Aquatic Ecosystem Health and Management Society

ELSEVIER

Aquatic Ecosystem Health and Management 3 (2000) 407–418

Aquatic Ecosystem Health & Management

www.elsevier.com/locate/aquech

Modification of an index of biotic integrity for assessing vernal ponds and small palustrine wetlands using fish, crayfish, and amphibian assemblages along southern Lake Michigan

T.P. Simon[a,*], R. Jankowski[b], C. Morris[b]

[a]*US Fish and Wildlife Service, 620 South Walker Street, Bloomington, IN 47403-2121, USA*
[b]*Department of Biological Sciences, Purdue University — North Central, 1401 S. Hwy 421, Westville, IN, USA*

Abstract

We developed an index of biotic integrity (IBI) based on crayfish, fish, and amphibian assemblages to assess vernal ponds and palustrine wetland habitats of less than 5 ha along the southern shore of Lake Michigan. We found that the modified IBI based on three crayfish, twelve fish, and seven amphibian species collected during our surveys provided a more complete assessment than one based on any single taxonomic group. The new scoring criteria included the number of amphibian and fish species, number of benthic species, percent of individuals as pioneer species, percent of individuals as exotic species and percent of individuals with complex reproductive modes for metrics developed for larger palustrine wetlands. Low-end scoring procedures were not required; however, species composition metrics that did not possess the specified attribute received a '0' score rather than a '1'. Correlation coefficients suggest that the reference conditions developed during this study of IBI metrics are able to differentiate high-quality biological assemblages from disturbance gradients that lowered biological integrity in small palustrine wetlands and vernal ponds. We found that the distribution of the index scores for Miller Woods was skewed to the low end of biological integrity with increased distance from Lake Michigan and proximity to edges. Published by Elsevier Science Ltd on behalf of AEHMS.

Keywords: Multimetric index; Structure and function; Reference conditions

---

1. Introduction

Vernal ponds and small palustrine wetlands, less than 5 ha, are significant habitats for amphibian and crayfish species (Page, 1985; Jezerinac et al., 1995; Minton, 1998). These wetland habitats have declined worldwide as a result of filling, hydrological alteration and urban encroachment (Danielson, 1998; Simon, 1999a). Wetland biological community reference condition expectations are generally lacking because the loss of more than 85% of palustrine wetlands in Indiana has left few that can serve to calibrate 'least-impacted' conditions (Davis and Simon, 1995; IDEM, 1998; Simon, 1998).

Biological assemblages in vernal ponds and small palustrine wetlands are dependent on water quantity and quality to exhibit biological integrity. For example, larval stages of amphibians typically require specific water depths in order to reach metamorphosis. In addition, many of these ponds lack fish, which would prey on benthic macroinvertebrates, zooplankton, and amphibian assemblages (Whitman et al., 1990; Rovelstad, 1995; Simon, 1999a). The presence of fish in these small wetlands causes

---

* Corresponding author. Tel.: +1-812-334-4261, ext.: 213; fax: +1-812-334-4273.

E-mail address: thomas_simon@fws.gov (T.P. Simon).

1463-4988/00/$20.00 Published by Elsevier Science Ltd on behalf of AEHMS.
PII: S1463-4988(00)00033-6

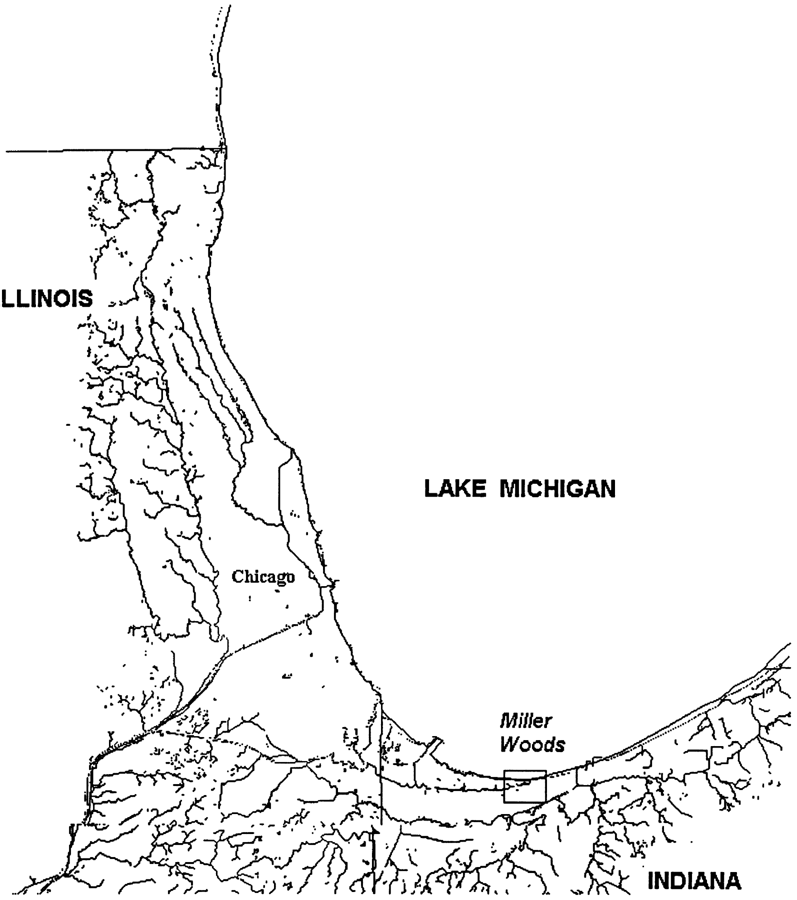


Fig. 1. Study area showing the location of Miller Woods along the southern shore of Lake Michigan.

cascading trophic level interactions that direct the function of vernal ponds and small palustrine wetlands (Rovelstad, 1995).

