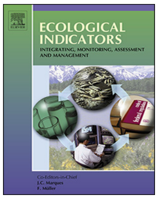
Ecological Indicators 98 (2019) 743–752

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind



# Performance of wetland environmental quality assessment indicators at evaluating palustrine wetlands in northeastern New York State

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ARTICLE INFO

*Keywords:*
Wetland assessment
Index of Biotic Integrity
1-2-3 framework
Ecological integrity

ABSTRACT

The United States Environmental Protection Agency delegates to States and Tribes primary responsibility for monitoring the condition of wetlands under their jurisdiction, and suggests that wetland assessment be performed in a buildable process deemed the 1-2-3 framework. Level One assessment uses remotely-sensed data, Level Two uses a checklist of site attributes during a single visit, and Level Three includes effortful field surveys of biotic and water quality indicators. We used 16 accepted wetland assessment metrics that varied in levels of effort to evaluate the ecological integrity of 71 palustrine wetlands in New York State, including wetlands with a broad range of disturbance histories. We detected significant correlations across multiple levels and within levels, which indicates that these metrics, regardless of effort, are measuring similar attributes of wetlands. Most metrics also successfully distinguished between three wetland disturbance groups: natural, restored, and Area of Concern. The implication of this finding is that the landscape setting (as assessed by Level One) is linked to the biotic wetland community (as assessed by Level Three), and can be used to predict the ecological condition of a wetland using less complex methods. The relationships did have limits, however, indicating that some metrics either cannot be substituted or may not be as effective as previously thought at evaluating ecological condition of palustrine wetlands. The positive associations among the Levels indicate that it is possible to efficiently and validly evaluate and monitor wetlands using the 1-2-3 framework with appropriately selected indicator metrics.

## 1. Introduction

The United States Clean Water Act 40 CFR, sections 303(d) and 305(b) require that states and Native American tribal governments report on the quality of waters within their borders, with the principal objective to restore and maintain the chemical, physical, and biological integrity of U.S. waters. While flowing waters and lakes have received much attention, the assessment of wetlands has been consistently neglected (USEPA, 2003). The 2017 National Water Quality Inventory Report to Congress, reported that the acreage of wetlands assessed by states amounted to 1.2% of the nation's total wetland resources, a 0.4% decrease since the 2004 report (USEPA, 2009, 2017). The United States Environmental Protection Agency (USEPA) is encouraging states and tribes to develop regional wetland assessment protocols, and in doing so to implement a hierarchical three-tiered approach, deemed the 1-2-3 framework (USEPA, 2006). This three-tier framework is an assessment process that uses three intensities of wetland assessment to generate a thorough evaluation of wetland ecological integrity (Fennessy et al., 2007). Each tier is based on one or more sets of indicator metrics. Good indicators (1) have a well-defined, objective, validated, and easily replicated methodology, (2) are practical to conduct in the field or using readily-available remotely-sensed data, and (3) provide a quantitative continuous range than spans the most impaired and degraded to the most pristine and highest quality wetlands.

### 1.1. Level One – landscape assessment

Level One is a landscape level assessment, typically done on a very coarse scale using remotely-sensed data with Geographic Information System (GIS) software. A large variety of Level One methods have been developed by states, ranging from very simple (e.g. percent forest cover, Brooks et al., 2004) to complex, multi-metric models (Comer and Hak,

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https://doi.org/10.1016/j.ecolind.2018.11.051
Received 16 February 2018; Received in revised form 15 November 2018; Accepted 17 November 2018

2012). The output of a Level One assessment is a determination of the ecological integrity of a wetland as indicated by landscape level factors such as land use and land cover, hydrology, and climate. The entire wetland assemblage of a state can be quickly assessed using this approach, since a site visit is not necessary. Other benefits of a Level One assessment include the relatively low cost, ease of regional transferability, and a wide range of available digital resources. The results of a Level One assessment can be used to target higher (Level Two and Three) assessments, identify priority or critical areas for conservation and management, and characterize habitat quality changes over space and time (Faber-Langendoen et al., 2008).

### 1.2. Level Two – rapid assessment

A Level Two wetland assessment is a medium intensity evaluation characterized by a Rapid Assessment Method (RAM). A RAM is a field-based method that employs a suite of field indicators covering the biological, hydrological, chemical, and functional components of a wetland that are associated with overall wetland integrity; this is often administered in the form of a checklist to use when making a site visit (Fennessy et al., 2007). A Level Two assessment is relatively easy and quick to execute, is somewhat transferable and adaptable, and is generally expected to have greater sensitivity to changes in ecological integrity than a Level One assessment (USEPA, 2006). The development of a Level Two protocol however can require a substantial investment in time and resources, necessitates expert knowledge of regional wetland ecosystems, and involves the evaluation, calibration, and independent validation of dozens of checklist components (Faber-Langendoen et al., 2008, 2012; Sutula et al., 2006). The results of a Level Two are typically either used as a stand-alone assessment or to target a Level Three assessment.

### 1.3. Level Three – intensive assessment

A Level Three wetland assessment is the most intensive evaluation method, necessitating rigorous data collection that typically employs a standardized sampling design. Level Three assessments could be based on biotic, such as vegetation, or physical, such as water quality, wetland components, but are most frequently performed by applying an Index of Biotic Integrity (IBI). IBIs can be generated for representative wetland biotic assemblages including: birds (Smith-Cartwright and Chow-Fraser, 2011), vegetation (Lopez and Fennessy, 2002; Mack, 2001a), macroinvertebrates (Burton et al., 1999), fish (Minns et al., 1994), and amphibians (Micacchion, 2002). The underlying assumption of an IBI is that a chosen biotic assemblage acts as an ecological indicator that integrates a variety of physical, chemical, biological, and hydrological information over time and space as a function of ecological integrity (Faber-Langendoen et al., 2008). IBIs are constructed by characterizing multiple indicator metrics for each chosen assemblage (e.g. species richness, relative abundance, presence/absence of species, etc.) and then scoring and weighting the metrics to produce a single ecological integrity score for a wetland (Faber-Langendoen et al., 2012, 2008; USEPA, 2002a,b). IBIs are typically intended for assessing a specific wetland class in a specific geographical region. They are rarely national in scope; rather, each state must adapt and validate its own IBI set (USEPA, 2002b). IBIs are expensive and time consuming, and are rarely used to evaluate large numbers of wetlands. Instead, Level Three assessments are used to refine the outcomes of Level One and Two assessments (USEPA, 2002a,b).

