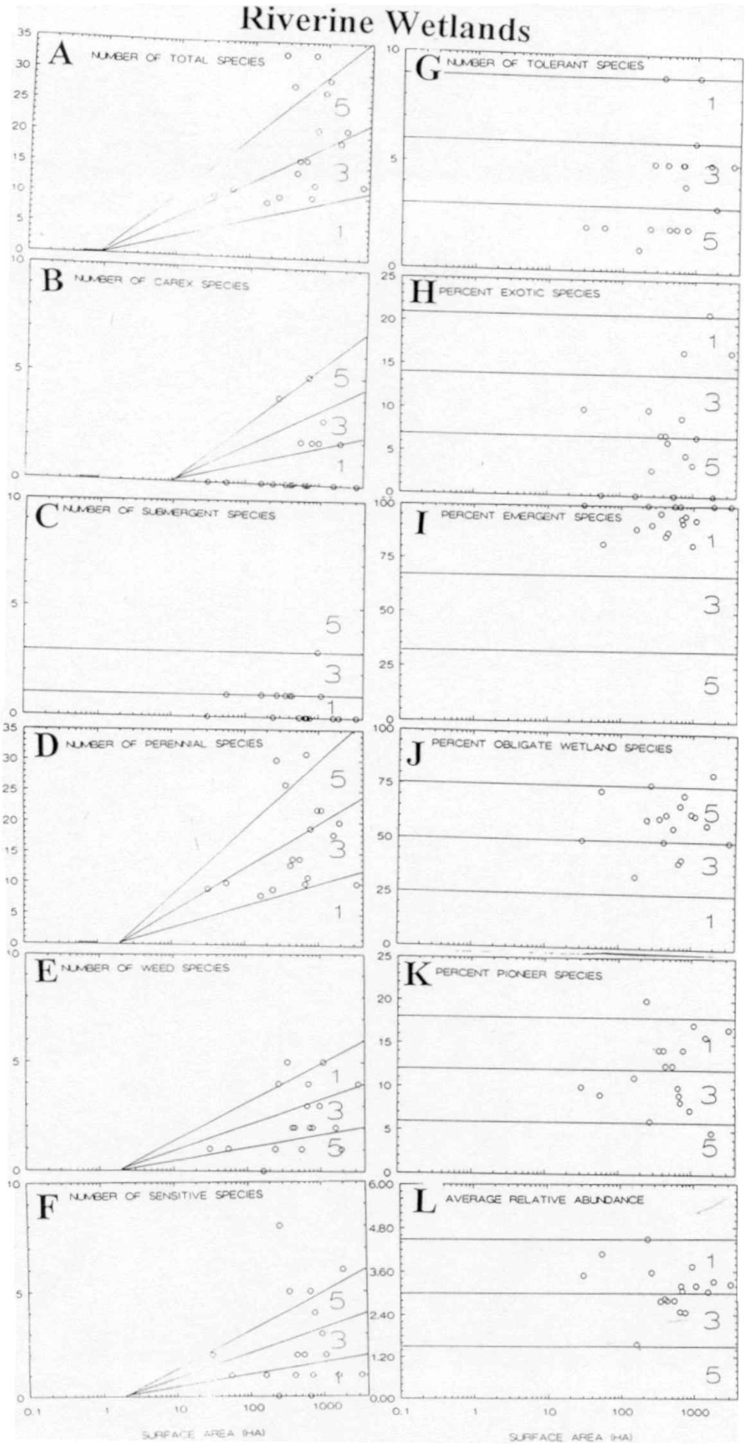

Figure 4 Attributes of aquatic plant communities plotted against surface area used in assessment of biotic integrity from riverine sites. A = number of species, B = number of *Carex* species, C = number of submergent species, D = number of perennial species, E = number of weed species, F = number of sensitive species, G = number of tolerant species, H = percent exotic species, I = percent emergent species, J = percent obligate wetland species, K = percent pioneer species, and L = average relative abundance based on mean species cover.

bers of species and were among the most degraded sites in the entire study.

Members of the genus *Carex* are worldwide in their distribution and are an important component of many regional wetlands (Bernard and Soukupova, 1988). We expected to find a greater number of *Carex* species associated with high quality wetlands. The number of *Carex* spp. was never more than two species at palustrine sites and ranged from zero to five at riverine sites (Fig. 4b). This metric was not found to be useful for assessing palustrine wetlands since these taxa were not well-represented, but should be investigated in other types of wetland habitats. We substituted the number of emergent species for number of *Carex* species in palustrine systems (Fig. 3b). Increased numbers of emergent species were expected with increasing biotic integrity. The emergent plant species found in palustrine wetlands ranged between two to 10 species.