Simon (1998) developed an index of biotic integrity (IBI) for fish assemblages in dunal palustrine wetlands based on Karr (1981) and Karr et al. (1986). This modified index (Simon, 1998) did not adequately assess the biological integrity of palustrine wetlands, smaller than 5 ha, based on reference conditions developed from 50 wetlands along southern Lake Michigan in Illinois and Indiana. Simon and Stewart (1998) used this modified index to describe a disturbance gradient from an industrial landfill in the Grand Calumet Lagoons. The index did not adequately assess two dunal ponds that were less than 2 ha in size because such wetlands naturally possess few fish species.

A variety of indicator assemblages have been used to assess wetlands (Danielson, 1998); however, few have actually been used to develop and calibrate an IBI. Moyle and Randall (2000) suggested the use of amphibian species for IBI development to assess Sierra Nevada watersheds. Amphibian assemblages are fairly diverse in Northwest Indiana and their relative abundance declines with the loss of permanent water (Minton, 1998). Moyle and Marchetti (1999) suggested the use of crayfish, mollusks and stonefly assemblages as IBI indicators for California streams that possess low species richness. Crayfish, which are perhaps the least-used indicator taxon, exhibit well-structured assemblage differences between degraded and pristine habitats (Lodge et al., 1986; Hill and Lodge, 1994). Fish were used extensively to evaluate aquatic habitats (Simon and Lyons, 1995; Simon, 1998a,b; Simon and Stewart, 1998); however, fish are inadequate when used alone for small wetland assessment.

The purpose of this paper is to evaluate the structure and function of small palustrine wetlands and vernal ponds to document assemblage characteristics, evaluate assemblage indicator benchmarks, and develop reference conditions for southern Lake Michigan. The results of this study were used to modify the palustrine wetland IBI developed by Simon (1998b), which is based exclusively on fish assemblages.

2. Methods and materials

2.1. Study area description

The study area includes vernal ponds and small palustrine wetlands in Northwest Indiana along the southern shore of Lake Michigan (Fig. 1). This area has been extensively changed by settlement during the last 250 years (Simon et al., 1989; IDNR, 1994). Most of the numerous small palustrine wetlands that existed at the turn of the century have been eliminated. Some of the wetlands that remain are protected as a part of the Indiana Dunes National Lakeshore (INDU) and Indiana Dunes State Park. They were previously studied by Shelford (1911) during ecological investigations of succession.

The Miller Woods subunit includes several hundred vernal ponds and small palustrine wetlands including some that are periodically connected, depending on hydrologic and groundwater conditions. These wetlands are the greatest concentration of remaining coastal palustrine wetlands in Northwest Indiana (IDNR, 1994). The Miller Woods subunit is surrounded by a variety of land uses ranging from residential and urban-industrial to some of the most pristine habitats that remain in Northwest Indiana.

2.2. Study design

We used a random stratified probability design (Overton et al., 1991) to assess biotic integrity of the ponds in Miller Woods. The study design we chose included the random selection of 62 wetlands from among the several hundred that occurred in Miller Woods. We numbered each of the wetlands occurring in Miller Woods and made a drawing slip for each. Each drawing slip had a single wetland number on it. Based on our stratified design strategy we sorted the drawing slips into four groups based on wetland size that ranged between 0.001 and 5 ha. We randomly drew 15 slips from each of four size classes. Two additional wetlands were selected for sampling in case of problems with access or other unforeseen circumstances. These wetlands were included into the final dataset. We used a subset of 25 wetlands from the 62 sampled that included 20 of the least-disturbed and 5 of the most-disturbed wetlands to calibrate the reference conditions for a newly modified index for small palustrine wetlands and vernal ponds. Site results were graphically depicted for each metric based on maximum length and width of ponds so that the final area was expressed in square meters.

2.3. Sampling effort, data collection, and reach selection

We used a 3 m common sense minnow seine with 3 mm bar mesh to collect amphibians, crayfish and fish from each of the 62 wetlands. Sampling was conducted between mid-June and mid-July. A three-person crew sampled all habitats in each wetland including littoral zones, deep pools, submerged vegetation beds, and backwaters or coves. Repeated seine sampling, including three seine hauls, within each pond was conducted for distances of 5 m to avoid snagging the net and losing the catch. Twenty-five wetlands were used to develop the reference condition expectation for the modified IBI in small palustrine wetlands. An additional 37 wetlands which were considered disturbed by various anthropogenic stresses (e.g. habitat degradation, exotic species introductions and land use) were used to test the classification ability of the newly modified index.

