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Development Of An Avian Index Of Biological Integrity For Kentucky Wetlands

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DEVELOPMENT OF AN AVIAN INDEX OF BIOLOGICAL INTEGRITY FOR KENTUCKY WETLANDS

BY

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Abstract

Bird communities are frequently used as bioindicators to assess environmental conditions, including in wetland habitats. I developed an avian index of biological integrity (IBI) for wetlands of Kentucky as an intensive assessment method to supplement an existing rapid assessment method used in regulatory programs. Birds are useful indicators because they are sensitive to environmental changes, abundant in various landscapes, occupy higher trophic levels, and can be sampled in a cost-effective manner. Breeding bird point count data from 103 sites were used to calculate a set of 49 avian community metrics. Avian metrics were tested for correlation with independent landscape, hydrology and habitat measures of wetland condition. High performing, non-repetitive metrics were tested using a model averaging approach to find the best set of avian community metrics that predicted an independent measure of wetland condition. Final metrics were scaled and assembled into an Avian IBI. I found four superior metrics to be significantly related to the independent disturbance index. The final metrics used to create the Avian IBI were percent presence of insectivores, percent presence of ground gleaners, percent presence of residents and Shannon Wiener Diversity Index. Both Shannon Wiener Diversity Index and percent presence of insectivores decreased with increasing disturbance. Percent presence of ground gleaners and percent presence of residents had a positive relationship to disturbance. Previous studies found similar results with insectivorous guilds being intolerant to human disturbance, whereas ground-gleaning guilds tend to be more tolerant. This cost-effective and time-efficient IBI complements existing assessment tools for wetlands of Kentucky.

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Chapter I: Introduction

Wetlands provide functions such as storage and transfer of water and biochemicals, decomposition of organic matter, and for living organisms being communities and habitats. These functions provide values to humans including flood control, filtering and cleansing runoff, timber production, food production and recreational uses (U.S. Environmental Protection Agency 2002*a*). The ecological processes, as well as the floral and faunal assemblages that occur in wetlands, are distinct compared to the other freshwater resources within the United States. Many floral and faunal assemblages rely on wetlands. For example, approximately half of migratory bird species in the United States and over 30% of flora and fauna listed under the Endangered Species Act are dependent on wetlands (Miller et al. 2016).

Wetlands across the United States are decreasing in total area and quality. Within the contiguous United States, less than half of the pre-Columbian wetlands remain (Dahl 1990). Historically there was great incentive to drain and remove wetlands to improve yields of farmland, and to reduce flooding and mosquito-borne disease. Fresh water systems have historically had higher declines in biodiversity, five times greater than in terrestrial systems (Ruaro and Gubiani 2013). Between 1986 and 1997, over 50 percent of freshwater wetlands had been lost to uplands due to urbanization and rural development (Dahl 2000). Along with other states, Kentucky has lost over 80% of its wetlands (Dahl 2000). The importance of wetlands has only recently been recognized within the United States. A major step towards protection was The Clean Water Act of 1972, which had a main goal of maintaining and restoring the chemical, physical, and biological integrity of the nation’s waters (U.S. Environmental

Protection Agency 2002*a*). This includes wetlands, but little was known of the quality of wetlands across the country. Federal and state agencies began their programs primarily focusing on assessing and conserving wetland acreage, with the goal of slowing the rate of wetland loss, with minor regard to the quality of the wetlands (U.S. Environmental Protection Agency 2002*a*). In 1988, the National Wetlands Policy Forum recommended to the federal government a policy of "no overall net-loss" of wetlands, with a long-term goal to conduct "significant restoration" of remaining wetlands. In 1990, the U.S. Congress adopted the no net loss policy (Stevenson and Hauer 2002). Between 1998 and 2004, for the first time, net wetland gains exceeded net wetland losses due to restoration programs and agricultural conservation programs, mostly of freshwater wetlands (Dahl 2006). Forested wetlands are the dominant type of freshwater wetland and are lost to upland habitat by natural succession, timber harvest and the destruction to hydrology from development and agriculture (Dahl 2006). In 2004, the Wetlands Initiative pursued the overall increase in wetland quality in addition to quantity, going beyond the traditional "no net loss" policy (Dahl 2006). Because Kentucky is among the states that have lost a large majority of historic wetlands, it is important to have monitoring in place for "no net loss" management decisions that protect the remaining wetlands and evaluate the condition of the state's wetlands.

Human activity affects the condition of landscapes and their ecological communities. Anthropogenic land uses vary in intensity and can disturb ecological communities through direct or secondary impacts. These can occur as a sole impact or through a combination of impacts (Brown and Vivas 2005). In addition, when measuring disturbances, it can be difficult to distinguish between natural and anthropogenic variation (Karr and Chu 1999). A way to avoid this difficulty is to take measurements at places with little or no human influence, often called “reference sites” to indicate the variability and disturbance that occurs naturally (Karr and Chu 1999). Other area can then be compared to reference sites to determine if disturbances are human-induced. However, wetlands with little or no human influence represent just small portion of the remaining wetlands, including within Kentucky. This makes it difficult to use reference sites when measuring disturbances to assess the integrity of a system (Carignan and Villard 2002). Furthermore, it is rare that a wetland, when disturbed, is influenced by only a single human activity (Karr and Chu 1999). When considering all these limitations, it can be difficult to measure disturbances that affect wetland condition.

There are a variety of disturbance assessment methods that inform management decisions. A challenge to the implementation of these assessments is to develop practical ways to measure the biological condition of wetlands in order to make informed resource management decisions aimed at minimizing loss of acreage and function. It is not practical to monitor every human activity that can damage wetlands. It is more scientifically and economically feasible to measure attributes of the wetland that reflect biological condition. Monitoring the biological components of wetlands through bioassessments is the most direct and effective way to evaluate biological condition (U.S. Environmental Protection Agency 2002*a*).

Assessments for wetlands rely on indicators of the human disturbance to evaluate the integrity of the ecological system within the wetland. The condition of wetlands can be assessed using three different types of methods, as recommended by the U.S. Environmental Protection Agency (2006). These types include (1) landscape, (2) rapid assessment, and (3) intensive assessment.

A common way to complete landscape assessment is by using geographic remote-sensing-based data. For example, the index of Landscape Development Intensity (LDI) developed by Brown and Vivas (2005) provides a quantitative measure of human disturbance at the landscape scale. The land uses within an "area of influence" buffer surrounding the wetland are assigned a coefficient associated with the degree of human use. For example, a business district may be assigned a coefficient of 10, for highest intensity land use, while natural forest may be assigned a coefficient of 1, for lowest intensity. The overall LDI is calculated as an area weighted average using the coefficients and area of each land use. The size of the buffer may affect the overall LDI score. Buffer size may vary depending on the landscape system for which a LDI calculated. Both a benefit and drawback to this method is it can be calculated from an office using GIS databases; it does not require a field visit. Using a GIS database, accuracy of level one can be limited by the resolution and development year of the data being used.

Rapid assessments, as a level 2 assessment, are used as qualitative approaches for evaluating wetland condition without intensive quantitative data (Cole 2006). Rapid assessment methods tend to be relatively simple in terms of data collection and typically include field visits of only a few hours. The Ohio Rapid Assessment Method (ORAM) and Kentucky Wetland Rapid Assessment Method (KY-WRAM) are examples (Mack 2006, Gara and Stapanian 2015, Kentucky Department of Environmental Protection Division of Water 2016). Rapid assessments typically focus on characterizing stressors known to limit wetland functions, therefore limiting the assessment to an evaluation of condition and not intensively measuring functions (U.S. Environmental Protection Agency 2006). Rapid assessments provide greater detail than a landscape assessment, but still only provide a qualitative measure of wetland condition.

Intensive assessments provide quantitative data, in comparison to the qualitative data provided by rapid assessments, but as the name suggests, they are more rigorous, field-based methods. The disadvantages with these methods includes requiring more time in the field and greater cost. However, level 3 assessments can be used to determine the causes of wetland degradation and to create performance standards for restoration and mitigation (U.S. Environmental Protection Agency 2006). Level 3 assessments are often indices of biological integrity. Indices of biological integrity (IBI) are multimetric indices and can be effective tools for management decisions regarding wetlands. Karr and colleagues (1986) defined biotic integrity as "the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region." IBIs were developed because the nonbiological techniques that had been used to monitor water resources did not accurately represent biological conditions (Karr 1990). Karr and colleagues (1986) developed IBIs for use within stream ecosystems, and the approach has since been applied to a variety of environments, including wetlands. Wetlands show considerable variation in geography, hydrology and biology. A single multimetric index is not likely applicable across all wetlands within the country (U.S. Environmental Protection Agency 2002*b*), thus many states have developed IBIs for their regional wetlands. A wetland IBI is useful for charactering the presence and severity of impairment within a state's wetlands, which, in turn, provides information for prioritizing sites for protection and restoration.

Since biological integrity is not directly measurable, IBIs use metrics that are assumed to be correlated with integrity and can be measured directly, thus making them useful to regulators (Karr et al. 1986, Karr 1990). IBI methodologies vary but typically use one or more of several basic approaches to quantify the ecological impact of human disturbance by focusing on indicator species such as the Swamp Sparrow (Howe et al. 2007), taxonomic groupings for example number of passerines (Wilson and Bayley 2012), or ecological based groups like an insectivore guild (Chin et al. 2015). There are now a large number of location- and taxa-specific versions of IBI's. Indicators of condition referenced in the literature included various methods that focus on invertebrates, fish, amphibians, birds, and mammals, and other taxonomic groups (Karr et al. 1986, Canterbury et al. 2000, Hilty and Merenlender 2000, Medeiros et al. 2015). IBIs typically focus on a single taxonomic group and are assembled by combining multiple metrics that represent the community composition and their response to anthropogenic disturbance.

In order to develop an effective IBI it is important to understand the relationship between the species and the environmental stress created by disturbance. The process of developing an IBI involves creating metrics that represent the best "fit" for the species or taxa response to wetland condition. Using several metrics in an IBI is important for reducing the effect of variation in individual parameters and representing multiple functional traits of the community, which can provide more insight to a broader range of human disturbance (Canterbury et al. 2000, Noson and Hutto 2005). Testing for redundancy between metrics and eliminating superfluous metrics will also reduce the effect of variation by reducing metrics that measure the same functional traits of the community. The U.S. EPA (2002*b*) recommended selecting at least five, and preferably tens metrics for an IBI. In contrast there may be advantages of few metrics. Gara and Stapanian (2015) developed a vegetation IBI based on floristic quality (VIBI-FQ) with only 2 metrics that applies to all habitat types in Ohio. The VIBI-FQ is simpler to calculate and requires less field work than the Ohio vegetation IBI. Use of multiple, non-redundant metrics allows the single IBI value to represent several aspects of a wetland community, simplifying the application of the IBI for managers.

There are multiple approaches available to develop an IBI and the approach used is important because it can affect conclusions about the level of impairment of a wetland (Chin et al. 2015). Chin and colleagues (2015) suggested three approaches to developing an avian IBI, including a generalist-specialist approach, multimetric guild-based approach, and a probabilistic approach. The generalist-specialist approach and the probabilistic approach can be more sensitive to identifying the high degree impaired and unimpaired sites. The generalist-specialist approach relies on relative abundance of species, weighted by coefficients that quantify their degree of specialization. Generalists tend to occupy habitats with higher levels of disturbance, whereas specialists are more likely to occupy habitats with lower levels of disturbance (DeLuca et al. 2004). A similar method used by Hilsenhoff (1982) used tolerance values within a biotic index to determine if a stream site was mostly comprised of more tolerant species, indicating disturbance, or of less tolerant species, indicating higher condition. The multimetric guild-based approach is based on guild-level sensitivity to landscape disturbance gradients (Chin et al. 2015), with guilds defined by diet, foraging behavior, habitat, nesting and migratory behaviors. For example, foliage gleaning insectivores are more likely to occur in forested areas with abundant foliage in canopy and understory strata, whereas ground gleaning insectivores prefer open understory forests and agricultural land. Guilds effectively indicate habitat disturbance (Croonquist and Brooks 1991, O’Connell et al. 1998). The probabilistic approach involves calculating occurrence functions of species along a landscape disturbance gradient, with the presence of wetland-dependent species of birds increasing as wetland condition improves (Howe et al. 2007). The index derived from the approach is one that provides a best fit based on the probability of observing a species given the site’s disturbance.

There are multiple methods for selection of metrics to be included in an IBI. Creating a disturbance gradient is an important first step. Assessing criteria to identify sites that are considered least and most disturbed, such as water quality and physical habitat, can be a method to establish a disturbance gradient (Whittier et al. 2007). Within a system with specific disturbances, the gradient can be created for that particular disturbance. For example, agriculture is a significant disturbance in western riparian streams, and so a gradient can focus on direct indicators of agriculture (Noson and Hutto 2005). Another method of identifying a disturbance gradient is to draw from rapid assessment method metrics and sub-metrics (Peterson and Niemi 2007, Veselka et al. 2010, Jones et al. 2016). In addition to the disturbance gradient, creating and evaluation metrics is an important step to a successful IBI. Whittier and colleagues (2007) along with Stoddard and colleagues (2008) used a similar method to develop an IBI that is based on a simple series of tests and criteria for metric selection and scoring.