The highest *Potamogeton* species richness exists in eastern North America (Wiegleb, 1988) and most species are found in lentic waters with sand substrates (Pip, 1987). Flow and water level fluctuation appear to affect the occurrence of some species with each having its preference for several chemical variables (Kadono, 1982). In lentic systems, the reference condition hypothesis was for a greater number of *Potamogeton* species with increased biological integrity. The number of *Potamogeton* species appeared to be a good indicator of high quality sites in palustrine wetlands. Although this metric did not show any relationship with surface area (Fig. 3c), fewer *Potamogeton* species were observed with increasing degradation and the most degraded palustrine sites had none. However, in riverine wetlands only one species was found. Since the number of *Potamogeton* species was not a useful metric in riverine wetlands, an alternative, more generalized metric incorporating the number of submergent species was used. The reference condition hypothesis was for an increasing number of submergent species with increasing biological integrity. Submergent plant species did not show a surface area relationship in riverine systems (Fig. 4c). There were typically three or fewer submergent species in our riverine wetland sites. However, much of our natural riverine wetland streams have been modified, thus limiting possible diversity. To account for this limitation, reference condition expectations were established higher than what was observed.

Disturbance can favor annuals over perennials and facilitate exotic invasions (Wienhold and van der Valk, 1989; Ehrenfeld and Schneider, 1991). Due to their greater exposure risk and the possible bioaccumulation of toxins over many years, the reference condition hypothesis was that perennial species have the potential of being more sensitive than annuals to longer-term impacts. This metric's reference condition expectation showed no relationship to surface area in palustrine wetlands (Fig. 3d), but appeared to have a surface area relationship in riverine systems (Fig. 4d), although it too was not significant (Table 2). The number of perennial species was used for both wetland types instead of the percentage, since the most disturbed sites had 100% perennial species and low species diversity.

Weeds tend to be more abundant under disturbed environmental conditions and are able to invade along edges (Baker, 1986; Bazzaz, 1986). The reference condition hypothesis was that there should be an inverse relationship between the number and percentage of these species and biological integrity. Regional texts were used to determine the list of weed species (Swink and Wilhelm, 1994; Eggers and Reed, 1997). In our study area, eight species were classified as weeds: *Polygonum persicaria*, *Polygonum punctatum*, *Rumex crispus*, *R. obtusifolius*, *Solanum dulcamara*, *Typha angustifolia*, *T. latifolia*, and *Urtica procera*. The number of weed species was chosen as a candidate metric for palustrine wetlands (Fig. 3e). The worst palustrine study site supported two weed species, in contrast, riverine wetlands had a maximum of five species. Thus, the PIBI could have used either the percentage or number of weed species (Fig. 4e).

Species tolerance and sensitivity

Swink and Wilhelm (1994) developed the coefficient of conservatism (CC) to rank species according to their habitat and historical placement in natural ecosystems. They assigned a rank value of zero where there was little confidence that the species comes from a natural area, while a ranking of ten suggested that it was found in a least-impacted natural area. We hypothesized that species with CC values of eight or above are sensitive and are the first to disappear under declining biological integrity. Nineteen species were considered sensitive and represented 20% of those found (e.g., *Sagittaria rigida, Peltandra virginica, Carex utriculata*, and *Utricularia minor*). We did not find a relationship between the number of sensitive species and surface area for either wetland type (Fig. 3f and 4f). Only five sites had no sensitive species, and three of these were among the most degraded sites.

Abundance of tolerant species is an indicator of degraded conditions and is inversely correlated with biological integrity (Davis and Simon, 1995). Tolerant species, those that increase with increasing degradation and disturbance (Karr, 1981), were defined as those with CC values of two or less or those described as tolerant by regional botanists (Swink and Wilhelm, 1994; Eggers and Reed, 1997). Species such as *Myosotis scorpioides, Eupatorium serotinum,* and *Equisetum arvense* were classified as tolerant. The reference condition expectation for this metric should show no relationship with surface area (Fig. 3g and 4g), since tolerant species should be no more abundant at small versus large least-impacted wetland systems. However, the largest riverine surface area sites had a statistically significant relationship with number of tolerant species that was attributed to greater impairment (Table 2).