Species composition and relative abundance data was based on enumeration, measurement of total length ranges, and batch weight of all individuals for each species (Gerking, 1955; Smith, 1979; Page, 1985; Minton, 1998). Data recorded for each survey included the number of each species of crayfish, fish and amphibian captured; sampling section length, which depended on the size of the pond; sampling site location; duration of sampling effort; and habitat conditions. General population data were gathered on

Table 1
Classification of species collected from vernal ponds and small palustrine wetlands (<5 ha) along the southern shore of Lake Michigan in Northwest Indiana. Status symbols include: N = native, NI = non-indigenous, and E = exotic. Reproductive guild symbols include: C = complex with parental care, M = simple, miscellaneous, and N = complex, no parental care

Species	Status	Tolerance	Guilds			Pioneer species
			Feeding	Habitat	Reproductive	
Crayfishes						
Cambaridae						
*Orconectes propinquus,*northern clearwater crayfish	N	Sensitive	Omnivore	Benthic	C	
O. rusticus, rusty crayfish	NI	Tolerant	Omnivore	Benthic	C	X
O. virilis, virile crayfish	N	Mod. Tolerant	Omnivore	Benthic	C	X
Fishes						
Esocidae						
Esox americanus, grass pickerel	N	Moderate	Carnivore	Non-benthic	M	
Umbridae						
Umbra limi, central mudminnow	N	Tolerant	Omnivore	Non-benthic	N	
Cyprinidae						
Carassius auratus, goldfish	E	Tolerant	Omnivore	Non-benthic	M	
Notemigonus crysoleucas, golden shiner	N	Moderate	Insectivore	Non-benthic	M	
Pimephales notatus, bluntnose minnow	N	Tolerant	Omnivore	Non-benthic	C	X
P. promelas, fathead minnow	N	Tolerant	Omnivore	Non-benthic	C	X
Ictaluridae						
Ameiurus melas, black bullhead	N	Tolerant	Omnivore	Benthic	C	
A. natalis, yellow bullhead	N	Tolerant	Omnivore	Benthic	C	
Centrarchidae						
Lepomis cyanellus, green sunfish	N	Tolerant	Insectivore	Non-benthic	C	X
L. gibbosus, pumpkinseed	N	Moderate	Insectivore	Non-benthic	C	
L. macrochirus, bluegill	N	Moderate	Insectivore	Non-benthic	C	
Micropterus salmoides, largemouth bass	N	Moderate	Carnivore	Non-benthic	C	
Amphibians						
Ranidae						
*Hyla v. verisicolor,*eastern gray treefrog	N	Sensitive	Omnivore	Non-benthic	M	
Psuedacris triseriata, chorus frog	N	Sensitive	Omnivore	Non-benthic	M	
Rana clamitans, green frog	N	Moderate	Omnivore	Non-benthic	M	X
R. catesbeiana, bullfrog	N	Moderate	Omnivore	Non-benthic	M	X
R. sylvatica, wood frog	N	Sensitive	Omnivore	Non-benthic	M	
Ambystomidae						
Ambystoma tigrinum, tiger salamander	N	Sensitive	Carnivore	Benthic	M	
Notophthalmus viridescens, red-spotted newt	N	Sensitive	Insectivore	Benthic	M	

all species captured in seining surveys. Relative abundance was expressed as catch-per-unit of effort (CPUE), that is, the number of organisms captured per three, 5 m seine hauls. Individuals in the catch were assigned to various guilds (species composition, tolerance, trophic, and reproductive) to assess the structure and function of wetland communities (Table 1). Guild assignments follow literature review

Table 2
Modified IBI for vernal ponds and small palustrine wetlands (<5 ha) along the southern shore of Lake Michigan

Metric	Score		
	5	3	1
Species richness and composition			
1. Number of total species	Varies with surface area (Fig. 2a)		
2. Number of amphibian and fish species	Varies with surface area (Fig. 2b)		
3. Number of benthic species	≥ 3	1–2	0
4. Number of sensitive species	≥ 4	2–3	< 2
5. Percent individuals as tolerant species	$< 33\%$	33–67%	$> 67\%$
Trophic Condition			
6. Percent individuals as omnivores	$\geq 67\%$	33–66%	$< 33\%$
7. Percent individuals as insectivores	$\geq 30\%$	15–29.9%	$< 15\%$
8. Percent individuals as pioneer species	$\leq 3\%$	3.1–5.9%	$\geq 6\%$
Abundance and Condition			
9. Relative abundance	Varies with surface area (Fig. 2i)		
10. Percent individuals with complex reproductive modes	$\geq 67\%$	33.1–66.9%	$\leq 33\%$
11. Percent individuals as exotic species	$\leq 15\%$	15.1–30%	$> 30\%$
12. Percent individuals with Deformities, Eroded fins, Lesions, or Tumors (DELT)	$< 0.1\%$	0.1–0.5%	$> 0.5\%$

assignments in Simon (1999b) and Goldstein and Simon (1999).

Wetland surface area (m^2) was used as a scalar to graphically depict wetland similarity, because drainage area of wetlands was often difficult to interpret (Hughes et al., 1981). Patterns in biological assemblage characteristics for select structure and function attributes (Simon, 1998) were evaluated on a watershed basis using a transformed log scale following standard IBI procedures in Karr (1981) and Karr et al. (1986).

