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Wetlands Health Indicators

Consideration of Geography and Wetland Geomorphic Type in the Development of Great Lakes Coastal Wetland Bird Indicators

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Abstract: We examined how geographic distribution of birds and their affinities to three geomorphic wetland types would affect the scale at which we developed indicators based on breeding bird communities for Great Lakes coastal wetlands. We completed 385 breeding bird surveys on 222 wetlands in the US portion of the basin in 2002 and 2003. Analyses showed that wetlands within two ecoprovinces (Laurentian Mixed Forest and Eastern Broadleaf Forest) had different bird communities. Bird communities were also significantly different among five lakes (Superior, Michigan, Huron, Erie, and Ontario) and among three wetland types (lacustrine, riverine, barrier-protected). Indicator values illustrated bird species with high affinities for each group (ecoprovince, lake, wetland type). Species with restricted geographic ranges, such as Alder and Willow Flycatchers (*Empidonax alnorum* and *E. traillii*), had significant affinities for ecoprovince. Ten bird species had significant affinities for lacustrine wetlands. Analyses on avian guild metrics showed that Lake Ontario wetlands had fewer long-distant migrants and warblers than other lakes. Numbers of short-distant migrants and total individuals in wetlands were higher in the Eastern Broadleaf Forest ecoprovince. Number of flycatchers and wetland obligate birds were not different among provinces, lakes, or wetland type. One potential indicator for wetland condition in Great Lakes wetlands, proportion of obligate wetland birds, responded negatively to proportion of developed land within 1 km of the wetland. We conclude that, although a guild approach to indicator development ameliorates species-specific geographic differences in distribution, individual species responses to disturbance scale will need to be considered in future indicator development with this approach.

Keywords: Great Lakes, wetlands, indicators, birds

Introduction

Birds have long been used as indicators of environmental condition because they are particularly sensitive to anthropogenic change from land use (Forman et al., 1976; Ambuel and Temple, 1983; Freemark and Merriam, 1986; O'Connor and Shrubb, 1986; Brooks et al., 1991; Niemi and McDonald, 2004) and environmental contaminants (Cramp and Conder, 1961; Hickey, 1969; Frederick et al., 2004). However, compared to other taxonomic groups, birds have only recently been incorporated into compre-

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hensive, multimetric indices of ecosystem condition. Exceptions have been the development of forest (O'Connell et al., 1998; Canterbury et al., 2000), riparian (Bryce et al., 2002), grassland (Browder et al., 2002), and rangeland (Bradford et al., 1998) condition indices using breeding bird community data. In addition, we recently developed a multimetric indicator using breeding birds as indicators of land-use condition in the Great Lakes Basin (Howe et al., in press).

Breeding bird indices have potential for indicating environmental condition in many ecosystem types and for broad regions, such as across North America. In studies that developed multi-taxon indicators, birds have shown to be excellent indicators of disturbance in lakes (O'Connor et al., 2000). Others have found that a breeding bird index used together with aquatic indicators provides a more comprehensive picture of stream condition than any one indicator alone (Bryce et al., 2002). Developing multi-taxon indicators of environmental condition are desirable because they can integrate stresses to ecosystems that occur at a variety of spatial scales (O'Connor et al., 2000). However, because individual species respond to habitat and landscape condition at different scales (Holland et al., 2004; Price et al., 2005), disparate species-specific scale relationships should be considered in the development of guild or multimetric response indices.

Wetland ecosystems have experienced the greatest amount of anthropogenic disturbance compared with other ecosystems across North America (Zedler, 2000). However, few published studies have used bird community data to assess the environmental condition of wetland ecosystems across large geographic areas. Adamus et al. (1987, 1991) developed wetland condition indicators using breeding bird data and DeLuca et al. [in review] recently developed a wetland bird indicator for the Chesapeake Bay. We are unaware of work completed for other coastal wetlands of the US.

We are seeking to develop indicators of coastal wetland condition across the US portion of the Great Lakes using breeding bird community data. This endeavor poses some challenges that are novel to this effort. First, many breeding bird species have distinct but limited geographic distributions across the Great Lakes basin. We ask whether a guild approach to indicator development ameliorates differences in geographic distribution of breeding birds across the Great Lakes basin. Additionally, at least three distinct wetland geomorphic types occur in the Great Lakes. We ask whether wetland breeding bird communities differ between wetland geomorphic type and, if so, how potential differences could be accounted for in the development of a wetland bird community index of Great Lakes coastal wetland condition.

Methods

Description of Study Area

The Great Lakes basin encompasses more than 765,000 km^2 and 17,000 km of shoreline, bordering nine states and the Canadian province of Ontario (Fig. 1). The US portion of the basin is home to over 33 million people (http://www.great-lakes.net/lakes/ref/ lakefact.html) and lies within two ecoprovinces (Bailey, 1989) (Fig. 1). The Laurentian Mixed Forest Province (LMF) includes all of Lake Superior, northern Lake Michigan, northern Lake Huron, and a small portion of eastern Lake Ontario. The southern province, the Eastern Broadleaf Forest (EBF), includes southern Lakes Michigan and Huron, all of Lake Erie, and most of Lake Ontario. The two ecoprovinces differ in climate, physiography, and the degree and types of human disturbance (Danz et al., 2005). The EBF has a longer history of human occupation, a higher human population density, and a watershed with a higher proportion of agriculture and greater atmospheric deposition (Danz et al., 2005) than the LMF province.