Metrics underwent a series of tests including classification, a range test focused on the spread of data within individual metrics, reproducibility using signal to noise ratio, adjustments based on correlation with natural gradients, a responsiveness test, a redundancy test, and scaling metric scores.

Indicators are undeniably appealing for conservationists, managers and policy makers as they are cost- and time-efficient and it is typically straightforward to describe results to decision makers and the public. Carignan and Villard (2002) argue that indicators should provide early warnings of environmental impacts, directly indicate the cause of change, not just the existence of change, and provide a continuous assessment over a range and intensity of stresses. Niemi and McDonald (2004) add that indicators should be able to assess existing and emerging problems. Important considerations also include the cost effectiveness, and the ease of measuring and detecting the indicator (Hilty and Merenlender 2000). Having an indicator that environmental managers and regulators can use to easily communicate to the public is specifically important (Niemi and McDonald 2004).

Birds are useful indicators because they are sensitive to environmental changes, respond rapidly to those changes, occupy diverse ecological niches, are easily identifiable without complex taxonomic keys and can be abundant in various landscapes (O'Connell et al. 1998, Glennon and Porter 2005, Noson and Hutto 2005). In addition, birds respond to human disturbances on both local and landscape scale (Miller et al. 2003). Therefore, bird communities can reflect the overall ecosystem condition and its components, including water quality, vegetation composition and structure, and productivity (Adamus et al. 2001). Birds can also be sampled in a cost-effective manner and their life histories have been well studied (Glennon and Porter 2005, Chin et al. 2015). Survey methods typically use a simple plot design and have minimal equipment needs. Birds also tend to be of interest to the public because bird watching is a popular recreational hobby and many people are concerned about bird conservation.

Birds occur in multiple wetland types and can be used to evaluate effects over time and over broad landscape scales (U.S. Environmental Protection Agency 2002*a*). Previous studies have concluded that different avian parameters were correlated with environmental conditions. Forested habitats have been evaluated using bird communities to develop indices of ecological condition (Canterbury et al. 2000, O'Connell et al. 2000, Alexandrino et al. 2017). Canterbury and colleagues (2000) used guilds for diet, foraging, nesting, and habitat assemblage and found that most guilds, and total species richness, showed weak responses to human disturbance, but that species in the shrubland and mature-forest habitat assemblages typically had more consistent and stronger responses to natural habitat variation. Alexandrino and colleagues (2017) found that species richness of threatened species responded strongly to a disturbance gradient, along with metrics that measured the abundance of small understory-midstory insectivores, abundance of forested species, and abundance of non-forest species. Bird-based indices have been created for riparian areas (Bryce et al. 2002, Miller et al. 2003, Shafii et al. 2012). Miller and colleagues (2003) concluded that migrants and low-nesting species were more closely associated with low levels of disturbance whereas resident and cavity-nesting species responded positively to disturbance. Bryce and colleagues (2002) found that most avian guilds decreased, including guilds of insectivores, foliage gleaners, and cavity nesters, as levels of human disturbance increased. In contrast, the abundance of tolerant species, species in the omnivore/granivore and ground-gleaner guilds, respond positively with human disturbance.

Some indices of ecological condition for wetlands, rely on using similar groupings of bird species, such as forested and riparian indices (Noson and Hutto 2005, Howe et al. 2007, Veselka et al. 2010, Wilson and Bayley 2012). Wilson and Bayley (2012) described a negative linear relationship of human disturbance with species richness, insectivores/granivore species, ground nesting species, temperate migratory species, canopy foraging species, and all passerines. In another study, Howe and colleagues (2007) analyzed specific species, rather than guilds or functional groups, and concluded that species such as Sandhill Crane and Sedge Wren had negative relationship to human disturbance, but that species such as European Starling and American Robin had strong positive relationships. Veselka and colleagues (2010) created an avian based index for separate wetland types and found that only percent of insectivorous species and percent year-round edge-tolerant species to be metrics that had a relationship with disturbance for all wetland types. Each of these studies found slightly different metrics to best describe wetland condition. A possible explanation for this difference is the regional differences in wetland type and bird communities. Thus, specific metrics that reflect wetland condition will likely differ among ecological systems. This suggests that Kentucky needs an avian IBI specific to the bird communities within the state’s wetlands.

Kentucky has developed and currently uses a rapid assessment method (KY-WRAM) for determining the condition of wetlands within the state (Kentucky

Department of Environmental Protection Division of Water 2016). The KY-WRAM is used to evaluate wetland condition in Kentucky and to aid in managing and developing policies associated with those wetlands. Recently, a vegetation IBI was developed; however, it has yet to be fully implemented as a regulatory tool. There are specific advantages of having a fauna-based IBI. A fauna-based IBI represents the consumer trophic levels within a biological community, in contrast to a flora-based IBI, which represents the primary producer level of a community. Because Kentucky has lost over 80% of its wetlands (Dahl 2000) it is important to have an appropriate intensive assessment method, such as an IBI, to determine the condition of the remaining high quality wetlands in order to preserve them and to assess mitigation practices.

A Kentucky specific avian IBI will provide an intensive, level 3, assessment method for wetlands. The KY-WRAM is a level 2, rapid assessment method. A comparison between the scores from the avian IBI, a level 3 assessment, and the KY-WRAM, a level 2 assessment, will help evaluate the KY-WRAM and Avian IBI responsiveness for application across the entire state. The objectives of this study were to identify avian metrics that correlate with wetland condition, to assemble those metrics into an avian index of biological integrity (Avian IBI) for wetlands of Kentucky and to compare its performance with the Kentucky wetland rapid assessment method.

Chapter II: Methods

Summary

Bird point count survey data from 103 sites sampled from 2013–2016 were used to calculate a set of 49 avian community metrics. These avian metrics were tested for correlation with independent landscape, hydrology and vegetation measures of wetland condition. High performing, non-repetitive metrics were tested using regression model averaging to find the best set of avian community metrics that predicted independent measures of wetland condition. The final metrics were scaled and assembled into an index of biological integrity. Using a response sample, the index was tested against KY-WRAM scores for responsiveness of the avian IBI across condition categories.

Site Selection

Site selection differed slightly between 2013–2015 and 2016–2017. The National Wetland Condition Assessment 2016 team at the U.S. Environmental Protection Agency (EPA) provided a list of potential field sites for the National Wetland Condition Assessment (NWCA) using a Generalized Random Tessellation Stratified (GRTS) survey design within a sample frame created from the U.S. Fish and Wildlife Service (USFWS) National Wetland Inventory and the current status and trends assessment sample frame from USFWS (U.S. Environmental Protection Agency 2016*a*). The Kentucky Division of Water and Eastern Kentucky University (EKU) conducted an intensification study of the NWCA by surveying 48 sites across the state selected from a comprehensive list that was narrowed based on landowner permission for access. NWCA field sites are 0.5 ha, with the exception of small wetlands that restrict sites to range from 0.1 ha to 0.5 ha. Bird surveys were conducted at 38 of

NWCA sites (2016–2017), all of which were conducted by Kaitlyn Kelly. Landowner permission was not obtained to access the other 11 NWCA sites for sampling. Most of these sites occurred in the Four Rivers basin, but also included sites in the Salt River, Kentucky River, Green River, and Licking River basins. Earlier surveys (2013–2015) were conducted by former EKU graduate students, Noelle Smith and John Ryan Polascik, at 65 additional sites. Data from these surveys were included in analysis to increase sample size and spatial scale. The sites sampled in 2013–2015 were selected using a GRTS sampling design from the National Wetland Inventory (NWI) database stratified across both river basins and vegetation types (Polascik 2015, Smith 2016, Guidugli-Cook et al. 2017). These sites were within the Kentucky River basin, Green River basin, Upper Cumberland basin, and Licking River basin (Polascik 2015, Smith 2016). The Big Sandy Basin was not represented in this analysis. A total of 103 sites were surveyed and included in the development analysis (Figure 1).

Following the approach used in other recent wetland assessment development processes, a separate set of holdout sites was used for evaluating responsiveness of the IBI to a rapid assessment method (Smith 2016, U.S. Environmental Protection Agency 2016*b*). Holdout sites were randomly selected from sites across the state where KY-WRAM had been previously scored (2011–2015), but at which avian data were not collected (n = 292). These sites were selected using the Create Random Points tool in ArcGIS (ESRI 2014). Sites were then selected starting at the first point in the list, with points skipped if they were located within 300 m of previously selected random sites. The total number of sites for evaluating responsiveness (N = 19) was approximately

20% of the sample size of the development sites (Smith 2016, U.S. Environmental Protection Agency 2016*b*). All holdout sites were surveyed in 2017 by Kaitlyn Kelly.

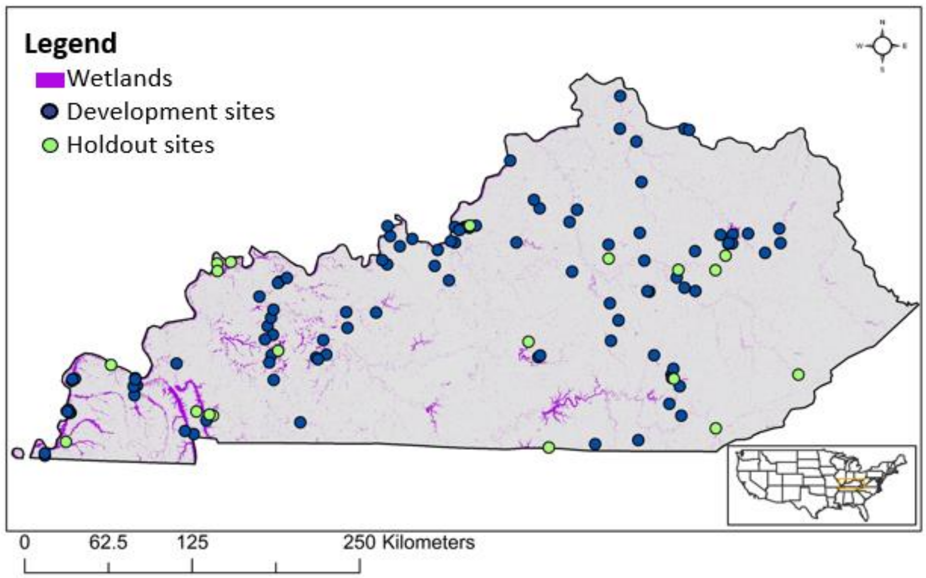

Figure 1. Map of avian sampling sites showing the 103 development sites (blue) and 19 holdout sites (green) surveyed across Kentucky in 2013–2017. The number of development sites sampled per basin were as follows: Four Rivers: N = 23, Green: N = 21, Salt: N = 22, Upper Cumberland: N = 9, Kentucky: N = 13, Licking: N = 15.

Bird Surveys

Bird surveys were conducted based on methods modified and combined from Hamel and colleagues (1996) and Conway (2009). The methods used in this study were similar to those used by other organizations to conduct bird surveys in Kentucky, such as the Kentucky Department of Fish and Wildlife Resources and the U.S Forest Service. Surveys were conducted during the breeding season, from mid-May to mid-July, and during the period between 30 min prior to sunrise and three hours after sunrise (Hamel et al. 1996). During the breeding season, the majority of bird species are most actively vocalizing during these peak morning hours, allowing for an accurate count of species and abundances. Surveys were not conducted during periods with moderate to heavy precipitation, dense fog, or strong winds greater than 19 mph (Hamel et al. 1996). Temperature, wind speed, and cloud cover were recorded at the start of each survey.

Bird surveys were conducted at the center of the NWCA field sites during 2016–2017 and were completed at the center of the KY-WRAM assessment area for all other sites (Hamel et al. 1996, Polascik 2015, Smith 2016). During surveys, the first detection of each individual bird was recorded during a 15-min period using a spot-map datasheet. Birds were recorded to a maximum distance of 100 m using five distance intervals (0–10 m, 11–25 m, 26–50 m, 51–75 m, 76–100 m). If the wetland was small or narrow, the birds detected outside the wetland, but within the 100 m radius were still recorded and included in the IBI calculation, as they contribute to metrics related to wetland disturbance. The point count radius was extended from the 50m, three interval method used by (Hamel et al. 1996). This increase in radius was intended to incorporate more species and detections. The increased number of intervals provided more specific locations of each individual detected, allowing for future modeling of detection error. The distance and compass direction of each individual was indicated using spot map contour lines (Hamel et al. 1996). The distance was determined by an experienced surveyor based on volume and apparent location during auditory detection and estimating distance by sight during visual detection. The time of detection for each individual was recorded using 1-min intervals (0–1 min = 1, 1–2 min = 2, etc.… up to 15 min). Experienced surveyors used the time interval information to reduce counting individuals more than once within the survey period and may be useful for future analysis of probability of availability using removal models. The first 10 min were strictly observational, whereas during the final 5 min of broadcast, calls of several bird species were used to solicit responses from species that are otherwise difficult to detect. Species on the broadcast included Sora, Virginia Rail, American Bittern, and Common Moorhen, plus those of Carolina Chickadees and Eastern Screech-Owls. Broadcasts were conducted with a small portable speaker and a digital audio player (Conway 2009). There were brief periods of silence between vocalizations to allow detection of species that responded. The entire recording (2:30 min duration) was played twice.

