Eastern Kentucky University
Encompass

Online Theses and Dissertations | Student Scholarship

January 2015

Validating A Kentucky Wetland Rapid Assessment Method For Forested Riverine Wetlands Using Vegetation, Bird Surveys, And Landscape Analysis

JohnRyan Andrew Polascik
Eastern Kentucky University

Follow this and additional works at: https://encompass.eku.edu/etd

Part of the Ecology and Evolutionary Biology Commons, and the Environmental Monitoring Commons

Recommended Citation

Polascik, JohnRyan Andrew, "Validating A Kentucky Wetland Rapid Assessment Method For Forested Riverine Wetlands Using Vegetation, Bird Surveys, And Landscape Analysis" (2015). *Online Theses and Dissertations*. 305.
https://encompass.eku.edu/etd/305

This Open Access Thesis is brought to you for free and open access by the Student Scholarship at Encompass. It has been accepted for inclusion in Online Theses and Dissertations by an authorized administrator of Encompass. For more information, please contact Linda.Sizemore@eku.edu.

VALIDATING A KENTUCKY WETLAND RAPID ASSESSMENT METHOD
FOR FORESTED RIVERINE WETLANDS
USING VEGETATION, BIRD SURVEYS, AND LANDSCAPE ANALYSIS

By

JohnRyan Andrew Polascik

Thesis Approved:

Chair, Advisory Committee

Member, Advisory Committee

Member, Advisory Committee

Dean, Graduate School

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a Master's degree at Eastern Kentucky University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of the source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Head of Interlibrary Services when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature ______________________

Date 4/14/15

VALIDATING A KENTUCKY WETLAND RAPID ASSESSMENT METHOD
FOR FORESTED RIVERINE WETLANDS
USING VEGETATION, BIRD SURVEYS, AND LANDSCAPE ANALYSIS

By

JohnRyan Andrew Polascik

Bachelor of Science

King's College

Wilkes-Barre, PA

2011

Submitted to the Faculty of the Graduate School of

Eastern Kentucky University

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

May, 2015

Copyright © JohnRyan Andrew Polascik, 2015

All Rights Reserved

DEDICATION

I dedicate this thesis to my family, specifically, my mother and father, Andrea Preputnick and John Joseph Polascik, without whom none of this would have been possible. They have taught me that dedication and passion can lead to great things. From a young age, I have always been taught the value of hard work. Their unconditional love and support have helped me discover my passion. I am lucky to be their son.

ACKNOWLEDGEMENTS

There are many people who deserve to be acknowledged for their contribution and support throughout this project. This project was founded on collaboration and support ranging from government agencies to friends and colleagues. I would still be in a swamp up to my neck in sedges and mosquitoes if it wasn't for their help. I would like to take this opportunity to thank everyone involved.

I would first like to acknowledge my sources of funding. The Kentucky Division of Water (KDOW) and the United States Environmental Protection Agency (USEPA) played a critical role in providing the initial wetland development grant making this project possible. I would also like to thank the Kentucky Water Resources Research Institute (KWRRI), the Wetland Foundation, the Kentucky Ornithological Society (KOS) and Eastern Kentucky University (EKU). Without the financial support from these organizations, completing a project of this scale would have been impossible.

I would like to recognize my advisor, Dr. David Brown, for his advice, support, and affording me the opportunity to be a part of this project. His dedication to his students is rivaled only by his dedication to four-square. I would also like to thank my committee members: Dr. Stephen Richter for his advice and dedication in the development of this project and Dr. Amy Braccia for her helpful advice during the development of my thesis and sharing her knowledge of forested floodplain wetland ecology and metric development.

The development of a Kentucky Wetland Rapid Assessment Method would not be possible without the multi-agency technical committee which included: EKU, KDOW, USEPA, the United States Forest Service (USFS), the Kentucky Department of Fish and

Wildlife Resources (KDFWR), the United States Fish and Wildlife Service (USFWS), the National Resources Conservation Services (NRCS), the Kentucky Department of Natural Resources (KDNR), the United States Army Corp of Engineers (USACE), and the Kentucky State Nature Preserves Commission (KSNPC).

I would like to take this opportunity to thank my good friend Tanner Morris. We've worked on this together since day one. We've learned new plants, co-wrote grants and reports, presented our work at conferences, learned all the statistics, and spent countless hours driving to wetlands across the state always excited to see something new. I would also like to thank John Yeiser, Jesse Godbold, Chelsea Cross, Alexi Dart-Padover, Will Overbeck, Chelsea Czor, and Todd Weinkem for help with the collection of the data used in this thesis. To Nick Revetta, Heidi Braunreiter, Brad McLeod, Louise Peppe-McLeod, and Marissa Buschow thank you all for your advice, support and friendship.

ABSTRACT

Within the last two centuries, Kentucky has undergone wetland losses exceeding 80 percent (approximately 500,000 hectares). As a response to these losses, the Kentucky Division of Water (KDOW) and Eastern Kentucky University (EKU) developed the Kentucky Wetland Rapid Assessment Method (KY-WRAM) to evaluate the condition of Kentucky's remaining wetlands. The goal of this study was to validate the KY-WRAM for forested riverine wetlands using a vegetation index of biotic integrity (VIBI), bird surveys, and landscape development index (LDI). Specific objectives of this study were to: 1) determine the correlation between bird species richness, VIBI, and LDI with the KY-WRAM in forested riverine wetlands; and 2) determine which combination of vegetation and landscape metrics best explain each of the KY-WRAM metric categories. At twenty five sites throughout the Green, Upper Cumberland, and Kentucky River Basins, a KY-WRAM, VIBI, LDI, and survey for bird species richness was conducted. A linear regression indicated that the KY-WRAM was significantly, positively correlated with the VIBI and bird species richness, while the KY-WRAM showed a negative, marginally significant correlation with the LDI. Model-averaging using model selection and parameter estimates indicated that the top models and predictor variables were (1) percent forested, (2) floristic quality assessment index score and percent adventive, and (3) percent adventive and *Carex* species richness for Metric 2 (Buffers and Surrounding Land Use); Metric 4 (Habitat Reference Comparison); and, Metric 6 (Vegetation, Interspersion, and Microtopography), respectively. Overall, the method's effectiveness was demonstrated by its ability to be predicted by biological and landscape indices at the method level and biological and landscape variables at the metric level.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I
INTRODUCTION

The use of Rapid Assessment Methods (RAMs) has become an integral part of the protection of our nation's wetlands in accordance with sections 401 and 404 of the U.S. Clean Water Act (33 U.S.C. § 1251). Since an overwhelming majority of wetlands in the United States have been filled or drained, and only 4 percent of wetlands have been assessed for quality as of 2002 (U.S. EPA 2002a, Fennessey et al. 2007), it is imperative to develop effective methods to evaluate and help protect wetlands. Despite the "no net loss" policy implemented by the federal government, wetland destruction persists. Evaluation and protection is particularly necessary in states that have experienced wetland loss. States like Ohio and California have experienced wetland losses exceeding 90 percent (Mitsch and Gosselink 2007). In response to their losses, Ohio and California have developed well-tested, rapid protocols for assessing wetland condition. Kentucky faces a similar situation and has lost more than 80 percent of its wetlands (Dahl and Johnson 1991), an area of approximately 500,000 hectares (Jones 2005). This emphasizes the need for a well-tested RAM that can efficiently assess biological and ecological integrity of this valuable habitat that once dominated Kentucky's landscape.

In general, wetland assessments follow a three-level framework that incorporates various methods based on the quantity of data gathered and the amount of time spent in the field (Fennessey et al. 2007). Level 1 methods are broad landscape-scale assessments often using remote-sensing. Level 2 methods are rapid assessments typically requiring no more than a half day in the field. Level 3 methods are intensive assessments using biotic surveys or physiochemical analysis (Fennessey et al. 2004, 2007). Additionally, each of these three levels can be used for the validation of another. Prior to level 1 assessments, validation of a method was reliant upon its intensive or rapid counterpart. As a result, this system of assessment development was dependent upon biotic and physiochemical analysis. For this reason, level 1 assessments provide an independent source of information that is vital to the process of rapid assessment development and validation.

Rapid Assessment Methods (RAM)

The wetland RAM first developed by the Ohio EPA consisted of six primary metric categories (Mack 2001a). The metrics currently assigned to the Ohio Rapid Assessment Method (ORAM) are: wetland area, buffers, hydrology, habitat alteration, special wetland communities, and vegetation, interspersion and microtopography (Mack 2001a). Due to the success of the ORAM as a level 2 assessment method for Ohio, the ORAM metrics were adapted as a foundation for the development of a wetland rapid assessment method for Kentucky in a collaborative effort between Eastern Kentucky University (EKU) and The Kentucky Division of Water (KDOW). The Kentucky Wetland Rapid Assessment Method (KY-WRAM) is based on the same main six metrics of the ORAM, but some submetrics added, removed, or revised to better correspond to the environmental conditions and stressors characterizing Kentucky's wetlands (Table 1).

Level 2 assessments were developed with the intent of classifying and categorizing wetlands and assigning it a quantitative score based on a brief field evaluation (Mack et al. 2000). Through this assessment, wetlands can be classified into 3

Table 1. A comparison of current Kentucky Wetland Rapid Assessment Method metrics from draft field form and Ohio Rapid Assessment Method metrics from version 5.0.

		KY-WRAM		ORAM	
	Metric	Number	Name	Number	Name
1	Wetland Size and Distribution	1a	Wetland Size	1	Wetland Area
		1b	Wetland Scarcity[b]		
2	Upland Buffers and Intensity of Surrounding Land Use	2a	Average Buffer Width around Wetland's Perimeter	2a	Average Buffer Width
		2b	Intensity of Surrounding Land Use within 1,000-feet of the Wetland	2b	Intensity of Surrounding Land Use
		2c	Connectivity to Other Natural Areas[b]		
3	Hydrology	3a	Input of Water from an Outside Source	3a	Sources of Water
		3b	Hydrological Connectivity	3b	Connectivity
		3c	Duration of Inundation/Saturation	3c	Maximum Water Depth[c]
		3d	Alterations to Natural Hydrologic Regime	3d	Duration of Inundation/Saturation
				3e	Modifications to Hydrology
4	Habitat Alteration and Habitat Structure Development	4a	Substrate/Soil Disturbance	4a	Substrate Disturbance
		4b	Habitat Alteration	4b	Habitat Development
		4c	Habitat Reference Comparison	4c	Habitat Alteration
5	Special Wetlands[a]	5a	Regulatory Protection/Critical Habitat	5	Special Wetland Communities
		5b	High Ecological Value/Ranked Community		
		5c	Low-Quality Wetland		
6	Vegetation, Interspersion, and Habitat Features	6a	Wetland Vegetation Components	6a	Wetland Vegetation Communities
		6b	Open Water, Mudflat and Aquatic Bed Habitats[b]	6b	Horizontal Community Interspersion
		6c	Coverage of Highly-Invasive Plant Species	6c	Coverage of Invasive Plant Species
		6d	Horizontal Interspersion	6d	Microtopography
		6e	Microtopographic Features		

[a]A change was made to metric; [b]A submetric was added; and [c]A submetric was removed

Sources: Kentucky Division of Water (2013a) KY-WRAM Field Form - Draft. Kentucky Division of Water. 200 Fair Oaks Lane, 4th floor, Frankfort, Kentucky.

Mack JJ (2001a) Ohio Rapid Assessment Method for wetlands, manual for using Version 5.0. Ohio EPA Technical Bulletin Wetland/2001-1-1. Ohio Environmental Protection Agency, Division of Surface Water, 401 Wetland Ecology Unit, Columbus, Ohio.

categories based on their function and integrity. Category 1 wetlands have lower function and integrity, Category 2 wetlands have moderate function and integrity, and Category 3 wetlands have superior wetland function and integrity (Mack 2001a).

Rapid assessments are designed to be fast and less rigorous than intensive assessments. To insure that they are accurate they must be validated using independent assessments including intensive surveys of biological communities and landscape-based analyses. Rapid assessment methods can also be validated by comparison to level 1 methods, which are increasingly accessible through the rapid increase of remote sensing data and analysis methods (i.e. GIS).

Landscape Analysis and Landscape Development Index (LDI)

One recent approach to quantifying disturbance on the landscape scale is the Landscape Development Index (LDI). The LDI quantifies and weights anthropogenic disturbance based on land use percentages (Brown and Vivas 2005). Since its recent development, the LDI has been adopted as a primary method of Level 1 assessment and validation for wetland rapid assessment (Mack 2004, Gara and Micacchion 2010).

Intensive Surveys and Indices of Biotic Integrity (IBI)

Biological integrity is the ability to support and maintain balanced, integrated functionality in the natural habitat of a given region (Karr and Dudley 1981, Karr 1991). The development of indices of biotic integrity (IBI) over the past several decades has led to the proliferation of IBIs at the regional scale. The history of IBIs originated with fish in streams to assess water quality standards in accordance with the Clean Water Act (Karr

1981). Since that time, IBIs for plants (Mack 2001b, Mack 2004, Miller et al. 2006, Mack 2007) amphibians (Micacchion 2004), macroinvertebrates (Kerans and Karr 1994), and birds (O'Connell et al. 2000, Veselka et al. 2004) have all been used to assess biotic integrity.

Historically, wetland vegetation has shown strong correlations between wetland quality and disturbance (Mack 2001b, U.S. EPA 2002b, Mack 2007). The use of plants as an indicator of quality was first demonstrated using the Floristic Quality Assessment Index for Northern Ohio (Andreas and Lichvar 1995). A wetland plant can be defined as a plant that is "growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content" (Cowardin et al. 1979). The use of hydrophytic vegetation as one of the defining characteristic of a wetland and its response to disturbances makes it the model assemblage for intensive data used for monitoring wetland quality.

Multiple studies have shown that bird communities can be successful predictors of wetland disturbance (Croonquist and Brooks 1991, Bryce et al. 2002) and of ecological condition (O'Connell et al. 2000). Similar research also indicates that the same methods used to rapidly assess wetlands are significantly correlated with avian species richness and diversity (Stapanian et al. 2004, Peterson and Niemi 2007, Stein 2009). These patterns have been shown repeatedly across several studies and have been used in the process of validating multiple rapid assessment methods. Historically, the studies showing this correlative data were conducted in estuarine and riverine wetlands using various sources of data (Peterson and Niemi 2007, Stein 2009). These studies also suggest that bird assemblages can be particularly useful as indicators in the design and validation of a rapid assessment method, specifically for metric development.

Several studies have attempted to define wetland bird species that can be used as indicators of wetland disturbance (Krzys et al. 2002, Stapanian et al. 2004, and Peterson and Niemi 2007). Peterson and Niemi (2007) further delineate the definition of wetland dependent species and classify wetland birds into obligate and ubiquitous wetland birds in relation to wetland quality. Obligatory bird species are specific to certain wetland types and can be indicators of high quality wetlands (i.e., Prothonotary Warbler). Ubiquitous bird species would be those that are found in wetlands with lower quality (i.e., Red-winged Blackbird). Based on Peterson and Niemi's results, several species were found to respond to certain attributes of wetlands in a predictable manner, justifying the use of avian species to serve as predictors of wetland quality.

Forested Riverine Wetlands

Forested riverine wetlands are dynamic and varied ecosystems that occur in floodplains with a primary source of water attributed to stream channels (Brinson 1993). Their functions and values within a landscape include, but are not limited to buffering and mitigating flood damage, water regulation and supply, serving as a buffer for nutrient and effluent run off to water supplies, provide valuable habitat to species that require dynamic hydrologic regimes, and provide recreational and cultural value. With the exception of estuaries, they are considered one of the most valuable habitats worldwide (Costanza et al. 1997). Mitsch and Gosselink (2007) define a riverine wetland ecosystem as an, "Ecosystem with a high water table because of proximity to an aquatic ecosystem, usually a stream or river. Also called a bottomland hardwood forest, floodplain forest, bosque, riparian buffer, and streamside vegetation strip." For the purposes of this study, a forested riverine wetland includes any riparian forest located within a floodplain and is hydrologically connected to a river through seasonal inundation.

Goal and Objectives

The overall goal of this study was to validate the KY-WRAM for forested riverine wetlands using intensive, level 3 assessments and landscape-based level 1 assessments. Specifically, I looked to evaluate the KY-WRAM at the metric level using intensive data collected to characterize wetland disturbance from two biotic perspectives and landscape-based data to characterize wetland disturbance from a landscape perspective. The two biotic communities that were used as intensive assessments were plant and bird communities. The purpose of using two assemblages for this study was to utilize their unique responses to wetland quality and disturbance. A level 1 landscape-based assessment was used as an independent measure of anthropogenic disturbance.

The first objective of this study was to determine the correlation of each of the vegetation, bird species richness, and landscape assessments with the total KY-WRAM score and its ability to predict anthropogenic disturbance in forested riverine wetlands. The second objective was to determine the relationship between specific vegetation and landscape metrics and each of the six KY-WRAM metric categories.

CHAPTER II
STUDY AREA

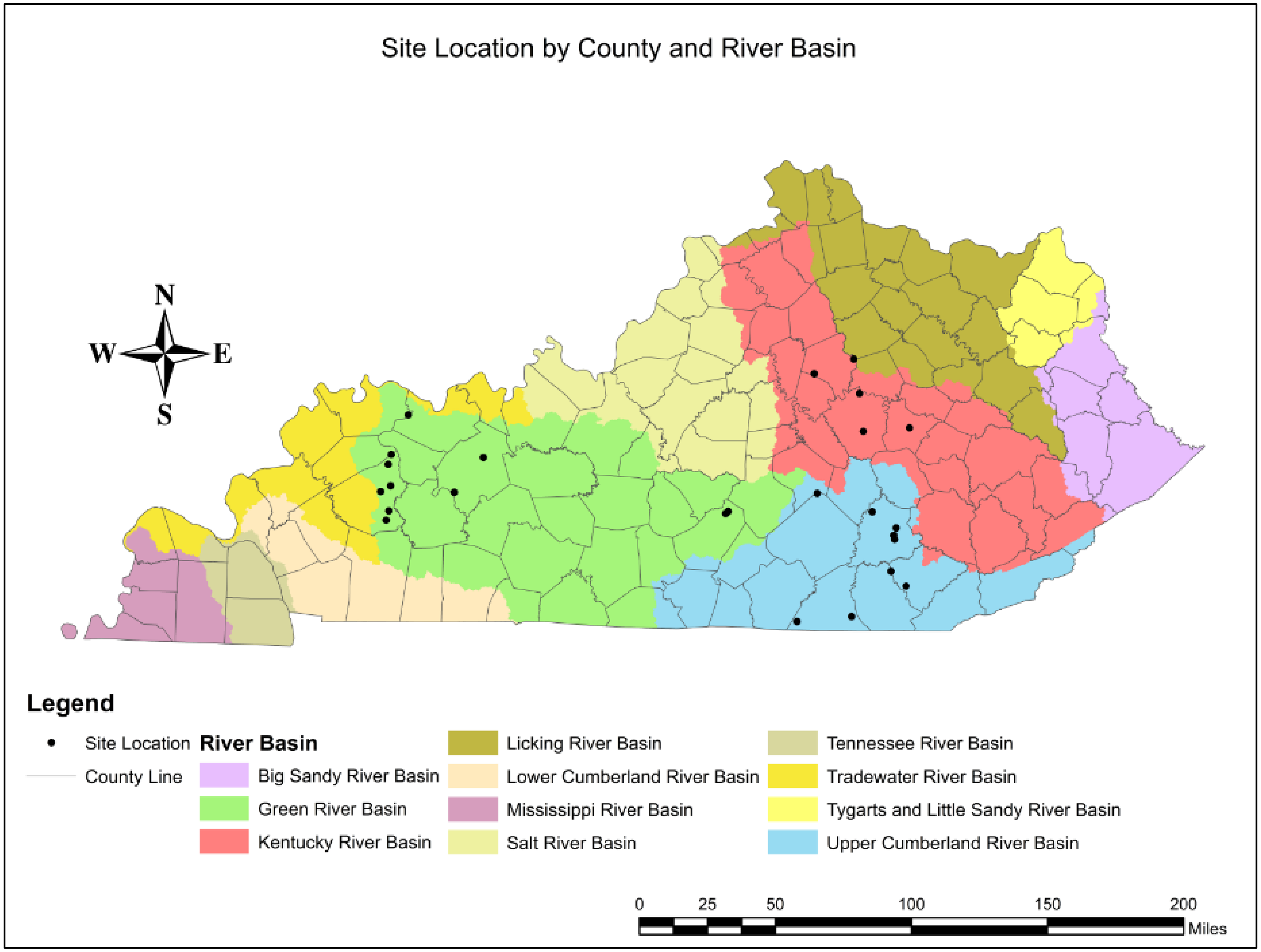
Sites were located within the Green (n=11), Upper Cumberland (n=9), and the Kentucky (n=5) river basins of Kentucky (Table 2, Figure 1). These sites represent 12 counties, including Henderson, Ohio, Muhlenberg, Hopkins, Adair, McCreary, Pulaski, Laurel, Knox, Madison, Fayette, and Estill (Figure 1). Study sites were located within two of Kentucky's three designated level II ecoregions, the Interior Low Plateau (IP) and the Appalachian Plateau (AP) (Figure 2). This study did not include wetlands located within the Mississippi Embayment (ME).

This study was designed to focus on forested riverine wetlands, which are observed to be the most abundant wetland type throughout the state. The topography includes rolling hills, ridges, and gaining streams while the geology is primarily alluvial. Approximately 82 percent of palustrine wetlands in Kentucky (excluding farm ponds) are classified as forested and forested/scrub-shrub (US FWS 2002). While forested riverine wetlands are found within the ME, they differ in their hydrologic regimes and plant communities (Jones 2005).

The AP extends as far north as New York and down through Eastern Kentucky into Georgia and Alabama. This region encompasses approximately 30 percent of Kentucky's total area and is dominated by mixed mesophytic forests (Jones 2005). Within the AP there are three designated level III ecoregions and nine level IV ecoregions. The level III ecoregions consist of the Central Appalachians (CA), the Southwestern Appalachians (SA) and the Western Allegheny Plateau (WAP) (Figure 3).

