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Using two classification schemes to develop vegetation indices of biological integrity for wetlands in West Virginia, USA

Walter Veselka IV · James S. Rentch · William N. Grafton · Walter S. Kordek · James T. Anderson

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Abstract Bioassessment methods for wetlands, and other bodies of water, have been developed worldwide to measure and quantify changes in "biological integrity." These assessments are based on a classification system, meant to ensure appropriate comparisons between wetland types. Using a local site-specific disturbance gradient, we built vegetation indices of biological integrity (Veg-IBIs) based on two commonly used wetland classification systems in the USA: One based on vegetative structure and the other based on a wetland's position in a landscape and sources of water. The resulting class-specific Veg-IBIs were comprised of 1–5 metrics that varied in their sensitivity to the disturbance gradient ($R^2 = 0.14 - 0.65$). Moreover, the sensitivity to the disturbance gradient increased as metrics from each of the two classification schemes were combined (added). Using this information to monitor natural and created wetlands will help natural resource managers track changes in biological integrity of wetlands in response to anthropogenic disturbance and allows the use of vegetative communities to set ecological performance standards for mitigation banks.

Keywords Vegetative communities · Disturbance · Index of biological integrity · Metrics · West Virginia · Wetlands

W.N. Grafton passed away 11 September 2009.

W. Veselka IV · J. S. Rentch · W. N. Grafton · J. T. Anderson
Division of Forestry and Natural Resources, West Virginia University, PO Box 6125, Percival Hall, Morgantown, WV 26506, USA

W. S. Kordek
Wildlife Resources Section, West Virginia Division of Natural Resources, PO Box 67, Ward Road, Elkins, WV 26241, USA

J. T. Anderson (✉)
Wildlife and Fisheries Resources Program, Division of Forestry and Natural Resources, West Virginia University, PO Box 6125, Percival Hall, Morgantown, WV 26506, USA
e-mail: wetland@wvu.edu

Introduction

Plant communities are a reflection of past and present hydrologic conditions (Kirkman et al. 2000; Magee and Kentula 2005; Rentch et al. 2008) and can indicate anthropogenic disturbances, such as sedimentation (Mahaney et al. 2004a, b), nutrient enrichment (Craft and Richardson 1997; Drohan et al. 2006), as well as changes in hydrology (Bonner et al. 2009; Koning 2005). The resulting vegetative communities are one component used to identify jurisdictional wetlands (USACOE 1987). This process uses the Cowardin et al. (1979) wetland classification scheme that is based on the vegetative structure of the wetland community and will be referred to as "Cowardin" here after. Currently the Cowardin system is used in West Virginia, USA for regulatory purposes (West Virginia State Code, Chapters 22–11, 22–26) to determine mitigation requirements for wetland impacts based on, in part, wetland type impacted in the permitting process. These requirements, with options including wetland mitigation banking credits, off- or onsite mitigation projects, or paying to an in lieu fee fund, are meant to ensure a "no net loss" of wetland acreage. However, there is no specific course of action for protecting against the loss of wetland biological integrity and function.

The EPA's "Compensatory Mitigation for Losses of Aquatic Resources" (40 CFR Part 230), calls for ecological performance standards meant to improve mitigation effectiveness and decision making in the permitting process. One tool in developing these performance standards are indices of biological integrity (IBIs). They can be used to monitor trends in wetland condition, providing a quantitative basis of comparison that can be used to prioritize wetland protection, management, or restoration efforts.

Wetland plant IBIs have been developed according to Cowardin (Galatowitsch et al. 2000; Mack 2004) or the hydrogeomorphic (HGM; Brinson 1993) classification approach (Gernes and Helgen 2002; Miller et al. 2006). The HGM classification is meant to compare wetlands that are functionally similar because it incorporates landscape position and hydrology into the classifications (Stevenson and Hauer 2002). Because of the regulatory mandate promoting the maintenance of wetland function and biological integrity in the landscape, this study uses both the Cowardin classifications and HGM-based classes. Moreover, we found that augmenting one approach with the alternative has been shown to increase avian IBI sensitivity to human impairment (Veselka et al. 2009).

The objective of our study was to identify plant community metrics suitable for inclusion into robust, statewide, vegetative indices of biological integrity (Veg-IBI) for West Virginia that have the capacity to detect and quantify changes in the vegetative community that are reflective of varying levels and types of human impairment. These IBIs will be used to set numeric standards used to gauge the effectiveness of mitigation banks, restoration projects, and to guide the development and calibration of future wetland rapid assessment procedures. Moreover, these indices were derived from Cowardin and HGM-based classification schemes, allowing us to compare, combine, and contrast the sensitivity of IBIs based on different wetland classifications to disturbances.