Disturbance Index

Landscape Development Intensity Index

The Landscape Development Intensity (LDI) index is a measurement of the amount of human disturbance to the local ecosystem based on the type of land uses surrounding the wetland (Brown and Vivas 2005). The effect on the ecological processes increases as the anthropogenic activity intensifies. A natural landscape has a relatively intact ecological system because it lacks agricultural, urban, or other types of development. The LDI was calculated using Geographic Information System (GIS) with land cover and land use data from Kentucky Land Cover (2005) Anderson Level II (http://kygisserver.ky.gov/geoportal/catalog/search/resource/details.page?uuid=%7B47906D61-FFB5-4A13-BF2A-EB6A14F17040%7D). The LDI total score was calculated using a 1,000-m buffer around the center of the KY-WRAM assessment area and the NWCA random point within the wetland. The percent of each land use present was calculated and multiplied by its associated development intensity coefficient. All land use present within the buffer was summed to calculate the total LDI score for a wetland.

Kentucky Wetland Rapid Assessment Method

Each wetland was scored using the KY-WRAM (Kentucky Department of Environmental Protection Division of Water 2016). KY-WRAM scores were calculated by summing ten metrics that include wetland size and distribution, intensity and connectivity of surrounding land use, hydrology, habitat alteration, presence or known occurrence of regulatory protected critical habitat and species, and vegetation, interspersion, and habitat features. Three submetrics from intensity of surrounding land use, two submetrics from hydrology, and three submetrics from habitat alteration were included with the LDI in a principal component analysis used to create an overall disturbance index.

Disturbance Index

A principal component analysis (PCA) was used to develop a disturbance index (DI) as an independent variable to describe a gradient of anthropogenic disturbance (Howe et al. 2007). Variables included within the PCA were the landscape development intensity (LDI) scores and a subset of KY-WRAM metrics (Table 1). Submetrics from the KY-WRAM included in the DI evaluate surrounding land use, hydrology and habitat alteration (Table 1). Each wetland received a DI score to be used to measure the strength of association with the avian metrics.

Table 1. Variables included in Disturbance Index (DI) from KY-WRAM submetrics and Landscape Development Intensity (LDI) index and loading scores for each variable. The first axis of the Principal Component Analysis (PCA) explained 51.9% of variation.

Metric 2. Buffers and Intensity of Surrounding Land Use	
2a. Average Buffer Width around the Wetland's Perimeter	0.333
2b. Intensity of Surrounding Land Use within 1,000 feet of the Wetland	0.337
2c. Connectivity to other Natural Areas	0.324
Metric 3. Hydrology	
3c. Duration of Inundation/Saturation	0.181
3d. Alterations to Natural Hydrologic Regime	0.372
Metric 4. Habitat Alteration and Habitat Structure Development	
4a. Substrate/Soil Disturbance	0.379
4b. Habitat Alteration	0.379
4c. Habitat Reference Comparison	0.353
Landscape Development Intensity Index	-0.271

Analysis

Candidate Metrics Development

Candidate metrics were developed from diversity indices and groupings by guilds. Guilds were based on life history and ecological traits and were used because they represent assemblages of species that exploit environmental resources in a similar manner (Miller et al. 2003, Glennon and Porter 2005; Table 2). Species were placed in guilds based on diet, foraging behavior, nesting, habitat, and migratory behaviors (Canterbury et al. 2000, Miller et al. 2003, Glennon and Porter 2005, Chin et al. 2015; Table 2). Diet guilds included granivorous, insectivorous, omnivorous and carnivorous species. Foraging guilds included foliage gleaners, bark gleaners, ground gleaners, hawkers and water-foraging (De Graaf et al. 1985). Nesting guilds included cavity-, ground-, canopy-, lower canopy-, bank burrow- and human structure-nesting species. Habitat guilds included forest, wetland, generalist, and grassland species. Habitat guilds were assigned using the primary breeding habitat listed by Partners in Flight (Panjabi et al. 2012). Migratory behavior guilds included short distance migrants, long distance migrants, and resident species.

For the assignment of species to migratory behavior guilds, the migration behaviors were recorded according to the behaviors exhibited by the breeding population within Kentucky. Range maps from Birds of North America database and eBird were used to assign migratory behaviors (Cornell Lab of Ornithology 2011, Audubon and Cornell Lab of Ornithology 2012). Migratory behaviors can vary within and among populations. Movement strategies can be influenced by location of breeding territory, age, and sex of individuals within a population. The short distance guild included species that are both short-distance complete migrants and partial migrants. Short distance complete migrants were all those that travel to the southern portion of the United States and areas surrounding the Gulf of Mexico, but with a center of distribution along the northern Gulf of Mexico. Partial migrants included species for which some individuals are year-round residents, and others are migrants (Chapman et al. 2011). Typically, northern breeders are more likely to migrate, in some cases leap-frogging resident populations (Newton 2008). Long distance migrants included all those that journey to neotropical areas, including land areas in and surrounding the Caribbean Sea and in South and Central America. Most of these migrants have breeding areas that are separated, typically by thousands of kilometers, from their non-breeding ranges. Resident species remain on the breeding grounds year-round in the state of Kentucky including those with localized movements, such as European Starlings that move to form flocks during the winter seasons and Green Herons that are considered to be vagrant in the winter. Residents included some species that have northern populations that migrate, but southern breeding populations, including in Kentucky, that remain sedentary, such as Northern Flickers and Red-winged Blackbirds. The resident guild also included some species generally considered to be partial migrants but within Kentucky are primarily residents, such as Blue Jays.

The guilds were used to calculate two different types of metrics. For each guild a percent abundance metric and a percent presence metric were calculated. The percent abundance metric was calculated by summing the total number of individuals from each species within the guild detected at the site and dividing by the total number of all individuals detected at the site. The percent presence metric was calculated by summing the total number of species within the guild detected at the site and dividing by the total species richness of the site. The percent presence metrics represented the avian community without the skew caused by inflated abundance data of flocking or grouping species. For example, flocks of Red-winged Blackbirds, or Great Blue Heron rookeries would inflate some abundance based metric calculations. In contrast, abundance metrics were still evaluated to assess the overall structure of the avian community.

Table 2. List of species and guild assignments used to determine candidate metrics to develop Avian Index of Biological Integrity. Migratory Behavior: SD = short distance, LD = long distance, R = resident. CCS PIF: Continental Concern Score from Partners in Flight. Nesting Behavior: CAN = canopy, LCAN = lower canopy, CAV = cavity, GRD = ground, BB = bank burrower, HUM = human structure. Foraging Behavior: SC = scanner, GG = ground gleaner, WG = water gleaner, FG = foliage gleaner, BG = bark gleaner, AE = aerial. Diet: MT = carnivore, IN = insectivore, GR = granivore, OM = omnivore. Habitat: FO = forest obligate, WET = wetland obligate, GEN = generalist.

Common Name	Scientific Name	Family	Alpha Code	Migratory Behavior	CCS PIF	Nesting Behavior	Foraging Behavior	Diet	Habitat
Cooper's Hawk	*Accipiter cooperii*	Accipitridae	COHA	SD	7	CAN	SC	MT	FO
Mississippi Kite	*Ictinia mississippiensis*	Accipitridae	MIKI	LD	11	CAN	SC	IN	FO
Red-shouldered Hawk	*Buteo lineatus*	Accipitridae	RSHA	R	8	CAN	SC	MT	FO
Red-tailed Hawk	*Buteo jamaicensis*	Accipitridae	RTHA	R	6	CAN	SC	MT	GEN
Belted Kingfisher	*Megaceryle alcyon*	Alcedinidae	BEKI	SD	11	BB	SC	MT	WET
Canada Goose	*Branta canadensis*	Anatidae	CAGO	SD	6	GRD	GG	GR	WET
Hooded Merganser	*Lophodytes cucullatus*	Anatidae	HOME	SD	8	CAV	WG	MT	WET
Mallard	*Anas platyrhynchos*	Anatidae	MALL	SD	7	GRD	GG	OM	WET
Wood Duck	*Aix sponsa*	Anatidae	WODU	R	6	CAV	GG	GR	WET
Chimney Swift	*Chaetura pelagica*	Apodidae	CHSW	LD	13	CAV	AE	IN	FO
Great Blue Heron	*Ardea herodias*	Ardeidae	GBHE	SD	8	CAN	WG	MT	WET
Green Heron	*Butorides virescens*	Ardeidae	GRHE	R	12	LCAN	WG	MT	WET
Cedar Waxwing	*Bombycilla cedrorum*	Bombycillidae	CEDW	SD	6	CAN	FG	OM	FO
Indigo Bunting	*Passerina cyanea*	Cardinalidae	INBU	SD	9	LCAN	FG	OM	FO
Northern Cardinal	*Cardinalis cardinalis*	Cardinalidae	NOCA	R	5	LCAN	GG	GR	FO
Scarlet Tanager	*Piranga olivacea*	Cardinalidae	SCTA	LD	12	CAN	FG	IN	FO
Summer Tanager	*Piranga rubra*	Cardinalidae	SUTA	LD	9	CAN	FG	IN	FO
Black Vulture	*Coragyps atratus*	Cathartidae	BLVU	R	5	GRD	GG	MT	GEN
Turkey Vulture	*Cathartes aura*	Cathartidae	TUVU	R	5	GRD	GG	MT	GEN
Killdeer	*Charadrius vociferus*	Charadriidae	KILL	SD	9	GRD	GG	IN	GEN
Mourning Dove	*Zenaida macroura*	Columbidae	MODO	R	6	LCAN	GG	GR	GEN
American Crow	*Corvus brachyrhynchos*	Corvidae	AMCR	SD	6	CAN	GG	OM	GEN

Table 2 (continued)

Common Name	Scientific Name	Family	Alpha Code	Migratory Behavior	CCS PIF	Nesting Behavior	Foraging Behavior	Diet	Habitat
Blue Jay	*Cyanocitta cristata*	Corvidae	BLJA	R	8	CAN	GG	OM	FO
Fish Crow	*Corvus ossifragus*	Corvidae	FICR	R	10	CAN	GG	OM	GEN
Yellow-billed Cuckoo	*Coccyzus americanus*	Cuculidae	YBCU	LD	12	CAN	FG	IN	FO
Chipping Sparrow	*Spizella passerina*	Emberizidae	CHSP	SD	8	CAN	FG	GR	FO
Eastern Towhee	*Pipilo erthrophthalmus*	Emberizidae	EATO	SD	11	GRD	GG	OM	FO
Field Sparrow	*Spizella pusilla*	Emberizidae	FISP	SD	12	GRD	GG	IN	FO
Song Sparrow	*Melospiza melodia*	Emberizidae	SOSP	R	8	LCAN	GG	IN	GEN
American Goldfinch	*Spinus tristis*	Fringillidae	AMGO	SD	6	LCAN	FG	GR	FO
House Finch	*Haemorhous mexicanus*	Fringillidae	HOFI	R	6	LCAN	GG	GR	GEN
Bank Swallow	*Riperia riperia*	Hirundinidae	BASW	LD	11	BB	AE	IN	GEN
Barn Swallow	*Hirundo rustica*	Hirundinidae	BARS	LD	8	HUM	AE	IN	GEN
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	Hirundinidae	NRWS	LD	10	CAV	AE	IN	GEN
Purple Martin	*Progne subis*	Hirundinidae	PUMA	LD	10	CAV	AE	IN	GEN
Tree Swallow	*Tachycineta bicolor*	Hirundinidae	TRSW	SD	10	CAV	AE	IN	GEN
Baltimore Oriole	*Icterus galbula*	Icteridae	BAOR	LD	10	CAN	FG	IN	WET
Brown-headed Cowbird	*Molothrus ater*	Icteridae	BHCO	SD	7	CAN	GG	OM	GEN
Common Grackle	*Quiscalus quiscula*	Icteridae	COGR	SD	9	CAN	GG	OM	GEN
Eastern Meadowlark	*Sturnella magna*	Icteridae	EAME	R	11	GRD	GG	IN	GL
Orchard Oriole	*Icterus spurius*	Icteridae	OROR	LD	10	CAN	FG	IN	FO
Red-winged Blackbird	*Agelaius phoeniceus*	Icteridae	RWBL	R	8	GRD	GG	OM	GEN
Yellow-breasted Chat	*Icteria virens*	Icteriidae	YBCH	LD	10	LCAN	FG	IN	FO
Brown Thrasher	*Toxostoma rufum*	Mimidae	BRTH	SD	11	LCAN	GG	OM	FO
Gray Catbird	*Dumetella carolinensis*	Mimidae	GRCA	SD	8	LCAN	GG	IN	FO
Northern Mockingbird	*Mimus polyglottos*	Mimidae	NOMO	R	8	LCAN	GG	OM	GEN
Northern Bobwhite	*Colinus virginianus*	Odontophoridae	NOBO	R	12	GRD	GG	GR	GL
Carolina Chickadee	*Poecile carolinensis*	Paridae	CACH	R	10	CAV	FG	OM	FO
Tufted Titmouse	*Baeolophus bicolor*	Paridae	TUTI	R	7	CAV	FG	OM	FO