Table 2. Wetland name, latitude, longitude, sample type (random or targeted), year sampled, river basin, level II ecoregion, level III ecoregion, and level IV ecoregion.

Site	Site Name	Latitude	Longitude	Sample Type	Year	River Basin	Level II Ecoregion	Level III Ecoregion	Level IV Ecoregion
1	KYW12-001	37.4921	-87.4302	Random	2012	Green	IP	IRVH	GRSWL
2	KYW12-016	37.2367	-85.176	Random	2012	Green	IP	IP-III	HER
3	KYW12-017	37.3764	-87.4113	Random	2012	Green	IP	IRVH	GRSWL
4	KYW12-020	37.7619	-87.3022	Random	2012	Green	IP	IRVH	WOB
5	KYW12-025	37.2406	-87.4193	Random	2012	Green	IP	IRVH	GRSWL
6	KYW12-030	37.5366	-86.7963	Random	2012	Green	IP	IRVH	CasH
7	KYW12-033	37.5462	-87.4110	Random	2012	Green	IP	IRVH	GRSWL
8	KYW12-037	37.1902	-87.4369	Random	2012	Green	IP	IRVH	GRSWL
9	KYW12-039	37.3470	-86.9867	Random	2012	Green	IP	IRVH	GRSWL
10	KYW12-212	37.2480	-85.1594	Random	2012	Green	IP	IP-III	HER
11	KYW12-226	36.6712	-84.3459	Random	2012	Upper Cumberland	AP	SA	CP
12	KYW12-227	37.1078	-84.0582	Random	2012	Upper Cumberland	AP	SA	CP
13	KYW12-240	36.8308	-83.9818	Random	2012	Upper Cumberland	AP	CA	DAP
14	KYW12-243	37.1474	-84.0416	Random	2012	Upper Cumberland	AP	SA	CP
15	KYW12-244	36.9123	-84.0808	Random	2012	Upper Cumberland	AP	SA	CP
16	KYW12-245	37.3417	-84.5625	Random	2012	Upper Cumberland	IP	IP-III	HER
17	KYW12-391	37.0857	-84.0532	Random	2012	Upper Cumberland	AP	SA	CP
18	KYW12-414	36.6483	-84.7062	Random	2012	Upper Cumberland	AP	SA	PE
19	KYW12-HPB	37.2372	-84.1984	Targeted	2012	Upper Cumberland	AP	SA	PE
20	KYW13-213	37.8789	-84.2706	Random	2013	Kentucky	IP	IP-III	OB
21	KYW13-214	37.6888	-83.9377	Random	2013	Kentucky	AP	WAP	NFPE
22	KYW13-222	37.6738	-84.2489	Random	2013	Kentucky	IP	IP-III	OB
23	KYW13-229	38.0666	-84.3055	Random	2013	Kentucky	IP	IP-III	IB
24	KYW13-MAD	37.3446	-87.4772	Targeted	2013	Green	IP	IRVH	GRSWL
25	KYW13-OHM	37.9899	-84.5725	Targeted	2013	Kentucky	IP	IP-III	IB



. Figure 1. Site location by county and river basin.

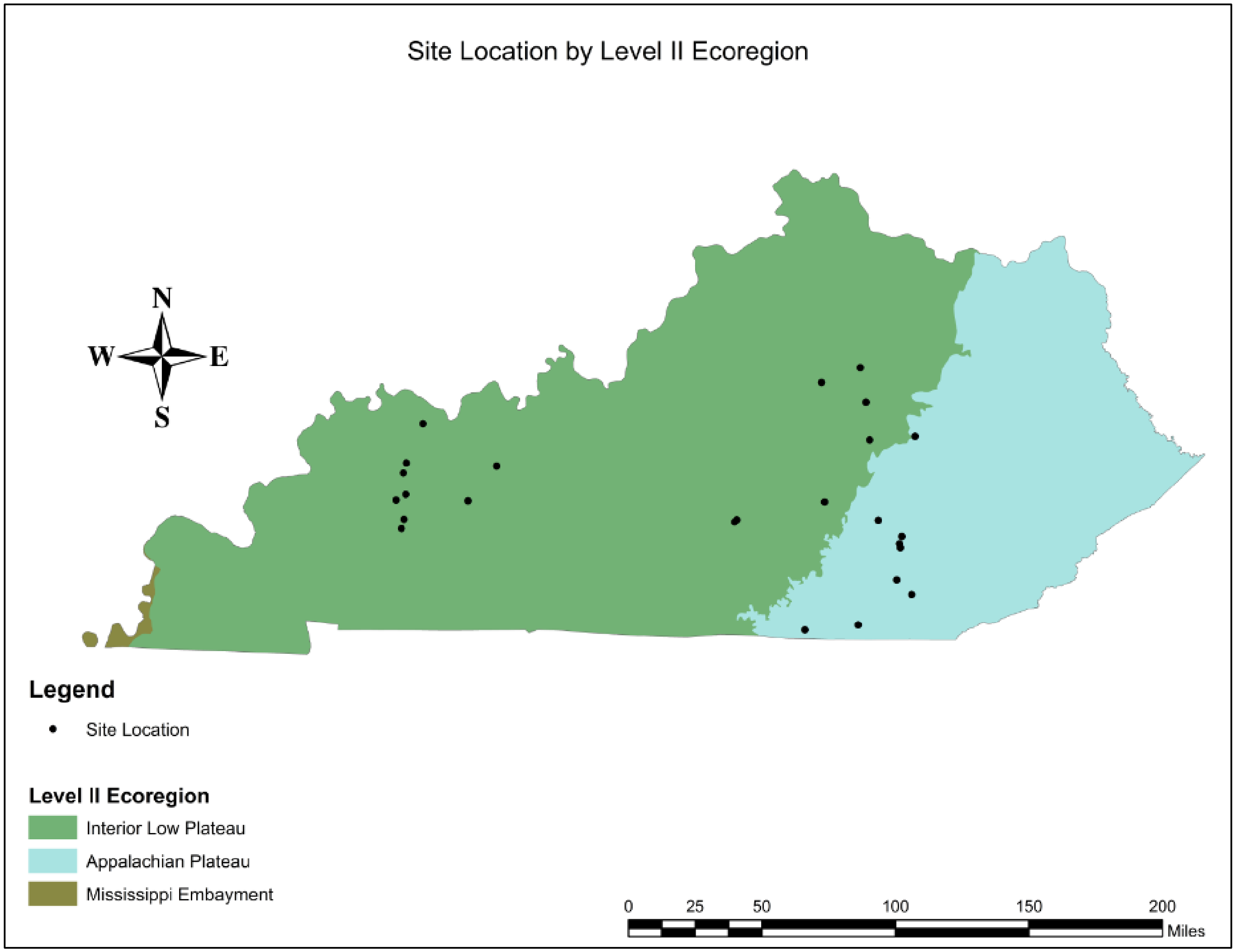


Figure 2. Site location by level II ecoregion.

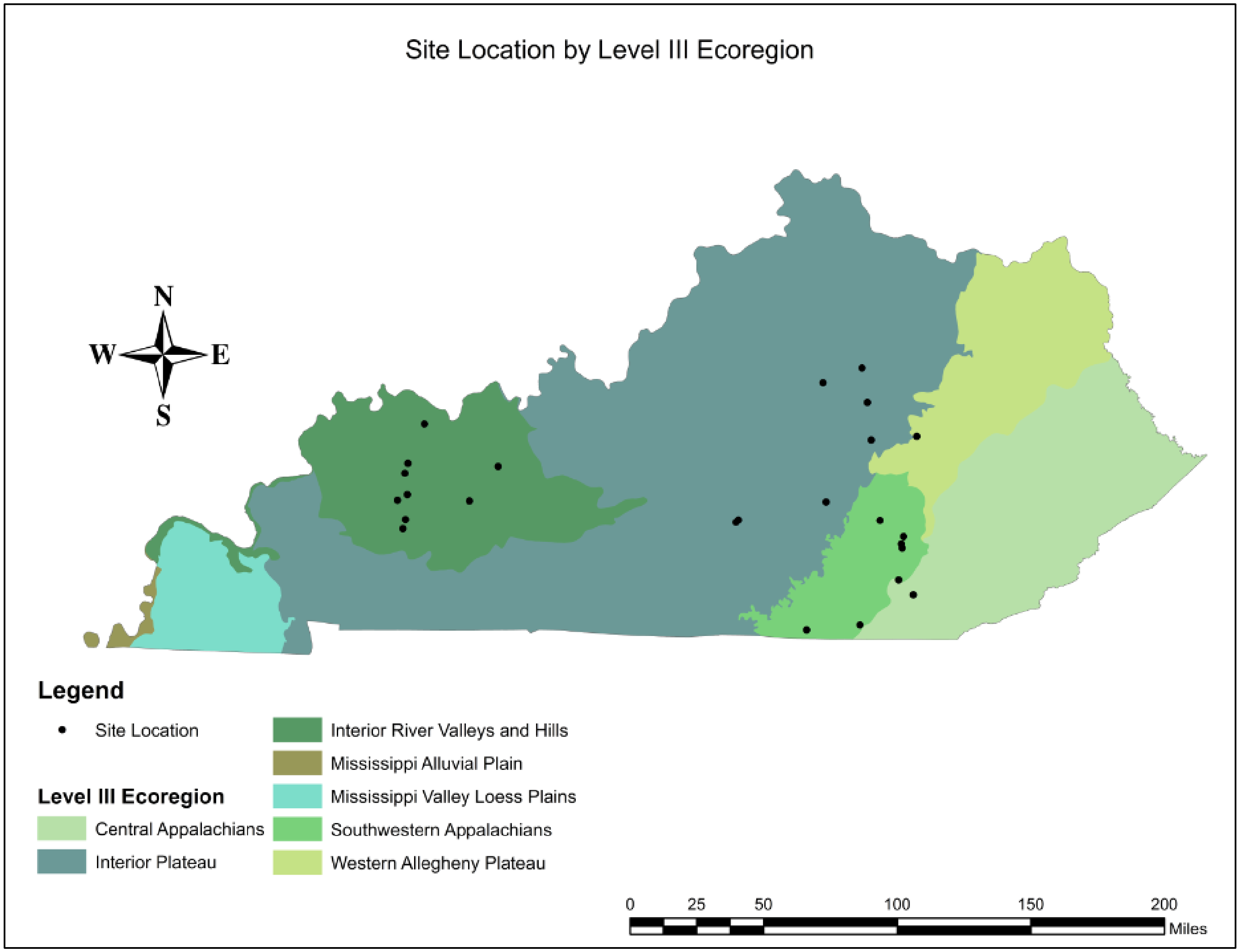


Figure 3. Site location by level III ecoregion.

Wetlands were sampled within all level III ecoregions (Table 2). The level IV ecoregions consist of Carter Hills (CarH), the Cumberland Mountains Thrust Block (CMTB), the Cumberland Plateau (CP), the Dissected Appalachian Plateau (DAP), the Knobs-Lower Scioto Dissected Plateau (KLSDP), the Monongahela Transitional Zone (MTZ), the Northern Forested Plateau Escarpment (NFPE), the Ohio/ Kentucky Carboniferous Plateau (OKCP), and the Plateau Escarpment (PE) (Figure 4). Of these nine level IV ecoregions, only four had wetlands sampled. These included the CP, the DAP, the KLSDP, and the PE (Table 2).

The IP extends from Indiana, Illinois and Ohio down through central Kentucky into Tennessee and Northern Alabama (Jones 2005). This region encompasses approximately 65 percent of Kentucky's total area and is dominated by the Oak/Hickory forests and western mesophytic forests (Jones 2005). Within the IP there are three designated level III ecoregions and thirteen level IV ecoregions. The level III ecoregions consist of the Interior Plateau (IP-III), the Interior River Valleys and Hills (IRVH) and the Mississippi Valley Loess Plains (MVLP) (Figure 3). Wetlands were only sampled within the IP-III and IRVH. The level IV ecoregions consist of the Caseyville Hills (CasH), the Crawford-Mammoth Cave Uplands (CHMCU), the Eastern Highland Rim (EHR), the Green River-Southern Wabash Lowlands (GRSWL), the Hills of the Bluegrass (HB), the Inner Bluegrass (IB), the Knobs-Norman Upland (KNU), the Loess Plains (LP), the Mitchell Plains (MP), the Outer Bluegrass (OB), the Outer Nashville Basin (ONB), the Wabash-Ohio Bottomland (WOB), the Western Highland Rim (WHR), and the Western Pennyroyal Karst Plains (WPKP) (Figure 4). Of these thirteen level IV ecoregions, only six had wetlands sampled (Table 2).

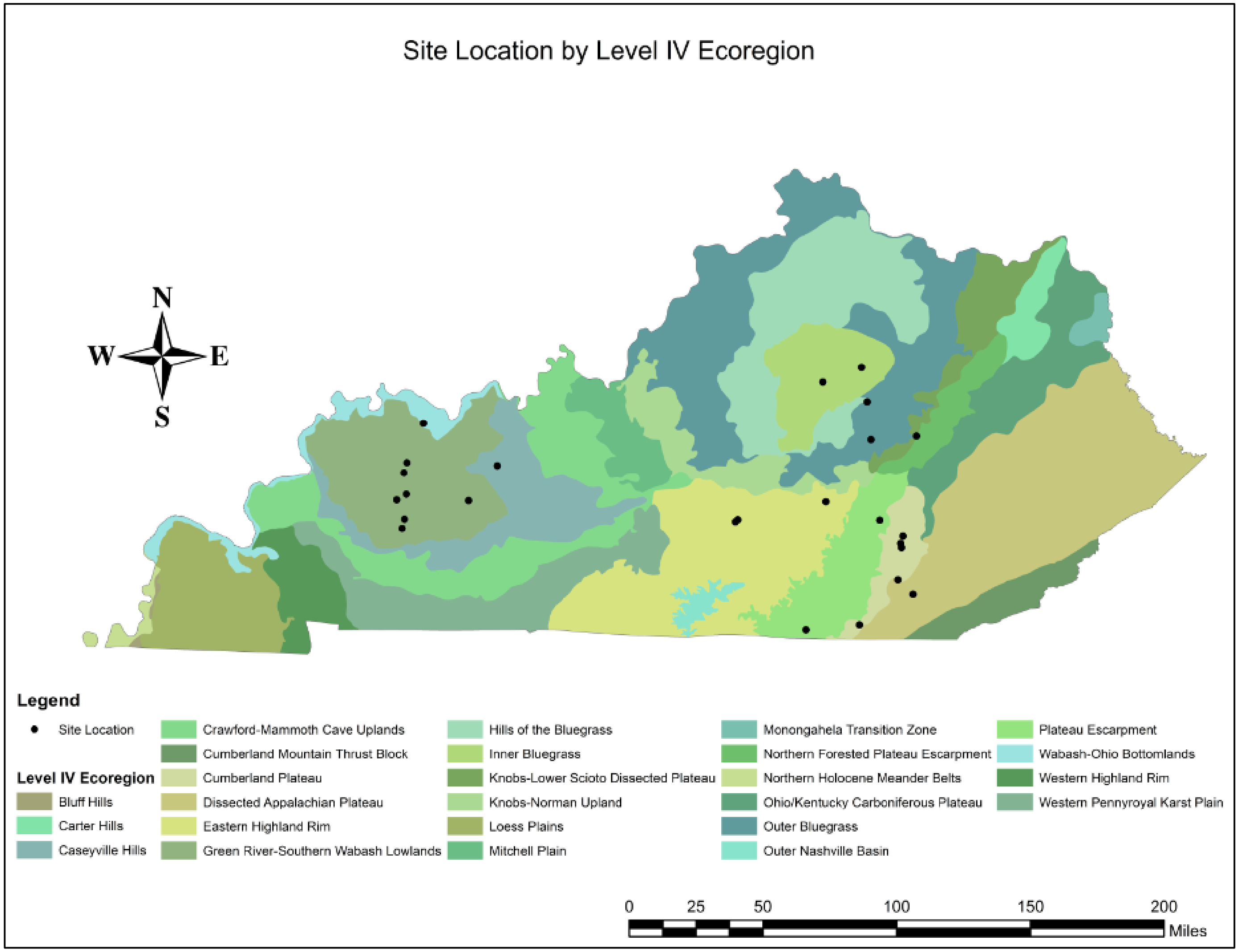


Figure 4. Site location by level IV ecoregion

CHAPTER III
METHODS

Site Selection

Sites were initially chosen by the Western Ecology Division of the US Environmental Protection Agency using a generalized random tessellation stratified (GRTS) sample design (Stevens and Olsen 2004). In addition, several sites were targeted as reference and disturbed to increase the frequency of high and low quality sites (Table 2). Reference site locations were obtained from the Kentucky State Nature Preserves Commission (KSNPC), while highly disturbed sites were targeted by searching imagery from the National Wetland Inventory (NWI) database and the Kentucky Land Cover Dataset (Kentucky Department of Geographic Information 2007). For all sites, the NWI was used to verify wetland existence, size, and Cowardin classification. For the final site selection process, following U.S. EPA guidelines for designing assessment method validation studies (U.S. EPA 2002c), I stratified the sample into three disturbance categories of equal size: disturbed, moderately disturbed and non-disturbed (i.e. reference). I used GIS analysis to determine landscape disturbance (see *Landscape Analyses* section of Methods) as a method of identifying sites that were targeted as the most disturbed.

KY-WRAM

A KY-WRAM was conducted at every site during the 2012 and 2013 field season. The protocol followed the latest draft of the KY-WRAM field form and guidance manual (KDOW 2013a, 2013b). The KY-WRAM was conducted by at least one individual “rater” and completed on the same day as the vegetation survey. All raters conducting a KY-WRAM received similar training prior to the field season. Scores from multiple raters at each site were averaged. The KY-WRAM is comprised of 6 metrics designed to measure disturbance and habitat quality. The maximum score possible was 99. Since some points are given for all wetlands, regardless of their condition, the minimum possible score for forested wetlands was 12.

Metric 1 – Wetland Size and Distribution, includes two submetrics: 1a. Wetland Size, and 1b. Wetland Scarcity. The maximum for this metric was 9 points. Wetland Size was determined using a combination of ArcGIS, NWI maps, soil maps, and field verification. If the size exceeded 125 acres, a score of 6 was assigned automatically. Wetland scarcity was determined within a 2-mile buffer around the NWI boundary of the wetland and based on inspection of satellite imagery and buffers. The percent of NWI wetlands within the 2-mile buffer was visually estimated by the rater and used to determine the submetric score. It was reasoned that wetlands located in landscapes with a scarcity of wetlands had a more important function and were thus given more points. If the total wetland area within the buffer represented less than 20 percent of the 2-mile buffer then the wetland received a maximum score of 3 for the submetric.

Metric 2 – Buffers and Intensity of Surrounding Land Use was comprised of three submetrics: 2a. Average Buffer Width, 2b. Intensity of Surrounding Land Use, and 2c. Connectivity to Other Natural Areas. The maximum number of points for this metric was 12. Average Buffer Width was determined in a standardized fashion using a 150-ft buffer calculated around the NWI wetland boundary. If all 150-ft surrounding the wetland were considered natural buffer, the submetric received the maximum score of 4.

Intensity of Surrounding Land Use was determined by estimating the percentage of land use types within a 1,000-ft buffer surrounding the wetland. Dominant land use was classified as >25% of the 1,000-ft buffer. Land use was categorized as very low intensity (4 points), low intensity (2 points), moderately high intensity (1 point), and high intensity (0 points). If more than one land use type was classified as dominant, points were averaged between categories. A maximum of 4 points was awarded if the majority of the land use was predominantly very low intensity. Connectivity to Other Natural Areas was determined by first calculating a 1,000-ft and 2,500-ft buffer, and then measuring the area within those buffers that was continuous natural area or connected by patch corridors. A maximum of 4 points was received if greater than 50% of the 2,500-ft buffer area was natural habitat or connected through a corridor.

Metric 3 – Hydrology was comprised of four submetrics: 3a. Input of Water, 3b. Hydrological Connectivity, 3c. Duration of Inundation/Saturation, and 3d. Alterations to Hydrologic Regime. The maximum number of points this metric could receive was 28. Input of Water was determined by the rater on site and sources could include surface water, ground water, or precipitation. All sites received 1 point for precipitation, and along with a combination of surface and ground water, a site could receive a maximum of 9 points for this submetric. The Hydrological Connectivity submetric was given points if the wetland was located within a 100-year floodplain, a corridor between a water source and human land use, or located in a wetland complex. The maximum potential score awarded for all three of these criteria was 6 points. Duration of Inundation/Saturation was determined by the rater throughout the site assessment based on indicators of hydroperiod. A maximum of 4 points was awarded if the wetland was semi- to permanently inundated/saturated. Alterations to Hydrologic Regime was scored based on a checklist survey of hydrologic disturbances and their intensity. If no hydrologic alterations were present, the wetland would receive a maximum of 9 points for this submetric.

Metric 4 – Habitat Alteration and Habitat Reference Comparison consisted of three submetrics: 4a. Substrate/Soil Disturbance, 4b. Habitat Alteration, and 4c. Habitat Reference Comparison. The maximum number of points for this metric was 20. Substrate/Soil Disturbance was determined based on a checklist of soil disturbances and their relative intensity. If no substrate or soil disturbance was apparent, a maximum of 4 points was awarded for this submetric. Habitat Alteration was also determined based on a checklist of disturbances and their intensity. If no habitat alterations were apparent, a site could receive a maximum of 9 points for this submetric. Habitat Reference Comparison was determined by best professional judgment of the rater by comparing the overall condition of the wetland to the best example of its type, a good example of its type, a fair example of its type, or a poor example of its type. If the habitat was a high-quality reference habitat, the submetric would score the maximum of 7 points.