Methods and materials

We stratified sampling across both wetland Cowardin classes and the major US Environmental Protection Agency's Level 3 aquatic ecoregions within West Virginia, USA: the Central Appalachians, the Ridge and Valley, and the Western Allegheny Plateau (Omernik 1987; Woods et al. 1999) by targeting previously studied wetlands (Balcombe et al. 2005) and selecting random 7.5-min quadrangles using a Geographic Information System database (Veselka et al. 2009). We conducted "reconnaissance" on the random quadrangles, selecting accessible sites that did not require extensive property ownership investigations or permissions due to project constraints. Because of a lack of a comprehensive wetland map by HGM classification, stratification by this scheme was not possible. However, due to the number of sites used in this study (151), we are confident we adequately sampled the major HGM classes found in West Virginia (Fig. 1; Veselka et al. 2009). We categorized wetlands by both the Cowardin and regional HGM subclass (Cole et al. 1997) type (Table 1). The regional HGM subclass categories provide more detail regarding a wetlands' position in the landscape (e.g., headwater floodplain) and sources of water (e.g., surface water depression) than the original HGM classification (e.g., riverine or basin, respectively; Brinson 1993). These partitions decreased sample size substantially. As a result, appropriate subclass designations were combined into designated HGM management classes to promote Veg-IBIs as intuitive tools targeted for use by natural resource agencies, the private sector, and

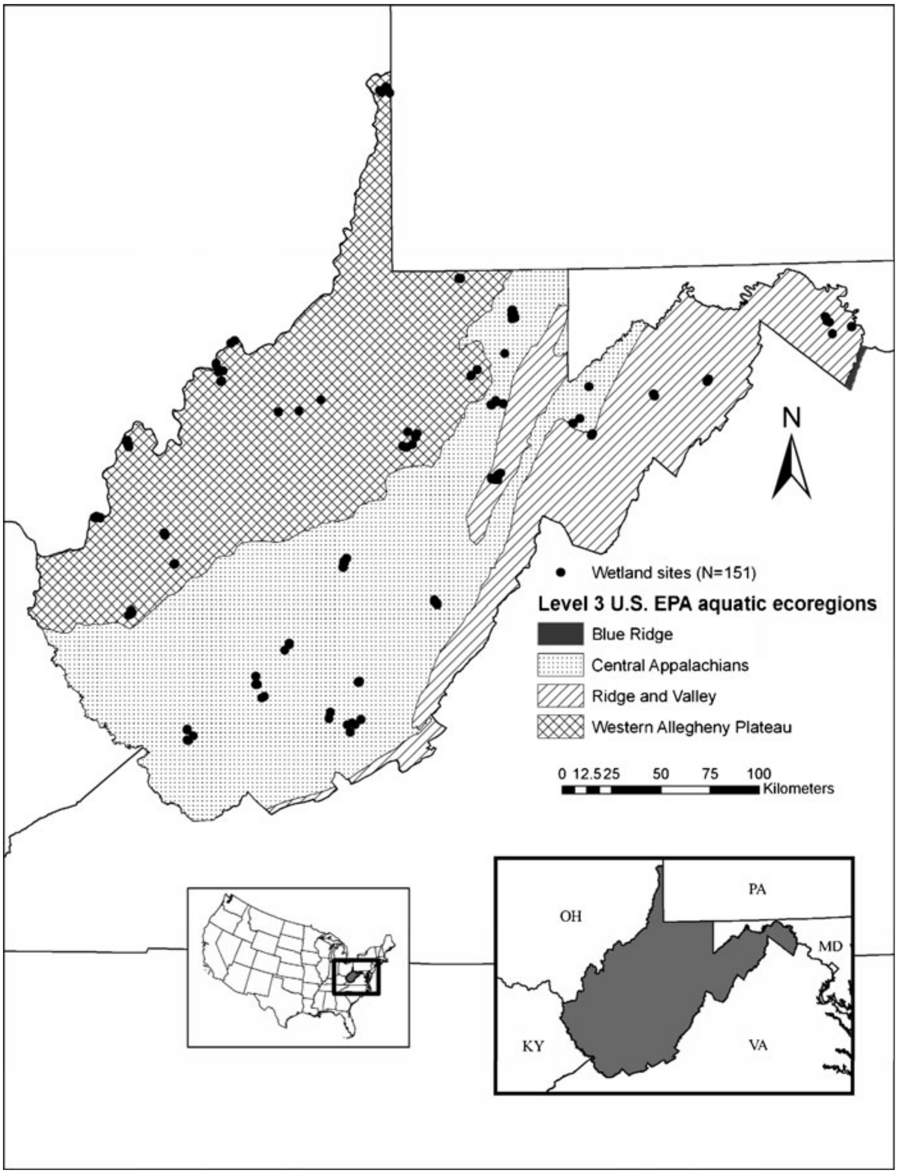

Fig. 1 Site locations of wetlands and ecoregions (Omernik 1987; Woods et al. 1999) used in developing class-specific vegetation indices of biological integrity (Veg-IBI) in West Virginia, USA from 2005–2006. Wetland sites were clustered; scale of map prevents all sites from being marked individually. Legend may indicate one to four wetlands per mark

