January 2016

# A Vegetation-Based Index of Biotic Integrity for Wetlands of Kentucky

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By

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Submitted to the Faculty of the Graduate School of
Eastern Kentucky University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
August, 2016

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. David Brown, not only for his guidance and help on this project, but also for his time spent mentoring me in this field. I owe many thanks to my committee members, Drs. Brad Ruhfel and Stephen Richter, for offering their time and expertise as I navigated the graduate school and thesis process. A special thanks is owed to Michelle Cook for being both a friend and a knowledgeable guide in all aspects of the project. This work was funded by a U.S. Environmental Protection Agency Wetland Program Development grant rewarded to Drs. Stephen Richter and David Brown via the Kentucky Division of Water (KDOW). I thank all involved, including Barb Scott at KDOW, for the opportunity to work on this project. Additionally I would like to acknowledge Kristin Hinkson and Kari Dupler for their assistance in the field and for their help throughout. I owe many thanks to Dr. Ron Jones, Heidi Braunreiter, and Will Overbeck for their assistance in plant identification and to Dr. Brad Ruhfel for teaching me the ways of the herbarium and the magic of plant systematics. Last but not least, I thank my family, Don Smith, Dane Smith, and Nick Kovacs, for being kind and keeping me pleasant, and my mom, Kathy Smith, for the encouragement and love that got me here.

ABSTRACT

Wetland ecosystems have experienced severe declines across the United States, prompting efforts to assess the status of remaining wetlands and regulate their development. The Clean Water Act and the policy of "No Net Loss" have resulted in a system of permitting and mitigation for impacts to wetlands. Professional judgments of wetland quality are inherent in regulatory decisions related to preservation and mitigation, but many states, and until recently including Kentucky, have no standard, quantifiable means of assessing wetlands to guide the decision process. A rapid assessment method has recently been developed for Kentucky, but there is no intensive assessment method for wetlands. Indices of biotic integrity (IBIs) are multimetric assessment methods that use characteristics of biological communities in wetlands as indicators of ecological integrity, or the degree to which a habit resembles a pristine reference condition. IBIs are increasingly being developed for specific regions and nationally as tools to aid in regulatory decisions and for ambient monitoring purposes.

The goal of this study was to develop a vegetation-based IBI (VIBI) to assess the condition of wetlands in Kentucky and test it against the recently developed Kentucky Rapid Assessment Method (KY-WRAM). Using survey data from 110 primarily riverine wetlands across five river basins in Kentucky from 2011 to 2015, I calculated 125 candidate vegetation metrics and tested their correlation to a disturbance index, which was comprised of aggregated measures of anthropogenic landscape, physical, and hydrological alterations. Forested, emergent, and shrub wetlands were included in the survey sample. Ultimately, one VIBI was developed for all wetland vegetation classes

and consisted of two metrics, MeanC, the average of all species CC values at a site, and Absolute Cover of Nonnatives. These metrics are broad enough to apply to a wide range of wetland vegetation classes and HGM types and reflect wetland condition via floristic quality and the degree of invasion by nonnatives. The final VIBI distinguished KY-WRAM category one wetlands from category three wetlands for both development ($F_{2,79} = 16.54$, $p<0.001$) and validation ($F_{2,13} = 15.59$, $p<0.001$) datasets.

Further work should test the applicability of this VIBI on wetlands in the two additional basins of Kentucky and on other wetland types, in addition to accumulating a greater sample size for some types tested in this study. Because emergent wetlands tended to score lower overall than forested wetlands, separate interpretation of emergent and forested wetland scores should be considered, but I recommend doing so only after more sites are added to the dataset.

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# CHAPTER I

## INTRODUCTION

Wetland ecosystems are among the most productive on Earth, providing ecosystem services that benefit both the natural world and society. Their hydrologic contributions include water quality improvement, floodwater and sediment retention, and groundwater recharge (Kusler et al., 1994; Mitsch and Gosselink, 2007). Additionally, the placement of wetlands at the interface of terrestrial and aquatic systems creates habitats that are often rich in biodiversity with many species that are restricted to wetland habitats (Mitsch and Gosselink, 2007). However, only recently have these valuable attributes been widely recognized, and wetland destruction since European colonization has claimed over half of wetland area in the contiguous United States (Dahl, 2011; Kusler et al., 1994). Kentucky has lost over 80% of its wetlands (Dahl, 2011), making once abundant floodplain forested and swamp forests rare and limited in size throughout the state (R.L. Jones, 2005).

Acknowledging the value of, and threat to, waters of the United States, the "Clean Water Act" (2002) designates the United States Environmental Protection Agency (USEPA) and state agencies regulatory authority over the country's waters, including wetlands. More recently, a related goal of "No Net Loss" for wetlands has led to a system in which wetlands permitted for development are either preserved or compensated for by the construction or restoration of mitigation wetlands ("Clean Water Act," 2002). Professional judgments of wetland quality are inherent in regulatory decisions to preserve or mitigate, but many states have no standard, quantifiable means of assessing wetlands to guide the decision process.

This lack of standardized quantifiable methods to evaluate wetland quality is problematic considering the complexity and diversity of wetland systems. Even when undisturbed by humans, the formative role of hydrology in shaping wetlands leads to dynamic systems that change with the season and between years (Kusler et al., 1994). Hydrologic patterns also vary with landscape position and create numerous wetland types that are capable of different ecosystem functions (Mitsch and Gosselink, 2007). This diversity complicates efforts to describe wetland condition. Despite extensive public and private efforts to achieve “No Net Loss”, a lack of systematic and sensitive assessment could lead to an overall loss of wetland function and ecosystem services if the quality of what is lost and gained is unknown (Kusler et al., 1994). Effective assessment tools enable regulators and land managers to make informed decisions regarding development and mitigation (Stapanian et al., 2013), allocate limited resources efficiently (Anderson, 1991), and monitor the state of natural wetlands in their region (Miller et al., 2006).

A variety of assessment methods have been developed to try to accurately gauge wetland ecosystems. Their goal is to measure the ecological integrity of wetlands, or the degree to which the system resembles and functions as it would in an unimpaired state (Karr, 1993; Mack et al., 2000). Most methods fit within a three tiered system of assessment proposed by the USEPA (2006). The three levels, including (1) landscape, (2) rapid, and (3) intensive assessment, rely on indicators of human disturbance to determine ecological integrity (USEPA, 2006). An indicator may be the disturbance itself, known as a stressor, or an element of the wetland that responds predictably to stressors (Karr, 1993; USEPA, 2006). The time investment and accuracy increases with each level, with level three assessments typically requiring the most effort. Kentucky has recently developed a level two rapid assessment method, but has no level three intensive method. Intensive assessment methods are usually based on biotic communities, and have included amphibians, vegetation, birds, and macroinvertebrates (Kearns and Karr, 1994; Mack, 2007; Micacchion, 2002; USEPA, 2015; Veselka et al., 2010). Organisms such as plants or invertebrates are imbedded in a system for a length of time and are dependent on its habitat and condition (Mack et al., 2000). Because of this direct link, they are a reflection of conditions over an extended period of time (Karr, 1993, Mack et al., 2000). This is an advantage over most abiotic indicators, which provide information from a moment in time (Mack et al., 2000).

Vegetation is a commonly used basis for intensive assessment methods of wetlands. Vegetation Indices of Biotic Integrity (VIBIs) combine attributes of a wetland's plant community and structure into metrics that are correlated with disturbance (Mack et al., 2000; Stapanian et al., 2013). These metrics are composed of plant community and structure attributes, and combinations of these attributes. During VIBI development, numerous metrics are tested against external measures of disturbance and the metrics most highly correlated with disturbance are ultimately included in the VIBI. Plants offer at least three important advantages as an indicator taxon. First, the variety of plant life in one wetland offers a wide range of physical attributes (e.g., growth form or size) and life history traits (e.g., native status or shade tolerance) from which to draw for the creation of metrics and refinement of a VIBI (Anderson and Davis, 2013; Mack and Kentula, 2010). Second, the immobility of plants provides a direct link to the soil and hydrologic conditions of their location (Dahl, 2011; Miller et al., 2006). Finally, plants are a wellstudied taxonomic group, and most of the species are relatively easy to identify (Mack and Kentula, 2010).

The advantages of using plants for wetland assessment have long been recognized, and vegetation indicators already play a role in wetland regulation and habitat quality assessments (Anderson and Davis, 2013). Hydrophytic vegetation is one of three categories used by the Army Corps of Engineers manual to delineate wetlands in the United States (USACOE, 2012, 1987). The indicator statuses of obligate, facultative (subdivided into FACW, FAC, FACU), and upland have been assigned to plant species for regions across the country to designate the likelihood of a species' presence in a wetland and are necessary in particular combinations for designation of an area as wetland (USACOE, 1987). Threatened and endangered plants are also used in regulation and can be grounds for preservation or increased levels of mitigation of a wetland. Early efforts to assess disturbance with vegetation indicators focused on measures of floristic quality (Swink and Wilhelm, 1994), and variations of these metrics have been widely used for research, regulation, and ambient monitoring (Bried et al., 2013; Gara, 2013; W.M. Jones, 2005). The basis of floristic quality assessments is the Coefficient of Conservatism (CC) value, an indication of the sensitivity of a plant to disturbance and its fidelity to a particular habitat (Swink and Wilhelm, 1994). Nonnatives receive a zero, weedy and generalist species are given low values, and sensitive species receive high values up to 10. CC values and floristic quality measures are used as potential metrics in many VIBIs (Mack and Kentula, 2010).

VIBIs have been developed for parts of Florida, Colorado, Pennsylvania, Minnesota, Wisconsin, Ohio, and other states (Gernes and Helgen, 2002; Lemly and

Rocchio, 2009; Lillie et al., 2002; Miller et al., 2006; Reiss, 2006). All of these are applicable to particular wetland functional types, ecoregions, or watersheds. Despite this, many share metrics, the most commonly used being measures of invasive species, species sensitive to anthropogenic disturbance, annual/perennial habit, and species richness (Mack and Kentula, 2010). This overlap is to be expected if different plant communities respond similarly to disturbance, which is a conceptual underpinning of VIBIs (Karr and Chu, 1999; Mack and Kentula, 2010). Extensive testing of Ohio's VIBI has shown it to be robust in wetlands across the state and in wetlands of varying functional types (Mack, 2001, 2007; Mack et al., 2000), suggesting that some VIBI metrics are both general and sensitive enough to consistently assess disturbance across a range of wetland types. However, Mack and colleagues (2000) found enough variation in Ohio's community classes to justify subdividing the VIBI into forested, emergent, and shrub. Each is composed of 10 metrics from a pool of 19. The Ohio VIBI has been a part of the state's regulatory system for approximately 10 years and is used in coordination with their rapid assessment method as well as for monitoring natural and mitigation wetlands (Gara, 2013). A case of the potential for wide applicability of IBIs is the recent vegetation multimetric index (VMMI) developed by the USEPA through the National Wetland Condition Assessment (USEPA, 2015), a nation-wide survey of wetland condition across the United States (USEPA, 2015). The VMMI that ultimately emerged from their development process consists of four metrics and is applicable to all wetlands across the country regardless of region or type (USEPA, 2015).

Kentucky has developed a level two rapid assessment method, the Kentucky Wetland Rapid Assessment Method (KY-WRAM), for use across the state (KDOW, 2013); however, there is no level three intensive IBI to validate the KY-WRAM or guide regulatory decisions. The goal of this project was to build on three prior years of data collection and metric analysis (Morris, 2015) to further refine a set of candidate metrics and to assemble a Kentucky specific VIBI. An additional goal was to provide further validation of the KY-WRAM, and so the VIBIs ability to identify KY-WRAM categories was also evaluated.

CHAPTER II

METHODS

*Site Selection*

Wetland sites were located on various public and private lands in the Green River (n = 18), Kentucky River (n = 34), Licking River (n = 15), Salt River (n = 23), and Upper Cumberland River (n = 20) basins (Figure 1). The basin divisions of this study are those used by Kentucky's 401 Water Quality Certification program. VIBI development included primarily riverine wetlands as defined by Brinson's (1993) hydrogeomorphic classification (HGM), which is based on geomorphic setting and hydrological characteristics. Riverine wetlands receive water inputs via overbank flow or seepage from a stream or river. Wetland vegetation included forested, emergent, and shrub community types. Focusing on similar wetland types reduces the variation present in characteristics that could affect the plant community, such as hydrological isolation. These natural differences add a potential source of variation in plant communities in addition to anthropogenic disturbance, obscuring the relationship of vegetation metrics to the disturbance measure. Riverine HGM type was chosen because it is the most common wetland type in Kentucky. Some upland embedded wetlands (Mushet et al., 2015) were also included from the 2011 season (Morris 2015).

Site selection was accomplished using both semi-random and targeted means to incorporate a full gradient of disturbance among sites. Semi-random selection used the Generalized Random Tessellation Stratified (GRTS) method (Stevens and Olsen, 2004), drawing from sites identified using National Wetland Inventory census data and topographic maps in coordination with the Kentucky Division of Water (KDOW). Sites were also targeted based on their level of anthropogenic disturbance to ensure a full gradient of condition. Morris (2015) details site selection procedures for 2011–2013.

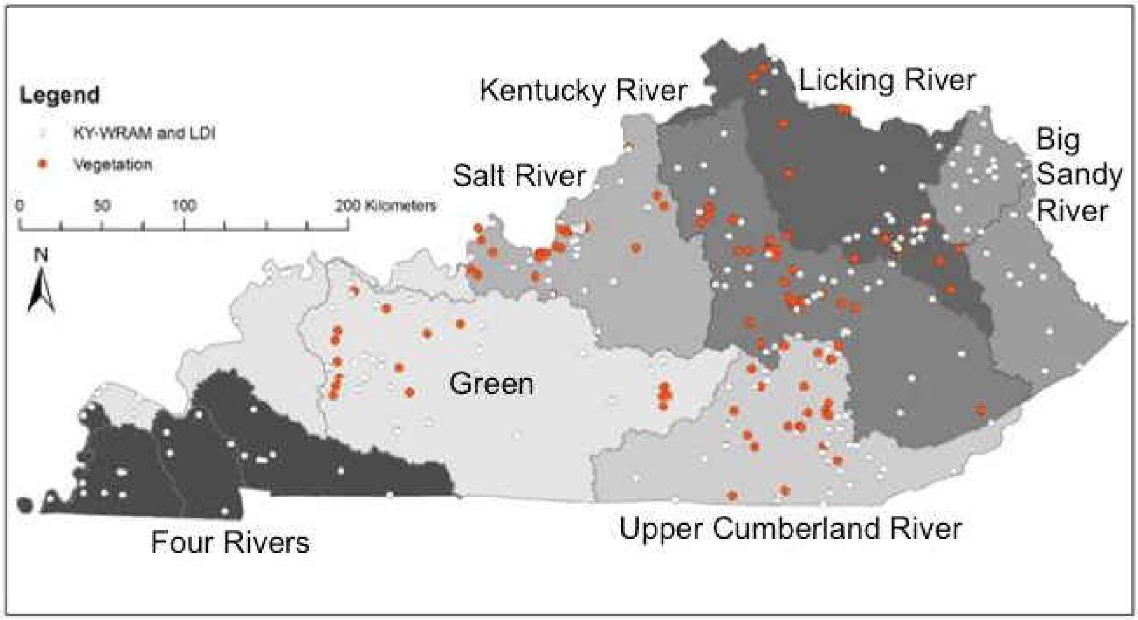


Figure 1. Map showing vegetation sites (orange) and additional KY-WRAM/ Landscape Development Intensity Index (LDI) sites (white). KY-WRAM and LDI assessments were used as disturbance measures and were collected at all vegetation sites.

*Vegetation Sampling*

Wetland plant community data for VIBI development was collected over the 2011 to 2015 growing seasons. Data collection followed protocols outlined by Mack (2007) for the Ohio VIBI. One survey was performed per dominant community (e.g., forested, emergent, or shrub) if more than one was present in a wetland. Best professional judgment was used to place plots in areas most representative of the wetland's plant community (Mack 2000). The Releve plot method described by Peet et al. (1998) and employed by the Ohio VIBI was used because of its modular flexibility and applicability to a wide range of communities. The Releve method uses 10 m x 10 m modules arranged most often in a 20 m x 50 m format (Figure 2). For irregularly shaped communities, modules were arranged to fit the wetland (e.g., 10 m x 100 m or 20 m x 20 m), and small wetlands (less than 0.1 ha) were sampled in their entirety.

VIBI plot modules were assigned an intensive or residual category. Typically, four modules were intensive and six modules were residual. In each intensive module, two nested corners were divided into three smaller quadrats, or levels. The taxonomy of R. L. Jones (2005) was used to identify species six meters or shorter at each level. Each was assigned a cover class for the full module. Remaining modules, or residuals, were searched for any additional species, and these were assigned a cover class. Woody vegetation over one meter tall was identified in every plot and the diameter at breast height (1.4 m) recorded. For species shorter than 1.4 m, the diameter of the widest point on the stem was recorded.