Metric 5 – Special Wetlands consisted of three submetrics: 5a. Regulatory Protection/Critical Habitat, 5b. High Ecological Value/Ranked Communities, and 5c. Low-Quality Wetland. The maximum number of points awarded for this metric was 10, although presence of multiple criteria could exceed that score. A unique feature of this metric was a possible 10 point deduction from the score based on the determination of Low-Quality Wetlands. Regulatory Protection/Critical Habitat was awarded 10 points if a federally threatened or endangered species or critical habitat was within the HUC-12 watershed. Federally listed species and habitat were determined using US Fish and Wildlife Services threatened and endangered species maps. If a state listed species was known to occur, 10 points were awarded for a S1 or mixed qualifier, 5 points were awarded for an S2 or mixed qualifier, or 3 points for an S3 or mixed qualifier. State listed species and rare communities within the watershed were determined by the Kentucky State Nature Preserves Commission by submitting x/y coordinates of the site. High Ecological Value/Ranked Communities that may occur as forested riverine wetlands include Wet Bottomland Hardwood Forests (S2) and Bottomland Slough (S2), both of which would receive a maximum of 5 points. Low Quality Wetlands were less than 1 acre and had either a coverage of invasive species that exceeded 75%, was nonvegetated mineland/excavated, or a constructed stormwater treatment pond. If a wetland met any of these three criteria, it received a deduction of 10 points from the overall score.

Metric 6 – Vegetation, Interspersion, and Habitat Features was comprised of five submetrics: 6a. Wetland Vegetation Components, 6b. Open Water, Mudflat, and Aquatic Bed Habitats, 6c. Coverage of Highly Invasive Plant Species, 6d. Horizontal Interspersion, and 6e. Microtopographic Features. The maximum number of points this metric could receive was 20. Wetland Vegetation Components were determined separately for forest, shrub and herbaceous layers. Within each layer, scores were assigned based on the size (less than or greater than 0.1 acre), the relative coverage (< or > 25% of the wetland area), and the diversity of native vegetation (low, moderate or high). If the vegetation component of a wetland for each of the three layers was greater than 0.1 acre, covered 25% of the total wetland area, and had high native diversity, it received 9 points. Open Water, Mudflat, and Aquatic Bed Habitats was scored based on the total area covered by any of these habitats, with a maximum score of 3 points for ≥ 2.5 acres. Coverage of Highly Invasive Plant Species was determined by the rater throughout the site assessment. A highly invasive plant list from the Kentucky Exotic Pest Plant Council (KY-EPPC 2013) was used in addition to a checklist provided on the field form. If less than 1% of aerial coverage was invasive species, the wetland received 1 point, however, if more than 75% of aerial coverage was invasive species, 5 points were deducted. Horizontal Interspersion was determined by the rater throughout the site assessment. If a wetland had a high degree of interspersion, it received the maximum of 5 points. Microtopographic Features were determined by the rater throughout the site assessment. This submetric included four categories comprised of hummocks/tussocks/mounds, large woody debris, large snags, and amphibian breeding/nursery habitat. Each of these four components was evaluated by the rater and could receive a maximum of 3 points each. A maximum of 12 points was received if each of the four components met the highest criteria.

Vegetation Surveys

At each site, intensive vegetation data were collected using the Ohio Vegetation Index of Biological Integrity (Mack 2007) modified for Kentucky's vegetation. Vegetation surveys of a wetland were conducted using a series of 10 plots or "modules" in a 2x5 arrangement numbered 1 through 10 counterclockwise (Peet et al. 1998). Each module had a dimension of 10-m^2 (0.01ha). Of the 10 modules, four (modules 2, 3, 8 and 9) were sampled intensively and six (modules 1, 4, 5, 6, 7 and 10) were treated as residual modules (Figure 5, Mack 2007). Intensive modules were surveyed for plant species at four scales: 0.01-m^2, 0.1-m^2, 1-m^2 and 10-m^2. Surveys at 0.01-m^2, 0.1-m^2, 1-m^2 scale were conducted at two opposite corners of a module. All plants that fell within the module were identified to the species level, and assigned to a cover class category (solitary/few, 0-1%, 1-2%, 2-5%, 5-10%, 10-25%, 25-50%, 50-75%, 75-95%, and 95-99%). Any specimen that could not be properly identified in the field was collected, number cataloged and pressed for later identification. Voucher specimens for each wetland were collected and used for reference within each site. Wetland vegetation was only surveyed within a hydrogeomorphic (HGM) riverine classification and did not include any emergent and/or shrub dominated wetland areas. Forested wetlands that included seep, groundwater or isolated depressional hydrology exclusively were excluded from this study. Once vegetation data were collected, it was categorized and calculated to produce vegetation metrics and combined to produce a score (see Mack 2007). An individual wetland had the potential to score between 0 and 100 on the VIBI.

Vegetation metrics used were from the Ohio VIBI (Mack 2004, *see pages 17 – 19*). Metrics calculated for the forested VIBI included: floristic quality assessment index (FQAI), shade, seedless vascular plants, percent bryophyte, percent hydrophyte, percent sensitive, percent tolerant, small tree, subcanopy importance value, and canopy importance value. Additional vegetation metrics calculated and used in validation analysis include: percent adventive, stems per hectare, *Carex* species richness, hydrophyte species richness, and dicot species richness (Table 3).

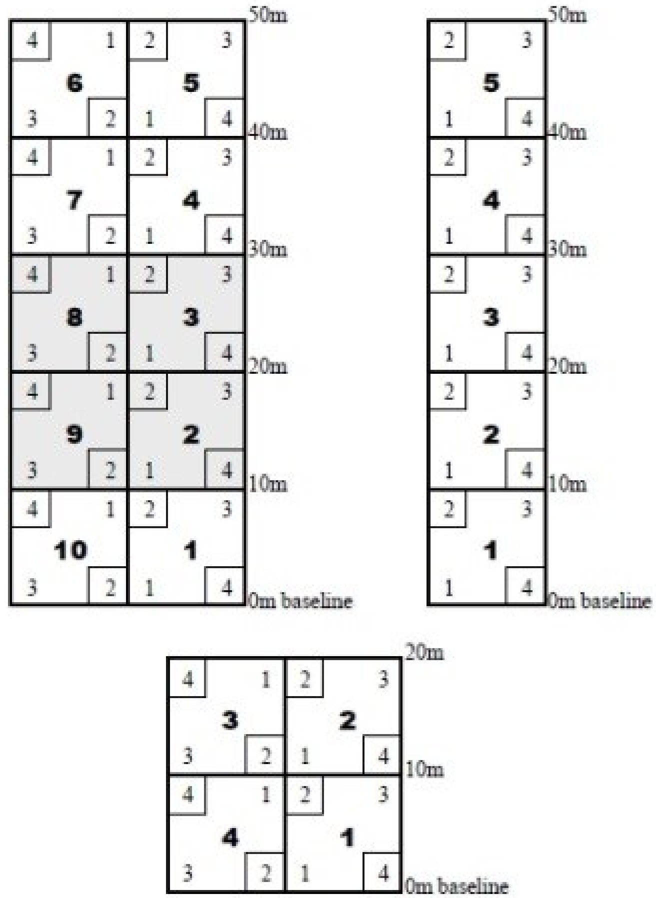


Figure 5. The nested plot design used for VIBI data collection. The arrangement shown at the top left was used at most sites, while the arrangement shown at the top right and center bottom are modified versions that were used where wetland size and shape shapes limited use of the standard arrangement.

Source: Mack JJ (2007) Integrated Wetland Assessment Program. Part 9: Field Manual for the Vegetation Index of Biotic Integrity for Wetlands v. 1.4. Ohio EPA Technical Report WET/2007-6. Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, Ohio.

Table 3. Variable abbreviations used in AIC and PCA analyses with variable descriptions. See Method section for variable definitions.

AIC	PCA	Description
KY-WRAM (response)		
Metric 1	k1	KY-WRAM Metric 1 score
Metric 2	k2	KY-WRAM Metric 2 score
Metric 3	k3	KY-WRAM Metric 3 score
Metric 4	k4	KY-WRAM Metric 4 score
Metric 5	k5	KY-WRAM Metric 5 score
Metric 6	k6	KY-WRAM Metric 6 score
Landscape (predictor)		
%cultivated	cult	Percent area cultivated within a 1000-m radius
%forested	forest	Percent area forested within a 1000-m radius
ldi		Landscape Development Intensity index score
Vegetation (predictor)		
%adventive	adv	Percent relative cover of adventive species in a VIBI survey
%hydrophyte		Percent relative cover of hydrophyte species in a VIBI survey
%sensitive		Percent relative cover of sensitive species in a VIBI survey
canopy iv	caniv	Canopy Importance Value
carex sr		Number of *Carex* species in a VIBI survey
dicot sr		Number of dicot species in a VIBI survey
fqai	fqai	Floristic Quality Assessment Index score
hydro sr		Number of dicot species in a VIBI survey
small tree	st	Number of small trees estimated per hectare in a VIBI survey
stems		Number of stems estimated per hectare in a VIBI survey
subcanopy iv	subiv	Subcanopy Importance Value
	shade	Number of shade tolerant species in a VIBI survey

Calculations followed those found in Mack 2007. The FQAI metric was calculated as:

$$I = \frac{\sum(\,CofC_i)}{\sqrt{N}}$$

where I is the FQAI score, $CofC_i$ is Coefficient of Conservatism of each species i and N is the number of species identified within a sample plot. The CofC is a value that ranks species based on their affinity for specific habitats and tolerance to disturbance from 1 (generalist; tolerant) to 10 (specialist; sensitive). The CofC list used for the Ohio VIBI and FQAI calculations did not include all plants for Kentucky. Therefore, a Kentucky-specific CofC list was used to modify the VIBI (Shea et al. 2010). The FQAI calculation includes non-native and introduced species, which are assigned CofC values of 0 and included in the total value of N. The shade metric was calculated as the sum of all shade tolerant or shade facultative species identified within the sample plot. SVP was calculated as the total number of species of fern or fern allies identified within the sample plot. Percent bryophyte is calculated as the estimated percent cover dominated by bryophyte species. The percent sensitive metric was calculated as the number of species considered "sensitive" (i.e. CofC value of 6–10) divided by the total number of species identified within the sample plot. The percent tolerant metric was calculated as the number of species considered tolerant (i.e. CofC of 0–2) divided by the total number of species identified within the sample plot. The small tree (i.e. pole timber) metric was calculated by summing the relative density of tree species in the 10–15-cm, 15–20-cm, and 20–25-cm diameter at breast height (DBH) size class. The relative density was calculated by dividing the number of stems for a certain species by the number of trees of all species (Mack 2007). The subcanopy importance value (IV) metric was calculated by summing the average IV of native, shade tolerant subcanopy species and the average IV of all native, facultative shade tolerant species (Mack 2007). The canopy IV metric was calculated by summing relative frequency, average relative density, and average basal area of native canopy species (Mack 2007). The percent adventive metric was calculated as the number of non-native and invasive species identified divided by the total number of species identified within the sample plot. The stems per hectare metric was calculated as the number of stems of native facultative wetland tree species (FacW) or obligate wetland tree species (Obl) sampled within the sample plot and extrapolated to estimate per hectare. The *Carex* species richness metric was calculated as the number of native *Carex* species found within the sample plot. The hydrophyte species richness metric was calculated as the number of native species considered hydrophytic with an indicator status of either FacW or Obl. The dicot species richness metric was calculated as the number of native dicotyledon species identified within the sample plot.

Bird Surveys

At each wetland site, a point count was conducted to quantify bird species richness. Point counts were conducted on forested riverine bird communities similar to those described by Peterson and Niemi (2007). Point counts were conducted within a 100-m radius for 15-minutes separated into three 5-minute intervals. Point counts were only conducted between the time period of 30 minutes before sunrise to 3 hours after sunrise. Species were documented on a spot map. All breeding birds were counted by either a visual (male and female) or audible (male only) detection, and if discernible, the age of an individual was also noted. The first two 5-minute intervals consisted of passive observational detection. The final interval included playback of wetland bird species that were otherwise difficult to detect. Point counts were not conducted during periods of inclement weather (i.e. precipitation, high winds or dense fog). In general, point counts were located near the approximate center of the VIBI plot. The latitude and longitude of each point count was documented using a Garmin eTrex 20 handheld GPS. All point counts were conducted between 15 June and 25 June 2013.

Landscape Analyses

For each site, a Landscape Development Index (LDI) was calculated. LDI analysis was done using a combination of ArcGIS v10.1 (Environmental Systems Research Institute 2011) and ground-truthing during site visits. The LDI was calculated as the summation of the percent of the total area of influence for each given land use type by the LDI coefficient for each given land use type, or

$$LDI_{total} = \sum \%LU_i \cdot LDI_i$$

where, LDI_{total} is the LDI ranking for landscape unit, $\%LU_i$ is the percent of the total area of influence in land use i, and LDI_i is the landscape development intensity coefficient for land use i (Brown and Vivas 2005).

LDI scores were calculated on a scale of 1 through 10, where 10 defined a completely disturbed area and 1 is defined as a reference habitat. The primary layer for this analysis consisted of the 2005 Kentucky Land Cover Dataset (Kentucky Department of Geographic Information 2007). The Kentucky Land Cover Dataset layer has a resolution of 30-m with a designated land use type and associated LDI coefficient for each grid pixel (Table 4). A 1000-m buffer around the point-count and VIBI survey was used for calculations. Mack (2006) used a similar LDI analysis to calibrate the Ohio VIBI using the 2001 NLCD and modifications of the LDI coefficients. Since this study was in an ecoregion similar to Ohio, I followed the LDI coefficients of Mack (2006, 2007), however, some of the land cover coefficients changed between land cover datasets. To account for this, I referenced primary literature for appropriate coefficients (Brown and Vivas 2004, Congalton and Green 2009).

Statistical Analyses

All analyses were conducted using Program R (R Development Core Team 2012). To determine the success of the KY-WRAM as a rapid method of describing the condition of wetlands, simple linear regressions were performed using the KY-WRAM against the landscape and the biotic assessments that included both vegetation-based and bird-based methods. The simple linear regressions provided a way of determining the success of an assessment method by plotting it against the score of other assessment methods. Simple linear regression typically includes a response and independent variable; however, the data collected did not include a direct biological response, rather a correlative relationship used to determine the success of the KY-WRAM. The variables used are not independent and dependent in the traditional sense of cause and effect. Since the goal of this study was to determine the KY-WRAM's success as a measure of wetland disturbance, KY-WRAM score was treated as the response variable.

Table 4. Land use categories from the 2005 Kentucky Land Cover Dataset and coefficients (LDIi) used in the Landscape Development Index calculation. Coefficients were based on Mack 2007 (a), Mack 2006 (b), Brown and Vivas 2005 (c), and Congalton and Green 2009 (d).

Land Use Type (numeric ID)	Land Use Type (description)	LDIi
11	Open Water	**1**[a]
21	Developed, Open Space	**6.92**[a,b]
22	Developed, Low Intensity	**7.55**[a,b]
23	Developed, Medium intensity	**9.42**[a,b]
24	Developed, High Intensity	**10**[c]
31	Barren Land	**8.32**[a,b]
41	Deciduous Forest	**1**[a,b]
42	Evergreen Forest	**1**[a,b]
43	Mixed Forest	**1**[a,b]
52	Scrub/Shrub	**1**[d]
71	Grassland/Herbaceous	**1**[d]
81	Pasture/Hay	**3.41**[a,b]
82	Cultivated Crops	**7**[a,b]
90	Woody Wetlands	**1**[a,b]
95	Emergent Herbaceous Wetlands	**1**[a,b]

Sources: Mack JJ (2007) Integrated Wetland Assessment Program. Part 9: Field Manual for the Vegetation Index of Biotic Integrity for Wetlands v. 1.4. Ohio EPA Technical Report WET/2007-6. Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, Ohio.

Mack JJ (2006) Landscape as a predictor of wetland condition: An evaluation of the landscape development index (LDI) with a large reference wetland dataset from Ohio. Environmental Monitoring and Assessment 120:221-241.

Brown MT, Vivas MB (2005) Landscape Development Intensity Index. Environmental Monitoring and Assessment 101:289-309.

Congalton R, Green K (2009) Assessing the Accuracy of Remotely Sensed Data: Principles and Practices, second edition. CRC/Taylor & Francis, Boca Raton, FL, USA.

Since the KY-WRAM is composed of multiple metrics representing different wetland functions and stressors, simply plotting the final score against the score of another assessment method would yield limited information. To help explain the relationship between vegetation and landscape variables and the KY-WRAM metrics, a multiple regression and model selection-based analysis was used to determine the importance of vegetation and landscape variables in predicting individual KY-WRAM metrics. An information-theoretic approach was incorporated to identify a best-fit model. This was accomplished by calculating Akaike's Information Criterion (AIC) for each model, or

$$AIC = -2\log(L) + 2K$$

where, *L* is calculated as the maximum likelihood for a candidate model, and *K* represents the number of parameters within the model. This AIC equation is generally used for applicably large datasets. A second-order bias correction (AIC_c) was used to account for the small data set (Burnham and Anderson 2004). An AIC_c is generally recommended for finite sample sizes (<40). The AIC_c is defined as

$$AIC_c = -2\log(L) + 2K + \frac{2K(K+1)}{n-K-1}$$

where, *n* represents the sample size. A series of *a priori* candidate models comprised of combinations of VIBI metrics and LDI components were used in each of the six AIC analyses (Anderson et al. 2000). A multi-model inference approach was used, as several variables and models were expected to be correlated with KY-WRAM metrics (Burnham and Anderson 2004). Top models were classified as having a $\Delta AIC_c < 2.0$. Models were considered similar if the ratio of Akaike weights between two models (i.e. Evidence Ratio) was < 2. Model-averaged parameter estimates of variables with 95% CI not overlapping with zero were considered to be statistically significant variables within the top models. AIC_c and model-averaged parameter estimates were conducted using the Vegan package with Program R (Oksanen et al. 2013).

For each AIC model, a test for multicolinearity was conducted among all predictor variables to eliminate redundant variables. If two predictor variables exceed an R^2 value greater than or equal to 0.7, the variable determined to be least biologically meaningful was excluded. The biological value of a variable was determined based on literature review and best professional judgment. Additionally, any variable that was not normally distributed was excluded.

A Principal Component Analysis (PCA) was utilized for the ordination of (1) bird species among sites and (2) KY-WRAM metrics to determine the variation within the dataset and correlation of variables. An environmental fit of vegetation metrics, landscape variables, and KY-WRAM metrics (for bird communities only) was plotted against the PC axes to determine relationships. PCA is an unconstrained method of ordination that plots a set of variables along orthogonal axes defined by the dataset (Borcard et al. 2011). For bird communities, the goals of this analysis were to 1) determine potential indicator species of high and low quality habitat, and 2) determine habitat variables associated with specific bird species. Axes for each of the two PCA analyses were comprised of combinations of either bird species or KY-WRAM metrics from the 25 sites. Raw presence-absence species data were transformed using a Hellinger transformation prior to the analysis.   This type of transformation has been shown to be appropriate for presence-absence community data in PCA analysis (Borcard et al. 2011). This transformation uses Ochiai distance and so avoids some of the assumptions associated with Euclidean distance such as normality and linearity. Preliminary inspection of PCA plots suggested there was no strong bias or arching effect that sometimes occurs with untransformed species community data in PCA (Legendre and Gallagher 2001). KY-WRAM metric loading scores were determined for importance within each of the PC axes. VIBI metrics and landscape variables were correlated against the PCA axes representing the combined KY-WRAM metrics. Bird species loading scores were determined for importance within each of the PC axes. KY-WRAM metrics, VIBI metrics, and landscape variables were fitted against bird species. Habitat variables were included using an environmental fitting procedure in Program R, Package Vegan using function envfit to explore the correlation between these variables and the PCA axes. The habitat variables included six metrics from the VIBI (*small tree*, *canopy IV*, *subcanopy IV*, *fqai*, *%adventive*, and *shade*), all six KY-WRAM metrics, and two landscape variables (*%forested* and *%cultivated*).

CHAPTER IV
RESULTS

The total KY-WRAM scores among wetlands ranged from 30.5 to 88.8 ($\bar{x} = 59.67; SD = 15.73$) (Table 5, Appendix A). The total VIBI scores ranged from 25 to 80 ($\bar{x} = 51.28; SD = 18.38$). A total of 236 plant species across 74 families were identified. The most abundant families were Sedges (Cyperaceae: 33 species), Grasses (Poaceae: 19 species), and Composite Flowers (Asteraceae: 18 species) (Table 6, Appendix A). The most abundant genus was *Carex* sedges: 28 species. Total LDI scores ranged from 1.37 to 6.33 ($\bar{x} = 3.25; SD = 1.58$). Total bird species richness ranged from 7 to 17 ($\bar{x} = 11; SD = 2.43$). A total of 51 bird species across 21 families were identified. The most abundant families were Wood Warblers (Parulidae: 13 species), Tyrant Flycatchers (Tyrannidae: 4 species), Woodpeckers (Picidae: 4 species), and Sparrows and allies (Emberizidae: 4 species) (Table 7, Appendix A). The most frequent species were Carolina Chickadee (*Poecile carolinensis*: 16 sites), Carolina Wren (*Thyrothorus ludovicianus*: 15 sites), Acadian Flycatcher (*Empidonax virescens*: 13 sites), Blue-gray Gnatcatcher (*Polioptila caerulea*: 13 sites), Ovenbird (*Seirus aurocapilla*: 13 sites), Red-eyed Vireo (*Vireo olivaceus*: 13 sites), and Yellow-billed Cuckoo (*Coccyzus americanus*: 13 sites).

Based on linear regression analyses, the KY-WRAM showed a marginally significant, negative relationship with the LDI ($R^2 = 0.13$; $F_{1,23} = 3.422$; $p = 0.077$) (Figure 6a, Appendix B), and a significant, positive relationship with the VIBI ($R^2 = 0.192$; $F_{1,23} = 5.455$; $p = 0.029$) (Figure 6b, Appendix B). Bird species richness showed a significant, positive relationship with the KY-WRAM ($R^2 = 0.192$; $F_{1,23} = 10.768$; $p = 0.029$) (Figure 6c, Appendix B). For the VIBI, there was a marginally significant, negative relationship with the LDI ($R^2 = 0.149$; $F_{1,23} = 4.013$; $p = 0.057$) (Figure 7a, Appendix E). Bird species richness showed a significant, positive relationship with the VIBI ($R^2 = 0.661$; $F_{1,23} = 44.750$; $p < 0.001$) (Figure 7b, Appendix E) and a significant, negative relationship with the LDI ($R^2 = 0.183$; $F_{1,23} = 5.140$; $p = 0.033$) (Figure 7c, Appendix E).