Patterns of rainfall and temperature across the basin explain a large portion of the variation in distribution of avian species across the region (see Venier et al., 2004). Anthropogenic stress has also affected native bird communities in the basin, with the eastern and southern portion of the basin having a longer history of land conversion, primarily due to agriculture and urbanization. These factors have historically and more recently impacted the distribution and abundance of avian species across the study area.

The Great Lakes basin is rich in coastal wetlands, but the amount of wetland habitat has declined by over 66% historically, and many remaining wetlands are threatened by development, drainage, or pollution (http://www.great-lakes.net/lakes/ref/lakefact.html). Wetlands in the basin have been classified by Keough et al. (1999) based on hydro-geomorphology. We sampled three types of wetlands: riverine, lacustrine, and barrier-protected. Riverine system wetlands occur in rivers and creeks that flow into the Great Lakes. Water quality in these wetlands is influenced primarily by water flowing from the watershed into the lake and less by seiches, lake currents, or wave action. In contrast, lacustrine wetlands, located within the lake bed,

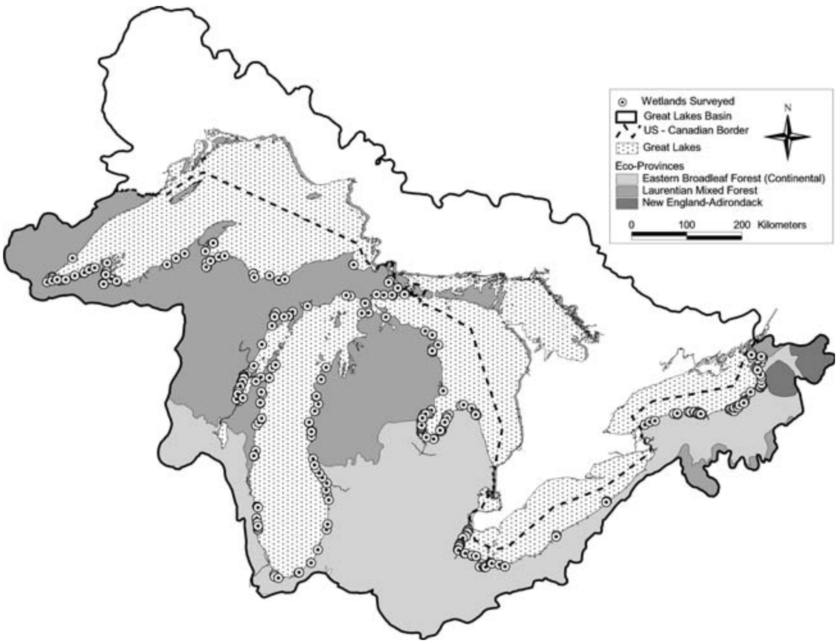

Figure 1. The Great Lakes basin, with the US portion shaded by ecoprovince.

Table 1. Number of Wetlands and Samples (Wetlands/Samples) by Ecoprovince, Lake, and Wetland Geomorphic Type[a]

		Lake				
Province	Wetland type	Superior	Michigan	Huron	Erie	Ontario
Laurentian Mixed Forest	Lacustrine	3/8	19/24	18/25		1/2
	Barrier-protected	20/34	20/37	5/12		1/1
	Riverine	18/32	14/24	3/3		2/6
Eastern Broadleaf Forest	Lacustrine			17/29	3/5	4/8
	Barrier-protected		11/14	4/7	15/29	8/17
	Riverine		9/13		6/7	21/48

[a] Total sample size was 385 surveys in 222 wetlands.

are strongly affected by lake water levels, seiches, and near shore currents. Barrier-protected wetlands were formerly lacustrine, but have been separated from the Great Lakes by a barrier beach or a human-constructed impoundment. Depending on location and the permeability of the barrier, these wetlands receive water from both watershed and Great Lakes sources.

Wetland Selection

Two hundred twenty-two wetlands were randomly selected across human disturbance gradients that were quantified separately for each ecoprovince (see Danz et al., 2005). We conducted 385 breeding bird surveys on 222 wetlands in 2002 and 2003 (Table 1; Fig. 1). Surveys were distributed across lakes and wetland types based on wetland availability and accessibility. Most sites occurred in Lake Michigan, and the fewest were in Lake Erie (Table 1). The Lake Michigan shoreline is almost entirely within the US portion of the basin, and Lake Erie has had the highest degree of wetland loss of all the lakes.