Plant vouchers were taken from each site for quality assurance by collecting a representative specimen for approximately 10% of species encountered. Unknown specimens were also taken for identification in the lab or by an outside botanist. While in the field, specimens were pressed, or collected in bags and kept in a cooler. At the lab, specimens were placed in a refrigerator and identified the next day or pressed and dried for later identification. Voucher specimens were submitted for processing and deposition in the Eastern Kentucky University Herbarium (EKY) and will eventually be imaged and available online (www.sernecportal.org).

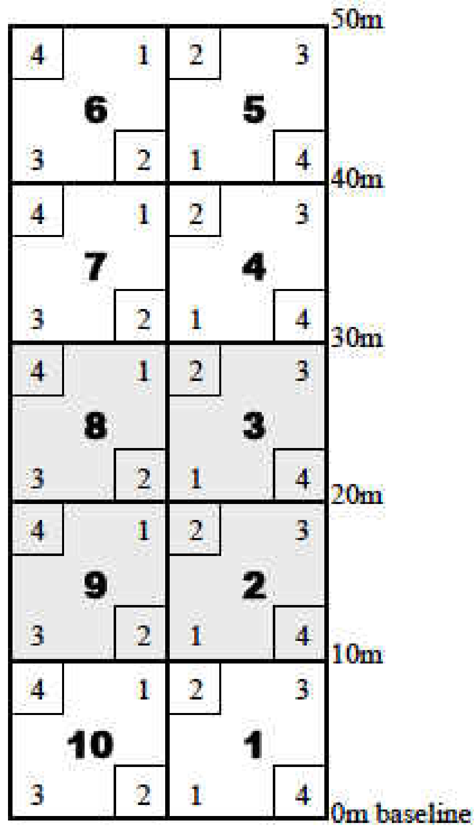


Figure 2. Releve plot design used in VIBI sampling. Modules 2, 3, 8, and 9 are intensive modules, and nested corners are sampled first. The remaining 6 residual modules are searched for additional species not found in the intensive modules. *Source:* Mack, J.J., 2007. Integrated Wetland Assessment Program. Part 9: field manual for the vegetation index of biotic integrity for wetlands, Version 1.4. Ohio EPA Technical Report WET/2007-6. State of Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, Ohio, 126 pp.

*Data Analysis*

Analysis for development of a Kentucky-specific VIBI included data from 110 sites. Wetlands were classified based on vegetation type as emergent (n = 38), forested (n = 61), or shrub (n = 11). In addition to 120 metrics compiled as part of a previous stage of this project (Morris, 2015), five metrics (Dominance, Count Monocot, Shannon-Weiner Diversity Index, Simpson's Diversity Index, and Weighted CC) were also added for this analysis based on recently published multimetric vegetation indices (Table 1) (Bourdaghs et al., 2015; Gara and Stapanian, 2015; USEPA, 2015). For calculation of metrics, an Excel sheet used by the Ohio VIBI (Ohio EPA, 2007) was modified to include all new metrics and an updated Kentucky plant species list. Excel functions for each metric produce a score by referencing the raw data and the plant species list. Plants found in Kentucky but absent from Ohio were added, and attributes of all plants were updated to reflect Kentucky specific communities. This is especially relevant to CC scores, which change with ecoregions. When available, the plant list used here incorporated CC values released by the Southeast Wetlands Working Group (2014), which are specific to physiographic provinces. For plants not included by the Southeastern Wetlands Working Group, values from a list created by the Kentucky State Nature Preserves Commission were used (KSNPC, 2014).

Table 1. Candidate metrics used in this study for the development of a Kentucky-specific VIBI (modified from Morris, 2015). Metrics that correlated most highly with the DI and were used in the model selection process are in bold. Final metrics included in the VIBI are indicated by asterisks (***).

| Metric | Calculation |
|---|---|
| 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 with FACW or OBL indicator status |
| 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 diameter classes |
| 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 (OBL, FACW) trees |
| Stems/ha wetland shrubs | Stems per hectare of native wetland (OBL, FACW) shrubs |
| %Unvegetated | Sum of percent unvegetated open water, bare ground, and relative cover of annual species |
| %Buttonbush | Sum of relative cover of *Cephalanthus occidentalis* |

Table 1 (continued).

| Metric | Calculation |
|---|---|
| %Perennial native hydrophytes | Sum of relative cover of perennial native hydrophyte (OBL, FACW) species |
| **MeanC (all species)*** ** | Average CofC score for all species, including nonnatives |
| MeanC (native) | Average CofC score for native species |
| Cover-weighted MeanC (all species) | Average of absolute cover multiplied by CofC score for all species |
| Cover-weighted MeanC (native) | Average of absolute cover multiplied by CofC score for native species |
| FQAI (all species) | Sum of CofC scores divided by number of all species |
| FQAI (native) | Sum of CofC scores divided by number of native species |
| Cover-weighted FQAI (all species) | Sum of absolute cover multiplied by CofC scores divided by number of all species |
| Cover-weighted FQAI (native) | Sum of absolute cover multiplied by CofC scores divided by number of native species |
| **AFQI** | Sum of CofC scores divided by 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 number of all species (invasive species are given CofC value of -1, -2, or -3) |
| 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 |

Table 1 (continued).

| Metric | Calculation |
|---|---|
| %Perennial | Number of perennial species divided by total number of species |
| 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 |
| 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 |

Table 1 (continued).

| Metric | Calculation |
|---|---|
| Count hydrophytes | Count of hydrophyte (FACW, OBL) species |
| %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 |
| **Dominance** | Cover-weighted meanC, including nonnative species |
| Weighted CC | Sum of each species' proportional abundance multiplied by its C-value |
| Count Monocot | Count of monocot species |
| Shannon-Wiener Diversity Index | Proportion of species *i* relative to the total number of species $p_i$, multiplied by the natural log of this proportion ($\ln p_i$). The product is summed across species and multiplied by -1 |
| Simpsons Diversity Index | The reciprocal of the summed squares of the proportion of species *i* relative to the total number of species $p_i$ |

*Disturbance Index*

At the heart of wetland assessment is an estimate of wetland anthropogenic disturbance, or wetland condition. There are numerous means of measuring disturbance that emphasize a particular cause or consequence of human activity. Combining multiple measures into a Disturbance Index (DI) creates a more robust estimate of disturbance. For this project, I tested the Landscape Development Intensity Index (LDI) and ten abiotic submetrics (Table 2) from the KY-WRAM (KDOW, 2013) for use in a DI that produced a disturbance value for each site (Brown and Vivas, 2005). The VIBI metrics were then tested for correlation with this DI.

Table 2. Abiotic KY-WRAM metrics and submetrics considered for use in the DI.

Metric 2. Buffers and Intensity of Surrounding Land Use

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

Metric 3. Hydrology

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

Metric 4. Habitat Alteration and Habitat Structure Development

4a. Substrate/Soil Disturbance
4b. Habitat Alteration
4c. Habitat Reference Comparison

The LDI is a measure of the potential amount of disturbance to an ecosystem based on the type of land uses in the surrounding watershed (Brown and Vivas, 2005). It recognizes the impact of mobile toxins, physical landscape alteration, and changes to environmental condition, like hydrology, on an ecosystem (Brown and Vivas, 2005). Brown and Vivas (2005) weighted each land-use type by a coefficient that reflects the energy use per unit area required by that land-use type. LDI coefficients range from one for natural areas with no human activity, to ten for intensive commercial land use (Brown and Vivas, 2006). For this study a 1-km buffer zone around each wetland was included in the LDI. Mack (2006) found the LDI had strong correlation in Ohio with independently developed measures of wetland disturbance using a 1-km radius. Calculation of the LDI score is as follows:

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

Where $LDI_{total}$ is the wetland LDI score; $\%LU_i$ is the percent of the total land area occupied by a particular land use *i*; and $LDI_i$ is the coefficient for land use $i$ (Brown and Vivas, 2006).

KY-WRAM assessments at each site provided additional data for use in the DI. The KY-WRAM consists of ten metrics divided into submetrics. The ten submetrics considered for inclusion in the DI evaluate surrounding land use, hydrology, and habitat alteration. Three buffer-related submetrics supplement the LDI, two describe general habitat conditions, and five submetrics evaluate soil and hydrology, which are the features used to delineate a wetland along with vegetation (USACOE, 1987). Biotic metrics were excluded from this analysis to avoid circularity in VIBI development (Mack, 2007). Because of the biological source of VIBI metric data, abiotic indicators from the KY-WRAM and the LDI provide a more independent comparison (Mack, 2007). A principal components analysis (PCA) using the LDI scores and the ten KY-WRAM submetric scores was performed in Program R version 3.1.1 (R Development Core Team, 2015), with the site scores from the first axis of the PCA serving as the DI. In addition to the 111 sites surveyed for the VIBI development, data from an additional 244 wetlands obtained during related work by KDOW and Eastern Kentucky University were included in the PCA.

*Metric Evaluation*

Once the DI was calculated, the relationship of vegetation metrics to the DI was examined in three stages with the goal of eliminating metrics to develop a final list of high performing candidate metrics for inclusion in the VIBI. Sites were divided into separate development and validation sets, with 80% of sites (n = 88) in the development group and 20% (n = 22) in the validation group. Only the development data were used in metric selection, and validation sites were reserved to test the final VIBI.

*1. Range Test*

For the first stage of metric selection, metrics had to pass a range test, as described in the National Wetland Condition Assessment Report (USEPA, 2015). This test ensured that no metrics included in the VIBI had extremely low variation or substantial skew. These characteristics inhibit a metric's ability to describe a gradient of wetland condition. The range test identified metrics for which 75% of the values across wetlands were equal to the minimum or maximum possible or observed value of a metric, and these were excluded for lack of variation.

*2. Correlation*

In the second stage of metric selection the remaining metrics were compared to the DI using Pearson's correlations. Two approaches were compared. First, wetland sites were separated into different plant communities (i.e., forested, shrub, emergent), and correlations of metrics with the DI were performed. The sample size of shrub wetlands (n = 9) was too small to be analyzed independently, so those site were not included in this step. In the second approach, all wetland sites were combined for a single correlation of metrics and the DI. Some IBI's (e.g., Ohio) have been developed to have separate versions based on plant community characteristics in emergent, forested, and shrub wetlands (Mack, 2001). However, many recent vegetation assessments like Ohio's VIBI-FQ method (Gara and Stapanian, 2015), Minnesota's state-wide wetland condition assessment (Bourdaghs et al., 2015), and the NWCA's VMMI (USEPA, 2015) have found single methods adequate for effectively determining condition across all wetland plant community types. By comparing top correlating metrics of emergent, forested, and all sites combined, I assessed whether a single VIBI was an appropriate method for Kentucky's wetlands.

Correlation coefficients and top metrics were similar across the groups of emergent, forested, and all sites. A single VIBI for all wetland plant community types was ultimately chosen over separate VIBIs. A Spearman's rank correlation of metrics with the DI was performed to ensure any non-parametric distribution of vegetation metrics was accounted for. These results were compared with those from the Pearson's correlation analysis. Metrics with a correlation coefficient of $r > 0.40$ in both the Spearman and Pearson correlations were considered in the next stage of VIBI development. A correlation matrix of the remaining top preforming metrics was examined for pairwise multicollinearity. No metrics were eliminated based on multicollinearity, but multicollinearity between metrics did inform multimetric model creation in the next stage.

*3. Model Selection*

I used multiple regression model selection to evaluate the performance of various combinations of the final set of high performing candidate metrics ($n = 12$). Aikaike's Information Criterion (AICc) method was used to find the best combination of metrics that predict the DI. I also examined the model averaged coefficient of individual variables in the top five models, all of which had weights higher than 0.04. Twenty models of two, four, and six metrics were created based on combinations of top metrics (USEPA, 2015). Creation of these models aimed to minimize multicollinearity ($r > 0.75$) within a model and include different metric types. These were guidelines rather than rules, however, and several models follow one but not both of these guidelines. Metric types still present at this stage included floristic quality, tolerance, and native status. Analyses were run in Program R, Version 3.1.1 (R Development Core Team, 2015) using package AICcmodavg (Mazerolle, 2015).

*VIBI Assembly*

Once the final metrics were selected, the middle 95$^{th}$ percentile of development data (Barbour et al., 1999) for all sites was divided into quintiles, which are five groups of equal size, and these were used to assign breakpoints for each of the final metrics. Quantiles with relatively few groups (e.g., quartiles and quintiles) are less affected by outliers than direct scaling and are more reflective of uneven distributions of data (e.g., skews or leaps in data). Wetlands with values in the range of the first quintile or lower were assigned a score of one, those in the second quintile were scored as two, and so on. Each metric in the VIBI had a range of possible scores from one to five points and were added together for the total score. Extreme values falling outside of the middle 95$^{th}$ percentile of data were assigned a one or five, respective of their high or low value. Because I determined there were two final metrics, the final VIBI was based on a 10-point scale (five possible points per metric) that was chosen for its interpretability and simplicity.

The VIBI was calculated for all sites, including development and validation sets, and a three-way Analysis of Variance (ANOVA) test was performed on both validation and development groups with KY-WRAM categories, vegetation class (emergent, forested, shrub), and basin as independent variables and the VIBI as the response. KY-WRAM was included to test the VIBI's effectiveness in discriminating between category one, the most disturbed, and category three, the least disturbed sites. KY-WRAM categories were established using the distribution of 353 sampled sites divided into quartiles of equal frequency, with the first quartile representing category one wetlands (0–39.9), the middle two quartiles (Q2 + Q3) representing category two wetlands (40–68.9), and the fourth quartile representing category three (69–100) (Brown et al., 2016). Differences in vegetation class were tested as this could indicate the need to interpret VIBI scores differently for separate vegetation classes. Basins were also included because previous work on the KY-WRAM development indicated that wetland condition differed among basins (Brown et al., 2016). A Tukey HSD pairwise multiple comparison test was then performed on all significant variables. Additionally, forested and emergent wetlands were separated and ANOVAs were performed on each dataset with KY-WRAM categories as the independent variable to further explore the differences in VIBI scores due to vegetation class.

# CHAPTER III

# RESULTS

Axis 1 of the initial PCA included LDI scores and all KY-WRAM abiotic metrics (n = 10) and explained 43% of the variation in disturbance measures, but two metrics (3a and 3b) had loading scores of less than 0.03 on Axis 1 (Table 3). These metrics were removed, and a PCA of remaining disturbance metrics was repeated. Axis 1 of the second PCA explained 53% of variation in the included disturbance measures and was used as the final DI for VIBI development.

The range test eliminated nine of the original 125 vegetation metrics (Table 4). The Pearson's correlation of metrics with the DI was run separately for four different site groupings (emergent, forested, shrub, and all sites combined). These produced lists of top metrics ($r > 0.4$) and correlation coefficients that were similar across emergent, forested, and all sites (shrub group sample size was too small to allow interpretation). Because of this similarity in the list of candidate metrics among the site groupings, and the importance of an accessible and widely applicable VIBI, I pursued development of a VIBI based on all wetland community types combined. A Spearman's correlation analysis using all sites produced the same 12 top ranking metrics ($r > 0.40$) as the Pearson's correlation, with the exception of two additional metrics that ranked highly in the Spearman's correlation but did not in the Pearson's correlation (Table 5). These two metrics were not used in the next stage of analysis. Multicollinearity of $r > 0.75$ was identified (Table 6) and informed the creation of models used in the AICc analysis.