Table 2 (continued)

Common Name	Scientific Name	Family	Alpha Code	Migratory Behavior	CCS PIF	Nesting Behavior	Foraging Behavior	Diet	Habitat
Black-throated Green Warbler	*Setophaga virens*	Parulidae	BTNW	LD	9	CAN	FG	IN	FO
Blue-winged Warbler	*Vermivora cyanoptera*	Parulidae	BWWA	LD	10	GRD	FG	IN	FO
Cerulean Warbler	*Setophaga cerulea*	Parulidae	CERW	LD	15	CAN	FG	IN	FO
Common Yellowthroat	*Geothlypis trichas*	Parulidae	COYE	SD	9	LCAN	FG	IN	GEN
Hooded Warbler	*Setophaga citrina*	Parulidae	HOWA	LD	9	LCAN	FG	IN	FO
Kentucky Warbler	*Geothlypis formosa*	Parulidae	KEWA	LD	14	GRD	GG	IN	FO
Louisiana Waterthrush	*Parkesia motacilla*	Parulidae	LOWA	LD	12	GRD	FG	IN	FO
Northern Parula	*Setophaga americana*	Parulidae	NOPA	LD	8	CAN	FG	IN	FO
Ovenbird	*Seiurus aurocapilla*	Parulidae	OVEN	LD	9	GRD	FG	IN	FO
Prairie Warbler	*Setophaga discolor*	Parulidae	PRAW	LD	14	CAN	FG	IN	FO
Prothonotary Warbler	*Protonotaria citrea*	Parulidae	PROW	LD	14	CAV	FG	IN	WET
Swainson's Warbler	*Limnothlypis swainsonii*	Parulidae	SWWA	LD	13	LCAN	GG	IN	FO
Worm-eating Warbler	*Helmitheros vermivorum*	Parulidae	WEWA	LD	13	GRD	FG	IN	FO
Yellow Warbler	*Setophaga petechia*	Parulidae	YEWA	LD	8	CAN	FG	IN	FO
Yellow-throated Warbler	*Setophaga dominica*	Parulidae	YTWA	LD	10	CAN	FG	IN	FO
Double-crested Cormorant	*Phalacrocorax auritus*	Phalacrocoracidae	DCCO	SD	8	CAN	WG	MT	WET
Downy Woodpecker	*Picoides pubescens*	Picidae	DOWO	R	7	CAV	BG	IN	FO
Hairy Woodpecker	*Picoides villosus*	Picidae	HAWO	R	6	CAV	BG	IN	FO
Northern Flicker	*Colaptes auratus*	Picidae	NOFL	R	9	CAV	BG	IN	FO
Pileated Woodpecker	*Dryocopus pileatus*	Picidae	PIWO	R	7	CAV	BG	IN	FO
Red-bellied Woodpecker	*Melanerpes carolinus*	Picidae	RBWO	R	7	CAV	BG	IN	FO
Red-headed Woodpecker	*Melanerpes erythrocephalus*	Picidae	RHWO	R	13	CAV	BG	IN	FO
Blue-gray Gnatcatcher	*Polioptila caerulea*	Polioptilidae	BGGN	SD	7	CAN	FG	IN	GEN
American Woodcock	*Scolopax minor*	Scolopacidae	AMWO	SD	13	GRD	GG	IN	FO
White-breasted Nuthatch	*Sitta carolinensis*	Sittidae	WBNU	R	6	CAV	BG	OM	FO
Eastern Screech-Owl	*Megascops asio*	Strigidae	EASO	R	10	CAV	SC	MT	FO
European Starling	*Sturnus vulgaris*	Sturnidae	EUST	R	7	CAV	GG	OM	GEN

Table 2 (continued)

Common Name	Scientific Name	Family	Alpha Code	Migratory Behavior	CCS PIF	Nesting Behavior	Foraging Behavior	Diet	Habitat
Carolina Wren	*Thryothorus ludovicianus*	Troglodytidae	CARW	R	7	CAV	GG	OM	FO
House Wren	*Troglodytes aedon*	Troglodytidae	HOWR	SD	5	CAV	FG	IN	FO
American Robin	*Turdus migratorius*	Turdidae	AMRO	SD	5	CAN	GG	OM	FO
Eastern Bluebird	*Sialis sialis*	Turdidae	EABL	SD	7	CAV	GG	OM	FO
Wood Thrush	*Hylocichla mustelina*	Turdidae	WOTH	LD	14	CAN	FG	IN	FO
Acadian Flycatcher	*Empidonax virescens*	Tyrannidae	ACFL	LD	11	LCAN	FG	IN	FO
Eastern Kingbird	*Tyrannus tyrannus*	Tyrannidae	EAKI	LD	11	CAN	AE	IN	GL
Eastern Phoebe	*Sayornis phoebe*	Tyrannidae	EAPH	SD	8	HUM	AE	IN	FO
Eastern Wood-Pewee	*Contopus virens*	Tyrannidae	EAWP	LD	10	CAN	AE	IN	FO
Great Crested Flycatcher	*Myiarchus crinitus*	Tyrannidae	GCFL	LD	8	CAV	AE	IN	FO
Blue-headed Vireo	*Vireo solitarius*	Vireonidae	BHVI	SD	7	LCAN	FG	IN	FO
Red-eyed Vireo	*Vireo olivaceus*	Vireonidae	REVI	LD	6	CAN	FG	IN	FO
Warbling Vireo	*Vireo gilvus*	Vireonidae	WAVI	LD	8	CAN	FG	IN	FO
White-eyed Vireo	*Vireo griseus*	Vireonidae	WEVI	SD	8	CAN	FG	IN	FO
Yellow-throated Vireo	*Vireo flavifrons*	Vireonidae	YTVI	LD	9	CAN	FG	IN	FO

The guilds were used as candidate metrics for the Avian IBI, along with species-specific Partners In Flight's continental concern score, Shannon Wiener Diversity Index, Simpsons Diversity Index, Inverse Simpson's Diversity Index and Species Richness. The Partners In Flight's continental concern score is the larger of two seasonal scores, continental combined score–breeding or continental combined score–non-breeding (Panjabi et al. 2012). Continental combined score–breeding was calculated for each species by summing the scores from the sections of threats to breeding habitat, breeding distribution, population trend, and population size. Continental combined score–non-breeding was calculated for each species by summing the scores from the sections of threats to non-breeding habitat, non-breeding distribution, population trend, and population size. The Shannon Wiener Diversity Index was calculated by the proportion of each particular species relative to the total number of species multiplied by the natural log of this proportion. The product was summed across all species present at the site and multiplied by -1. Both variants of Simpsons index were calculated where D is the summed squares of the proportion of each particular species relative to the total number of species present. Simpsons Diversity Index is calculated as 1 – D. Inverse Simpsons Diversity Index is calculated as the reciprocal, 1/D. These diversity indices and groupings by guilds were treated as candidate metrics and tested to determine if they were representative of the wetland condition.

Metric Evaluation

The 49 candidate metrics were tested for multicollinearity, and metrics that were highly correlated ($r > 0.8$) to each other were deemed redundant. Each type of metric, percent abundance and percent presence, were tested only within that type. The metric with the highest correlation to the DI were retained, while the other multicollinear metrics were dropped out of the candidate metric set. Metrics were then tested for correlation to the DI. Correlation to the DI was measured for each metric using both linear and quadratic formulas. Metrics that had a correlation value < 0.25 were dropped from the candidate metric set. From the remaining metrics, models were created with the DI using individual metrics, all possible 2 metric combinations and all global models. Multiple global models were possible if the candidate metric set included both the percent presence and percent abundance metrics for a guild because they were deemed correlated and not placed in the same global model. Model averaging was used to determine the significant metrics by testing whether the 85% confidence intervals of β (regression coefficients) of each metric crossed zero (Arnold 2010). The significant metrics were retained as final metrics in the IBI. For each of the final metrics, the middle 95th percentile of holdout site data was used to calculate quintiles (i.e. five groups with equal frequency of sites; Barbour et al. 1999, Smith 2016). The quintiles, were used to assign breakpoints for the scoring system (Shafii et al. 2012). For each of the final metrics, wetlands that had values in the range of the first quintile were assigned a score of one, those that had values in the second quintile range were assigned a score of two, and so on up to five. The metric scores were then summed for the overall Avian IBI score for each site.

Responsiveness with KY-WRAM

Approximately 20% of sites were excluded from the development analysis as a holdout sample and used for the responsiveness analysis (Smith 2016, U.S.

Environmental Protection Agency 2016*b*). Using the final scoring system, an Avian IBI score was calculated for each site within the holdout dataset. Using a one-way analysis of variance (ANOVA), the holdout dataset was used to compare if the Avian IBI mean scores differed among KY-WRAM categories. A Tukey post-hoc test was performed to test for pairwise differences among KY-WRAM categories. Due to the small sample size of the response sites, a one-way ANOVA and Tukey test was also performed to compare Avian IBI mean scores among KY-WRAM categories for all sites (N = 122), including holdout and development sites. To further test the Avian IBI response across the state, a two-way ANOVA and descriptive statistics were calculated to evaluate Avian IBI scores and KY-WRAM categories across river basins. Due to the small sample size of category 1 sites across all basins, they were omitted from the analysis across river basins.

Chapter III: Results

Metric Evaluation

Of the 49 candidate metrics that were tested, only 9 remained after removing metrics that displayed multicollinearity (N = 11) or had low correlation (< 0.25) with the DI (N = 29; Table). The quadratic formulas used to test correlation to the DI resulted in minimal improvement in correlation coefficients. Quadratic correlation coefficients did not increase more than 0.05 from linear correlation coefficients. The quadratic correlation coefficients did not have a large increase to suggest a better fit to the DI, therefore only linear correlation to the DI was used. Model averaging with individual metrics, all possible 2 metric combinations and all global models were tested for significant metrics (Table 4). The significant 5 metrics included Shannon Wiener Diversity Index, percent abundance of insectivores, percent presence of insectivores, percent presence of ground gleaners, and percent presence of residents (Table), none of which had regression coefficient 85% confidence intervals that crossed zero (Figure 2).

Percent presence of insectivores (Figure 3, r = -0.453), percent abundance of insectivores (r = -0.462) and Shannon Wiener Diversity Index (Figure 4, r = -0.270) were negatively correlated to the DI. Percent presence of ground gleaners (Figure 5, r = 0.395) and percent presence of residents (Figure 6, r = 0.343) were positively correlated to the DI. Percent abundance of insectivores and percent presence of insectivores were intercorrelated (r = 0.89), and so only one could be used within the final Avian IBI. Percent presence of insectivores had a higher estimate from model averaging and smaller confidence intervals, despite having a lower direct correlation with the DI, so it was retained as a final metric for the Avian IBI (Table , Figure 2). These remaining metrics were not highly intercorrelated (Table). The final metrics used to create the Avian IBI were thus percent presence of insectivores, percent presence of ground gleaners, percent presence of residents and Shannon Wiener Diversity Index.

Avian IBI Scoring

The scoring distribution for each of the final four metrics were divided into quintiles, with scoring values assigned based on the direction of the relationship to the DI (i.e., positive or negative). Quintiles were used because they divide the metrics into a moderate number of categories and scores will be out of a total of 20 points. Both Shannon Wiener Diversity Index and percent presence of insectivores had higher values in less disturbed wetlands, and therefore result in higher Avian IBI scores when those metrics have higher values. Percent presence of ground gleaners and percent presence of residents had a positive relationship to disturbance and had higher Avian IBI scores at lower metric values. The overall Avian IBI score can range from 4, scoring 1 in all metrics and indicating a high level of disturbance, to 20, scoring 5 in all metrics and indicating little disturbance (Table).

Table 3. List of the 49-candidate metrics evaluated for possible inclusion in an Avian Index of Biological Integrity. Metrics moderately to highly correlated with the Disturbance Index (r > 0.25) and uncorrelated with other metrics are indicated with a single asterisk (*). The final metrics that were significant within model averaging are indicated with a superscript F.