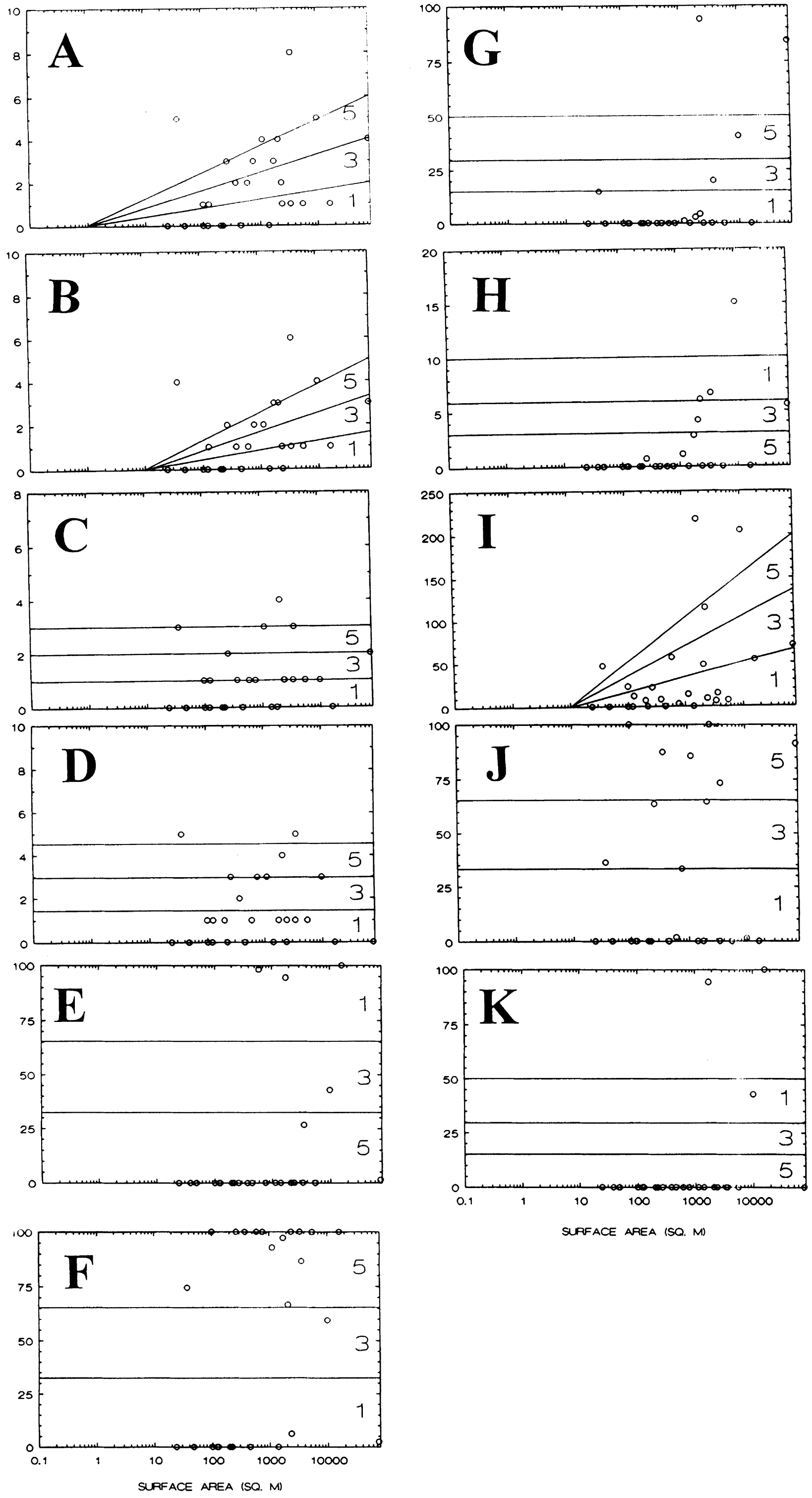
2.4. Statistics

Statistical patterns in assemblage attributes were examined with multivariate analysis of variance (MANOVA; SAS, 1985) to determine relative correlation regression coefficient of variance contributions between characteristics and reference wetland surface area. We evaluated 42 attributes of wetland assemblage characteristics identified by Simon and Lyons (1995), Simon (1998) and Moyle and Marchetti (1999) in a review of depauperate species metrics that would best represent amphibian and fish populations in small palustrine wetlands and vernal ponds along southern Lake Michigan. Relationships between surface area and other metrics were determined using squared multiple correlations at a significance level of $r^2 \geq 0.5$ (Zar, 1984). Community differences between metric expectations were examined with a non-parametric Kruskal–Wallis test followed by a Mann–Whitney *U*-test (Conover, 1971). All results are reported at a significance level of $p < 0.10$ (Zar, 1984).

3. Results

3.1. Modifying the IBI for small palustrine wetlands and vernal ponds

The lack of a single indicator assemblage to assess small palustrine wetlands required that we include a variety of assemblages in our modified wetland index. The fish assemblage of many small wetlands includes a maximum of two species (Simon, 1998). This low species richness hampered attempts to categorize wetland quality. Reference conditions for small palustrine wetlands and vernal ponds were developed from least-impacted wetlands in the Miller Woods subunit. Simon (1998) found that wetlands smaller than 1 ha were generally too small to sustain a reproducing fish


A
0
2
4
6
8
10
5
3
1
B
0
2
4
6
8
10
5
3
1
C
0
2
4
6
8
5
3
1
D
0
2
4
6
8
10
5
3
1
E
0
25
50
75
100
1
3
5
F
0
25
50
75
100
5
3
1
0.1
1
10
100
1000
10000
SURFACE AREA (SQ. M)
G
0
25
50
75
100
5
3
1
H
0
5
10
15
20
1
3
5
I
0
50
100
150
200
250
5
3
1
J
0
25
50
75
100
5
3
1
K
0
25
50
75
100
1
3
5
0.1
1
10
100
1000
10000
SURFACE AREA (SQ. M)

assemblage and recommended against using the palustrine wetland IBI unless the assessment was carefully analyzed to ensure it was complementary to the intentions designed in the original analysis.