Table 3. Loading scores on Axis 1 from PCA analyses performed to create a DI. Metrics with low loading scores in the first PCA (PCA1) were removed and PCA2 was performed. Aside from the LDI, disturbance metrics consisted of submetrics from the KY-WRAM.

| **Disturbance Metric** | **Loading scores from Axis 1** | |
|---|---|---|
| | **PCA 1** | **PCA 2** |
| LDI | -0.2706 | -0.2698 |
| 2A | 0.3336 | 0.3338 |
| 2B | 0.3357 | 0.3352 |
| 2C | 0.3266 | 0.3261 |
| 3A | 0.0071 | --- |
| 3B | -0.0265 | --- |
| 3C | 0.1826 | 0.1819 |
| 3D | 0.3641 | 0.3644 |
| 4A | 0.3795 | 0.3801 |
| 4B | 0.4006 | 0.4012 |
| 4C | 0.3535 | 0.3545 |

Table 4. Metrics eliminated in the first stage of metric selection because of their failure to pass the range test.

| **Metrics eliminated by range tests** |
|---|
| Percent Intolerant |
| Simpsons Diversity Index |
| Percent Open Water |
| Percent Unvegetated Water |
| Percent Bare Ground |
| MeanC Native Species |
| Relative Cover Intolerant |
| Relative Cover Native |
| Percent Hydrophyte |

Table 5. Top metrics (r > 0.40) from Pearson's and Spearman's Rank Correlation analyses of metrics with the DI. All top metrics from the Pearson's correlation were also among the top Spearman's. Two metrics with top Spearman's correlations did not have high Pearson's correlations, and are in italics.

| **Metric** | **Pearson's (r)** |
|---|---|
| Percent Nonnative | -0.545 |
| MeanC | 0.542 |
| Nonnative:Native | -0.529 |
| Percent Intolerant | 0.524 |
| Count Nonnative | -0.462 |
| Dominance | 0.456 |
| Tolerant:Intolerant | -0.455 |
| Absolute Cover Nonnative | -0.444 |
| Absolute Cover Tolerant | -0.441 |
| Relative Cover Nonnative | -0.433 |
| Relative Cover Tolerant | 0.415 |
| AFQI | 0.402 |

| **Metric** | **Spearman's (r)** |
|---|---|
| MeanC | 0.548 |
| Nonnative:Native | -0.547 |
| Tolerant:Intolerant | -0.547 |
| Percent Intolerant | 0.547 |
| Percent Nonnative | -0.532 |
| Count Nonnative | -0.473 |
| *Absolute Cover Tolerant:Intolerant* | *-0.470* |
| Dominance | 0.461 |
| Absolute Cover Tolerant | -0.458 |
| Absolute Cover Nonnative | -0.443 |
| Relative Cover Nonnative | -0.428 |
| Relative Cover Tolerant | 0.413 |
| *Percent Bryophyte* | *0.410* |
| AFQI | 0.405 |

Table 6. Correlation matrix for top metrics. Highlighted values indicate multicollinearity (r > 0.75).

| | Percent Nonnative | MeanC | Nonnative:Native | Percent Tolerant | Count Nonnative | Dominance | Tolerant:Intolerant | Rel.Cov.Tolerant | Abs.Cov.Nonnative | Abs.Cov.Tolerant | Rel.Cov.Nonnative | AFQI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Percent Nonnative | 1.00 | x | x | x | x | x | x | x | x | x | x | x |
| MeanC | -0.89 | 1.00 | x | x | x | x | x | x | x | x | x | x |
| Nonnative:Native | 0.98 | -0.87 | 1.00 | x | x | x | x | x | x | x | x | x |
| Percent Tolerant | 0.89 | -0.94 | 0.87 | 1.00 | x | x | x | x | x | x | x | x |
| Count Nonnative | 0.85 | -0.76 | 0.84 | 0.77 | 1.00 | x | x | x | x | x | x | x |
| Dominance | -0.65 | 0.70 | -0.67 | -0.64 | -0.63 | 1.00 | x | x | x | x | x | x |
| Tolerant:Intolerant | 0.86 | -0.90 | 0.88 | 0.96 | 0.73 | -0.66 | 1.00 | x | x | x | x | x |
| Rel.Cov.Tolerant | 0.64 | -0.67 | 0.69 | 0.69 | 0.64 | -0.79 | 0.73 | 1.00 | x | x | x | x |
| Abs.Cov.Nonnative | 0.43 | -0.35 | 0.47 | 0.39 | 0.45 | -0.53 | 0.38 | 0.63 | 1.00 | x | x | x |
| Abs.Cov.Tolerant | 0.40 | -0.42 | 0.43 | 0.45 | 0.43 | -0.55 | 0.42 | 0.77 | 0.84 | 1.00 | x | x |
| Rel.Cov.Nonnative | 0.66 | -0.58 | 0.71 | 0.80 | 0.65 | -0.75 | 0.65 | 0.80 | 0.79 | 0.61 | 1.00 | x |
| AFQI | -0.70 | 0.76 | -0.69 | -0.40 | -0.34 | 0.47 | -0.69 | -0.40 | -0.17 | -0.21 | -0.35 | 1.00 |

Twenty a priori models (Table 7) were created using the 12 remaining top vegetation metrics as covariate predictors of the DI. AICc model selection identified two top models ($\Delta$AICc < 2.0), together containing four vegetation metrics. Model averaging of individual variables found both variables in the top model, MeanC and Absolute Cover Nonnative, to be significant. I used the four metrics in the two top models to create another set of candidate models (Table 8) that included each metric alone, combinations of groups of metrics (floristic quality, nativity, tolerance), and combinations of metrics that avoided multicollinearity. The best performing model was again MeanC + Absolute Cover Nonnative. Because this model weight was highest in both AICc analyses, these two metrics were chosen for inclusion in the final VIBI.

Quintile divisions based on the middle 95$^{th}$ percentile of metric data were used to establish breakpoints for VIBI scoring (Table 9). The final VIBI score for a wetland is its MeanC and Absolute Cover Nonnative scores added together for a potential VIBI score of 10 points. The range of raw MeanC scores fell between 2.4 and 4.9 (out of 10) and Absolute Cover Nonnative values were between 0 and 3.4. A value of one indicates 100% plot cover by nonnative species (cover estimates allow for species to overlap one another).

Based on a three-way ANOVA of development data with VIBI score as the response, the effect of all independent variables was significant (Table 10). According to Tukey HSD pairwise comparisons, the mean of category 3 (good condition) wetland VIBI scores was significantly different than both category one (poor condition) and category 2 (fair condition) (Figure 3). On average, category three wetlands scored 3.64 points higher than category one ($Q = 6.05$, $p < 0.001$) and 2.46 points higher than category two ($Q = 5.71$, $p < 0.001$). Category one and category two wetland scores did not differ ($Q = 1.96$, $p = 0.126$) .

Emergent wetlands were found to have significantly lower scores than both forested and shrub (Figure 4). Forested wetland mean VIBI scores were 1.88 points higher than emergent wetlands ($Q = -4.43$, $p < 0.001$), and shrub were 2.11 higher than emergent on average ($Q = 2.71$, $p = 0.022$). Shrub mean VIBI scores were not significantly different than forested wetlands ($Q = 0.29$ , $p = 0.952$). Four of the ten basin pairwise comparisons were significantly different (Table 11, Figure 5).

The ANOVA on validation sites with VIBI score as the response variable showed the effect of the KY-WRAM to be significant ($F_{2,13} = 15.590$, $p < 0.001$). Again, category three wetlands showed significantly higher mean VIBI scores than categories one and two (Figure 6). Category three wetlands scored an average of 5.17 points higher than category one ($Q = 5.07$, $p = 0.001$) and 4.11 points higher than category two ($Q = 5.14$, $p = 0.001$). Categories one and two were not significantly different ($Q = 1.04$, $p = 0.569$).

In separate two-way ANOVAs of all emergent wetlands and all forested wetlands, KY-WRAM effect on VIBI score was also significant in both cases (Emergent: $F_{2,31} = 5.53$, $p = 0.009$; Forested: $F_{2,54} = 23.90$, $p < 0.001$). Basin had a significant effect only for forested wetlands ($F_{4,54} = 7.77$, $p < 0.001$). For emergent wetlands, all three categories were significantly different from one another, with category three scores higher than catgory one ($Q = 4.87$, $p = 0.001$, Figure 7) and category two ($Q = 2.78$, $p = 0.025$). Category two scores were also higher than category one ($Q = 2.54$, $p = 0.042$). Forested wetland scores for category three were significantly higher than categories two ($Q = 6.31$, $p < 0.001$) and one ($Q = 2.50$, $p = 0.040$), but there was no significant difference for categories one and two ($Q = 0.96$, $p = 0.001$, Figure 8). Differences between forested wetland scores for basin are listed in Table 12.

Table 7. Models for first round of multiple linear regression analysis and AICc model selection.

| Model | K | AICc | ΔAIC | AICc Weight |
|---|---|---|---|---|
| MeanC + AbsCovNonnative | 4 | -2.6293 | 0 | 0.4555 |
| Percent Nonnative + AbsCovTolerant | 4 | -1.2524 | 1.3769 | 0.2288 |
| Percent Nonnative + MeanC + Nonnative:Native + Percent Tolerant | 6 | 1.0806 | 3.7099 | 0.0713 |
| Nonnative:Native + AbsCovTolerant | 4 | 1.4934 | 4.1227 | 0.058 |
| MeanC + AbsCovNonnative + Dominance + Count Nonnative | 6 | 1.9177 | 4.547 | 0.0469 |
| MeanC + Nonnative:Native + RelCovNonnative + AbsCovTolerant | 6 | 3.3185 | 5.9478 | 0.0233 |
| AFQI + AbsCovNonnative + Percent Tolerant + Dominance | 6 | 3.8914 | 6.5207 | 0.0175 |
| Dominance + MeanC + RelCovNonnative + RelCovTolerant | 6 | 4.0535 | 6.6828 | 0.0161 |
| Percent Nonnative + Dominance | 4 | 4.1839 | 6.8132 | 0.0151 |
| AFQI + Percent Nonnative + Tolerant:Intolerant + AbsCovNonnative + Dominance + RelCovNonnative | 8 | 4.3691 | 6.9983 | 0.0138 |
| MeanC + Percent Tolerant + Dominance + RelCovTolerant + AbsCovNonnative + Tolerant:Intolerant | 8 | 4.8441 | 7.4734 | 0.0109 |
| Native:Nonnative + AbsCovTolerant + RelCovNonnative + AFQI | 6 | 5.0633 | 7.6926 | 0.0097 |
| MeanC + Dominance | 4 | 5.4207 | 8.05 | 0.0081 |
| MeanC + AFQI + Percent Nonnative + RelCovTolerant + AbsCovNonnative + Percent Tolerant | 8 | 5.6053 | 8.2346 | 0.0074 |
| MeanC + Dominance + AFQI + RelCovTolerant + Nonnative:native + AbsCovTolerant | 8 | 5.9339 | 8.5632 | 0.0063 |
| Nonnative:Native + Dominance | 4 | 6.2666 | 8.8959 | 0.0053 |
| Percent Nonnative + Count Nonnative + Dominance + Tolerant:Intolerant + RelCovTolerant + AbsCovNonnative | 8 | 7.8542 | 10.4835 | 0.0024 |
| MeanC + Nonnative:Native + AFQI + Dominance + AbsCovTolerant + RelCovNonnative | 8 | 8.0267 | 10.656 | 0.0022 |
| Dominance + Tolerant:Intolerant + AbsCovTolerant + Count Nonnative | 6 | 9.5959 | 12.2252 | 0.001 |
| Dominance + AFQI | 4 | 11.7233 | 14.3526 | 0.0003 |
| Percent Nonnative + MeanC +Nonnative:Native + Percent Tolerant + Count Nonnative + Dominance + Tolerant:Intolerant + RelCovTolerant + AbsCovNonnative + AbsCovTolerant + RelCovNonnative + AFQI | 14 | 14.0551 | 16.6844 | 0.0001 |

Table 8. Models from second round of multiple linear regression and AICc model selection analysis. These models included the top two models from the first round of models (see Table 7) and different combinations of the four metrics in those two models.

| **Model** | **K** | **AICc** | **ΔAIC** | **AICc Weight** |
|---|---|---|---|---|
| MeanC + AbsCoverNonnative | 4 | -2.6292 | 0.0000 | 0.3526 |
| Percent Nonnative + AbsCovTol | 4 | -1.2524 | 1.3769 | 0.1771 |
| MeanC + AbsCovTol + AbsCovNonnative | 5 | -0.4794 | 2.1499 | 0.1204 |
| Percent Nonnative + AbsCovNonnative | 4 | -0.4735 | 2.1558 | 0.1200 |
| MeanC + AbsCovTol | 4 | -0.3181 | 2.3112 | 0.1110 |
| MeanC + AbsCovTol + Percent Nonnative | 5 | -0.0882 | 2.5411 | 0.0990 |
| Percent Nonnative | 3 | 4.3242 | 6.9535 | 0.0191 |
| MeanC | 3 | 4.7188 | 7.3481 | 0.0089 |
| AbsCovNonnative | 3 | 16.0094 | 18.6387 | 0.0000 |
| AbsCovTol | 3 | 6.2294 | 18.8587 | 0.0000 |

Table 9. Breakpoints and scores for the two final metrics included in the VIBI. For each wetland the value of each metric was converted to a score based on the ranges listed below. Scores for the two metrics were then added together to get the VIBI score of each site.

| **Metric** | **Score** | **Range** |
|---|---|---|
| MeanC | 1 | 0–3.37 |
| | 2 | 3.38–3.68 |
| | 3 | 3.69–4.13 |
| | 4 | 4.14–4.44 |
| | 5 | 4.45+ |
| Absolute Cover Nonnative | 1 | 0.57 + |
| | 2 | 0.16–0.56 |
| | 3 | 0.07–0.15 |
| | 4 | 0.02–0.06 |
| | 5 | 0–0.01 |

Table 10. Source tables from three-way ANOVAs of factors affecting VIBI scores using separate analysis for development and validation data.

Development ANOVA

| Source | df | SS | MS | F | P |
|---|---|---|---|---|---|
| KY-WRAM | 2 | 115.22 | 57.61 | 16.54 | <0.001 |
| Vegetation | 2 | 33.304 | 16.65 | 4.78 | 0.011 |
| Basin | 4 | 88.819 | 22.21 | 6.38 | <0.001 |
| Residuals | 79 | 275.15 | 3.48 | | |

Validation ANOVA

| Source | df | SS | MS | F | P |
|---|---|---|---|---|---|
| KY-WRAM | 2 | 89.89 | 44.94 | 15.59 | <0.001 |
| Vegetation | 2 | 13.66 | 6.83 | 2.37 | 0.133 |
| Basin | 4 | 7.24 | 1.83 | 0.63 | 0.651 |
| Residuals | 13 | 37.48 | 2.88 | | |

Table 11. Post hoc Tukey HSD on basin using development data.

| Pairwise Comparison | | Mean Difference | Q | P-value |
|---|---|---|---|---|
| Green | Kentucky | 2.82 | 4.82 | <0.001 |
| Green | Licking | 0.88 | 1.26 | 0.711 |
| Green | Salt | 1.83 | 2.85 | 0.042 |
| Green | Upper Cumberland | 0.88 | 1.26 | 0.711 |
| Kentucky | Licking | -1.94 | -3.10 | 0.022 |
| Kentucky | Salt | -0.99 | -1.76 | 0.408 |
| Kentucky | Upper Cumberland | -1.94 | -3.10 | 0.022 |
| Licking | Salt | 0.95 | 1.40 | 0.632 |
| Licking | Upper Cumberland | 0.00 | 0 | 1.000 |
| Salt | Upper Cumberland | -0.95 | -1.40 | 0.679 |

Table 12. Post hoc Tukey HSD on basin using for all forested sites.

| Pairwise Comparison | | Mean Difference | Q | P-value |
|---|---|---|---|---|
| Green | Kentucky | 3.00 | 4.55 | <0.001 |
| Green | Licking | 1.44 | 1.88 | 0.336 |
| Green | Salt | 1.07 | 1.56 | 0.528 |
| Green | Upper Cumberland | 1.00 | 1.34 | 0.665 |
| Kentucky | Licking | -1.56 | 2.22 | 0.189 |
| Kentucky | Salt | -1.93 | 3.13 | 0.022 |
| Kentucky | Upper Cumberland | -2.00 | 2.95 | 0.037 |
| Licking | Salt | -0.37 | 0.51 | 0.986 |
| Licking | Upper Cumberland | -0.44 | 0.56 | 0.979 |
| Salt | Upper Cumberland | -0.07 | 0.99 | 1.000 |

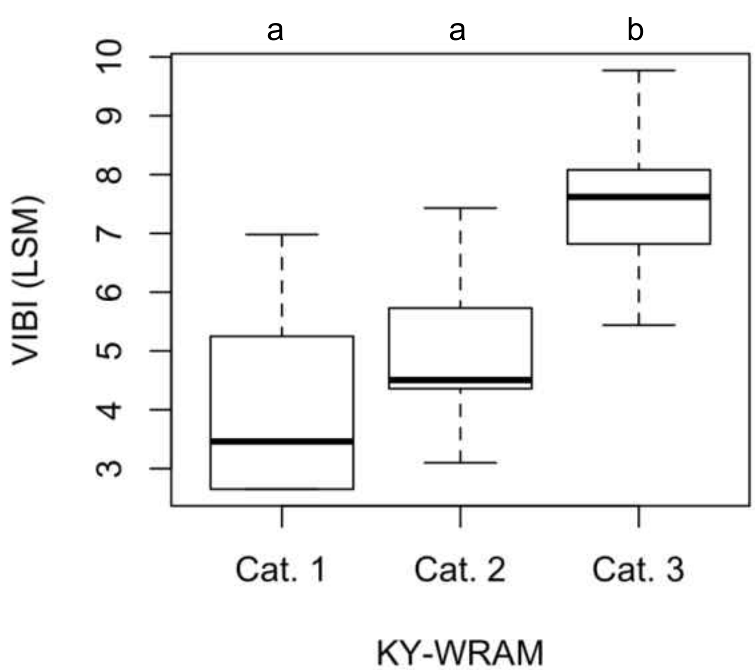


Figure 3. Boxplot of VIBI scores using least square means (LSM) in relation to KY-WRAM categories based on the development dataset. Shared letters above bars indicate groups that do not differ.