Bird Survey Methods

We used the National Marsh Bird Monitoring program protocol (Ribic et al., 1999) to survey breeding birds in the Great Lakes basin over a 2-year period (2002 and 2003). Up to three points or subsamples were conducted per wetland depending on size. Surveys were conducted by observers trained in the survey protocol (Hanowski and Niemi, 1995), between 0500 and 0930, and when weather conditions were suitable for surveying singing and calling birds (no rain and winds <15 kph). Observers were tested for their ability to identify birds and screened for their ability to hear within normal hearing ranges defined by audiologists (Hanowski and Niemi, 1995). Birds were counted in a 100-m radius semi-circle from a fixed survey point located on the edge of the wetland. Because traversing wetland habitat is time-consuming and difficult, this method saves time and effort. We recorded the location of each point with a hand-held GPS unit so that repeat surveys could be conducted at exact locations. The survey protocol included an initial 10-minute listening period followed by a taped broadcast of secretive marsh birds in the following order: Least Bittern *(Ixobrychus exilis)*, Virginia Rail *(Rallus limicola)*, Sora *(Porzana carolina)*, Common Moorhen *(Gallinula chloropus)*, and Pied-billed Grebe *(Podilymbus podiceps)*. All surveyors used a recording of songs or calls provided by the Cornell Laboratory of Ornithology. To control for broadcast volume, all surveyors used compact disc players with similar wattage and standardized volume.

Statistical Analysis

Of the 114 bird species observed on surveys, we used 86 species having affinities for wetlands and assigned these species to guilds based on published literature (see Hanowski et al., 2003). Bird species were classified as wetland obligate if they were dependent on wetland habitat for both nesting and foraging. We chose these response variables because at least some species within these guilds have responded negatively to human disturbance (Wilcove and Terborgh, 1984; Terborgh, 1989). In contrast, some bird species within the short-distant migrant guild have been previously shown to increase in human-disturbed landscapes, especially those with an agricultural component (Bryce et al., 2002).

To characterize influences of geography and wetland type on bird abundance, we carried out mixed model analysis of variance (ANOVA) for each of the five guilds using the log (number of individuals per survey + 1) as the response variable. The fixed main effects and interactions were lake (five levels), ecoprovince (two levels), and wetland type (three levels). Wetlands (and points within wetlands) were random effects. We used back-transformed least-squared means and 95% confidence intervals to compare mean abundance across the main effects. Least-squared means were adjusted for other effects in the ANOVA.

We used a graphical approach rather than hypothesis testing to investigate abundance patterns for four species with uneven abundances across the study region. We compared least-squared means for main effects as was done for the guild responses, but we did not compute 95% confidence intervals. Violations of the normality and equal variance assumptions for ANOVA made the hypothesis tests impractical. Two species, Willow Flycatcher and Alder Flycatcher (*Empidonax traillii* and *E. alnorum*) were selected because they have restricted geographic distributions in the basin. Two warbler species, the Yellow Warbler *(Dendroica petechia)* and Common Yellowthroat *(Geothlypis trichas)* were selected because they have broad geographic distribution, but could be restricted by habitat characteristics that may be different among wetland geomorphic types. For example, Yellow Warblers occur in wetlands that have a woody vegetation component, usually willow (*Salix* species) (Lowther et al., 1999), and the Common Yellowthroat is generally associated with wetlands that have more herbaceous vegetation (Guzy and Ritchison, 1999).

We carried out correspondence analysis (CA) on raw abundances per survey to display patterns of bird community composition across the basin. For clarity, we included only 27 species that occurred on more than 5% of the surveys and used the "downweight rare species" option in PC-ORD (McCune and Mefford, 1999).

We used multi-response permutation procedure (MRPP) to test for differences in community composition between lakes, provinces, wetland types, and wetland types within provinces. MRPP is a non-parametric procedure for testing the hypothesis of no difference between two or more a priori groups of entities (Mielke, 1984). Our groups were sites within each effect and the entities were raw abundances of 86 species. The effect size delta, the chance-corrected within group agreement, describes the separation between the groups in multivariate space; delta is 1.0 if all sites within a group are identical, and is zero if sites between groups are no different than sites within groups. *P*-values are assessed with a permutation procedure (McCune and Mefford, 1999).

Although the MRPP analysis tells us if bird communities are different between groups, it does not allow us to determine which individual species are different between the groups. We used indicator species analysis (Dufrene and Legendre, 1997) in PC-ORD to describe species affinity for individual levels within four main effects: province, lake, wetland type, and wetland type by province. One