Model selection results indicated that among the vegetation and landscape variables, a single variable, *fqai* best explained the KY-WRAM metric for wetland area (Table 8a, Appendix C). The evidence ratio between the top two models was 1.44. A multi-model inference approach was used due to the high degree of uncertainty between the top models with similar AIC_c weights (ω). The six top models were used in model averaging because they had a $\Delta AIC_c < 2.0$. Their cumulative ω was 0.6. All of the top models had just a single variable including, *fqai*, *ldi*, *%cultivated*, *%forested*, *%adventive*, and *stems*. I examined parameter estimates to determine effect sizes of each variable. The model-averaged 95% confidence intervals (CI) for the effect of *fqai*, *ldi*, *%adventive*, *%forested*, *%cultivated* and *stems* all included zero (Table 9a, Appendix C). This indicated that all of the top models had a small effect size.

Model selection results indicated that among the vegetation and landscape variables, the best model for explaining the wetland buffers KY-WRAM metric included the *%forested* variable (Table 8b, Appendix C). The evidence ratio between the top two models was 1.3. A multi-model inference approach was used due to the high degree of uncertainty between the top models with similar ω. The four top models were used in model averaging because they had a $\Delta AIC_c < 2.0$. Their cumulative ω was 0.62. Top models were *%forested*, *%adventive + %forested*, *%cultivated + %adventive + ldi*, and *fqai + %forested*. I examined parameter estimates to determine effect sizes of each variable. The model-averaged 95% CI for the effect of *fqai*, *ldi*, *%cultivated*, *%sensitive*, and *%adventive* all included zero, indicating a small effect size for these variables (Table 9b, Appendix C). The model-averaged 95% CI for the effect of *%forested* (β = 0.080; SE = 0.021; CI = 0.037, 0.122) did not include zero which indicated a large effect size and importance within the top models.

Model selection results indicate that *ldi* was the best model for the effect of vegetation and landscape variables on wetland hydrology (Table 8c, Appendix C). The evidence ratio between the top two models was 2.51. A multi-model inference approach was used due to the high degree of uncertainty between the top models with similar ω. There were three top models considered with a $\Delta AIC_c < 2.0$. Their cumulative ω was 0.34. Top models were *ldi*, *%hydrophyte*, and *fqai*. I examined parameter estimates to determine effect sizes of each variable. The model-averaged 95% CI for the effect of *ldi*, *%hydrophyte*, *fqai*, *carex sr*, *hydro sr*, and *stems* all included zero, indicating a smaller effect size for these variables (Table 9c, Appendix C).

Model selection results indicate that *ldi + %adventive + %forested* was the best model for the effect of vegetation and landscape variables on wetland habitat alteration (Table 8d, Appendix C). The evidence ratio between the top two models was 1.03. A multi-model inference approach was used due to the high degree of uncertainty between the top models with similar ω. There were five top models considered with a ΔAIC_c < 2.0. Their cumulative ω was 0.58. Top models were *ldi + %adventive + %forested*, *ldi + %adventive*, *fqai + %forested*, *ldi + %adventive + canopy iv*, and *%forested*. I examined parameter estimates to determine effect sizes of each variable. The model-averaged 95% CI for the effect of *subcanopy iv*, *canopy iv*, *ldi*, *small tree*, and *%adventive* all included zero, indicating a smaller effect size for these variables (Table 9d, Appendix C). The model-averaged 95% CI for the effect of *fqai* (β = 0.330; SE = 0.160; CI = 0.016, 0.644) and *%adventive* (β = -0.129; SE = 0.048; CI = -0.224, -0.035) did not include zero, indicating a larger effect size and importance of the variables in the top models.

Model selection results indicate that *%sensitive* was the best model for the effect of vegetation and landscape variables on special wetlands (Table 8e, Appendix C). The evidence ratio between the top two models was 1.09. A multi-model inference approach was used due to the high degree of uncertainty between the top models with similar ω. There were seven top models considered with a ΔAIC_c < 2.0. Their cumulative ω was 0.59. Top models were *%sensitive*, *fqai*, *%cultivated*, *dicot sr*, *carex sr*, *ldi*, and *%adventive*. I examined parameter estimates to determine effect sizes of each variable. The model-averaged 95% CI for the effect of *ldi*, *%sensitive*, *%cultivated*, *%adventive*, *fqai*, *carex sr*, and *dicot sr* all included zero, indicating a smaller effect size for these variables (Table 9e, Appendix C).

Model selection results indicate that *%adventive + carex sr* was the best model for the effect of vegetation and landscape variables on wetland vegetation, interspersion and microtopography (Table 8f, Appendix C). The evidence ratio between the top two models was 1.3. A multi-model inference approach was used due to the high degree of uncertainty between the top models with similar ω. There were four top models considered with a $\Delta AIC_c < 2.0$. Their cumulative ω was 0.79. Top models were *%adventive + carex sr*, *%adventive + ldi + carex sr*, *fqai + %adventive*, and *fqai + %adventive + carex sr*. I examined parameter estimates to determine effect sizes of each variable. The 95% CI for the effect of *ldi*, *%cultivated*, and *fqai* all included zero, indicating a smaller effect size for these variables (Table 9f, Appendix C). The model-averaged 95% CI for the effect of *%adventive* (β = -0.189; SE = 0.051; CI = -0.288, -0.090) and *carex sr* (β = 0.552; SE = 0.252; CI = 0.058, 1.047) did not include zero which indicated a large effect size and importance of the variables in the top models.

Results of the Principal Component Analysis for KY-WRAM metrics showed axes PC1 and PC2 explained 51.2% of the variation among the dataset (Table 10a, Appendix D). The PC1 and PC2 axis explained 29.4% and 21.8% of the variation, respectively (Figure 8, Appendix E). KY-WRAM metrics 1, 3, and 5 loaded strongly on PC1, while metrics 2 and 6 loaded strongly on PC2 (Table 10b, Appendix D). VIBI metrics and landscape variables that showed strong correlations with PC1 were forest and fqai (Table 10c, Appendix D). Results of the Principal Component Analysis for bird species showed axes PC1 and PC2 explained 22.2% of the variation among the datasets (Table 11a, Appendix D). The PC1 and PC2 axes explained 12.7% and 9.5% of the variation in bird species, respectively (Figure 9, Appendix E). Specific bird species loading scores were determined to be associated strongly with a PC axes if it exceeded a threshold of > 0.2 (Table 11b, Appendix D). KY-WRAM metrics, VIBI metrics, and landscape variables that showed strong negative correlations with PC1 were cult while variables that showed strong positive correlations with PC1 were fqai, shade, k2, and k4 (Table 11c, Appendix D).

CHAPTER V
DISCUSSION

The regression analyses suggest the KY-WRAM total score was predicted by the VIBI score. This was expected as both methods were adapted from the Ohio EPA and both have been rigorously tested and shown to be correlated with wetland quality (Mack et al. 2000, Mack 2004). However, a large portion of the variation between the KY-WRAM and the VIBI relationship remains unexplained. This is probably due in large part to geographic variation in the plant communities and the possibility that several of the VIBI metrics do not reflect Kentucky's forested wetland quality. For instance, the VIBI metric for seedless vascular plant did not appear to be a strong predictor of wetland floristic quality within this study. Historically, ferns and fern allies have been documented as predictors of forested wetland quality (Mack 2001b, 2004). However, forested riverine wetlands throughout Kentucky may have some inherently different forest structures and natural disturbance regimes that do not demonstrate these correlations. The two major ecoregions in this study (the Interior Low Plateau and Appalachian Plateau) exhibited different subcanopy and herbaceous layer structures. The most obvious sites where the seedless vascular plant metric might not be predictive of wetland quality were in the Green river basin. Plant communities were accounted for by adjusting coefficient of conservatism ranks to fit Kentucky's species list and species distribution. However, despite the relatively close proximity between Kentucky and Ohio, where both the VIBI and ORAM originated, the dominant forested community types differ between wetlands in Ohio (ephemeral/depressional) and Kentucky (forested riverine). Of the wetlands sampled, no site received a total KY-WRAM score under 30 and only three sites received scores between 30 and 40. This is possibly due to the design of the KY-WRAM and the nature of forested wetlands. Generally, these forested riverine wetlands retain functions even when subjected to low to moderate levels of disturbance, and tend to score points in the categories of size and scarcity (metric 1), hydrology (metric 3), habitat reference (metric 4) and vegetation (metric 6).

Bird species richness was a successful predictor of the KY-WRAM. This has been similarly tested and observed in Ohio by Stapanian et al. (2004) using the ORAM; however wetland types between studies varied. For instance, Stapanian et al. (2004) targeted shrub-scrub wetlands with a forested buffer whereas this study targeted forested wetlands with no specific criteria for buffers. They found total bird species richness to be significantly related to total ORAM scores. Both studies had similar total RAM score ranges: 45 – 86.5 in Ohio (Stapanian et al. 2004), compared to 30.5 – 88.8 in this study. Although both results were significant, this suggests a similar pattern and problem of limited scoring boundaries with a particular wetland type and an unknown relationship between bird species richness and RAM score. For bird species richness to be a successful predictor of the KY-WRAM, it is likely responding similarly to multiple metrics of the KY-WRAM.

Based on the results of the PCA ordination plot of bird species, several species were observed to be strongly related to KY-WRAM metrics, VIBI metrics, and landscape variables. Most notably, Carolina Chickadee (*Poecile carolinensis*), Carolina Wren (*Thryothorus ludovicianus*), House Wren (*Troglodytes aedon*), American Robin (*Turdus migratorius*), Field Sparrow (*Spizella pusilla*), Indigo Bunting (*Passerina cyanea*), Mourning Dove (*Zenaida maacroura*), Eastern Towhee (*Pipilo erthrophthalmus*), and Northern Cardinal (*Cardinalis cardinalis*) were observed to be positively associated with percent cultivated. Species positively associated with metric 2, metric 4, FQAI, and percent shade tolerant plant species were Wood Thrush (*Hylocichla mustelina*), Scarlet Tanager (*Piranga olivacea*), Kentucky Warbler (*Oporonis formosus*), Hooded Warbler (*Wilsonia citrina*), and Ovenbird (*Seiurus aurocapilla*). Although the results of the PCA and cumulative proportion of the two PC axes explained only 22.2% of the variation in the bird dataset, it appears that those species that did show strong responses were responding similarly to several landscape variables (percent cultivated), KY-WRAM metrics (buffers and surrounding land use and habitat reference comparison), and VIBI metrics (floristic quality and percent shade tolerant species). The result of low percent of variation explained in the dataset is likely due to the weak associations of multiple species to PC axes and clustered within the center of the PCA plot. The gradients that do appear to be associated with PC1, however.

Based on personal observation of the wetlands sampled, several notable functional, migratory, and foraging guilds were observed among forested riverine bird communities. Since observations and surveys were conducted during the breeding season, functional (i.e. ground nesting, double brood species, canopy nesting) and foraging guilds (i.e. insectivorous, omnivorous, granivorous) were observed in all wetlands and generally observed to be associated with metrics such as surrounding land use, buffer width, and habitat reference. Other measures of bird community composition (i.e. diversity and evenness) were not observed throughout forested riverine wetlands regardless of quality. Generally, larger groups of bird species were not observed at sites throughout the breeding season.

As expected, the KY-WRAM showed a negative relationship with the LDI; however, this relationship was not significant. This was likely due to the frequency of disturbance type in the regions sampled. The most disturbed sites sampled in this study had a high percent of agricultural land use in the surrounding landscape. Generally, the majority of wetland disturbance surrounding sites were from pasture and hay (LDI coefficient = 3.71) and cultivated crops (LDI coefficient = 7) primarily throughout the Green river basin. This resulted in a narrow range of disturbance where few wetlands exhibited a surrounding landscape with an LDI greater than 6.33. Mack (2006) found similar results when comparing results from the forested VIBI with LDI in forested riverine wetlands of Ohio ($R^2 = 0.525$, $p = 0.012$, $n = 11$) where LDI scores did not exceed 7. Despite efforts to target disturbed wetlands, no sites had LDI scores exceeding 6.33. This may also suggest that disturbance at a landscape scale of the remaining forested wetlands is relatively intermediate in degree throughout Kentucky.

Model results and parameter estimates for the analysis of metric 1 suggest that none of the top models or variables were successful or meaningful predictors of wetland area. Scores from metric 1 ranged from 5 to 9. With the exception of one site, all sites scored between a 3 and a 6 for submetric 1a (wetland size) and scored either a 2 or a 3 for submetric 1b (wetland scarcity). While the scoring ranges for wetland size varied, the scoring boundaries were limited to a maximum of 6 and considered anything greater than 50 acres, however, several sites exceeded 1,000 acres. The results of low evidence or heavily weighted top model and no variable with meaningful parameter estimates suggest that landscape and vegetation variables do not successfully predict wetland size or scarcity. This is likely due to the low variability observed for metric 1 within the dataset (Table 5). Previous research has indicated that wetland size may not be a reliable indicator of wetland functions and values (Snodgrass et al. 2000, Babbitt 2005); however, these studies show the importance of amphibians and smaller, isolated wetlands. Regardless of the findings within this study, wetland size and scarcity are undoubtedly important components of wetland assessments for regulatory purposes, specifically for mitigation.

Model results and parameter estimates for the analysis of metric 2 suggest that percent forested area within a 1,000-m buffer was a successful predictor of buffers and surrounding land use of a wetland. The variable of *%forested* was in 3 of the 4 top models and had a significant, positive parameter estimate. This suggests its importance in predicting surrounding land use. Metric 2 is primarily estimated based on desktop or map based analysis of satellite imagery. A high percent forested area surrounding a wetland generally suggests a wide buffer width surrounding a wetland, low intensity of surrounding land use, and connectivity to other natural areas. While metric 2 and *%forested* are highly correlated, the two variables are calculated with somewhat different methods. For example, *%forested* is determined using buffers, analyses, and calculated via standardized methods of detecting forested areas. Metric 2 is calculated using estimated methods via the rater either in the field or by desktop. The strong relationship with *%forested* suggests that metric 2 accurately predicts surrounding land use as determined using the KY-WRAM.

Model results and parameter estimates for the analysis of metric 3 suggest that none of the top models or variables were successful or meaningful predictors of wetland hydrology. The results of no significant or heavily weighted top model and no variable with meaningful parameter estimates suggest that landscape and vegetation variables do not successfully predict hydrology. Scores of metric 3 ranged from 9 to 24. Scores ranged between 5 and 9 for submetric 3a (input of water from an outside source), scores ranged from 2 to 6 for submetric 3b (hydrologic connectivity), scores ranged from 1 to 4 for submetric 3c (duration of inundation), and scores ranged from 1 to 9 for submetric 3d (alteration to natural hydrologic regime). The scoring boundaries were limited to a maximum of 28, although no site received a score greater than 24. The scoring of metric 3 was limited to a minimum of 9. This lower limit occurred because all sites in this study received 4 points for being within a floodplain, 1 point for receiving water from precipitation (submetric 3a), 2 points for being within a 100-year floodplain (submetric 3b), 1 point for being seasonally saturated within the upper 12 inches of soil (submetric 3c), and 1 point for alterations severely impacting the hydrology of the wetland (submetric 3d). While none of the variables showed significant parameter estimates and confidence intervals, top predictor variables included *ldi*, *%hydrophyte*, and *fqai*. One possible explanation for the result of no top model or significant parameter estimates could be the narrow range of metric 3 scores. The forested riverine wetlands sampled in this study exhibited similar hydrologic regimes, inundation periods, and connectivity, and they likely represent most wetlands of this type across the state of Kentucky. However, other studies have described positive relationships between species richness and connectivity (Bornette et al. 1998) and flooding disturbance regimes (Bornette and

Amoros 1996), and an increase in non-native species through habitat alterations (Matthews et al. 2009). Additionally, the alteration of hydrology and natural hydrologic regimes can directly influence and potentially shift the ecosystems within aquatic/terrestrial transition zone of the floodplain that are adapted to water inputs on a regular and semi-regular basis (Junk et al. 1989).

Analysis and model selection of metric 4 suggests that floristic quality and percent adventive species were successful predictors of habitat alteration and habitat structure development. The parameters fqai and %adventive were in 1 and 3 of the top 5 models, respectively. A positive parameter estimate was observed for *fqai* while a negative parameter estimate was observed for *%adventive*. Biologically, it was expected that the KY-WRAM sub-metric for habitat reference condition would be positively associated with floristic quality, whereas the KY-WRAM submetric for habitat alteration would be related to percent cover of non-native and invasive species. The results of this study suggest that conditions of plant quality, as captured by VIBI metrics, are a stronger predictor of habitat quality as measured by KY-WRAM metric 4 than landscape-based parameters such as *ldi*, *%forested*, and *%cultivated*. Similarly, the ORAM metric of habitat alteration was determined to be one the major components predicting OH VIBI in forested wetlands (Stapanian et al. 2013).

Model results and parameter estimates for the analysis of metric 5 suggest that none of the parameters or candidate models were successful or meaningful predictors of special wetlands. Scores of metric 5 ranged from 0 to 10. Scores ranged between 0 and 10 for submetric 5a (regulatory protection/critical habitat), scores ranged from 0 to 8 for submetric 5b (high ecological value/ranked communities), and all sites received a score of 0 for submetric 5c (low-quality wetland). Results of this analysis suggest that none of the parameters and candidate models used in the analysis predict metric 5. This observed effect is likely related to the fact that metric 5 can receive points for multiple factors that may not be biologically related, including the presence of critical habitat, regulatory protection, state-ranked communities. The combination of these components makes it more likely that the metric will receive points and from a statistical standpoint, offers little predictive ability using linear data. The majority of points were received from submetric 5a due to federal or state listed species within the HUC-12 watershed and submetric 5b for critical habitat. None of the wetlands within the dataset received negative points from submetric 5c. These results suggest that the special wetlands metric is not validated by standard landscape or biotic variables, but this metric undoubtedly addresses important management factors not addressed in other metrics. Because of the distribution of scores for this metric, it's possible that this metric should be analyzed differently by using a generalized linear model. Alternatively, the metric could be broken down further to look at performance at the submetric level.

Analysis and model selection of metric 6 suggest that *Carex* species richness and percent adventive species were successful predictors of vegetation, interspersion, percent cover of invasive plant species, and microtopographic features. The parameters *carex* sr and *%adventive* were in 3 and 4 of the top 4 models, respectively. A positive parameter estimate was observed for *carex sr* while a negative parameter estimate was observed for percent adventive species. It was expected that a measure of vegetation diversity, interspersion, invasive plant cover, and microtopographic features to be associated with

Carex species richness and percent adventive species quantified within a wetland. The relationship between wetland habitat and *Carex* species richness was likely driven, in part, by the fact that *Carex* was the most abundant genus observed throughout the study. This strong relationship suggests that *Carex* species richness could serve as a proxy for diversity, habitat quality, and microtopography in forested riverine wetlands (Hipp 2008). While *Carex* species richness is not currently among the forested VIBI metrics, it has demonstrated the ability to determine wetland condition. Percent adventive species was expected to be negatively associated with a measure of vegetative quality. While *%adventive* estimated by quantitative plot-based measurements, submetric 6c (cover of highly invasive plant species) was estimated by the rater in the field. Similarly, ORAM metric (vegetation, interspersion, and microtopography) was observed as a significant predictor of the OH VIBI in forested wetlands (Stapanian et al. 2013). The strong correlation between these two measures suggests that field raters conducting rapid assessments can efficiently estimate invasive species coverage within a wetland.

Overall, the KY-WRAM was observed to be a successful predictor of wetland quality in forested riverine wetlands when tested against biotic (VIBI and bird species richness) and landscape-based (LDI) indicators at the method level. Although bird species richness was not rigorously tested as an independent wetland assessment method for Kentucky, it did provide some perspective for a biological community with a quick response to anthropogenic disturbances. The results of this study indicated relationships between bird species richness and other assessment methods. Thus, future research should explore new metrics based on the observations of this study to describe avian communities and variation in these metrics should be tested for their response to disturbance in Kentucky's wetlands. Future research should also include additional sites of different Cowardin and HGM classification, include additional river basins within the dataset to explore the possibility of geographic variation in scoring and species composition, and include any additional IBIs or IBI modifications for Kentucky to continue the evaluation of the KY-WRAM.

The overall breakdown of the KY-WRAM by metrics revealed that there were correlations between metric 2 and *%forested*; metric 4 and *fqai* and *%adventive*; and metric 6 with *carex sr* and *%adventive*. This suggests that vegetation and landscape variables effectively predict the KY-WRAM metrics that provide a rapid estimate of similar categories. I did not include the total VIBI as a predictor variable in modelling KY-WRAM metric scores, in part because of inconsistencies between Kentucky's wetlands and the metrics of the Ohio VIBI. However, as a Kentucky-specific VIBI becomes available, the inclusion of the total VIBI score would be warranted in future studies. A further improvement in my modeling approach might involve narrowing the list of candidate models by eliminating those with low weights- in this study, the each KY-WRAM metric was investigated with more 20 candidate models. To some degree, the model weights of the best models were reduced by inclusion of a large number of models with low performance. Although metrics 1, 3, and 5 were not predicted by any of the vegetation or landscape variables due to the low variation in scoring (metrics 1 and 5) and the use of variables within the model that were not able to explain the metric (metric 3), their inclusion in the KY-WRAM is necessary and has an inherent importance for regulatory purposes including mitigation and habitat protection. These metrics provide a valuable assessment of wetland condition in the determination of wetland size, hydrology and hydrologic alterations, and regulatory protection at the state and federal level.

LITERATURE CITED

Anderson DR, Burnham KP, Thompson WL (2000) Null hypothesis testing: Problems, prevalence and an alternative. Journal of Wildlife Management 64:912-923.

Babbitt KJ (2005) The relative importance of wetland size and hydroperiod for amphibians in southern New Hampshire, USA. Wetlands Ecology and Management 13:269-279.

Borcard D, Gillet F, Legendre P (2011) Numerical Ecology with R. Springer, New York, NY, USA.

Bornette G, Amoros C (1996) Disturbance regimes and vegetation dynamics: role of floods in riverine wetlands. Journal of Vegetation Science 7:615-622.

Bornette G, Amoros C, N. Lamouroux (1998) Aquatic plant diversity in riverine wetlands: the role of connectivity. Freshwater Biology 39:267-283.