trained volunteer groups to enable the tracking of wetland biological integrity trends over time and ensure compliance of antidegradation standards (Brooks et al. 1998; Veselka et al. 2009). These classes differ in name and definition, providing more details about a wetland's function than the original HGM classifications (Brinson 1993; e.g. there is no "impoundment" in the original classifications) and are meant as a compromise, striking a balance between the detailed HGM subclasses and the broader original classification. Riparian depressions, surface water depressions, and isolated depressions were all combined into a depression management class; headwater floodplains and mainstem floodplains were lumped into a floodplain management class; and headwater impoundments and mainstem impoundments were grouped into an impoundment class. Slope and fringing wetlands remained separate categories as defined by Cole et al. (1997). Human-made wetlands, created as mitigation or otherwise, were designated the design mimics according to the HGM management class, in this study, depression, impoundment, or fringing wetlands.

Table 1 Total number of sites by regional hydrogeomorphic (HGM) subclass, designated HGM management class, and Cowardin class by ecoregion for use in developing class specific vegetation wetland indices of biological integrity (Veg-IBI) in West Virginia, USA from 2005–2006

	Level 3 US Environmental Protection Agency aquatic ecoregion[a]			Total
	Ridge and Valley	Central Appalachian	Western Alleghany Plateau	
Hydrogeomorphic subclass[b]				
Surface water depression[c]	0	2	5	7
Riparian depression	10	24	25	59
Isolated depression[c]	0	2	4	6
Headwater floodplain	10	15	4	29
Mainstem floodplain[c]	2	2	1	5
Headwater impoundment[c]	1	12	4	17
Mainstem impoundment[c]	0	2	4	6
Fringing[c]	0	2	11	13
Slope[c]	4	4	0	8
Floodplain-in-stream[c]	0	0	1	1
Designated HGM management class				
Depression	10	28	34	72
Floodplain	12	17	6	35
Impoundment	1	14	8	23
Fringing[c]	0	2	11	13
Slope[c]	4	4	0	8
Cowardin class				
Emergent	15	34	26	75
Scrub-shrub	6	17	21	44
Forested	6	14	11	31
Aquatic bed[c]	0	0	1	1
Total	27	65	59	151

[a] Omernik (1987) modified by Woods et al. (1999)
[b] Cole et al. (1997)
[c] Removed from analysis due to small sample size

The sampling regime included single wetlands (48 of 151) and 20 wetland complexes in which we sampled from two to five sites per complex. Sites were analyzed independently because each was subject to a unique set of localized disturbances, no adjacent sites had the same Cowardin classification, and all were located $\geq$ 300 m from one another (Veselka et al. 2009).

Vegetation surveys

Our vegetation survey methodology was modeled after multiple techniques described in Tiner (1999). Quantitative vegetation sampling was conducted once per wetland site in July or early August of 2005 or 2006. Vegetation sampling was conducted using a nested quadrat design to match the relative size of each vegetation stratum (Balcombe et al. 2005; FICWD 1989). The dominant plant community, as determined by area, was identified in each wetland and sampled. Vegetation strata were classified into tree, shrub, and herbaceous layers (USACOE 1987). Trees were sampled using a single, representative 10-m radius circular plot; the shrub layer was sampled in a 6-m radius circular plot using the same center point nested within the tree stratum; and a minimum of four 0.5-m radius herbaceous plots were randomly sampled within the 10-m radius plot.

The tree stratum consisted of trees with a diameter at breast height (DBH) (1.37 m) >12.0 cm for one stem or a cumulative DBH >20 cm for two stems and was used to calculate basal area per species (Beltz et al. 1992). Woody vegetation between 10 cm and 6 m in height and having a DBH less than the tree stratum criteria were considered shrubs. Each shrub species was recorded, and the diameter of each individual shrub's canopy was estimated and converted into percent cover. Each species of herbaceous plants and woody vegetation (<10 cm), as well as exposed substrate, woody debris, bare ground, open water, and bryophytes, were recorded using a modified Daubenmire (1968) cover class scale with values from 1 to 10 (Tiner 1999) that estimated percent cover. The midpoints of each cover class were used to generate candidate metric values. Herbaceous quadrats were scattered randomly, and additional quadrats sampled until two or less new species were detected after the initial four quadrats.