Metrics were revised and modified to reflect the differences in assemblage structure and function of small palustrine wetlands and vernal ponds (Table 2). Metrics were divided into four broad evaluation classes: (1) species richness and composition; (2) trophic structure; (3) community function; and (4) individual condition.

3.2. Assemblage assessment: species distribution and relative abundance

We collected three species of crayfish, twelve fish species and seven species of amphibians during our investigation of vernal ponds and small palustrine wetlands (Table 1). Species that numerically dominated palustrine wetlands included pumpkinseed (*Lepomis gibbosus*), golden shiner (*Notemigonus crysoleucas*) and goldfish (*Carassius auratus*). High-quality wetlands had as many as three different frog species including bullfrog (*Rana catesbeiana*), green frog (*R. clamitans*) and wood frog (*R. sylvatica*). The most frequently occurring species included northern clearwater crayfish (*Orconectes propinquus*, 36.7% of sites), tiger salamander (*Ambystoma tigrinum*, 30%), and rusty crayfish (*O. virilis*, 16.7%). Several species were collected from a single site including largemouth bass (*Micropterus salmoides*), grass pickerel (*Esox americanus*) and yellow bullhead (*Ameiurus natalis*).

3.3. Species richness and composition

Small palustrine wetlands and vernal ponds showed a surface-area relationship with the total number of species (Fig. 2a) and with the number of amphibian and fish species (Fig. 2b) metrics. Few fish species were generally expected in small ponds; however, higher numbers of amphibian and crayfish species were observed in higher-quality wetlands. We found that the presence of fish and amphibian species in a wetland was a good indication that it was a permanent year-round water source. Evidence for the permanence of water is the presence of long-lived salamander species such as tiger salamander or native fish species such as grass pickerel, pumpkinseed, bluegill (*L. macrochirus*) or green sunfish, *L. cyanellus.* The number of amphibian and fish species was substituted for the number of centrarchid species because usually not more than one sunfish species was found in small wetlands (Fig. 2b). We substituted the number of benthic species for the number of darter and madtom species because these taxa did not exist in small wetlands (Fig. 2c). Benthic species are niche equivalents that would respond to similar perturbations as darters and madtom species.

3.4. Community functional attributes

We retained the number of sensitive species (Fig. 2d) and the percent individuals as tolerant species (Fig. 2e) metrics following the same rationale as Simon (1998) but included classifications for crayfish (Page, 1985; Lodge et al., 1986; Jezerinac et al., 1995) and amphibians (Minton, 1998). Trophic composition metrics remained the same. We retained the percent individuals as omnivores (Fig. 2f), insectivores (Fig. 2g), and pioneer species (Fig. 2h) metrics.

The scoring criterion for small palustrine wetlands was significantly different from larger palustrine wetlands because omnivores are expected to dominate these smaller wetlands (Table 2). We found that more than 67% of the community were omnivores, which were significantly different (Mann–Whitney *U*-test statistic $= 29.1$, $p \leq 0.0001$) from those in larger palustrine wetlands. Simon (1998) found that less than 12.5% of the fish assemblage in larger high-quality wetlands would be expected to be omnivores. The increased number of crayfish and generalist feeding tadpoles are the primary cause of increased omnivore expectations in small wetlands and vernal ponds (Lodge and Hill, 1994). Insectivore

Fig. 2. Reference conditions showing IBI metric scores of “5” (representing reference conditions), “3” (deviates somewhat from reference conditions), and “1” (deviates strongly from reference conditions) for a modified IBI for small palustrine wetlands and vernal ponds. (a) Total number of species, (b) number of fish and amphibian species, (c) number of benthic species, (d) number of sensitive species, (e) percent individuals as tolerant species, (f) percent individuals as omnivores, (g) percent individuals as insectivores, (h) percent individuals as pioneer species, (i) relative abundance of all species, (j) percent individuals as complex spawners, and (k) percent individuals as exotic species.

expectations are similar for large palustrine wetlands, based on fish assemblages (Simon, 1998), and the percentage for small wetlands and vernal ponds (Table 2). These two expectations were not significantly different (Mann–Whitney *U*-test statistic $= 6.86$, $p \leq 0.552$) and were separated by less than 2%.

The percent of pioneer species expected for high-quality small palustrine wetlands and vernal ponds was also significantly different (Mann–Whitney *U*-test statistic $= 18.88$, $p \leq 0.0001$) from those in larger palustrine wetlands. Small palustrine wetlands and vernal ponds had less than 3% of the total individuals as pioneer species, while larger palustrine wetlands had maximum expectations of 24.7%. This difference may be the lack of fish species in many smaller ponds and the lack of few pioneering amphibian species. We did not observe a surface-area relationship with any of the functional metrics (Fig. 2) because they are measures of total organic carbon and macroinvertebrate densities that are not scaling factors.

3.5. Relative abundance and individual condition

We retained the relative abundance metric following Simon (1998). However, the CPUE is based on three, 5 m seine hauls rather than four as used in the previous study. Relative abundance showed a relationship with surface area (Fig. 2i).

We replaced the number of simple lithophils with the number of complex reproductive modes (Fig. 2j). Complex reproductive modes include those of organisms that construct nests, are ovigerous, or carry ova, sperm, or young for extended periods of time, and provide various levels of parental care. These species progeny typically include large amounts of yolk during larval stages (Simon, 1999b). All crayfish species were included because they are ovigerous spawners (Page, 1985). These species carry sperm and ova that are cemented to the female's abdomen and develop into larval instars that molt and remain attached to the female. All of the fish species in the genera *Pimephales*, *Ameiurus* and *Lepomis* build nests and provide extensive parental care for developing eggs, embryos, and larvae (Simon, 1999b). Increased parental involvement in the protection of eggs and embryos suggests an evolutionary complexity toward more sophisticated reproductive modes. This evolutionary progression in small palustrine wetlands may reflect limited space and increased vulnerability to predators.