Brinson MM (1993) A hydrogeomorphic classification for wetlands. Technical Report WRP-DE-4. Vicksburg, MS: U.S. Army Engineers Waterways Experiment Station.

Brown MT, Vivas MB (2005) Landscape Development Intensity Index. Environmental Monitoring and Assessment 101:289-309.

Bryce SA, Hughes RM, Kaufmann PR (2002) Development of a bird integrity index: Using bird assemblages as indicators of riparian condition. Environmental Management 30(2):294-310.

Burnham KB, Anderson DR (2004) Multimodel inference: understanding AIC and BIC in model selection. Sociological Methods and Research 33:261-305.

Congalton R, Green K (2009) Assessing the Accuracy of Remotely Sensed Data: Principles and Practices, second edition. CRC/Taylor & Francis, Boca Raton, FL, USA.

Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, van del Belt M (1997) The value of the worlds ecosystem services and natural capital. Nature 387:253-260.

Cowardin LM, Carter V, Golet FC, LaRoe ET (1979) Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service, FWS/OBS-79/31, December 1979.

Croonquist MJ, Brooks RP (1991) Use of avian and mammalian guilds as indicators of cumulative impacts in riparian-wetland areas. Environmental Management 15(5):701-714.

Dahl TE, Johnson CE (1991) Status and Trends of Wetlands in the Conterminous United States, Mid-1970's to Mid-1980's. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 28 pages.

Environmental Systems Research Institute (2011) ArcGIS, version 10.1. Environmental Systems Research Institute, Incorporated, Redlands.

Fennessy MS, Jacobs AD, Kentula ME (2004) Review of Rapid Methods for assessing wetland condition. EPA/620/R-04/009. U.S. Environmental Protection Agency, Washington, D.C.

Fennessy MS, Jacobs AD, Kentula ME (2007) An evaluation of rapid methods for assessing the ecological condition of wetlands. Wetlands 27(3):543-560.

Gara BD, Micacchion M (2010) Assessment of wetland mitigation projects in Ohio. Volume 2: Developing a GIS-based tool to optimize vernal pool wetland mitigation site selection. Ohio EPA Technical Report WET/2010-1B. Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, Ohio.

Hipp AL (2008) A field guide to Wisconsin sedges. The University of Wisconsin Press, Madison, WI, USA.

Jones RL (2005) Plant Life of Kentucky: An Illustrated Guide to the Vascular Flora. University Press of Kentucky. Lexington, KY, USA.

Junk WJ, Bayley PB, Sparks RE (1989) The flood pulse concept in river-floodplain systems. Pages 110-127 in Proceedings of the International Large River Symposium. Canadian Special Publications Fisheries. Aquatic Sciences 106.

Karr JR (1981) Assessment of biotic integrity using fish communities. Fisheries 6(6):21-27.

Karr JR (1991) Biological integrity: a long-neglected aspect of water resource management. Ecological Applications 1:66-84.

Karr JR, Dudley DR (1981) Ecological perspectives on water quality goals. Environmental Management 5:55-68.

Kentucky Exotic Plant Pest Council (2013) Exotic Invasive Plants of Kentucky, third edition. http://www.se-eppc.org/ky/list.htm. Accessed October, 2013.

Kentucky Division of Water (2013a) KY-WRAM Field Form - Draft. Kentucky Division of Water. 200 Fair Oaks Lane, 4th floor, Frankfort, Kentucky.

Kentucky Division of Water (2013b) KY-WRAM Guidance Manual - Draft. Kentucky Division of Water. 200 Fair Oaks Lane, 4th floor, Frankfort, Kentucky.

Kentucky Division of Geographic Information (2007) Kentucky 2005 Anderson Level II - Land Cover. ftp://ftp.kymartian.ky.gov/kls/KY_LC2005.zip. Accessed August, 2013.

Kerans BL, Karr JR (1994) A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. Ecological Applications 4:768-785.

Krzys G, Waite TA, Stapanian MA, Vucetich JA (2002) Assessing avian richness in remnant wetlands: Towards an improved methodology. Wetlands 22(1):186-190.

Legendre P, Gallagher ED (2001) Ecologically meaningful transformations for ordination of species data. Oecologia 129:271-280.

Mack JJ (2001a) Ohio Rapid Assessment Method for wetlands, manual for using Version 5.0. Ohio EPA Technical Bulletin Wetland/2001-1-1. Ohio Environmental Protection Agency, Division of Surface Water, 401 Wetland Ecology Unit, Columbus, Ohio.

Mack JJ (2001b) Vegetation Indices of Biotic Integrity (VIBI) for Wetlands: Ecoregional, Hydrogeomorphic, and Plant Community Comparison with Preliminary Aquatic Life Use Designations. Final Report to U.S. EPA Grant No. CD985875, Volume 1. Wetland Ecology Group, Division of Surface Water, Ohio Environmental Protection Agency, Columbus, OH.

Mack JJ (2004) Integrated Wetland Assessment Program. Part 4: Vegetation Index of Biotic Integrity (VIBI) and Tiered Aquatic Life Uses (TALUs) for Ohio wetlands. Ohio EPA Technical Report WET/2004-4. Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, Ohio.

Mack JJ (2006) Landscape as a predictor of wetland condition: An evaluation of the landscape development index (LDI) with a large reference wetland dataset from Ohio. Environmental Monitoring and Assessment 120:221-241.

Mack JJ (2007) Integrated Wetland Assessment Program. Part 9: Field Manual for the Vegetation Index of Biotic Integrity for Wetlands v. 1.4. Ohio EPA Technical Report WET/2007-6. Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, Ohio.

Mack JJ, Micacchion M, Augusta L, Sablak GR (2000) Vegetation Indices of Biotic Integrity (VIBI) for Wetlands and Calibration of the Ohio Rapid Assessment Method for Wetlands v. 5.0. Final Report to U.S. EPA. Ohio Environmental Protection Agency, Division of Surface Water, 401 Wetland Ecology Unit, Columbus, Ohio.

Matthews JR, Peralta AL, Soni A, Baldwin P, Kent AD, Endress AD (2009) Local and landscape correlates of non-native species invasion in restored wetlands. Ecography 32:1031-1039.

Micacchion M (2004) Integrated Wetland Assessment Program. Part 7: Amphibian Index of Biotic Integrity for Ohio Wetlands. Ohio EPA Technical Report WET/2004-7. Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, Ohio.

Miller SJ, Wardrop DH, Mahaney WM, Brooks RP (2006) A plant-based index of biological integrity (IBI) for headwater wetlands in central Pennsylvania. Ecological Indicators 6:290-312.

Mitsch WJ, Gosselink JG (2007) Wetlands, fourth edition. John Wiley & Sons, Inc., New York, NY, USA.

O'Connell TJ, Jackson LE, Brooks PR (2000) Bird guilds as indicators of ecological condition in the central Appalachians. Ecological Applications 10(6):1706-1721.

Oksanen J, Blanchet FG, Kindt R, Legendre P, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Stevens MHM, Wagner H (2013) Vegan: Community Ecology Package. R package version 2.0-7. http://CRAN-R-project.orgpackage=vegan. Accessed February, 2013.

Peet RK, Wentworth TR, White PS (1998) A flexible, multipurpose method for recording vegetation composition and structure. Castanea 63(3):262-274.

Peterson AC, Niemi GJ (2007) Evaluation of the Ohio Rapid Assessment Method for wetlands in the Western Great Lakes: An analysis using bird communities. Journal of the Great Lakes Research 33(3):280-291.

R Development Core Team (2012) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from http://R-project.org. Accessed February, 2013.

Shea M, White D, Ladd M, Evans M (2010) Floristic quality assessment for Kentucky. Unpublished report to the Kentucky State Nature Preserves Commission.

Snodgrass JW, Komoroski MJ, Bryan AL Jr., Burger J (2005) Relationships among isolated wetland size, hydroperiod, and amphibian species richness: Implications for wetland regulations. Conservation Biology 14:414-419.

Stapanian MA, Waite TA, Krzys G, Mack JJ, Micacchion M (2004) Rapid assessment indicator of wetland integrity as an unintended predictor of avian diversity. Hydrobiologia 520:119-126.

Stapanian MA, Mack JJ, Adams JV, Gara B, Micacchion M (2013) Disturbance metrics predict a wetland vegetation index of biotic integrity. Ecological Indicators 24:120-126.

Stein ED, Fetscher AE, Clark RP, Wiskind A, Grenier JL, Sutula M, Collins JN, Grosso C (2009) Validation of a Wetland Rapid Assessment Method: Use of EPA's Level 1-2-3 Framework for Method Testing and Refinement. Wetlands 29(2):648-665.

Stevens DL, Olsen AR (2012) Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99(465):262-278.

US Environmental Protection Agency (2002a) National Water Quality Inventory: 2000 Report. U.S. Environmental Protection Agency, Office of Water, Washington, DC, USA, EPA- 841-R-02-001.

US Environmental Protection Agency (2002b) Methods for evaluating wetland condition: Using vegetation to assess environmental conditions in wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-020.

US Environmental Protection Agency (2002c) Methods for evaluating wetland condition: Biological assessment methods for birds. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-023.

US Fish and Wildlife Service (2002) National Wetlands Inventory website. US Department of the Interior, Fish and Wildlife Service, Washington, D.C. http://www.fws.giv/wetlands/.

Veselka W, Anderson JT, Kordek WS (2004) Using dual classification in the development of avian wetland indices of biological integrity for wetlands in West Virginia, USA. Environmental Monitoring and Assessment 164:533-48.

APPENDIX A

Scoring Summaries and Plant/Bird Species List

Table 5. Scoring summaries for Kentucky Wetland Rapid Assessment Method and individual metrics, Vegetation Index of Biotic Integrity, Landscape Development Intensity Index, and Bird Species Richness. Site summaries comprise minimum and maximum value of scores across all sites, mean score by basin and mean score across all sites. Mean scores include 95% confidence intervals.

	$\bar{x}$ (± 95% CI)				**Range**	
Survey Method	**K**	**G**	**UC**	**All Sites**	**Min.**	**Max.**
Kentucky Wetland Rapid Assessment Method	56.3 (±6.71)	52.8 (±9.08)	69.95 (±9.86)	59.67 (±6.17)	30.5	88.8
Metric 1 – Wetland Size	7 (±1.07)	7.34 (±0.73)	7.44 (±0.8)	7.31 (±0.47)	5	9
Metric 2 – Buffers	4.9 (±1.68)	4.82 (±1.52)	7.82 (±2.21)	5.91 (±1.2)	0.2	12
Metric 3 – Hydrology	19 (±3.51)	14.25 (±2.09)	18.05 (±2.37)	16.57 (±1.61)	9	24
Metric 4 – Habitat Alteration	10.2 (±2.16)	10.38 (±1.91)	14.53 (±2.83)	11.84 (±1.56)	5.5	20
Metric 5 – Special Wetlands	5.6 (±3.85)	3.91 (±2.78)	8.44 (±1.7)	5.88 (±1.71)	0	10
Metric 6 – Vegetation, Interspersion, and Habitat Features	9.6 (±3.8)	12.1 (±2.65)	13.68 (±3.15)	12.17 (±1.82)	3	19.6
Vegetation Index of Biotic Integrity	31 (±5.11)	44.82 (±8.02)	70.44 (±4.04)	51.28 (±7.2)	25	80
Landscape Development Intensity Index	4.12 (±1.51)	3.25 (±0.85)	2.78 (±1.07)	3.25 (±0.62)	1.37	6.33
Bird Species Richness	8.6 (±1.00)	10.27 (±0.92)	13.22 (±1.34)	11 (±0.95)	7	17

Table 6. All plant species recorded at sampling sites including scientific name, common name, family, wetland classification, and coefficient of conservatism (CofC). CofC values are ranked from least conservative (0) to most conservative (10) (Shea et al. 2010). Invasive species (*) are not ranked.

Scientific Name	Common Name	Family	Wet Class	CofC
Acer negundo	Boxelder Maple	Aceraceae	Fac	1
Acer rubrum	Red Maple	Aceraceae	Fac	3
Acer saccharinum	Silver Maple	Aceraceae	FacW	2
Aesculus flava	Yellow Sweet Buckeye	Hippocastanaceae	FacU	6
Aesculas glabra	Ohio Buckeye	Hippocastanaceae	FacU	3
Agrimonia parviflora	Many-flowered Agrimony	Rosaceae	FacW	4
Alisma subcordatum	Common Water-plantain	Alismataceae	Obl	3
Alliaria petiolate	Garlic Mustard	Brassicaceae	FacU	*
Allium vineale	Field Garlic	Liliaceae	FacU	*
Alnus serrulata	Smooth Alder	Betulaceae	Obl	6
Ambrosia artemisifolia	Common Ragweed	Asteraceae	FacU	0
Ambrosia trifida	Giant Ragweed	Asteraceae	FacU	0
Amphicarpaea bracteata	Hog-peanut	Fabaceae	Fac	4
Apios americana	Potato-bean	Fabaceae	FacW	4
Arisaema dracontium	Green Dragon	Araceae	FacW	6
Arundinaria gigantea	River Cane	Poaceae	FacW	5
Asclepias incarnata	Swamp Milkweed	Asclepidaceae	Obl	5
Asimina triloba	North American Papaw	Annonaceae	FacU	7
Asplenium platyneuron	Ebony spleenwort	Aspleniaceae	FacU	3
Aster lanceolatus	Narrow-leaved Michaelmas Daisy	Asteraceae	Obl	4
Aster prenanthoides	Crooked-stem Aster	Asteraceae	Fac	5
Athyrium filix-femina	Lady-fern	Dryopteridaceae	Fac	7
Berberis thunbergii	Japanese Barberry	Berberidaceae	FacU	*
Betula nigra	River Birch	Betulaceae	FacW	4
Bidens connata	Beggar-ticks	Asteraceae	FacW	5
Bidens frondosa	Beggar-ticks	Asteraceae	FacW	1
Bignonia capreolata	Cross-vine	Bignoniaceae	Fac	6
Boehmeria cylindrical	Bog-hemp	Urticaceae	FacW	5
Botrychium biternatum	Sparse-lobed Grape Fern	Ophioglossaceae	Fac	6
Botrychium virginianum	Rattlesnake Fern	Ophioglossaceae	FacU	6
Calystegia sepium	Hedge Bindweed	Convolvulaceae	Fac	1
Campsis radicans	Trumpet Creeper	Bignoniaceae	Fac	1
Carex blanda	Woodland Sedge	Cyperaceae	Fac	2
Carex conjuncta	Soft Fox Sedge	Cyperaceae	FacW	5
Carex crinita var. crinita	Fringed Sedge	Cyperaceae	Obl	6

Table 6. Continued.

Scientific Name	Common Name	Family	Wet Class	CofC
Carex crus-corvi	Raven's-foot Sedge	Cyperaceae	Obl	5
Carex davisii	Davis' Sedge	Cyperaceae	Fac	5
Carex festucacea	Fescue Sedge	Cyperaceae	Fac	7
Carex debilis var. debilis	White-edged Sedge	Cyperaceae	Fac	7
Carex frankii	Frank's Sedge	Cyperaceae	Obl	3
Carex gigantea	Large Sedge	Cyperaceae	Obl	7
Carex gracillima	Graceful Sedge	Cyperaceae	FacU	6
Carex granularis	Meadow Sedge	Cyperaceae	FacW	5
Carex grayi	Gray's Sedge	Cyperaceae	FacW	6
Carex grisea	Narrow-leaved Sedge	Cyperaceae	Upl	4
Carex hirtifolia	Hairy-leaved Sedge	Cyperaceae	Upl	7
Carex hyalinolepis	Shoreline Sedge	Cyperaceae	Upl	5
Carex intumescens	Bladder Sedge	Cyperaceae	FacW	6
Carex louisianica	Louisiana's Sedge	Cyperaceae	Obl	7
Carex lupulina	Hop Sedge	Cyperaceae	Obl	6
Carex muskingumensis	Muskingum Sedge	Cyperaceae	Obl	8
Carex radiata	Star Sedge	Cyperaceae	Upl	6
Carex rosea	Stellate Sedge	Cyperaceae	Upl	5
Carex sparganoides	Bur-reed Sedge	Cyperaceae	FacU	5
Carex squarrosa	Squarrose Sedge	Cyperaceae	FacW	5
Carex stipata	Awl-fruited Sedge	Cyperaceae	Obl	5
Carex swanii	Swan's Sedge	Cyperaceae	FacU	5
Carex tribuloides	Blunt Broom Sedge	Cyperaceae	FacW	3
Carex typhina	Cattail Sedge	Cyperaceae	FacW	7
Carex vulpinoidea	Fox Sedge	Cyperaceae	Obl	3
Carpinus caroliniana	American Hornbeam	Betulaceae	Upl	6
Carya carolinae-septentrionalis	Carolina Shagbark-hickory	Juglandaceae	Upl	7
Carya cordiformis	Bitternut	Juglandaceae	FacU	5
Carya laciniosa	Big Shellbark	Juglandaceae	Fac	6
Carya ovata	Shagbark Hickory	Juglandaceae	FacU	5
Celtis laevigata	Sugarberry	Ulmaceae	FacW	3
Celtis occidentalis	Hackberry	Ulmaceae	FacU	3
Cephalanthus occidentalis	Buttonbush	Rubiaceae	Obl	3
Cercis canadensis	Redbud	Caesalpiniaceae	FacU	3
Chasmanthium latifolium	River Oats	Poaceae	FacU	4
Cicuta maculate	Spotted Cowbane	Apiaceae	Obl	2

Table 6. Continued.

Scientific Name	Common Name	Family	Wet Class	CofC
Cinna arundinacea	Wood Reedgrass	Poaceae	FacW	5
Circaea lutetiana	Enchanter's Nightshade	Onagraceae	FacU	4
Commelina communis	Dayflower	Commelinaceae	Fac	*
Commelina virginica	Virginia Day-flower	Commelinaceae	FacW	4
Cornus drummondii	Rough Leaved Dogwood	Cornaceae	Fac	4
Cornus florida	Flowering Dogwood	Cornaceae	FacU	5
Cryptotaenia canadensis	Wild Chervil	Apiaceae	Fac	4
Cuscuta gronovii	Love-vine	Cuscutaceae	Upl	4
Dicanthelium acuminatum	Tall Rough Panic-grass	Poaceae	Fac	5
Dicanthelium clandestinum	Deer Tongue	Poaceae	Fac	3
Dioscorea oppositifolia	Chinese Yam	Dioscoreaceae	Upl	*
Dioscorea villosa	Colic-root	Dioscoreaceae	FacU	4
Diospyros virginiana	Persimmon	Ebenaceae	Fac	2
Duchesnea indica	Indian Strawberry	Rosaceae	FacU	*
Elaeagnus umbellata	Autumn Olive	Podostemaceae	Upl	*
Eleocharis obtusa	Blunt Spikerush	Cyperaceae	FacW	1
Elymus hystrix	Bottlebrush	Poaceae	Upl	5
Elymus riparius	Nodding Wild Rye	Poaceae	FacW	5
Elymus macgregorii	Early Wild Rye	Poaceae	Fac	6
Elymus virginicus var. varginicus	Virginia Wild Rye	Poaceae	Upl	5
Euonymus alatus	Winged Spindle-tree	Celastraceae	Upl	*
Euonymus fortunei	Winter Creeper	Celastraceae	Upl	*
Eupatorium coelestinum	Mistflower	Asteraceae	Fac	3
Eupatorium fistulosum	Joe-pye-weed	Asteraceae	FacW	5
Eupatorium perfoliatum	Common Thoroughwort	Asteraceae	FacW	3
Fagus grandifolia	American Beech	Fagaceae	FacU	5
Fraxinus pennsylvanica	Green Ash	Oleaceae	FacW	3
Galium aparine	Cleavers	Rubiaceae	FacU	0
Galium tinctorium	Stiff Marsh Bedstraw	Rubiaceae	Obl	5
Geum canadense	Wild Avens	Rosaceae	FacU	2
Geum virginianum	Rough Avens	Rosaceae	Fac	5
Glechoma hederacea	Ground Ivy	Lamiaceae	FacU	*
Gleditsia triacanthos	Honey-locust	Caesalpiniaceae	Fac	1
Glyceria septentrionalis	Floating Manna-grass	Poaceae	Obl	7
Glyceria striata	Fowl Manna-grass	Poaceae	Obl	4
Hamamelis virginicus	Witch-hazel	Hamamelidaceae	FacU	6
Hibiscus laevis	Halberd-leaved Rose-Mallow	Malvaceae	Obl	4
Houstonia purpurea	Large Houstonia	Rubiaceae	Upl	4

Table 6. Continued.

Scientific Name	Common Name	Family	Wet Class	CofC
Hypericum prolificum	Shrubby St. John's-wort	Clusiaceae	FacU	4
Ilex deciduas	Possum-haw	Aquifoliaceae	FacW	5
Ilex opaca	American Holly	Aquifoliaceae	FacU	5
Impatiens capensis	Spotted Touch-me-not	Balsaminaceae	FacW	2
Iris virginica var. shrevei	Southern Blue Flag	Iridaceae	Upl	7
Juglans nigra	Black Walnut	Juglandaceae	FacU	4
Juncus effuses	Soft Rush	Juncaceae	Obl	4
Juncus diffusissimus	Diffuse Rush	Juncaceae	FacW	4
Juncus tenuis	Slender Rush	Juncaceae	Fac	0
Juniperus virginiana	Eastern Red Cedar	Cupressaceae	FacU	1
Leersia lenticularis	Catchfly-grass	Poaceae	Obl	8
Leersia oryzoides	Rice Cutgrass	Poaceae	Obl	3
Leersia virginica	Cutgrass	Poaceae	FacW	2
Ligustrum sinense	Japanese Privet	Oleaceae	Upl	*
Lindera benzoin	Spicebush	Lauraceae	FacW	5
Liquidambar styraciflua	Sweetgum	Hamamelidaceae	Fac	3
Liriodendron tulipifera	Tulip-poplar	Magnoliaceae	FacU	2
Lobelia cardinalis	Cardinal-flower	Campanulaceae	FacW	5
Lonicera japonica	Japanese Honeysuckle	Caprifoliaceae	Fac	*
Lonicera maackii	Shrub Honeysuckle	Caprifoliaceae	Upl	*
Lonicera morrowii	Shrub Honeysuckle	Caprifoliaceae	FacU	*
Ludwigia palustris	Marsh Purslane	Onagraceae	Obl	5
Luzula acuminate	Hairy Woodrush	Juncaceae	Fac	5
Lycopus americanus	Cut-leaved Water Hoarhound	Lamiaceae	Obl	4
Lycopus virginicus	Spring Scorpion-grass	Lamiaceae	Obl	4
Lysimachia ciliate	Fringed Loosestrife	Primulaceae	FacW	5
Lysimachia nummularia	Moneywort	Primulaceae	FacW	*
Magnolia acuminata	Cucumber-tree	Magnoliaceae	Upl	7
Magnolia macrophyla	Big-leaved Magnolia	Magnoliaceae	Upl	8
Magnolia tripetala	Umbrella Magnolia	Magnoliaceae	FacU	7
Microstegium vimineum	Japanese Stilt Grass	Poaceae	Fac	*
Mimulus alatus	Sharp-winged Monkey-flower	Scrophulariaceae	Obl	4
Morus rubra	Red Mulberry	Moraceae	FacU	2
Nyssa sylvatica	Black Tupelo	Nyssaceae	Fac	4
Onoclea sensibilis	Sensitive Fern	Dryopteridaceae	FacW	4
Ostrya virginiana	American Hop-hornbeam	Betulaceae	FacU	6
Oxalis grandis	Great Yellow Wood-sorrel	Oxalidaceae	Upl	6

Table 6. Continued.