Additionally, the quantitative data collection was augmented by a qualitative walk-through of the discreet wetland community to document the presence of species not detected in the initial vegetation survey according to time dictated by best-professional judgment but generally when no new species were encountered over a 5-min period (Balcombe et al. 2005; Tiner 1999). The walk-through allowed us to evaluate other metrics that may have been limited in their effectiveness because of non-detection using the previously discussed methodology. For example, the Floristic Quality Assessment Index (FQAI) scores are based on the presence of plant species and are immune to the influence of the abundance of any single plant species (Rentch and Anderson 2006). The quantitative and qualitative data of each stratum were then used to derive the candidate metrics that were tested for inclusion into the Veg-IBI (Table 2), allowing a greater number of candidate metrics.

Data analysis

The designated HGM management and Cowardin classes used in the analyses were not mutually exclusive. For example, a palustrine emergent wetland (Cowardin) may be classified as a headwater floodplain or a riparian depression (HGM) depending on the position in the landscape. Likewise, a slope wetland (HGM) could be either a palustrine emergent or scrub-shrub wetland, depending on vegetation development. Of note, in the first example, the data would be used to derive both the HGM- and Cowardin-based IBIs; in the latter, the data would only be used to derive the Cowardin-based IBIs due to the small sample size of slope wetlands ($n = 8$). Only the results from the designated HGM management class and Cowardin classification scheme analyses with sufficient sample size are presented, not the HGM subclasses.

Our disturbance gradient was based on metrics characterizing surrounding land-use activity, width and condition of the representative vegetative community buffer zone, and alteration to the hydrology, habitat, or substrate of the wetland within the plant community [adopted from the Ohio Rapid Assessment Method version 5.0 (ORAM)] (Table 3) (Mack 2001). These metrics and submetrics formed a disturbance score that ranged from 4 to 39; the lower the score, the more apparent the evidence of human impairment.

Reference and stressed designations were developed independently for Cowardin and the designated HGM management classes across the entire state and not subdivided by level 3 ecoregions (Omernik 1987; Woods et al. 1999). These designations were purposefully based on human impairment characteristics throughout West Virginia. Using all sites within a particular class, regardless of ecoregion, the 75th and 25th percentile of the disturbance index scores were used to categorize reference and stressed conditions, respectively (Barbour et al. 1995). Reference sites were often the same for both Cowardin and HGM sites; however, due to sample size variations between classifications, this was not always the case. Sites in between these percentiles, as well as reference and stressed sites, were used in the analyses to quantify the classification scheme's overall response to disturbance. Reference sites were not intended to be pristine or free from any evidence of human manipulation but rather represented examples of what can be realistically expected from a minimally impacted wetland in West Virginia (Omernik 1995).

Class-specific Veg-IBIs were developed for wetland classes with five or more reference and five stressed sites (Chipps et al. 2006; Veselka et al. 2009). Because of the clustered nature of the sites spread throughout the state, individual wetlands were only sampled during 1 year of the study period, not both in an effort to maximize sampling effort (Reiss 2006; O'Connell et al. 1998). All statistical tests were conducted at an a priori alpha level of 0.05.

Table 2 Candidate metrics, the survey plot the metrics were derived from, the expected response to disturbance, and descriptions tested for inclusion into vegetation indices of biological integrity (Veg-IBI) for wetlands in West Virginia, USA from 2005–2006

Candidate vegetation metrics	Citation	Survey plot[a]	Expected response to disturbance	Description of metric
MeanC	Miller et al. (2006); Rentch and Anderson (2006)	WT	–	Average Coefficient of Conservatism per wetland
AdjFQAI	Miller et al. (2006); Rentch and Anderson (2006), Mack (2004)	WT	–	Adjusted Floristic Quality Assessment Index
FernRC	Miller et al. (2006)	Herbaceous	–	Relative cover of fern allies
MonoRC	Miller et al. (2006)	Herbaceous	+	Relative cover of monocot species
NativeGramRC	Miller et al. (2006)	Herbaceous	–	Relative cover of native graminoids
InvGrassRC	Miller et al. (2006); Mack (2004)	Herbaceous	+	Relative cover of invasive graminoids
NativeDicotRC	Mack (2004)	Herbaceous	–	Relative cover of native dicots
DicotRC	Miller et al. (2006)	Herbaceous	–	Relative cover of dicots
CarexRC	Miller et al. (2006); Mack (2004)	Herbaceous	–	Relative cover of *Carex* species
TolerantRC	Miller et al. (2006); Mack (2004)	Herbaceous	+	Relative cover of tolerant species (Coefficient of Conservatism ≥ 2)
NativeHydroHrbRC	Miller et al. (2006); Mack (2004)	Herbaceous	–	Relative cover of native species with facultative wetness rating or greater
PhaInvGrassRC	Miller et al. (2006)	Herbaceous	+	Relative cover of *Phalaris* species and invasive graminoids
ShrubNativePC	Mack (2004)	Shrub	–	Percent cover of native shrubs
FAConlyHrbRC	Miller et al. (2006)	Herbaceous	+	Relative cover of facultative-only rated species
ShrNativeHydroPC	Mack (2004)	Shrub	–	Percent cover of native hydrophytic shrub species
MeanIV	Mack (2004)	Tree	–	Mean Importance Value (IV) of trees in plot
TreeFACupMeanIV		Tree	–	Mean Importance Value (IV) of facultative or greater rated trees
TreeFACWupMeanIV		Tree	–	Mean Importance Value (IV) of facultative -wet or greater rated trees
MeanDBH	Miller et al. (2006)	Tree	–	Mean diameter-at-breast height of trees
InvGramWTRich		WT	+	Richness of invasive graminoid species
NonNativePlantWTRich	Miller et al. (2006)	WT	+	Richness of non-native plant species
ShrubRich	Miller et al. (2006)	Shrub	–	Richness of shrub species
NativeShrubRich	Miller et al. (2006)	Shrub	–	Richness of native shrub species