The USEPA suggests that to fully understand the complexity of a wetland ecosystem, all levels of the three-tier framework should be used, each one addressing different management questions or monitoring objectives. For example, lower level assessments can be used to report on status and trends of wetlands and to identify target regions of concern, and higher level assessments can be used to report on the success of specific wetland projects. Results from higher levels can also be used to enhance the utility or test the effectiveness of lower levels (USEPA, 2006). To model the application and effectiveness of the three-tiered framework, the USEPA launched the National Wetland Condition Assessment (NWCA), evaluating over 1100 wetlands nationally in 2011 (USEPA, 2016). The detailed and validated methodology of the NWCA aims to serve as a foundation for States and Tribes to build individualized protocols. Currently it is widely accepted that a higher level of effort and sampling intensity yields a more precise, accurate, and effective wetland evaluation (USEPA, 2006). This assumption however has rarely been tested empirically.

We used a suite of Level One, Level Two, and Level Three landscape, biotic, and water quality metrics to assess the ecological integrity of 71 wetlands across the St. Lawrence River Valley (SLRV) of northeastern New York State. The objectives of our study were to (1) determine how similar the metrics within a Level and between Levels are at ranking the wetland set, (2) determine which metrics work best at showing a full disturbance range, and (3) make recommendation on which Level methods are most appropriate for use in regions similar to the SLRV. We hypothesize that there will be strong relationships between all three levels of assessment suggesting that lower tier assessment methods can be effective at evaluating wetland ecological integrity, and at a lower level of effort.

## 2. Materials and methods

### 2.1. Study area

The SLRV is approximately 8200 $km^2$ across three counties in New York State, and is defined by the St. Lawrence River to the north, the Adirondack Mountains to the south and east, and Lake Ontario to the west (Fig. 1). The dominant land cover in the SLRV is deciduous forest (30%) and the dominant land use is pasture and hay field (23%); wetlands make up 17% of the valley landscape (Homer et al., 2015). We surveyed 71 palustrine wetlands belonging to the emergent, forested, or scrub-shrub classes (Cowardin et al., 1979) ranging in size from 0.2 ha to 104 ha. We selected wetlands that spanned a gradient of disturbance; therefore, wetland sites were located in a variety of landscape contexts, including row crop, hayfield, animal agriculture, residential development, forest, and managed wildlife conservation areas. The landscape setting of surveyed wetlands reflected a variety of environmental stressors including agricultural runoff (sediment, animal wastes, and chemical fertilizers), buffer impairment (vegetation loss, shoreline modification and hardening), road impacts (road salt, habitat fragmentation), hydrological modification, livestock grazing, and invasive plant and animal species. Further information on the surveyed wetlands and their landscapes are in Stryszowska et al. (2016) and Benson et al. (2017).

### 2.2. Wetland classes

Surveyed wetlands fell into three disturbance history categories; natural, restored, and degraded. Twenty-four of the surveyed wetlands were natural wetlands, 31 were restored under two major federal habitat restoration programs (U.S. Fish and Wildlife Service's Partners for Fish and Wildlife Program, National Resources Conservation Service's Wetlands Reserve Program), and 16 wetlands were located within the Massena Great Lakes Area of Concern (AOC), a federally-designated area of environmental concern affected by industry, landscape, and hydrological modification associated with the St. Lawrence Seaway and the Moses-Saunders Hydroelectric Power Dam (NYSDEC, 1990). We used these three classes as an independent measure of wetland integrity. The three classes were assumed to have integrated a variety of landscape and local disturbances such as nutrient enrichment, hydrological modification, invasive species, and sedimentation, where natural wetlands experienced the lowest level of disturbance and AOC wetlands experienced the highest.

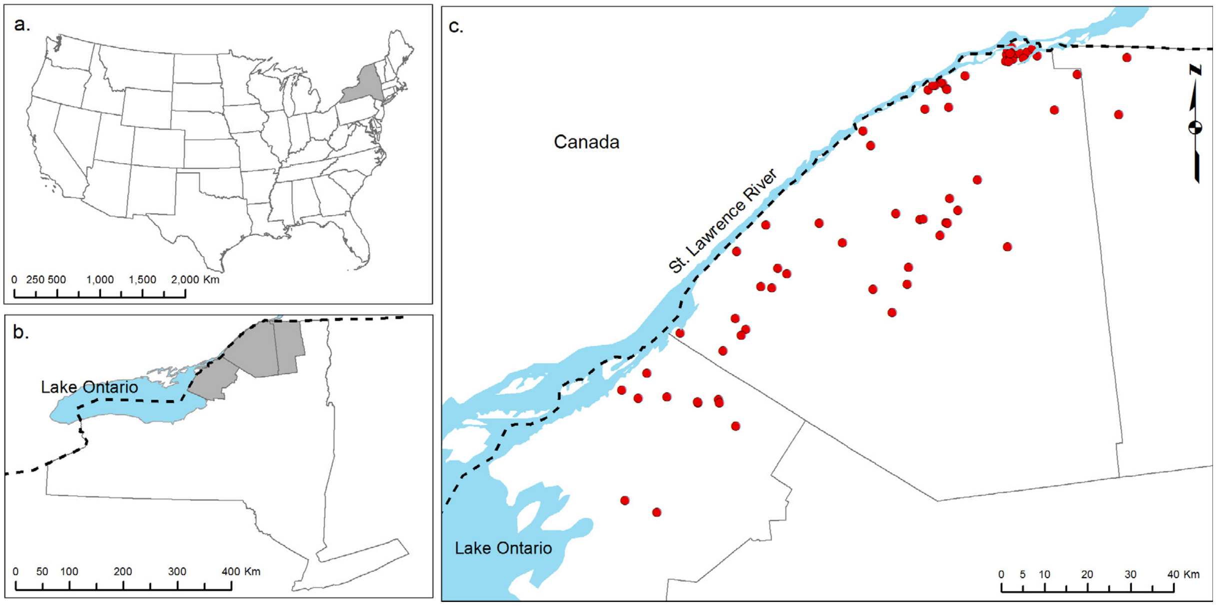

**Fig. 1.** The study area is located in (a) the Northeastern United States; and (b) northern New York State. Seventy-one palustrine wetland sites were surveyed in the St. Lawrence River Valley (c).

### 2.3. *Level One: Landscape assessment*

We used four Level One methods to characterize each wetland based on the surrounding landscape. Two of the methods were basic checklists and diagrams. The Minnesota Disturbance Gradient (MDG) is a score adapted from a checklist developed for depressional wetlands in Minnesota, USA (Gernes and Helgen, 2002). The original score is based on five factors: disturbance within a 50 m buffer, disturbance within a 500 m buffer, habitat, hydrology, and chemical pollution, and ranges from 0 (no evidence of disturbance) to 100 (high level of disturbance). We chose to omit the metric associated with chemical measurements of the water and sediments (and adjusted the final score by lowering it by 25 points), because those were outside our scope of our work. Our final MDG scores ranged from 0 (no evidence of disturbance) to 75 (high level of disturbance). The Ohio Disturbance Gradient (ODG) is a rule-based diagram developed to objectively quantify relative levels of disturbance based on the dominant local landscape characteristics (Lopez and Fennessy, 2002). The classification system scores each wetland based on the surrounding land cover, the land cover of a 100 m buffer, and hydrological modification in the wetland, and ranges from 1 (low impact) to 24 (high impact). Each wetland was scored using the MDG and the ODG by a single rater with the aid of ArcGIS digital orthoimagery and digitally-drawn buffers.