The percentage of exotic species is a negative measure of disturbance in small palustrine wetlands and vernal ponds (Fig. 2k). We found goldfish and rusty crayfish increased in abundance in ponds that were disturbed by human activity. Goldfish are suspected pet releases in the INDU and may influence native zooplankton and invertebrate communities by their presence (Rovelstad, 1995). Rusty crayfish are imported by anglers for use as bait and were often observed in ponds that were adjacent to angler trails that lead to Lake Michigan. We do not expect either exotic goldfish or non-indigenous rusty crayfish in palustrine wetlands or vernal ponds with biological integrity.

The occurrence of deformities, eroded fins, lesions and tumors (DELT) commonly are correlated with exposure to toxins and reflect the lowest extremes of biotic integrity and are indicators of poor environmental health (Sanders et al., 1999). We did not find any DELT anomalies among the organisms we collected in the INDU.

4. Discussion

4.1. Community structure and function patterns

A depauperate fish assemblage is expected for small palustrine wetlands and vernal ponds, so that alternative assemblage indicators were needed to classify wetland quality (Simon, 1998). We combined crayfish, amphibian, and fish assemblages to quantify adequately the range of species interactions that are typical in these wetland complexes. Small palustrine wetlands and vernal ponds possess few sensitive species, few pioneer species, a high percentage of omnivores and insectivores, and tend to either possess all or no tolerant species. Metrics chosen as substitute metrics in the modified IBI all contribute significantly to explained variance (Table 3). The percentage of omnivores, DELT, pioneer species, exotic species, and relative abundance metrics were not statistically important. However, these attributes explain degraded assemblage structure and function that were undersampled in our reference database. Complex reproductive modes are a significant evolutionary attribute of small palustrine wetlands. The need to ensure that progeny are provided with large yolk reserves and parental protection may be a result of a harsh environment or may be a direct result of biotic interactions and predation pressures. Unprotected young are increasingly vulnerable to predators and would thus reduce parental fitness when they do not survive to reproduce (Simon, 1999b). The increased numbers of omnivores suggest that species are capable of feeding on a variety of resources ranging from detritus to animal protein.

4.2. Community assessment

Unlike larger palustrine wetlands, smaller wetlands and vernal ponds do not require low-end scoring modifications to classify adequately their biotic integrity. Although anthropogenic disturbances cause changes in the food base and result in the capture of fewer individuals, these wetlands are often so small that over-rating the location is not possible. Simon (1998) used low-end scoring in larger palustrine wetlands because of species interactions that could over-rate wetlands when low numbers of individuals in the catch made percentage metrics unpredictable. Small palustrine wetlands did not show similar unpredictable trends in percentage metrics scores.

We evaluated the remaining data from 37 wetlands in the Miller Woods subunit and found that sites with degraded habitat always scored low (Mann–Whitney U-test $= 44.45$, $p < 0.0001$), as did sites with close proximity to residential areas (Mann–Whitney U-test $= 45.08$, $p < 0.0001$), and sites with exotic species (Mann–Whitney U-test $= 45.86$, $p < 0.0001$) when compared to the reference wetlands. These disturbed wetlands usually received the lowest IBI scores. To assure accurate classification when species composition deviates strongly from the reference condition, we recommend that scores of zero be given instead of scores of ‘1’. We did not give scores of zero for percentile metrics. Using zero scores will reduce natural variation in scores that may be a result of no species present instead of being misinterpreted as poor metric attribute achievement.

Table 3
Mean, standard deviation, and range of reference condition assemblage characteristics from 25 small palustrine wetlands and vernal ponds in northwest Indiana. Correlation coefficient (r^2) reflects statistical significance between each metric and surface area

Character	$\bar{X}$	SD	Range	r^2
Number of total species	1.8	2.06	0–8	0.301
Number of amphibian and fish species	1.3	1.58	0–6	0.304
Number of benthic species	0.96	1.14	0–4	0.430
Number of sensitive species	1.3	1.58	0–5	0.046
Percent individuals as tolerant species	13.0	31.27	0–100%	0.992
Percent individuals as omnivores	49.5	47.36	0–100%	0.960
Percent individuals as insectivores	9.4	24.19	0–93.9%	0.952
Percent individuals as pioneer species	1.5	3.36	0–15.1%	0.952
Relative abundance	33.61	57.33	0–218	0.997
Percent individuals as complex reproductive modes	30.0	8.48	0–100%	0.953
Percent individuals as exotic species	8.48	26.36	0–100%	0.033
Percent individuals with Deformities, Eroded fins, Lesions, or Tumors (DELT)	0	0	0	–

4.3. Small palustrine wetland and vernal pond biological integrity in the Miller Woods subunit

The random probability design used in this study enabled an unbiased estimate of the proportion of high-quality palustrine wetlands in the southern Lake Michigan drainage. Larsen (1995) suggested that the use of the random grid design to characterize the status of resource types in a sample survey can infer an unbiased estimate of the population of interest. The representation and characterization of the status of wetlands in this study were based on the largest composition of small dunal palustrine wetlands remaining in southern Lake Michigan, using randomly selected units based on equally weighted sizes and inclusion probabilities.