WT walk-through of wetland community and all species detected in other survey methods
[a]Herbaceous layer a series of 0.5 m radius, shrub layer 6 m radius, tree layer 10 m radius

The vegetation plot measurements were used to derive candidate metric values that were evaluated for their capacity to discriminate between reference and stressed sites. Potentially responsive metrics were identified, specific to each classification scheme, across the state of West Virginia using box-and-whisker plots (Barbour et al. 1996). Metrics were then screened for redundancy using Spearman's R correlation and considered redundant if R values exceeded 0.80 (Hughes et al. 1998). If metrics were correlated, the metric with the greatest discrimination efficiency in

Table 3 Metrics and sub-metrics selected from the Ohio Rapid Assessment Method (Mack 2001) used to define the disturbance gradient for use in developing vegetation indices of biological integrity (Veg-IBI) for wetlands in West Virginia, USA from 2005–2006

Scoring value	Disturbance component
	Buffers and surrounding land use
	Calculate the average buffer width. Select only one and assign score.
7	WIDE. Buffers average 50m or more around wetland perimeter.
4	MEDIUM. Buffers average 25m to <50m around wetland perimeter.
1	NARROW. Buffers average 10m to <25m around wetland perimeter.
0	VERY NARROW. Buffers average <10m around wetland perimeter.
	Intensity of surrounding land use. Select one or double check and average.
7	VERY LOW. 2nd growth or older forest, prairie, savannah, wildlife area, etc.
5	LOW. Old field (>10 years), shrubland, young second growth forest.
3	MODERATELY HIGH. Residential, fenced pasture, park, conservation tillage, new fallow field.
1	HIGH. Urban, industrial, open pasture, row cropping, mining, construction.
	Hydrology
	Modifications to natural, hydrologic regime. Score one or double check and average.
12	None or none apparent. There are no modifications or no modifications that are apparent to the rater.
7	Recovered. The wetland appears to have recovered from past modifications which altered the wetland's natural hydrologic regime.
3	Recovering. The wetland appears to be in the process of recovering from past modifications which altered the wetland's natural hydrologic regime.
1	Recent or no recovery. The modifications have occurred recently, and / or the wetland has not recovered from past modifications and / or the modifications are ongoing.
	Habitat alteration and development
	Substrate disturbance. Score one or double check and average.
4	None or none apparent. There are no modifications or no modifications that are apparent to the rater.
3	Recovered. The wetland appears to have recovered from past disturbances.
2	Recovering. The wetland appears to be in the process of recovering from past disturbances.
1	Recent or no recovery. The modifications have occurred recently, and / or the wetland has not recovered from past disturbances and/ or the disturbances are ongoing.
	Habitat alteration. Score one or double check and average.
9	None or none apparent. There are no alterations or no alterations that are apparent to the rater.
6	Recovered. The wetland appears to have recovered from past alterations.
3	Recovering. The wetland appears to be in the process of recovering from past alterations.
1	Recent or no recovery. The modifications have occurred recently, and / or the wetland has not recovered from past alterations and/ or the alterations are ongoing.

correctly classifying reference from stressed sites was retained for further analyses (Maxted et al. 2000). Remaining metrics were evaluated using an analysis of variance (ANOVA) test for an ecoregion interaction, a classification scheme interaction, and the two-way interaction of both (Veselka et al. 2009). The resulting suite of metrics was evaluated a final time with a series of class-specific multivariate ANOVA tests to identify any cumulative effect of the metric values of reference and stressed sites to ecoregion or classification scheme influences (Veselka et al. 2009). Metrics were then scored on a continuous 0–10 scale, using the 95th and 5th percentile of all IBI scores to represent the highest and lowest value (Blocksom 2003; Bryce et al. 2002; Veselka et al. 2009).