Two additional Level One assessments were performed using GIS exclusively. The Landscape Development Intensity (LDI) index is a protocol developed by Brown and Vivas (2005) for watersheds and wetlands in Florida. The index is a function of non-renewable energy (i.e., electricity, fuels, fertilizers, pesticides, irrigation water) use per unit area of land use, from which an emergy coefficient is developed for each land use type. We used the 2011 USGS NLCD raster file at 30 m resolution to adapt Florida's LDI coefficients and calculate the LDI index. Brown and Vivas (2005) report emergy coefficients for 27 classes of land use; our NLCD raster used only 16 classes. The Florida LDI coefficients were equated to the most equivalent NLCD land use class, guided by Mack (2006) (Table 1). For each land use class, we calculated percent cover within a 100 m buffer from the edge of each wetland polygon. The equation for calculating the LDI index is, $\mathrm{LDI}_{\mathrm{Total}} = \Sigma(\%\mathrm{LU}_i{*}\mathrm{LDI}_i)$ where, $\mathrm{LDI}_{\mathrm{Total}}$ = the LDI score, $\%\mathrm{LU}_i$ = percent of total area of land use i within a 100 m buffer, and $\mathrm{LDI}_i$ = landscape development intensity coefficient for land use i (Brown and Vivas, 2005). The LDI index ranges from 1 (landscape with low-intensity uses) to 10 (landscape with high energy-intensive uses). The second remote assessment was a calculation of percent forest cover within a 1 km radius from the center point of each wetland (variable: Forest). Forest cover consisted of the aggregate upland deciduous, evergreen, and mixed NLCD forest classes.

### 2.4. *Level Two: Rapid assessment*

We used the Ohio Rapid Assessment Method (ORAM), (variable: ORAM) Version 5.0 for wetlands as our sole Level Two assessment (Mack, 2001b). The method was developed for freshwater wetlands in Ohio, USA for regulatory purposes. ORAM is comprised of several sections including background information about wetland size, location, and class, narrative questions about wetland habitat, and quantitative ratings of various wetland categories. For our study, the narrative rating was omitted because of its specificity to Ohio. The quantitative ratings section consists of six categories: wetland area, buffer land cover/use, hydrology, habitat types, special wetland classes, and plant communities; each category is subdivided into multiple metrics. For our study, we omitted two hydrology metrics (groundwater as a source and presence of a 100 year floodplain) that lacked data. We adjusted the total ORAM score by making the hydrology metric worth 3 points less and making the plant communities metric worth 3 points more. The total ORAM score is the sum of all the metric scores and ranges from 0 (very poor condition) to 100 (reference condition). Detailed ORAM field methods and protocols are described elsewhere (Mack, 2001b). Each of the 71 wetlands was evaluated using ORAM by a single rater in July and August 2013. Out of the 16 metrics scored, four were evaluated in the laboratory using ArcGIS and digital orthoimagery and 12 were assessed in the field during a one-hour site visit per wetland.

### 2.5. *Level Three: Intensive site assessment*

The wetland biotic assessment data were collected between 2009 and 2015. Avian ten-minute point counts followed by vocalization playback surveys were completed on two mornings per site and were scheduled to coincide with bird breeding periods. Survey points in each wetland were located on the open water – emergent vegetation interface. Monitoring methods were based on the Standardized North

**Table 1**
The NLCD land use class emergy coefficients equated to the most equivalent Florida land use classes. The coefficients were used to calculate the LDI for each wetland in this study.

| FL land use class | NLCD land use class | Emergy coefficient |
|---|---|---|
| Natural open water | Open water | 1.00 |
| Natural system | Palustrine forested wetland | 1.00 |
| Natural system | Palustrine scrub/shrub wetland | 1.00 |
| Natural system | Palustrine emergent wetland | 1.00 |
| Natural system | Deciduous forest | 1.00 |
| Natural system | Evergreen forest | 1.00 |
| Natural system | Mixed forest | 1.00 |
| Natural system | Scrub/shrub | 1.00 |
| Recreational/open space – low-intensity | Bare land | 1.83 |
| Improved pasture (without livestock) | Grassland/herbaceous | 2.77 |
| Improved pasture – low intensity (with livestock) | Pasture/Hay | 3.41 |
| Single family residential – low intensity | Developed, open space | 6.92 |
| Agriculture – high intensity | Cultivated crops | 7.00 |
| Single family residential – high density | Developed, low intensity | 7.55 |
| Low – intensity commercial | Developed, medium intensity | 8.00 |
| Central business district (average 2 stories) | Developed, high intensity | 9.42 |

American Marsh Bird Monitoring Protocol (Bibby et al., 2000; Conway, 2011). We conducted nighttime anuran (frog and toad) calling surveys on three nights scheduled to overlap peak anuran breeding periods, coinciding with three air temperature ranges (5–9 °C, 10–16 °C, and > 16 °C). We based monitoring techniques on those described by Heyer et al. (1994) and the Marsh Monitoring Program (2009). We surveyed submerged, emergent, and upland vascular wetland plants using a transect plot method during a single summer visit per wetland. A transect was located at the vantage point used for bird and anuran surveys and two more transects were located at 50 m intervals away from the first. We placed a single, one meter squared quadrat at each of three elevations ( + 20 cm, 0 cm, − 20 cm) along each transect, for a total of nine quadrats per wetland; the 0 cm elevation was estimated by observing field indicators of the maximum spring water level line (U.S. Army Corps of Engineers, 1987). At each quadrat, all vascular plants were identified to the lowest taxonomic level and percent cover was recorded for each plant taxon. We collected water samples using clean sampling techniques modeled after Turk (2001) and other protocols. Each wetland was sampled once during the summer, in two locations, using 1 L acid washed polyethylene bottles, at approximately 1 m depth, and within 3 m of the emergent vegetation. We measured temperature and conductivity on site using a YSI Model 600XL probe. All samples were stored on ice in a cooler and were processed on the same day. The final list of measured water quality metrics included nitrate, temperature, conductivity, turbidity, total phosphorus, pH, and chlorophyll-a. Detailed methods on the biotic surveys and water quality measurement are provided in Stryszowska et al (2016).