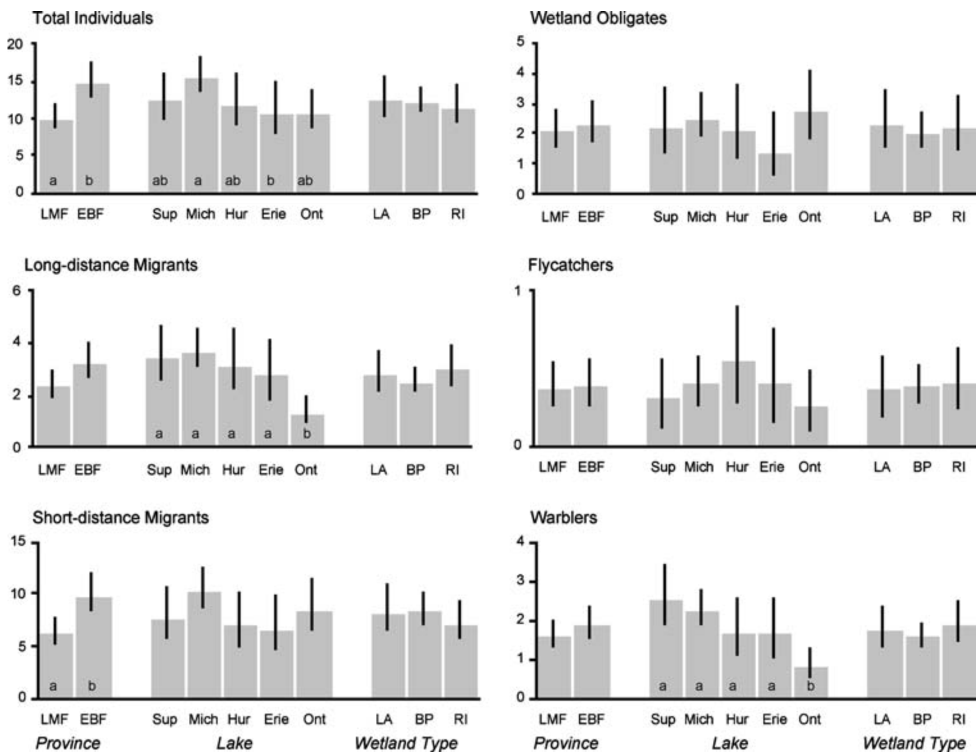

Figure 2. Back-transformed least-squared means and 95% confidence intervals for main effects. Means are adjusted for other effects in the model. Within each significant main effect, letters indicate significantly different means at $\alpha = 0.05$ using Tukey's adjustment.

analysis was carried out for each effect. This method uses an a priori grouping of sites and calculates an index of affinity for each species in each group level. The index incorporates two important measures of species occurrence, uniqueness to a particular group and frequency within that group. Indicator values (IV) range from 0 to 100; values nearer 100 indicate stronger affinities for a particular site grouping. The statistical significance of the maximum indicator value for each of the four indicator values was evaluated with a Monte Carlo process using 1000 permutations (McCune and Mefford, 1999).

Land Cover Summaries

For land cover summaries of each buffer, we used classified Landsat sensor data from a variety of sources (NLCD, C-CAP, GAP, WISCLAND) assembled into spatially and thematically compatible layers. These layers provided the most recent and best available synoptic land cover classification available for the entire US Great Lakes basin. Land cover data was summed for each circular 1-km buffer surrounding each wetland sample point, and proportions of each land cover class were calculated. We summed proportion of land cover classes designated as residential, commercial, and roads, and used this value as the independent stress measure for each wetland.

RESULTS

Geographic Differences in Bird Communities and Guild

More individual birds were counted on wetlands within the EBF ecoprovince ($P < 0.001$), and a significant ($P < 0.04$) lake effect was detected for total number of individuals (Fig. 2). Lake Erie wetlands had fewer birds than Lake Michigan wetlands (Fig. 2).

The number of long-distant migrants counted in wetlands in Lake Ontario was lower ($P < 0.001$) than in all other lakes (Fig. 2). Wetlands within the EBF province had more short-distant migrant individuals than wetlands in the LMF province ($P < 0.01$). There were no differences ($P > 0.15$) in numbers of wetland obligate birds or flycatchers for any effect (Fig. 2). However, the number of warblers was lower ($P < 0.001$) in Lake Ontario wetlands than in all other lakes (Fig. 2).

Bird community composition was significantly different across wetland geomorphic type, lake, and province based on the MRPP (Table 2). There were also significant differences in composition between wetland type within provinces. The first two axes of the CA explained 21% of the species variation across wetlands (Fig. 3). Axis 1 separated sites across an east–west geographic gradient with Lake Superior wetlands

Table 2. Multi-response Permutation Procedure Results for Wetland Breeding Bird Community Data from Great Lakes Coastal Wetlands[a]

Effect	delta	*P*
Province	0.020	<0.001
Lake	0.040	<0.001
Wetland type	0.003	0.005
Wetland type* province	0.026	<0.001

[a] The analysis was based on 86 bird species observed on 385 surveys on 222 coastal wetlands in 2002 and 2003.

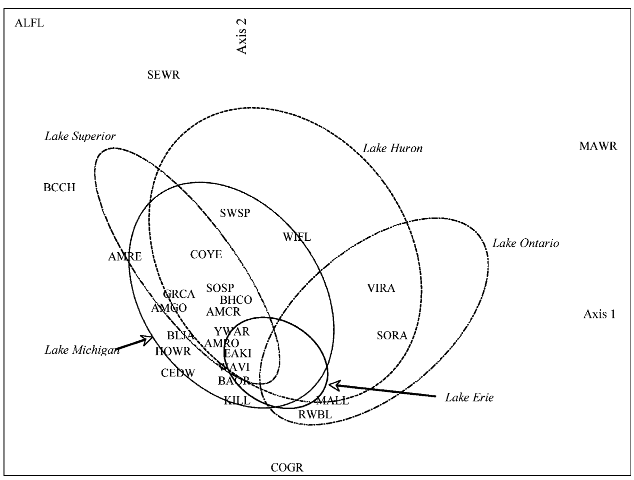

Figure 3. Correspondence analysis diagram for 27 species present on at least 5% of surveys. Ellipses bound the majority of sites from each lake. Refer to http://www.glei.nrr.umn.edu/default/documents/Pubs/ecohealth-appA.pdf for species codes.