Candidate Metrics	Calculation
Partners in Flight's Continental Concern Score	Summing the scores from the sections of threats to breeding habitat, breeding distribution, population trend, and population size
Shannon Wiener Diversity Index*[F]	The proportion of each particular species relative to the total number of species multiplied by the natural log of this proportion, the product was summed across all species present at the site and multiplied by -1
Simpsons Diversity Index*	1 - the summed squares of the proportion of each particular species relative to the total number of species present
Inverse Simpsons Diversity Index	The reciprocal of the summed squares of the proportion of each particular species relative to the total number of species present
Species Richness	Count of species present
Percent Granivorous Abundance	Sum of granivorous individuals present divided by total individuals present
Percent Insectivorous Abundance*	Sum of insectivorous individuals present divided by total individuals present
Percent Omnivorous Abundance	Sum of omnivorous individuals present divided by total individuals present
Percent Carnivorous Abundance	Sum of carnivorous individuals present divided by total individuals present
Percent Foliage Gleaners Abundance	Sum of foliage gleaning individuals present divided by total individuals present
Percent Bark Gleaners Abundance	Sum of bark gleaning individuals present divided by total individuals present
Percent Ground Gleaners Abundance*	Sum of ground gleaning individuals present divided by total individuals present
Percent Hawkers Abundance	Sum of hawking individuals present divided by total individuals present
Percent Water Foragers Abundance	Sum of water foraging individuals present divided by total individuals present
Percent Cavity Nesting Abundance	Sum of cavity nesting individuals present divided by total individuals present
Percent Ground Nesting Abundance	Sum of ground nesting individuals present divided by total individuals present
Percent Canopy Nesting Abundance	Sum of canopy nesting individuals present divided by total individuals present
Percent Lower Canopy Nesting Abundance	Sum of lower canopy nesting individuals present divided by total individuals present
Percent Bank Burrow Nesting Abundance	Sum of bank burrow nesting individuals present divided by total individuals present
Percent Human Structure Nesting Abundance	Sum of human structure nesting individuals present divided by total individuals present
Percent Forest Species Abundance	Sum of forest individuals present divided by total individuals present
Percent Wetland Species Abundance	Sum of wetland individuals present divided by total individuals present
Percent Habitat Generalist Species Abundance	Sum of habitat generalist individuals present divided by total individuals present
Percent Grassland Species Abundance	Sum of grassland individuals present divided by total individuals present

Table 3 (continued).

Candidate Metrics	Calculation
Percent Long-distant Migrant Species Abundance	Sum of long-distant migrating individuals present divided by total individuals present
Percent Resident Species Abundance*	Sum of resident individuals present divided by total individuals present
Percent Granivorous Presence*	Count of granivorous species present divided by total species present
Percent Insectivorous Presence*[F]	Count of insectivorous species present divided by total species present
Percent Omnivorous Presence	Count of omnivorous species present divided by total species present
Percent Carnivorous Presence	Count of carnivorous species present divided by total species present
Percent Foliage Gleaners Presence*	Count of foliage gleaning species present divided by total species present
Percent Bark Gleaners Presence	Count of bark gleaning species present divided by total species present
Percent Ground Gleaners Presence*[F]	Count of ground gleaning species present divided by total species present
Percent Hawkers Presence	Count of hawking species present divided by total species present
Percent Water Foragers Presence	Count of water foraging species present divided by total species present
Percent Cavity Nesting Presence	Count of cavity nesting species present divided by total species present
Percent Ground Nesting Presence	Count of ground nesting species present divided by total species present
Percent Canopy Nesting Presence	Count of canopy nesting species present divided by total species present
Percent Lower Canopy Nesting Presence	Count of lower canopy nesting species present divided by total species present
Percent Bank Burrow Nesting Presence	Count of bank burrow nesting species present divided by total species present
Percent Human Structure Nesting Presence	Count of human structure nesting species present divided by total species present
Percent Forest Species Presence	Count of forest species present divided by total species present
Percent Wetland Species Presence	Count of wetland species present divided by total species present
Percent Habitat Generalist Species Presence	Count of habitat generalist species present divided by total species present
Percent Grassland Species Presence	Count of grassland species present divided by total species present
Percent Short-distant Migrant Species Presence	Count of short-distant migrating species present divided by total species present
Percent Long-distant Migrant Species Presence	Count of long-distant migrating species present divided by total species present
Percent Resident Species Presence* [F]	Count of resident species present divided by total species present

Table 4. Akaike's Information Criterion (AIC) of the individual, two-metric and global models used for model averaging.

Model Names	K	AICc	Δ AICc	Model Likelihood	AICc Weight	Log-Likelihood	Cumulative Weight
Percent Presence of Insectivores + Percent Presence of Ground Gleaners	4	399.979	0.000	1.000	0.295	-195.783	0.295
Percent Abundance of Insectivores + Percent Presence of Ground Gleaners	4	402.029	2.050	0.359	0.106	-196.808	0.401
Percent Presence of Ground Gleaners + Percent Presence of Residents	4	402.065	2.086	0.352	0.104	-196.826	0.505
Percent Presence of Ground Gleaners	3	402.784	2.805	0.246	0.073	-198.269	0.578
Shannon Wiener Diversity Index + Percent Presence of Ground Gleaners	4	402.944	2.965	0.227	0.067	-197.266	0.645
Percent Presence of Granivores + Percent Presence of Ground Gleaners	4	403.240	3.261	0.196	0.058	-197.414	0.703
Percent Presence of Insectivores + Percent Presence of Foliage Gleaners	4	403.322	3.343	0.188	0.055	-197.455	0.758
Percent Abundance of Residents + Percent Presence of Ground Gleaners	4	404.181	4.203	0.122	0.036	-197.884	0.794
Percent Presence of Ground Gleaners + Percent Presence of Foliage Gleaners	4	404.911	4.933	0.085	0.025	-198.249	0.819
Shannon Wiener Diversity Index + Percent Presence of Insectivores	4	405.016	5.037	0.081	0.024	-198.302	0.843

Table 4 (continued)

Model Names	K	AICc	Δ AICc	Model Likelihood	AICc Weight	Log-Likelihood	Cumulative Weight
Shannon Wiener Diversity Index + Percent Presence of Insectivores + Percent Presence of Ground Gleaners + Percent Presence of Residents + Percent Presence of Granivores + Percent Presence of Foliage Gleaners	8	405.176	5.198	0.074	0.022	-193.814	0.865
Percent Abundance of Ground Gleaners + Percent Presence of Insectivores	4	405.617	5.638	0.060	0.018	-198.602	0.883
Percent Presence of Insectivores + Percent Presence of Residents	4	405.962	5.983	0.050	0.015	-198.775	0.897
Percent Abundance of Insectivores + Percent Presence of Foliage Gleaners	4	406.441	6.462	0.040	0.012	-199.014	0.934
Percent Abundance of Insectivores	3	406.998	7.020	0.030	0.009	-200.377	0.964
Percent Presence of Insectivores	3	408.042	8.063	0.018	0.005	-200.898	0.969
Percent Abundance of Insectivores + Percent Abundance of Ground Gleaners	4	408.153	8.175	0.017	0.005	-199.870	0.974
Percent Abundance of Residents + Percent Presence of Insectivores	4	408.490	8.511	0.014	0.004	-200.039	0.978
Shannon Wiener Diversity Index + Percent Abundance of Insectivores + Percent Presence of Ground Gleaners + Percent Abundance of Residents + Percent Presence of Granivores + Percent Presence of Foliage Gleaners	8	408.699	8.721	0.013	0.004	-195.576	0.982
Percent Abundance of Insectivores + Percent Abundance of Residents	4	408.887	8.908	0.012	0.003	-200.237	0.985

Table 4 (continued)

Model Names	K	AICc	Δ AICc	Model Likelihood	AICc Weight	Log-Likelihood	Cumulative Weight
Percent Presence of Granivores + Percent Presence of Insectivores	4	410.002	10.023	0.007	0.002	-200.795	0.997
Percent Abundance of Ground Gleaners + Percent Presence of Residents	4	412.201	12.223	0.002	0.001	-201.894	0.997
Shannon Wiener Diversity Index + Percent Abundance of Insectivore + Percent Abundance of Ground Gleaners + Percent Presence of Residents + Percent Presence of Granivores + Percent Presence of Foliage Gleaners	8	412.555	12.576	0.002	0.001	-197.503	0.998
Shannon Wiener Diversity Index + Percent Abundance of Insectivore + Percent Abundance of Ground Gleaners + Percent Abundance of Residents + Percent Presence of Granivores + Percent Presence of Foliage Gleaners	8	412.882	12.904	0.002	0.000	-197.667	0.998
Percent Abundance of Ground Gleaners + Percent Presence of Granivores	4	413.179	13.200	0.001	0.000	-202.383	0.999
Shannon Wiener Diversity Index + Percent Abundance of Ground Gleaners	4	413.467	13.488	0.001	0.000	-202.527	0.999
Percent Abundance of Ground Gleaners + Percent Presence of Foliage Gleaners	4	415.427	15.448	0.000	0.000	-203.507	0.999
Percent Presence of Granivores + Percent Presence of Foliage Gleaners	4	415.721	15.742	0.000	0.000	-203.654	1.000
Shannon Wiener Diversity Index + Percent Presence of Foliage Gleaners	4	415.941	15.962	0.000	0.000	-203.764	1.000
Percent Presence of Foliage Gleaners + Percent Presence of Residents	4	416.747	16.769	0.000	0.000	-204.167	1.000

Table 4 (continued)

Model Names	K	AICc	Δ AICc	Model Likelihood	AICc Weight	Log-Likelihood	Cumulative Weight
Percent Presence of Foliage Gleaners	3	417.380	17.401	0.000	0.000	-205.567	1.000
Percent Presence of Residents	3	418.694	18.715	0.000	0.000	-206.224	1.000
Percent Abundance of Residents + Percent Presence of Granivores	4	420.963	20.984	0.000	0.000	-206.275	1.000
Percent Abundance of Residents	3	422.636	22.657	0.000	0.000	-208.195	1.000
Shannon Wiener Diversity Index	3	423.737	23.758	0.000	0.000	-208.746	1.000
Percent Presence of Granivores	3	424.595	24.617	0.000	0.000	-209.175	1.000

Table 5. Model averaged regression coefficient estimates and 85% Confidence Intervals (CI) of candidate metrics. The significant candidate metrics are indicated with an asterisk and metrics included in the Avian IBI are in bold.

Candidate Metrics	Estimate	Lower 85% CI	Upper 85% CI	r to Disturbance Index
Shannon Wiener Diversity Index*	-0.78	-1.54	-0.01	-0.270
Percent Abundance of Insectivores*	-2.46	-4.54	-0.37	-0.462
Percent Abundance of Ground Gleaners	1.43	-0.46	3.32	0.395
Percent Abundance of Residents	0.69	-1.2	2.57	0.288
Percent Presence of Insectivores*	-2.92	-4.85	-1	-0.453
Percent Presence of Ground Gleaners*	3.98	2.16	5.81	0.495
Percent Presence of Residents*	2.12	0.12	4.12	0.343
Percent Presence of Granivores	2.14	-1.58	5.87	0.255
Percent Presence of Foliage Gleaners	-0.88	-3.59	1.82	-0.359

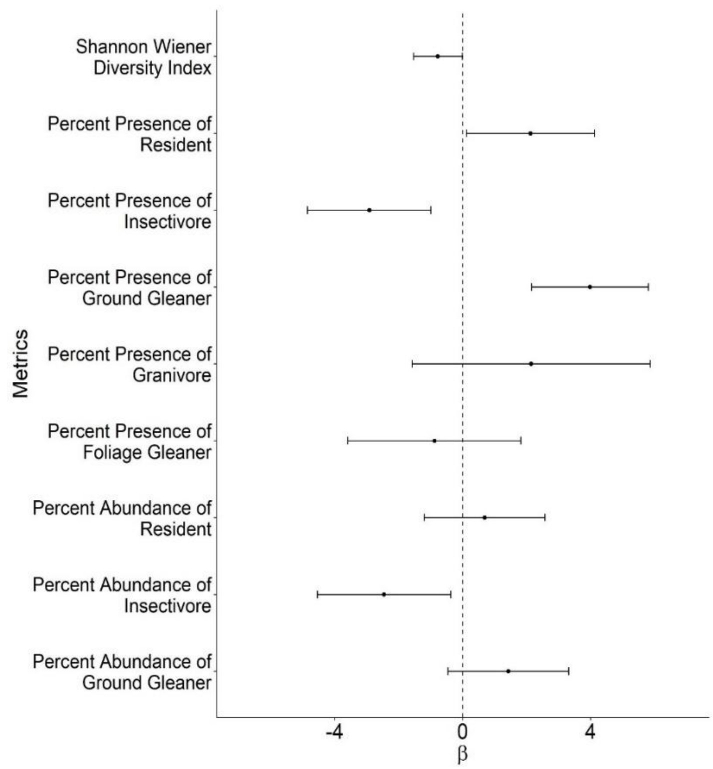

Figure 2. Model-averaged estimates of effect sizes (β) with 85% confidence intervals. Metrics were retained as candidates for the final avian IBI if confidence intervals did not overlap zero. Of the five that did not cross zero, percent abundance of insectivores was dropped because it is highly correlated to percent presence of insectivores and between the two metrics had a lower model-averaged estimate.