We used the species richness per wetland of anurans (variable: ASR), birds (variable: BSR), and vegetation (variable: VSR) as basic Level Three metrics. For more complex metrics, we mainly used IBIs developed for and validated in the Laurentian Great Lakes region, including amphibians (Burton et al., 2008), birds (DeLuca et al., 2004), vegetation (Burton et al., 2008; Swink and Wilhelm, 1979), and water quality (Chow-Fraser, 2006). The amphibian and bird IBIs are based on classifying the species assemblages into guilds. For the amphibian IBI (variable: AIBI), frogs and toads were classified into woodland species (*Hyla versicolor, Pseudacris crucifer, Pseudacris maculata, Rana sylvatica*) and total species. Three metrics were derived from these guilds: relative total species richness, relative woodland species richness, and probability of detection of woodland-associated species. For relative species richness, the total possible frog and toad species richness and the total possible woodland species richness for the region were determined by examining state amphibian distribution maps. We set a conservative value of 1 for the probability of detection of woodland-associated species because we only visited each wetland site in a single location. The sum of the three metrics was the final AIBI score for each wetland and ranged from 0 (no anurans) to 100 (diverse anuran assemblage).

For the bird IBI, we used the index of marsh bird community integrity (variable: IMBCI) developed for Chesapeake Bay, USA wetlands (DeLuca et al., 2004). The IMBCI combines guild-based community structure with species attributes. Bird species were determined to belong to the wetland obligate guild if they rated a five on Croonquist and Brooks' (1991) wetland dependence list. Species attributes represented foraging, nesting, migration, and breeding range and ranged from a score of 1 (generalist) to 4 (specialist) for each attribute. Scores for each attribute were determined by using rankings developed by Croonquist and Brooks (1991) and the bird species guides developed by the Cornell Lab of Ornithology (http://www.birds.cornell.edu, 18, December 2016) (see Table 2 in DeLuca et al., 2004). The final IMBCI score is a sum of all the species attributes for all bird species found in a wetland and the number of wetland obligate species. The score starts at 0 (only generalist species present) and goes up indefinitely depending on the number of specialized species that can potentially be found in a wetland.

We used metrics of the Floristic Quality Index to assess the herbaceous vegetation community at each wetland. All metrics were centered on each species' Coefficient of Conservatism (C) value (Swink and Wilhelm, 1979), which expresses the propensity of plants to occupy least-altered habitat. Each plant species was assigned a C value using Bried et al., (2012). Taxa identified only to the genus level were excluded from analysis. All non-native taxa (USDA NRCS, 2015) were given a C value of zero and were included in all metric calculations. Using C, the mean C (variable: mC) was calculated for each wetland site by dividing the sum of all C values by the number of plant species. The mC ranges from 0 (wetland occupied by generalist or non-native plant species) to 10 (wetland occupied by native plant species that require unaltered habitat). The mC is then multiplied by the square root of the total species number to yield the floristic quality index (variable: FQI) (Burton et al., 2008; Feldmann et al., 2012; Herman et al., 2001; Swink and Wilhelm, 1979). The FQI starts at 0 (wetland occupied by generalist or non-native plant species) and increases indefinitely depending on the number of species requiring unaltered wetland habitat in the region. Following Miller and Wardrop (2006) we calculated I, which adjusts the FQI to be less sensitive to species richness and ranges from a score of 1 to 100. Following Milburn et al. (2007) we calculated the weighted FQI (variable: wFQI) to incorporate the percent cover of each plant species. The wFQI ranges from 0 (high proportion generalist or non-native plants) to 1 (low proportion generalist or non-native plants). The mean conservatism ratio (variable: mCR) was calculated as per Burton et al. (2008) by dividing the mC of all species by the mC of only native species. The mCR is a measure of the prevalence of non-native species and ranges from 0 (wetland occupied by non-native species) to 1

**Table 2**
Sixteen wetland assessment metrics, grouped into three levels of intensity, used to rank 71 wetlands on a gradient of ecological integrity. Each metric is followed by the possible range of scores for that metric where the higher score indicates higher ecological integrity. For some metrics, the maximum obtainable metric value is dictated by the local species pool, indicated by (Pool). The 71 sample wetlands are further broken down into Restored, Natural, and AOC wetlands. Marked with an "*" are metrics that correctly classified wetlands into the Restored, Natural, and AOC categories.

| | All | | Natural | | Restored | | AOC | |
|---|---|---|---|---|---|---|---|---|
| Metric | N | Mean ± SD | N | Mean ± SD | N | Mean ± SD | N | Mean ± SD |
| *Level 1* | | | | | | | | |
| Minnesota Disturbance Gradient (MDG) (0–75)* | 71 | 49.4 ± 14.2 | 24 | 55.8 ± 14.1 | 31 | 48.6 ± 11.6 | 16 | 41.3 ± 15.2 |
| Ohio Disturbance Gradient (ODG) (0–24)* | 71 | 15.5 ± 6.1 | 24 | 19.8 ± 4.8 | 31 | 14 ± 6.2 | 16 | 11.8 ± 3.6 |
| Landscape Development Index (LDI) (1–10) | 71 | 8.3 ± 0.7 | 24 | 8.7 ± 0.4 | 31 | 7.9 ± 0.8 | 16 | 8.7 ± 0.6 |
| Percent Forest Cover (Forest) (0–100) | 71 | 44.4 ± 18.9 | 24 | 47 ± 21.7 | 31 | 41.2 ± 20.9 | 16 | 46.9 ± 6.4 |
| *Level 2* | | | | | | | | |
| Ohio Rapid Assessment Method (ORAM) (0–100)* | 71 | 60 ± 13.6 | 24 | 67.4 ± 11.6 | 31 | 58.7 ± 13.4 | 16 | 51.5 ± 11.5 |
| *Level 3* | | | | | | | | |
| Index of Marsh Bird Community Integrity (IMBCI) (0–Pool)* | 71 | 6.4 ± 2.7 | 24 | 7.1 ± 2.9 | 31 | 6.3 ± 2.8 | 16 | 5.3 ± 1.5 |
| Bird Species Richness (BSR) (0–Pool)* | 71 | 18.6 ± 3.7 | 24 | 19.6 ± 3.5 | 31 | 18.2 ± 4.1 | 16 | 17.7 ± 3.1 |
| Amphibian Index of Biotic Integrity (AIBI) (0–100)* | 71 | 89.3 ± 16.1 | 24 | 94.3 ± 10.8 | 31 | 92.3 ± 11.5 | 16 | 76.2 ± 22.6 |
| Anuran Species Richness (ASR) (0–10) | 71 | 4.9 ± 2.0 | 24 | 5.3 ± 1.7 | 31 | 5.4 ± 1.8 | 16 | 3.1 ± 1.8 |
| Mean Coefficient of Conservatism (mC) (0–10)* | 68 | 2.8 ± 0.4 | 23 | 3.0 ± 0.4 | 29 | 2.7 ± 0.4 | 16 | 2.5 ± 0.4 |
| Floristic Quality Index (FQI) (0–Pool)* | 68 | 13.9 ± 3.5 | 23 | 15 ± 3 | 29 | 14.8 ± 3.4 | 16 | 10.6 ± 2 |
| Weighed Floristic Quality Index (wFQI) (0–1)* | 68 | 0.44 ± 0.13 | 23 | 0.50 ± 0.12 | 29 | 0.42 ± 0.1 | 16 | 0.37 ± 0.15 |
| Adjusted Floristic Quality Index (I) (0–100)* | 68 | 31 ± 3.8 | 23 | 33.2 ± 3.2 | 29 | 30.7 ± 3.4 | 16 | 28.5 ± 3.5 |
| Mean Conservatism Ratio (mCR) (0–1)* | 68 | 0.79 ± 0.09 | 23 | 0.84 ± 0.08 | 29 | 0.78 ± 0.1 | 16 | 0.74 ± 0.07 |
| Vegetation Species Richness (VSR) (0–Pool) | 68 | 25.8 ± 9.3 | 23 | 25.2 ± 8.2 | 29 | 30 ± 9.2 | 16 | 19.1 ± 6.7 |
| Water Quality Index (WQI) (−3–3)* | 63 | 0.65 ± 0.65 | 21 | 0.73 ± 0.46 | 31 | 0.69 ± 0.54 | 11 | 0.34 ± 1.12 |