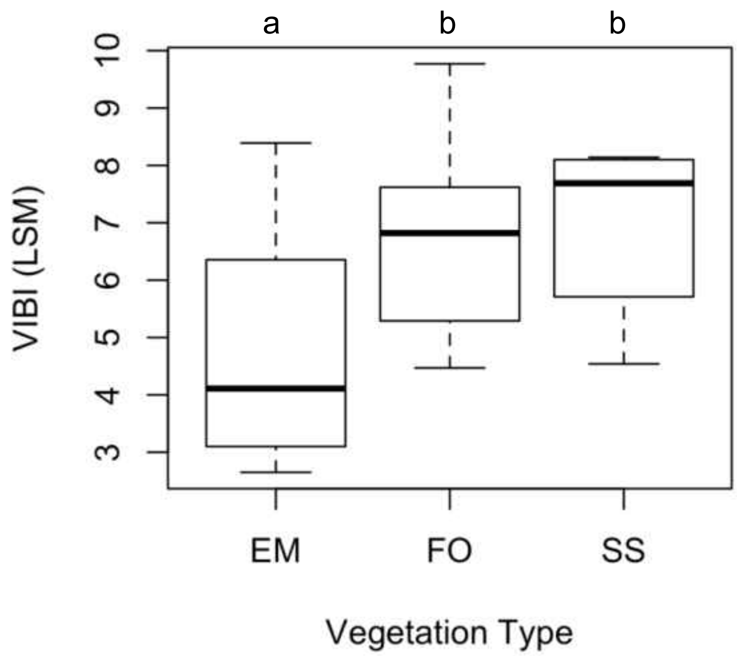


Figure 4. Boxplot of VIBI scores using least square means (LSM) in relation to vegetation type (emergent, forested, shrub) based on the development dataset. Shared letters above bars indicate groups that do not differ.

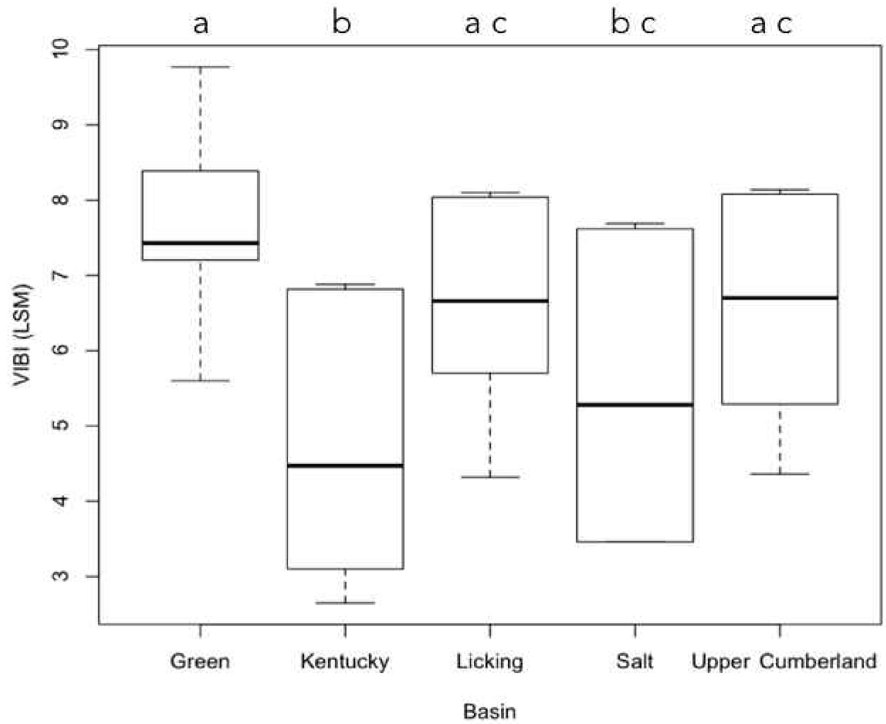


Figure 5. Boxplot of VIBI scores using least square means (LSM) in relation to basins based on the development dataset. Shared letters above bars indicate groups that do not differ.

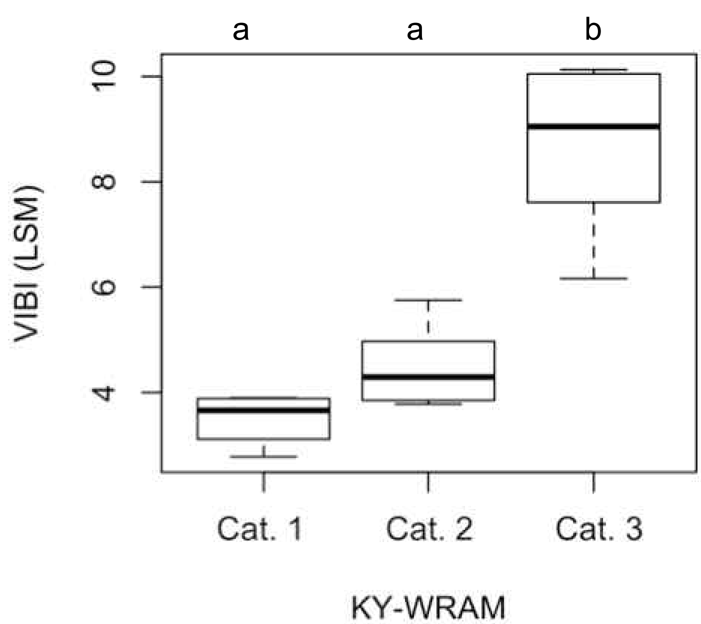


Figure 6. Boxplot of VIBI scores using least square means (LSM) in relation to KY-WRAM based on the validation dataset. Shared letters above bars indicate groups that do not differ.

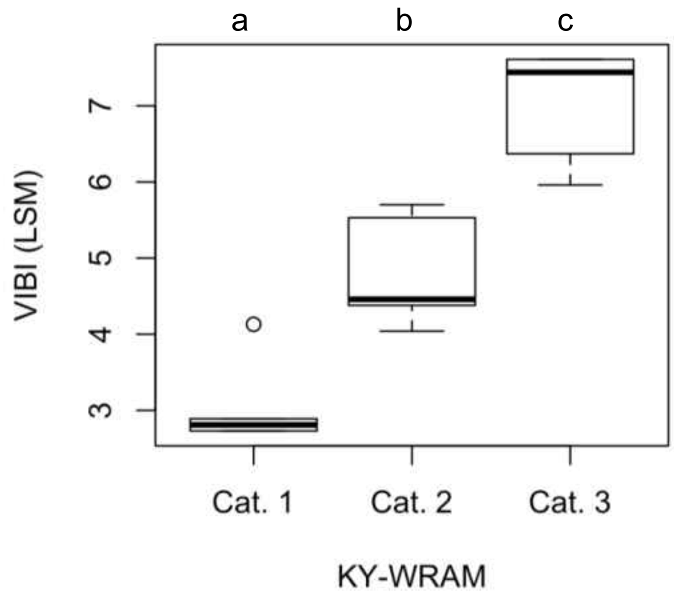


Figure 7. Boxplot of VIBI score and KY-WRAM categories for all emergent sites graphed using least square means (LSM). Shared letters above bars indicate groups that do not differ.

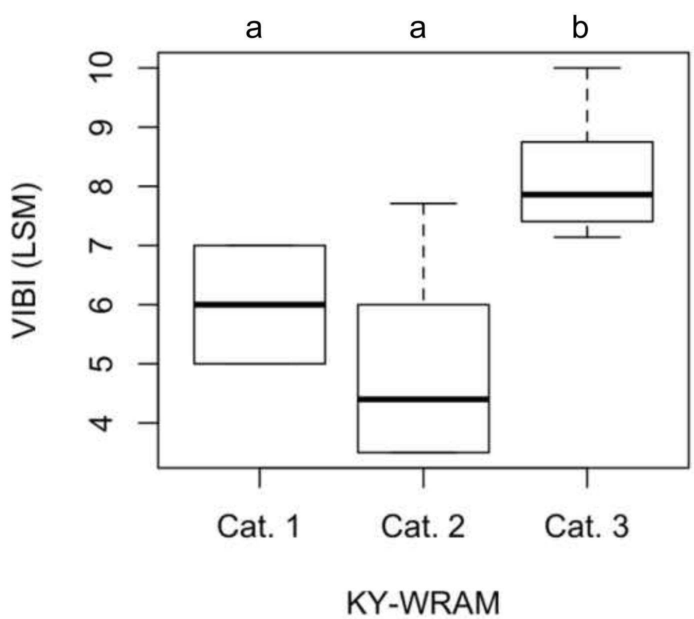


Figure 8. Boxplot of VIBI scores and KY-WRAM categories for all forested sites graphed using least square means (LSM). Shared letters above bars indicate groups that do not differ.

# CHAPTER IV

# DISCUSSION

Although a majority of the 125 metrics tested did not show a clear relationship to the DI, metrics related to floristic quality, tolerance level, and native status were the exception and tended to outperform other metrics. The similar correlations of these metrics with the DI across emergent, forested, and all wetlands together indicate that, though these communities have different species assemblages and structure, there are vegetation metrics that consistently detect and describe underlying changes in condition of the vegetation communities, and by extension, the wetland. Versions of the two metrics in the final VIBI, MeanC and Absolute Cover Nonnatives, are among the most commonly used metrics in IBIs and numerous studies have supported their efficacy in estimating wetland condition (Mack and Kentula, 2010). The VIBI effectively discriminated high quality wetlands from the poor and fair categories, as determined by the KY-WRAM, which supports its applicability as a tool in regulation, monitoring, and research. There was variation in VIBI scores among basins and wetland vegetation types, suggesting some differences in MeanC, Absolute Cover Nonnative, or both are due to the location and dominant plant community of wetlands.

*Disturbance Index*

An accurate measure of anthropogenic disturbance is a crucial component of IBI development, particularly when the development process relies on correlation or model selection. Potential vegetation metrics are ultimately chosen based on their relationship with this single measure. The LDI was used as a measure of disturbance in later iterations of Ohio's OVIBI (Mack, 2007) and, using a 1-km radius, has been shown to reliably predict wetland disturbance (Mack 2007, 2006). Other multimetric indices have combined chemical and physical indicators of stress with buffer information like the LDI to estimate disturbance (Mack, 2001; Miller et al., 2006; USEPA, 2015). The PCA used in this study combined on-site stressor indicators and the LDI to create a final disturbance index that reflects conditions both within and around the wetland. Two hydrology metrics (3a. Input of Water From an Outside Source and 3b. Hydrological Connectivity) did not load onto the main axis of the PCA and were excluded from a subsequent PCA analysis. Because hydrology has such a large effect on the plant community of a wetland and on the functioning of a wetland as a whole (Mitch and Gosselink, 2007; Toner and Keddy, 1997), alteration to hydrology was expected to vary in a similar manner as other habitat, soil, and buffer measures of alteration. This difference may be because both dropped metrics pertain to the input of water and specifically award points to wetlands located in floodplains and experiencing overbank flow, emphasizing the beneficial functions of riverine wetlands (Mitch and Gosselink, 2007). Because our sample of wetlands is almost mainly composed of riverine sites, one would expect less variation in these measures than other abiotic KY-WRAM anthropogenic disturbance measures. These two hydrology measures might reflect a gradient of anthropogenic disturbance in the larger context of Kentucky's wetland ecosystem that includes more sites isolated from surface water connections. The hydrology metrics included in the DI address overall alteration and duration of inundation or saturation, which are more independent of wetland type than sources of water, and could show a gradient of anthropogenic disturbance across our sample.

*Individual Metric Selection*

The top metrics from three separate Pearson's correlations of emergent, forested, and all sites combined with the DI were consistently related to floristic quality, tolerance level, and native status. While both floristic quality and tolerance level are based on CC values, floristic quality metrics incorporate each individual species' value into a single measure, while tolerance-based metrics categorize guilds of species, most of which employ a similar r-selected life history strategy (Miller et al., 2006). All species with CC values greater than two are grouped together into a single category ("intolerant"), giving the species with the highest CC values less weight than they have in floristic quality metrics.

While top metrics for emergent, forested, and all sites were similar, it should be noted that the list of top emergent metrics does include some metrics that were not present in the top of forested or all sites correlations (e.g., dicot and count native woody). Because of the extent of overlap between the metrics that are present in all three groupings, however, I concluded that a single VIBI could reflect disturbance for all wetland vegetation types. Many other studies have also found vegetation assessments applicable to multiple wetland plant communities. Ohio's recent VIBI-FQ applies just two metrics to forested, emergent, and shrub classes (Gara and Stapanian, 2015). It uses broad metrics based on dominance and diversity that include all taxa rather than focusing on particular groups of species. Minnesota's recent state-wide baseline wetland assessment used a single cover-weighted CC metric on all wetland types (Bourdaghs et al., 2015). In the development of a VMMI, the NWCA (USEPA, 2015) created site groups based on different wetland types, including by vegetation. While separate VMMIs for herbaceous and woody wetlands did perform well, they found the most robust VMMI was for all sites combined, which spanned a high variety of wetland types since it included a random sample of wetlands across all 50 states (USEPA, 2015).

The majority of metrics used in these assessments and indices (Bourdaghs et al., 2015; Gara and Stapanian, 2015; USEPA, 2015) are broader and applicable to all species, unlike metrics that are growth habit or taxa specific (e.g., count shrub or percent Carex). The metrics that correlated most highly with the DI in this study are also broader in nature. Natural variability across wetland types and vegetation classes could cause taxa and growth habit specific metrics to perform differently for reasons other than anthropogenic disturbance (Bried et al., 2013; Matthews et al., 2005). By including mostly riverine wetlands this variability was narrowed somewhat. However, the size and flow of the proximate stream or river and the wetland's distance from it result in a variety of natural disturbance regimes and water levels that support different vegetation communities and stages of succession (Toner and Keddy, 1997). For example, a high functioning wetland in the immediate floodplain of a large river would not support the same *Carex*-rich community as a wetland located alongside a small stream that was infrequently and shallowly inundated.

The variation between dominant plant communities can also affect a metric's ability to detect anthropogenic disturbance consistently, thus, some studies have found the separation of vegetation classes necessary for accurate assessments. Ohio's OVIBI is composed of three separate groups of metrics for emergent, forested, and shrub wetlands, and includes metrics covering woody vegetation, grasses, and *Carex*. There are also a number of VIBIs that have been developed for specific wetland types and regions

(Bourdaghs et al., 2006; Gernes and Helgen, 2002; Miller et al., 2006) that do not attempt to develop a method that is applicable state-wide or to a broader variety of wetland types. These studies were able to avoid some of the problems associated with natural variability by focusing their target group of wetlands.

With all sites combined, the top Pearson's correlations of metrics with the DI from this project included three floristic quality metrics, four tolerance metrics, and five native status metrics. These three metric types are nonspecific in terms of vegetation community, explain different aspects of the community, and have a mix of positive and negative relationships with the DI. The Spearman's rank correlation added one tolerance metric and a taxa-based byrophyte metric. The tolerance metric was very similar to other metrics already included in the list. The percent bryophyte metric was most highly correlated with the shrub group, and showed low correlation ($r < 0.4$) with emergent and forested when Spearman's Rank correlations were performed on vegetation classes separately. Because of these considerations and their absence from the Pearson's correlation, these two metrics were not included in the subsequent stages of development.

*Modeling metric combinations*

While correlation analysis was used to indicate one-way associations of vegetation metrics with the DI, determining the combined effects of metrics requires more complex models. Multiple linear regression finds the amount of variation explained by metrics combined, which better reflects the structure of a final VIBI. Multicollinear metrics are often avoided for a VIBI because they explain similar aspects of the variation in disturbance and thus contribute less to the VIBI's ability to reflect condition than variables that are not multicollinear (Mack, 2001; Whittier et al., 2007). Nonetheless, some VIBIs include redundant metrics, if there is no additional cost or downside to collecting the data (Miller et al., 2006). Many of our top performing metrics were multicollinear. Rather than falling along the previously mentioned metric categories of floristic quality, tolerance, and nativity, however, the cover-based metrics— relative and absolute cover nonnative, relative and absolute cover tolerant, and dominance (a cover-weighted floristic quality metric)— grouped together, while metrics lacking cover values clustered and were more often multicollinear. The former capture the evenness of a community and are calculated as dominance ratios, as defined by Mack (2000). The latter metrics include no information about cover. Rather, richness, a richness ratio, or a single value per species is used in their calculations.

The multiple linear regression and AICc modeling outcomes reflect this pattern of having two distinct types of metrics. The MeanC and Absolute Cover Nonnatives model ranked highest in both AICc rounds, and consists of a taxonomic composition metric and a community structure metric. They are also representative of floristic quality and native status, two of three metric categories of the top candidate metrics. While the presence of these categories may contribute to why the model is most effective, the NWCA's VMMI development process included the creation of models that specifically combined different metric categories, but they found this was not an important characteristic of robust models (USEPA, 2015).

In the second round of AICc modeling, the original two models, MeanC + Absolute Cover Nonnative and Percent Nonnative + Absolute Cover Tolerant, out performed new models, including those with just a single metric. Because of its consistent performance, MeanC + Absolute Cover Nonnative was chosen as the final

VIBI. The low intercorrelation value of these two metrics likely contributed to their combined efficacy in predicting disturbance. While MeanC is multicollinear with six of the top 12 metrics, Absolute Cover Nonnative exhibited multicollinearity with only two other metrics. Absolute Cover Nonnative is likely related to some aspect of disturbance that is otherwise not detected by most of the other top metrics (see further discussion below). Thus, it is included in the best model despite its lower individual correlation with disturbance than many of the other top metrics.

