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Vegetation-Based Metrics Of Biotic Integrity For Assessing The Ecological Condition Of Wetlands Of Kentucky

Tanner Matthew Morris
Eastern Kentucky University

VEGETATION-BASED METRICS OF BIOTIC INTEGRITY FOR ASSESSING THE ECOLOGICAL CONDITION OF WETLANDS OF KENTUCKY

By

Tanner Matthew Morris

Thesis Approved:

Chair, Advisory Committee

Member, Advisory Committee

Member, Advisory Committee

Dean, Graduate School

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VEGETATION-BASED METRICS OF BIOTIC INTEGRITY FOR ASSESSING THE ECOLOGICAL CONDITION OF WETLANDS OF KENTUCKY

By
TANNER MATTHEW MORRIS

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ABSTRACT

Over the last two centuries, wetland acreage across the world has significantly declined due to human disturbances. It has been estimated that Kentucky has lost over 80% of its wetland area. In response to these losses occurring across the United States, the Clean Water Act was passed to halt this dramatic decline and to restore the ecological integrity of waters of the United States. To enforce the Clean Water Act, a number of ecological assessment techniques have been developed to quantify the ecological quality of the waters of the United States. Kentucky recently adopted a rapid method for assessing the ecological condition of wetlands, but there is no standardized means to rigorously assess the ecological quality of its wetlands. Indices of biotic integrity (IBI) represent such a rigorous method and has become one of the most common approaches for intensive ecological assessment. IBIs evaluate the ecological condition of a site based on indicator organisms that reflect current and past anthropogenic disturbances of the area. In this study I report on initial efforts to develop a vegetation-based IBI for Kentucky (KY VIBI). Ohio has a state-wide applicable vegetation-based IBI (VIBI) for wetlands that has undergone multiple iterations of testing and refinement over more than 10 years. Due to the geographic and vegetative similarities between Ohio and Kentucky, Ohio's VIBI (OH VIBI) was used as a model to begin developing a state-wide applicable vegetation-based IBI for Kentucky.

A unique approach was used to begin the process of developing the KY VIBI. I developed a set of candidate metrics that included unmodified and slightly modified OH VIBI metrics, unmodified metrics from a VIBI study conducted in Colorado, and newly hypothesized metrics based on similar studies and my own professional knowledge of the plant communities of wetlands in Kentucky. The candidate metrics were tested for their response to disturbance indices using correlation analysis with data obtained from 68 wetland sites in Kentucky. Since metric response is expected to vary along a disturbance gradient, the resultant ecological condition of a site can be evaluated based on a core set of metrics that are related to anthropogenic disturbance. Sites were distributed across wetland types (emergent, forest, and shrub), as well as across the three major river basins

(Green River, Kentucky River, and Upper Cumberland River). The disturbance indices were created by combining the non-biological submetrics of a newly developed rapid assessment method, the Kentucky Wetland Rapid Assessment Method (KY-WRAM), and the landscape disturbance index (LDI). The KY-WRAM and LDI were statistically combined using Principal Components Analysis (PCA) to create new disturbances indices. Combining these two separate measures of anthropogenic disturbance in a PCA resulted in better metric correlation compared to using either the KY-WRAM or LDI individually. The first two PC axes explained 48.35% and 13.47% of the total variation, respectively, and so those two axes were retained for comparison to the candidate KY VIBI metrics. Loading scores of variables were relatively strongly weighted on just the first or second axis of the PCA, suggesting good, simple structure in the PCA.

A list of the best ten candidate metrics were selected for each wetland type (emergent, shrub, and forest) based on their correlation and apparent response to disturbance, along with using best professional judgment. Many of the best metrics are related to invasiveness, tolerance, and floristic quality scores (e.g. Mean Coefficient of Conservatism for all Species, % Non-native Species, % Intolerant). Although the OH VIBI provided a sound methodological foundation for developing a VIBI for Kentucky, the results presented here suggest that many of the metrics in the current OH VIBI do not accurately reflect the biological effects of disturbance in Kentucky's wetlands, at least for the three river basins sampled for this study. The ten best candidate metrics will need to be further tested and evaluated for performance in other basins of Kentucky to ensure complete and proper calibration. Also, the individual metrics will need to be scaled, combined, and possibly weighted to create an index. By selecting and utilizing a different set of metrics with stronger association to disturbance we can more accurately describe wetland quality in the state of Kentucky.

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I. INTRODUCTION

A primary goal of the Clean Water Act is to maintain and restore the physical, chemical, and biological integrity of the "waters" of the United States (33 U.S.C.§ 1251). Wetlands are considered a type of "water" of the United States and jurisdictional wetlands of Kentucky fall into this category. Like many other states, Kentucky has seen a significant decrease in the total acreage of wetlands since colonization. Over the last two centuries, Kentucky has lost over 80 percent of its wetlands (Dahl and Johnson 1991). According to Jones (2005), this equates to a loss of roughly 500,000 hectares. The most recent Status and Trends Report from the United States Fish and Wildlife Service found that declines in wetland acreage continued from 2004 to 2009 for forested freshwater wetlands in the conterminous states (Dahl 2011). This is especially problematic for Kentucky, since forested freshwater wetlands make up the majority of wetlands found in the state (Richter et al., in press). Land development, agriculture, mining, and other human disturbances have contributed to this decline through dredging, draining, filling, leveling, and flooding of wetlands (Mitsch and Gosselink 2007).

Although a "no net loss" policy of wetland acreage has been enacted by the federal government (Resolve 2003), there has been less legal and political attention given to the ecological integrity (quality) of wetlands. Ecological integrity is important because it is related to the value of the functions and services wetlands provide (Mack 2007a). Wetlands with high ecological integrity provide benefits such as flood damage mitigation along our nation's rivers, lakes, and streams by storing and slowly releasing flood waters (Mitsch and Gosselink 2007). Wetlands also help maintain and improve the quality of our nation's water by reducing sediment loads, removing nutrients, and trapping toxic compounds (Mitsch and Gosselink 2007). They also provide critical habitat for many different plants and animals. More than one third of federally threatened and endangered plant and animal species are found in wetlands (Dahl and Johnson 1991). These unique, fragile ecosystems are easily degraded and destroyed by human disturbances, particularly when hydrology is altered (Mitsch and Gosselink 2007).

It is imperative for state and federal wetland protection programs to have methods that assess the ecological integrity of wetlands because wetlands which exhibit higher functions and provide more ecosystem services should be afforded more protection. These programs should also quantify the ecological integrity of wetlands in order to determine ecological success or failure of mitigation projects, and to set appropriate permitting and mitigation thresholds based on a wetland's quality (Mack 2007a). Kentucky currently has no statewide methods to measure the ecological integrity of its wetlands. In terms of mitigation wetlands, one cannot expect that acreage restored will compensate for the complex functions of natural wetlands that are lost when they are permitted and destroyed. Rigorous ecological performance goals are needed to ensure these complex functions are replaced since many studies have shown that mitigation wetlands often fail to develop characteristics similar to those of natural wetlands (e.g. Kentula et al. 1992; Mack and Micacchion 2006; Burgin 2010; Moreno-Mateos et al. 2012). The determination of success or failure for wetland mitigation projects can only be accomplished through quantitative ecological assessment.

Recently, a cooperative project between Eastern Kentucky University, the Kentucky Division of Water, and an interagency technical committee, resulted in the development of a rapid wetland assessment method for the state, the Kentucky Wetlands Rapid Assessment Methods (KY-WRAM). This assessment method provided a regulatory tool for state and federal agencies to better manage wetland resources in Kentucky. However, regulatory decisions would be strengthened if the rapid wetland assessment method could be complemented by intensive assessment methods specific to Kentucky's wetlands. For example, if the rapid assessment method score for a wetland borders between two categories, an alternative intensive assessment method could be used to help determine the proper wetland categorization. The U.S Environmental Protection Agency (USEPA) suggests that both rapid and intensive methods have important roles in a successful wetland protection program (Stein et al. 2009).

Biological integrity is the ability of an ecosystem to support a community of organisms that have a species composition, diversity, and function similar to that of a natural habitat of that region (Karr and Dudley 1981). The organisms that inhabit the ecosystem can be used as indicators of the quality of the ecosystem since they are subjected to a range of human and natural disturbance (Mack 2007a). In response to the Clean Water Act's goal of restoring the biological integrity of waters of the United States, a number of indices of biotic integrity (IBIs) have been developed using a variety of taxonomic groups (Mack 2007a). Fish and macroinvertebrates were the first biological indicators used in IBIs for the assessment of streams (e.g. Karr and Kerans 1992; Barbour et al. 1992; Bode and Novak 1995; Hornig et al. 1995; Simon and Emery 1995; Hughes et al. 1998; Karr and Chu 1999). More recently, amphibians, plants, and birds have been used in IBIs designed to assess wetland habitats (e.g. USEPA 2002; Miccachion 2004; Miller et al. 2006; Mack 2007a). The IBI approach evaluates the ecological condition of an area by utilizing indicator taxa or metrics that reflect current and past disturbances of a site (Karr and Chu 1999). Nearly all ecological assessment techniques are based on the assumptions that the ecological condition of an ecosystem will vary along a disturbance gradient, and that the resultant state can be evaluated based on a core set of metrics that are related to disturbance (Stein et al. 2009).

The USEPA proposed a 1-2-3 level assessment framework for ecological assessment and monitoring (Stein et al. 2009). Level 1 involves remote, landscape-scale habitat assessment. Level 2 is a rapid assessment of the site based on key habitat features and typically takes no more than a couple hours in the field and requires only a moderate level of expertise. Level 3 assessment involves intensive collection of data for indicator organisms (e.g. IBI), typically identifying organisms at the species-level, or the lowest taxonomic level possible (Kentula 2007). Due to the potentially demanding process of identifying organisms to species-level, a high level of expertise is required for level 3 assessments. The focus of this thesis is the development of a level 3 wetland assessment technique.

The metrics of level 3 wetland assessments are typically measures of specific biological attributes that reflect some element of ecological condition, and can be related to key wetland functions (Mack 2007a; Stein et al. 2009). For example, the percent cover of sensitive, tolerant, or invasive plant species are commonly used in metrics for vegetation-based IBIs because the cover of these organisms reflects an ecological condition that varies with past and current disturbance. An increase in invasive plant species cover in wetlands has been linked to anthropogenic disturbance in the areas adjoining wetlands (Silliman and Bertness 2004). Invasive plant species have been shown to have negative effects on the ecological condition of wetlands by altering geomorphological processes, hydrological cycling, biogeochemical cycling, natural disturbance regimes, stand structure, and resource competition (Gordon 1998). Zedler and Kercher (2004) found invasive plant species have persistent and substantial effects on habitat structure, biodiversity, and food web interactions. Undoubtedly, the alteration of these processes by invasive plant species influences the many functions and services wetlands provide such as carbon sequestration, wildlife habitat, nutrient removal, sediment removal, groundwater recharge, flood abatement, and biological diversity (Mitsch and Gosselink 2007). A good IBI should include additional metrics that reflect a variety of the functions of wetlands.

The most obvious taxonomic group for developing a wetland IBI is vascular plants (Mack 2007a). Vascular plants are large, observable, and important components of wetland ecosystems. They are also easy to identify down to species-level with a minimal amount of training relative to other biotic assemblages (i.e. macroinvertebrates) (Miller et al. 2006). Since plants are immobile, they are subject to physical, chemical, and biological changes in the surrounding environment, and these changes are regularly expressed in the plant community. Plants can almost be considered as physical features like soil or hydrology in addition to being living organisms (Cronk and Fennessey 2001). For these reasons and the fact that plant species vary in sensitivity to anthropogenic disturbance, plant communities are excellent indicators of ecological condition (Miller et al. 2006). Sedimentation, nutrient enrichment, and hydrological modifications are examples of the major stressors that result from human disturbances that can alter plant community composition. Certain plants cannot cope with these stressors and are reduced or eliminated from the system, while other plants adapted to deal with stress invade and thrive (Miller et al. 2006). These shifts, along with other attributes in the plant community, can be systematically quantified and incorporated into a set of IBI metrics that reflect the ecological condition of the area (Miller et al. 2006).

Vegetation plays an important and critical role in the regulation and protection of wetlands. It is one of three necessary criteria used to delineate wetland boundaries for jurisdictional determinations (Miller et al. 2006). For an area to be classified as a "jurisdictional wetland" under the US Army Corps of Engineers wetland delineation manual, it must meet strict criteria in three categories: (1) hydrology, (2) soil, and (3) vegetation. In order for an area to be considered a jurisdictional wetland, the vegetation criterion of the manual states that hydrophytic vegetation must be present. According to the manual, hydrophytic vegetation is present when at least 50% of the considered species have a wetland indicator status of obligate wetland (OBL, 99% chance it occurs in wetlands), facultative wetland (FACW, 67% to 99% chance it occurs in wetlands), or facultative wetland (FAC, 34% to 66% chance it occurs in wetlands) (Environmental Laboratory 1987). Vegetation is also extensively used in rare plant surveys, which are aimed at identifying potential high quality wetland areas for regulatory purposes and conservation planning. Wetland areas that have been identified to contain federally endangered or threatened plant species may warrant special protection. The presence of state endangered or threatened plant species in wetland areas may also warrant special protection in some states.

Few wetland IBIs have been published and of those, some have important limitations such as being based on data sets from only 1 or 2 years, having limited geographic application, and employing unstandardized sampling techniques (Mack 2007a). States with such deficiencies in their wetland IBIs include: Massachusetts, Minnesota, Indiana, Wisconsin, North Dakota, and Pennsylvania (Carlisle et al. 1999; Gernes and Helgen 1999; Simon et al. 2001; Lillie et al. 2002; Dekeyser et al. 2003; Miller et al. 2006). However, in some states, such as Ohio, wetland IBIs have undergone multiple testing iterations with large reference data sets and have statewide applications (Mack 2004; 2007a). The Ohio vegetation-based IBI (OH VIBI) is applicable to wetlands across the different ecoregions of the state (Mack 2007a). Due to the geographic proximity and similarity between ecoregions and vegetation of Ohio to Kentucky, and the fact that the OH VIBI has undergone rigorous testing and refinement, the OH VIBI was selected as a model for developing the Kentucky vegetation-based IBI (KY VIBI).

It is important to assess and monitor the condition of wetlands, and the VIBI can be a powerful tool to accomplish this. The condition of many wetlands around the country is unknown (Miller et al. 2006). In fact, Fennessy and colleagues (2007) estimate that only 4% of wetlands in the United States have been monitored. Many wetland programs have limited resources, including funding, so managers need data about wetland condition to prioritize resources and make informed decisions (Miller et al. 2006); the VIBI can help provide such information. The VIBI can be used to identify high quality wetlands, which can be used as models for mitigation design and as reference sites. The VIBI can also be used to establish water quality standards for basins, ensure permit conditions are met, and measure performance standards as part of compliance determination of mitigation wetlands (Miller et al. 2006).

Rapid assessment methods (RAMs) are becoming more common for agencies to use as regulatory tools since they require less time, are relatively easy to use, and are less expensive compared to intensive assessment methods such as hydrogeomorphic (HGM) and IBIs (Fennessy et. al 2007; Stein et al. 2009). Ohio (Mack 2001), California (Sutula et al. 2006), and Delaware (Jacobs 2007) have developed the most notable rapid methods (Stepanian et al. 2013). Rapid assessment methods (level 2) are validated by comparison against intensive data (level 3) or broad landscape scale data (level 1) to demonstrate proper categorization of wetland quality along a disturbance gradient.