(wetland occupied by native species only).

We used a combination of our water quality metrics to calculate a Water Quality Index (variable: WQI). WQIs were developed by Chow-Fraser (2006) based on 12 water quality parameters that are significantly related to Great Lakes basin-wide land use stressors and sensitive to road density (deCatanzaro et al., 2009). We used a subset model (Equation #3 in Chow-Fraser, 2006) that best incorporated our water quality metrics: $\mathrm{WQI} = 10.753047–0.946098 \times \log \mathrm{Turbidity}\ (\mathrm{NTU}) - 0.837294 \times \log \mathrm{Conductivity}\ (\mu\mathrm{S/cm}) - 1.319621 \times \log \mathrm{Temperature}\ (^{\circ}\mathrm{C}) - 4.604864 \times \log \mathrm{pH} - 0.387189 \times \log \mathrm{Total\ phosphorus}\ (\mu\mathrm{g/L}) - 0.353713 \times \log \mathrm{Total\ nitrogen}\ (\mu\mathrm{g/L}) - 0.337888 \times \log \mathrm{Chlorophyll}\text{-}a\ (\mu\mathrm{g/L})$ The final WQI score ranges from − 3 (highly degraded water quality) to + 3 (excellent water quality).

### 2.6. Statistical analysis

Metrics were adjusted so that the polarity of impairment was the same for all. To test how each metric associated with others, we calculated bivariate, one-tailed correlation statistics; Pearson's correlation coefficient when data were bivariate normally distributed or else Spearman's Rank correlation. To maintain an experiment-wise Type I error rate of 5%, we used a Bonferroni correction on all bivariate correlations, which resulted in a critical p-value of 0.0004. The statistical software R version 2.15.1 was used for all analyses (R Core Team, 2012).

## 3. Results

Out of the 16 metrics, five metrics scored wetlands across the full gradient of possible conditions (Forest, MDG, ODG, ASR, and wFQI), and four had good distributions up to a ceiling defined by the local species pool (IMBCI, BSR, FQI, and VSR). The remaining seven metrics either did not reach the upper limits of the scale (high ecological integrity; mC and I), lower limits of the scale (degraded wetlands; AIBI, ORAM, mCR, and AIBI), or either limit (WQI) (Fig. 2, Table 2). Of the Level One metrics, the LDI had the poorest gradient distribution, indicating that all wetlands were surrounded by low energy-intense land use. The Level Two metric, ORAM, had a good distribution but lacked sites at the floor of the scale, the most degraded wetlands. Of the Level Three metrics, mC and I had the poorest distribution, with a range covering only 20% of the full range of scores, insufficiently capturing the high integrity wetlands.

### 3.1. Level One metrics

The strongest Level One metric correlation was between ODG and LDI (r = 0.67) (Table 3). Level One metrics MDG, ODG, and LDI were significantly correlated with ORAM, and the highest correlation was between ORAM and MDG (r = 0.75). Metric ODG was significantly correlated with three of 11 Level Three metrics and with six of 15 total metrics. Forest did not have a significant correlation with any other metric.

### 3.2. ORAM

ORAM was significantly correlated with three out of the four Level One metrics and one out of the 11 Level Three metrics; mCR (Table 3). The strongest correlation was between ORAM and MDG (r = 0.75). ORAM correlated much more strongly with Level One metrics than Level Three.

### 3.3. Level Three metrics

Level Three metrics were positively correlated among each-other (Table 3). The six plant metrics were significantly and strongly positively correlated; the highest correlation being between I and mC (r = 0.95). ASR and AIBI were also strongly correlated as was BSR and IMBCI. Plant metrics mC, FQI, and mCR were the only ones that correlated with Level One metrics. Neither the species richness metrics nor the bird and anuran IBIs were associated with lower-level metrics. The metric mCR was the only one that was significantly correlated with ORAM. The strongest between-level correlation was between mCR and ODG (r = 0.49). The metric mCR correlated significantly with seven of 15 total metrics, the most of any metric. WQI did not have a significant correlation with any other metric (Table 3).