Using the metrics appropriate for each classification, Veg-IBIs were formed by summing all metrics selected for inclusion. The disturbance gradient and the distribution of the Veg-IBI scores for the reference sites were used to set numeric thresholds describing wetland condition (Gerritsen et al. 2000). Categorical threshold limits for Veg-IBI scores were set using the 75th, 25th, and 5th percentiles for reference sites (Hill et al. 2003; McCormick et al. 2001). The relation between Veg-IBI scores and the disturbance score were examined and plotted using simple linear regression specific to each Veg-IBI classification (Veselka et al. 2009).

In addition to scoring each wetland with an individual designated HGM management and Cowardin class Veg-IBI score, we formed specific hybrid Veg-IBIs by combining the two classification schemes (Veselka et al. 2009). Respondent metric values from each classification scheme were added together, regardless of sample size, as each IBI was based on a minimum reference and stressed criteria. If both classification systems used the same metric, the values were averaged together. Based on increasing the number of responsive metrics specific to a local wetland NWI and HGM classification, we evaluated combining these schemes to determine if the process resulted in enhanced IBI sensitivity to disturbance.

Results

Metric performance

Based on at least five reference and five stressed sites, we formed statewide Veg-IBIs for Cowardin class emergent, scrub-shrub, and forested wetlands, as well as depression, floodplain, and impoundment designated HGM management class wetlands. A complete list of sites and corresponding attribute data (e.g., ecoregion, location, class, etc.), including metric scores and summary statistics by ecoregion may be found in Veselka (2008).

After screening metrics for discrimination capability, redundancy, ecoregion, and classification scheme effects, the resulting class-specific Veg-IBIs included between 1 and 5 metrics capable of discriminating between reference and stressed sites (Table 4). Five of the six derived indices were significantly related to disturbance scores (Table 5). Only the impoundment designated HGM management class Veg-IBI scores failed to exhibit a significant relation with the disturbance gradient, despite being able to discriminate between reference and stressed sites greater than 70% of the time.

The Veg-IBI based on Cowardin classifications all exhibited a significant relation with the disturbance gradient. Within the emergent class Veg-IBI, only the adjusted FQAI metric consistently discriminated between reference and stressed sites. The disturbance scores accounted for 14% of the variation in scores.

The scrub-shrub Veg-IBI was composed of 2 metrics: the relative cover of *Carex* species and the relative cover of tolerant plant species. The disturbance scores accounted for 20% of the variation in the scrub-shrub Veg-IBI scores resulting from these metrics. The adjusted FQAI metric was removed from inclusion in the scrub-shrub Veg-IBI after a significant ecoregion ($F_{2,22} = 6.34$; $p = 0.011$) and classification effect was found ($F_{4,22} = 4.52$; $p = 0.015$). The percent cover of native hydrophytic shrubs metric was also removed because of a significant ecoregion effect ($F_{2,22} = 8.87$; $p = 0.003$).

Five metrics formed the forested Veg-IBI. These metrics were the adjusted FQAI score, the relative cover of ferns and fern allies, the relative cover of *Carex* species, the relative cover of native hydrophytic herbaceous vegetation, and the relative cover of invasive graminoids including *Phalaris arundinacea*. The disturbance gradient accounted for 35% of the variation in the forested Veg-IBI scores. The relative cover of native graminoid species ($F_{2,15} = 7.74$; $p = 0.017$) and relative cover of tolerant species ($F_{2,15} = 5.61$; $p = 0.035$) were eliminated from consideration as suitable metrics because of a significant two-way interaction effect between the designated HGM management class and ecoregion.

In the context of designated HGM management classes, with the exception of the impoundments, both the floodplain and depression

Table 4 Mean values and standard error (SE) of candidate vegetation community metrics evaluated by class according to designated hydrogeomorphic management class and the Cowardin classification schemes in building vegetation indices of biological integrity (Veg-IBI) for wetlands in West Virginia, USA from 2005–2006