*Biological significance of the final metrics*

The MeanC metric is an average of the CC values for all species at a site. It is a variation of the floristic quality assessment index (FQAI), which was originally developed to assess natural areas in the Chicago region (Swink and Wilhelm, 1994). MeanC and the qualitatively similar FQAI are widely used in IBIs and other vegetation assessment contexts and have repeatedly shown a relationship with anthropogenic disturbance (Bried et al., 2013; Lopez and Fennessy, 2002; Mack and Kentula, 2010; Matthews et al., 2005). MeanC avoids the richness bias of some versions of floristic quality metrics (Matthews et al., 2005) and has been found to be a robust indicator of anthropogenic disturbance, showing consistent performance for wetlands sampled across seasons (Bried et al., 2013; Matthews et al., 2005). This is particularly important for a method such as the VIBI that would be used to compare wetlands sampled at different times in the growing season. MeanC also stayed consistent over a seven year period despite low species similarity at resampled wetlands that had experienced no direct anthropogenic disturbance since their first sample (Bried et al., 2013). This suggests that species of similar CC values replace one another in an undisturbed context (Bried et al., 2013), and MeanC is a stable indication of floristic quality. MeanC is also suited for the sampling protocol of this VIBI, as plots of no greater than 0.1 ha are sampled with this method, and MeanC has been shown to perform reliably in small areas (Bourdaghs et al., 2006). MeanC was found to be lower in isolated wetlands, and Matthews and colleagues (2005) hypothesized this was due to the inability of sensitive wetland taxa to disperse across upland habitat matrix. This may be less of an issue in riverine wetlands, however, which are inherently connected to other water bodies and have been found to have higher richness than isolated depressional wetlands because of this connectivity (Bried et al., 2013).

The presence of a nonnative metric in the final model reflects the severe threat that nonnative and invasive plants pose to wetlands (Mack and Kentula, 2010; Zedler and Kercher, 2004). Nonnatives are both an indication of a disturbed habitat and a contributor to the degradation of a wetland by their displacement of native species, effects on hydrology and chemical cycling, and the frequency with which they become monospecific (Cronk and Fennessey, 2001; Zedler and Kercher, 2004; Bourdaghs et al., 2015). The disruption caused by nonnative and invasive species can also create space for more nonnatives (With, 2002). In Kentucky's riverine wetlands, channelization and ditching surrounding agriculture or development are major sources of alteration (R.L. Jones, 2005) and may affect flooding regime or hydroperiod of wetlands. Disturbance to hydrology and water quality is known to increase the abundance and dominance of nonnative species and decrease sensitive taxa (Cronk and Fennessy, 2001; Ehrenfeld and Schneider, 1991). It can also lead to dryer wetlands, leaving the area susceptible to more upland tolerant nonnatives. Fragmentation is another form of alteration that exposes wetlands to more invasions (Yates et al., 2004; With, 2002), and Kentucky, like many states, has experienced extensive fragmentation (Dahl, 2011). Considering the widespread problem of invasives and nonnatives, it is not surprising that metrics related to invasive species are the single most frequently used type of metric in wetland vegetation-based assessment methods (Mack and Kentula, 2010).

A benefit of IBIs, or any aggregate approach to biological condition assessment, is that a bias in a metric does not have as much influence as it would with a single metric floristic assessment (Deimeke et al., 2013). The use of multiple metrics that reflect different aspects of the community and its structure produces a more complex representation of wetland condition. MeanC has been criticized for lacking dominance or abundance information (Gara and Stapanian, 2015), but its pairing with Absolute Cover Nonnatives helps supplement the method with cover based information. Deimeke and colleagues (2013) described changes in community composition of forested wetlands over seven years that resulted in extremely low species similarity over time, but the overall IBI scores, which were composed of 6 metrics including a MeanC and an invasive metric, remained consistent despite the species differences.

*VIBI assembly*

Our sample was large enough with all wetlands grouped together (n = 110) to support the use of the 95$^{th}$ percentile of data to create metric breakpoints for scoring sites using the VIBI. This method eliminates extreme outliers so that score thresholds are less sample specific and is commonly used in setting multimetric breakpoints (Barbour et al., 1999; Gernes and Helgen, 2002; Mack, 2001). The use of percentile breakpoints rather than direct scaling also prevents outliers from skewing scores and better reflects the distribution of the data. Mack (2001, 2007) used quartile scaling, and the USEPA's aquatic IBI protocol (Barbour et. al., 1998) also recommend using tertiles or quartiles. Our analysis chose quintiles to fit a five point per metric scoring system and assigned an increase of one point for each threshold level. The total VIBI of ten points shares the base 10 scale of KY-WRAM's 100—point total score, but does not have the range of the KY-WRAM. With only two metrics, 100 points was thought to be a larger than necessary range of scores.

The range of the raw MeanC scores is small, with 95% of the data falling between 2.4 and 4.9 (out of 10). This is to be expected given the metric is an average of CC values. Averages inherently push values toward the center of their distribution, so even a site with many high CC values would be moderated by lower values. A reference habitat will likely contain some species with wide ecological affinities that receive lower scores despite being native. A very high MeanC would reflect not just a reference community, but a rare community (Gara and Stapanian, 2015). The narrow range of the MeanC data could be reflective of Kentucky's riverine wetlands, which are rarely free from some nonnative influence because of the connectivity inherent in riverine systems and because of the extensive anthropogenic disturbance in the state. Exotic and weedy species, which have CC scores of 0, 1 or 2, strongly dampen averages.

The range of values for Absolute Cover Nonnative range was much greater. Ninety-five percent of the wetland values for this metric were between 0 and 3.4, with a value of 1 indicating 100% plot cover by nonnative species (cover estimates allow for species to overlap one another, thus values can exceed 1.0). A right skew is evident in the quintile values, with the 60$^{th}$ to 80$^{th}$ percentiles showing an increase from 0.14 to 0.55.

The few wetlands with metric values ≥ 0.55 were dominated by invasive species. Sites at which native communities are able to exclude colonization, or are otherwise buffered from nonnatives should exhibit low Absolute Cover Nonnative values. Once invasives become established at a site, however, they often exhibit rapid growth (Cronk and Fennessy, 2001). This can lead to wetland drying and transition to upland habitat, or leave the wetland vulnerable to further invasion. Absolute Cover Nonnative scores would be higher in both cases, leaving relatively few wetlands in an intermediate stage of invasion, and thus few wetlands would be expected to have an intermediate score for that metric.

*Validation*

The three-way ANOVA on development dataset discriminated category three wetlands from the more disturbed category one and two wetlands. This was the case for the validation hold out sample as well, indicating the VIBI is a useful tool for discriminating reference or minimally disturbed wetlands from more degraded wetlands. The national VMMI, developed as part of the NWCA, was also validated by distinguishing least from most disturbed wetlands (USEPA, 2015). Similarly, Gara and Stapanian (2015) included only the highest and lowest scoring 10% of wetlands as identified by the VIBI-FQ in a test of the method's congruence with the older OVIBI (Gara and Stapanian, 2015).

Development data also revealed emergent wetlands to have lower scores than forested, and numerous differences in average basin scores. Vegetation differences were expected because of the inherent differences in emergent and forested communities and are explored below. Because of the impact that region, as represented by basin in our study, can have on the flora present in an area and on abiotic factors like soil, some differences between basins was also expected. The validation ANOVA did not repeat these findings for vegetation class and basin, however. It could be evidence that differences in VIBI score for vegetation types and basin are not as pronounced as the development sample indicated. The small sample size of the validation group should also be considered. In the case of basins, the validation sample (n = 20) is likely too small to show meaningful differences after splitting it among the five basins. Although vegetation type (i.e., forested, shrub, emergent) has fewer groups than basin, the small sample size may make systematic variation difficulty to detect.

A closer look at the differences in KY-WRAM categories and VIBI scores reveals a pattern of increasing VIBI scores as KY-WRAM category increases from one to three for both development and validation datasets. It is detecting a gradient of anthropogenic disturbance, but less reliably for the lower, more degraded portion of sites. Of the three disturbance categories, category one has the smallest sample (n = 22 for development and validation together). Separately, VIBI scores for emergent and forested wetlands reveal similar patterns. For emergent wetlands, all categories are distinct, while for forested wetlands, scores of categories one and two overlap. In all cases, however, category three is statistically and graphically distinct from categories one and two. Although at this stage the data should be interpreted with caution because of the small sample size, further work on the VIBI should focus on understanding and calibrating for the current overlap of KY-WRAM categories. Natural variability, for example, can obscure the signal of anthropogenic disturbance for some metrics. Although our sample of wetlands is mainly from a riverine HGM class, this is a broad categorization that groups wetlands of heterogeneous community composition and structure (Mack 2007). Higher levels of natural variation among wetlands should be expected to obscure the ability of metrics to accurately reveal patterns of anthropogenic disturbance, and this may be a factor in the lack of differentiation between VIBI scores of category one and two wetlands.

Emergent wetlands scored lower on average than forested wetlands in this study, a pattern also seen with the OVIBI (Mack, 2007). When wetlands were ranked by condition, the VIBI-FQ in Ohio found emergent wetlands disproportionately represented in the lowest 10%, though forested wetlands were underrepresented in the top 10% of wetlands in the same study (Gara and Stapanian, 2015). In Kentucky this may be related to the disturbance history of emergent wetlands. Kentucky is thought to have been almost completely forested (R.L. Jones, 2005), so many emergent habitats have histories of extreme anthropogenic disturbance, even if they are currently functioning well and maintained in the emergent stage by natural disturbance. This historic anthropogenic disturbance may have contributed to more tolerant species being present in the wetland long term via niches established during these earlier periods of heavy disturbance. Additionally, agriculture and grazing are at the periphery of many wetlands, and introduced grasses and weeds from these environments are more likely to thrive in the similarly sunny emergent wetlands than in the shaded environment of forested wetlands. Issues in assessing forested wetlands could also be contributing to the gap between scores. Mack (2007) makes two observations about Ohio's forested wetlands and the OVIBI that may be relevant to Kentucky. He argues that in a historically forested area, degraded emergent wetlands could be considered the most degraded condition of forested wetlands (Mack, 2007). This would inflate the number of lowest scoring wetlands for the emergent group, by including sites that should otherwise be considered as part of the forested group. Additionally, Mack (2007) sampled many highly degraded wetlands that retained their overhead canopy layer, inflating their OVIBI score through tree based metrics. While this study's VIBI does not include specific tree or canopy metrics, MeanC could be artificially raised by the presence of native tree species indicative of former conditions and persisting through a lag effect.

Because of this difference in scores, interpretation of the final VIBI should be different for forested and emergent wetlands. Thus, I recommend developing a separate sets of VIBI category breakpoints for forested and emergent wetlands. Because the VIBI has practical applications that could include identifying antidegradation classes or evaluating mitigation success, significant differences in scores between groups of sites unrelated to disturbance must be corrected for. This approach of having different VIBI category breakpoints for different vegetation types maintains simplicity by applying the same metrics and calculations to all wetlands, and only requires divergent procedures in the application and interpretation of the scores instead of in the earlier calculation steps. Minnesota's baseline condition assessment uses a similar approach, with different scoring interpretation for different wetland types (Bourdaghs et al., 2015), and Ohio's VIBI has numerous antidegradation category breakpoints for specific wetland types by ecoregion (Mack, 2004). The sample size of this study is not large enough to support the establishment of separate breakpoints for VIBI interpretation of emergent and forested wetlands. While a trend in the VIBI relationship with KY-WRAM categories is apparent, setting breakpoints at this point would risk being more specific to the sample than reflective of the population. A goal of further work on the project should be to increase the number of emergent and forested wetlands, and set breakpoints once a larger and more representative sample is achieved. Possible methods of establishing these thresholds include the method used by the NWCA (USEPA, 2015), which used the distribution of reference wetlands as a guide. Shrub wetlands are underrepresented in this study, and were not analyzed independently. To gain a better understanding of their relationship to disturbance and the appropriateness of this VIBI in assessing shrub wetland condition, particular effort should be made to include shrub wetlands in future VIBI research.

*Management Implications*

This VIBI was tested on riverine wetlands in five of Kentucky's river basins, thus its ability to detect wetland condition is only known for wetlands in that scope. Because the VIBI's two metrics of MeanC and Absolute Cover Nonnative could be applied to any site, there is potential for use on a variety of wetlands and further testing should be done to assess its applicability elsewhere and in different HGM types. While five of Kentucky's seven major river basins were sampled, a larger sample would give a more complete picture of how regional variation influences VIBI performance. As further work is done, the potential influence of interannual variation in climate should also be considered, as hydrology, which varies with climate among years, strongly affects wetland plant communities. Because the VIBI was developed based on natural wetlands, its performance at mitigation wetlands remains unknown. The early successional stage of new mitigation wetlands and the fast pace of community change may require different vegetation metrics to capture an accurate depiction of wetland condition (Gara and Stapanian, 2015). Overall, this VIBI includes metrics that are straightforward to understand and interpret and applicable to any vegetation community, which is particularly valuable if the method is to be accessible to a diverse audience and widely implemented. Potential uses of the VIBI could include the determination of antidegradation categories, for example in cases where the KY-WRAM score falls between categories, as in Ohio's regulatory program (Stapanian et al., 2013). With further testing, it may also be applicable to monitoring the success of mitigation wetlands. The VIBI is also a tool that could be used for research and ambient monitoring and could be employed by land managers, agencies, and universities.

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APPENDIX 1

Appendix 1. List of all sites included in study with classification information and final assessment metrics. Dataset column specifies development (D) or validation (V); vegetation types include emergent (EM), forested (FO), and shrub (SS); disturbance index (DI), landscape development intensity index (LDI) and Kentucky Rapid Assessment Method scores were used at various stages of development as measures of anthropogenic disturbance.

| Site | Latitude | Longitude | Data -set | Veg. | Basin | DI | LDI | KYWRAM | VIBI | Mean C |
|---|---|---|---|---|---|---|---|---|---|---|
| KYW11-002 | 37.42510 | -84.10340 | V | SS | Upper Cumb. | 0.48 | 1.30 | 73.9 | 9 | 4.4 |
| KYW11-009 | 37.38590 | -84.01990 | V | EM | Upper Cumb. | 0.01 | 1.26 | 48.8 | 7 | 3.9 |
| KYW11-010 | 37.38830 | -84.01120 | V | SS | Upper Cumb. | 0.54 | 1.20 | 79.0 | 10 | 4.9 |
| KYW11-014 | 37.45700 | -83.96186 | V | FO | Upper Cumb. | 0.26 | 1.80 | 71.7 | 10 | 4.5 |
| KYW11-034 | 37.07992 | -84.03849 | D | EM | Upper Cumb. | 0.03 | 2.59 | 69.0 | 6 | 4.5 |
| KYW11-037 | 37.99821 | -84.44169 | V | EM | Kentucky | -0.38 | 7.02 | 39.6 | 3 | 2.0 |
| KYW11-038 | 38.04650 | -84.42442 | D | FO | Kentucky | -0.18 | 5.05 | 49.3 | 3 | 3.7 |
| KYW11-040 | 37.72754 | -84.30166 | D | EM | Kentucky | -0.20 | 5.20 | 35.7 | 3 | 2.6 |
| KYW11-041 | 37.70106 | -84.27527 | D | FO | Kentucky | 0.17 | 4.26 | 69.0 | 9 | 4.2 |
| KYW11-042 | 37.70359 | -84.27333 | D | FO | Kentucky | 0.03 | 4.30 | 63.5 | 6 | 4.1 |
| KYW11-045 | 38.14537 | -84.90257 | D | SS | Kentucky | -0.06 | 3.86 | 44.8 | 5 | 3.5 |
| KYW11-046 | 37.71080 | -84.18016 | D | FO | Kentucky | 0.32 | 2.68 | 72.0 | 7 | 3.7 |
| KYW11-048 | 37.46696 | -84.33289 | D | FO | Kentucky | -0.22 | 3.79 | 40.5 | 4 | 3.6 |
| KYW12-001 | 37.49210 | -87.43020 | D | FO | Green | -0.40 | 5.96 | 40.0 | 8 | 4.1 |
| KYW12-014 | 37.59080 | -86.56930 | D | EM | Green | -0.18 | 3.11 | 46.5 | 8 | 4.3 |
| KYW12-016 | 37.23670 | -85.17600 | D | FO | Green | -0.11 | 2.11 | 52.5 | 7 | 4.4 |
| KYW12-017 | 37.37640 | -87.41130 | D | FO | Green | 0.07 | 3.29 | 74.3 | 10 | 4.5 |
| KYW12-020 | 37.76190 | -87.30220 | D | FO | Green | -0.11 | 4.04 | 44.9 | 10 | 4.7 |
| KYW12-025 | 37.24050 | -87.42060 | D | FO | Green | 0.09 | 2.13 | 59.7 | 5 | 4.0 |
| KYW12-027 | 37.21050 | -86.91110 | V | FO | Green | -0.04 | 3.15 | 69.1 | 10 | 4.7 |
| KYW12-030 | 37.53660 | -86.79630 | D | FO | Green | -0.18 | 2.52 | 46.0 | 10 | 4.6 |
| KYW12-032 | 37.14150 | -85.17130 | D | EM | Green | -0.39 | 1.97 | 32.2 | 4 | 3.9 |
| KYW12-033 | 37.54620 | -87.41100 | D | FO | Green | -0.20 | 4.57 | 59.8 | 4 | 3.9 |
| KYW12-034 | 37.67100 | -87.07810 | D | EM | Green | -0.25 | 4.15 | 40.5 | 4 | 3.5 |
| KYW12-037 | 37.19020 | -87.43690 | D | FO | Green | 0.13 | 1.89 | 54.2 | 10 | 4.6 |
| KYW12-039E | 37.34700 | -86.98670 | D | EM | Green | 0.21 | 2.39 | 77.9 | 8 | 4.2 |
| KYW12-039F | 37.34700 | -86.98670 | D | FO | Green | 0.21 | 2.39 | 31.3 | 10 | 4.6 |
| KYW12-057 | 37.28390 | -87.39530 | D | EM | Green | 0.38 | 1.45 | 73.8 | 8 | 4.1 |
| KYW12-088 | 37.19660 | -85.17570 | D | EM | Green | 0.26 | 1.91 | 72.4 | 9 | 4.8 |
| KYW12-144 | 37.19960 | -85.13880 | D | EM | Green | 0.15 | 2.01 | 69.4 | 5 | 4.1 |
| KYW12-212 | 37.24800 | -85.15940 | V | FO | Green | -0.27 | 1.78 | 33.5 | 4 | 3.7 |