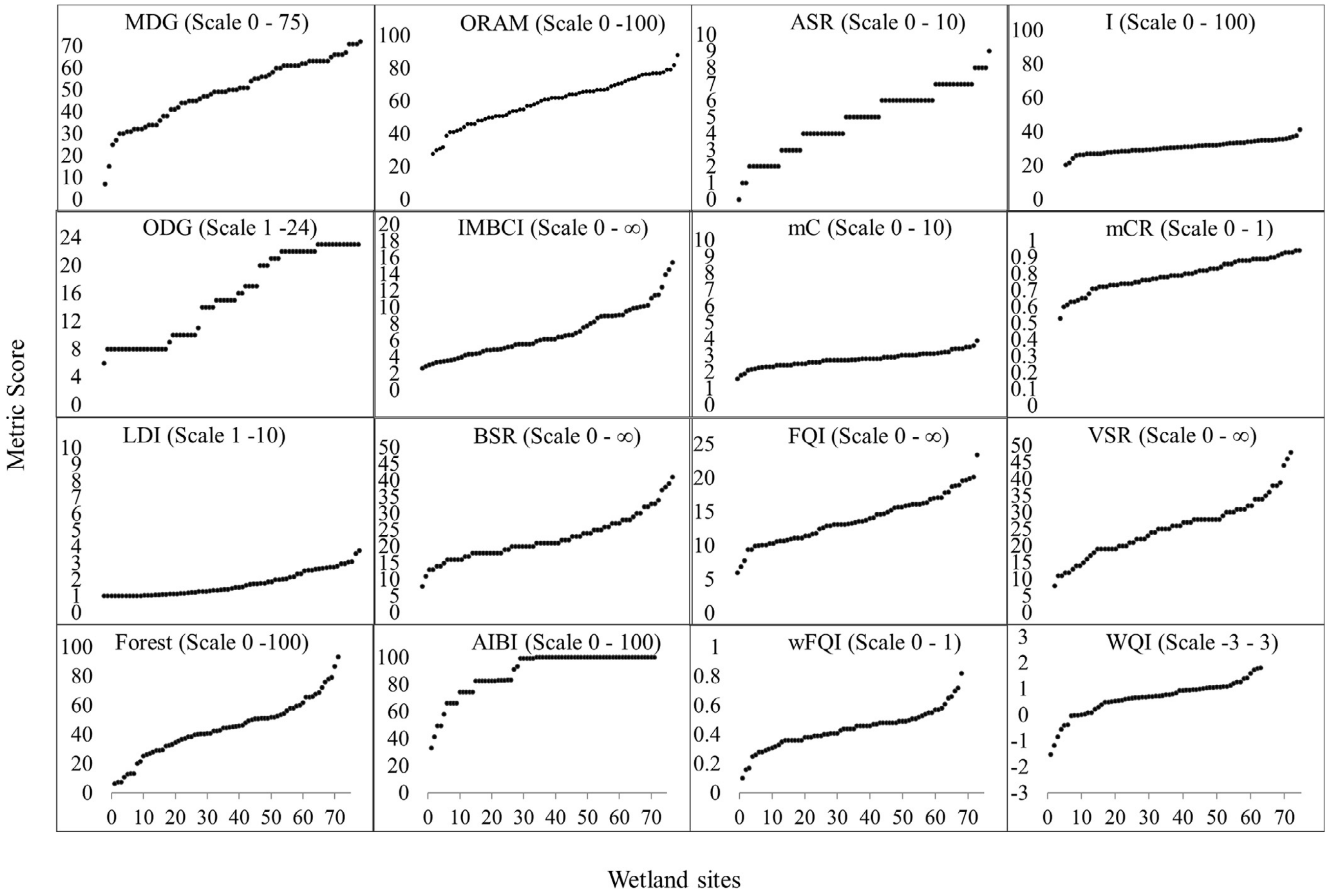

**Fig. 2.** The gradients of possible conditions of wetland ecological integrity as captured by the 16 metrics used in this study. For all metrics, low metric scores indicate poor ecological integrity.

## 4. Discussion

USEPA gives States and Tribes primary responsibility to monitor and report on the condition of their wetlands, as is being currently done for streams and lakes (USEPA, 2003). It further suggests that wetland assessment be performed in a buildable process deemed the 1-2-3 framework, which uses three levels of assessment effort. The USEPA acknowledges that States and Tribes don't necessarily use all three levels, but draw on one or more to build their assessment and monitoring programs. Our study used 16 previously tested wetland assessment metrics that varied in levels of effort to evaluate the ecological integrity of palustrine wetlands in the SLRV. We detected significant correlations across multiple levels, and for metrics within levels, which indicates that these metrics, regardless of effort, are measuring similar attributes of wetlands. The metrics also reliably classified groups of natural, restored, and AOC wetlands. The implication of this finding is that the landscape setting (as assessed by Level One) is linked to the biotic wetland community (as assessed by Level Three), and can be used to predict the ecological condition of a wetland using less complex methods. The relationships did have limits, however, indicating that

**Table 3**
One-tailed, Pearson and Spearman Rank correlations between pairs of 16 wetland assessment metrics. Bonferroni corrected significant results ($p < 0.0004$) are in bold.

| | MDG | ODG | LDI | Forest | ORAM | IMBCI | BSR | AIBI | ASR | mC | FQI | wFQI | I | mCR | VSR | WQI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MDG | | | | | | | | | | | | | | | | |
| ODG | **0.63** | | | | | | | | | | | | | | | |
| LDI | 0.28 | **0.67** | | | | | | | | | | | | | | |
| Forest | 0.03 | 0.35 | **0.48** | | | | | | | | | | | | | |
| ORAM | **0.75** | **0.51** | **0.48** | 0.07 | | | | | | | | | | | | |
| IMBCI | 0.19 | 0.10 | -0.05 | -0.03 | 0.19 | | | | | | | | | | | |
| BSR | 0.35 | 0.22 | 0.07 | 0.05 | 0.30 | **0.46** | | | | | | | | | | |
| AIBI | 0.10 | 0.10 | 0.04 | 0.14 | 0.00 | 0.06 | 0.23 | | | | | | | | | |
| ASR | 0.17 | 0.09 | 0.00 | 0.06 | 0.11 | 0.17 | 0.32 | **0.89** | | | | | | | | |
| mC | 0.24 | **0.44** | 0.40 | 0.21 | 0.36 | 0.01 | -0.04 | 0.22 | 0.26 | | | | | | | |
| FQI | 0.30 | **0.44** | 0.33 | 0.28 | 0.37 | 0.06 | 0.05 | 0.33 | 0.38 | **0.66** | | | | | | |
| wFQI | 0.18 | 0.12 | 0.14 | -0.03 | 0.23 | -0.11 | -0.14 | 0.25 | 0.29 | **0.58** | 0.31 | | | | | |
| I | 0.22 | 0.35 | 0.32 | 0.16 | 0.28 | 0.03 | -0.01 | 0.18 | 0.20 | **0.95** | **0.55** | **0.56** | | | | |
| mCR | 0.26 | **0.49** | **0.43** | 0.22 | **0.42** | -0.13 | -0.03 | 0.14 | 0.24 | **0.81** | **0.72** | **0.42** | **0.61** | | | |
| VSR | 0.21 | 0.29 | 0.15 | 0.19 | 0.19 | 0.03 | 0.14 | 0.24 | 0.26 | 0.09 | **0.78** | -0.01 | 0.00 | 0.29 | | |
| WQI | -0.10 | 0.07 | 0.31 | 0.15 | 0.08 | -0.02 | -0.15 | 0.01 | -0.02 | 0.14 | 0.19 | -0.08 | 0.19 | 0.05 | 0.21 | |

some metrics either cannot be substituted or may not be as effective as previously thought at evaluating ecological condition.