In regions where there is little information on tolerance, the number or percentage of exotic species can be substituted as a metric. Exotic species are not indigenous to an area or have largely spread as a result of intentional or accidental introduction (Mooney and Drake, 1986; Center et al., 1991; Natural Areas Association, 1992; McKnight, 1993; Mills et al., 1993). Twelve exotic species were found in our study, including *Rumex crispus*, *Nasturtium officinale*, *Lythrum salicaria* and *Myriophyllum spicatum*. The reference condition expectation hypothesis was that the percentage of exotic species would be inversely related to biological integrity. No relationship between the percentage of exotic species and surface area was observed for either wetland type (Fig. 3h and 4h, Table 2). The most degraded sites had the highest percentage of exotic species.

Functional aspects of aquatic macrophyte communities

We view the percent of emergent species as a guild measurement that describes the 'layered edge' of aquatic plants that often surround high quality wetlands. These layered edges are a measure of the buffering capacity of wetlands and are a measure of riparian corridor quality. The reference condition expectation hypothesis for percent emergent species was that increased percentages would be observed with increased biological integrity. We did not expect a relationship between surface area and percent emergent species for reference condition expectations (Fig 3i and 4i). Reference condition expectations were higher for emergent plant species in riverine wetlands than in palustrine systems (Table 1). The higher expectations for riverine sites were due to the increased number of floating and submerged species in lentic study sites. The percentage of emergent species needs to be reverse scored because of the loss of the more sensitive species in the more degraded sites. For example, some very degraded sites may be largely made up of *Typha* or *Phragmites*.

Eggers and Reed (1997) defined obligate wetland plants as those species occurring in wetlands with an estimated probability of greater than 99% under natural conditions. The reference condition hypothesis was that obligate wetland species are guild specialists that decline with increasing hydrologic disturbance. We found no relationship between surface area and percentages of obligate wetland species since these species are expected regardless of wetland size (Fig. 3j and 4j). Declining percentages of obligate wetland species were observed at degraded sites in palustrine and riverine wetlands.

Pioneer species are early successional plants that first colonize disrupted habitats and show dramatic annual differences in population and species density (Whittaker, 1993). Typically, pioneers are native species that depend upon a seedbank and would appear after disturbance or lowering of water levels. They differ from tolerant species since they are more abundant only when newly disturbed habitats are colonized and as succession progresses, they usually decline over time. Pioneer species are not generally invasive or able to replace established species, as can weedy species. Species such as *Impatiens capensis* and *Lobelia cardinalis* are examples of pioneer species. Our reference condition expectation hypothesis was that increased percentages of pioneer species would be inversely related to biological integrity. Neither palustrine (Fig. 3k) nor riverine (Fig. 4k) wetlands had percentages of pioneer species greater than 20 % and no relationship with surface area was observed. Palustrine wetland sites along a disturbance gradient showed an increased number of pioneer species.

Individual health, condition, and abundance

For each study site, the modified Braun-Blanquet cover abundance values were averaged for each species over the site cover estimates to calculate a mean relative abundance. This mean cover abundance is comparable to evenness. The reference condition expectation hypothesis was that a direct relationship may exist between high mean relative abundance and biological integrity. No relationship was observed between surface area and mean relative abundance at riverine sites (Fig. 3l) but there was a significant relationship for palustrine sites (Fig. 4l). Mean relative abundance values were 1.4 to 3.0 for palustrine and riverine wetlands. Values less than 1.4 may be indicative of disturbed habitats, while values greater than 2.8 would indicate least-impacted natural areas.

The percentage of physical abnormalities is meant to identify the lowest levels of biological integrity (Karr, 1981; Karr et al., 1986). Aquatic macrophyte communities may possess eroded leaves and stalks or lesions caused by boring insects, rust, ozone or acidic air deposition. Deformities in plants including eroded stems and leaves (DEL), can include the presence of asymmetry and developmental instability (Freeman et al., 1993; Tracy, 1995). Freeman et al. (1993) found that within plant variance in leaf symmetry included differences in whorl variance of leaf length, leaf width, and the ratio of leaf length to leaf width. The reference condition expectation hypothesis was that the percentage of DEL would be inversely correlated with biological integrity. Although this was not measured during this study, it could prove to be an important metric for conditions of the grossest environmental degradation and should be further examined. A single incidence of DEL on a single individual is not sufficient to downgrade a site, rather it should represent a common (>50%) condition among most individuals of a single species. This characteristic was estimated since it must affect a low percentage of species at a site in order for that site to be considered a least-impacted natural area. The difference between leaf erosion and normal die-off in the fall should be examined. A hindrance to development of DEL as a metric in the field would be the difficulty inherent in discriminating between normal leaf plasticity and abnormal asymmetry.