In a review of rapid assessment methods, Fennessy et al. (2004) found rapid assessment methods are typically validated and calibrated against intensive biological assessment data. When the first RAMs were developed in the early 1990s, it was common practice to validate them against intensive wetland assessment methods simultaneously being developed because both level 2 and level 3 assessment methods respond in a similar fashion to disturbance (Mack 2007a; Stepanian et al. 2013). In essence, RAMs were used to validate intensive assessments, and intensive assessments were used to validate RAMs, due to the lack of an alternative scale to measure human disturbance. This somewhat circular development process was used by the Ohio EPA in the early 2000s with the development of the ORAM and OH VIBI (Mack 2001; 2004). By using one method to validate another, a control is essentially absent. This process of validation and development can become problematic if any one method does not properly characterize wetland condition. The Ohio EPA acknowledged this problem and was able to rectify it by validating both the ORAM and VIBI against an independent measure, the Landscape Development Index (LDI) (Brown and Vivas 2005; Mack 2007a). The LDI is an index that quantifies human disturbance of geographic areas by multiplying land-use percentages with a weighted factor based on the energy required to maintain that land use (Brown and Vivas 2005; Mack 2007a; Gara and Micacchion 2010). Recently, it has become clear that newly developed assessment techniques should be validated against independent data sources, and that the circular use of data from related assessment methods should be avoided. To avoid circularity, the candidate metrics developed and tested in this study were compared to an independent disturbance index developed from a combination of LDI data and select non-biological metrics of the Kentucky rapid assessment data that reflect anthropogenic stressors to wetlands.

The OH VIBI has become a critical part of regulatory decision making for the Ohio EPA. The VIBI allows for long-term monitoring of wetland sites, assists managers to determine whether development can occur around wetlands, and helps managers learn about changes that occur in wetland plant communities over time (Stepanian et al. 2013). The VIBI and ORAM have been integrated into the Ohio EPA's section 401 regulatory program as an extension of the Clean Water Act, thus allowing the state to regulate impacts to aquatic resources in waters of the United States (Clean Water Act 2002; Stepanian et al. 2013). Together, the VIBI and ORAM are important assessment tools for managers, and both are used to determine antidegradation categories of wetlands. Whenever an ORAM score falls between two antidegradation categories (i.e., in a gray zone), the VIBI is used to determine the appropriate category (Stepanian et al. 2013). The VIBI is also used to monitor wetland mitigation projects to ensure they are achieving desirable performance standards, which gives regulatory agencies important information to leverage maintenance by developers if standards are not met.

There are a total of 19 metrics currently used as part of the OH VIBI (Mack 2007b; Stepanian et al. 2013). There are three different versions of the OH VIBI that are used based upon the dominant plant community of a wetland: VIBI-emergent, VIBI-shrub, and the VIBI-forest. Each of these VIBIs consists of a set of 10 metrics, which are summed to calculate a VIBI score (Table 1). Each individual metric can receive a score of 0, 3, 7, or 10. The maximum score for the combined set of ten metrics is 100. Many of these metrics are only relevant to certain wetland types. For example, the percent bryophyte, pole timber, and canopy metrics are used only in the VIBI-forest because they have little relevance in emergent and shrub wetlands.

Table 1. List of the metrics used in the Ohio Vegetation Index of Biotic Integrity (OH VIBI) for emergent, shrub, and forest wetland communities.

Ohio Vegetation Index of Biotic Integrity Metrics	Emergent	Shrub	Forest
Number of Carex spp.	X	X	
Number of Cyperaceae spp.	X		
Number of native dicot spp.	X	X	
Number of native shrub spp.	X	X	
Number of native hydrophyte spp.	X	X	
Number of native shade spp.			X
Number of seedless vascular plant spp.		X	X
Ratio of annual to perennial species	X		
Floristic Quality Assessment Index (FQAI)	X	X	X
% Bryophyte			X
% Cover shade-tolerant hydrophyte species			X
% Cover tolerant plant spp.	X	X	X
% Cover sensitive plant spp.	X	X	X
% Cover invasive graminoid spp.	X		
Pole timber (small tree) density			X
Native shade subcanopy importance value		X	X
Canopy important value			X
Mean standing biomass	X		
% Cover unvegetated	X		

The objective of this study is to begin the process of developing a quantitative method to assess the ecological integrity of the wetlands of Kentucky. When completed, the KY VIBI can be used to help improve and bolster regulatory decisions at both the state and federal level. Since the complete development of an IBI is beyond the timeframe for a master's thesis, this project lays the groundwork for future development, including testing and refinement of metrics of the KY VIBI. In this study I report candidate metrics for the KY VIBI that show correlation with an independent index of disturbance. I report a separate set of metrics for wetlands of three vegetation classes: emergent, forest, and shrub.

II. METHODS

Summary

Wetland sites were identified and selected to represent a gradient of human disturbance. Candidate metrics for the KY VIBI were identified from similar published studies, including all of the metrics used in the OH VIBI. Additionally, I developed a new set of hypothesized metrics to explain the vegetation community of wetlands. All of the candidate metrics are theoretically associated with the functions of wetlands found in Kentucky. Vegetation data, including species and cover, were collected from wetlands during the summer sampling periods of 2011, 2012, and 2013 to test for correlation between candidate metrics and two indices of disturbance. The disturbance indices were created by combining the non-biological submetrics of the KY-WRAM and a LDI in a principal components analysis (PCA). The first and second PCA axes (PC1 and PC2) were used as separate measures of disturbance. Pearson's correlation analysis was used to test the performance of each candidate metric with the disturbance indices. Metrics that demonstrated a strong correlation with disturbance were retained, and candidate metrics with a weak correlation were eliminated from consideration for the KY VIBI. The metrics with a strong correlation with the disturbance indices were also tested for multicollinearity. If two or more metrics demonstrated a strong correlation with one another, only the metric with the strongest correlation with the disturbance indices was retained. Ten metrics for each wetland type (emergent, shrub, and forest) were selected for consideration for the first version of the KY VIBI based upon their association with the disturbance indices.

Site Selection

Sites were selected to represent a gradient of disturbance. Sites were also selected to capture a range of different plant communities, HGM classes, and ecoregions. Kentucky has three main ecological regions: the Appalachian Plateaus (AP), the Interior

Low Plateaus (IP), and the Mississippi Embayment (ME) (Woods et al. 2002). Due to time constraints and the limited number of sites that could be sampled during the growing season (May–September), sampling efforts were concentrated in the Green River, Upper Cumberland River, and Kentucky River basins located in the IP and AP, to ensure that a full disturbance gradient was captured for each basin. A complete gradient of disturbance is recommended for proper metric calibration in the IBI approach (Mack 2007a).

In 2012 and 2013, sites were selected from the Green River, Upper Cumberland River, and the Kentucky River basins using a Generalized Random Tessellation Stratified procedure (GRTS) to create a list of potential wetland sampling sites (Stevens and Olsen 2004). The GRTS is a GIS-based approach that reduces the clumping of random samples by spatially balancing the sample to reflect natural patterns of density. The GRTS for this study was based on a National Wetland Inventory layer of all the emergent, forested, and shrub wetlands of Kentucky, and was run separately for each basin. The GRTS site selection process produced many sites that were categorized in the mid-to low-range of disturbance. Therefore in order to capture the entire range of disturbance, highly degraded sites, such as those found in urban and agricultural settings, along with high-quality reference sites were targeted to better represent the full range of disturbance found across the wetlands in the three basins. Information about several of the high quality sites was provided by the Kentucky State Nature Preserves Commission. In 2011, sites were intensively sampled for vegetation as they were in 2012 and 2013, but were not chosen from a GRST design because the goal was to target isolated depressional wetlands, a wetland type not typically mapped on available GIS layers.

Vegetative Sampling Methods

Vegetation in wetlands was sampled using the methodology described in Peet et al. (1998) and the VIBI manual (Mack 2007b). The plot configurations used to sample areas are a modification of the Whittaker plot design described in Shmida (1984). These plots are effective for sampling most types of vegetative communities in the eastern United States (Peet et al. 1998). This plot design is time-efficient, flexible, reproducible, compatible with data from other methods, provides species counts and cover, and addresses the problems of spatial autocorrelation found in other methods (Mack 2007a). At most sites (n = 32), a standard 20 m x 50 m plot layout containing 10 modules of 10 m x 10 m each was used (Figure 1). At other wetlands, where the typical 20 m x 50 m plot layout would not fit, alternate plot arrangements depending on the shape and size of the wetland were used (e.g. 10 m x 50 m, 20 m x 20 m, 20 m x 40 m, etc.). Plots were placed in the wetland so that the long axis minimized the environmental heterogeneity within the plot. If more than one dominant vegetative community was present in the wetland, then separate plots were used to assess each of the dominant communities. Typically, four modules in the plot were treated as intensive modules. In smaller wetlands where the four intensive modules would not fit, fewer modules were utilized. Vegetation was sampled in the intensive modules with a series of nested quadrats. The nested quadrat approach forces the assessor to examine each module thoroughly. For each intensive module, the species were identified and recorded as occurring within the smallest nested quadrat (0.1 m^2), then the next largest quadrat (1.0 m^2), and so forth (10 m^2 and 100 m^2) until the entire 10 m x 10 m intensive module had been searched. All species less than six meters in height that occurred within an intensive module were identified and assigned a cover class on a scale of 1–10 (1 = solitary or few individuals, 2 = 0–1%, 3 = 1–2%, 4 = 2–5%, 5 = 5–10%, 6 = 10–25%, 7 = 25–50%, 8 = 50–75%, 9 = 75–95%, 10 = 95–99%). For these intensive modules, species cover class values are estimated for the 0.01 ha (100 m^2) area of the intensive module. The remaining modules (termed residual modules) were searched for any species not encountered within the intensive modules, and a cover class was assigned for the residual area (typically 0.06 ha or 600 m^2 in a 2 x 5 plot arrangement). Additionally, in each module, the diameter at breast height (dbh) of all woody species greater than 1 meter in height was measured with a dbh tape and recorded. The field data sheets provided in the OH VIBI manual were used to record these data (Mack 2007b).

The OH VIBI protocol used in this study is similar to the National Wetland Condition Assessment (NWCA) protocol that was used to assess wetlands during the first-ever national survey on the ecological condition of wetlands that occurred in 2011

(USEPA 2011). In the NWCA assessment protocol, plots are not arranged in a contiguous fashion like they are in the OH VIBI; rather they are separated from each other and are arranged in a systematic, almost circular pattern. However, the NWCA and OH VIBI protocols share critical features. Specifically, individual plots (i.e. modules) are the same size (10 m x 10 m), and vegetation is assessed using the same nested quadrat approach. One important distinction is that in the NWCA protocol species are assigned a cover percentage (to nearest whole percent) for vegetation that is rooted in or overhanging the plot; this is different than the OH VIBI protocol in which only vegetation rooted within the plot is assigned a cover class on a scale of 1–10. Additionally, cover percentages and dbh are assigned and measured for all tree species greater than 5 cm dbh according to the NWCA protocol; whereas according to the OH VIBI protocol only dbh is measured for woody species greater than 1 m in height (no size limit on dbh) and cover is not estimated. The similarities should allow future studies to combine data from both approaches.

Vegetation voucher specimens of a few representative species were collected at each site sampled. Unknown specimens were also collected for later identification. Identification numbers for unknown and voucher specimens were recorded in a field notebook. Voucher and unknown specimens were placed in zip-lock bags and put in a cooler at the field sites. Specimens were then transferred to a refrigerator located in the Wetland Ecology lab at EKU until they could be processed and identified at a later date (usually the next day). Voucher and unknown specimens were verified using taxonomic keys (e.g. Jones 2005) in the lab and then placed in a field press with blotting paper, newspaper, and cardboard. Specimens were then labeled with a corresponding identification number, date, site location, associated species, and vegetation community. The field presses were then placed in an area that allowed them to dry. Specimens were not accessioned into the EKU herbarium.

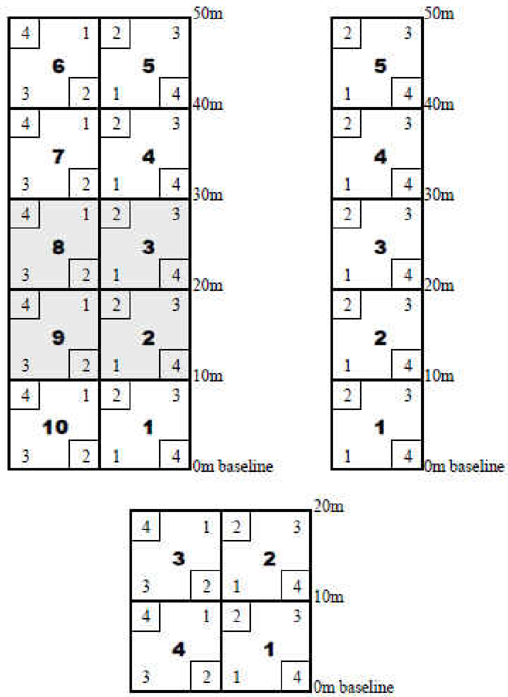

Figure 1. OH VIBI possible vegetation plot sampling configurations. Standard plot design (upper left) consisting of 10 modules in a 2 x 5 arrangement with the four modules sampled intensively colored gray. Most wetlands (n = 32) were sampled with standard (2 x 5) plot design. In instances where a standard plot design would not fit, alternate plot layouts (n = 36) were used (e.g. 2 x 2, 1 x 4, 2 x 4, etc.). In alternate plot layouts where more than four modules were used, only four of the modules were sampled intensively. In alternate plot layouts where less than four modules where used, all the modules were sampled intensively.

Source: Mack, J.J. 2007b. Integrated wetland assessment program. Part 9: field manual for the vegetation index of biotic integrity for wetlands version 1.4. Ohio EPA Technical Report WET/2007-6. Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, OH. http://www.epa.ohio.gov/dsw/wetlands/WetlandEcologySection_reports.aspx. Accessed January, 2012.

Development of Metrics

All 19 of the OH VIBI metrics were included in the list of candidate metrics for the KY VIBI. An additional 102 metrics were included as candidate metrics (Table 2). The majority of these metrics come from the metric list of a Colorado-based VIBI development study (Lemly and Rocchio 2009). Several newly hypothesized metrics were also included in the candidate metrics list: Mean Wetland Indicator, Cover-weighted Mean Wetland Indicator, % Native Wetland Shrub, Relative Cover Native Wetland Shrub, Absolute Cover Native Wetland Shrub, Absolute Cover Sensitive, and Prevalence.

Table 2. List of candidate metrics for the KY VIBI (some metrics taken from Mack 2007b, and Lemly and Rocchio 2009).