Appendix 1
(continued).

| Site | Latitude | Longitude | Data -set | Veg. | Basin | DI | LDI | KYWRAM | VIBI | Mean C |
|---|---|---|---|---|---|---|---|---|---|---|
| KYW12-226 | 36.67090 | -84.34510 | D | FO | Upper Cumb. | 0.47 | 1.42 | 88.8 | 9 | 4.5 |
| KYW12-227 | 37.10790 | -84.05860 | D | FO | Upper Cumb. | 0.03 | 5.08 | 72.4 | 8 | 4.7 |
| KYW12-233 | 36.97800 | -84.59580 | D | EM | Upper Cumb. | -0.06 | 3.25 | 53.8 | 8 | 4.1 |
| KYW12-240 | 36.83080 | -83.98180 | V | FO | Upper Cumb. | 0.39 | 1.50 | 82.4 | 9 | 4.8 |
| KYW12-243 | 37.14740 | -84.04160 | D | FO | Upper Cumb. | -0.38 | 3.30 | 38.5 | 5 | 4.2 |
| KYW12-244 | 36.91230 | -84.08080 | D | FO | Upper Cumb. | -0.14 | 4.42 | 60.0 | 5 | 4.3 |
| KYW12-245 | 37.34170 | -84.56250 | D | FO | Upper Cumb. | 0.18 | 1.36 | 71.7 | 4 | 4.1 |
| KYW12-250 | 37.11390 | -84.68690 | D | EM | Upper Cumb. | 0.26 | 1.54 | 64.2 | 2 | 3.0 |
| KYW12-391 | 37.08490 | -84.05440 | D | FO | Upper Cumb. | 0.12 | 4.82 | 72.2 | 9 | 4.7 |
| KYW12-414 | 36.64830 | -84.70620 | V | FO | Upper Cumb. | 0.40 | 1.31 | 67.7 | 5 | 4.1 |
| KYW12-453 | 38.01870 | -85.91300 | V | FO | Pond Creek | 0.27 | 2.58 | 81.0 | 10 | 4.6 |
| KYW12-463 | 38.12320 | -85.70070 | V | FO | Pond Creek | -0.23 | 4.78 | 46.5 | 5 | 4.0 |
| KYW12-465 | 38.09320 | -85.84170 | V | FO | Pond Creek | -0.07 | 3.16 | 59.0 | 5 | 3.9 |
| KYW12-466 | 38.11300 | -85.80080 | D | FO | Pond Creek | 0.14 | 4.26 | 72.5 | 4 | 3.6 |
| KYW12-490 | 38.10900 | -85.75780 | D | FO | Pond Creek | -0.04 | 5.33 | 56.5 | 4 | 3.6 |
| KYW12-510 | 38.11940 | -85.77340 | V | FO | Pond Creek | -0.36 | 5.50 | 34.5 | 5 | 3.6 |
| KYW12-BRC | 37.02362 | -84.31689 | D | EM | Upper Cumb. | 0.54 | 1.29 | 77.8 | 4 | 4.0 |
| KYW12-HPB | 37.24030 | -84.20180 | D | FO | Upper Cumb. | 0.47 | 1.36 | 80.0 | 6 | 4.5 |
| KYW12-LCW | 37.08751 | -82.99304 | V | FO | Kentucky | 0.33 | 1.46 | 68.3 | 4 | 4.0 |
| KYW13-212 | 38.18250 | -84.84980 | D | FO | Kentucky | 0.32 | 3.26 | 78.8 | 8 | 4.3 |
| KYW13-213 | 37.87900 | -84.27070 | V | FO | Kentucky | 0.06 | 1.95 | 56.5 | 2 | 3.1 |
| KYW13-214 | 37.69140 | -83.93470 | D | FO | Kentucky | 0.10 | 2.62 | 61.7 | 3 | 3.4 |
| KYW13-222 | 37.67290 | -84.24910 | D | FO | Kentucky | 0.00 | 4.82 | 57.8 | 5 | 3.7 |
| KYW13-223 | 38.15860 | -84.68050 | D | EM | Kentucky | -0.22 | 4.43 | 27.5 | 4 | 2.5 |
| KYW13-228 | 38.22720 | -84.83750 | D | SS | Kentucky | -0.05 | 4.20 | 74.2 | 9 | 4.4 |
| KYW13-229 | 38.06650 | -84.30520 | D | FO | Kentucky | -0.08 | 4.57 | 53.0 | 2 | 3.2 |
| KYW13-230 | 37.66800 | -83.84270 | D | FO | Kentucky | 0.37 | 1.80 | 77.8 | 6 | 4.1 |
| KYW13-232 | 37.98740 | -84.64700 | D | FO | Kentucky | 0.08 | 3.06 | 75.8 | 7 | 4.8 |
| KYW13-287E | 37.48070 | -84.49700 | V | EM | Kentucky | 0.22 | 3.80 | 77.5 | 10 | 4.6 |
| KYW13-287F | 37.48070 | -84.49700 | D | FO | Kentucky | 0.22 | 3.80 | 77.5 | 7 | 4.1 |
| KYW13-288 | 38.21870 | -84.85360 | V | SS | Kentucky | -0.05 | 4.20 | 74.2 | 6 | 4.0 |
| KYW13-294 | 37.71140 | -84.19500 | D | FO | Kentucky | 0.22 | 2.03 | 69.0 | 6 | 4.3 |
| KYW13-346 | 37.71070 | -84.20140 | D | FO | Kentucky | 0.38 | 1.80 | 56.5 | 4 | 2.7 |
| KYW13-393 | 37.99220 | -84.37040 | D | EM | Kentucky | -0.19 | 3.40 | 43.5 | 3 | 3.0 |
| KYW13-430 | 38.04260 | -83.61940 | D | FO | Licking | 0.26 | 2.65 | 58.5 | 7 | 4.2 |
| KYW13-432 | 38.93970 | -84.52460 | D | FO | Licking | -0.15 | 3.50 | 44.8 | 5 | 3.2 |

Appendix 1 (continued).

| Site | Latitude | Longitude | Data -set | Veg. | Basin | DI | LDI | KYWRAM | VIBI | Mean C |
|---|---|---|---|---|---|---|---|---|---|---|
| KYW13-434 | 37.98490 | -83.55290 | D | SS | Licking | 0.46 | 1.64 | 89.5 | 7 | 4.2 |
| KYW13-436 | 38.75320 | -83.86860 | D | EM | Licking | 0.04 | 2.20 | 48.5 | 2 | 3.0 |
| KYW13-437 | 37.93640 | -83.83880 | V | FO | Licking | 0.05 | 2.59 | 47.0 | 5 | 4.0 |
| KYW13-439 | 37.97710 | -83.11140 | V | EM | Licking | 0.03 | 1.17 | 44.8 | 3 | 3.3 |
| KYW13-443 | 38.68080 | -84.32390 | D | EM | Licking | 0.26 | 3.75 | 81.0 | 7 | 4.0 |
| KYW13-460 | 38.98910 | -84.45580 | D | FO | Licking | 0.00 | 2.84 | 51.0 | 7 | 3.8 |
| KYW13-466 | 37.98240 | -83.52210 | D | FO | Licking | 0.38 | 1.47 | 82.0 | 8 | 4.0 |
| KYW13-471 | 37.91330 | -83.24500 | D | FO | Licking | -0.02 | 2.72 | 53.5 | 6 | 4.2 |
| KYW13-478 | 38.04650 | -83.38460 | D | FO | Licking | 0.49 | 1.31 | 84.5 | 9 | 4.7 |
| KYW13-479 | 38.40830 | -84.28450 | D | FO | Licking | -0.17 | 3.88 | 38.5 | 6 | 3.5 |
| KYW13-490 | 38.04370 | -83.51570 | D | FO | Licking | 0.44 | 1.21 | 78.8 | 6 | 3.5 |
| KYW13-494 | 37.98160 | -83.55600 | D | EM | Licking | 0.32 | 1.56 | 84.0 | 8 | 4.2 |
| KYW13-496 | 38.76120 | -83.90950 | D | SS | Licking | 0.30 | 2.24 | 78.0 | 8 | 4.3 |
| KYW13-631 | 37.86060 | -86.45260 | D | EM | Salt | -0.28 | 1.02 | 33.5 | 3 | 1.9 |
| KYW13-635 | 38.11870 | -86.45270 | D | SS | Salt | 0.15 | 3.03 | 77.0 | 7 | 3.7 |
| KYW13-647 | 37.88940 | -86.49570 | D | FO | Salt | 0.36 | 1.70 | 60.5 | 4 | 3.5 |
| KYW13-649 | 37.98300 | -85.99510 | D | FO | Salt | 0.38 | 1.07 | 79.5 | 9 | 4.4 |
| KYW13-659 | 38.00900 | -85.35650 | D | EM | Salt | -0.17 | 3.02 | 42.0 | 4 | 3.3 |
| KYW13-660 | 37.95970 | -86.02500 | D | FO | Salt | 0.50 | 1.06 | 76.0 | 10 | 4.9 |
| KYW13-663 | 37.98290 | -86.34610 | D | EM | Salt | 0.03 | 1.86 | 31.0 | 3 | 2.7 |
| KYW13-664 | 37.75460 | -85.92870 | D | FO | Salt | 0.42 | 2.47 | 79.0 | 10 | 4.4 |
| KYW13-668 | 37.85190 | -86.05010 | D | EM | Salt | -0.42 | 4.14 | 19.0 | 3 | 3.4 |
| KYW13-672 | 38.00910 | -85.87720 | D | EM | Salt | -0.11 | 1.98 | 55.0 | 6 | 3.6 |
| KYW13-676 | 37.98270 | -86.02730 | D | FO | Salt | 0.43 | 1.13 | 80.0 | 9 | 4.4 |
| KYW13-677 | 38.56060 | -85.40590 | V | EM | Salt | -0.13 | 2.14 | 38.3 | 2 | 2.2 |
| KYW13-679 | 38.05110 | -86.42880 | D | FO | Salt | 0.43 | 1.26 | 71.0 | 10 | 4.5 |
| KYW13-681 | 38.11470 | -85.88040 | D | FO | Salt | -0.35 | 5.41 | 43.3 | 4 | 3.1 |
| KYW13-690 | 38.23840 | -85.15670 | D | EM | Salt | -0.37 | 3.60 | 32.0 | 2 | 2.7 |
| KYW13-692 | 37.98310 | -85.97470 | D | FO | Salt | 0.43 | 1.73 | 73.0 | 8 | 4.9 |
| KYW13-706 | 38.29550 | -85.20460 | D | EM | Salt | -0.18 | 3.47 | 32.0 | 2 | 1.9 |
| KYW13-BBS | 37.74586 | -84.06538 | D | EM | Kentucky | 0.28 | 1.84 | 70.8 | 5 | 4.0 |
| KYW13-BGAD1 | 37.70516 | -84.21402 | V | EM | Kentucky | -0.04 | 2.01 | 49.3 | 5 | 3.7 |
| KYW13-BRW | 37.68533 | -84.27982 | D | EM | Kentucky | -0.12 | 3.36 | 44.0 | 2 | 3.4 |
| KYW13-CLA | 37.99533 | -84.44310 | D | SS | Kentucky | -0.37 | 6.56 | 45.5 | 2 | 3.0 |
| KYW13-CPD | 36.91435 | -84.54922 | D | SS | Upper Cumb. | 0.53 | 1.23 | 79.0 | 10 | 5.2 |
| KYW13-HWM | 37.24299 | -84.50019 | D | EM | Upper Cumb. | 0.37 | 2.33 | 67.0 | 10 | 5.4 |
| KYW13-I751 | 37.81403 | -84.32422 | D | EM | Kentucky | -0.47 | 4.50 | 44.0 | 4 | 3.7 |
| KYW13-I752 | 37.95261 | -84.38812 | D | EM | Kentucky | -0.47 | 3.91 | 28.0 | 2 | 2.5 |
| KYW13-JPF | 37.98871 | -84.42099 | D | EM | Kentucky | -0.35 | 4.79 | 62.0 | 3 | 3.6 |

Appendix 1 (continued).

| Site | Latitude | Longitude | Data-set | Veg. | Basin | DI | LDI | KYWRAM | VIBI | Mean C |
|---|---|---|---|---|---|---|---|---|---|---|
| KYW13-MBS | 37.01703 | -84.23006 | V | SS | Upper Cumb. | 0.51 | 1.27 | 75.0 | 4 | 3.9 |
| KYW13-OHM | 37.98989 | -84.57246 | D | FO | Kentucky | -0.38 | 6.28 | 45.5 | 2 | 3.1 |
| KYW14-BGADD2 | 37.66908 | -84.23332 | D | EM | Kentucky | -0.25 | 3.96 | 46.3 | 6 | 3.5 |
| KYW14-CurryWay | 37.59498 | -84.56801 | D | EM | Kentucky | -0.42 | 3.81 | 32.8 | 4 | 3.0 |

APPENDIX 2

Appendix 2. List of all species encountered in VIBI surveys, including family and coefficient of conservatism value (CC).

| | Species | Family | CC |
|---|---|---|---|
| **GYMNOSPERMS** | | | |
| | *Juniperus virginiana* | Cupressaceae | 1 |
| | *Pinus virginiana* | Pinaceae | 2 |
| | *Pinus echinata* | Pinaceae | 5 |
| | *Pinus strobus* | Pinaceae | 6 |
| | *Tsuga canadensis* | Pinaceae | 6 |
| **ANGIOSPERMS** | | | |
| **Seedless Vascular Plants** | | | |
| | *Asplenium platyneuron* | Aspleniaceae | 3 |
| | *Cystopteris protrusa* | Dryopteridaceae | 6 |
| | *Onoclea sensibilis* | Dryopteridaceae | 5 |
| | *Polystichum acrostichoides* | Dryopteridaceae | 4 |
| | *Athyrium filix-femina* | Dryopteridaceae | 6 |
| | *Equisetum arvense* | Equisetaceae | 3 |
| | *Equisetum hyemale* | Equisetaceae | 4 |
| | *Isoetes engelmannii* | Isoetaceae | 7 |
| | *Ophioglossum vulgatum* | Ophioglossaceae | 6 |
| | *Botrychium biternatum* | Ophioglossaceae | 6 |
| | *Botrychium dissectum* | Ophioglossaceae | 6 |
| | *Botrychium virginianum* | Ophioglossaceae | 6 |
| | *Osmunda cinnamomea* | Osmundaceae | 7 |
| | *Osmunda regalis* | Osmundaceae | 7 |
| | *Phegopteris hexagonoptera* | Thelypteridaceae | 7 |
| | *Thelypteris noveboracensis* | Thelypteridaceae | 6 |
| **Monocots** | | | |
| | *Acorus calamus* | Acoraceae | 0 |
| | *Sagittaria latifolia* | Alismataceae | 5 |
| | *Sagittaria montevidensis* | Alismataceae | 5 |
| | *Sagittaria calycina* | Alismataceae | 6 |
| | *Alisma subcordatum* | Alismataceae | 4 |
| | *Arisaema triphyllum subsp. Triphyllum* | Araceae | 3 |
| | *Arisaema dracontium* | Araceae | 6 |
| | *Arisaema triphyllum* | Araceae | 6 |

Appendix 2 (continued).