Scientific Name	Common Name	Family	Wet Class	CofC
Oxalis stricta	Upright Yellow Wood-sorrel	Oxalidaceae	Upl	0
Oxalis violacea	Violet Wood-sorrel	Oxalidaceae	Upl	5
Parthenocissus quinquefolia	Virginia Creeper	Vitaceae	FacU	2
Passiflora lutea	Passion-flower	Passifloraceae	Upl	3
Penthorum sedoides	Ditch-stonecrop	Crassulaceae	Obl	2
Phalaris arundinaceae	Reed Canary Grass	Poaceae	Obl	*
Phyla lanceolata	Frog-fruit	Verbenaceae	Obl	1
Phytolacca americana	Pokeweed	Phytolaccaceae	FacU	1
Pilea pumila	Clearweed	Pinaceae	FacW	3
Pinus strobus	White Pine	Pinaceae	FacU	4
Plantago major	Common Plantain	Plantanginaceae	FacU	*
Platanthera clavellata	Club-spur Orchid	Orchidaceae	FacW	6
Platanthera flava	Pale Green Orchid	Orchidaceae	FacW	6
Platanthera peramoena	Purple Fringeless Orchid	Orchidaceae	FacW	5
Platanus occidentalis	American Sycamore	Platanaceae	FacW	3
Poa pratensis	Kentucky Bluegrass	Poaceae	FacU	*
Poa sylvestris	Sylvan Spear-grass	Poaceae	FacW	6
Podophyllum peltatum	May-apple	Berberidaceae	FacU	6
Polygonatum pubescens	Hairy Solomon's Seal	Liliaceae	Upl	5
Polygonum cespitosum	Oriental Ladysthumb	Polygonaceae	FacU	*
Polygonum cuspidatum	Japanese Knotweed	Polygonaceae	FacU	*
Polygonum pennsylvanicum	Pinkweed	Polygonaceae	FacW	2
Polygonum virginianum	Virginia Knotweed	Polygonaceae	Fac	3
Polystichum acrostichoides	Christmas-fern	Dryopteridaceae	FacU	4
Prenanthes altissima	Tall Rattlesnake-root	Asteraceae	FacU	5
Proserpinaca palustris	Mermaid-weed	Haloragaceae	Obl	9
Prunella vulgaris	Heal-all	Lamiaceae	FacU	*
Prunus serotina	Black Cherry	Rosaceae	FacU	3
Pycnanthemum verticillatum var. verticillatum	Torrey's Mountain-mint	Lamiaceae	Fac	7
Pyrus communis	Pear	Rosaceae	Upl	*
Quercus bicolor	Swamp White Oak	Fagaceae	FacW	8
Quercus lyrata	Over-cup Oak	Fagaceae	Obl	8
Quercus michauxii	Swamp Chestnut Oak	Fagaceae	FacW	7
Quercus palustris	Pin Oak	Fagaceae	FacW	6
Quercus phellos	Willow Oak	Fagaceae	Fac	8
Quercus rubra	Red Oak	Fagaceae	FacU	6

Table 6. Continued.

Scientific Name	Common Name	Family	Wet Class	CofC
Quercus velutina	Black Oak	Fagaceae	Upl	5
Ranunculus hispidus	Hispid Buttercup	Ranunculaceae	Fac	4
Rhododendron arborescens	Smooth Azalea	Ericaceae	Fac	8
Rosa multiflora	Multiflora Rose	Rosaceae	FacU	*
Rosa palustris	Swamp-rose	Rosaceae	Obl	6
Rubus allegheniensis	Mountain Blackberry	Rosaceae	FacU	2
Rudbekia laciniata	Green-headed Coneflower	Asteraceae	FacW	5
Rumex crispus	Yellow Dock	Polygonaceae	FacU	*
Rumex obtusifolius	Bitter Dock	Polygonaceae	FacU	*
Rumex verticillatus	Swamp Dock	Polygonaceae	Obl	5
Sagittaria latifolia	Duck-potato	Alismataceae	Obl	4
Salix nigra	Black Willow	Salicaceae	FacW	3
Sambucus canadensis	Common Elderberry	Caprifoliaceae	FacW	2
Sanicula trifoliata	Large-fruited Snakeroot	Apiaceae	Upl	4
Saururus cernuus	Swamp-lily	Saururaceae	Obl	6
Schoenoplectus tabernaemontani	Soft-stemmed Bulrush	Cyperaceae	Obl	3
Scirpus atrovirens	Dark-green Bulrush	Cyperaceae	Obl	3
Scirpus georgianus	Dark-green Bulrush	Cyperaceae	Obl	3
Scirpus polyphyllus	Leafy Bulrush	Cyperaceae	Obl	3
Scutellaria lateriflora	Mad-dog Skullcap	Lamiaceae	FacW	5
Sedum ternatum	Wild Stonecrop	Crassulaceae	Upl	5
Senico aureus	Golden Ragwort	Asteraceae	FacW	5
Senico glabellus	Butterweed	Asteraceae	Obl	2
Silphium perfoliatum	Cup-plant	Asteraceae	FacU	6
Sium suave	Hemlock	Apiaceae	Obl	6
Smilax glauca	Sawbrier	Smilacaceae	FacU	3
Smilax hispida	Hispid Greenbrier	Smilacaceae	Fac	3
Smilax rotundifolia	Common Greenbrier	Smilacaceae	Fac	4
Solanum carolinense	Horse-nettle	Solanaceae	Upl	*
Solidago canadensis	Canada Goldenrod	Asteraceae	Upl	4
Sorghum halepense	Johnson-grass	Poaceae	FacU	*
Stachys tenuifolia	Hedge Nettle	Lamiaceae	Obl	4
Symphiocarpus orbiculatus	Coralberry	Caprifoliaceae	Upl	2
Thalictrum pubescens	Tall Meadow-rue	Ranunculaceae	FacW	4
Thalictrum thalictroides	Rue-anemone	Ranunculaceae	FacU	5
Thelypteris noveboracensis	New York Fern	Thelypteridaceae	Fac	5
Toxicodendron radicans	Poison Ivy	Anacardiaceae	Fac	2

Table 6. Continued.

Scientific Name	Common Name	Family	Wet Class	CofC
Tradescantia subaspera var. montana	Zigzag Spiderwort	Commelinaceae	Upl	7
Trillium erectum	Purple Trillium	Liliaceae	FacU	6
Tsuga canadensis	Eastern Hemlock	Pinaceae	FacU	6
Typha latifolia	Common Cat-tail	Typhaceae	Obl	1
Ulmus americana	American Elm	Ulmaceae	FacW	5
Ulmus rubra	Slippery Elm	Ulmaceae	Fac	4
Urtica dioica	Stinging Nettle	Urticaceae	FacU	4
Verbesina alternifolia	Wingstem	Asteraceae	Fac	2
Vernonia gigantea	Tall Ironweed	Asteraceae	Fac	2
Viburnum dentatum	Southern Arrow-wood	Caprifoliaceae	Fac	7
Viburnum rufidulum	Southern Black-haw	Caprifoliaceae	Upl	4
Viola canadensis	Canada Violet	Violaceae	Upl	6
Viola cucullata	Marsh Blue Violet	Violaceae	FacW	4
Vitis aestivalis	Summer Grape	Vitaceae	FacU	3
Vitis cinerea	Graybark Grape	Vitaceae	FacW	3
Vitis riparia	Frost Grape	Vitaceae	FacW	4
Xanthium strumarium	Common Cocklebur	Asteraceae	Fac	*

Table 7. All bird species recorded at sampling sites including common name, scientific name, family, alpha code, species frequency by river basin, and all sites.

Scientific Name	Common Name	Family	Alpha Code	Frequency*			
				K	G	UC	All Sites
Agelaius phoeniceus	Red-winged Blackbird	Icteridae	RWBL	0.20	0.09	0.00	0.08
Aix sponsa	Wood Duck	Anatidae	WODU	0.11	0.00	0.00	0.04
Anas platyrhynchos	Mallard	Anatidae	MALL	0.00	0.00	0.10	0.04
Baeolophus bicolor	Tufted Titmouse	Paridae	TUTI	0.20	0.55	0.60	0.48
Buteo lineatus	Red-shouldered Hawk	Accipitridae	RSHA	0.00	0.00	0.40	0.16
Cardinalis cardinalis	Northern Cardinal	Cardinalidae	NOCA	0.60	0.27	0.30	0.36
Chaetura pelagica	Chimney Swift	Apodidae	CHSW	0.00	0.09	0.00	0.04
Coccyzus americanus	Yellow-billed Cuckoo	Cuculidae	YBCU	0.40	0.64	0.40	0.52
Colaptes auratus	Northern Flicker	Picidae	NOFL	0.00	0.00	0.10	0.04
Contopus virens	Eastern Wood-Pewee	Tyrannidae	EAWP	0.60	0.36	0.10	0.32
Corvus brachyrhynchos	American Crow	Corvidae	AMCR	0.00	0.18	0.20	0.16
Cyanocitta cristata	Blue Jay	Corvidae	BLJA	0.40	0.18	0.60	0.36
Dryocopus pileatus	Pileated Woodpecker	Picidae	PIWO	0.20	0.09	0.10	0.12
Dumetella carolinensis	Gray Catbird	Mimidae	GRCA	0.20	0.00	0.10	0.08
Empidonax virescens	Acadian Flycatcher	Tyrannidae	ACFL	0.00	0.64	0.70	0.52

* Frequency is based on the percentage of sites that a species was observed.

Table 7. Continued.

Scientific Name	Common Name	Family	Alpha Code	Frequency*			
				K	G	UC	All Sites
Geothlypis trichas	Common Yellowthroat	Parulidae	COYE	0.00	0.09	0.00	0.04
Helmitheros vermivorus	Worm-eating Warbler	Parulidae	WEWA	0.00	0.00	0.10	0.04
Hylocichla mustelina	Wood Thrush	Turdidae	WOTH	0.20	0.00	0.70	0.28
Icteria virens	Yellow-breasted Chat	Parulidae	YBCH	0.20	0.00	0.00	0.04
Icterus glabula	Baltimore Oriole	Icteridae	BAOR	0.00	0.00	0.10	0.04
Limnothlypis swainsonii	Swainson's Warbler	Parulidae	SWWA	0.00	0.00	0.10	0.04
Melanerpes carolinus	Red-bellied Woodpecker	Picidae	RBWO	0.00	0.18	0.30	0.20
Melospiza melodia	Song Sparrow	Emberizidae	SOSP	0.00	0.09	0.10	0.08
Myiarchus crinitus	Great Crested Flycatcher	Tyrannidae	GCFL	0.00	0.00	0.40	0.16
Oporonis formosus	Kentucky Warbler	Parulidae	KEWA	0.00	0.09	0.90	0.36
Parkesia motacilla	Louisiana Waterthrush	Parulidae	LOWA	0.20	0.18	0.20	0.20
Parula americana	Northern Parula	Parulidae	NOPA	0.20	0.73	0.30	0.48
Passerina cyanea	Indigo Bunting	Cardinalidae	INBU	0.40	0.64	0.20	0.44
Picoides pubescens	Downy Woodpecker	Picidae	DOWO	0.00	0.18	0.10	0.12
Pipilo erthrophthalmus	Eastern Towhee	Emberizidae	EATO	0.00	0.18	0.40	0.24

* Frequency is based on the percentage of sites that a species was observed

Table 7. Continued.

Scientific Name	Common Name	Family	Alpha Code	Frequency*			
				K	G	UC	All Sites
Piranga olivacea	Scarlet Tanager	Thraupidae	SCTA	0.00	0.00	0.20	0.08
Piranga rubra	Summer Tanager	Thraupidae	SUTA	0.00	0.27	0.10	0.16
Poecile carolinensis	Carolina Chickadee	Paridae	CACH	0.80	0.64	0.40	0.60
Polioptila caerulea	Blue-gray Gnatcatcher	Polioptilidae	BGGN	0.20	0.55	0.70	0.52
Protonotaria citrea	Prothonotary Warbler	Parulidae	PROW	0.00	0.64	0.00	0.28
Sayornis phoebe	Eastern Phoebe	Tyrannidae	EAPH	0.00	0.00	0.10	0.04
Seiurus aurocapilla	Ovenbird	Parulidae	OVEN	0.20	0.36	0.90	0.52
Setophaga dominica	Yellow-throated Warbler	Parulidae	YTWA	0.40	0.27	0.10	0.24
Setophaga virens	Black-throated Green Warbler	Parulidae	BTNW	0.00	0.00	0.10	0.04
Sialia sialis	Eastern Bluebird	Turdidae	EABL	0.00	0.09	0.00	0.04
Sitta carolinensis	White-breasted Nuthatch	Sittidae	WBNU	0.40	0.09	0.20	0.20
Spinus tristis	American Goldfinch	Fringillidae	AMGO	0.00	0.45	0.10	0.24
Spizella pusilla	Field Sparrow	Emberizidae	FISP	0.00	0.09	0.00	0.04
Thryothorus ludovicianus	Carolina Wren	Troglodytidae	CARW	0.80	0.73	0.30	0.60
Troglodytes aedon	House Wren	Troglodytidae	HOWR	0.40	0.00	0.00	0.08

* Frequency is based on the percentage of sites that a species was observed

Table 7. Continued.

Scientific Name	Common Name	Family	Alpha Code	Frequency*			
				K	G	UC	All Sites
Turdus migratorius	American Robin	Turdidae	AMRO	0.60	0.00	0.10	0.16
Vermivora pinus	Blue-winged Warbler	Parulidae	BWWA	0.00	0.00	0.10	0.04
Vireo griseus	White-eyed Vireo	Vireonidae	WEVI	0.00	0.09	0.30	0.16
Vireo olivaceus	Red-eyed Vireo	Vireonidae	REVI	0.40	0.45	0.60	0.48
Wilsonia citrina	Hooded Warbler	Parulidae	HOWA	0.00	0.00	0.60	0.20
Zenaida maacroura	Mourning Dove	Columbidae	MODO	0.00	0.09	0.10	0.08

* Frequency is based on the percentage of sites that a species was observed

APPENDIX B
Regressions Figures

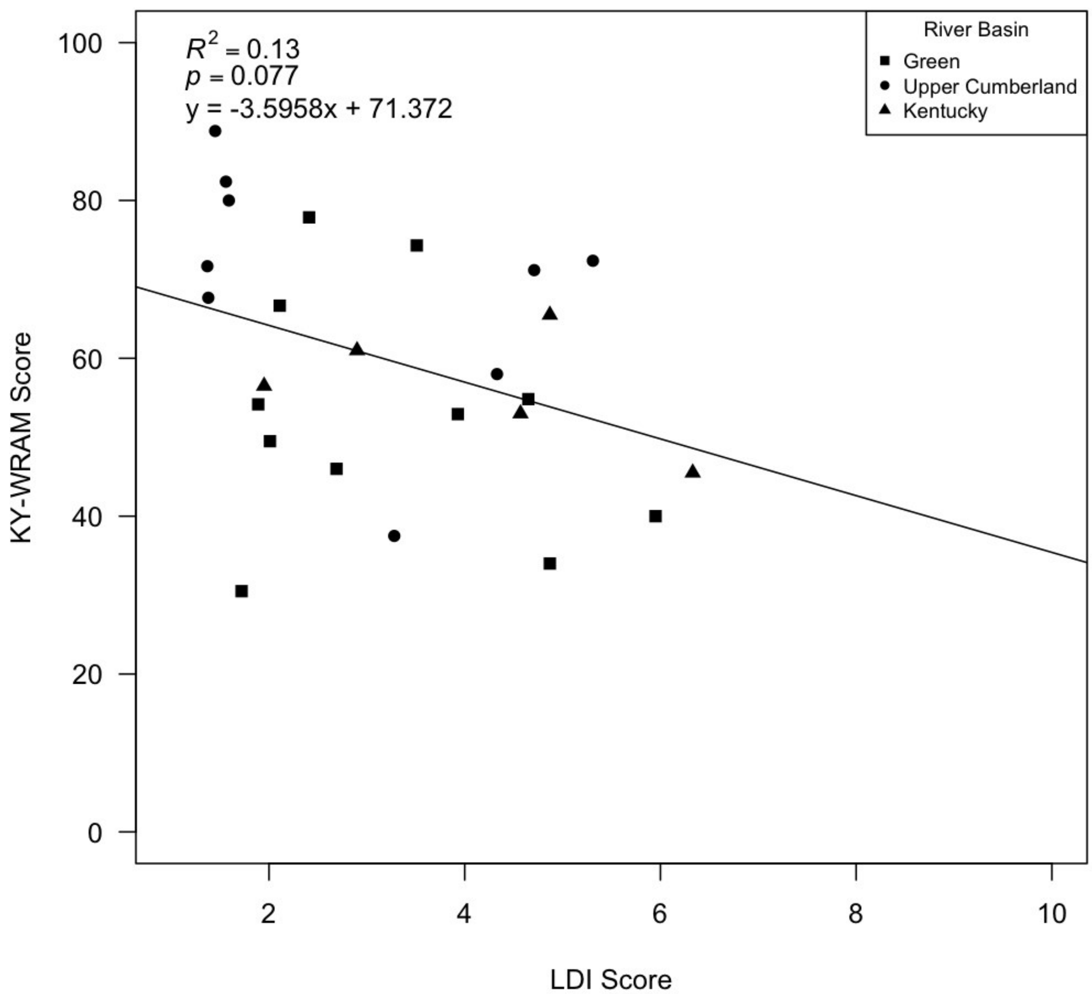


Figure 6a. Linear regression between the KY-WRAM score and LDI score. Different symbols represent river basin for each site.

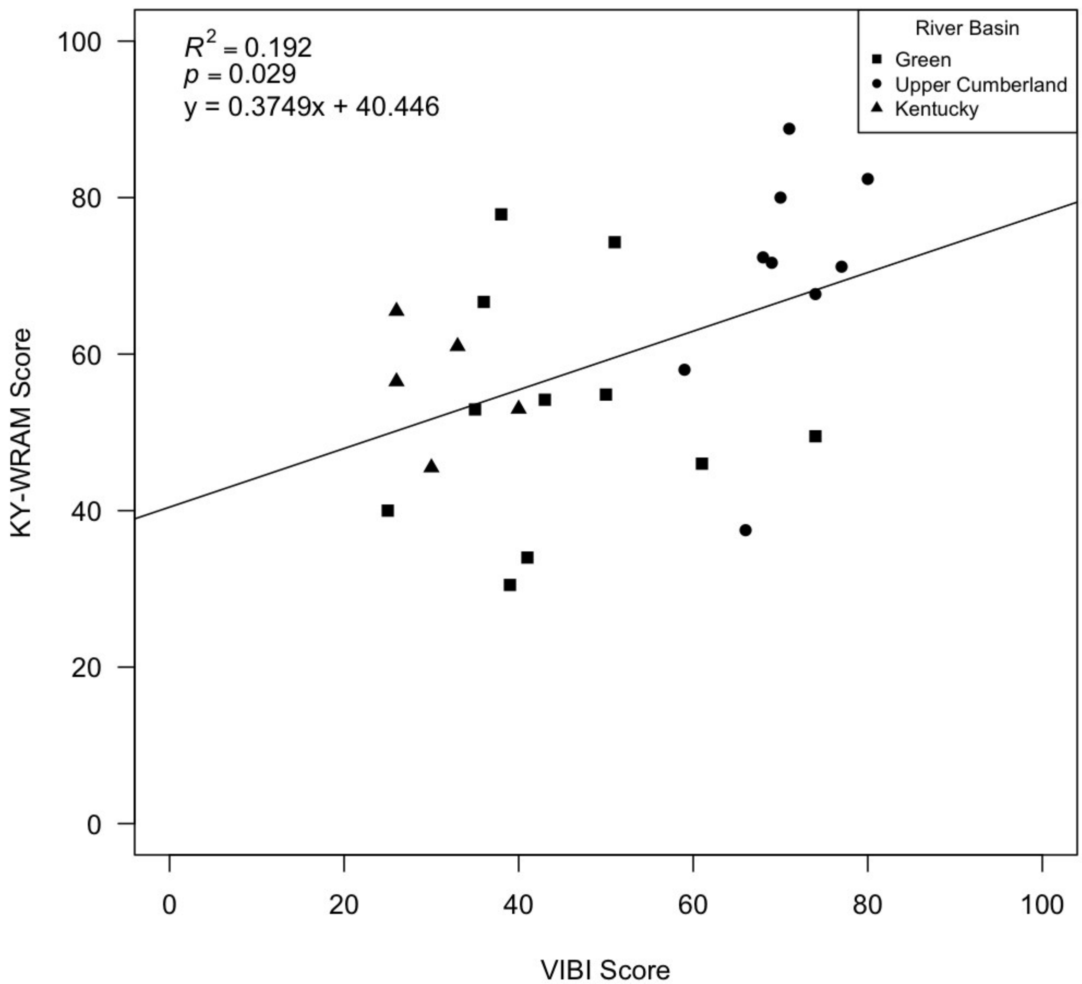


Figure 6b. Linear regression between the KY-WRAM score and VIBI score. Different symbols represent river basin for each site.