Based on our random stratified study design, less than 4.6% of the small wetlands in the Miller Woods subunit were expected to represent least-impacted wetlands (Fig. 3). Our results suggest that large percentages (78.5%) of the wetland distribution of IBI scores were skewed towards the lowest end of biotic integrity. Our data suggest that, with the

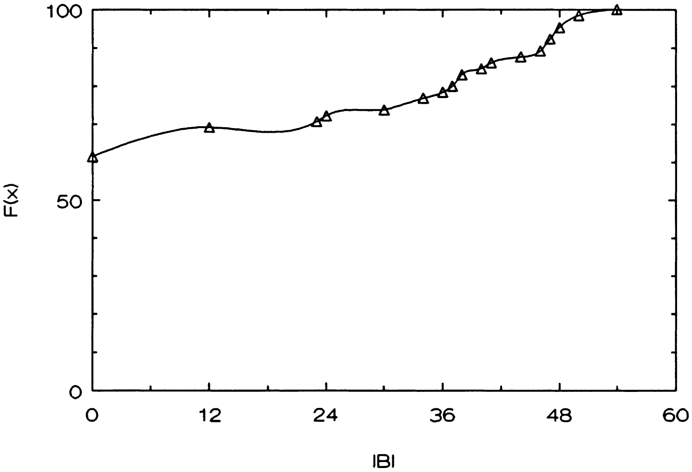


Fig. 3. Cumulative frequency distribution comparing the IBI score distributions and the proportion of sites $F(x)$ for 62 random probability sites in Miller Woods.

exception of prohibiting filling, little effort has been made to protect the quality of the majority of these palustrine wetlands. Additional indicators, such as macroinvertebrate or aquatic plant assemblages, may be necessary to more fully characterize the condition of small palustrine wetlands. However, our modified IBI provides an important tool for characterizing small palustrine wetlands and vernal ponds. Despite the presence of only a few reference sites remaining in Miller Woods, Biotic integrity conditions reflected in IBI scores for the 25 sites that were used to calibrate the reference condition ranged from ‘Good’ to ‘Very Poor’ (Fig. 4). The modified IBI for small palustrine wetlands and vernal ponds shows that excellent scores are not a function of wetland size.

This study demonstrates that the palustrine IBI metrics developed for larger dunal wetlands (Simon, 1998b; Simon and Stewart, 1998) required modification for wetlands less than 5 ha and vernal ponds. The

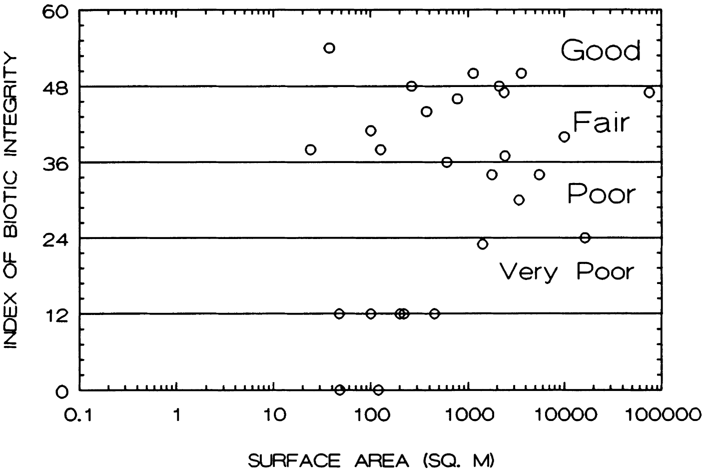


Fig. 4. Relationship between the IBI score and surface area for 25 reference wetlands sites in the Miller Woods subunit, Indiana Dunes National Lakeshore.

revised IBI metrics are sensitive to changes in amphibian, fish and crayfish assemblage structure and are capable of detecting differences in habitat, land use, and human disturbance gradients. A few recommendations include: (1) no modification of percentage metrics is necessary for low-end scoring; (2) scores of zero will remove natural variation differences when none of the metric attributes are present; and (3) additional indicators should be developed to classify accurately wetland condition rather than their physical presence. Biological reference conditions for small palustrine wetlands and vernal ponds need to be developed and calibrated within a regional framework. The stratified random probability design enabled us to classify objectively site biological integrity conditions by removing inherent tendencies of biologists to sample only those wetlands with easy access or with desirable features that may represent a small portion of the resource universe.

Acknowledgements

We appreciate the constructive review of this manuscript by two anonymous reviewers and E. Price for field assistance. Thanks to A. Arends and B. Daum, Indiana Dunes National Lakeshore, for assistance in acquiring collection permits. Conversations with D.P. Larsen, T. Olsen and S. Paulsen enabled the construction and implementation of the random probability sampling design used in this study. Opinions expressed do not necessarily reflect those of the US Fish and Wildlife Service.

References

Conover, W.J., 1971. Practical Nonparametric Statistics, Wiley, New York.

Danielson, T., 1998. Wetland Biocriteria: Technical Guidance Document. US Environmental Protection Agency, Washington, DC.

Davis, W.S., Simon, T.P. (Eds.), 1995. Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making Lewis, Boca Raton.

Gerking, S.D., 1955. Key to the fishes of Indiana. Investig. Indiana Lakes Streams 4, 49–86.

Goldstein, R.M., Simon, T.P., 1999. Towards a united definition guild structure of North American freshwater fishes. In: Simon, T.P. (Ed.). Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities, CRC Press, Boca Raton, pp. 123–159.