Metric	**Description**
Dicot	Count of native dicot species
Shade	Number of shade or partial shade species
Natwtldshrub	Count of native wetland shrubs (FACW, OBL)
Hydrophyte	Count of native species (FACW, OBL)
SVP	Count of seedless vascular plants (ferns and fern allies)
% Bryophyte	Sum of relative cover for bryophytes (includes *Riccia* and *Ricciocarpus*)
% Invasive graminoids	Sum of relative cover of *Phalaris, Typha,* and *Phragmites*
Small tree	Sum of relative tree density for 10-15 cm, 15-20 cm, and 20-25 cm
Subcanopy IV	Sum of average importance value of native shade tolerant subcanopy species and native facultative shade subcanopy species
Canopy IV	Average importance value of native canopy (tree) species
Biomass	Average of grams per square meter of standing biomass samples
Stems/ha wetland trees	Stems per hectare of native wetland trees (FACW, OBL)
Stems/ha wetland shrubs	Stems per hectare of native wetland shrubs (FACW, OBL)
% Unvegetated	Sum of percent unvegetated open water, bare ground, and relative cover of annual species
% Buttonbush	Sum of relative cover of *Cephalanthus occidentalis*
% Perennial native hydrophytes	Sum of relative cover of perennial native hydrophyte species (FACW, OBL)
Mean C (all species)	Average CofC score for all species
Mean C (native)	Average CofC score for native species
Cover-weighted mean C (all species)	Average of absolute cover multiplied by CofC score for all species
Cover-weighted mean C (native)	Average of absolute cover multiplied by CofC score for native species
FQAI (all species)	Sum of CofC scores divided by the square root of the number of all species
FQAI (native)	Sum of CofC scores divided by the square root of the number of native species
Cover-weighted FQAI (all species)	Sum of absolute cover multiplied by CofC scores divided by the square root of the number of all species
Cover-weighted FQAI (native)	Sum of absolute cover multiplied by CofC scores divided by the square root of the number of native species
AFQI	Sum of CofC scores divided by the square root of the number of all species (invasive species are given CofC value of -1, -2, or -3)
Cover-weighted AFQI	Sum of absolute cover multiplied by CofC scores divided by the square root of the number of all species (invasive species are given CofC value of -1, -2, or -3)

Table 2 (continued)

Metric	Description
Count intolerant	Count of all intolerant species
% Intolerant	Number of intolerant species divided by total number of species
Absolute cover intolerant	Sum of absolute cover of intolerant species
Relative cover intolerant	Sum of relative cover of intolerant species
Tolerant : intolerant ratio	Ratio of tolerant species to intolerant species
Absolute cover tolerant : intolerant ratio	Ratio of absolute cover of tolerant species to absolute cover of intolerant species
Count tolerant	Count of tolerant species
% Tolerant	Number of tolerant species divided by total number of species
Relative cover tolerant	Sum of relative cover of tolerant species
Absolute cover tolerant	Sum of absolute cover of tolerant species
Count all species	Count of all species
Count native	Count of native species
Count non-native	Count of non-native species
% Non-native	Number of non-native species divided by total number of species
Absolute cover non-native	Sum of absolute cover of non-native species
Relative cover non-native	Sum of relative cover of non-native species
Absolute cover native	Sum of absolute cover of native species
Relative cover native	Sum of relative cover of native species
Non-native : native ratio	Ratio of non-native species to native species
Count annual	Count of annual species
% Annual	Number of annual species divided by total number of species
Absolute cover annual	Sum of absolute cover of annual species
Relative cover annual	Sum of relative cover of annual species
Annual : perennial ratio	Ratio of annual species to perennial species
Absolute cover annual : perennial ratio	Ratio of absolute cover of annual species to absolute cover of perennial species
Count native annual	Count of native annual species
% Native annual	Number of native annual species divided by total number of species
Absolute cover native annual	Sum of absolute cover of native annual species
Relative cover native annual	Sum of relative cover of native annual species
Native annual : native perennial ratio	Ratio of native annual species to native perennial species
Absolute cover native annual : native perennial ratio	Ratio of absolute cover native annual species to absolute cover of native perennial species
Count perennial	Count of perennial species
% Perennial	Number of perennial species divided by total number of species

Table 2 (continued)

Metric	Description
Absolute cover perennial	Sum of absolute cover of perennial species
Relative cover perennial	Sum of relative cover of perennial species
Count native perennial	Count of native perennial species
% Native perennial	Number of native perennial species divided by total number of species
Absolute cover native perennial	Sum of absolute cover of native perennial species
Relative cover native perennial	Sum of relative cover of native perennial species
Count woody	Count of woody species
% Woody	Number of woody species divided by total number of species
Absolute cover woody	Sum of absolute cover of woody species
Relative cover woody	Sum of relative cover of woody species
Count native woody	Count of native woody species
% Native woody	Number of native woody species divided by total number of species
Absolute cover native woody	Sum of absolute cover of native woody species
Relative cover native woody	Sum of relative cover of native woody species
Count forb	Count of forb species
% Forb	Number of forb species divided by the total number of species
Absolute cover forb	Sum of absolute cover of forb species
Relative cover forb	Sum of relative cover of forb species
Forb : graminoid ratio	Ratio of forb species to graminoid species
Absolute cover forb : graminoid ratio	Ratio of absolute cover of forb species to absolute cover of graminoid species
Count native forb	Count of native forb species
% Native forb	Number of native forb species divided by the total number of species
Absolute cover native forb	Sum of the absolute cover of native forb species
Relative cover native forb	Sum of relative cover of native forb species
Native forb : native graminoid ratio	Ratio of native forb species to native graminoid species
Absolute cover native forb : native graminoid ratio	Ratio of absolute cover of native forb species to absolute cover of native graminoid species
Count graminoid	Count of graminoid species
% Graminoid	Number of graminoid species divided by total number of species
Absolute cover graminoid	Sum of absolute cover of graminoid species
Relative cover graminoid	Sum of relative cover of graminoid species
Count native graminoid	Count of native graminoid species
% Native graminoid	Number of native graminoid species divided by total number of species
Absolute cover native graminoid	Sum of absolute cover of native graminoid species

Table 2 (continued)

Metric	Description
Relative cover native graminoid	Sum of relative cover of native graminoid species
Count shrub	Count of shrub species
% Shrub	Number of shrub species divided by total number of species
Absolute cover shrub	Sum of absolute cover of shrub species
Relative cover shrub	Sum of relative cover of shrub species
Count native wetland shrub	Count of native wetland (FACW, OBL) shrub species
% Native wetland shrub	Number of native wetland shrub species (FACW, OBL) divided by total number of species
Relative cover native wetland shrub	Sum of relative cover of native wetland shrub species (FACW, OBL)
Count native shrub	Count of native shrub species
% Native shrub	Number of native shrub species divided by total number of species
Absolute cover native shrub	Sum of absolute cover of native shrub species
Relative cover native shrub	Sum of relative cover of native shrub species
Count hydrophytes	Count of hydrophyte species (FACW, OBL)
% Hydrophytes	Number of hydrophyte species (FACW, OBL) divided by total number of species
Absolute cover hydrophytes	Sum of absolute cover of hydrophyte species (FACW, OBL)
Relative cover hydrophytes	Sum of relative cover of hydrophyte species (FACW, OBL)
Mean wetland indicator	Sum of wetland indicator scores (e.g. OBL = 10, FACW+ = 9, FACW = 8, etc.) divided by total number of species
Count Carex	Count of all species in genus Carex
% Carex	Number of Carex species divided by total number of species
Absolute cover Carex	Sum of absolute cover of Carex species
Relative cover Carex	Sum of relative cover of Carex species
Count Cyperaceae	Count of all species in family Cyperaceae
Absolute cover Cyperaceae	Sum of absolute cover of Cyperaceae species
Relative cover Cyperaceae	Sum of relative cover of Cyperaceae species
Absolute cover sensitive	Sum of absolute cover of sensitive species (i.e. CofC ≥ 6)
Relative cover sensitive	Sum of relative cover of sensitive species (i.e. CofC ≥ 6)
Prevalence index	Sum of cover-weighted wetland indicator scores divided by total cover
Cover-weighted mean wetland indicator	Sum of cover-weighted wetland indicator scores divided by total number of species

Data Analysis

The candidate KY VIBI metrics were calculated for each wetland with data collected during the 2011, 2012, and 2013 summer sampling periods from wetlands in Kentucky. In order to accomplish this, a plant species database of the vascular flora of Kentucky was used for metric calculation (Shea et al. 2010). This database contains all of the plant species attribute data that are necessary for metric calculation including the Coefficient of Conservatism (CofC) values, nativity status, life form code, and wetland indicator status. The Kentucky CofC values range from 0 to 10 and are assigned to all native plant species. This value is based upon a species' affinity for growing in specific habitats. Species that can occupy a wide range of habitats are assigned a value closer to 0, whereas species that occupy a narrow range of habitats are assigned a value closer to 10 (Andreas et al. 2004; Rocchio 2007, Shea et al. 2010). These CofC values are used to determine floristic quality and are used in the floristic quality assessment index (FQAI) metric and variations of that metric, as species are categorized as either tolerant, midrange, or sensitive based upon their CofC values. Species with values ranging from 0 to 2 are considered tolerant, values ranging from 3 to 5 are considered moderate, and values ranging from 6 to 10 are considered sensitive. Non-native species are given a default value of 0 for the floristic quality assessment index (FQAI) metric and all variations of the FQAI metric.

As part of a separate metric calculation, invasive species were also assigned negative CofC values based upon their level of invasiveness. These values are necessary to calculate the adjusted floristic quality index (AFQI) metric and all variations of the AFQI metric. The Kentucky Exotic Pest Plant Council (KY EPPC) has a published list of invasive species that occur in the state and their appropriate invasiveness categories (Kentucky Exotic Pest Plant Council 2013). Invasive species were assigned values ranging from -3 to 0, based upon the KY EPPC list.

The prevalence metric is used by the U.S. Army Corps of Engineers (USACE) in regional delineation supplements to determine if an area has hydrophytic vegetation indicators of a wetland. Since this metric is already used by a regulatory agency to determine the presence or absence of wetland vegetation, it was a logical metric to incorporate into the candidate metric list. This metric is calculated by the sum of cover-weighted wetland indicator scores (e.g. OBL = 10, FACW+ = 9, FACW = 8, FACW- = 7, FAC+ = 6, FAC = 5, FAC- = 4, FACU+ = 3, FACU = 2, FACU- = 1, UPL = 0) divided by the total cover.

I evaluated the candidate metrics by comparing each metric to an independent measure of wetland disturbance. This statistical comparison was used to identify the metrics most strongly associated with disturbance and to eliminate poorly performing metrics from the candidate list for the KY VIBI. Two types of data were collected from each wetland to develop independent composite indices of wetland disturbance. The disturbance indices were created by combining the LDI and the non-biological submetrics of the KY-WRAM.

The LDI was calculated for each wetland site sampled in Kentucky. The LDI is an index that quantifies human disturbance of geographic areas by multiplying land use percentages with a weighted factor based on the energy required to maintain that land use (Brown and Vivas 2005; Mack 2007a; Gara and Micacchion 2010). The LDI is calculated by the following equation:

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

where, LDI_{total} is the LDI ranking for a 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 type i (Table 3, Brown and Vivas 2005). Higher LDI scores indicate areas that require large amounts of energy to maintain, such as paved parking lots, which are typically associated with more disturbances; conversely lower LDI scores indicate more natural areas, such as lakes, ponds, forests, and grasslands (Table 4). I used ArcMap 10.0 to calculate LDI scores for each site (Environmental Systems Research Institute 2011). The 2005 National Land Cover Database raster layer for Kentucky (ky_lc2005) was used as the base layer for calculating land use values. This dataset was downloaded from *ftp://ftp.kymartian.ky.gov/kls/KY_LC2005.zip* (Kentucky Division of Geographic Information 2007). Calculations at each site were based on a 1000-m buffer around the wetland's outer boundary as determined by National Wetland Inventory polygons and field-truthing. Means for LDI scores are presented as mean ± 1 SE.

Each wetland was also scored using the KY-WRAM (KYDOW 2013a). The KY-WRAM includes six metrics that together describe the stressors and functions of a wetland (KYDOW 2013b). Each metric consists of two or more component sub-metrics. Ten submetrics from the KY-WRAM were used for my analyses (Table 5). These submetrics come from three of the six primary metrics in the KY-WRAM: Metric 2 (buffers and intensity of surrounding land use), Metric 3 (hydrology), and Metric 4 (habitat alteration and habitat structure development). These submetrics are primarily non-biological and characterize wetland stressors that reflect elements of post and current disturbance. The total possible score of these submetrics was 60 points. I included the LDI value and the ten non-biological KY-WRAM submetrics in a PCA using Program R, Package Vegan (R Core Team 2013). Scores from the PCA axis 1 (PC1) and axis 2 (PC2) were used as composite disturbance indices. The primary disturbance metric (PC1) was tested for normality across sites within wetland types (i.e. emergent, shrub, and forest) and basins (i.e. Green River, Kentucky River, and Upper Cumberland) using the Kolmogorov-Smirnov (K-S) test. Means for PC1 scores are presented as mean ± 1 SE. The KY VIBI candidate metrics were tested for association with the disturbance index using Pearson's correlation. After narrowing the list based on correlation with the disturbance index, I tested for multicollinearity among the remaining candidate metrics by calculating pairwise Pearson's correlations and inspecting matrix scatterplots. All correlation analysis and scatterplots were conducted using SPSS version 21 (IBM SPSS 2012).

Table 3. Definition of LDI formula terms.

Abbreviation	Explanation
LU	Number of 30 x 30 pixels of a specific Land Use Type within a calculated buffer.
%LU	Land Use converted to a percentage. *%LU* = (Number of specific land use pixels)/(Total number of pixels in buffer).
LDI_i	LDI coefficient. Given to each land use type. 1 = natural system, 10 = completely disturbed.
LDI	All $\%LU \cdot LDI_i$ are summed, resulting in a number between 1 and 10. 1 indicates a natural system surrounding the wetland, 10 indicates a completely disturbed surrounding.

Table 4. Values for LDI coefficients based on land use types listed in *ky_lc2005* raster.

Land Use Type (color and number value)	Land Use Type	LDIi
11	Open Water	**1** (Mack 2007)
21	Developed, Open Space	**6.92** (Mack 2006, 2007)
22	Developed, Low Intensity	**7.55** (Mack 2006, 2007)
23	Developed, Medium intensity	**9.42** (Mack 2006, 2007)
24	Developed, High Intensity	**10** (Brown and Vivas 2005)
31	Barren Land	**8.32** (Mack 2006, 2007)
41	Deciduous Forest	**1** (Mack 2006, 2007)
42	Evergreen Forest	**1** (Mack 2006, 2007)
43	Mixed Forest	**1** (Mack 2006, 2007)
52	Scrub/Shrub	**1** (Congalton and Green 2009)
71	Grassland/Herbaceous	**1** (Congalton and Green 2009)
81	Pasture/Hay	**3.41** (Mack 2006, 2007)
82	Cultivated Crops	**7** (Mack 2006, 2007)
90	Woody Wetlands	**1** (Mack 2006, 2007)
95	Emergent Herbaceous Wetlands	**1** (Mack 2006, 2007)

Table 5. List and description of KY-WRAM submetrics used along with the LDI in the PCA to create disturbance indices.

Metric 2. Buffers and Intensity of Surrounding Land Use

2a. Average Buffer Width around the Wetland's Perimeter – Maximum 4 points.
2b. Intensity of Surrounding Land Use within 1,000 feet of the Wetland – Maximum 4 points.
2c. Connectivity to Other Natural Areas – Maximum 4 points.

Metric 3. Hydrology

3a. Input of Water From an Outside Source – Maximum 9 points.
3b. Hydrological Connectivity – Maximum 6 points.
3c. Duration of Inundation/Saturation – Maximum 4 points.
3d. Alterations to Natural Hydrologic Regime – Maximum 9 points.

Metric 4. Habitat Alteration and Habitat Structure Development

4a. Substrate/Soil Disturbance – Maximum 4 points.
4b. Habitat Alteration – Maximum 9 points.
4c. Habitat Reference Comparison – Maximum 7 points.

III. RESULTS

In total, 68 wetland sites were sampled from 2011 to 2013 (Figure 2, Table A-1). Twenty-one sites were located in the Upper Cumberland River basin, 29 in the Kentucky River basin, and 18 in the Green River basin. Additionally, 25 of the sites were classified as emergent, 37 were classified as forested, and 6 were classified as shrub. Of the 68 sites sampled, 454 species of vascular plants were encountered. Of the 454 species, 60 species were considered non-native, and 8 were state-listed as threatened or endangered (Table A-2).

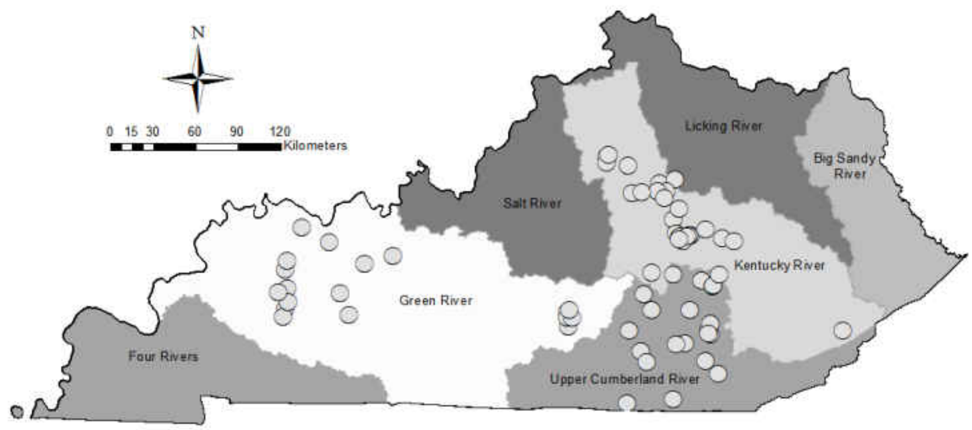

Figure 2. VIBI sampling sites from 2011–2013 in the Green River, Upper Cumberland, and Kentucky River basins.

LDI scores ranged from 1.2–7.0 with a mean ± SE of 3.1 ± 0.2. The sum of the KY-WRAM submetric scores ranged from 13.2–53.8 with a mean ± SE of 34.0 ± 1.2 (Table A-3).

The first two PC axes explained 48.35% and 13.47% of the total variation, respectively, and so those two axes were retained for comparison to the candidate KY VIBI metrics (Table 6).