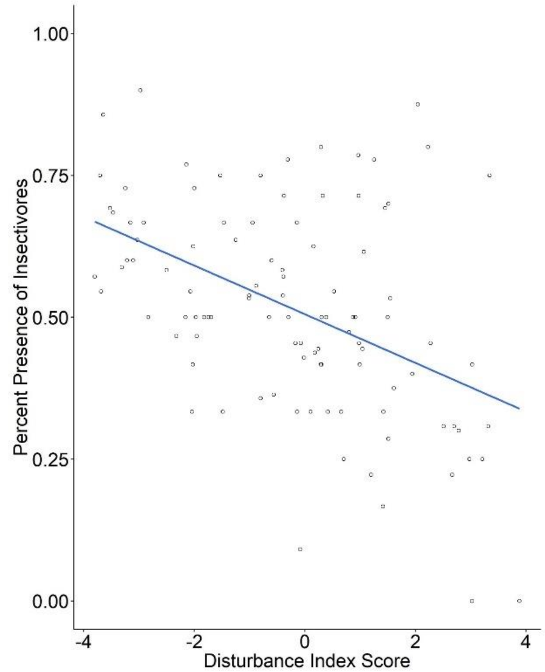

Figure 3. Correlation of percent presence of insectivores with the Disturbance Index (r = -0.453).

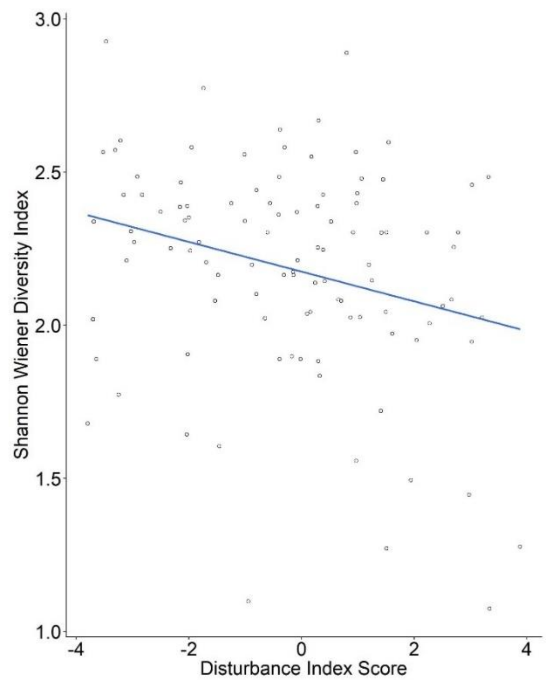

Figure 4. Correlation of Shannon Wiener Diversity Index with the Disturbance Index (r = -0.270).

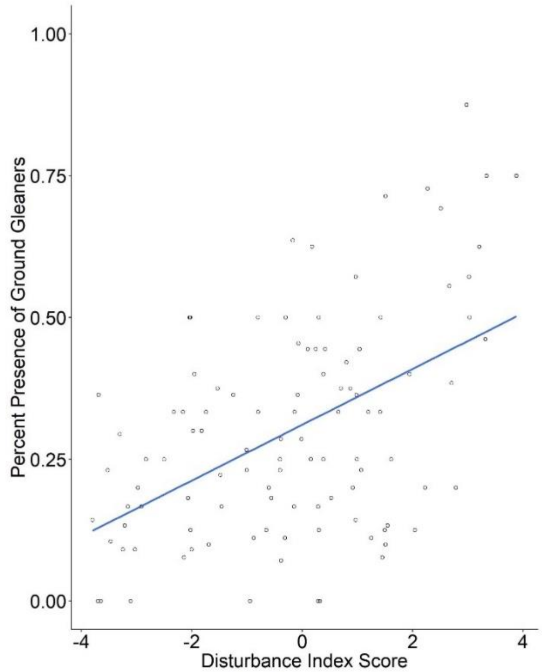

Figure 5. Correlation of percent presence of ground gleaners with the Disturbance Index (r = 0.395).

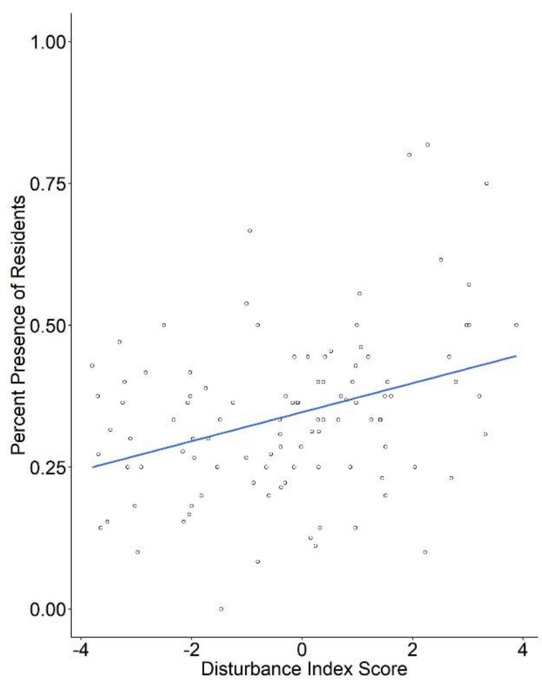

Figure 6. Correlation of percent presence of residents with the Disturbance Index (r = 0.343).

Table 6. Correlation coefficients of the metrics included in the Avian IBI from testing multicollinearity.

	Percent Presence of Insectivores	Percent Presence of Ground Gleaners	Percent Presence of Residents
Shannon Wiener Diversity Index	0.161	-0.311	-0.278
Percent Presence of Insectivores	--	-0.612	-0.392
Percent Presence of Ground Gleaners		--	0.428

Table 7. Scoring breakpoints of the four final metrics for Avian IBI.

	Score 1	**Score** 2	**Score** 3	**Score** 4	**Score** 5
Shannon Wiener Diversity Index	≤ 2.04	2.05 – 2.20	2.21 – 2.34	2.35 – 2.46	≥2.47
Percent Presence of Insectivores	≤ 34.8	34.9 – 46.7	46.8 – 53.3	53.4 – 62.4	≥ 62.5
Percent Presence of Ground Gleaners	≥ 44.4	33.3 – 44.3	23.5 – 33.2	14.4 – 23.4	≤ 14.3
Percent Presence of Residents	≥ 42.8	36.3 – 42.7	30.7 – 36.2	25.1 – 30.6	≤ 25.0

Responsiveness with the KY-WRAM

The Avian IBI scores of the holdout sample were significantly different among KY-WRAM categories ($F_{2,16}$ = 4.239, P = 0.033). However, the relatively conservative Tukey post-hoc tests indicated no pairwise differences between the categories (Figure 7). Pairwise comparison of category 1 with categories 2 and 3 approached significance (P = 0.065 and P = 0.055, respectively). The pairwise comparison of category 2 and 3 (P = 0.990) indicates high overlap in Avian IBI scores. Using the development sites to obtain a larger sample size, the Avian IBI scores were significantly different among KY-WRAM categories ($F_{2,119}$ = 9.746, P < 0.001). The Tukey post-hoc test indicated separation between all categories (1 vs. 2: P = 0.033; 1 vs. 3: P < 0.001; 2 vs. 3: P = 0.032; Figure 8).

The two-way ANOVA of development site avian IBI scores among moderate and high condition KY-WRAM categories and basins indicated no differences among basins (P = 0.073, Table), and there was no interaction of KY-WRAM categories and basins (P=0.846, Table). The mean Avian IBI score across moderate and high KY-WRAM categories within all river basins showed the expected relationship of lower scores in category 2 to higher scores in category 3 (Table).

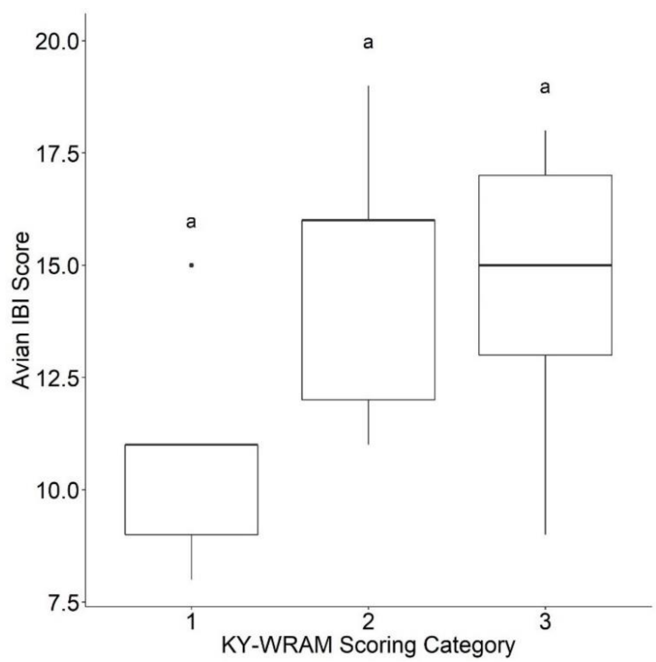

Figure 7. Boxplot of Avian IBI scores in relation to KY-WRAM categories based on the holdout dataset (n = 19). Shared letters above bars indicate groups that do not differ.

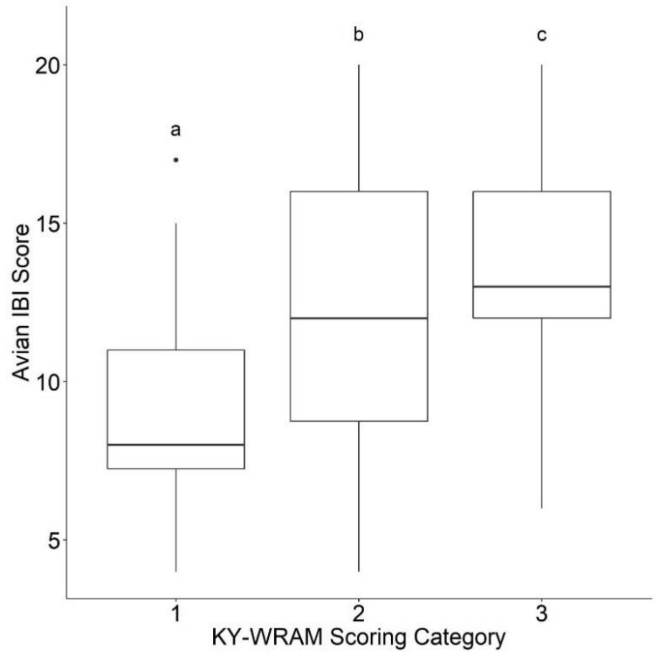

Figure 8. Boxplot of Avian IBI scores in relation to KY-WRAM categories based on the development and holdout dataset combined (n = 122). Shared letters above bars indicate groups that do not differ.

Table 8. Two-way ANOVA evaluating Avian IBI scores across moderate and high Kentucky Wetland Rapid Assessment Method (KY-WRAM) categories and river basin.

Source	Df	Sum Sq	Mean Sq	F value	P value
KY-WRAM Category	1	81.9	81.95	5.486	0.022
Basin	5	157.6	31.5	2.110	0.073
KY-WRAM Category:Basin	5	30.0	6.0	0.402	0.846
Residuals	86	1195	14.9		

Table 9. The sample size, mean, and standard error of Avian IBI scores from the development dataset grouped by river basin and Kentucky Wetland Rapid Assessment Method (KY-WRAM) categories with low condition sites excluded because of low sample size within most basins.

River Basin	KYWRAM Category	n	Mean of Avian IBI Score	Standard Error
Four Rivers	2	9	12.55	1.16
	3	14	14.71	0.65
Green	2	17	13.71	0.99
	3	3	14.00	3.46
Kentucky	2	8	9.38	1.74
	3	4	10.75	2.87
Licking	2	6	10.83	1.58
	3	8	12.50	0.63
Salt	2	9	8.78	1.29
	3	6	13.00	0.63
Upper Cumberland	2	2	11.50	5.50
	3	6	15.17	2.06

Chapter IV: Discussion

The majority of the 49 candidate metrics did not have a strong or clear relationship with the DI. After evaluation of metrics, the final avian IBI included four metrics: Shannon Weiner Diversity index, percent presence of insectivores, percent presence of ground gleaners, and percent presence of residents. The avian IBI has a total possible score out of 20, higher scores indicating higher wetland condition. Percent presence of ground gleaners and percent presence of residents responded positively to the DI, likely due to their ability to exploit resources within disturbed sites, therefore beneficial to be near humans. Insectivore metrics are commonly used metrics in avian IBIs, exhibiting a negative response to disturbance. Using development and holdout sites, the avian IBI discriminated across KY-WRAM categories. The avian IBI did not indicate separation across Kentucky river basins. Analyses showed that the avian IBI responded similarly across Kentucky, supporting its application within regulation and monitoring alongside the KY-WRAM.