### 4.1. Natural, restored, and AOC wetlands

Our wetland set included three groups made up of natural, restored, and AOC wetlands. The occurrence of these classes offered a unique opportunity to provide a general determination of wetland integrity, independent of the assessment metrics. It could be assumed that natural wetlands experience the lowest level of disturbance whereas AOC wetlands experience the highest. Given this built-in disturbance gradient, our metrics could be evaluated for reliability as indicators of disturbance. As expected, natural wetlands averaged the highest metric scores and AOC wetlands averaged the lowest (Table 2). Overall, 12 out of 16 tested metrics accurately classified these three sets of wetlands into their expected disturbance categories (Table 2). It is evident that most of the tested metrics are effective at discriminating between general disturbance categories and responding to a disturbance gradient.

### 4.2. Level One metrics

The four Level One metrics performed well at characterizing the full gradient of possible conditions overall (Fig. 2). The metric LDI was the only one that had an incomplete gradient distribution; it did not classify any wetlands as highly disturbed. Other studies successfully used

LDI to characterize wetlands (Mack, 2006; Reiss and Brown, 2007). A metric that performs poorly at spanning a gradient lacks sufficient sensitivity to respond to disturbance or to differentiate between disturbance classes (USEPA, 2002b). The incomplete LDI condition gradient could indicate a problem with the metric, a problem with our wetland set, or both. We think that the landscape setting for the wetlands in our study may have been too rural to represent some of the high intensity land uses incorporated into the LDI, such as commercial and business district properties. LDI seems to be more sensitive to high intensity land uses and does not highlight the potentially nuanced impacts (e.g. hydrological modification) associated with natural land cover. The metrics Forest and LDI did not correctly classify wetlands into their natural, restored, and AOC disturbance categories, ranking restored wetlands as the most disturbed (Table 2). This is not surprising as many restored wetlands are located on agricultural lands, as part of conservation easement programs. This setting results in wetlands being surrounded by low natural land cover. This inconsistency is not necessarily a flaw of the metrics, but rather a function of our specific wetland set.

The ease of use of the various Level One metrics was similar, requiring some knowledge about and access to GIS software and datasets, and a little familiarity with the wetland site to be assessed. The ODG and MDG did not require the use of GIS but did require some knowledge of hydrological modifications to a wetland site, which can be difficult to ascertain from aerial images and would, for best results, necessitate a site visit. In addition, scoring wetlands using MDG and ODG required understanding of wetland ecology and hydrology. The metrics Forest and LDI are GIS-based but, unlike MDG and ODG, can be completed without visiting a wetland site and without any knowledge of site history, ecology, or hydrology. This, seemingly useful, aspect of GIS-based assessment methods may have ultimately limited them in effectively evaluating the ecological integrity of wetlands. LDI correlated with only two higher Level metrics and Forest did not correlate with any (Table 3). LDI and Forest may not be good indicators of the complex ecology of a wetland; for example, wetland sites that scored high integrity in Forest and LDI, had low anuran species richness (ASR). The strengths of the Level One metrics are their ease and speed of use, which reduces the need for time and resources. It does seem however, that some knowledge of wetland ecology and hydrology is useful is capturing wetland complexity. We found that whereas LDI and Forest performed poorly at assessing wetland ecological integrity, MDG and ODG are strong candidates to use in place of more effortful higher-level metrics.

### 4.3. Level Two: ORAM

The rapid assessment method ORAM was the single Level Two assessment used in this study. It requires, at minimum, an hour-long visit to a wetland site. The ORAM checklist is detailed and takes into consideration a multitude of wetland characteristics such as hydrology, habitat structure, plant communities, and landscape setting, which is significantly more information than provided by the Level One assessments. Although ORAM was not originally designed to be used for determining the ecological value of wetlands or quantifying biodiversity, ORAM scores have been found to correlate well with more intensive wetland assessment methods, even outside of Ohio (Mack, 2007; Peterson and Niemi, 2007; Stapanian et al., 2004). We found strong positive correlations between ORAM and 3 of 4 Level One metrics; MDG and ORAM had the strongest inter-level correlation in this study (Table 3). Whereas ORAM requires a more rigorous wetland visit, background information, and aerial photo interpretation, the correlation of ORAM with lower level metrics indicates that ORAM scores can potentially be forecast using a much less effortful method. ORAM had a significant relationship with only one Level Three metric, suggesting that despite a complex protocol, ORAM does poorly at representing biotic and abiotic wetland components. Since the completion of this study, New York State has developed a state-specific RAM. It would be informative to explore the relationship between the New York RAM and the remainder of the metrics.

### 4.4. Level Three metrics

We used 11 Level Three metrics covering plants, birds, anurans, and water quality. Plant metrics were the only Level Three metrics that did not span the full gradient of their scales; some had values that clustered at either the low or the high end of the gradient scale (Fig. 2). The majority of the vegetation metrics were dependent on the coefficient of conservatism (C) (i.e. mC, FQI, wFQI, I, and mCR). The generally low C values of the sampled plant species indicate that the wetlands were dominated by ruderal plant types, heavily skewing the scale gradients. Plants with high fidelity to undisturbed areas (high C values) may be rare in this region, limiting the complete metric range. This may not affect the applicability of C-based metrics because the disturbance gradient is still sufficiently represented within the limited metric range. All of the C-based plant metrics accurately classified the wetland set into the natural, restored, and AOC disturbance categories (Table 2) indicating that they are sensitive enough to discern between broad disturbance classes.

As expected, there was considerable collinearity among many of the Level Three metrics, particularly the various vegetation metrics (Table 3). This is a useful finding because practitioners may wonder which vegetation metric to use, given there is a growing number of metrics available (Chamberlain and Brooks, 2016; Milburn et al., 2007; Miller and Wardrop, 2006); our results show that different vegetation metrics evaluate the condition of a wetland similarly. The bird and anuran species richness metrics also correlated well with the indices derived from them (AIBI and IMBCI), reducing the need to use both to represent wetland condition.

When correlating Level Three metrics with the lower Levels, only three vegetation metrics correlated with Level One or Level Two metrics (mC, mCR, FQI; Table 3). From a vegetation perspective, this is an interesting finding because some of the simplest Level One metrics did not take vegetation into consideration at all (ODG and LDI), but rather looked at landscape setting. Landscape setting, land use patterns, and wetland buffer size, composition, and condition may thus have a strong influence on the floristic makeup of a wetland (Miller et al., 1997;

Mitsch and Gosselink, 2007). Alternately, despite the inclusion of a vegetation component, ORAM did not correlate well with Level Three vegetation metrics. Lower level assessments may provide an adequate method to describe at least the floristic component of a wetland without the need to sample in the field or to have plant identification expertise. This is a promising finding, since collecting vegetation data in the field is one of the most time consuming methods of evaluating wetlands.