The ordination plot shows the KY-WRAM submetrics associated with disturbances to the landscape, soil, and hydrology shared variance and loaded strongly on PC1 (Table 7 & Figure 3). The LDI also loaded strongly on PC1, but in the opposite direction as the KY-WRAM submetrics. This was expected since the values are opposite in relation to disturbance: low LDI reflects a low degree of disturbance, whereas high KY-WRAM reflects a low degree of disturbance. The variables that loaded strongly on PC2 were associated with hydrologic connectivity and inputs. Low PC1 scores (negative values) indicate sites that had relatively high levels of disturbance, whereas relatively high PC1 scores are indicative of low disturbance sites. The KY-WRAM submetrics 3a (hydrology input) and 3b (hydrology connectivity) loaded strongly on PC2. For this axis, lower scoring sites had relatively higher disturbance.

Emergent wetlands (n = 25) had a mean PC1 value ± SE of 0.138 ± 0.131, and the scores were normally distributed (K-S test: $X^2 = 0.145$, df = 25, p = 0.183). Forested wetlands (n = 37) had a mean PC1 value ± SE of -0.035 ± 0.095, and the scores were normally distributed (K-S test: $X^2 = 0.060$, df = 37, p = 0.200). Shrub wetlands (n = 6) had a mean PC1 value ± SE of -0.360 ± 0.347, and the scores were normally distributed ($X^2 = 0.278$, df = 6, p = 0.163). The Green River basin (n = 19) had a mean PC1 value ± SE of 0.197 ± 0.124, and the scores were normally distributed (K-S test: $X^2 = 0.115$, df = 19, p = 0.200). The Kentucky River basin (n = 28) had a mean PC1 value ± SE of 0.184 ± 0.112, and the scores were normally distributed (K-S test: $X^2 = 0.099$, df = 28, p = 0.200). The Upper Cumberland River basin (n = 21) had a mean PC1 value ± SE of -0.423 ± 0.128, and the scores were normally distributed (K-S test: $X^2 = 0.138$, df = 21, p = 0.200).

A high proportion of the correlation coefficients between candidate metrics and disturbance indices (PC1 and PC2) were very low (Table A-4). For example, for the emergent sites (n = 25) only 31 metrics had correlation coefficients greater than 0.3 with PC1, and only 16 metrics had correlation coefficients greater than 0.3 with PC2. In general, correlations with PC2 tended to be lower than with PC1. Because PC2 had explained less of the variance among the disturbance variables and tended to have lower correlation with metrics, I used correlations of metrics with PC1 as the primary criterion for selecting or eliminating candidate metrics. Metrics were ranked according to correlation coefficients to aid in the metric elimination and selection process. In instances where there were two or more metrics that were variations of the same basic metric (e.g. Count Carex, % Carex, Absolute Cover Carex, Relative Cover Carex) that had similar Pearson correlation values with PC1 or PC2, the metric with the highest correlation value was selected and the others were eliminated. This step was not based on statistical multicollinearity. In instances where correlations with PC1 were nearly identical between non-biologically related metrics, PC2 was used as an alternate criterion for selecting or eliminating metrics. PC2 was also used to select several biologically unique metrics that did not show significant, correlation to PC1, but had statistically significant correlation to PC2. A list of 12 metrics for each wetland type was compiled using this approach.

Multicollinearity among the top 12 metrics for emergent (Fig. 4, Table 8), forested (Fig. 5, Table 9), and shrub (Fig. 6, Table 10) wetlands was low, in general, but there were a few metrics correlated with each other. For example, the non-native to native ratio metric and the AFQI metric each displayed strong correlations with several other metrics in the emergent multicollinearity matrix. For the forested multicollinearity matrix, the mean C of all species metric was strongly correlated with the percent intolerant metric. In the shrub multicollinearity matrix, the relative cover native annual metric and the absolute cover native annual to perennial ratio metric were highly correlated with each other. Due to multicollinearity with other metrics, several metrics were eliminated from the list of top 12 metrics based on their r-values to create a list of the ten best metrics for each wetland type (Table 11, 12, 13).

Table 6. Eigenvalues and the proportion of the total variance explained by each axis of the Principal Components Analysis. The top two axes (PC1 and PC2) were used to describe disturbance.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11
Eigenvalue	5.3187	1.4818	1.1774	1.0107	0.5931	0.4067	0.3502	0.2124	0.1825	0.1514	0.1152
Proportion Explained	0.4835	0.1347	0.1070	0.0919	0.0539	0.0370	0.0318	0.0193	0.0166	0.0138	0.0105

Table 7. PCA metric loading scores representing the contribution of each variable to PC1 and PC2.

	Fig. 3 Labels	PC1	PC2
LDI Score	Ldi	0.3069	-0.0682
Buffer Width	k2a	-0.3413	-0.1652
Surrounding Land Use	k2b	-0.3624	0.0944
Connectivity	k2c	-0.3463	-0.0328
Hydrology Input	k3a	-0.0474	-0.6121
Hydrology Connectivity	k3b	-0.0073	-0.6935
Hydrologic Duration	k3c	-0.1082	0.2673
Hydrological Alterations	k3d	-0.3630	-0.0938
Soil Disturbance	k4a	-0.3499	0.0473
Habitat Alteration	k4b	-0.3905	-0.0310
Reference Comparison	k4c	-0.3425	0.1383

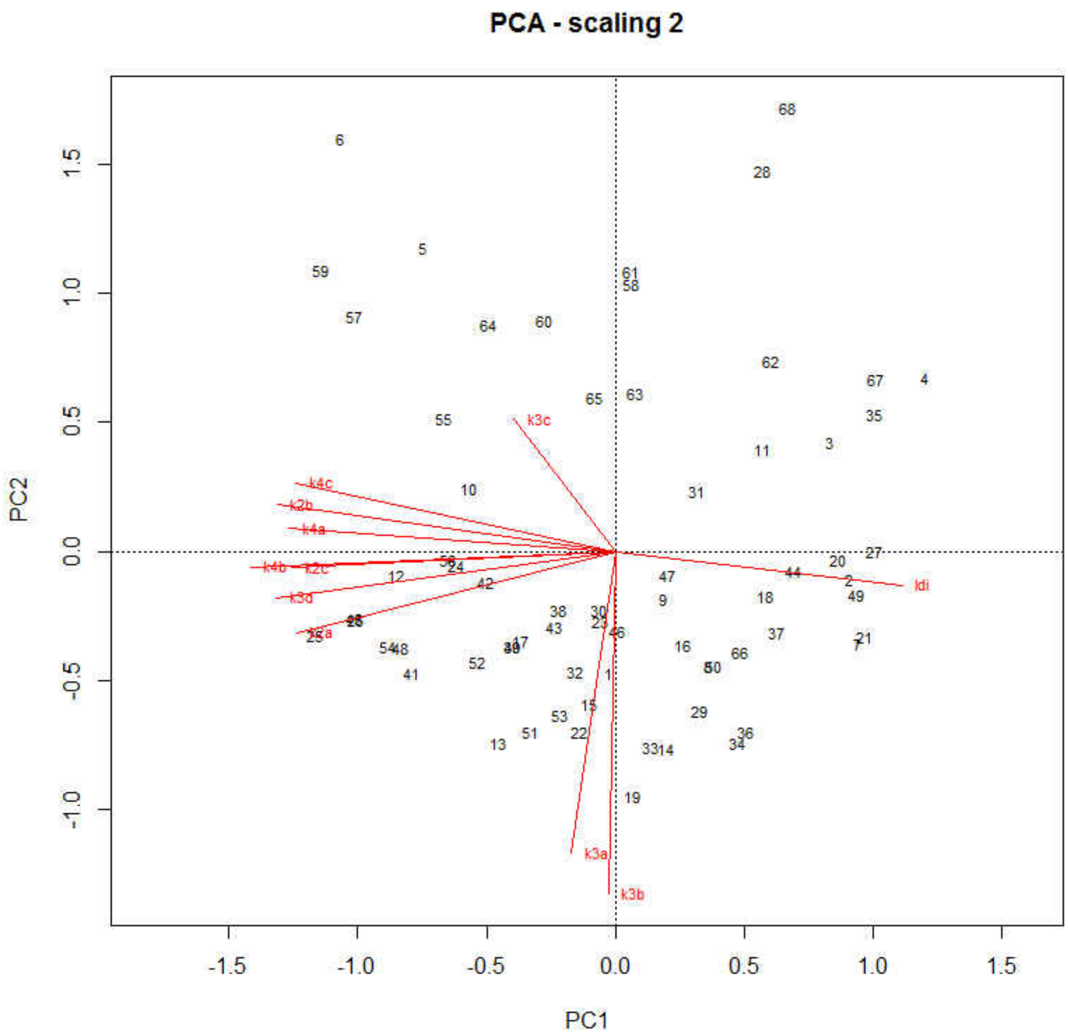

Figure 3. Ordination graph of PCA (scaling = 2) showing site scores and metric loadings on PC1 and PC2 axes. Sites are labeled with numbers that correspond to Table A-2. Disturbance metrics are labeled with numbers that correspond to Table 7.

Table 8. Matrix of Pearson correlation coefficients for the top 12 emergent metrics used to check for multicollinearity among metrics. Two-tailed p-values are shown in italics below each r-value.

	Dicot	Mean C all species	AFQI	Percent intolerant	Absolute cover tolerant	Percent non-native species	Non-native : native ratio	Relative cover native woody	Percent native forb	Percent Carex	Relative cover sensitive	Prevalence
Dicot	1											
Mean C all species	0.399 *0.048*	1										
AFQI	0.772 *0.000*	0.860 *0.000*	1									
Percent intolerant	0.283 *0.170*	0.943 *0.000*	0.751 *0.000*	1								
Absolute cover tolerant	-0.257 *0.214*	-0.616 *0.001*	-0.549 *0.004*	-0.607 *0.001*	1							
Percent non-native species	-0.371 *0.068*	-0.864 *0.000*	-0.763 *0.000*	-0.875 *0.000*	0.577 *0.003*	1						
Non-native : native ratio	-0.359 *0.078*	-0.825 *0.000*	-0.730 *0.000*	-0.852 *0.000*	0.558 *0.004*	0.989 *0.000*	1					
Relative cover native woody	0.608 *0.001*	0.474 *0.017*	0.625 *0.001*	0.365 *0.073*	-0.365 *0.073*	-0.451 *0.024*	-0.416 *0.038*	1				
Percent native forb	0.334 *0.102*	0.439 *0.028*	0.418 *0.038*	0.522 *0.007*	-0.293 *0.156*	-0.540 *0.005*	-0.560 *0.004*	0.061 *0.773*	1			
Percent Carex	-0.003 *0.990*	-0.339 *0.097*	-0.145 *0.489*	-0.297 *0.149*	-0.047 *0.823*	0.324 *0.115*	0.266 *0.199*	-0.102 *0.628*	-0.327 *0.111*	1		
Relative cover sensitive	0.182 *0.383*	0.485 *0.014*	0.467 *0.018*	0.398 *0.049*	-0.396 *0.050*	-0.395 *0.051*	-0.357 *0.080*	0.157 *0.454*	0.229 *0.271*	0.001 *0.997*	1	
Prevalence	0.493 *0.012*	0.376 *0.064*	0.499 *0.011*	0.275 *0.183*	-0.059 *0.779*	-0.266 *0.198*	-0.231 *0.268*	0.530 *0.006*	0.199 *0.340*	-0.349 *0.087*	0.007 *0.975*	1

Table 9. Matrix of Pearson correlation coefficients for the top 12 forested metrics used to check for multicollinearity among metrics. Two-tailed p-values are shown in italics below each r-value.

	Mean C all species	Dicot	Percent intolerant	Relative cover tolerant	Absolute cover intolerant : tolerant ratio	Percent non-native species	Non-native : native ratio	Relative cover native annual	Absolute cover native annual : perennial ratio	Absolute cover perennial	Percent native shrub	Absolute cover forb
Mean C all species	1											
Dicot	0.027 *0.872*	1										
Percent intolerant	0.892 *0.000*	0.032 *0.851*	1									
Relative cover tolerant	-0.242 *0.149*	-0.004 *0.980*	-0.118 *0.486*	1								
Absolute cover intolerant : tolerant ratio	-0.168 *0.319*	0.006 *0.973*	-0.085 *0.618*	0.929 *0.000*	1							
Percent non-native species	-0.544 *0.000*	-0.044 *0.795*	-0.540 *0.001*	0.180 *0.286*	0.100 *0.557*	1						
Non-native : native ratio	-0.505 *0.001*	-0.065 *0.701*	-0.495 *0.002*	0.196 *0.245*	0.115 *0.499*	0.991 *0.000*	1					
Relative cover native annual	0.040 *0.814*	0.135 *0.426*	0.083 *0.625*	0.010 *0.953*	0.016 *0.927*	-0.124 *0.465*	-0.108 *0.524*	1				
Absolute cover native annual : perennial ratio	0.113 *0.504*	0.048 *0.779*	0.155 *0.359*	-0.005 *0.978*	0.007 *0.967*	-0.176 *0.298*	-0.159 *0.348*	0.971 *0.000*	1			
Absolute cover perennial	-0.217 *0.197*	0.122 *0.473*	-0.198 *0.239*	0.065 *0.702*	0.013 *0.940*	0.593 *0.000*	0.612 *0.000*	-0.061 *0.718*	-0.146 *0.389*	1		
Percent native shrub	0.267 *0.110*	0.019 *0.912*	0.181 *0.284*	-0.372 *0.023*	-0.401 *0.014*	-0.453 *0.005*	-0.438 *0.007*	0.050 *0.770*	0.100 *0.555*	-0.435 *0.007*	1	
Absolute cover forb	-0.177 *0.294*	0.065 *0.704*	-0.131 *0.440*	0.059 *0.728*	0.058 *0.734*	0.614 *0.000*	0.614 *0.000*	0.192 *0.255*	0.114 *0.502*	0.804 *0.000*	-0.557 *0.000*	1

Table 10. Matrix of Pearson correlation coefficients for the top 12 shrub metrics used to check for multicollinearity among metrics. Two-tailed p-values are shown in italics below each r-value.

	Mean C all species	Dicot	Percent intolerant	Relative cover tolerant	Absolute cover intolerant : tolerant ratio	Percent non-native species	Non-native : native ratio	Relative cover native annual	Absolute cover native annual : perennial ratio	Absolute cover perennial	Percent native shrub	Absolute cover forb
Mean C all species	1											
Dicot	-0.775 *0.071*	1										
Percent intolerant	0.973 *0.001*	-0.805 *0.053*	1									
Relative cover tolerant	-0.949 *0.004*	0.704 *0.119*	-0.882 *0.020*	1								
Absolute cover intolerant : tolerant ratio	-0.904 *0.013*	0.733 *0.097*	-0.889 *0.018*	0.961 *0.002*	1							
Percent non-native species	-0.901 *0.014*	0.901 *0.014*	-0.901 *0.014*	0.906 *0.013*	0.942 *0.005*	1						
Non-native : native ratio	-0.887 *0.018*	0.884 *0.020*	-0.896 *0.016*	0.902 *0.014*	0.955 *0.003*	0.997 *0.000*	1					
Relative cover native annual	-0.876 *0.022*	0.835 *0.039*	-0.802 *0.055*	0.921 *0.009*	0.877 *0.022*	0.943 *0.005*	0.922 *0.009*	1				
Absolute cover native annual : perennial ratio	-0.860 *0.028*	0.864 *0.026*	-0.802 *0.055*	0.881 *0.020*	0.846 *0.034*	0.946 *0.004*	0.923 *0.009*	0.993 *0.000*	1			
Absolute cover perennial	-0.704 *0.119*	0.786 *0.064*	-0.632 *0.178*	0.816 *0.047*	0.818 *0.046*	0.893 *0.016*	0.883 *0.020*	0.950 *0.004*	0.944 *0.005*	1		
Percent native shrub	0.738 *0.094*	-0.792 *0.060*	0.627 *0.182*	-0.788 *0.063*	-0.693 *0.127*	-0.816 *0.048*	-0.778 *0.068*	-0.950 *0.004*	-0.948 *0.004*	-0.921 *0.009*	1	
Absolute cover forb	-0.838 *0.037*	0.894 *0.016*	-0.801 *0.056*	0.779 *0.068*	0.725 *0.103*	0.890 *0.017*	0.854 *0.030*	0.931 *0.007*	0.962 *0.002*	0.840 *0.036*	-0.916 *0.010*	1

Table 11. List of best ten candidate metrics for KY VIBI-Emergent with Pearson correlation coefficients with PC1 and PC2. Two-tailed p-values are shown in italics below each r-value.