Metric Evaluation

Metrics were evaluated in a manner similar to the multi-metric guild-based approach described by Chin and colleagues (2015). Guild-based metrics tend to relate to disturbance in either positive or negative patterns, without higher levels of complexity, making interpretation of the metrics straightforward (Chin et al. 2015). I decided not to use a generalist-specialist approach because many of the species in the wetland bird communities of Kentucky tend to be generalists, and there is no well-established list of assigning species to these categories. Also, because it is possible to have a species that is both a generalist and specialist based on different life history attributes, categorization would be based on best professional judgement and better addressed by a committee of experts than by a single researcher. For example, red-winged blackbirds are specialists for breeding, only having territories around water, but forage opportunistically, which is a generalist attribute (DeLuca et al. 2004). I decided not to use a probabilistic approach because it would work better in habitats occupied by waterbirds (Howe et al. 2007, Chin et al. 2015), which are not present in high numbers in most of Kentucky's wetlands.

Biological characteristics within ecosystems can change nonlinearly in response to anthropogenic and natural disturbances. When evaluating metrics, quadratic equations were tested to evaluate potential non-linear patterns. While the correlation coefficients from the quadratic equation increased slightly from the linear correlation coefficients, the increases were minimal and visual inspection indicated it was not enough to justify the more complex approach. Increasing the number of terms and the degree of a formula, such as by adding a squared term to a linear formula, will almost always result in an increase in the correlation coefficient because the shape of the line covers more area, providing a slightly better fit through the data points. Linear formulas are less complicated to calculate as part of an IBI score, and simpler to convey to wetland managers and the public, thus they are more parsimonious and preferred if the change in correlation coefficient is minimal, as was the case in this study.

The PIF CCS scores were not considered a useful metric because they had a correlation coefficient below the cutoff ($r = 0.25$). O'Connell (2009) used a similar method utilizing Partners in Flight conservation value scores to assess if their current bird assessment, the Bird Community Index (BCI), could be improved by using a broad geographical scale, expanding on the life-history guild-based method. He found that the PIF conservation scores provided assessment similar to the BCI used in the region but tended to respond less to net land use changes.

Several metrics were correlated with the DI above the set criteria ($r = 0.25$) but were not found significant during model averaging. These metrics were percent presence of granivores, percent presence of foliage gleaners, percent abundance of residents, and percent abundance of ground gleaners. Within an Oregon riparian avian IBI, the foliage gleaner metric was negatively associated with a disturbance gradient (Bryce et al. 2002). The majority of foliage gleaners detected in this study were also within the insectivore guild. While these two guilds were not found to be highly intercorrelated to have foliage gleaners removed as a candidate metric, insectivores were a significant metric, which may have contributed to why foliage gleaners passed the first two metric screening tests. Bryce and colleagues (2002) also included a combined granivore and omnivore guild as a final metric that was positively associated with a disturbance gradient. A study that created an IBI for prairie wetlands also combined granivores with another guild, but with insectivores (Wilson and Bayley 2012). These studies may have combined the granivore guild with another because of low species number or low abundance. This study only had seven granivore species present in point counts and of these species, only one, Northern Cardinal, was present at the majority of sites. The granivorous species that occurred at relatively few sites may have been driving the association to the DI. However, the low number of species and abundance likely contributed to the large 85% confidence interval for the regression coefficient of this metric.

The model averaging was tested at 85% confidence interval of regression coefficients as recommended by Arnold (2010) to support additional metrics, rather than 95% confidence intervals as commonly practiced elsewhere. Using 85% confidence intervals with model averaging, the model is not associated with p-values and therefore is AIC compatible (Arnold 2010).Using an 85% confidence interval allowed for the inclusion of more metrics into the IBI, ensuring a more robust index. Two metrics, Shannon Wiener Diversity Index and percent presence of residents, would have been removed as final metrics if I had used a criterion of overlapping with zero based on 95% confidence intervals. An IBI with relatively few metrics can limit the robustness of the index to respond over a broad range of disturbance (Canterbury et al. 2000, Noson and Hutto 2005), thus I decided to use the narrower confidence intervals as a tradeoff to include more metrics even if some of those had a more variable response to the DI.

Five metrics were found to be significant using the model averaging approach. Percent abundance of insectivores and percent presence of insectivores were both significant, but I determined that only one should be included in the final Avian IBI. While percent abundance of insectivores had a higher correlation coefficient to the DI, it had a lower regression coefficient estimate and larger confidence intervals. Therefore, since percent presence of insectivores performed better than percent abundance of insectivores with model averaging it was included in the final Avian IBI.

Of the final four avian metrics, two were positively related to disturbance and two were negatively related. This provides the final Avian IBI an equal balance of patterns of relationship to the DI. The inclusion of the Shannon Wiener Diversity Index incorporated another way to measure the community instead of only guild-based metrics within the Avian IBI. The guild-based metrics are all percent-presence based. These types of metrics may have performed better because abundance could also be affected by landscape attributes not associated to disturbance such as the spatial arrangement of the species-specific preferred habitat, for example, the amount of edge habitat available (Miller et al. 2007).

Percent presence of ground gleaners and percent presence of residents were positively related to the disturbance index. The species found within these guilds are able to exploit resources, such as new foraging and nesting sites, within disturbed areas. Thus, the reward for being in proximity to humans may outweigh the disadvantages (Miller et al. 2003). The percent presence of ground gleaners metric includes Blue Jay, American Robin, Field Sparrow and European Starling, species which typically associate with human disturbed landscapes. Previous studies have also found that ground gleaning metrics respond positively to human disturbances (O'Connell et al. 2000, Bryce et al. 2002). Among the four final metrics, percent presence of ground gleaners had a stronger correlation to the DI and a higher model averaging estimate of effect size than any other metric. The percent presence of residents metric contains species that are stereotypically known as "backyard birds" such as Carolina Chickadee, European Starling, Mourning Dove and Northern Cardinal. These species are often found at bird feeders or within residential areas, indicating a relatively high tolerance to human modified habitats. Multiple studies have found that residential species respond positively to human disturbance, and have been repeatedly included in avian IBI's (O'Connell et al. 2000, Miller et al. 2003, Veselka et al. 2010). Percent presence of residents had a model averaged confidence interval that was close to overlapping 0 (lower CI = 0.12), and a slightly weaker correlation coefficient to the DI compared to percent presence of ground gleaners. Percent presence of residents was retained as a final metric likely because these species, being tolerant of humans, indicate that the landscape surrounding the wetland is more anthropogenically developed. In some instances, the point count survey area extended beyond the edge of the wetland, so in highly disturbed areas this would include more resident species.

Percent presence of insectivores and Shannon Wiener Diversity Index were negatively correlated to disturbance. The insectivore guild had more species than any other and includes all Parulidae, Picidae, Tyrannidae, and Vireonidae species. Most species within these families associate with forested habitats, which is the dominant vegetation type for wetlands of Kentucky (Guidugli-Cook et al. 2017). Preferring forested habitats, these species are not closely associated with highly developed areas. Percent presence of insectivores had a stronger correlation coefficient to the DI and a high model averaging estimate of effect size, compared to Shannon Wiener Diversity Index, the other negatively associated metric. Previous studies that associate bird communities to disturbances have found that insectivores have strong negative associations with human disturbance in different habitat types and continents (Brazner et al. 2007, Veselka et al. 2010, Wilson and Bayley 2012, Alexandrino et al. 2017). Brazner and colleagues (2007) analyzed multiple assemblages to include in an IBI based on taxonomic and functional indicators. They found potential indicators that identify environmental stress across a range of condition in the Great Lakes, including the abundance of insectivorous birds. Wilson and Bayley (2012) focused on northern prairie wetlands and developed an IBI based entirely on metrics derived from the community of wetland obligate songbirds. Of the 5 metrics included in their songbird IBI, all of which were negatively associated to the stress gradient, the strongest linear relationship was the percent presence of insectivores and granivores metric. Alexandrino and colleagues (2017) identified nine insectivore-based metrics within a forested biome in Brazil and all had a significant linear relationship to human disturbance (R^2 >0.2). Out of these nine metrics, small understory-midstory insectivores, a positive indicator of quality of that forest strata, was chosen as a final metric. They attributed the strong correlation to the food availability and the microhabitat conditions within the strata and suggested that the small understory-midstory insectivore metric also reflects landscape characteristics.

Diversity indices are a conventional measure of biological condition (Alexandrino et al. 2017), and have been included in many studies because diversity is a key part of the definition of biological integrity. Although previous studies have tested avian species richness and diversity indices for possible inclusion in IBIs, these metrics are not commonly found to be significantly correlated to disturbance (Bradford et al. 1998, Canterbury et al. 2000, Francl and Schnell 2002, Alexandrino et al. 2017). In this study, the Shannon Wiener Diversity Index was found to be important within the model averaging, but among all of the final metrics, it had the lowest correlation coefficient to the DI and lowest model averaged regression coefficient estimate. Model averaging resulted in this metric approaching 0 (upper CI = -0.01). The Shannon Wiener Diversity Index had a smaller range than the other metrics, which may have contributed to the weak effect size. A large majority of the sites fall within a score of 2.0 to 2.7. A possible explanation that the Shannon Wiener Diversity Index was found to be significant was that it contributed to explaining variation in the DI that was not explained by the other three metrics.

When assembling the Avian IBI scoring breakpoints, only the middle 95 percentile of the scores for each metric were used (Smith 2016). This approach was used to remove any outliers from skewing the breakpoints. The metrics were separated into quintiles by establishing four breakpoints, which created five groups with equal numbers of sites per metric. Each of these breakpoints was given a score from 1–5 based on the relationship the metric has with the DI. The Avian IBI has a maximum value of 20 points, with 5 points available for each metric. With only 4 metrics, breaking the range up into equal parts that still represent the variation of condition is important along with an easily interpretable total. A total of 20 is relatively easy to interpret on a traditional 100% scaling system.

The Avian IBI has 4 final metrics. IBIs with few metrics can potentially not provide insight to the broad range of human disturbance. In general, it is preferred to have around 10 metrics in an IBI (U.S. Environmental Protection Agency 2002*b*). However, it is also preferred to have high performing, non-repetitive metrics. In order to have 10 metrics, the Avian IBI would have included metrics that were either not high performing or repetitive. With only 4 metrics, the Avian IBI has metrics that respond positively to the DI and metrics that respond negatively, representing both types of relationships to disturbance. It also includes guild-based metrics and a community-based metric.

Future modeling could include detection probabilities. Distance and time to detection information could be used to model detection error and to make density adjustments (Sólymos et al. 2013). Removal models and distance models are able to estimate the probability a bird sings during the count and given its distance from the observer, if it does sing will it be detected. In this study, a major assumption of the point counts was equal detectability among species. While the final guild-based metrics in the Avian IBI were all based on percent presence, the adjustments to density has the potential for percent abundance metrics to be high performing.

The Avian IBI developed in this study is specific to Kentucky wetlands. This study found no significant metrics related to open water species, instead the metrics are based other species found in wetland habitats. The species within the dataset, and thus within the guilds and diversity index that form the IBI, are primarily passerines, with smaller numbers of species from other groups including woodpeckers, hawks, and swallows. Other avian IBI studies for wetlands are dominated by data and metrics with waterbirds, ducks, and other species that tend to associate with open water, larger wetland size, or marsh vegetation. DeLuca and colleagues (2004) focused on the gradient between generalists and specialists for constructing metrics for marshes of the Chesapeake Bay. Their metrics included foraging habitat across a gradient of generalist to marsh obligate, and nesting substrate across a gradient of non-marsh nesters to marsh ground nesters. These metrics were intended to more heavily weight secretive marsh birds. This index was used later by Smith-Cartwright and Chow-Fraser (2011) to assess if a marshbird based index could be used at a basin-wide scale in the Great Lakes region. They found the index was unable to differentiate wetlands of low and high disturbance across the region. Waterbird distribution and abundance is affected by the fluctuations in hydrology and corresponding changes in emergent vegetation (Timmermans et al. 2008, Chin et al. 2014). Waterbird-based IBIs can be useful in some situations, such as when waterfowl management is a primary goal. However, waterfowl communities are known to respond to broad-scale changes in habitat and food availability, whereas IBI's are typically developed based on disturbance gradients across smaller spatial extents (Wilson and Bayley 2012). Our surveys lacked high abundances of waterfowl and waterbirds. A study in West Virginia had similar findings that were attributed to the lack of open water in many of the natural wetlands of the state (Veselka et al. 2010). Likewise, a northern prairie wetland study in Canada also did not find any waterbird metrics sensitive to a stress gradient (Wilson and Bayley 2012). Just like Veselka and colleagues (2010) found, the majority of Kentucky wetlands are forested, especially across the eastern portion of the state. Eastern Kentucky's terrain is not favorable for large wetlands and complexes, the wetlands present typically lack large expanses of open water and are therefore unable to support large abundances of these species. However, within the western portion of the state, numerous large wetlands on Wildlife Management Areas are manipulated as moist-soil complexes to have open water available for waterfowl during the winter, rather than during breeding season when the data for this study was collected. Most waterfowl species that occur in Kentucky migrate north, and therefore are absent during the breeding season. This would explain why relatively few waterbirds were detected during surveys. However, due to the possibility of the presence of waterbirds, especially secretive marsh birds such as American Bittern and Virginia Rail, the inclusion of waterbirds in the playback during surveys is still important, otherwise waterbird species would most likely go undetected, even if present. Using playback allows for conclusions about waterbirds to be based on lack of presence rather than lack of observation.