located along the left side of the diagram and Lake Ontario on the opposite side. There was little, or no, overlap of wetland sites within Lakes Superior and Ontario in the CA space depicted with the first two axes (Fig. 3). The Marsh Wren *(Cistothorus palustris)* was associated with Lake Ontario sites and the Alder Flycatcher, Black-capped Chickadee *(Poecille atricapillus)*, and American Redstart *(Setophaga ruticilla)* were associated with wetlands in Lake Superior. Along axis 2 of the CA, wetlands with Sedge Wrens *(Cistothorus platensis)* were located along the positive side of the axis, and wetlands with more Red-winged Blackbirds *(Agelaius phoeniceus)* and Common Grackles *(Quiscalus quiscula)* were positioned along the negative side of axis 2 (Fig. 3). Lakes Erie and Ontario wetlands were positioned on the negative side of axis 2, and wetlands within Lake Superior were located along the positive side of axis 2.

The abundance of Willow and Alder Flycatchers in wetlands by province illustrates the distinct pattern of geographic distribution of these two species (Fig. 4). The Willow Flycatcher occupies the southern and western portions of the basin (see http://www.glei.nrr.umn.edu/default/documents/Pubs/ecohealth-appA.pdf) and the Alder Flycatcher occurs primarily in wetlands in the north and west portions of the basin. In contrast, abundance patterns of two warbler species, the Common Yellowthroat and Yellow Warbler, did not illustrate the distinct geographic distributional pattern as did the flycatcher species. Both of these species have North American continent-wide ranges (http://www.glei.nrr.umn.edu/default/documents/Pubs/ecohealth-appA.pdf), and we would expect them to be present in any suitable wetland within the Great Lakes basin (Fig. 4). In general, Common Yellowthroats were more abundant in the LMF and Yellow Warblers were more abundant in the EBF, and numbers for both species were lower in Lake Ontario wetlands (Fig. 4).

In the indicator value analysis by ecoprovince, 20 species had significant IVs (Table 3). Nine species had higher affinities for the LMF province with the Common Yellowthroat and Swamp Sparrow *(Melospiza georgiana)* having the highest IVs. In the EBF province, 11 species had significant IVs, with the Red-winged Blackbird and Marsh Wren having the highest IVs (Table 3).

Lake Huron had the most species (nine) with significant affinities for that lake based on IVs, followed by Lake Erie with eight species (Table 3). The Common Yellowthroat had the highest IV in Lake Huron and the Red-winged Blackbird had the highest IV in Lake Erie (Table 3). Lake Superior had four species with significant IVs and the American Redstart had the highest value (Table 3). The Swamp Sparrow was one of five species in Lake Michigan with significant IVs, and this species also had the highest value. In Lake Ontario, the Marsh Wren had the highest IV of the four species with significant affinities for wetlands in that Lake (Table 3).

Wetland Geomorphology

Total number of individual birds and bird numbers counted within six guild types did not differ among wetland geomorphic type ($P > 0.4$) (Fig. 3), and no interactions were indicated among lake and wetland geomorphic type and province and geomorphic type ($P > 0.06$). However, results of the MRPP showed that bird communities differed among wetland geomorphic type ($P < 0.001$) (Table 2).

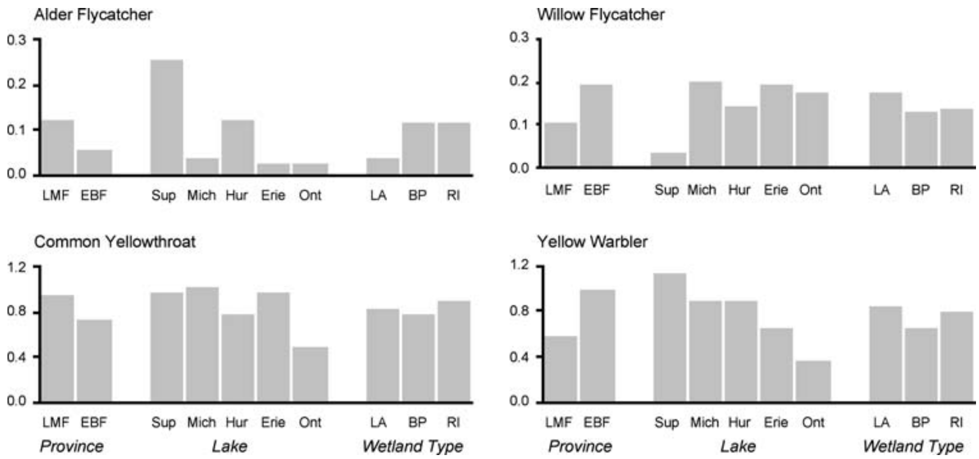

Figure 4. Back-transformed least-squared means for main effects for four species. Least-squared means are adjusted for other effects.

Lacustrine wetland types had the most species with significant affinities based on wetland geomorphology. Ten species had significant IVs for lacustrine wetlands, including the Song Sparrow *(Melospiza melodia)* which had the highest IV of all species (Table 3). Four species had significant IVs for barrier-protected wetlands, and the American Goldfinch *(Carduelis tristis)* had the highest IV for this wetland type (Table 3). Only two species were significantly associated with riverine wetlands, the Least Bittern and Wood Duck *(Aix sponsa)*.