Metric	PC1	PC2
Dicot	-0.397* *0.050*	0.174 *0.405*
Mean C All Species	-0.576** *0.003*	0.163 *0.437*
% Intolerant	-0.509** *0.009*	0.061 *0.773*
Absolute Cover Tolerant	0.491* *0.013*	-0.009 *0.964*
% Non-native Species	0.557** *0.004*	-0.011 *0.960*
Relative Cover Native Woody	-0.373 *0.066*	0.276 *0.182*
% Native Forb	-0.405* *0.045*	-0.175 *0.403*
% Carex	0.378 *0.062*	0.027 *0.899*
Relative Cover Sensitive	-0.090 *0.670*	0.451* *0.024*
Prevalence	-0.244 *0.240*	0.422* *0.036*

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 12. List of best ten candidate metrics for KY VIBI-Forest with Pearson correlation coefficients with PC1 and PC2. Two-tailed p-values are shown in italics below each r-value.

Metric	PC1	PC2
Stems/ha Wetland Shrubs	-0.244 *0.146*	0.172 *0.309*
Mean C All Species	-0.226 *0.179*	-0.143 *0.399*
Cover Weighted FQAI All Species	-0.215 *0.200*	0.196 *0.246*
Absolute Cover Intolerant : Tolerant Ratio	0.337* *0.041*	-0.032 *0.849*
Absolute Cover Non-native Species	0.402* *0.014*	-0.069 *0.685*
% Bryophyte	-0.251 *0.134*	-0.115 *0.498*
Relative Cover Native Perennial	-0.118 *0.487*	-0.433** *0.007*
Absolute Cover Native Woody	-0.066 *0.700*	0.449** *0.005*
Absolute Cover Native Shrub	-0.305 *0.066*	0.341* *0.039*
Count Native Woody	-0.254 *0.130*	0.121 *0.474*

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 13. List of best ten candidate metrics for KY VIBI-Shrub with Pearson correlation coefficients with PC1 and PC2. Two-tailed p-values are shown in italics below each r-value.

Metric	PC1	PC2
Mean C All Species	-0.929** *0.007*	0.886* *0.019*
Dicot	0.882* *0.020*	-0.673 *0.143*
% Intolerant	-0.891* *0.017*	0.765 *0.077*
Relative Cover Tolerant	0.932** *0.007*	-0.913* *0.011*
Absolute Cover Intolerant : Tolerant Ratio	0.912* *0.011*	-0.780 *0.068*
% Non-native Species	0.979** *0.001*	-0.770 *0.074*
Absolute Cover Native Annual : Perennial Ratio	0.984** *0.000*	-0.838* *0.037*
Absolute Cover Perennial	0.906* *0.013*	-0.742 *0.091*
% Native Shrub	-0.895* *0.016*	0.862* *0.027*
Absolute Cover Forb	0.942** *0.005*	-0.786 *0.064*

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

IV. DISCUSSION

The majority of the sites sampled for this study were randomly chosen, and as expected for a normal distribution, disturbance scores of sites tended to fall near the estimated mean disturbance value. Thus, our efforts to sample more sites of relatively low and high quality through targeted sampling was valuable for discerning the correlation of disturbance with vegetation metrics and allowing a more complete range of disturbance to be captured. The fact that disturbance levels among sites were normally distributed for wetland types (emergent, shrub, and forest) and study basins (Green River, Upper Cumberland River, and Kentucky River) suggests that wetland sites were representative within those types and basins sampled.

The combination of LDI scores with the non-biological submetrics of the KY-WRAM appears to have created a good representation of disturbance. Variable loading scores for the PCA were relatively strongly weighted on just the first and second axis, and variables tended to load strongly on just one axis; therefore, there was good, simple structure in the principal component analysis. Since PC1 explained such a large amount of the variation (48.35%), it was used as the primary index of disturbance for selection of candidate metrics. PC2 was used to select or eliminate metrics when correlation with PC1 scores was nearly identical between metrics. PC2 was also used to select a couple of biologically unique metrics for each wetland type since correlation scores were statistically significant with PC2 but had little to no correlation with PC1. Metrics demonstrated a higher correlation to the disturbance index scores rather than just using the LDI scores, based on preliminary analysis that is not reported here. It appears the composite disturbance indices used here, which combines remote sensing and field assessments, is a robust way to characterize disturbance and has benefits compared to the simpler approach of just using LDI scores to characterize disturbance. However, additional possibilities to improve this disturbance index should be examined in future research. For instance, the LDI coefficients could be adjusted slightly to better fit land uses found in Kentucky, and to create more categories of disturbance. Another possibility is to give higher weight to areas (pixels) closer to the wetland in the LDI calculation.

Additionally, it may be possible to look more closely at the KY-WRAM submetrics and include only those with the strongest loading scores as part of the disturbance index. It might also be beneficial to examine other factors that might help explain the natural environmental variability between wetlands to improve index sensitivity, accuracy, and applicability. Such other factors may be geology, watershed, soil type, climate, ecoregion, and growing season. It would also be beneficial to use ordination or other multivariate statistics techniques to show how the three wetland types (emergent, shrub, and forest) differ from each other in terms of disturbance and species compositions. Such an analysis would provide further evidence and validation of whether it is appropriate to use or eliminate certain metrics for the three wetland types.

A list of the best ten candidate metrics was selected for each wetland type; this was based upon their correlation and response to disturbance, and inspection of scatterplots for multicollinearity. Many of the metrics in the list are related to invasiveness, tolerance, and floristic quality scores (e.g. Mean C All Species, % Non-native Species, % Intolerant). These kinds of metrics are biologically relevant to all three of the wetland types. For example, every plant species that occurs in Kentucky is assigned a CofC value, which reflects the species' fidelity for particular habitats. This CofC value can then be used to interpret how intact a community is, since species which have higher CofC values occupy a narrower range of habitats that likely only occur in conditions of relatively low human disturbance. The average CofC of all species (Mean C All Species) reflects the overall habitat quality of the area, so this metric would be biologically relevant to all three of the wetland types since all wetland types would be expected to respond to disturbance in similar manners. Additionally, invasive species will readily invade disturbed habitats, regardless of habitat type. Therefore, the % Non-native Species metric would be expected to be biologically relevant to the three wetland types.

The best ten candidate metric list also includes metrics that are specific to certain wetland types. For example, the list for emergent wetlands included Dicot, % Native Forb, and % Carex metrics. This makes sense biologically because in emergent wetlands herbaceous plants such as herbs, forbs, and graminoids make up the majority of the plant community, therefore disturbances would likely be reflected in these metrics. Sedges were frequently a dominant component of emergent wetlands, but typically not to the same degree in forested wetlands, so we would expect that a metric that quantifies the cover of sedges, such as the % Carex metric would be a good candidate for the list for emergent wetlands.

The best ten candidate metric list for forested wetlands included Stems/ha Wetland Shrubs, % Bryophyte, Absolute Cover Native Woody, and Count Native Woody metrics. All of these reflect biological characteristics of forested wetlands, but not emergent wetlands. For example, the % Bryophyte metric is biologically relevant for forested wetlands since bryophytes are common in most forests in Kentucky, especially in wet areas such as wetlands. Typically, bryophytes tend to have higher cover and higher species richness in forested wetlands that experience low amounts of disturbance; and conversely, bryophytes species richness and cover are lower in forests that experience high amounts of disturbance (Frego 2007). In other wetland types, such as emergent wetlands, bryophytes would not be as abundant since emergent wetlands are typically open and sunny habitats, areas where bryophytes typically do not occur. Thus, we would not expect this metric to be included in the list for emergent wetlands. Additionally, since trees and shrubs are not dominant components of emergent wetlands, metrics such as Stems/ha Wetland Shrubs, Absolute Cover Native Woody, and Count Native Woody would not make biological sense for emergent wetlands, but are biologically relevant to forested wetlands.

The % Native Shrub metric occurred in the list of the best ten candidate metrics for shrub wetlands, but not in the lists for emergent or forested wetlands. Shrub wetlands that experience little to no disturbance were typically dominated by native species such as buttonbush (*Cephalanthus occidentalis*), willows (*Salix spp.*), dogwoods (*Cornus spp.*), and swamp rose (*Rosa palustris*). In shrub wetlands that experience more disturbance, non-native species such as amur honeysuckle (*Lonicera maackii*), autumn olive (*Elaeagnus umbellata*), burning bush (*Euonymus alatus*), and multiflora rose *(Rosa multiflora*) tended to be more prevalent. The % Native Shrub metric reflects this pattern and thus creates a simple summary measure of wetland disturbance in shrub wetlands.

Several of the metrics currently used in the OH VIBI showed little to no response to disturbance. For example, metrics such as SVP (seedless vascular plants), Natwtldshrub, Small Tree, and Hydrophyte that are used in the OH VIBI-forest showed little or no relationship to disturbance when applied to forested wetlands in Kentucky. This is surprising because the OH VIBI has been shown to correlate well with disturbance. However, validation studies of the OH VIBI do not report correlations of specific metrics with disturbance, and it is possible that some of the metrics, when taken separately, were not strongly correlated with disturbance. Alternatively, the forested wetlands of Ohio may have a fundamentally different response to disturbance compared to those in Kentucky. For example, most of Ohio's wetlands are found in historically glaciated regions where depressional HGM classes are more common, whereas the majority of Kentucky's wetlands are found along streams and rivers and thus in the riverine HGM class. Seedless vascular plants (i.e. ferns and fern allies) would be expected to be found in more depressional habitats since these depressional wetlands have more stable and predictable hydroperiods and typically experience less natural disturbance. In contrast, riverine wetlands have more natural disturbance from seasonal flooding events that cause sedimentation and scouring, and are thus less conducive for growth and persistence of most ferns and fern allies. Although the OH VIBI provided a sound methodological foundation for developing a VIBI for Kentucky, the results presented here suggest that many of the metrics in the current OH VIBI do not accurately reflect the biological effects of disturbance in Kentucky's wetlands, at least for the three river basins sampled for this study. By selecting and utilizing a different set of metrics with stronger association to disturbance we can more accurately describe wetland quality in the state of Kentucky.

It is worth noting that metric correlation coefficients were in general, much lower for forested wetlands than for the other two wetland types (emergent and shrub). One possible explanation for this is that forested wetlands might be affected by disturbances, such as historical conditions, that are not properly captured by the disturbance index. Another possible explanation is that forested wetlands are more dynamic systems than the other two wetland types, and metric variability is controlled by external environmental factors such as ecoregion, geology, soil type, watershed, etc. that are not accounted for in the disturbance index. More sampling at higher and lower quality sites, along with including other external environmental factors to improve the disturbance index, would likely increase r-values for all wetland types, especially forested wetlands.

The sampling effort for this study, spread over a three year period, yielded high levels of replication for two of three wetland types (emergent and forested). Due to the low number of shrub sites that were sampled, any conclusions drawn from the analysis of the shrub sites should be considered preliminary. Additionally, efforts to concentrate sampling to three basins yielded high levels of replication in each basin. The wetland sites that were sampled as part of this study are representative of the wetland communities and wetland types typically found in those basins; however, there are limitations to extending these findings to other basins across the state. For example, the Four Rivers basin found in the far western portion of Kentucky is primarily located in the Mississippi Embayment ecoregion, which has very different hydrology and vegetation as compared to other ecoregions of the state. The wetlands found in this ecoregion typically consist of large bottomland swamp forests and lowlands often dominated by cypress (*Taxodium distichum*) and other water-dwelling oaks (*Quercus spp.*). These bottomland swamp forests and lowlands are much different wetland communities than the sites sampled as part of this study. There are also other wetland communities, albeit uncommon, that exist in Kentucky that were not captured in this study that may respond to disturbances differently. Such wetland communities include acidic seeps/bogs, isolated ridgetop depressions, sinkhole/depression marshes, and wet meadows.

Since the majority of wetlands in Kentucky are classified as either emergent or forested, future testing should continue to emphasize these wetland types. Focusing on the most common wetland types should help explain more of the variation in the response of wetland vegetation to disturbance and quality, and improve metric calibration. Shrub wetlands should also be sampled in greater numbers to increase the reliability of the correlation analysis of vegetation metrics compared to disturbance indices since the final metrics selected for the shrub wetlands were based on a very small sample size. It is possible that shrub wetlands are more common in other basins, but they were uncommon in the three basins that were the focus of this study. However, they were frequent enough to warrant separate set of metrics. The distinct structure and community composition of shrub wetlands compared to forested and emergent wetlands is further justification for using a separate set of metrics for this wetland type. If resources permit, a sample of 50 or more wetlands per habitat type would be preferred for proper metric calibration.

The list of the best ten candidate metrics presented in this thesis is based on a large sample of wetlands and thus represents a solid starting point, but should not be treated as a completed set of VIBI metrics. The combination of metrics may better reflect disturbance and more accurately assess wetland quality than individual metrics standing alone, especially if the individual metrics are affected by different types of disturbance. The use of both PC1 and PC2 was appropriate for the metric elimination and final selection process since both apparently reflect different disturbances. Metrics that were intercorrelated or closely related to each other (biologically) were eliminated to achieve a list of the best candidate metrics in which each metric represented a unique component that might respond to disturbance in a different manner. Future research should combine these metrics into an IBI and then test the overall correlation of the IBI with a disturbance index. To achieve a final version of the KY VIBI, additional steps may include: creating metric scoring break-points, weighting metrics based on their correlation with disturbance, replacing or modifying metrics that are weakly correlated with disturbance, and scaling metrics to sum to a maximum of 100 points. Closer examination should be given to metrics with non-linear relationships (e.g. curvilinear) to disturbance, since this study did not address such possibilities. To ensure proper calibration of metrics for each of the three wetland types, further sampling and analysis will need to be conducted on this list of metrics. Such work should continue to consider some of the metrics that were dropped from this analysis, especially those metrics that showed moderate correlations with disturbance or those that were dropped because of inter-correlation with retained metrics. Further testing should include all of the remaining basins of Kentucky, including the Salt River, the Licking River, and the basins of western Kentucky.

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APPENDIX

Table A-1. List of vascular plant species encountered during sampling. Non-native species are underlined, and state-listed species (e.g. potentially-threatened, threatened, endangered) are in bold.