Plant index of biotic integrity

A plant index of biotic integrity was calculated for 28 riverine and palustrine sites (Table 2). We modified Karr's (1981) description of IBI class scoring attributes for fish to reflect those appropriate for aquatic plant assemblages (Table 3). Based on knowledge of the area and other aquatic indicators (Stewart and Butcher, 1997; Stewart et al., 1997, 1998b,c, 2000; Gillespie et al., 1998; Simon, 1998b; Simon and Stewart, 1998, 1999), the PIBI provided comparable assessments with other indicators and was able to discriminate the condition of these riverine and palustrine wetlands. Sites that received the highest PIBI scores were less affected by anthropogenic disturbance, that is, non-point source landfill, ditched stream channels, and impervious surfaces.

Palustrine wetlands had PIBI scores related to their proximity to an industrial landfill. The far-field (sites furthest from the landfill) Middle Lagoon sites had PIBI scores ranging from 'fair' to 'good', while the near-field (sites closest or adjacent to the landfill) West Lagoon sites scored 'poor' or 'very poor' (Table 3). None of the sites in our study had scores in the excellent range, but a single site in the West Pond scored 'good-excellent' (Table 3). The West Pond was a near-field site sampled on the opposite shore from an industrial landfill. This site had high quality wetlands despite the adjacent landfill, including several rare taxa, and a mixture of emergent, floating, and submergent plants (e.g., three *Potamogeton* species and two *Utricularia* species), and the highest average coefficient of conservatism (Stewart et al., 1999a).

The riverine wetlands in this study represent a significant disturbance gradient (Stewart et al., 1997). The Kintzele Ditch watershed has the most disturbed land use (Hardy, 1984), lower quality wetlands, poorer water quality (Stewart et al., 1997), degraded diatom communities (Stewart et al., 1999c), and site-related differences in macroinvertebrate communities (Stewart et al., 2000). The PIBI for the Kintzele Ditch watershed was lower in privately-owned areas than in the state and national park. Derby Ditch PIBI scores were intermediate between the other two systems. Dunes Creek PIBI scores, with few exceptions, were the highest among the three riverine systems, reflecting its more natural wetlands and that the majority of its sites were on public lands. For example, DC2 (PIBI = 50), DC3 (49), and DC5 (46) were fairly high quality wetlands, while DC4 (PIBI = 32) was a shaded site located along a small wooded riparian corridor and had few wetland plants. Site DC6 (PIBI = 31) was located outside of the state park beside a railroad and drained a residential area.

Discussion

Concepts toward the development of an index of biological integrity

The index of biotic integrity was first used to evaluate fish communities of small streams in the Central United States (Karr, 1981; Karr et al., 1986; Davis and Simon, 1995). The index removes investigator bias by using characteristics, termed 'metrics', to provide descriptions of community stability. Karr (1981) used three categories of metrics to describe communities including species richness and composition, trophic guilds, and individual health, condition, and abundance metrics. The index of biotic integrity has been extensively modified based on regional use, resource type, and organismal indicator and is viewed as a family of indices (Simon, 1998b; Simon and Stewart, 1998; Stewart et al., 1999a). When we developed the PIBI, we considered the intentions of the original metrics when replacing the original IBI metrics with an equivalent plant metric (Karr et al., 1986).

Species richness and composition metrics including diversity and indicator characteristics are specialist metrics that can describe changes in condition of the resource (Karr et al., 1986; Stewart et al., 1999a). According to the intermediate disturbance hypothesis, the number of species is often greatest in areas of intermediate disturbance; pristine conditions will sometimes have fewer species and these will often be different species than those found under disturbed conditions (Connell, 1978). This trend has not been confirmed for aquatic plant communities and was not incorporated into the original IBI from which this work is patterned; however, we attempted to consider this possibility in setting reference condition expectations for relative abundance.