Candidate vegetation metrics	Wetland classification[a]					
	Designated HGM management class			Cowardin classification		
	Depression	Floodplain	Impoundment	Emergent	Scrub-shrub	Forested
MeanC	4.196 (0.067)[R]	4.465 (0.129)[I]	4.863 (0.127)[R]	4.335 (0.074)[R]	4.585 (0.108)[R]	4.220 (0.103)[R]
AdjFQAI	39.977 (0.804)[I]	43.013 (1.501)[a]	47.897 (1.41)[E]	41.616 (0.872)[I]	44.479 (1.247)[E]	40.186 (1.209)[I]
FernRC	0.011 (0.004)[a]	0.060 (0.024)[a]	0.006 (0.003)[a]	0.012 (0.005)[a]	0.011 (0.004)[a]	0.065 (0.027)[I]
MonoRC	0.538 (0.033)[a]	0.432 (0.051)[a]	0.618 (0.059)[I]	0.585 (0.030)[a]	0.507 (0.043)[a]	0.323 (0.049)[a]
CarexRC	0.070 (0.014)[a]	0.086 (0.025)[I]	0.058 (0.026)[I]	0.061 (0.014)[a]	0.071 (0.017)[I]	0.086 (0.021)[I]
TolerantRC	0.156 (0.031)[a]	0.141 (0.036)[a]	0.057 (0.035)[a]	0.132 (0.029)[a]	0.102 (0.030)[I]	0.153 (0.036)[E]
NativeHydroHrbRC	0.777 (0.026)[a]	0.706 (0.044)[a]	0.934 (0.027)[a]	0.825 (0.024)[a]	0.78 (0.036)[a]	0.662 (0.041)[I]
PhaInvGrassRC	0.099 (0.028)[a]	0.068 (0.026)[a]	0.048 (0.035)[a]	0.108 (0.028)[a]	0.056 (0.023)[a]	0.045 (0.016)[I]
ShrubNativePC	0.230 (0.043)[I]	0.266 (0.063)[E]	0.210 (0.077)[a]	0.096 (0.019)[a]	0.510 (0.073)[R]	0.289 (0.055)[a]
ShrNativeHydroPC	0.200 (0.041)[R]	0.244 (0.064)[a]	0.208 (0.077)[a]	0.077 (0.016)[a]	0.465 (0.074)[E]	0.166 (0.042)[a]
MeanIV	19.735 (4.171)[a]	22.17 (5.237)[I]	5.435 (3.126)[a]	8.444 (3.024)[a]	18.182 (5.653)[a]	38.825 (4.463)[a]
NonNativePlant-WTRich	3.653 (0.378)[R]	3.141 (0.596)[I]	1.043 (0.341)[a]	3.013 (0.362)[a]	2.523 (0.482)[R]	3.839 (0.547)[F]
NativeShrubRich	2.417 (0.295)[E]	2.257 (0.310)[I]	1.696 (0.424)[a]	1.307 (0.197)[a]	2.864 (0.303)[a]	4.097 (0.492)[F]
NativeGramRC[b]	0.425 (0.035)[a]	0.394 (0.050)[a]	0.436 (0.075)[a]	0.492 (0.032)[a]	0.393 (0.047)[a]	0.223 (0.040)[E]
TreeFACup-MeanIV[b]	19.509 (4.306)[a]	14.387 (3.902)[E]	5.663 (3.199)[a]	7.100 (2.760)[a]	10.649 (4.463)[a]	40.471 (5.506)[a]
TreeFACWup-MeanIV[b]	17.488 (4.185)[a]	7.700 (2.565)[a]	6.574 (4.068)[a]	6.168 (2.586)[a]	9.577 (4.388)[a]	31.117 (5.963)[a]
MeanDBH[b]	6.139 (1.177)[a]	11.022 (2.299)[R]	3.824 (2.106)[a]	2.069 (0.756)[a]	3.966 (1.320)[a]	22.661 (1.422)[a]
NativeDicotRC[b]	0.303(0.030)[a]	0.307 (0.0304)[a]	0.313 (0.058)[a]	0.271 (0.027)[a]	0.358 (0.039)[a]	0.375 (0.041)[a]
DicotRC[b]	0.363 (0.031)[a]	0.36 (0.047)[a]	0.321 (0.059)[a]	0.309 (0.028)[a]	0.397 (0.042)[a]	0.481 (0.048)[a]
FAConlyHrbRC[b]	0.027 (0.006)[a]	0.044 (0.013)[a]	0.021 (0.013)[a]	0.019 (0.007)[a]	0.023 (0.008)[a]	0.080 (0.015)[a]
InvGramWTRich[b]	0.556 (0.090)[a]	0.571 (0.185)[a]	0.130 (0.095)[a]	0.600 (0.106)[a]	0.318 (0.102)[a]	0.516 (0.138)[a]
ShrubRich[b]	2.819 (0.339)[a]	2.600 (0.358)[a]	1.783 (0.444)[a]	1.533 (0.227)[a]	3.114 (0.340)[a]	4.839 (0.545)[F]

I included in class-specific Veg-IBI, *R* redundancy with other metrics, *F* failure due to lack of scoring range, *E* excluded due to significant ecoregion or classification effect

[a]Failure to discriminate between reference and stressed sites

[b]Metrics excluded from all of the resulting class-specific Veg-IBI due to redundancy, failure in scoring range, significant ecoregion or classification scheme effect, inability to discriminate between reference and stressed sites

Veg-IBIs were significantly related to the disturbance scores and, on average, exhibited greater sensitivity than their Cowardin counterparts. Five metrics were included in the floodplain Veg-IBI. These metrics were the mean Coefficient of Conservatism, the relative cover of *Carex* species, the mean IV of tree species, non-native plants from walk-through richness, and native shrub richness. Our disturbance gradient accounted for 56% of the variation in the floodplain Veg-IBI scores. As in the headwater floodplain Veg-IBI, the mean IV of tree species with a facultative or greater rating was eliminated due to a Cowardin effect ($F_{2,18} = 9.39$; $p = 0.005$). The percent cover of native shrub species displayed a Cowardin effect ($F_{2,18} = 57.01$; $p = < 0.001$), an ecoregion effect ($F_{2,18} = 19.99$; $p = < 0.001$, and an interaction effect ($F_{4,18} = 20.32$; $p = < 0.001$).