Species	Species	Species
Acer negundo	*Aster ontarionis*	***Carex gigantea***
Acer rubrum	*Aster pilosus*	*Carex glaucodea*
Acer saccharinum	*Aster prenanthoides*	*Carex gracillima*
Acer saccharum	*Athyrium filix-femina*	*Carex granularis*
<u>*Acorus calamus*</u>	***Bartonia virginica***	*Carex grayi*
Aesculus flava	<u>*Berberis thunbergii*</u>	*Carex grisea*
Aesculus glabra	*Betula nigra*	*Carex hirsutella*
Agrimonia parviflora	*Bidens cernua*	*Carex hirtifolia*
Aletris farinosa	*Bidens connata*	*Carex hyalinolepis*
Alisma subcordatum	*Bidens coronata*	*Carex intumescens*
<u>*Alliaria petiolata*</u>	*Bidens discoidea*	***Carex joorii***
Allium canadense	*Bidens frondosa*	*Carex lupulina*
<u>*Allium vineale*</u>	*Bignonia capreolata*	*Carex lurida*
Alnus serrulata	*Boehmeria cylindrica*	*Carex muskingumensis*
Ambrosia artemesiifolia	*Botrychium biternatum*	*Carex prasina*
Ambrosia trifida	*Botrychium dissectum*	*Carex radiata*
Amelanchier arborea	*Botrychium virginianum*	*Carex rosea*
Ammania robusta	*Brasenia schreberi*	*Carex scoparia*
Ampelamus albidus	<u>*Bromus tectorum*</u>	*Carex shortiana*
Ampelopsis cordata	*Cacalia atriplicifolia*	*Carex sparganioides*
Amphicarpaea bracteata	*Calystegia sepium*	*Carex squarrosa*
Andropogon gerardii	*Campsis radicans*	*Carex stipata*
Andropogon glomeratus	*Cardamine rhomboidea*	*Carex swanii*
Apios americana	<u>*Carduus nutans*</u>	*Carex tenera*
Apocynum cannabinum	*Carex amphibola*	*Carex tribuloides*
Arisaema dracontinum	*Carex blanda*	*Carex typhina*
Arundinaria gigantea	*Carex conjuncta*	*Carex vulpinoidea*
Asclepias hirtella	*Carex crinita*	*Carpinus caroliniana*
Asclepias incarnata	*Carex cristatella*	*Carya carolinae-septentrionalis*
Asclepias syriaca	*Carex crus-corvi*	*Carya cordiformis*
Asclepias variegata	*Carex debilis*	*Carya glabra*
Asiminia triloba	*Carex digitalis*	*Carya laciniosa*
Aslpenium platyneuron	*Carex festucacea*	*Carya ovata*
Aster lanceolatus	*Carex frankii*	*Carya tomentosa*

Table A-1 (continued)

<u>Species</u>	<u>Species</u>	<u>Species</u>
Celtis laevigata	*Dioscorea villosa*	*Fragaria virginiana*
Celtis occidentalis	*Diospyros virginiana*	*Fraxinus americana*
Cephalanthus occidentalis	<u>*Dipsacus fullonum*</u>	*Fraxinus pennsylvanica*
Ceratophyllum demersum	***Drosera brevifolia***	*Fraxinus profunda*
Cercis canadensis	<u>*Duchesnea indica*</u>	*Galium aparine*
Chamaecrista fasciculata	<u>*Echinichloa crusgalli*</u>	*Galium tinctorium*
Chasmanthium latifolium	*Echinodorus cordifolius*	*Geum canadense*
<u>*Chenopodium album*</u>	*Eclipta prostrata*	*Geum laciniatum*
Cicuta maculata	<u>*Eleagnus umbellata*</u>	*Geum virginianum*
Cinna arundinacea	*Eleocharis acicularis*	<u>*Glechoma hederacea*</u>
Circaea lutetiana	*Eleocharis erythropoda*	*Gleditsia triacanthos*
<u>*Cirsium arvense*</u>	*Eleocharis obtusa*	*Glyceria septentrionalis*
Clematis virginiana	*Eleocharis ovata*	*Glyceria striata*
<u>*Commelina communis*</u>	*Eleocharis palustris*	*Gratiola neglecta*
Commelina virginica	*Eleocharis quadrangulata*	*Hamamelis virginiana*
Conoclinium coelestinum	*Elephantopus carolinianus*	*Helenium autumnale*
<u>*Convolvulus arvensis*</u>	*Elymus hystrix*	*Helenium flexuosum*
Conyza canadensis	*Elymus riparius*	*Helianthus decapetalus*
Cornus amomum	*Elymus villosus*	*Hibiscus laevis*
Cornus drummondii	*Elymus virginius*	*Hibiscus moscheutos*
Cornus florida	*Epilobium coloratum*	*Houstonia purpurea*
Cornus foemina	*Equisetum arvense*	***Hypericum crux-andrea***
<u>*Coronilla varia*</u>	*Erechtites hieracifolia*	*Hypericum hypericoides*
Crateagus crus-galli	*Erigeron annuus*	*Hypericum mutilum*
Cryptotaenia canadensis	*Erigeron philadelphicus*	*Hypericum prolificum*
Cuscuta gronovii	*Eryngium prostratum*	*Hypericum punctatum*
Cyperus erythrorhizos	<u>*Euonymus alatus*</u>	*Ilex decidua*
Cyperus esculentus	<u>*Euonymus fortunei*</u>	*Ilex opaca*
Cyperus flavescens	*Eupatorium fistulosum*	*Ilex verticillata*
Cyperus lupulinus	*Eupatorium maculatum*	*Impatiens capensis*
Cyperus strigosus	*Eupatorium perfoliatum*	<u>*Ipomoea purpurea*</u>
Cypripedium acaule	*Eupatorium rotundifolium*	<u>*Iris pseudacorus*</u>
Cysopteris protrusa	*Eupatorium rugosum*	*Iris virginica*
Danthonia spicata	*Eupatorium serotinum*	*Isoetes engelmanii*
<u>*Daucus carota*</u>	*Eupatorium sessilifolium*	*Itea virginiana*
<u>*Digitaria sanguinalis*</u>	*Fagus grandifolia*	*Juglans nigra*
Diodia virginiana	<u>*Festuca elatior*</u>	*Juncus acuminatus*
<u>*Dioscorea polystachya*</u>	<u>*Festuca ovina*</u>	*Juncus anthelatus*

Table A-1 (continued)

Species	Species	Species
Juncus canadensis	*Lygodium palmatum*	*Phalaris arundinacea*
Juncus coriaceus	*Lysimachia ciliata*	*Phlox paniculata*
Juncus diffisisimus	*Lysimachia nummularia*	*Phragmites australis*
Juncus effusus	*Lysomachia lanceolata*	*Phyla lanceolata*
Juncus marginatus	*Maclura pomifera*	*Phytolacca americana*
Juncus tenuis	*Magnolia tripetala*	*Pilea pumila*
Juniperus virginiana	*Mentha piperata*	*Pinus echinata*
Lactuca canadensis	*Microstegium vimineum*	*Pinus strobus*
Lamium purpureum	*Mimulus alatus*	*Pinus virginiana*
Laportea canadensis	*Mimulus ringens*	*Plantago major*
Leersia lenticularis	*Morus alba*	*Platanthera ciliaris*
Leersia oryzoides	*Morus rubra*	*Platanthera clavellata*
Leersia virginica	*Muhlenbergia frondosa*	*Platanthera flava*
Lemna minor	*Najas guadalupensis*	*Platanus occidentalis*
Lespedeza virginica	*Najas minor*	*Poa palustris*
Leucanthemum vulgare	*Nelumbo lutea*	*Poa pratensis*
Ligustrum sinense	*Nuphar advena*	*Poa sylvestris*
Ligustrum vulgare	*Nyssa sylvatica*	*Podophyllum peltatum*
Lilium canadense	***Oenothera linifolia***	*Polygala sanguinea*
Lindera benzoin	*Onoclea sensibilis*	*Polygonatum biflorum*
Lindernia dubia	*Ophioglossum vulgatum*	*Polygonatum pubescens*
Liquidambar styraciflua	*Osmunda cinnamomea*	*Polygonum amphibium*
Liriodendron tulipifera	*Osmunda regalis*	*Polygonum cespitosum*
Lobelia cardinalis	*Ostrya virginiana*	*Polygonum cuspidatum*
Lobelia inflata	*Oxalis corniculata*	*Polygonum hydropiper*
Lobelia nutallii	*Oxalis stricta*	*Polygonum hydropiperoides*
Lobelia siphilitica	*Oxalis violacea*	*Polygonum pensylvanicum*
Lonicera japonica	*Oxydendron arboreum*	*Polygonum persicaria*
Lonicera maackii	*Panicum acuminatum*	*Polygonum punctatum*
Lonicera morrowii	*Panicum anceps*	*Polygonum sagittatum*
Lotus corniculatus	*Panicum clandestinum*	*Polygonum virginianum*
Ludwigia alternifolia	*Panicum dichotomum*	*Polystichum acrostichoides*
Ludwigia hirtella	*Panicum rigidulum*	*Populus deltoides*
Ludwigia palustris	*Panicum scoparia*	*Populus grandidentata*
Ludwigia peploides	*Parthenocissus quinquefolia*	*Potamogeton crispus*
Luzula acuminata	*Paspalum laeve*	*Potamogeton nodosus*
Lycopus americanus	*Passiflora lutea*	*Prenanthes altissima*
Lycopus virginicus	*Penthorum sedoides*	*Proserpinaca palustris*

Table A-1 (continued)

Species	Species	Species
Prunella vulgaris	*Rumex obtusifolius*	*Solanum dulcamara*
Prunus serotina	*Rumex verticillatus*	*Solidago canadensis*
Pycnanthemum tenuifolium	*Sabatia angularis*	*Solidago gigantea*
Pycnanthemum verticillatum	*Sagittaria calycina*	*Solidago ulmifolia*
Pyrus communis	*Sagittaria latifolia*	*Sorghum halapense*
Quercus alba	*Salix exigua*	*Sparganium americanum*
Quercus bicolor	*Salix nigra*	*Spiraea tomentosa*
Quercus coccinea	*Salvia lyrata*	*Spiranthes gracilis*
Quercus lyrata	*Sambucus canadensis*	*Spirodela polyrhiza*
Quercus macrocarpa	*Sanicula canadensis*	*Stachys tenuifolia*
Quercus marilandica	*Sanicula gregaria*	*Symphoricarpos orbiculatus*
Quercus michauxii	*Sanicula trifoliata*	*Taraxacum officinale*
Quercus palustris	*Sassafras albidum*	*Taxodium distichum*
Quercus phellos	*Saururus cernuus*	*Teucrium canadense*
Quercus prinus	*Schoenoplectus tabernaemontani*	*Thalictrum pubescens*
Quercus rubra	*Scirpus atrovirens*	*Thelypteris noveboracensis*
Quercus stellata	*Scirpus cyperinus*	*Toxicodendron radicans*
Quercus velutina	*Scirpus georgianus*	*Tridens flavus*
Ranunculus hispidus	*Scirpus pendulus*	*Trifolium pratense*
Ranunculus sceleratus	*Scirpus polyphyllus*	*Trifolium repens*
Rhexia mariana	*Scirpus pungens*	*Trillium erectum*
Rhexia virginica	*Scleria triglomerata*	*Tsuga canadensis*
Rhododendron arborescens	*Scutellaria integrifolia*	*Typha angustifolia*
Rhus copallinum	*Scutellaria lateriflora*	*Typha latifolia*
Rhynchospora globularis	*Sedum ternatum*	*Typha x glauca*
Rhynscospora capitellata	*Senecio aureus*	*Ulmus americana*
Robinia pseudoacacia	*Senecio glabellus*	*Ulmus rubra*
Rosa carolina	*Senna marilandica*	*Urtica dioica*
Rosa multiflora	*Sicyos angulatus*	*Utricularia gibba*
Rosa palustris	*Siplhium perfoliatum*	*Uvularia grandiflora*
Rosa setigera	*Sisyrinchium albidum*	*Vaccinium corymbosum*
Rubus allegheniensis	*Sisyrinchium angustifolium*	*Verbena hastata*
Rubus occidentalis	*Sium suave*	*Verbesina alternifolia*
Rudbeckia laciniata	*Smilax bona-nox*	*Verbesina occidentalis*
Ruellia carolinensis	*Smilax glauca*	*Vernonia gigantea*
Ruellia humilis	*Smilax hispida*	*Viburnum dentatum*
Ruellia strepens	*Smilax rotundifolia*	*Viburnum rifidulum*
Rumex crispus	*Solanum carolinense*	*Viola canadensis*

Table A-1 (continued)

Species	Species	Species
Viola cucullata		
Viola hirsutula		
Viola sororia		
Vitis cinerea		
Vitis riparia		
Vitis vulpina		
Wolffia columbiana		
Xanthium strumarium		
Xanthorhiza simplicissima		
Xyris torta		

Table A-2. Summary information for each wetland site sampled including vegetation type and LDI score.

Site ID	Fig. 3 Label	Year	Type	HGM	Plant Community	Basin	LDI Score
KYW13-SCR2	1	2013	Emergent	Riverine Headwaters	Marsh	Upper Cumberland	2.343
KYW13-JPF	2	2013	Emergent	Human Impoundment	Marsh	Kentucky	4.790
KYW13-I75-2	3	2013	Emergent	Riverine Headwaters	Marsh	Kentucky	3.911
KYW13-I75-1	4	2013	Emergent	Human Impoundment	Marsh	Kentucky	4.497
KYW13-HWM	5	2013	Emergent	Depression	Wet meadow	Upper Cumberland	2.333
KYW13-CPD	6	2013	Shrub	Depression	Shrub swamp	Upper Cumberland	1.228
KYW13-CLA	7	2013	Shrub	Human Impoundment	Shrub swamp	Kentucky	6.556
KYW13-BRW	8	2013	Emergent	Riverine Headwaters	Marsh	Kentucky	3.355
KYW13-BGAD1	9	2013	Emergent	Beaver Impoundment	Marsh	Kentucky	2.012
KYW13-BBS	10	2013	Emergent	Riverine Mainstem	Marsh	Kentucky	1.843
KYW13-393	11	2013	Emergent	Riverine Headwaters	Marsh	Kentucky	3.405
KYW13-346	12	2013	Forest	Riverine Mainstem	Swamp forest	Kentucky	1.799
KYW13-294	13	2013	Forest	Riverine Headwaters	Swamp forest	Kentucky	2.030
KYW13-288	14	2013	Shrub	Riverine Mainstem	Shrub swamp	Kentucky	5.057
KYW13-232	15	2013	Forest	Riverine Mainstem	Swamp forest	Kentucky	3.063
KYW13-229	16	2013	Forest	Riverine Channel	Swamp forest	Kentucky	4.570
KYW13-228	17	2013	Emergent	Riverine Mainstem	Marsh	Kentucky	4.198
KYW13-223	18	2013	Emergent	Depression	Marsh	Kentucky	4.428
KYW13-222	19	2013	Forest	Riverine Headwaters	Swamp forest	Kentucky	4.823
KYW13-MAD	20	2013	Forest	Riverine Mainstem	Swamp forest	Green	4.874
KYW13-OHM	21	2013	Forest	Riverine Mainstem	Swamp forest	Kentucky	6.283
KYW13-214	22	2013	Forest	Riverine Mainstem	Swamp forest	Kentucky	2.623
KYW13-213	23	2013	Forest	Riverine Mainstem	Swamp forest	Kentucky	1.953
KYW13-212	24	2013	Forest	Riverine Mainstem	Swamp forest	Kentucky	3.264
KYW12-BRC	25	2012	Emergent	Riverine Channel	Marsh	Upper Cumberland	1.285
KYW12-HPB	26	2012	Forest	Riverine Mainstem	Swamp forest	Upper Cumberland	1.359
KYW12-001	27	2012	Forest	Depression	Swamp forest	Green	5.956
KYW12-014	28	2012	Emergent	Human Impoundment	Marsh	Green	3.106
KYW12-016	29	2012	Forest	Riverine Channel	Swamp forest	Green	2.112

Table A-2 (continued)

Site ID	Fig. 3 Label	Year	Type	HGM	Plant Community	Basin	LDI Score
KYW12-017	30	2012	Forest	Depression	Swamp forest	Green	3.286
KYW12-020	31	2012	Forest	Riverine Mainstem	Swamp forest	Green	4.044
KYW12-025	32	2012	Forest	Riverine Headwaters	Swamp forest	Green	2.128
KYW12-027	33	2012	Forest	Riverine Mainstem	Swamp forest	Green	3.149
KYW12-030	34	2012	Forest	Riverine Mainstem	Swamp forest	Green	2.517
KYW12-032	35	2012	Emergent	Depression	Wet meadow	Green	1.967
KYW12-033	36	2012	Forest	Riverine Headwaters	Swamp forest	Green	4.566
KYW12-034	37	2012	Emergent	Human Impoundment	Wet meadow	Green	4.152
KYW12-037	38	2012	Forest	Riverine Mainstem	Swamp forest	Green	1.888
KYW12-039E	39	2012	Emergent	Riverine Mainstem	Marsh	Green	2.386
KYW12-039F	40	2012	Forest	Riverine Mainstem	Swamp forest	Green	2.386
KYW12-057	41	2012	Emergent	Depression	Marsh	Green	1.453
KYW12-088	42	2012	Emergent	Human Impoundment	Marsh	Green	1.908
KYW12-144	43	2012	Emergent	Human Impoundment	Marsh	Green	2.012
KYW12-212	44	2012	Forest	Riverine Mainstem	Swamp forest	Green	1.783
KYW12-226	45	2012	Forest	Depression	Swamp forest	Upper Cumberland	1.417
KYW12-227	46	2012	Forest	Depression	Swamp forest	Upper Cumberland	5.075
KYW12-233	47	2012	Emergent	Lake Fringe	Marsh	Upper Cumberland	3.249
KYW12-240	48	2012	Forest	Riverine Mainstem	Swamp forest	Upper Cumberland	1.505
KYW12-243	49	2012	Forest	Riverine Mainstem	Swamp forest	Upper Cumberland	3.304
KYW12-244	50	2012	Forest	Riverine Mainstem	Swamp forest	Upper Cumberland	4.421
KYW12-245	51	2012	Forest	Riverine Mainstem	Swamp forest	Upper Cumberland	1.359
KYW12-250	52	2012	Emergent	Riverine Channel	Wet meadow	Upper Cumberland	1.540
KYW12-391	53	2012	Forest	Riverine Mainstem	Swamp forest	Upper Cumberland	4.822
KYW12-414	54	2012	Forest	Riverine Mainstem	Swamp forest	Upper Cumberland	1.308
KYW12-LCW	55	2012	Forest	Depression	Swamp forest	Kentucky	1.461
KYW11-046	56	2011	Forest	Depression	Swamp forest	Kentucky	2.676
KYW11-002	57	2011	Shrub	Depression	Shrub swamp	Upper Cumberland	1.303
KYW11-009	58	2011	Emergent	Depression	Wet meadow	Upper Cumberland	1.257
KYW11-010	59	2011	Shrub	Depression	Shrub swamp	Upper Cumberland	1.202