| Species | Family | CC |
|---|---|---|
| *Podophyllum peltatum* | Berberidaceae | 6 |
| *Carex amphibola* | Cyperaceae | 5 |
| *Carex annectens* | Cyperaceae | 4 |
| *Carex baileyi* | Cyperaceae | 7 |
| *Carex blanda* | Cyperaceae | 4 |
| *Carex caroliniana* | Cyperaceae | 5 |
| *Carex conjuncta* | Cyperaceae | 6 |
| *Carex crinita* | Cyperaceae | 6 |
| *Carex cristatella* | Cyperaceae | 6 |
| *Carex crus-corvi* | Cyperaceae | 6 |
| *Carex davisii* | Cyperaceae | 7 |
| *Carex debilis* | Cyperaceae | 7 |
| *Carex festucacea* | Cyperaceae | 5 |
| *Carex frankii* | Cyperaceae | 3 |
| *Carex gigantea* | Cyperaceae | 8 |
| *Carex glaucodea* | Cyperaceae | 5 |
| *Carex gracillima* | Cyperaceae | 6 |
| *Carex granularis* | Cyperaceae | 5 |
| *Carex grayi* | Cyperaceae | 6 |
| *Carex grisea* | Cyperaceae | 6 |
| *Carex hirsutella* | Cyperaceae | 4 |
| *Carex hirtifolia* | Cyperaceae | 7 |
| *Carex hyalinolepis* | Cyperaceae | 6 |
| *Carex intumescens* | Cyperaceae | 7 |
| *Carex joorii* | Cyperaceae | 8 |
| *Carex laevivaginata* | Cyperaceae | 7 |
| *Carex lupuliformis* | Cyperaceae | 8 |
| *Carex lupulina* | Cyperaceae | 6 |
| *Carex lurida* | Cyperaceae | 5 |
| *Carex muskingumensis* | Cyperaceae | 8 |
| *Carex plantaginea* | Cyperaceae | 7 |
| *Carex prasina* | Cyperaceae | 7 |
| *Carex radiata* | Cyperaceae | 8 |
| *Carex rosea* | Cyperaceae | 5 |
| *Carex scoparia* | Cyperaceae | 6 |
| *Carex shortiana* | Cyperaceae | 6 |
| *Carex sparganioides* | Cyperaceae | 5 |
| *Carex squarrosa* | Cyperaceae | 6 |
| *Carex stipata* | Cyperaceae | 6 |

Appendix 2 (continued).

| Species | Family | CC |
|---|---|---|
| *Carex swanii* | Cyperaceae | 5 |
| *Carex tenera* | Cyperaceae | 6 |
| *Carex tribuloides* | Cyperaceae | 4 |
| *Carex typhina* | Cyperaceae | 7 |
| *Carex vulpinoidea* | Cyperaceae | 3 |
| *Cyperus erythrorhizos* | Cyperaceae | 4 |
| *Cyperus esculentus* | Cyperaceae | 1 |
| *Cyperus flavescens* | Cyperaceae | 3 |
| *Cyperus lupulinus* | Cyperaceae | 3 |
| *Cyperus strigosus* | Cyperaceae | 3 |
| *Eleocharis acicularis* | Cyperaceae | 4 |
| *Eleocharis erythropoda* | Cyperaceae | 7 |
| *Eleocharis obtusa* | Cyperaceae | 3 |
| *Eleocharis ovata* | Cyperaceae | 5 |
| *Eleocharis palustris* | Cyperaceae | 5 |
| *Eleocharis quadrangulata* | Cyperaceae | 6 |
| *Rhynchospora capitellata* | Cyperaceae | 7 |
| *Rhynchospora globularis* | Cyperaceae | 7 |
| *Rhynchospora glomerata* | Cyperaceae | 6 |
| *Schoenoplectus tabernaemontani* | Cyperaceae | 5 |
| *Scirpus atrovirens* | Cyperaceae | 5 |
| *Scirpus cyperinus* | Cyperaceae | 4 |
| *Scirpus pendulus* | Cyperaceae | 5 |
| *Scirpus polyphyllus* | Cyperaceae | 7 |
| *Scirpus pungens* | Cyperaceae | 5 |
| *Scleria triglomerata* | Cyperaceae | 7 |
| *Iris cristata* | Iridaceae | 6 |
| *Iris pseudacorus* | Iridaceae | 0 |
| *Iris versicolor* | Iridaceae | 6 |
| *Iris virginica* | Iridaceae | 7 |
| *Sisyrinchium albidum* | Iridaceae | 7 |
| *Sisyrinchium angustifolium* | Iridaceae | 4 |
| *Juncus acuminatus* | Juncaceae | 4 |
| *Juncus anthelatus* | Juncaceae | 5 |
| *Juncus brachycarpus* | Juncaceae | 5 |
| *Juncus canadensis* | Juncaceae | 7 |
| *Juncus coriaceus* | Juncaceae | 6 |
| *Juncus diffusissimus* | Juncaceae | 4 |
| *Juncus effusus* | Juncaceae | 4 |
| *Juncus marginatus* | Juncaceae | 5 |

Appendix 2 (continued).

| Species | Family | CC |
|---|---|---|
| *Juncus tenuis* | Juncaceae | 2 |
| *Luzula acuminata* | Juncaceae | 7 |
| *Lemna minor* | Lemnaceae | 3 |
| *Spirodela polyrhiza* | Lemnaceae | 3 |
| *Wolffia columbiana* | Lemnaceae | 4 |
| *Aletris farinosa* | Liliaceae | 8 |
| *Allium canadense* | Liliaceae | 3 |
| *Allium vineale* | Liliaceae | 0 |
| *Maianthemum racemosum* | Liliaceae | 5 |
| *Polygonatum biflorum* | Liliaceae | 5 |
| *Polygonatum pubescens* | Liliaceae | 5 |
| *Prosartes lanuginosa* | Liliaceae | 7 |
| *Trillium erectum* | Liliaceae | 8 |
| *Uvularia grandiflora* | Liliaceae | 6 |
| *Uvularia perfoliata* | Liliaceae | 5 |
| *Najas guadalupensis* | Najadaceae | 5 |
| *Najas minor* | Najadaceae | 0 |
| *Cypripedium acaule* | Orchidaceae | 7 |
| *Platanthera ciliaris* | Orchidaceae | 8 |
| *Platanthera clavellata* | Orchidaceae | 8 |
| *Platanthera flava* | Orchidaceae | 7 |
| *Spiranthes lacera var. gracilis* | Orchidaceae | 5 |
| *Tipularia discolor* | Orchidaceae | 5 |
| *Agrostis gigantea* | Poaceae | 0 |
| *Andropogon gerardii* | Poaceae | 7 |
| *Andropogon glomeratus* | Poaceae | 4 |
| *Andropogon virginicus* | Poaceae | 2 |
| *Arthraxon hispidus* | Poaceae | 0 |
| *Arundinaria gigantea* | Poaceae | 5 |
| *Bromus pubescens* | Poaceae | 7 |
| *Bromus racemosus* | Poaceae | 0 |
| *Bromus tectorum* | Poaceae | 0 |
| *Chasmanthium latifolium* | Poaceae | 6 |
| *Cinna arundinacea* | Poaceae | 5 |
| *Danthonia spicata* | Poaceae | 3 |
| *Diarrhena americana* | Poaceae | 7 |
| *Digitaria sanguinalis* | Poaceae | 0 |
| *Echinochloa crusgalli* | Poaceae | 0 |
| *Echinochloa walteri* | Poaceae | 5 |
| *Eleusine indica* | Poaceae | 0 |

Appendix 2 (continued).

| Species | Family | CC |
|---|---|---|
| *Elymus hystrix* | Poaceae | 5 |
| *Elymus riparius* | Poaceae | 6 |
| *Elymus villosus* | Poaceae | 4 |
| *Elymus virginicus* | Poaceae | 5 |
| *Elytrigia repens* | Poaceae | 0 |
| *Festuca arundinacea* | Poaceae | 0 |
| *Festuca ovina* | Poaceae | 0 |
| *Festuca pratensis* | Poaceae | 0 |
| *Glyceria septentrionalis* | Poaceae | 7 |
| *Glyceria striata* | Poaceae | 5 |
| *Leersia lenticularis* | Poaceae | 7 |
| *Leersia oryzoides* | Poaceae | 5 |
| *Leersia virginica* | Poaceae | 4 |
| *Microstegium vimineum* | Poaceae | 0 |
| *Muhlenbergia frondosa* | Poaceae | 6 |
| *Panicum acuminatum* | Poaceae | 5 |
| *Panicum anceps* | Poaceae | 4 |
| *Panicum boscii* | Poaceae | 4 |
| *Panicum clandestinum* | Poaceae | 3 |
| *Panicum dichotomum* | Poaceae | 4 |
| *Panicum rigidulum* | Poaceae | 5 |
| *Panicum scoparium* | Poaceae | 4 |
| *Panicum virgatum* | Poaceae | 6 |
| *Paspalum laeve* | Poaceae | 3 |
| *Phalaris arundinacea* | Poaceae | 2 |
| *Phleum pratense* | Poaceae | 0 |
| *Phragmites australis subsp. Australis* | Poaceae | 0 |
| *Poa cuspidata* | Poaceae | 7 |
| *Poa palustris* | Poaceae | 5 |
| *Poa pratensis* | Poaceae | 0 |
| *Poa sylvestris* | Poaceae | 6 |
| *Setaria faberi* | Poaceae | 0 |
| *Sorghastrum nutans* | Poaceae | 4 |
| *Sorghum halepense* | Poaceae | 0 |
| *Tridens flavus* | Poaceae | 2 |
| *Potamogeton crispus* | Potamogetonaceae | 0 |
| *Potamogeton foliosus* | Potamogetonaceae | 6 |
| *Potamogeton nodosus* | Potamogetonaceae | 6 |
| *Saururus cernuus* | Saururaceae | 6 |

Appendix 2 (continued).

| | Species | Family | CC |
|---|---|---|---|
| | *Smilax hispida* | Smilacaceae | 3 |
| | *Smilax bona-nox* | Smilacaceae | 4 |
| | *Smilax glauca* | Smilacaceae | 4 |
| | *Smilax rotundifolia* | Smilacaceae | 4 |
| | *Sparganium americanum* | Sparganiaceae | 7 |
| | *Sparganium eurycarpum* | Sparganiaceae | 7 |
| | *Typha angustifolia* | Typhaceae | 0 |
| | *Typha x glauca* | Typhaceae | 0 |
| | *Typha latifolia* | Typhaceae | 2 |
| | *Xyris torta* | Xyridaceae | 7 |
| **Dicots** | | | |
| | *Justicia americana* | Acanthaceae | 5 |
| | *Ruellia caroliniensis* | Acanthaceae | 4 |
| | *Ruellia humilis* | Acanthaceae | 5 |
| | *Ruellia strepens* | Acanthaceae | 5 |
| | *Acer negundo* | Aceraceae | 3 |
| | *Acer rubrum* | Aceraceae | 4 |
| | *Acer saccharinum* | Aceraceae | 4 |
| | *Acer saccharum* | Aceraceae | 4 |
| | *Echinodorus cordifolius* | Alismataceae | 7 |
| | *Amaranthus retroflexus* | Amaranthaceae | 0 |
| | *Rhus copallinum* | Anacardiaceae | 2 |
| | *Toxicodendron radicans* | Anacardiaceae | 3 |
| | *Asimina triloba* | Annonaceae | 6 |
| | *Cicuta maculata* | Apiaceae | 6 |
| | *Conium maculatum* | Apiaceae | 0 |
| | *Cryptotaenia canadensis* | Apiaceae | 6 |
| | *Daucus carota* | Apiaceae | 0 |
| | *Eryngium prostratum* | Apiaceae | 7 |
| | *Sanicula canadensis* | Apiaceae | 3 |
| | *Sanicula gregaria* | Apiaceae | 4 |
| | *Sanicula trifoliata* | Apiaceae | 4 |
| | *Sium suave* | Apiaceae | 7 |
| | *Apocynum cannabinum* | Apocynaceae | 3 |
| | *Ilex decidua* | Aquifoliaceae | 6 |
| | *Ilex opaca* | Aquifoliaceae | 6 |
| | *Ilex verticillata* | Aquifoliaceae | 7 |
| | *Aralia spinosa* | Araliaceae | 5 |
| | *Asarum canadense* | Aristolochiaceae | 6 |

Appendix 2 (continued).

| Species | Family | CC |
| --- | --- | --- |
| *Ampelamus albidus* | Asclepiadaceae | 1 |
| *Asclepias hirtella* | Asclepiadaceae | 8 |
| *Asclepias incarnata* | Asclepiadaceae | 5 |
| *Asclepias syriaca* | Asclepiadaceae | 1 |
| *Asclepias variegata* | Asclepiadaceae | 7 |
| *Ambrosia artemisiifolia* | Asteraceae | 0 |
| *Ambrosia trifida* | Asteraceae | 2 |
| *Arnoglossum atriplicifolia* | Asteraceae | 5 |
| *Aster lanceolatus* | Asteraceae | 4 |
| *Aster lateriflorus* | Asteraceae | 3 |
| *Aster ontarionis* | Asteraceae | 3 |
| *Aster pilosus* | Asteraceae | 0 |
| *Aster prenanthoides* | Asteraceae | 5 |
| *Bidens cernua* | Asteraceae | 4 |
| *Bidens connata* | Asteraceae | 5 |
| *Bidens coronata* | Asteraceae | 4 |
| *Bidens discoidea* | Asteraceae | 5 |
| *Bidens frondosa* | Asteraceae | 2 |
| *Bidens polylepis* | Asteraceae | 0 |
| *Carduus nutans* | Asteraceae | 0 |
| *Chrysanthemum leucanthemum* | Asteraceae | 0 |
| *Cirsium arvense* | Asteraceae | 0 |
| *Cirsium vulgare* | Asteraceae | 0 |
| *Conoclinium coelestinum* | Asteraceae | 3 |
| *Conyza canadensis* | Asteraceae | 0 |
| *Eclipta prostrata* | Asteraceae | 2 |
| *Elephantopus carolinianus* | Asteraceae | 4 |
| *Erechtites hieracifolia* | Asteraceae | 1 |
| *Erigeron annuus* | Asteraceae | 1 |
| *Erigeron philadelphicus* | Asteraceae | 3 |
| *Erigeron strigosus* | Asteraceae | 3 |
| *Eupatorium coelestinum* | Asteraceae | 3 |
| *Eupatorium fistulosum* | Asteraceae | 5 |
| *Eupatorium maculatum* | Asteraceae | 10 |
| *Eupatorium perfoliatum* | Asteraceae | 5 |
| *Eupatorium purpureum* | Asteraceae | 5 |
| *Eupatorium rotundifolium* | Asteraceae | 5 |
| *Eupatorium rugosum* | Asteraceae | 3 |
| *Eupatorium serotinum* | Asteraceae | 3 |
| *Eupatorium sessilifolium* | Asteraceae | 8 |

Appendix 2 (continued).

| Species | Family | CC |
| --- | --- | --- |
| *Helenium autumnale* | Asteraceae | 4 |
| *Helenium flexuosum* | Asteraceae | 4 |
| *Helianthus decapetalus* | Asteraceae | 6 |
| *Lactuca serriola* | Asteraceae | 0 |
| *Prenanthes altissima* | Asteraceae | 5 |
| *Rudbeckia hirta* | Asteraceae | 1 |
| *Rudbeckia laciniata* | Asteraceae | 6 |
| *Senecio aureus* | Asteraceae | 5 |
| *Senecio glabellus* | Asteraceae | 2 |
| *Silphium perfoliatum* | Asteraceae | 6 |
| *Solidago canadensis* | Asteraceae | 1 |
| *Solidago flexicaulis* | Asteraceae | 6 |
| *Solidago gigantea* | Asteraceae | 4 |
| *Solidago ulmifolia* | Asteraceae | 4 |
| *Taraxacum officinale* | Asteraceae | 0 |
| *Verbesina alternifolia* | Asteraceae | 4 |
| *Verbesina occidentalis* | Asteraceae | 3 |
| *Vernonia gigantea* | Asteraceae | 3 |
| *Xanthium strumarium* | Asteraceae | 1 |
| *Impatiens capensis* | Balsaminaceae | 4 |
| *Berberis thunbergii* | Berberidaceae | 0 |
| *Alnus serrulata* | Betulaceae | 6 |
| *Betula nigra* | Betulaceae | 5 |
| *Carpinus caroliniana* | Betulaceae | 6 |
| *Corylus americana* | Betulaceae | 4 |
| *Ostrya virginiana* | Betulaceae | 6 |
| *Bignonia capreolata* | Bignoniaceae | 5 |
| *Campsis radicans* | Bignoniaceae | 2 |
| *Catalpa bignonioides* | Bignoniaceae | 0 |
| *Paulownia tomentosa* | Bignoniaceae | 0 |
| *Alliaria petiolata* | Brassicaceae | 0 |
| *Cardamine rhomboidea* | Brassicaceae | 6 |
| *Iodanthus pinnatifidus* | Brassicaceae | 7 |
| *Rorippa palustris* | Brassicaceae | 4 |
| *Rorippa sylvestris* | Brassicaceae | 0 |
| *Brasenia schreberi* | Cabombaceae | 6 |
| *Cercis canadensis* | Caesalpiniaceae | 3 |
| *Gleditsia triacanthos* | Caesalpinaceae | 3 |
| *Campanula americana* | Campanulaceae | 4 |
| *Lobelia cardinalis* | Campanulaceae | 6 |