When we examined wetland geomorphic types within lakes together, we again found that lacustrine wetland types in the EBF had the most species (seven) with significant IVs (Table 3). The Marsh Wren had the highest IV in this group. Barrier-protected wetlands in the EBF had five species with significant IVs, including the Red-winged Blackbird with the highest value of all species (Table 3). Similar to the analysis that included wetland geomorphic type alone, riverine wetlands within both provinces had only one species in the LMF ecoprovince and two species in the EBF ecoprovince with species with significant IVs (Table 3).

Our guild analysis indicated that number of wetland obligate birds/sample did not differ among ecoprovince, lakes, or wetland type (Fig. 2). This response metric and potential wetland condition indicator, plotted against an anthropogenic stress gradient defined by proportion of disturbed land use classes in 1-km buffers around each sample point illustrated a negative response curve in each ecoprovince (Fig. 5). However, there are several wetlands in both ecoprovinces that have low proportions of wetland obligate individuals and low stress scores.

DISCUSSION

Results from these analyses are highly relevant to the development of biotic indicators of wetland condition. Developing indicators for an extensive region such as the Great Lakes basin presents several challenges that have not been addressed in previous indicator development. Much of the work completed to date has been done on smaller scales like from watersheds (e.g., Willamette Valley [Bryce et al., 2002]), or for specific ecosystems such as rangeland (Bradford et al., 1998), grasslands (Browder et al., 2002), riparian forests (Brooks et al., 1998), or lakes (O'Connor et al., 2000). Authors of these works have cautioned that multimetric indicators developed and calibrated for their region or ecosystem, should not be applied to other regions or ecosystems.

We originally hypothesized that differences in bird communities across the basin could be due to wetland geomorphic type, species geographic range distributions, landscape context, or local habitat features. In the analyses completed here, we only considered variation attributable to geography and wetland geomorphology. Future analyses will include local habitat features as well as landscape context. These were not considered here, because they also represent measures of anthropogenic stress to wetlands in the Great Lakes basin. However, it is likely that landscape scale disturbances may have already impacted breeding bird communities in coastal wetlands, especially in the EBF (see below). However, our first objective was to determine an appropriate scale and decide whether we need to consider wetland type when developing indicators for this large region.

Table 3. Indicator Values for 86 Bird Species Observed on Wetland Breeding Bird Surveys in Great Lakes Lacustrine Wetlands in 2002 and 2003[a]

	Province		Lake					Wetland type			Wetland type by ecoprovince					
											Lacustrine		Protected		Riverine	
Species	LMF	EBF	SU	MI	HU	ER	ON	LA	PR	RI	LMF	EBF	LMF	EBF	LMF	EBF
Canada Goose	1	4	1	0	0	3	1	1	1	3	0	0	0	2	1	1
Mute Swan	0	2	0	0	0	1	1	0	0	1	0	1	0	0	0	1
Wood Duck	0	2	0	0	0	0	**9**	0	0	**3**	0	0	0	1	1	3
Mallard	5	5	1	1	3	1	4	2	3	4	2	1	2	1	2	3
Blue-winged Teal	**4**	0	0	1	**5**	0	0	2	1	1	2	0	1	0	1	0
Northern Shoveler	0	0	0	0	1	0	0	0	0	1	0	0	0	0	2	0
Ring-necked Duck	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0
Ring-necked Pheasant	1	1	0	1	1	1	0	2	1	0	0	2	0	0	0	0
Pied-billed Grebe	0	2	0	**6**	0	0	0	**9**	0	0	0	**9**	0	0	0	0
Double-crested Cormorant	0	1	0	0	0	**4**	0	1	1	0	1	0	0	2	0	0
American Bittern	0	**3**	0	2	0	0	1	2	0	0	0	**4**	0	0	0	1
Least Bittern	0	**6**	0	0	0	0	**5**	0	0	**4**	0	0	0	0	0	**8**
Great Blue Heron	0	5	0	0	0	**12**	1	0	2	2	0	0	0	4	0	3
Great Egret	0	7	0	2	0	**13**	0	3	3	0	0	5	0	5	0	0
Snowy Egret	0	1	0	0	0	2	0	0	1	0	0	0	0	1	0	0
Green Heron	1	1	0	0	1	1	1	0	1	1	0	0	0	1	1	0
Black-crowned Night-heron	0	2	0	3	0	0	0	**4**	0	0	1	5	0	0	0	0
Yellow-crowned Night-heron	0	1	0	0	0	0	1	1	0	0	0	2	0	0	0	0
Bald Eagle	0	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0
Northern Harrier	0	1	0	0	0	0	1	0	1	0	0	0	0	1	0	0
Virginia Rail	3	5	0	2	2	1	3	3	2	2	2	2	1	2	1	2
Sora	6	1	0	5	**6**	0	0	**6**	2	0	5	1	2	0	0	0
Common Moorhen	0	**4**	0	1	0	0	**4**	1	0	1	0	2	0	0	0	3
American Coot	0	2	0	3	1	0	0	**6**	0	0	1	**5**	0	0	0	0
Sandhill Crane	3	0	1	0	1	0	0	3	0	0	4	0	1	0	0	0
Killdeer	2	5	0	4	1	**6**	0	**6**	2	0	1	**6**	0	2	0	0
Spotted Sandpiper	1	3	0	**19**	0	0	0	**11**	0	0	2	**13**	0	0	0	0
Wilson's Snipe	2	0	0	2	1	0	0	0	0	0	1	0	1	0	0	0
Ring-billed Gull	1	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0
Herring Gull	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0
Caspian Tern	0	1	0	1	0	0	0	1	0	0	0	2	0	0	0	0
Common Tern	0	0	0	1	0	0	0	1	0	0	0	2	0	0	0	0
Black Tern	0	1	0	0	0	2	0	0	0	0	0	0	0	1	0	0
Black-billed Cuckoo	0	0	1	0	0	0	0	0	0	1	0	0	0	0	2	0
Yellow-billed Cuckoo	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0
Ruby-throated Hummingbird	1	0	0	2	0	0	0	1	0	0	1	1	0	0	0	0
Belted Kingfisher	1	2	2	0	0	0	2	1	1	1	0	2	2	0	0	1
Red-headed Woodpecker	0	1	0	0	1	0	0	0	1	0	0	0	0	1	0	0
Red-bellied Woodpecker	1	0	0	0	3	0	0	0	1	0	0	0	1	0	0	0
Downy Woodpecker	0	3	0	0	0	**6**	0	1	2	0	0	0	0	2	0	1
Hairy Woodpecker	0	0	0	0	1	0	0	0	0	1	0	0	0	0	2	0
Northern Flicker	2	3	1	0	2	0	1	0	4	2	0	0	3	1	0	2
Alder Flycatcher	**21**	0	**28**	2	1	0	0	2	8	4	1	0	**14**	0	8	0