Unique plant community guild membership and life histories have evolved in response to different habitats (Swink and Wilhelm, 1994). Existing on the margins of wetlands are a group of plants that maintain an affinity to differing water levels (Eggers and Reed, 1997). This complexity is incorporated into guild metrics including percent emergent and percent obligate wetland species. A healthy riverine complex may have layers of emergent species along the stream edge where some submergent plants would be expected. A healthy palustrine complex may be similar, but has a greater complement of submergent and floating species. In the most degraded situations, we found that floating and submergent growth forms disappeared (Stewart et al., 1999a). Additional metrics may focus on changes in habitats and water levels, that is, including soil saturation for emergent species or tolerance to depth changes, which could be an indicator of stability, erosion, turbidity, or increases in total dissolved solids.

The CC originally developed for the Chicago region was used to determine tolerance and sensitivity measures (Swink and Wilhelm, 1994). For regions not as well known as the southern shore of Lake Michigan, further research effort will be needed to classify species. Modifications for other regions may require additional metric substitutions including percentages of floating species or regionally important indicator species. Additional metrics may include littoral, profundal, or emergent riparian zone aquatic macrophytes. Substitution for tolerance metrics may include the percentage or number of exotic and invasive taxa. For aquatic macrophytes, a species list of various indicator species that would be extremely sensitive to changes in habitat should be produced. Karr et al. (1986) suggested that this list should be less than 5 to 10% of the total species possible, so that the initial loss of these taxa would indicate the beginning of a decline in biological integrity. Our list included 20% of the combined species list; however, the list for each of the two wetland types approximated the 10% cutoff.

Karr (1981) and Karr et al. (1986) used abundance, the proportion of hybrids, and the presence of disease to evaluate individual health, condition, and abundance. We chose not to include the proportion of hybrids metric in our PIBI because of the difficulty in determining hybridization. Substitute metrics for the proportion of hybrids could include reproductive guilds, such as the percentage of rhizome reproducing species as a measure of disturbed habitats. The presence of increased cloning or presence of monotypic stands would indicate a reduction in biological integrity.

Biological integrity response for two wetland types

Biological endpoints currently used by botanists include loss of sensitive species (Lovett Doust and Lovett Doust, 1995), presence of exotic species (D.A. Albert, Michigan Natural Features Inventory, Lansing, Michigan, pers. comm.), or declines in species richness and diversity (Elzinga et al., 1998). The development of a multi-metric index for plant assemblages improves upon univariate indices that may lack the ability to measure a complex system. As a result, a PIBI can detect a broad range of response signatures to disturbance. This assists in effectively evaluating the quality of remaining wetlands and in establishing restoration standards.

The need to separate riverine from palustrine wetlands was demonstrated by cluster analysis, multidimensional scaling, and diversity indices. Wetland sites located in different ecological regions should be calibrated for the PIBI based on varying conditions and expectations. Once the proposed PIBIs were calibrated in this study, the results showed similar responses for the two wetland types tested. These responses were irrespective of the source of the wetland damage, whether it was a combination of contaminants, degraded habitat, or associated hydrological changes. The least-impacted sites in this study scored reasonably close together, 50 or better, and the poorest sites scored in the mid- twenties to low-thirties.

Conclusions

Wetland aquatic plant communities are being destroyed by development, drainage, exotic species invasion, and changes in lake and river water quality. These threats to wetland conservation must be controlled or valuable components of the aquatic community and their associated functions will be lost. The development of a PIBI will identify and classify high quality wetlands and further the protection of biotic integrity and diversity.

The PIBI incorporates critical attributes of wetland plant assemblages previously identified by botanists. The loss of sensitive species, number of weed species (Baker, 1986; Bazzaz 1986), and the substitute metric, number of exotic species (Mooney and Drake, 1986; Center et al., 1991; Natural Areas Association, 1992; McKnight, 1993; Mills et al., 1993) are important metric components of riverine and palustrine PIBIs. These should be used in conjunction with the coefficient of community and floristic quality index that were developed to assess the degree of conservatism of a wetland (Swink and Wilhelm, 1994; Herman et al., 1997), and are considered complementary univariate biocriterion tools.

A PIBI provides a powerful management tool enabling a rapid assessment of wetland quality. This index incorporates several attributes from structural, functional, and tolerance groups of metrics to derive a wetland condition score. Presently, wetland delineation only identifies the presence of a wetland for regulatory purposes (Stewart et al., 1999a), while our multimetric index provides information on wetland health.

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