None of the vertebrate metrics correlated with either of the lower levels suggesting that anurans and birds may be responding to attributes of a wetland or landscape that are not captured by the lower level metrics. Vertebrate metrics also did not correlate with the Level Three plant metrics. Ecological indicators such as the species richness of vertebrates may not be validly substituted by lower level methods, or even substituted by intensive vegetation sampling, if a full representation of wetland environmental condition is needed. Alternately, it is possible that neither species richness nor IBIs for vertebrate indicators are good indicators of wetland ecological integrity. For example, frogs and toads may be responding to the presence of fish in a wetland and birds may be responding to community dynamics and movement patterns on a much larger scale than what is represented at the wetland site level. More research may help clarify what disturbance and other factors locally and regionally determine vertebrate diversity metrics in wetlands.

The WQI is the only metric of sixteen that did not correlate with any other metric either within or between Levels (Table 3). It is surprising that the WQI does not correlate with Level One or Two metrics, given these metrics strongly incorporate the surrounding landscape in their assessment, and landscape is known to affect water quality (deCatanzaro and Chow-Fraser, 2011; Trebitz et al., 2007). It may be that water quality may not be a good representative of wetland habitat quality. Water quality samples offer just a brief snapshot in time of a complex and variable chemical system; in our case two sample locations per wetland on a single summer day. Water quality in wetlands is much more variable in short timescales and over small distances than are rivers and lakes. For example, throughout a diurnal cycle, water temperature has peaks and lows in response to the sun. Similarly dissolved oxygen peaks during the day when plants are photosynthesizing and can plummet at night. Plant uptake and decomposition has an effect on nutrient concentrations (Johnson, 1991). Finally, because wetlands tend to be very shallow and have deep sediment deposits, frequent sediment resuspension alters turbidity, temperature, and phosphorus retention (Wang and Mitsch, 2000). The variability in water quality through time and space may be just too large to say anything about the general wetland condition.

### 4.5. Applications

Wetland assessment and monitoring protocols have become a research focus for states and regions as they pursue compliance with the Clean Water Act and strive to manage their wetland resources. The collaboration between scientists and regulatory personnel in groups such as Mid-Atlantic Wetlands Workgroup and the Great Lakes Coastal Wetland Consortium has generated important literature on individual assessment methods (e.g. Burton et al., 2008; Mack, 2007; Sutula et al., 2006; Uzarski et al., 2017; Wardrop et al., 2007), but research to explore and apply the 1-2-3 framework is still scarce. Our project aimed to understand the relationships between all three levels of the 1-2-3 framework so that a practical application of the framework could become more feasible. Positive correlations among higher and lower level assessment methods indicate that the metrics of the three levels vary together. Given these positive associations, a lower level assessment can potentially be used to evaluate the ecological integrity of a wetland in place of a higher level metric, when time and resources are limited.

USEPA is encouraging states and tribes to regularly report on the condition of their wetlands. Having the flexibility to choose from a variety of metrics, of both low and high effort, and knowing that the final assessment result will have validity can help move states in the direction of reporting to USEPA. Instead of spending considerable effort developing their own assessment methods, states can use existing metrics and indices to start regularly evaluating their wetland resources. In addition, having the option of using lower level metrics can help government agencies report on a larger number of wetlands rather than spending significant effort on evaluating just a few using Level Three methods. We do not suggest that Level One methods replace excellent programs such as the North American Breeding Bird Survey or the Marsh Monitoring Program. Such programs offer long term, data-rich information on the community structure of various ecological indicators for specific sites; these programs can also contribute to regional or national assessments of wetland condition (Cosentino et al., 2014, Marsh et al., 2017). Additionally, these programs involve and motivate citizen scientists in wetland and species conservation. When agencies do not have the resources to carry out or continue such programs, using lower intensity methods can be a practical solution to wetland monitoring and conservation. If time and resources are available however, it is always prudent to use an assessment method that provides more information on which to evaluate a wetland site.

The application of the 1-2-3 framework is not exclusive to the regulatory realm. Wetland conservation initiatives can use the framework and the results of this study to improve wetland research, restoration, and management programs. The USDA National Resources Conservation Service is struggling with how to conduct mandated monitoring of the condition of the thousands of wetlands it has restored across the United States, in the face of significant budget and staffing limitations. The Great Lakes Restoration Initiative (GLRI) for example aims to restore, protect, and enhance 60,000 acres of Great Lakes coastal wetlands (Great Lakes Interagency Task Force, 2014). To demonstrate that this objective is met will be based on sound wetland assessment procedures, which can benefit from considering the 1-2-3 framework. The framework can extend globally as well. The Ramsar Convention on Wetlands recognizes the importance of wetland inventory, assessment, and monitoring (Ramsar Convention Secretariat, 2010). Their scientific review panel is creating and updating guidance documents to keep participating countries informed about the best way to meet the objectives of wetland conservation; incorporating 1-2-3 framework assessment methods with acceptable positive association between levels into the guidance documents can help international conservation and governmental environmental agencies meet their inventory, assessment, and monitoring goals.

## Acknowledgements

Biotic surveys were done under permit of NYSDEC, and protocols were approved by the Clarkson University IACUC. Funding in support of this Project was provided by the St. Lawrence River Research and Education Fund, the Northern New York Audubon and the Joseph Cullman Conservation Foundation, New York State Wildlife Grant #T-9-2, and the University of Michigan Water Center Grant. We thank all of the private landowners and public agencies that granted access to wetlands on their properties to collect the data that are the basis of this study. For their indispensable help we would like to thank: Angelena Ross, Jim Pullano, Kimberley Farrell, Gian Dodici, Carl Schwartz, Tom Jasikoff, Glenn Johnson, Cody Merrill, Jayson Hajek, Maria Hargis, Robyn Andrusyszyn, Eric Marcy, Kallen Frey, Brittany Guarna, Laura Barlow, Jeremy Ozolins, Nychele Carley, John Sherry, Felix Grimberg, Matthew Valente, Jon Podoliak, Kate Gilpin, and Stefanie Kring.

## Funding

This work was supported by the University of Michigan Water Center/Erb Family Foundation, United States, Northern New York Audubon Joseph and Joan Cullman Conservation Fund, United States, the St .Lawrence River Research & Education Fund, United States, and

US Fish & Wildlife Service/New York State Department of Environmental Conservation State Wildlife Grants Program, United States (Grant #T-9-2); we greatly appreciate the support of these funders.

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