Table 3. Continued[a]

	Province		Lake					Wetland type			Wetland type by ecoprovince					
											Lacustrine		Protected		Riverine	
Species	LMF	EBF	SU	MI	HU	ER	ON	LA	PR	RI	LMF	EBF	LMF	EBF	LMF	EBF
Willow Flycatcher	3	**17**	0	2	6	6	8	5	6	5	1	7	2	5	1	6
Eastern Phoebe	2	0	0	0	3	0	0	0	1	1	0	0	2	0	0	0
Great Crested Flycatcher	3	1	0	0	4	2	0	2	1	0	1	1	1	0	1	0
Eastern Kingbird	3	7	0	4	2	5	1	4	4	1	1	4	1	4	1	1
Warbling Vireo	5	10	0	5	7	7	1	**11**	4	2	3	**9**	1	3	1	1
Blue Jay	2	5	1	0	3	5	0	1	4	2	0	0	0	5	1	1
American Crow	3	3	2	1	3	0	0	0	3	3	0	0	1	3	2	1
Tree Swallow	1	3	0	1	0	**12**	0	0	**7**	0	0	0	2	**6**	0	0
Cliff Swallow	1	0	0	0	2	0	0	0	0	0	0	0	1	0	1	0
Barn Swallow	0	**4**	0	0	0	7	0	0	**4**	0	0	0	0	7	0	0
Black-capped Chickadee	8	2	4	0	**7**	0	0	0	**7**	3	0	0	**9**	1	1	2
House Wren	3	3	0	2	3	**6**	0	2	3	1	0	3	2	1	1	0
Sedge Wren	**19**	1	6	6	7	0	0	7	5	3	7	1	7	0	5	0
Marsh Wren	2	**32**	0	10	2	5	**18**	**16**	4	7	2	**21**	0	6	0	8
Veery	**4**	0	**5**	1	0	0	0	1	1	1	1	0	2	0	1	0
American Robin	10	16	1	4	**11**	7	5	4	14	9	2	2	5	**11**	4	5
Gray Catbird	5	**12**	1	1	**8**	4	2	2	4	10	1	2	1	4	3	6
Brown Thrasher	0	1	0	1	1	0	0	0	1	0	0	1	1	0	0	0
European Starling	1	4	0	3	1	0	1	1	3	1	1	0	0	2	0	1
Cedar Waxwing	5	4	1	1	**10**	1	0	3	4	2	2	1	2	3	1	1
Blue-winged Warbler	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0
Yellow Warbler	29	31	16	10	14	15	7	21	21	18	10	11	9	12	10	8
Chestnut-sided Warbler	**5**	0	**4**	0	2	0	0	0	1	1	1	0	2	0	3	0
American Redstart	**11**	1	**12**	1	4	0	0	1	4	6	1	0	3	1	**8**	0
Northern Waterthrush	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0
Mourning Warbler	1	0	0	0	2	0	0	1	0	0	1	0	0	0	0	0
Common Yellowthroat	**50**	21	22	13	**23**	12	4	23	27	20	11	12	**20**	7	18	5
Clay-colored Sparrow	0	0	0	0	1	0	0	1	0	0	2	0	0	0	0	0
Savannah Sparrow	4	0	1	**5**	0	0	0	2	1	0	2	1	2	0	1	0
Nelson's Sharp-tailed Sparrow	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0
Song Sparrow	33	24	11	**19**	15	9	5	**29**	18	12	15	14	10	8	8	5
Swamp Sparrow	**32**	17	16	**19**	11	1	7	**24**	11	16	10	**15**	8	3	15	3
Rose-breasted Grosbeak	2	1	0	0	**6**	0	0	2	0	1	3	0	0	0	1	0

[a] IVs were calculated by province (LMF, Laurentian Mixed Forest; EBF, Eastern Broadleaf Forest); lake (SU, Superior; MI, Michigan; HU, Huron; ER, Erie; ON, Ontario); and wetland geomorphic type (LA, lacustrine; PR, barrier-protected; RI, riverine). Values in bold indicate a significant IV for the species in each category.