Appendix 2 (continued).

| Species | Family | CC |
|---|---|---|
| *Lobelia inflata* | Campanulaceae | 3 |
| *Lobelia nuttallii* | Campanulaceae | 8 |
| *Lobelia siphilitica* | Campanulaceae | 5 |
| *Lonicera japonica* | Caprifoliaceae | 0 |
| *Lonicera maackii* | Caprifoliaceae | 0 |
| *Lonicera morrowii* | Caprifoliaceae | 0 |
| *Sambucus canadensis* | Caprifoliaceae | 2 |
| *Symphoricarpos orbiculatus* | Caprifoliaceae | 2 |
| *Viburnum dentatum* | Caprifoliaceae | 6 |
| *Viburnum rufidulum* | Caprifoliaceae | 4 |
| *Stellaria media* | Caryophyllaceae | 0 |
| *Euonymus alatus* | Celastraceae | 0 |
| *Euonymus americanus* | Celastraceae | 6 |
| *Euonymus atropurpureus* | Celastraceae | 7 |
| *Euonymus fortunei* | Celastraceae | 0 |
| *Ceratophyllum demersum* | Ceratophyllaceae | 5 |
| *Chenopodium album* | Chenopodiaceae | 0 |
| *Hypericum crux-andreae* | Clusiaceae | 8 |
| *Hypericum hypericoides* | Clusiaceae | 5 |
| *Hypericum mutilum* | Clusiaceae | 4 |
| *Hypericum prolificum* | Clusiaceae | 5 |
| *Hypericum punctatum* | Clusiaceae | 3 |
| *Triadenum walteri* | Clusiaceae | 7 |
| *Commelina communis* | Commelinaceae | 0 |
| *Commelina virginica* | Commelinaceae | 5 |
| *Calystegia sepium* | Convolvulaceae | 2 |
| *Convolvulus arvensis* | Convolvulaceae | 0 |
| *Ipomoea lacunosa* | Convolvulaceae | 3 |
| *Ipomoea pandurata* | Convolvulaceae | 2 |
| *Ipomoea purpurea* | Convolvulaceae | 0 |
| *Cornus alternifolia* | Cornaceae | 7 |
| *Cornus amomum* | Cornaceae | 6 |
| *Cornus drummondii* | Cornaceae | 5 |
| *Cornus florida* | Cornaceae | 5 |
| *Cornus foemina* | Cornaceae | 7 |
| *Nyssa sylvatica* | Cornaceae | 6 |
| *Sedum ternatum* | Crassulaceae | 5 |
| *Sicyos angulatus* | Cucurbitaceae | 4 |
| *Cuscuta gronovii* | Cuscutaceae | 4 |
| *Dioscorea polystachya* | Dioscoreaceae | 0 |

Appendix 2 (continued).

| Species | Family | CC |
|---|---|---|
| *Dioscorea villosa* | Dioscoreaceae | 6 |
| *Dipsacus sylvestris* | Dipsacaceae | 0 |
| *Drosera brevifolia* | Droseraceae | 8 |
| *Diospyros virginiana* | Ebenaceae | 4 |
| *Elaeagnus umbellata* | Elaeagnaceae | 0 |
| *Oxydendrum arboreum* | Ericaceae | 5 |
| *Rhododendron arborescens* | Ericaceae | 7 |
| *Vaccinium corymbosum* | Ericaceae | 7 |
| *Acalypha virginica* | Euphorbiaceae | 3 |
| *Acalypha virginica var. rhomboidea* | Euphorbiaceae | 1 |
| *Euphorbia maculata* | Euphorbiaceae | 0 |
| *Amphicarpaea bracteata* | Fabaceae | 5 |
| *Apios americana* | Fabaceae | 5 |
| *Chamaecrista fasciculata* | Fabaceae | 1 |
| *Coronilla varia* | Fabaceae | 0 |
| *Desmodium nudiflorum* | Fabaceae | 5 |
| *Lespedeza cuneata* | Fabaceae | 0 |
| *Lespedeza virginica* | Fabaceae | 4 |
| *Lotus corniculatus* | Fabaceae | 0 |
| *Medicago lupulina* | Fabaceae | 0 |
| *Robinia pseudoacacia* | Fabaceae | 1 |
| *Senna marilandica* | Fabaceae | 5 |
| *Trifolium pratense* | Fabaceae | 0 |
| *Trifolium repens* | Fabaceae | 0 |
| *Vicia sativa* | Fabaceae | 0 |
| *Wisteria frutescens* | Fabaceae | 6 |
| *Fagus grandifolia* | Fagaceae | 5 |
| *Quercus alba* | Fagaceae | 5 |
| *Quercus bicolor* | Fagaceae | 7 |
| *Quercus coccinea* | Fagaceae | 5 |
| *Quercus lyrata* | Fagaceae | 7 |
| *Quercus macrocarpa* | Fagaceae | 6 |
| *Quercus marilandica* | Fagaceae | 4 |
| *Quercus michauxii* | Fagaceae | 7 |
| *Quercus palustris* | Fagaceae | 6 |
| *Quercus phellos* | Fagaceae | 5 |
| *Quercus prinus* | Fagaceae | 6 |
| *Quercus rubra* | Fagaceae | 6 |
| *Quercus shumardii* | Fagaceae | 6 |
| *Quercus stellata* | Fagaceae | 5 |

Appendix 2 (continued).

| Species | Family | CC |
|---|---|---|
| *Quercus velutina* | Fagaceae | 5 |
| *Bartonia virginica* | Gentianaceae | 8 |
| *Sabatia angularis* | Gentianaceae | 5 |
| *Itea virginica* | Grossulariaceae | 7 |
| *Proserpinaca palustris* | Haloragaceae | 7 |
| *Hamamelis virginiana* | Hamamelidaceae | 6 |
| *Liquidambar styraciflua* | Hamamelidaceae | 4 |
| *Aesculus flava* | Hippocastanaceae | 7 |
| *Aesculus glabra* | Hippocastanaceae | 7 |
| *Hydrangea arborescens* | Hydrangeaceae | 5 |
| *Carya carolinae-septentrionalis* | Juglandaceae | 7 |
| *Carya cordiformis* | Juglandaceae | 6 |
| *Carya glabra* | Juglandaceae | 4 |
| *Carya laciniosa* | Juglandaceae | 6 |
| *Carya ovata* | Juglandaceae | 5 |
| *Carya tomentosa* | Juglandaceae | 5 |
| *Juglans nigra* | Juglandaceae | 4 |
| *Glechoma hederacea* | Lamiaceae | 0 |
| *Lamium purpureum* | Lamiaceae | 0 |
| *Lycopus americanus* | Lamiaceae | 5 |
| *Lycopus virginicus* | Lamiaceae | 5 |
| *Meehania cordata* | Lamiaceae | 7 |
| *Mentha arvensis* | Lamiaceae | 3 |
| *Mentha piperita* | Lamiaceae | 0 |
| *Prunella vulgaris* | Lamiaceae | 2 |
| *Pycnanthemum tenuifolium* | Lamiaceae | 5 |
| *Salvia lyrata* | Lamiaceae | 3 |
| *Scutellaria incana* | Lamiaceae | 6 |
| *Scutellaria integrifolia* | Lamiaceae | 6 |
| *Scutellaria lateriflora* | Lamiaceae | 6 |
| *Stachys tenuifolia* | Lamiaceae | 7 |
| *Teucrium canadense* | Lamiaceae | 4 |
| *Lindera benzoin* | Lauraceae | 6 |
| *Pycnanthemum verticillatum* | Lamiaceae | 8 |
| *Sassafras albidum* | Lauraceae | 2 |
| *Utricularia gibba* | Lentibulariaceae | 7 |
| *Utricularia vulgaris* | Lentibulariaceae | 6 |
| *Ammannia robusta* | Lythraceae | 3 |
| *Rotala ramosior* | Lythraceae | 4 |
| *Liriodendron tulipifera* | Magnoliaceae | 2 |

Appendix 2 (continued).

| Species | Family | CC |
|---|---|---|
| *Magnolia tripetala* | Magnoliaceae | 7 |
| *Hibiscus laevis* | Malvaceae | 5 |
| *Hibiscus moscheutos* | Malvaceae | 5 |
| *Sida spinosa* | Malvaceae | 0 |
| *Rhexia mariana* | Melastomataceae | 6 |
| *Rhexia virginica* | Melastomataceae | 6 |
| *Menispermum canadense* | Menispermaceae | 6 |
| *Maclura pomifera* | Moraceae | 0 |
| *Morus alba* | Moraceae | 0 |
| *Morus rubra* | Moraceae | 2 |
| *Nelumbo lutea* | Nelumbonaceae | 6 |
| *Nuphar advena* | Nymphaceae | 4 |
| *Fraxinus americana* | Oleaceae | 4 |
| *Fraxinus pennsylvanica* | Oleaceae | 5 |
| *Fraxinus profunda* | Oleaceae | 8 |
| *Ligustrum vulgare* | Oleaceae | 0 |
| *Circaea lutetiana* | Onagraceae | 4 |
| *Epilobium coloratum* | Onagraceae | 6 |
| *Ludwigia alternifolia* | Onagraceae | 5 |
| *Ludwigia hirtella* | Onagraceae | 8 |
| *Ludwigia palustris* | Onagraceae | 4 |
| *Ludwigia peploides* | Onagraceae | 4 |
| *Oenothera linifolia* | Onagraceae | 8 |
| *Oxalis corniculata* | Oxalidaceae | 0 |
| *Oxalis stricta* | Oxalidaceae | 0 |
| *Oxalis violacea* | Oxalidaceae | 5 |
| *Sanguinaria canadensis* | Papaveraceae | 8 |
| *Passiflora lutea* | Passifloraceae | 3 |
| *Phytolacca americana* | Phytolaccaceae | 1 |
| *Plantago lanceolata* | Plantaginaceae | 0 |
| *Plantago major* | Plantaginaceae | 0 |
| *Plantago rugelii* | Plantaginaceae | 2 |
| *Platanus occidentalis* | Platanaceae | 4 |
| *Phlox paniculata* | Polemoniaceae | 4 |
| *Phlox maculata* | Polemoniaceae | 7 |
| *Polemonium reptans* | Polemoniaceae | 7 |
| *Polygala sanguinea* | Polygalaceae | 6 |
| *Polygonum amphibium* | Polygonaceae | 7 |
| *Polygonum aviculare* | Polygonaceae | 0 |
| *Polygonum cespitosum* | Polygonaceae | 0 |

Appendix 2 (continued).

| Species | Family | CC |
|---|---|---|
| *Polygonum cuspidatum* | Polygonaceae | 0 |
| *Polygonum hydropiper* | Polygonaceae | 1 |
| *Polygonum hydropiperoides* | Polygonaceae | 6 |
| *Polygonum pensylvanicum* | Polygonaceae | 2 |
| *Polygonum persicaria* | Polygonaceae | 0 |
| *Polygonum punctatum* | Polygonaceae | 3 |
| *Polygonum sagittatum* | Polygonaceae | 5 |
| *Polygonum setaceum* | Polygonaceae | 6 |
| *Polygonum virginianum* | Polygonaceae | 4 |
| *Portulaca oleracea* | Portulacaceae | 0 |
| *Rumex altissimus* | Polygonaceae | 5 |
| *Rumex crispus* | Polygonaceae | 0 |
| *Rumex obtusifolius* | Polygonaceae | 0 |
| *Rumex verticillatus* | Polygonaceae | 7 |
| *Lysimachia ciliata* | Primulaceae | 6 |
| *Lysimachia lanceolata* | Primulaceae | 6 |
| *Lysimachia nummularia* | Primulaceae | 0 |
| *Clematis virginiana* | Ranunculaceae | 4 |
| *Hydrastis canadensis* | Ranunculaceae | 7 |
| *Ranunculus abortivus* | Ranunculaceae | 2 |
| *Ranunculus hispidus* | Ranunculaceae | 6 |
| *Ranunculus sardous* | Ranunculaceae | 0 |
| *Ranunculus sceleratus* | Ranunculaceae | 2 |
| *Thalictrum pubescens* | Ranunculaceae | 7 |
| *Xanthorhiza simplicissima* | Ranunculaceae | 8 |
| *Rhamnus caroliniana* | Rhamnaceae | 4 |
| *Agrimonia parviflora* | Rosaceae | 5 |
| *Amelanchier arborea* | Rosaceae | 6 |
| *Crataegus crus-galli* | Rosaceae | 4 |
| *Duchesnea indica* | Rosaceae | 0 |
| *Fragaria virginiana* | Rosaceae | 2 |
| *Geum canadense* | Rosaceae | 4 |
| *Geum laciniatum* | Rosaceae | 7 |
| *Geum virginianum* | Rosaceae | 6 |
| *Potentilla canadensis* | Rosaceae | 3 |
| *Potentilla norvegica* | Rosaceae | 2 |
| *Potentilla simplex* | Rosaceae | 1 |
| *Prunus serotina* | Rosaceae | 3 |
| *Pyrus callieryana* | Rosaceae | 0 |
| *Pyrus communis* | Rosaceae | 0 |

Appendix 2 (continued).

| Species | Family | CC |
|---|---|---|
| *Rosa carolina* | Rosaceae | 3 |
| *Rosa multiflora* | Rosaceae | 0 |
| *Rosa palustris* | Rosaceae | 6 |
| *Rosa setigera* | Rosaceae | 3 |
| *Rubus allegheniensis* | Rosaceae | 2 |
| *Rubus hispidus* | Rosaceae | 6 |
| *Rubus occidentalis* | Rosaceae | 1 |
| *Spiraea tomentosa* | Rosaceae | 6 |
| *Cephalanthus occidentalis* | Rubiaceae | 6 |
| *Diodia virginiana* | Rubiaceae | 3 |
| *Galium aparine* | Rubiaceae | 0 |
| *Galium circaezans* | Rubiaceae | 3 |
| *Galium concinnum* | Rubiaceae | 5 |
| *Galium tinctorium* | Rubiaceae | 6 |
| *Houstonia purpurea* | Rubiaceae | 4 |
| *Populus deltoides* | Salicaceae | 4 |
| *Populus grandidentata* | Salicaceae | 4 |
| *Populus heterophylla* | Salicaceae | 8 |
| *Salix exigua* | Salicaceae | 2 |
| *Salix nigra* | Salicaceae | 4 |
| *Penthorum sedoides* | Saxifragaceae | 4 |
| *Tiarella cordifolia* | Saxifragaceae | 7 |
| *Lygodium palmatum* | Schizaeaceae | 6 |
| *Chelone glabra* | Scrophulariaceae | 7 |
| *Gratiola neglecta* | Scrophulariaceae | 4 |
| *Leucospora multifida* | Scrophulariaceae | 3 |
| *Lindernia dubia* | Scrophulariaceae | 5 |
| *Mimulus alatus* | Scrophulariaceae | 5 |
| *Mimulus ringens* | Scrophulariaceae | 6 |
| *Veronica peregrina var. peregrina* | Scrophulariaceae | 1 |
| *Physalis longifolia* | Solanaceae | 1 |
| *Solanum carolinense* | Solanaceae | 0 |
| *Solanum dulcamara* | Solanaceae | 0 |
| *Solanum nigrum* | Solanaceae | 2 |
| *Taxodium distichum* | Taxodiaceae | 7 |
| *Celtis laevigata* | Ulmaceae | 4 |
| *Celtis occidentalis* | Ulmaceae | 5 |
| *Ulmus alata* | Ulmaceae | 4 |
| *Ulmus americana* | Ulmaceae | 5 |
| *Ulmus rubra* | Ulmaceae | 6 |

Appendix 2 (continued).

| Species | Family | CC |
|---|---|---|
| *Boehmeria cylindrica* | Urticaceae | 5 |
| *Laportea canadensis* | Urticaceae | 6 |
| *Pilea pumila* | Urticaceae | 4 |
| *Urtica dioica* | Urticaceae | 0 |
| *Phryma leptostachya* | Verbenaceae | 4 |
| *Phyla lanceolata* | Verbenaceae | 3 |
| *Verbena hastata* | Verbenaceae | 6 |
| *Verbena urticifolia* | Verbenaceae | 3 |
| *Viola canadensis* | Violaceae | 7 |
| *Viola cucullata* | Violaceae | 6 |
| *Viola hirsutula* | Violaceae | 5 |
| *Viola pubescens* | Violaceae | 5 |
| *Viola sororia* | Violaceae | 3 |
| *Ampelopsis cordata* | Vitaceae | 4 |
| *Parthenocissus quinquefolia* | Vitaceae | 2 |
| *Vitis cinerea* | Vitaceae | 5 |
| *Vitis riparia* | Vitaceae | 5 |
| *Vitis vulpina* | Vitaceae | 4 |