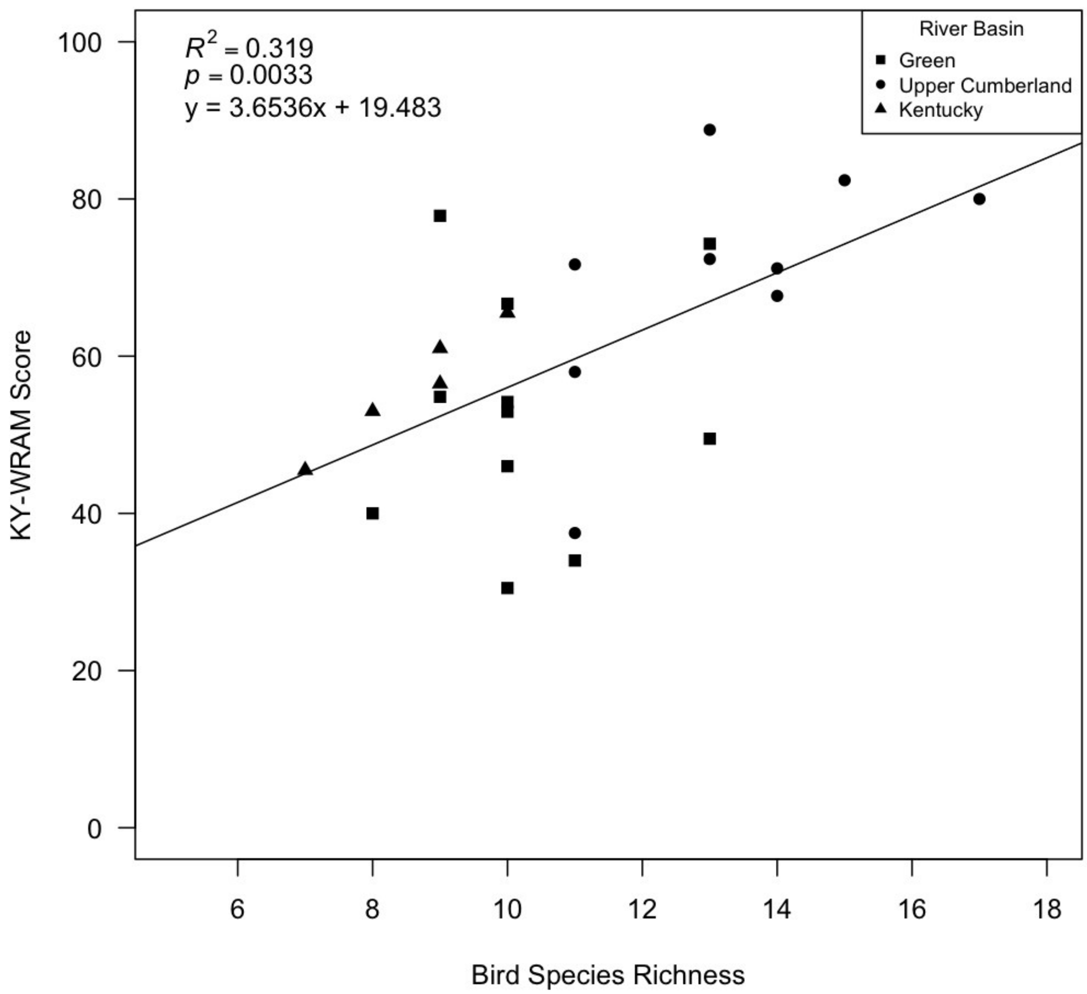


Figure 6c. Linear regression between KY-WRAM score and bird species richness. Different symbols represent river basin for each site.

APPENDIX C

AIC Models and Parameter Estimates

Table 8a. Model selection for the effects of vegetation and land use variables on wetland size and distribution (Metric 1).

Model	K	AIC_c	ΔAIC_c	ω	LL
fqai	3	84.69	0.00	0.14	-38.77
ldi	3	85.41	0.73	0.10	-39.14
%cultivated	3	85.59	0.90	0.09	-39.22
%forested	3	85.64	0.95	0.09	-39.25
%adventive	3	85.65	0.96	0.09	-39.25
stems	3	85.65	0.96	0.09	-39.25
fqai + ldi	4	86.90	2.21	0.05	-38.45
fqai + %cultivated	4	87.15	2.46	0.04	-38.57
fqai + %forested	4	87.22	2.54	0.04	-38.61
fqai + stems	4	87.52	2.84	0.03	-38.76
fqai + %adventive	4	87.54	2.85	0.03	-38.77
ldi + stems	4	88.25	3.56	0.02	-39.12
%adventive + ldi	4	88.26	3.57	0.02	-39.13
%cultivated + ldi	4	88.27	3.58	0.02	-39.13
%cultivated + stems	4	88.42	3.73	0.02	-39.21
%cultivated + %adventive	4	88.43	3.75	0.02	-39.22
%adventive + %forested	4	88.47	3.79	0.02	-39.24
fqai + %cultivated + ldi	5	89.96	5.28	0.01	-38.40
fqai + ldi + %forested	5	90.02	5.33	0.01	-38.43
fqai + %cultivated + stems	5	90.26	5.57	0.01	-38.55
fqai + %cultivated + %adventive	5	90.31	5.62	0.01	-38.57
fqai + %forested + stems	5	90.34	5.65	0.01	-38.59
%cultivated + ldi + %forested	5	91.02	6.33	0.01	-38.93
ldi + %forested + stems	5	91.15	6.47	0.01	-39.00
%cultivated + ldi + stems	5	91.40	6.71	0.00	-39.12
%cultivated + %adventive + ldi	5	91.42	6.73	0.00	-39.12
%cultivated + %forested + stems	5	91.58	6.89	0.00	-39.21
fqai + %cultivated + %forested + %adventive + ldi + stems	8	101.51	16.82	0.00	-38.25

Table 8b. Model selection for the effects of vegetation and land use variables on upland buffers and intensity of surrounding land use (Metric 2).

Model	**K**	**AIC_c**	**ΔAIC_c**	**ω**	**LL**
%forested	3	110.95	0.00	0.20	-51.09
%adventive + %forested	4	111.47	0.52	0.15	-50.73
%cultivated + %adventive + ldi	5	111.69	0.74	0.14	-49.27
fqai + %forested	4	111.87	0.92	0.13	-50.94
ldi + %forested	4	113.44	2.49	0.06	-51.72
%adventive + ldi + %forested	5	113.67	2.71	0.05	-50.25
%forested + %sensitive	4	113.77	2.82	0.05	-51.88
fqai + %cultivated + %forested	5	114.12	3.16	0.04	-50.48
ldi + %sensitive	4	114.13	3.18	0.04	-52.07
%cultivated + ldi	4	114.13	3.18	0.04	-52.07
fqai + %forested + ldi	5	114.42	3.47	0.04	-50.63
%adventive + ldi	4	115.60	4.65	0.02	-52.80
fqai + ldi	4	115.63	4.68	0.02	-52.82
ldi	3	116.54	5.59	0.01	-54.70
%cultivated + ldi + %sensitive	5	116.99	6.04	0.01	-51.92
fqai + %cultivated + %forested + %adventive + ldi + %sensitive	8	120.26	9.31	0.00	-47.63
%cultivated + %adventive	4	120.89	9.94	0.00	-55.44
fqai + %cultivated	4	121.11	10.16	0.00	-55.55
%cultivated	3	121.11	10.16	0.00	-56.99
fqai + %cultivated + %sensitive	5	124.15	13.20	0.00	-55.50
fqai	3	127.52	16.57	0.00	-60.19
fqai + %adventive	4	129.44	18.48	0.00	-59.72
fqai + %sensitive	4	130.36	19.40	0.00	-60.18
%adventive	3	131.77	20.82	0.00	-62.31
%sensitive	3	132.53	21.58	0.00	-62.70
%adventive + %sensitive	4	134.52	23.57	0.00	-62.26

Table 8c. Model selection for the effects of vegetation and land use variables on wetland hydrology (Metric 3).

Model	**K**	**AIC$_c$**	**ΔAIC$_c$**	**ω**	**LL**
ldi	3	145.03	0.00	0.19	-68.94
%hydrophyte	3	146.87	1.84	0.08	-69.86
fqai	3	146.98	1.95	0.07	-69.92
stems	3	147.26	2.23	0.06	-70.06
%hydrophyte + ldi	4	147.27	2.24	0.06	-68.64
hydro sr	3	147.47	2.44	0.06	-70.16
carex sr	3	147.53	2.50	0.05	-70.19
ldi + stems	4	147.63	2.60	0.05	-68.82
ldi + hydro sr	4	147.71	2.68	0.05	-68.85
fqai + ldi	4	147.73	2.70	0.05	-68.87
ldi + carex sr	4	147.89	2.86	0.05	-68.94
fqai + hydro sr	4	149.36	4.33	0.02	-69.68
fqai + carex sr	4	149.50	4.47	0.02	-69.75
stems + %hydrophyte	4	149.50	4.47	0.02	-69.75
fqai + stems	4	149.52	4.49	0.02	-69.76
hydro sr + %hydrophyte	4	149.65	4.62	0.02	-69.82
carex sr + %hydrophyte	4	149.67	4.64	0.02	-69.84
fqai + hydro sr	4	149.81	4.78	0.02	-69.90
stems + carex sr	4	150.06	5.03	0.02	-70.03
stems + hydro sr	4	150.08	5.05	0.02	-70.04
carex sr + hydro sr	4	150.23	5.20	0.01	-70.11
ldi + hydro sr + %hydrophyte	5	150.27	5.24	0.01	-68.56
fqai + ldi + carex sr	5	150.84	5.81	0.01	-68.84
fqai + stems + carex sr	5	152.25	7.22	0.01	-69.55
fqai + hydro sr + %hydrophyte	5	152.51	7.48	0.00	-69.68
stems + hydro sr + %hydrophyte	5	152.62	7.59	0.00	-69.73
carex sr + hydro sr + %hydrophyte	5	152.68	7.65	0.00	-69.76
ldi + carex sr + hydro sr	5	152.68	7.65	0.00	-69.76
fqai + ldi + stems + carex sr + hydro sr + %hydrophyte	8	161.91	16.88	0.00	-68.46

Table 8d. Model selection for the effects of vegetation and land use variables on habitat alteration and habitat structure (Metric 4).

Model	K	AIC_c	ΔAIC_c	ω	LL
ldi + %adventive + %forested	5	136.65	0.00	0.16	-61.75
ldi + %adventive	4	136.71	0.05	0.16	-63.35
fqai + %forested	4	137.70	1.04	0.10	-63.85
ldi + %adventive + canopy iv	5	137.81	1.16	0.09	-62.33
%forested	3	138.35	1.70	0.07	-65.60
fqai + %adventive + subcanopy iv	5	138.96	2.30	0.05	-62.90
ldi + %adventive + subcanopy iv	5	139.32	2.67	0.04	-63.08
fqai + %adventive + small tree	5	139.48	2.82	0.04	-63.16
fqai + %adventive + canopy iv	5	139.52	2.87	0.04	-63.18
fqai	3	139.77	3.12	0.03	-66.32
fqai + %forested + canopy iv	5	139.86	3.21	0.03	-63.35
fqai + ldi	4	140.04	3.38	0.03	-65.02
%adventive	3	140.49	3.83	0.02	-66.67
%forested + small tree	4	140.50	3.85	0.02	-65.25
ldi + %forested	4	140.86	4.20	0.02	-65.43
ldi	3	142.06	5.40	0.01	-67.46
fqai + canopy iv	4	142.10	5.45	0.01	-66.05
fqai + subcanopy iv	4	142.45	5.80	0.01	-66.23
fqai + small tree	4	142.61	5.96	0.01	-66.31
fqai + ldi + small tree	5	143.19	6.54	0.01	-65.02
%forested + subcanopy iv + canopy iv	5	143.67	7.01	0.00	-65.25
ldi + subcanopy iv	4	143.92	7.27	0.00	-66.96
%adventive + subcanopy iv + canopy iv	5	143.96	7.31	0.00	-65.40
ldi + canopy iv	4	144.69	8.03	0.00	-67.34
subcanopy iv	3	144.97	8.32	0.00	-68.91
fqai + subcanopy iv + canopy iv	5	145.11	8.45	0.00	-65.98
small tree	3	145.36	8.71	0.00	-69.11
canopy iv	3	145.65	9.00	0.00	-69.25
subcanopy iv + small tree	4	147.47	10.82	0.00	-68.74
canopy iv + subcanopy iv	4	147.69	11.03	0.00	-68.84
canopy iv + small tree	4	148.11	11.46	0.00	-69.05
fqai + ldi + %adventive + %forested + subcanopy iv + canopy iv + small tree	9	149.23	12.58	0.00	-59.62
subcanopy iv + canopy iv + small tree	5	150.61	13.95	0.00	-68.73

Table 8e. Model selection for the effects of vegetation and land use variables on special wetlands (Metric 5).

Model	K	AIC_c	ΔAIC_c	ω	LL
%sensitive	3	148.89	0.00	0.12	-70.87
fqai	3	149.07	0.18	0.11	-70.96
%cultivated	3	149.45	0.56	0.09	-71.15
dicot sr	3	149.69	0.80	0.08	-71.28
carex sr	3	149.99	1.10	0.07	-71.42
ldi	3	150.50	1.60	0.06	-71.68
%adventive	3	150.50	1.61	0.06	-71.68
fqai + %sensitive	4	150.97	2.08	0.04	-70.49
fqai + %cultivated	4	151.37	2.48	0.04	-70.69
%sensitive + %adventive	4	151.75	2.86	0.03	-70.87
carex sr + dicot sr	4	151.79	2.90	0.03	-70.90
fqai + carex sr	4	151.85	2.96	0.03	-70.92
fqai + %adventive	4	151.87	2.98	0.03	-70.94
fqai + dicot sr	4	151.91	3.02	0.03	-70.96
fqai + ldi	4	151.93	3.03	0.03	-70.96
ldi + %cultivated	4	152.26	3.37	0.02	-71.13
ldi + dicot sr	4	152.53	3.64	0.02	-71.27
ldi + carex sr	4	152.66	3.77	0.02	-71.33
fqai + %sensitive + %cultivated	5	153.27	4.38	0.01	-70.06
ldi + %sensitive + %cultivated	5	153.34	4.45	0.01	-70.09
%sensitive + %cultivated + %adventive	5	153.54	4.65	0.01	-70.19
%sensitive + carex sr + dicot sr	5	154.00	5.11	0.01	-70.42
fqai + %sensitive + carex sr	5	154.13	5.24	0.01	-70.49
fqai + ldi + %cultivated	5	154.41	5.52	0.01	-70.63
%adventive + carex sr + dicot sr	5	154.84	5.95	0.01	-70.84
fqai + carex sr + dicot sr	5	154.87	5.98	0.01	-70.86
fqai + ldi + %adventive	5	155.03	6.14	0.01	-70.93
ldi + %cultivated + %adventive	5	155.23	6.34	0.01	-71.03
fqai + ldi + %sensitive + %cultivated + %adventive + carex sr + dicot sr	9	169.29	20.40	0.00	-69.65

Table 8f. Model selection for the effects of vegetation and land use variables on vegetation, interspersion, and habitat features (Metric 6).

Model	K	AIC_c	ΔAIC_c	ω	LL
%adventive + carex sr	4	136.51	0.00	0.27	-63.25
%adventive + ldi + carex sr	5	137.04	0.53	0.21	-61.94
fqai + %adventive	4	137.62	1.12	0.16	-63.81
fqai + %adventive + carex sr	5	137.75	1.24	0.15	-62.29
%adventive	3	139.59	3.09	0.06	-66.22
fqai + %cultivated + %adventive	5	139.81	3.30	0.05	-63.32
%cultivated + %adventive	4	140.03	3.52	0.05	-65.01
%adventive + ldi	4	140.99	4.49	0.03	-65.50
%cultivated + %adventive + ldi	5	142.89	6.38	0.01	-64.86
fqai + %cultivated + %adventive + ldi + carex sr	7	143.09	6.59	0.01	-61.25
carex sr	3	145.40	8.89	0.00	-69.13
ldi + carex sr	4	147.08	10.58	0.00	-68.54
fqai + carex sr	4	147.48	10.98	0.00	-68.74
%cultivated + carex sr	4	147.60	11.10	0.00	-68.80
fqai + ldi + carex sr	5	149.94	13.43	0.00	-68.39
fqai	3	150.11	13.60	0.00	-71.48
%cultivated + ldi + carex sr	5	150.14	13.63	0.00	-68.49
fqai + %cultivated + carex sr	5	150.33	13.82	0.00	-68.58
fqai + %cultivated	4	152.89	16.39	0.00	-71.45
fqai + ldi	4	152.95	16.44	0.00	-71.47
%cultivated	3	153.07	16.56	0.00	-72.96
ldi	3	153.38	16.87	0.00	-73.28
%cultivated + ldi	4	155.87	19.36	0.00	-72.93
fqai + %cultivated + ldi	5	156.05	19.54	0.00	-71.45

Table 9a. Model-averaged estimates of vegetation and land use metrics as explanatory variables for KY-WRAM Metric 1 based on the top models from Table 8a.

Parameter	**β Estimate**	**SE**	**95% CI**
ldi	0.094	0.184	-0.266 – 0.455
%cultivated	0.003	0.010	-0.017 – 0.027
%adventive	-0.002	0.017	-0.036 – 0.032
fqai	0.049	0.049	-0.047 – 0.145
%forested	-0.001	0.012	-0.025 – 0.022
stems	0.000	0.000	-0.001 – 0.001

Table 9b. Model-averaged estimates of vegetation and land use metrics as explanatory variables for KY-WRAM Metric 2 based on the top models from Table 8b. Metrics labelled with a (*) were statistically significant, and confidence intervals do not overlap zero.

Parameter	**β Estimate**	**SE**	**95% CI**
fqai	0.116	0.086	-0.053 – 0.284
ldi	-0.831	0.515	-1.840 – 0.178
%cultivated	-0.041	0.021	-0.081 – 0.000
*%forested**	0.080	0.022	0.038 – 0.123
%sensitive	0.006	0.026	-0.046 – 0.057
%adventive	-0.051	0.030	-0.109 – 0.007

Table 9c. Model-averaged estimates of vegetation and land use metrics as explanatory variables for KY-WRAM Metric 3 based on the top models from Table 8c.

Parameter	**β Estimate**	**SE**	**95% CI**
ldi	-0.797	0.525	-1.826 – 0.232
%hydrophyte	-0.031	0.041	-0.112 – 0.050
fqai	0.109	0.176	-0.236 – 0.454
carex sr	-0.065	0.305	-0.663 – 0.534
hydro sr	0.035	0.136	-0.232 – 0.301
stems	0.001	0.001	-0.002 – 0.003

Table 9d. Model-averaged estimates of vegetation and land use metrics as explanatory variables for KY-WRAM Metric 4 based on the top models from Table 8d. Metrics labelled with a (*) were statistically significant, and confidence intervals do not overlap zero.

Parameter	**β Estimate**	**SE**	**95% CI**
subcanopy iv	-0.418	12.554	-25.024 – 24.188
canopy iv	-9.049	28.208	-64.337 – 46.238
*fqai**	0.330	0.160	0.016 – 0.644
ldi	-0.636	0.805	-2.214 – 0.925
small tree	-1.009	8.990	-18.628 – 16.610
%forested	-0.074	0.039	-0.004 – 0.150
*%adventive**	-0.129	0.048	-0.224 – -0.035

Table 9e. Model-averaged estimates of vegetation and land use metrics as explanatory variables for KY-WRAM Metric 5 based on the top models from Table 8e.

Parameter	**β Estimate**	**SE**	**95% CI**
ldi	-0.041	0.627	-1.271 – 1.188
%sensitive	0.064	0.056	-0.045 – 0.173
%cultivated	-0.035	0.037	-0.107 – 0.037
%adventive	-0.013	0.064	-0.139 – 0.113
fqai	0.181	0.191	-0.193 – 0.556
carex sr	0.193	0.331	-0.456 – 0.842
dicot sr	-0.085	0.121	-0.152 – 0.322

Table 9f. Model-averaged estimates of vegetation and land use metrics as explanatory variables for KY-WRAM Metric 6 based on the top models from Table 8f. Metrics labelled with a (*) were statistically significant, and confidence intervals do not overlap zero.

Parameter	**β Estimate**	**SE**	**95% CI**
*%adventive**	-0.189	0.051	-0.288 – -0.090
ldi	-0.589	0.437	-1.445 – 0.267
*carex sr**	0.552	0.252	0.058 – 1.047
%cultivated	-0.032	0.030	-0.090 – 0.026
fqai	0.231	0.145	-0.055 – 0.517

APPENDIX D
PCA Eigenvalues, Variance, and Loading Values

Table 10a. Principal Component Analysis eigenvalues and the proportional and cumulative variation of axes for Figure 8. Two axes explained 51.2% of the variation present in the sampled data of KY-WRAM metrics.

	PC1	**PC2**
Eigenvalue	2.350	1.741
Proportion Explained	0.294	0.218
Cumulative Proportion	0.294	0.512

Table 10b. Principal Component Analysis loading values for KY-WRAM metrics in Figure 8. Important variables establishing each axis are in bold.

Metric	PC1	PC2
k1	**-0.506**	0.069
k2	0.354	**-0.519**
k3	**-0.505**	-0.351
k4	0.197	-0.267
k5	**0.566**	0.238
k6	-0.059	**0.689**

Table 10c. Vector coefficients and goodness of fit statistics (R^2) for habitat variables fit to the KY-WRAM PCA in Figure 8 using Program R Package Vegan, function envfit. Significant variables designated with a (*) indicate significance of $P < 0.05$, and a (**) indicate significance of $P < 0.01$.