Approximately one-third of the breeding bird species within the Great Lakes basin have restricted geographic distributions (see http://www.glei.nrr.umn.edu/default/documents/Pubs/ecohealth-appA.pdf) and, as expected, wetland breeding bird communities were found to be different across the Great Lakes basin. Species with restricted ranges were more likely to have significant affinities with an ecoprovince or lake based on their IVs, suggesting that indicators should be developed for each ecoprovince separately. This was the approach that was used in our multimetric indicators using upland breeding bird species in the Great Lakes Basin (see Howe et al., in press).

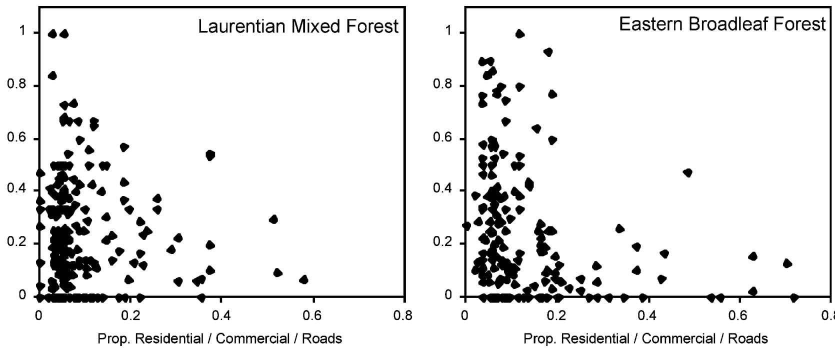

Figure 5. Proportion of wetland obligate individuals per survey versus proportion of land cover in residential, commercial, industrial, and road classes in a 1-km buffer surrounding survey locations.

In the example presented, Alder Flycatchers had a significant affinity with the LMF ecoprovince and Lake Superior, and Willow Flycatchers had a significant IV in the EBF ecoprovince. Because of geographic limitations, either of these species alone could not be used as a basin-wide indicator. However, species with restricted ranges may replace each other functionally across large geographic ranges. For example, Alder and Willow Flycatchers likely perform the same ecological function in a wetland, and a response variable of "flycatchers" would serve to standardize the geographic distribution limits of species within this functional guild. Although these two species did not occur in the same wetland, abundance of flycatchers within wetlands did not differ across the basin. These results suggest that a guild approach should be used across ecoprovinces.

Another reason to separate ecoprovinces when developing indicators is that it is likely that variation in abundance of birds within response guilds across the basin have already been altered by the current condition of the landscape around the wetlands (Riffell et al., 2003). On average, wetlands in the EBF are in a landscape that has greater development and agriculture than most wetlands in the LMF (Danz et al., 2005). Atlhough, wetlands in the EBF province had more individuals, they also had more short-distant migrants. Previous studies have found that numbers of long-distant migrants in communities decrease as anthropogenic disturbance increases and that short-distant migrants increase (Bryce et al., 2002; O'Connell et al., 2000). This difference in response guild among provinces is also reflected in species affinities for either Lake or province. For example, the Red-winged Blackbird and Common Grackle had strong affinities for the EBF province, both are short-distant migrants, and both are adaptable to human disturbance.

Although bird community composition differed among wetland type, bird guild response metrics that we analyzed were not different among wetland geomorphic type. As we illustrated with the indicator value analysis, lacustrine wetlands have the most unique bird communities, but this could be due to local level habitat. Therefore, wetland habitat data collected at sites could be incorporated to determine whether differences can be explained by wetland habitat variables. If so, it may not be necessary to develop separate indicators for wetland geomorphic type for Great Lakes coastal wetlands. However, because wetlands of different geomorphic types receive water in different ways within watersheds, taxa such as fish and plants directly in contact with water may be differentially affected by stressors to wetlands of different geomorphic types.

The intent of our work here was not to fully develop a wetland condition indicator based on breeding bird community data, but to examine two factors that will need to be considered in developing indicators for Great Lakes coastal wetlands, biogeography and wetland geomorphic type. Ecologically, the most important bird species in these wetlands are wetland obligate birds. Developing stress responses for this bird group presents some challenges because species have diverse body sizes (from herons and egrets to wrens) and life history strategies (piscivores to insectivores). Therefore, individual species are likely incorporating local landscape and site level habitat conditions at different scales. The example that we provide for this guild response to anthropogenic disturbance illustrates an overall negative response to increasing amounts of disturbance. However, there were several wetlands in each ecoprovince that had low proportions of wetland obligate individuals and also low amounts of stress in the adjacent landscape. It is clear that there are several other factors that are unaccounted for in our example of the response of this metric to anthropogenic stress. Site disturbance from invasive plant species or alteration in water flow may have already altered bird community composition. These are not reflected in our landscape condition metric. Within wetland habitats, species-specific response scales will need to be considered in final indicator development.

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