Responsiveness with KY-WRAM

The Avian IBI was applied to an independent holdout dataset to reduce introducing circularity (Shafii et al. 2012). The holdout dataset had a small sample size and did not show a strong pattern of differences in Avian IBI scores among KY-WRAM categories. The holdout dataset had a significant overall ANOVA test; however, the relatively conservative pairwise comparisons from the Tukey post-hoc test did not find a difference among between the KY-WRAM categories. The holdout dataset had 19 sites, of which, seven were category 1, five were category 2, and seven were category 3. Of the 19 sites, six received the full ten points awarded from KY-WRAM metric 5, which awards points based on presence and known occurrence of critical habitat and species. These points elevated the total KY-WRAM score to the next condition category, of which five of six sites went from category 2 to category 3. The sites within category 1 had average Avian IBI score 10.57, with relatively little variation (Standard deviation = 2.37), and one apparent outlier that scored 15. The category 2 sites were relatively evenly distributed between Avian IBI scores of 11 and 19. Sites within category 3 mostly scored above 13 on the Avian IBI. The holdout dataset had an approximately even number of sites within all KY-WRAM categories but the sample size may have been too small to detect separation of Avian IBI scores among KY-WRAM categories. In addition, the KY-WRAM metric 5 points may have reduced the power to detect true differences related to key wetland functions by scoring moderate condition wetlands as category 3. The random site selection approach that I used favored selection of the more frequent moderately-disturbed sites, and was thus less likely to result in selection of sites at either end of the disturbance gradient (i.e., highly disturb or pristine; Stoddard et al. 2008), in particular since most of Kentucky's wetlands are Category 2 (Guidugli-Cook et al. 2017). The result of this site selection process would make it more difficult to find differences between reference and most-disturbed sites because of the sample size of each. The development dataset was used in conjunction with the holdout dataset to increase the probability of detecting separation among KY-WRAM categories by increasing the number of sites. In the development dataset there were eleven category 1, fifty-one category 2, and forty-one category 3 sites. Relative to the distribution of KY-WRAM scores from a larger state-wide assessment (Guidugli-Cook et al. 2017), the dataset from this study was skewed towards having more category 3 (high condition) sites. Analysis that included the development dataset indicated separation among all three KY-WRAM categories.

The development process for this avian IBI included sites from all basins in Kentucky except the Big Sandy River basin located in the eastern most portion of the state. Due to the low sample size in category 1, only category 2 and 3 were used to determine if the avian IBI performs similar across basins. The KY-WRAM categories were found to be significantly different. Category 2 sites had lower average avian IBI scores than category 3 sites (Table). Among basins, avian IBI scores were not significantly different. It appears that some of the basins may be slightly different. Additional sampling across all basins could give more insight as to whether differences occur across river basins. KY-WRAM scores varied among basins with higher total scores in western Kentucky (Guidugli-Cook et al. 2017). Differences in scores among bases for both KY-WRAM and avian IBI are to be expected between the western and eastern basins. Such differences are due to the wetlands in the basins and do not necessarily indicate problems with the methods themselves. KY-WRAM category and basin did not show interactive effects on the average avian IBI score, suggesting that the index performs similarly across basins when distinguishing KY-WRAM categories. This absence of a significant interaction provides evidence the Avian IBI performs well across the state.

While the overall ANOVA test and the pairwise comparisons of responsiveness using the combined dataset indicated significant separation of Avian IBI scores among KY-WRAM categories, the boxplot visually shows considerable overlap of Avian IBI scores among the categories (Figure 8). One potential explanation of this pattern is that the KY-WRAM and Avian IBI reflect different sets of wetland functions. The KY-WRAM is a condition assessment that captures a wide range of functions using qualitative and quantitative information. In contrast, the Avian IBI focusses on the biological function of a taxonomically specific community and uses exclusively quantitative data. For example, Kentucky wetlands in the eastern mountainous region tend to be small, seasonally saturated/inundated wetlands compared to the western inundated wetlands along the floodplains of the Mississippi river. Small wetlands tend to score lower on the KY-WRAM yet were historically abundant in eastern Kentucky and provide important ecosystem services. In the entire United States between 1998 and 2004, 52% of the freshwater wetlands lost were less than one acre in size (Dahl 2006).

Ephemeral wetlands are important biologically to numerous species, such as salamanders, and are scored lower than wetlands that hold water year-round, at least on the KY-WRAM hydrology metric. While the KY-WRAM has numerous metrics, some of them do not take into account the biological condition, whereas the Avian IBI focuses exclusively on a single biological community. Because the Avian IBI focuses on the biological community it scores the condition of the wetland without major influence from the geography and hydrology.

Further analysis and validation of the Avian IBI may be warranted. At the time of analysis, there was no independent dataset to create a disturbance index. I minimized circularity using the KY-WRAM metrics as variables to create the DI and also as a test of how well the Avian IBI responds across the state. Using submetrics from the KY-WRAM that were associated with physical habitat condition and not biological metrics for DI variables reduced circularity. In addition, use of the PCA instead of directly using KY-WRAM submetrics scores further reduced circularity. Level 3 independent measures of ecological condition can be used to validate and calibrate a rapid assessment. An additional test to validate and calibrate a rapid assessment is to evaluate the overall condition by assessing the relationship with a level 1 landscape measure, such as an LDI (Stein et al. 2009). Development of such an independent assessment of disturbance would be valuable for further validation and calibration of KY-WRAM and Avian IBI.

The Avian IBI could also be improved by continuing sampling to acquire even numbers of sites across all basins and even numbers of sites among KY-WRAM categories to have improved representation across the DI. The DI was skewed towards moderate wetlands and had low site numbers in poor condition. The KY-WRAM has the same pattern, with only eleven sites in category 1 and the most sites in category 2. Further sampling focused on poor condition as well as pristine condition wetlands could further calibrate the Avian IBI.

Limitations and Assumptions

Using the GRTS method for selecting sites, the previous studies had stratified across vegetation types and basins. It turned out that some of the emergent and scrub shrub wetlands identified on NWI were actually found to be forested when the site was visited (Guidugli-Cook et al. 2017). The sites surveyed in conjunction with the NWCA were primarily forested as well. Within the development dataset the majority of sites were forested (N = 75), with lower sampling in scrub shrub (N = 9) and emergent (N = 19) sites. Guild based metrics allow for inclusion of the different types of wetlands. For example, insectivores fill the same feeding niche within each of the communities, though the species might not be the same between the vegetation types but they utilize the community in a similar fashion. Site selection was designed to stratify across the major river basins of Kentucky. Three basins had higher sampling, Four Rivers basin (n = 23), Green River basin (n = 21) and Salt River basin (n = 22), and the other three basins had lower sampling effort, Kentucky (n = 13), Licking (n = 15), and Upper Cumberland (n = 9). The Big Sandy River basin did not have any sites sampled. Climate and land cover patterns differ across the river basins of the state. Typically western Kentucky has a longer growing season than the higher elevations in eastern Kentucky (Kentucky Department of Environmental Protection Division of Water 2016). The higher elevations and topographic complexity of eastern Kentucky also limits the size of wetlands, whereas the western portion has lower elevations and many wetlands are hydrologically connected with the Mississippi or Ohio River allowing for larger wetlands within floodplains (Richter et al. 2017). While site selection stratification across vegetation and basins did not produce even sampling, the final sites are generally representative of the wetlands of Kentucky.

Point count surveys were conducted in different locations within the wetland. During 2013–2015, bird surveys were conducted at the center of the KY-WRAM assessment area, whereas during 2016–2017 it was conducted at the center point of the NWCA assessment area. Both assessments try to include the majority of the wetland and therefore center points can be considered similar between the two methods. Using a 100m point count radius captures most of the wetland inhabitants, regardless of where the center point was established.

The disturbance index was created using a PCA with the LDI scores and KY-WRAM submetrics as variables. The LDI measures disturbances on the landscape while the KY-WRAM submetrics measure disturbances within the wetland, both types of disturbances affect the biological condition of the wetland. Studies have used rapid assessment methods overall scores as a measure of disturbance when creating an IBI. The Ohio vegetation IBI used the Ohio Rapid Assessment Method (ORAM) as their human disturbance gradient (Mack et al. 2008). The ORAM scores were also compared directly with bird community parameters for an Avian IBI (Peterson and Niemi 2007). Submetrics from the KY-WRAM used for this study were those characterizing physical habitat condition, not biological metrics (Jones et al. 2016). The KY-WRAM metrics included in the DI for the development of the Avian IBI is similar to those that Jones and colleagues (2016) used to develop a vegetative IBI. They used ORAM metrics that included buffer width, intensity of surrounding land use, hydrologic alteration, substrate and soil disturbance and habitat alteration. These methods are also similar to those used by Veselka and colleagues (2010), in which metrics and sub-metrics from the ORAM that specifically quantified human disturbances pertaining to buffer zones and land use, habitat, hydrology and substrate alteration on a local scale were used as the human disturbance gradient to test metric responsiveness for an avian wetland IBI. This study added submetrics that describe hydrologic connectivity and duration of inundation/saturation. However, duration of inundation/saturation had a lower loading score than the other submetrics, so its contribution to the DI is minimal. Duration of inundation/saturation does not always positively correspond with wetland condition. For example, a healthy ephemeral wetland can have shorter inundation/saturation period than a poor condition emergent wetland (Kentucky Department of Environmental Protection Division of Water 2016), but the seasonally inundated wetland will receive a lower score in this submetric than a semi- to permanently inundated wetland. Since the KY-WRAM is a composite of many factors, other characteristics that reflect high function will more strongly influence the overall score, so that it reflects the actual condition, but at any particular wetland an individual metric may not have the expected correspondence with disturbance. The DI also avoids directly using KY-WRAM scores, and instead uses scores from the first principal component of a PCA, which accounts for the most variability in the KY-WRAM submetrics and LDI. Although there is still some reason for concern about circularity when using the rapid assessment metrics for creating the disturbance index, and then evaluating the responsiveness of the IBI based on rapid assessment scores, I think this is a small problem and collectively the approach demonstrates that the Avian IBI reflects wetland condition as measured by the bird community.

Implementation of the Avian IBI

The KY-WRAM and the Avian IBI could be used in combination to provide a more informative assessment. The Avian IBI measures actual inhabitants of the wetland for assessing biological condition (Bryce et al. 2002). The KY-WRAM provides a broad overview of wetland condition, whereas, the Avian IBI gives a narrower focus on the biological condition within the wetland. Similar to the implementation recommendation that Stapanian and colleagues (2013) made for the Ohio VIBI, the final Avian IBI can be used to make management decision such as during Section 404 and 401 permitting processes of the Clean Water Act. For example, the Avian IBI can be used at sites that fall near the breakpoints of the KY-WRAM. The additional information from the intensive biological assessment would help place the wetland in the correct KY-WRAM category. A Kentucky vegetation IBI has also been developed (Smith 2015), while not yet implemented, it could be combined with the KY-WRAM and Avian IBI to provide an even more robust assignment of the condition category. It is beneficial to have two separate state IBIs as Wilson and Bayley (2012) found that their two-taxon IBI, vegetation and avian, had a slightly stronger relationship to a stress gradient than the single-taxon IBI, but it did not warrant the extra cost and effort of sampling both communities. They also found that the two single-taxa IBIs were correlated to each other, thus showing that one community could act as a surrogate and be used to predict the health of another wetland community within the ecosystem. Within Kentucky wetland assessments, this could prove to be beneficial logistically and lower costs by requiring only needing a botanist or ornithologist. However, future work should test whether the combined KY-VIBI and Avian IBI better reveal differences among KY-WRAM categories. The use of the KY-WRAM in combination with a level 3 IBI would provide a consistent and rapid method, as well as provide detailed information on biological function, and can therefore serve as valuable tools for assessing performance of restoration and mitigation sites (Stein et al. 2009).

Beyond the permitting process, it is important to have a baseline knowledge about the wetlands of Kentucky, especially given ongoing environmental changes such as climate change. The Avian IBI provides a tool to assess wetland condition of any wetlands in the state, and not just those that are being assessed for development. O'Connell and colleagues (1998) created a regional bird community index (BCI), and later extended it for use in broad ecological assessments with data from the North American Breeding Bird Survey (O'Connell et al. 2007). The BBS protocol is similar to the protocol used in this study (BBS counts are shorter), and it may be possible use BBS data to calculate the Avian IBI. Also, avid birders, Audubon groups, and the state ornithological society, which apply the protocol on their regularly visits to wetlands, could take on a citizen science application of the Avian IBI by creating a broader wetland monitoring network for the state. Such a network could serve as an early warning system or a prioritization tool and lead to protection of the highest quality wetlands.

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