Variable	**PC1**	**PC2**	**R^2**
cult	-0.776	0.631	0.165
forest**	0.897	-0.441	0.398
fqai*	0.975	0.223	0.306
shade	0.948	-0.318	0.085
st	-0.735	0.678	0.028
subiv	0.999	-0.042	0.017
caniv	-0.826	0.563	0.055
adv	-0.661	-0.751	0.169

Table 11a. Principal Component Analysis eigenvalues and the proportional and cumulative variation of axes for Figure 9. Three axes explained 22.2% of the variation present in the sampled data of bird species.

	PC1	**PC2**
Eigenvalue	6.340	4.736
Proportion Explained	0.127	0.095
Cumulative Proportion	0.127	0.222

Table 11b. Principal Component Analysis loading values for bird species in Figure 9. Important variables establishing each axis are in bold.

Species	**PC1**	**PC2**	**Species**	**PC1**	**PC2**
ACFL	0.175	0.131	MALL	0.053	-0.084
AMCR	0.072	0.136	MODO	-0.101	-0.172
AMGO	-0.014	**0.219**	NOCA	-0.084	**-0.214**
AMRO	-0.161	-0.129	NOFL	0.114	0.079
BAOR	-0.003	-0.113	NOPA	0.102	**0.347**
BGGN	**0.278**	0.192	OVEN	**0.241**	0.012
BLJA	-0.049	-0.053	PIWO	0.107	-0.008
BTNW	0.131	0.06	PROW	0.018	**0.323**
BWWA	0.188	**-0.247**	RBWO	0.081	0.002
CACH	**-0.264**	-0.044	REVI	0.183	0.058
CARW	**-0.212**	0.022	RSHA	0.116	**-0.219**
CHSW	-0.050	0.036	RWBL	-0.134	-0.003
COYE	-0.039	0.020	SCTA	**0.207**	-0.187
DOWO	-0.068	0.008	SOSP	-0.036	0.045
EABL	0.004	0.138	SUTA	-0.055	0.095
EAPH	0.188	**-0.247**	SWWA	0.131	0.06
EATO	-0.102	**-0.204**	TUTI	-0.059	-0.07
EAWP	-0.157	-0.06	WBNU	-0.052	-0.035
FISP	-0.115	-0.128	WEVI	0.075	0.069
GCFL	0.118	-0.053	WEWA	0.188	**-0.247**
GRCA	-0.105	-0.089	WODU	0.053	-0.085
HOWA	**0.300**	-0.078	WOTH	0.194	-0.192
HOWR	-0.167	-0.065	YBCH	-0.135	-0.037
INBU	-0.114	-0.100	YBCU	0.027	**0.207**
KEWA	**0.272**	-0.130	YTWA	-0.047	0.113
LOWA	0.108	0.028			

Table 11c. Vector coefficients and goodness of fit statistics (R^2) for habitat variables fit to the KY-WRAM PCA in Figure 9 using Program R Package Vegan, function envfit. Significant variables designated with a (*) indicate significance of $P < 0.05$, a (**) indicate significance of $P < 0.01$, and a (***) indicate significance of $P < 0.001$.

Variable	**PC1**	**PC2**	**R^2**
forest	0.721	0.692	0.148
cult*	-0.912	-0.409	0.273
k1	0.192	-0.981	0.033
k2**	0.990	0.134	0.581
k3	0.970	-0.244	0.114
k4**	0.982	-0.190	0.442
k5	0.832	-0.555	0.133
k6	0.949	0.316	0.052
fqai**	0.899	-0.437	0.482
shade***	0.820	-0.572	0.519
st	-0.542	0.841	0.159
subiv	0.981	-0.196	0.096
caniv	-0.926	0.378	0.196
adv	0.954	-0.300	0.015

APPENDIX E
Supplemental Figures

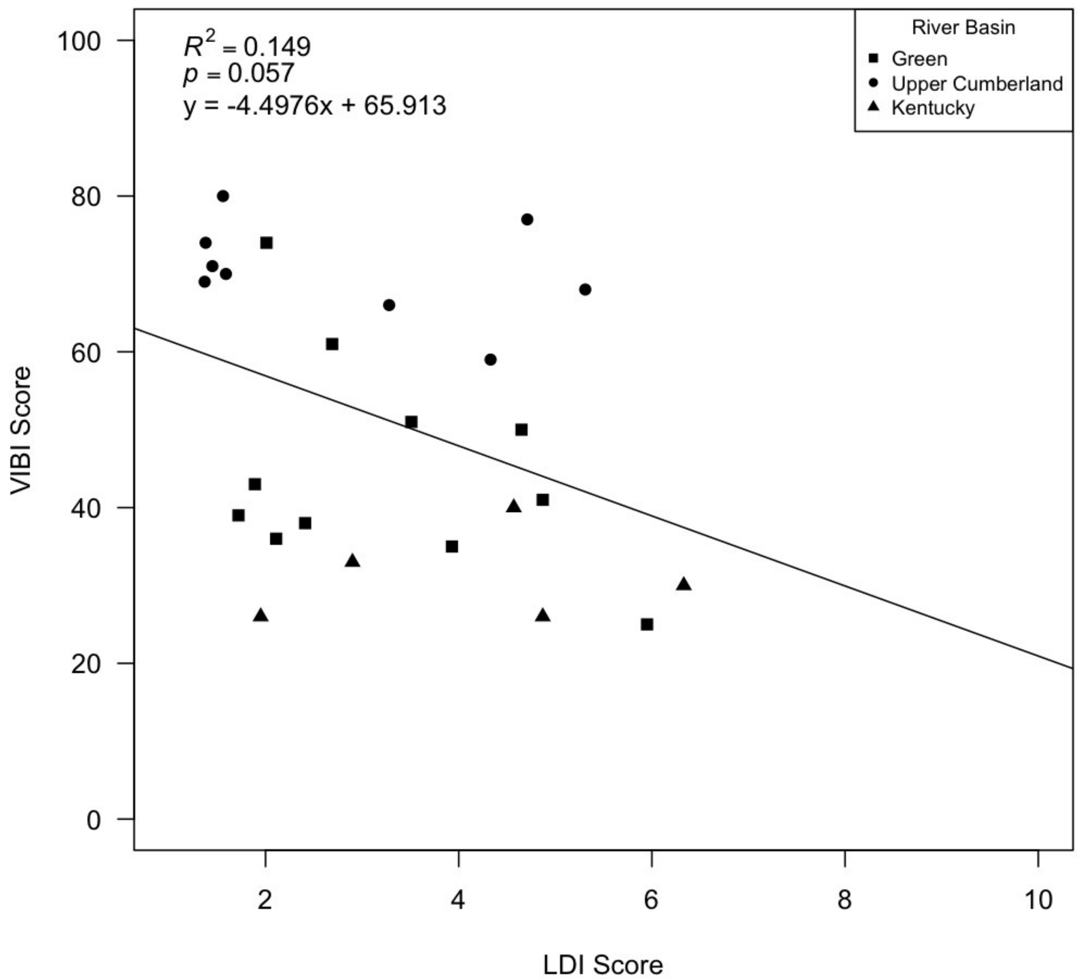


Figure 7a. Linear regression between the VIBI score and LDI score. Different symbols represent river basin for each site.

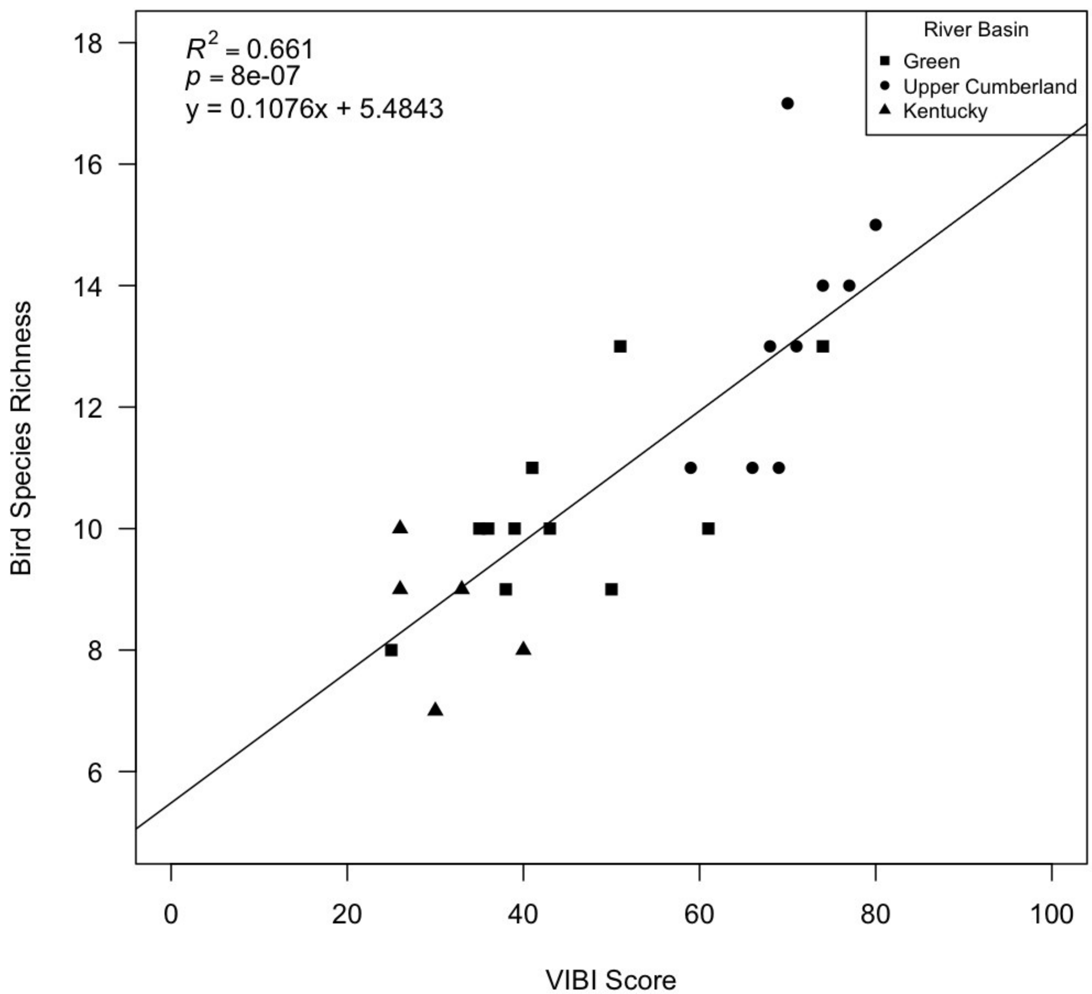


Figure 7b. Linear regression between bird species richness and VIBI score. Different symbols represent river basin for each site.

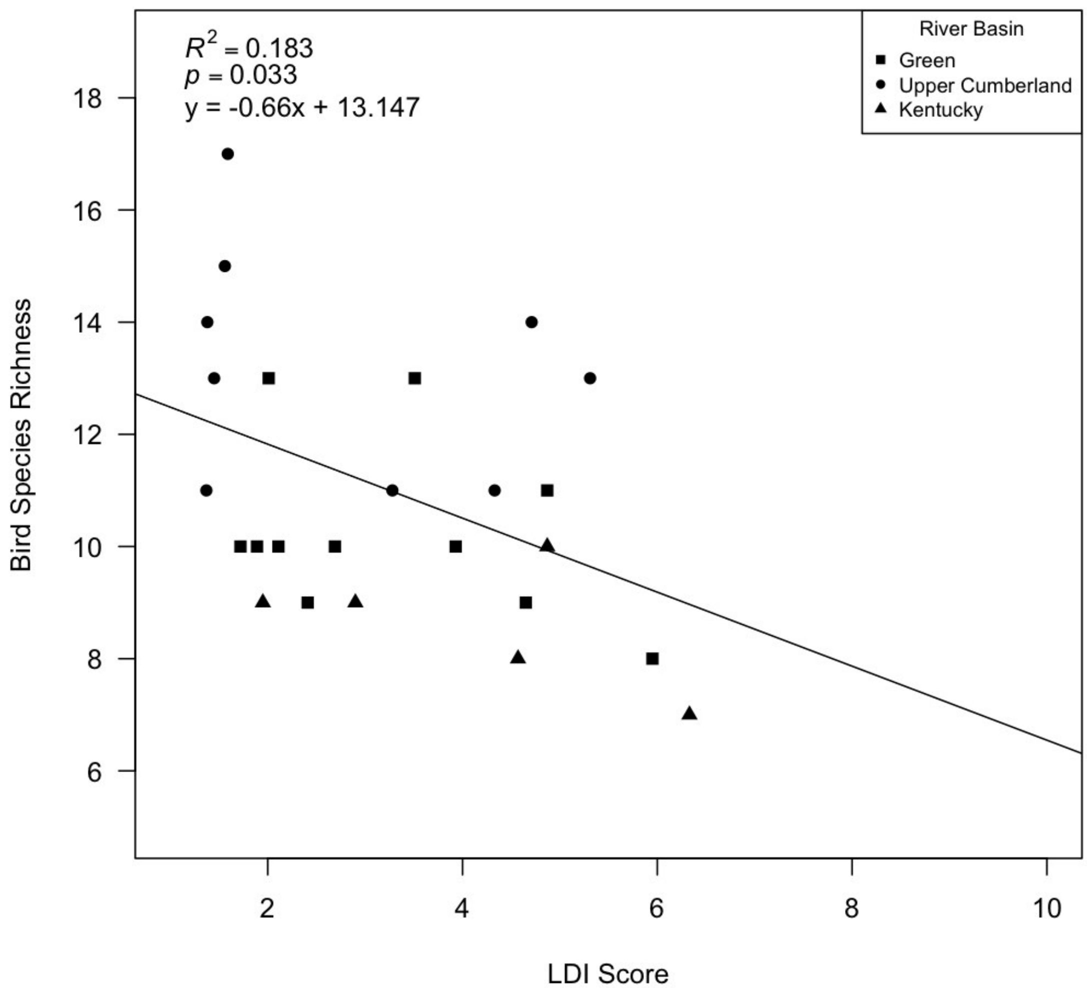


Figure 7c. Linear regression between bird species richness and LDI score. Different symbols represent river basin for each site.

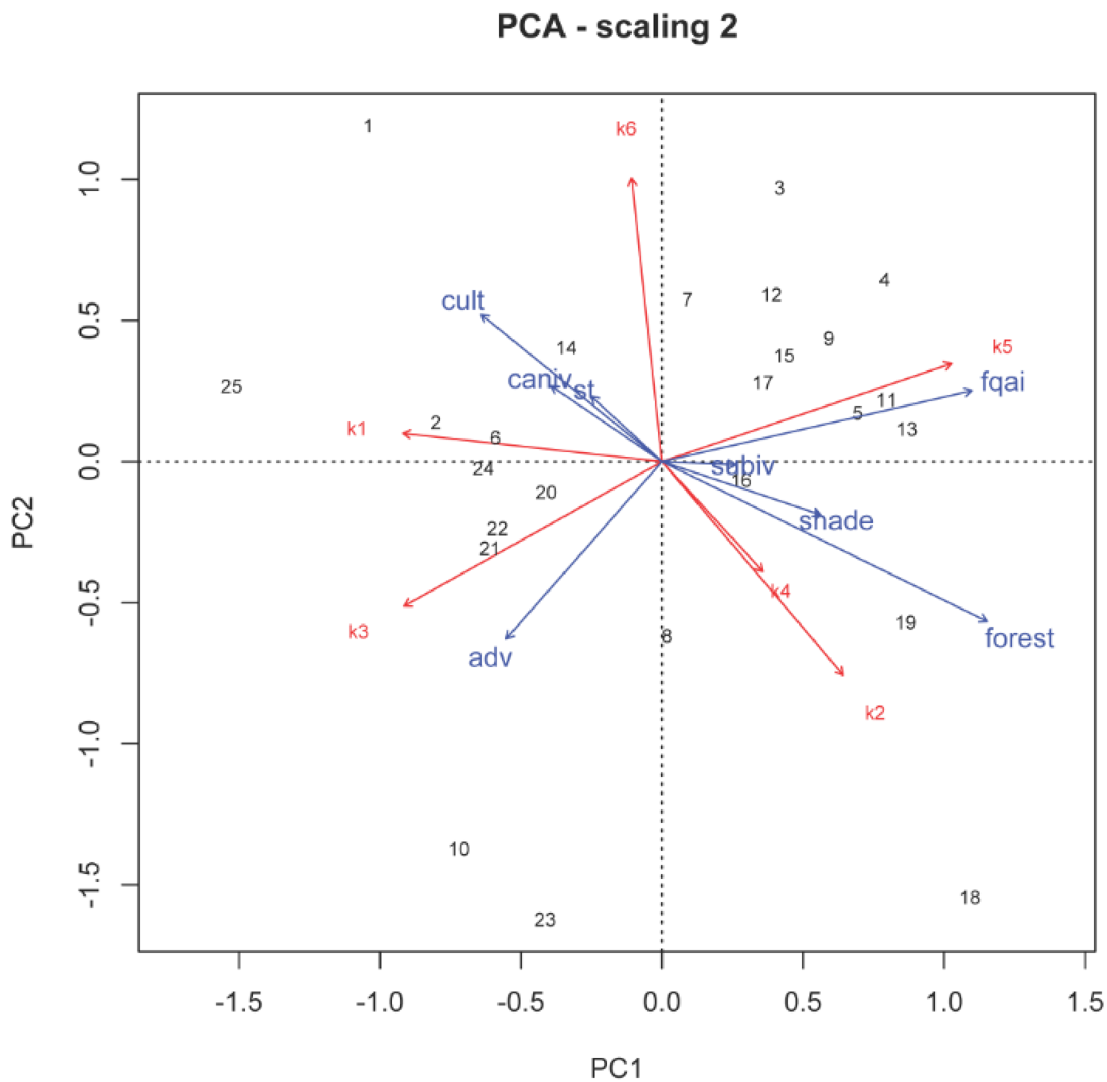


Figure 8. Principal Component Analysis (PCA) of KY-WRAM metrics across all sites. Vectors indicate increasing direction of change of each metric. Red variables represent KY-WRAM metrics. Blue variables represent an environmental fitting function of vegetation metrics and landscape variables related to KY-WRAM metrics. Numbers represent specific sites (see Table 2).

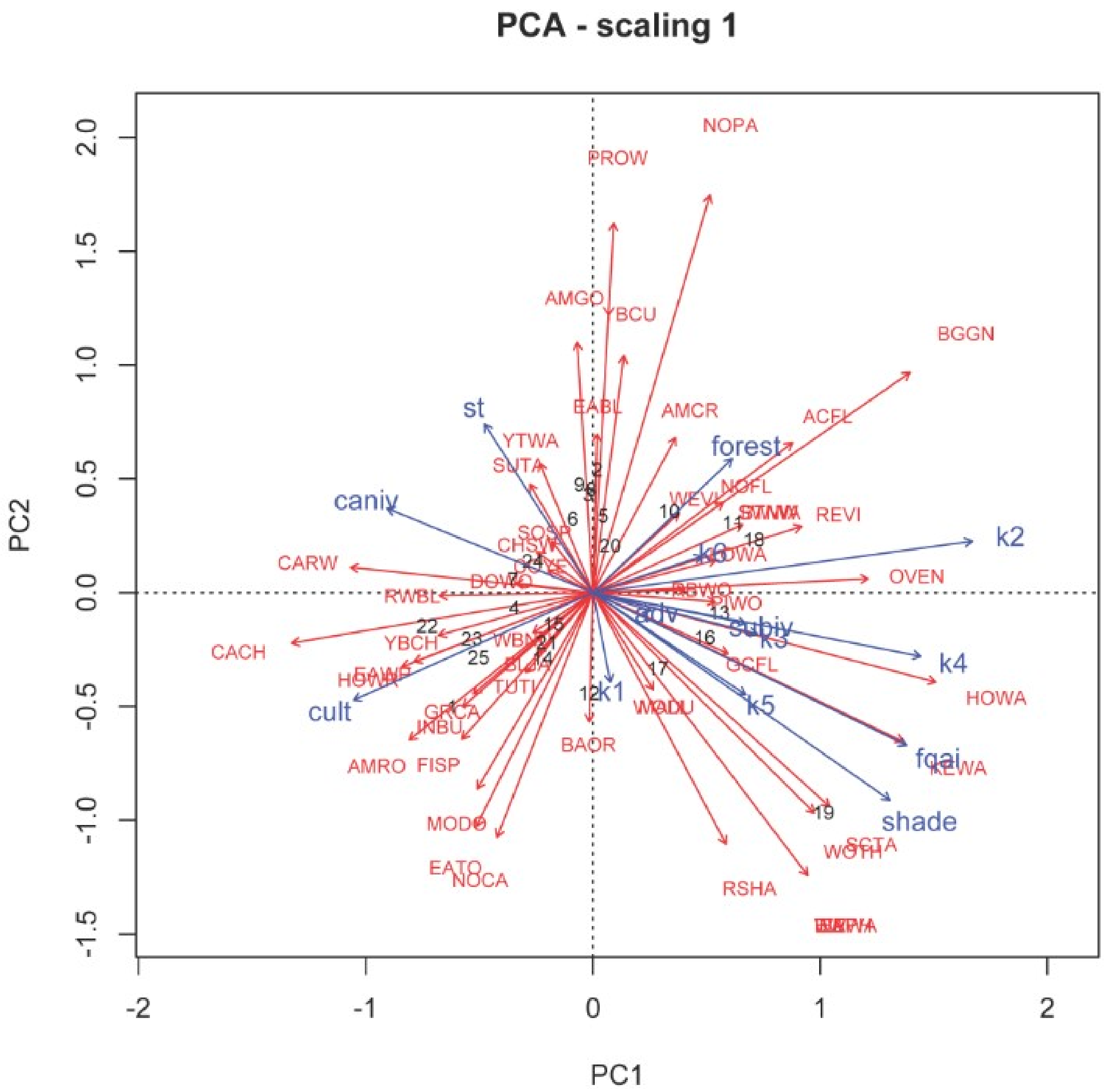


Figure 9. Principal Component Analysis (PCA) of bird species across all sites. Vectors indicate increasing direction of change of each species. Red variables represent bird species. Blue variables represent an environmental fitting function of vegetation metrics, KY-WRAM metrics, and landscape variables in relation to bird species. Numbers represent specific sites (see Table 2).