Table A-2 (continued)

Site ID	Fig. 3 Label	Year	Type	HGM	Plant Community	Basin	LDI Score
KYW11-041	60	2011	Forest	Depression	Swamp forest	Kentucky	4.258
KYW11-042	61	2011	Forest	Depression	Swamp forest	Kentucky	4.301
KYW11-040	62	2011	Emergent	Riverine Mainstem	Wet meadow	Kentucky	5.198
KYW11-034	63	2011	Emergent	Human Impoundment	Marsh	Upper Cumberland	2.593
KYW11-014	64	2011	Forest	Depression	Swamp forest	Upper Cumberland	1.799
KYW11-018	65	2011	Shrub	Depression	Shrub swamp	Upper Cumberland	1.601
KYW11-038	66	2011	Forest	Depression	Swamp forest	Kentucky	5.055
KYW11-037	67	2011	Emergent	Riverine Mainstem	Wet meadow	Kentucky	7.018
KYW11-048	68	2011	Forest	Depression	Swamp forest	Kentucky	3.790

Table A-3. KY-WRAM submetric scores for each wetland site. Refer to Table 5 for submetric descriptions.

	KY-WRAM Submetrics										
Site	2A	2B	2C	3A	3B	3C	3D	4A	4B	4C	TOTAL
KYW13-SCR2	3	4	2	9	2	3	5	2	3	3	36
KYW13-JPF	0	1	0	5	4	3	3	2	3	2	23
KYW13-I75-2	3	1.5	0	1	4	3	1	2	1	1	17.5
KYW13-I75-1	0	1	0	5	0	3	1	1	2	1	14
KYW13-HWM	4	3	2	1	0	2	9	4	7	7	39
KYW13-CPD	3	4	4	1	0	4	8	4	9	7	44
KYW13-CLA	2	0.5	0	5	4	3	3	2	3	1	23.5
KYW13-BRW	3	2	0	9	2	4	5	2	3	2	32
KYW13-BGAD1	3	2.5	2	5	4	3	3	2	3	3	30.5
KYW13-BBS	4	4	2	5	2	3.5	7	3	7	4	41.5
KYW13-393	3	1	0	1	4	3.5	5	2	3	1	23.5
KYW13-346	4	4	4	5	2	1.5	9	4	7	4	44.5
KYW13-294	4	1	2	9	2	2.5	8	3.5	8	4	44
KYW13-288	3	1.5	2	5	6	3	5	3	5	2	35.5
KYW13-232	2.5	1.25	1	7	4	3	8	3	6	4.5	40.25
KYW13-229	3	1	0	5	4	3	5	3	7	2	33
KYW13-228	3	2	1	5	5	3.5	7	4	8.5	5	44
KYW13-223	3	0.75	0	3	4	2	3.5	2.75	4.5	1	24.5
KYW13-222	4	2	0	9	4	4	7	2.5	5	3	40.5
KYW13-MAD	0	0	2	5	2	1	3	2	3	3	21
KYW13-OHM	2	0.5	0	5	4	3	2	2	3	1	22.5
KYW13-214	3	2.5	2	5	6	3	8	2.5	5	3	40
KYW13-213	2	2.5	0	5	4	2	7	4	5	3	34.5
KYW13-212	3	2	2	5	4	4	9	4	8	6	47
KYW12-BRC	4	4	4	5	5	3.25	9	4	9	6.5	53.75
KYW12-HPB	4	4	2	5	4	2	9	4	9	7	50
KYW12-001	0.2	0	0	3.4	3.2	1.2	3.4	2.4	3.4	2.4	19.6
KYW12-014	2.5	1	0	1	0	4	2	2	3	3.5	19
KYW12-016	2.75	0.875	1	5	5	1.875	4.5	2.75	3	2.5	29.25
KYW12-017	2	0.7	0.8	5	3.6	2	7	3.4	7.2	5.6	37.3
KYW12-020	2.643	1.429	1.143	2.143	2.857	1.357	3.571	3.214	5	2.571	25.929
KYW12-025	3	2.333	2	5	4.667	1.833	3.667	3.5	6.333	3.667	36
KYW12-027	2.75	1.5	2	5	5.5	1.5	4	2.875	5.25	3.25	33.625
KYW12-030	2.5	1	2	5	5	1	3	2	3	2.5	27
KYW12-032	0	1.333	0.667	1	3.333	1.167	1.333	1.333	1.333	1.667	13.166

Table A-3 (continued)

	KY-WRAM Submetrics										
Site	2A	2B	2C	3A	3B	3C	3D	4A	4B	4C	TOTAL
KYW12-033	2.667	0.333	0	5	4.667	1	4.333	2.5	4.333	4	28.833
KYW12-034	3	1.667	1.333	3.667	4	1.5	3	1.667	2.333	1.667	23.834
KYW12-037	3.333	2.333	2	5	3.333	2.333	7.333	2.833	5	3.667	37.167
KYW12-039E	3.429	2.929	2.571	5	5.143	3.643	5.714	3.143	7	3.714	42.286
KYW12-039F	3.429	2.929	2.571	5	5.143	3.643	5.714	3.143	7	3.714	42.286
KYW12-057	4	3.714	4	5.571	5.429	3.857	6.857	3.214	7	4.857	48.499
KYW12-088	3.25	2.625	3.5	4	5	3.25	5	4	5.5	5	41.125
KYW12-144	2.75	1.625	2	4	5.5	3	6.5	2.75	6.25	5.5	39.875
KYW12-212	2	1	2	5	2	1	1	1.5	2	2	19.5
KYW12-226	4	3.4	3.6	5	4	2.5	8.6	3.9	8.8	6.4	50.2
KYW12-227	2.857	1.857	1.143	5	4	2.714	6.286	3.214	6	4.143	37.214
KYW12-233	2.75	2.375	1.5	4	3.5	2.25	4.75	2.25	4.625	2.5	30.5
KYW12-240	3.5	3.313	3.75	5	4.75	2.563	7.25	3.75	8.25	5.625	47.75
KYW12-243	0.667	0.333	0.667	5	2.667	1	1.667	1.833	2.667	2	18.5
KYW12-244	1.5	1.25	2	5	4	1.25	4	2.5	5	3.5	30
KYW12-245	2.667	2.5	2.333	5	6	2.5	9	3	5	3.667	41.667
KYW12-250	3.667	3.083	3	5	4.667	2.667	7.5	2.917	6.5	4.333	43.333
KYW12-391	2.333	2.667	2	5	5.333	1.667	6.667	3.5	7.333	5	41.5
KYW12-414	4	4	4	5	3.333	1.667	9	3.667	8.667	3.333	46.667
KYW12-LCW	3.167	2.833	3.667	5	1	3.5	6.333	3.75	7.333	4.833	41.417
KYW11-046	3	3	4	4	4	3	6	4	9	4	44
KYW11-002	4	3.75	3.5	3	0	2.875	9	4	9	5.25	44.375
KYW11-009	2.667	4	2.667	2.667	0	2.833	2.333	2.667	3.5	1	24.333
KYW11-010	4	4	4	2.667	0	3.333	9	4	9	6.333	46.333
KYW11-041	3	2	0	4	0	3.667	7.5	4	7	5.667	36.833
KYW11-042	2.333	1.167	0	1.333	0.667	2.667	6	3.333	7	5.333	29.833
KYW11-040	0.667	1	0	4	1.333	4	4	3.667	2.833	2.333	23.833
KYW11-034	2	1.5	2	4	2	4	5	2.5	3.7	5	31.7
KYW11-014	4	2.667	2.667	2.667	0.667	3.333	7	3	6	5	37
KYW11-018	3	3.333	2	4	1.333	3.833	3.167	2.667	6.833	1	31.167
KYW11-038	2.333	0.333	0	4	4	2	9	2.667	3.333	2	29.667
KYW11-037	0	0.167	0	4	1.333	4	3.167	3.333	2	1	19
KYW11-048	0	1.5	0	0	0	3	4	2	2.5	5	18

Table A-4. Summary of Pearson correlation coefficients for each candidate metric compared to PC1 and PC2. Two-tailed p-values are shown in italics below each r-value.

	Emergent N = 25		Forest N = 37		Shrub N = 6	
	PC1	PC2	PC1	PC2	PC1	PC2
Dicot	-0.397*	0.174	-0.154	0.105	0.882*	-0.673
	0.050	*0.405*	*0.363*	*0.535*	*0.020*	*0.143*
Shade	-0.362	0.136	-0.162	-0.107	-0.290	0.436
	0.076	*0.516*	*0.339*	*0.528*	*0.577*	*0.388*
Count native wetlandshrub	-0.298	0.153	0.024	0.224	-0.777	0.906*
	0.148	*0.465*	*0.889*	*0.183*	*0.069*	*0.013*
Hydrophyte	-0.237	0.002	-0.015	0.219	0.803	-0.807
	0.254	*0.992*	*0.931*	*0.192*	*0.055*	*0.052*
Seedless vascular plants	-0.076	0.368	-0.011	-0.025	-0.639	0.594
	0.719	*0.070*	*0.948*	*0.885*	*0.172*	*0.214*
Percent bryophyte	-0.220	0.383	-0.251	-0.115	-0.446	0.616
	0.290	*0.059*	*0.134*	*0.498*	*0.375*	*0.192*
Percent invasive	0.443*	0.191	-0.033	-0.105	0.198	0.024
	0.026	*0.360*	*0.846*	*0.537*	*0.707*	*0.963*
Small tree	0.033	0.494*	0.034	0.173	-0.240	0.167
	0.877	*0.012*	*0.842*	*0.307*	*0.647*	*0.752*
Subcanopy importance value	-0.031	0.324	-0.064	-0.058	-0.547	0.418
	0.885	*0.114*	*0.706*	*0.734*	*0.261*	*0.409*
Canopy importance value	0.017	0.262	-0.122	0.117	0.396	-0.561
	0.936	*0.205*	*0.472*	*0.492*	*0.437*	*0.247*
Biomass	-0.265	0.091	.[a]	.[a]	0.163	0.045
	0.200	*0.666*			*0.758*	*0.932*

Table A-4 (continued)

	Emergent N = 25		Forest N = 37		Shrub N = 6	
	PC1	PC2	PC1	PC2	PC1	PC2
Stems per hectare wetland trees	0.023 *0.912*	0.123 *0.557*	-0.034 *0.842*	-0.053 *0.757*	0.269 *0.607*	-0.697 *0.124*
Stems per hectare wetland shrubs	-0.042 *0.841*	0.144 *0.492*	-0.244 *0.146*	0.172 *0.309*	0.021 *0.968*	-0.021 *0.969*
Percent unvegetated	0.039 *0.853*	-0.006 *0.979*	0.099 *0.560*	0.153 *0.365*	-0.207 *0.694*	0.215 *0.682*
Percent buttonbush	-0.107 *0.611*	-0.130 *0.536*	-0.181 *0.284*	0.321 *0.053*	-0.768 *0.075*	0.771 *0.073*
Percent perennial	-0.164 *0.433*	0.202 *0.333*	-0.079 *0.641*	0.118 *0.486*	0.052 *0.922*	-0.217 *0.680*
Mean C all species	-0.576** *0.003*	0.163 *0.437*	-0.226 *0.179*	-0.143 *0.399*	-0.929** *0.007*	0.886* *0.019*
Mean C native species	-0.526** *0.007*	0.186 *0.375*	-0.204 *0.226*	-0.067 *0.696*	-0.876* *0.022*	0.892* *0.017*
Cover weighted mean C all species	-0.257 *0.215*	-0.251 *0.226*	-0.210 *0.211*	0.128 *0.451*	-0.697 *0.124*	0.536 *0.273*
Cover weighted mean C native species	-0.224 *0.281*	-0.243 *0.242*	-0.206 *0.222*	0.144 *0.396*	-0.675 *0.142*	0.518 *0.293*
FQAI all species	-0.479* *0.015*	0.291 *0.159*	-0.080 *0.639*	0.052 *0.759*	-0.407 *0.423*	0.491 *0.323*
FQAI native species	-0.454* *0.023*	0.298 *0.148*	-0.064 *0.708*	0.079 *0.641*	-0.241 *0.645*	0.376 *0.463*

Table A-4 (continued)

	Emergent N = 25		Forest N = 37		Shrub N = 6	
	PC1	PC2	PC1	PC2	PC1	PC2
Cover weighted FQAI all species	-0.263	-0.238	-0.215	0.196	-0.736	0.567
	0.205	*0.252*	*0.200*	*0.246*	*0.096*	*0.241*
Cover weighted FQAI native species	-0.239	-0.237	-0.210	0.203	-0.718	0.553
	0.249	*0.254*	*0.212*	*0.228*	*0.108*	*0.255*
AFQI	-0.509**	0.269	-0.093	0.038	-0.597	0.599
	0.009	*0.194*	*0.585*	*0.821*	*0.211*	*0.209*
Cover weighted AFQI	-0.262	-0.239	-0.213	0.190	-0.736	0.567
	0.206	*0.250*	*0.205*	*0.260*	*0.096*	*0.241*
Count intolerant	-0.396	0.259	-0.014	0.178	0.331	-0.259
	0.050	*0.211*	*0.935*	*0.291*	*0.521*	*0.620*
Percent intolerant	-0.509**	0.061	-0.246	-0.122	-0.891*	0.765
	0.009	*0.773*	*0.142*	*0.472*	*0.017*	*0.077*
Absolute cover intolerant	-0.243	-0.159	-0.176	0.267	-0.554	0.206
	0.241	*0.447*	*0.297*	*0.110*	*0.254*	*0.695*
Relative cover intolerant	-0.410*	0.100	-0.216	0.103	-0.733	0.396
	0.042	*0.634*	*0.199*	*0.543*	*0.097*	*0.437*
Tolerant : intolerant ratio	0.413*	0.024	0.228	0.010	0.911*	-0.708
	0.040	*0.909*	*0.175*	*0.955*	*0.012*	*0.115*
Absolute cover intolerant : tolerant ratio	0.325	0.158	0.337*	-0.032	0.912*	-0.780
	0.113	*0.449*	*0.041*	*0.849*	*0.011*	*0.068*
Count tolerant	0.108	-0.042	0.169	0.194	0.952**	-0.739
	0.609	*0.841*	*0.317*	*0.251*	*0.003*	*0.094*

Table A-4 (continued)