Hill, A.M., Lodge, D.M., 1994. Diel changes in resource demand: competition and predation in species replacement among crayfishes. Ecology 75, 2118–2126.

Hughes, R.M., Larsen, D.P., Omernik, J.M., 1981. Regional reference sites: a method for assessing stream potentials. Environ. Manag. 10, 629–635.

IDEM (Indiana Department of Environmental Management), 1998. Indiana Water Quality Report 1998. IDEM 34/02/002. Ind. Dept. Env. Manag., Indianapolis, IN.

IDNR (Indiana Department of Natural Resources), 1994. Water Resource Availability in the Lake Michigan Region, Indiana. Ind. Dept Nat. Res., Div. Water, Water Res. Assess., pp. 94–104.

Jezerinac, R.F., Stocker, G.W., Tarter, D.C., 1995. The crayfishes (Decapoda: Cambaridae) of West Virginia. Bull. Ohio Biol. Surv. 10, 193.

Karr, J.R., 1981. Assessment of biotic integrity using fish communities. Fisheries (Bethesda) 6, 21–27.

Karr, J.R., Fausch, K.D., Angermeier, P.L., Yant, P.R., Schlosser, I.J., 1986. Assessing biological integrity in running waters: a method and its rationale. Ill. Nat. Hist. Surv. Spec. Publ., 5.

Larsen, D.P., 1995. The role of ecological sample surveys in the implementation of biocriteria. In: Davis, W.S., Simon, T.P. (Eds.). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making, Lewis, Boca Raton, pp. 287–300.

Lodge, D.M., Hill, A.M., 1994. Factors governing species composition, population size, and productivity of cool-water crayfishes. Nord. J. Freshw. Res. 69, 111–136.

Lodge, D.M., Kratz, T.K., Capelli, G.M., 1986. Long-term dynamics of three crayfish species in Trout Lake, Wisconsin. Can. J. Fish. Aquat. Sci. 43, 993–998.

Minton, S.A., 1998. The Amphibians and Reptiles of Indiana, Indiana Academy of Science, Indianapolis.

Moyle, P.B., Marchetti, M.P., 1999. Applications of indices of biotic integrity to California streams and watersheds. In: Simon, T.P. (Ed.). Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities, CRC Press, Boca Raton, pp. 367–380.

Moyle, P.B., Randall, P.J., 2000. Evaluating the biotic integrity of watersheds in the Sierra Nevada, California. Conserv. Biol. (in press).

Overton, W.S., White, D., Stevens Jr., D.L., 1991. Design Report for EMAP, The Environmental Monitoring and Assessment Program. EPA 600-3-91-053. US Environmental Protection Agency, Office of Research and Development, Washington, DC.

Page, L.M., 1985. The crayfishes and shrimps (Decapoda) of Illinois. Ill. Nat. Hist. Surv. Bull. 33, 335–448.

Rovelstad, S.J., 1995. Structure of interdunal pond communities: laboratory evidence for and indirect mutualism. PhD dissertation, University of Illinois, Chicago.

Sanders, R.E., Miltner, R.J., Yoder, C.O., Rankin, E.T., 1999. The use of external deformities, erosion, lesions, and tumors (DELT anomalies) in fish assemblages for characterizing aquatic resources: a case study of seven Ohio streams. In: Simon, T.P. (Ed.). Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities, CRC Press, Boca Raton, pp. 225–248.

SAS (Statistical Analysis Systems), 1985. SAS User's Guide: Statistics. Version 5 ed. SAS Institute, Cary, NC.

Shelford, V.E., 1911. Ecological succession. II. Pond fishes. Biol. Bull. 21, 127–151.

Simon, T.P., 1998. Modification of an index of biotic integrity and development of reference condition expectations for dunal, palustrine wetland fish communities along the southern shore of Lake Michigan. Aquat. Ecosys. Health Manag. 1, 49–62.

Simon, T.P. (Ed.), 1999a. Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities CRC Press, Boca Raton.

Simon, T.P., 1999b. Assessment of Balon's reproductive guilds with application to midwestern North American freshwater fishes. In: Simon, T.P. (Ed.). Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities, CRC Press, Boca Raton, pp. 97–122.

Simon, T.P., Bright, G.R., Rud, J., Stahl, J., 1989. Water quality characterization of the Grand Calumet River basin using the index of biotic integrity. Proc. Indiana Acad. Sci. 98, 257–265.

Simon, T.P., Lyons, J., 1995. Application of the index of biotic integrity to evaluate water resource integrity in freshwater ecosystems. In: Davis, W.S., Simon, T.P. (Eds.). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making, Lewis, Boca Raton, pp. 245–262.

Simon, T.P., Stewart, P.M., 1998. Application of an index of biotic integrity for dunal, palustrine wetlands: emphasis on assessment of nonpoint source landfill effects on the Grand Calumet Lagoons. Aquat. Ecosys. Health Manag. 1, 63–74.

Smith, P.W., 1979. The Fishes of Illinois, University of Illinois Press, Champaign, IL.

Whitman, R.L., Peloquin, R.L., Werth, R.J., 1990. The ecology of Miller Woods: Indiana Dunes National Lakeshore. Nat. Park Serv., Res. Prog. Rep. 90-01.

Zar, J.H., 1984. Biostatistical Analysis, . 2nd ed.Prentice-Hall, Englewood Cliffs, NJ.