	Emergent N = 25		Forest N = 37		Shrub N = 6	
	PC1	PC2	PC1	PC2	PC1	PC2
Percent tolerant	0.430*	-0.151	0.246	0.043	0.905*	-0.784
	0.032	*0.472*	*0.143*	*0.801*	*0.013*	*0.065*
Relative cover tolerant	0.477*	0.051	0.321	-0.114	0.932**	-0.913*
	0.016	*0.807*	*0.053*	*0.501*	*0.007*	*0.011*
Absolute cover tolerant	0.491*	-0.009	0.350*	-0.071	0.856*	-0.866*
	0.013	*0.964*	*0.034*	*0.674*	*0.030*	*0.026*
Count all species	-0.263	0.135	-0.104	0.118	0.850*	-0.653
	0.204	*0.521*	*0.539*	*0.488*	*0.032*	*0.160*
Count native species	-0.307	0.193	-0.147	0.155	0.708	-0.560
	0.135	*0.355*	*0.386*	*0.359*	*0.115*	*0.248*
Count non-native species	0.405*	0.006	0.232	0.047	0.966**	-0.724
	0.045	*0.977*	*0.167*	*0.784*	*0.002*	*0.103*
Percent non-native species	0.557**	-0.011	0.224	-0.038	0.979**	-0.770
	0.004	*0.960*	*0.182*	*0.822*	*0.001*	*0.074*
Absolute cover non-native species	0.399*	0.004	0.402*	-0.069	0.842*	-0.498
	0.048	*0.985*	*0.014*	*0.685*	*0.035*	*0.315*
Relative cover non-native species	0.292	-0.069	0.325*	-0.049	0.839*	-0.483
	0.157	*0.743*	*0.050*	*0.775*	*0.037*	*0.331*
Absolute cover native	-0.114	-0.285	-0.116	0.231	-0.316	0.033
	0.586	*0.168*	*0.496*	*0.169*	*0.542*	*0.950*
Relative cover native	-0.229	0.121	-0.185	0.112	-0.500	0.031
	0.271	*0.566*	*0.273*	*0.508*	*0.313*	*0.953*

Table A-4 (continued)

	Emergent N = 25		Forest N = 37		Shrub N = 6	
	PC1	PC2	PC1	PC2	PC1	PC2
Non-native : native ratio	0.536^{**}	0.054	0.250	-0.046	0.963^{**}	-0.739
	0.006	*0.799*	*0.136*	*0.786*	*0.002*	*0.093*
Count annual	-0.049	-0.168	-0.088	0.076	0.935^{**}	-0.912^{*}
	0.815	*0.422*	*0.603*	*0.653*	*0.006*	*0.011*
Percent annual	0.080	-0.191	-0.139	-0.064	0.880^{*}	-0.933^{**}
	0.704	*0.360*	*0.412*	*0.706*	*0.021*	*0.007*
Absolute cover annual	0.042	-0.241	0.003	0.172	0.690	-0.442
	0.840	*0.245*	*0.987*	*0.309*	*0.129*	*0.381*
Relative cover annual	0.054	-0.192	0.047	0.129	0.606	-0.360
	0.798	*0.359*	*0.783*	*0.445*	*0.202*	*0.483*
Annual : perennial ratio	0.117	-0.126	-0.192	-0.001	0.813^{*}	-0.903^{*}
	0.578	*0.549*	*0.256*	*0.997*	*0.049*	*0.014*
Absolute cover annual : perennial ratio	-0.009	-0.187	0.062	0.102	0.447	-0.222
	0.965	*0.370*	*0.715*	*0.549*	*0.374*	*0.673*
Count native annual	-0.123	-0.286	-0.005	0.243	0.886^{*}	-0.917^{*}
	0.558	*0.166*	*0.978*	*0.147*	*0.019*	*0.010*
Percent native annual	0.001	-0.323	-0.044	0.103	0.792	-0.906^{*}
	0.994	*0.115*	*0.797*	*0.544*	*0.061*	*0.013*
Absolute cover native annual	-0.054	-0.332	-0.060	0.280	0.979^{**}	-0.890^{*}
	0.798	*0.105*	*0.724*	*0.093*	*0.001*	*0.017*
Relative cover native annual	0.019	-0.267	-0.078	0.275	0.984^{**}	-0.883^{*}
	0.928	*0.197*	*0.648*	*0.100*	*0.000*	*0.020*

Table A-4 (continued)

	Emergent N = 25		Forest N = 37		Shrub N = 6	
	PC1	PC2	PC1	PC2	PC1	PC2
Native annual : perennial ratio	0.082	-0.256	-0.092	0.131	0.768	-0.885*
	0.695	*0.217*	*0.589*	*0.438*	*0.074*	*0.019*
Absolute cover native annual : perennial ratio	-0.051	-0.242	-0.090	0.263	0.984**	-0.838*
	0.810	*0.245*	*0.596*	*0.115*	*0.000*	*0.037*
Count perennial	-0.266	0.141	-0.059	0.086	0.871*	-0.664
	0.198	*0.502*	*0.729*	*0.611*	*0.024*	*0.151*
Percent species perennial	-0.206	-0.072	0.021	-0.208	0.656	-0.444
	0.322	*0.731*	*0.903*	*0.217*	*0.157*	*0.378*
Absolute cover perennial	0.118	-0.186	0.067	-0.177	0.906*	-0.742
	0.574	*0.374*	*0.696*	*0.294*	*0.013*	*0.091*
Relative cover perennial	0.243	0.058	-0.020	-0.431**	0.872*	-0.675
	0.241	*0.784*	*0.906*	*0.008*	*0.024*	*0.142*
Count native perennial	-0.300	0.184	-0.075	0.103	0.747	-0.567
	0.145	*0.380*	*0.658*	*0.544*	*0.088*	*0.240*
Percent native perennial	-0.315	0.056	-0.017	-0.171	0.341	-0.181
	0.125	*0.790*	*0.921*	*0.311*	*0.508*	*0.731*
Absolute cover native perennial	0.009	-0.141	-0.075	-0.188	0.836*	-0.732
	0.967	*0.501*	*0.657*	*0.266*	*0.038*	*0.098*
Relative cover native perennial	0.094	0.132	-0.118	-0.433**	0.771	-0.628
	0.655	*0.530*	*0.487*	*0.007*	*0.073*	*0.181*
Count woody	-0.183	0.368	-0.160	0.155	-0.177	0.324
	0.381	*0.070*	*0.343*	*0.358*	*0.737*	*0.531*

Table A-4 (continued)

	Emergent N = 25		Forest N = 37		Shrub N = 6	
	PC1	PC2	PC1	PC2	PC1	PC2
Percent woody	-0.043 *0.836*	0.224 *0.283*	-0.025 *0.884*	0.081 *0.635*	-0.775 *0.070*	0.675 *0.141*
Absolute cover woody	-0.266 *0.198*	0.178 *0.395*	0.023 *0.890*	0.440** *0.006*	-0.580 *0.228*	0.348 *0.499*
Relative cover woody	-0.369 *0.069*	0.281 *0.174*	0.089 *0.601*	0.429** *0.008*	-0.785 *0.064*	0.534 *0.275*
Count native woody	-0.230 *0.268*	0.363 *0.074*	-0.254 *0.130*	0.121 *0.474*	-0.361 *0.482*	0.425 *0.400*
Percent native woody	-0.144 *0.492*	0.212 *0.308*	-0.123 *0.467*	0.040 *0.816*	-0.809 *0.051*	0.679 *0.138*
Absolute cover native woody	-0.270 *0.191*	0.174 *0.405*	-0.066 *0.700*	0.449** *0.005*	-0.580 *0.227*	0.348 *0.499*
Relative cover native woody	-0.373 *0.066*	0.276 *0.182*	0.019 *0.912*	0.399* *0.014*	-0.786 *0.064*	0.534 *0.275*
Count forb	-0.295 *0.153*	0.023 *0.914*	-0.041 *0.812*	0.070 *0.681*	0.969** *0.001*	-0.808 *0.052*
Percent forb	-0.130 *0.535*	-0.243 *0.242*	-0.041 *0.812*	-0.148 *0.383*	0.924** *0.009*	-0.798 *0.057*
Absolute cover forb	0.036 *0.863*	-0.222 *0.287*	0.076 *0.655*	-0.162 *0.337*	0.942** *0.005*	-0.786 *0.064*
Relative cover forb	0.110 *0.600*	-0.036 *0.863*	0.001 *0.997*	-0.331* *0.045*	0.885* *0.019*	-0.711 *0.113*

Table A-4 (continued)

	Emergent N = 25		Forest N = 37		Shrub N = 6	
	PC1	PC2	PC1	PC2	PC1	PC2
Forb : graminoid ratio	-0.206	-0.132	-0.067	-0.146	0.825*	-0.552
	0.324	*0.529*	*0.696*	*0.389*	*0.043*	*0.256*
Absolute cover forb : graminoid ratio	0.102	0.203	-0.036	-0.141	0.394	-0.313
	0.626	*0.331*	*0.833*	*0.404*	*0.440*	*0.545*
Count native forb	-0.373	0.061	-0.053	0.121	0.917*	-0.778
	0.066	*0.770*	*0.756*	*0.475*	*0.010*	*0.068*
Percent native forb	-0.405*	-0.175	-0.060	-0.082	0.825*	-0.728
	0.045	*0.403*	*0.725*	*0.630*	*0.043*	*0.101*
Absolute cover native forb	-0.083	-0.184	-0.091	-0.155	0.595	-0.590
	0.692	*0.380*	*0.592*	*0.361*	*0.213*	*0.218*
Relative cover native forb	-0.017	0.031	-0.100	-0.315	0.539	-0.498
	0.937	*0.881*	*0.555*	*0.058*	*0.269*	*0.315*
Native forb : graminoid ratio	-0.269	-0.096	-0.199	-0.119	0.810	-0.527
	0.193	*0.649*	*0.237*	*0.482*	*0.051*	*0.283*
Absolute cover native forb : graminoid ratio	0.106	0.180	-0.158	-0.160	0.154	-0.059
	0.616	*0.390*	*0.350*	*0.344*	*0.771*	*0.911*
Count graminoid	0.021	0.057	-0.092	0.148	0.641	-0.593
	0.921	*0.787*	*0.588*	*0.382*	*0.170*	*0.215*
Percent graminoid	0.087	-0.181	0.003	0.012	0.423	-0.536
	0.678	*0.386*	*0.985*	*0.942*	*0.404*	*0.273*
Absolute cover graminoid	0.152	-0.257	0.002	-0.007	0.828*	-0.637
	0.468	*0.215*	*0.989*	*0.969*	*0.042*	*0.173*

Table A-4 (continued)

	Emergent N = 25		Forest N = 37		Shrub N = 6	
	PC1	PC2	PC1	PC2	PC1	PC2
Relative cover graminoid	0.179	-0.177	-0.013	-0.137	0.773	-0.554
	0.393	*0.398*	*0.941*	*0.418*	*0.071*	*0.254*
Count native graminoid	-0.046	0.042	-0.061	0.180	0.525	-0.507
	0.828	*0.843*	*0.722*	*0.285*	*0.285*	*0.304*
Percent native graminoid	0.067	-0.171	0.036	0.041	0.173	-0.337
	0.749	*0.413*	*0.831*	*0.811*	*0.743*	*0.514*
Absolute cover native graminoid	0.078	-0.268	-0.027	0.009	0.774	-0.625
	0.712	*0.196*	*0.874*	*0.960*	*0.071*	*0.185*
Relative cover native graminoid	0.144	-0.168	-0.064	-0.124	0.716	-0.544
	0.493	*0.423*	*0.707*	*0.464*	*0.110*	*0.264*
Count shrub	-0.347	0.329	-0.061	0.312	-0.236	0.550
	0.089	*0.108*	*0.718*	*0.060*	*0.652*	*0.259*
Percent shrub	-0.234	0.166	-0.066	0.333*	-0.830*	0.867*
	0.259	*0.427*	*0.700*	*0.044*	*0.041*	*0.025*
Absolute cover shrub	-0.105	-0.048	-0.091	0.290	-0.353	0.413
	0.616	*0.822*	*0.591*	*0.082*	*0.493*	*0.415*
Relative cover shrub	-0.129	0.039	-0.090	0.284	-0.355	0.593
	0.539	*0.853*	*0.597*	*0.088*	*0.490*	*0.215*
Percent native wetland shrub	-0.242	-0.029	0.027	0.203	-0.821*	0.767
	0.244	*0.892*	*0.873*	*0.227*	*0.045*	*0.075*
Relative cover native wetland shrub	-0.107	-0.004	-0.187	0.297	-0.354	0.588
	0.612	*0.985*	*0.267*	*0.074*	*0.491*	*0.220*

Table A-4 (continued)

	Emergent N = 25		Forest N = 37		Shrub N = 6	
	PC1	PC2	PC1	PC2	PC1	PC2
Count native shrub	-0.416*	0.309	-0.216	0.298	-0.587	0.774
	0.039	*0.133*	*0.199*	*0.073*	*0.221*	*0.071*
Percent native shrub	-0.341	0.141	-0.200	0.305	-0.895*	0.862*
	0.095	*0.501*	*0.234*	*0.066*	*0.016*	*0.027*
Absolute cover native shrub	-0.110	-0.051	-0.305	0.341*	-0.355	0.414
	0.600	*0.808*	*0.066*	*0.039*	*0.490*	*0.414*
Relative cover native shrub	-0.136	0.033	-0.246	0.303	-0.358	0.594
	0.516	*0.876*	*0.142*	*0.068*	*0.486*	*0.214*
Count hydrophytes	-0.237	0.002	-0.015	0.219	0.803	-0.807
	0.254	*0.992*	*0.931*	*0.192*	*0.055*	*0.052*
Percent hydrophytes	-0.162	-0.298	0.064	0.026	0.351	-0.556
	0.439	*0.147*	*0.705*	*0.880*	*0.495*	*0.252*
Absolute cover hydrophytes	-0.091	-0.124	0.061	-0.012	-0.573	0.670
	0.664	*0.555*	*0.718*	*0.941*	*0.234*	*0.146*
Relative cover hydrophytes	-0.134	-0.006	0.034	-0.148	-0.558	0.671
	0.522	*0.979*	*0.843*	*0.381*	*0.250*	*0.145*
Mean wetland indicator	-0.074	-0.312	0.026	0.024	0.515	-0.646
	0.724	*0.129*	*0.879*	*0.888*	*0.296*	*0.166*
Count Carex	0.214	0.051	-0.030	0.066	-0.235	0.137
	0.305	*0.808*	*0.862*	*0.698*	*0.654*	*0.796*
Percent Carex	0.378	0.027	0.059	0.024	-0.771	0.539
	0.062	*0.899*	*0.728*	*0.890*	*0.073*	*0.270*

Table A-4 (continued)

	Emergent N = 25		Forest N = 37		Shrub N = 6	
	PC1	PC2	PC1	PC2	PC1	PC2
Absolute Cover Carex	0.089	-0.19	-0.014	0.1	-0.41	0.621
	0.672	*0.363*	*0.935*	*0.554*	*0.419*	*0.188*
Relative Cover Carex	0.11	-0.167	0.042	0.008	-0.399	0.617
	0.599	*0.425*	*0.806*	*0.961*	*0.433*	*0.192*
Count Cyperaceae	0.06	-0.074	-0.057	0.085	0.347	-0.384
	0.774	*0.725*	*0.735*	*0.618*	*0.5*	*0.453*
Percent Cyperaceae	0.031	-0.211	0.04	0.034	-0.314	0.051
	0.883	*0.311*	*0.815*	*0.84*	*0.545*	*0.923*
Absolute cover Cyperaceae	-0.193	-0.35	-0.014	0.101	-0.235	0.527
	0.356	*0.087*	*0.935*	*0.554*	*0.653*	*0.283*
Relative Cover Cyperaceae	-0.158	-0.342	0.043	0.006	-0.255	0.541
	0.452	*0.094*	*0.802*	*0.971*	*0.626*	*0.268*
Absolute cover sensitive	-0.054	0.372	-0.127	0.124	-0.73	0.873*
	0.797	*0.067*	*0.454*	*0.464*	*0.1*	*0.023*
Relative cover sensitive	-0.09	0.451*	-0.123	0.009	-0.592	0.821*
	0.67	*0.024*	*0.469*	*0.956*	*0.216*	*0.045*
Prevalence	-0.244	0.422*	0.186	0.112	-0.467	0.341
	0.24	*0.036*	*0.27*	*0.508*	*0.351*	*0.508*
Cover weighted mean wetland indicator	-0.121	-0.255	-0.033	0.087	-0.497	0.271
	0.564	*0.219*	*0.846*	*0.61*	*0.316*	*0.603*

* Correlation was significant at the 0.05 level (2-tailed).

** Correlation was significant at the 0.01 level (2-tailed).

[a] Cannot be computed because at least one of the variables was constant.