With regards to the depression Veg-IBI scores, 31% of the variation in scores was attributed to the disturbance gradient. The scores of the depression Veg-IBI consisted of 2 metrics; the adjusted FQAI and the percent cover of native shrubs. The native shrub richness metric was removed after determining it exhibited a significant Cowardin classification effect ($F_{3,36} = 4.00$; $p = < 0.017$).

The metrics making up the impoundment Veg-IBI, which did not exhibit a significant relation

Table 5 Relations between the resulting class-specific vegetation indices of biological integrity (Veg-IBI) for wetlands in West Virginia, USA and the disturbance gradient from 2005–2006

Vegetation IBI	Metrics in Veg-IBI	*N*	*df*	*F* value	*p* value	R^2	Equation
Designated HGM management class							
Depression	2	72	1, 70	31.79	< 0.001	0.31	$y = 0.32 + 0.34$ (disturbance score)
Floodplain	5	35	1, 33	42.16	< 0.001	0.56	$y = -0.78 + 0.81$ (disturbance score)
Impoundment	2	23	1, 21	0.65	0.431	0.03	$y = 3.48 + 0.10$ (disturbance score)
Cowardin class							
Emergent	1	75	1, 73	11.91	0.001	0.14	$y = 3.47 + 0.12$ (disturbance score)
Scrub-shrub	2	44	1, 42	10.33	0.003	0.20	$y = 3.13 + 0.66$ (disturbance score)
Forested	5	31	1, 29	16.62	0.001	0.35	$y = 3.50 + 0.79$ (disturbance score)
Hybrid class							
Emergent/depression	2	38	1, 36	2.28	0.140	0.06	$y = 4.23 + 0.10$ (disturbance score)
Emergent/floodplain	6	16	1, 14	16.96	0.001	0.55	$y = 2.30 + 0.94$ (disturbance score)
Emergent/impoundment	3	14	1, 12	3.16	0.483	0.04	$y = 10.45 + 0.12$ (disturbance score)
Scrub-shrub/depression	4	19	1, 17	14.64	0.001	0.46	$y = 2.70 + 0.78$ (disturbance score)
Scrub-shrub/floodplain	6	8	1, 6	8.52	0.027	0.59	$y = -3.53 + 1.36$ (disturbance score)
Scrub-shrub/impoundment	3	7	1, 5	0.29	0.613	0.05	$y = 11.41 + 0.18$ (disturbance score)
Forested/depression	6	14	1, 12	8.56	0.013	0.42	$y = 6.17 + 0.89$ (disturbance score)
Forested/floodplain	9	11	1, 9	18.74	0.002	0.68	$y = 1.35 + 1.59$ (disturbance score)
Forested/impoundment[a]		2					

[a] Insufficient sample size

($p = 0.431$), included 2 metrics capable of discriminating between reference and stressed sites, the relative cover of monocot species, and the relative cover of *Carex* species. The robust adjusted FQAI metric was excluded after the post hoc ANOVA showed a significant relation to both Cowardin class ($F_{2,12} = 5.91$; $p = 0.031$) and ecoregion classification ($F_{2,12} = 6.07$; $p = 0.030$) in impoundment wetlands.

Dual classification approaches for the Veg-IBI

The sensitivity to disturbance increased in some instances when metric scores of the corresponding HGM classification were added. The emergent Veg-IBI sensitivity to disturbance increased when metrics from the floodplain designated HGM management class was combined with the emergent Veg-IBI (Table 5). However, the increase was negligible when compared to the sensitivity of the floodplain Veg-IBI alone.

Alternatively, when the metric scores from the scrub-shrub and forested Veg-IBI were combined with the corresponding designated HGM management class, the sensitivity increased in relation to both the Cowardin class Veg-IBI and the designated HGM management class Veg-IBI (Table 5). Impoundment Veg-IBI metrics, when evaluated with the scrub-shrub and forested Veg-IBI metrics, were still not significantly influenced by the disturbance gradient.

Discussion

Study design

Vegetation communities with high biological integrity are the desired endpoint representing least impaired wetland conditions (Brooks et al. 1998). Based on our objectives and analysis, the elimination of an ecoregion effect on the series of class-specific Veg-IBI enabled us to have a sufficient sample size to examine and contrast the more recent HGM approach (Brinson 1993) with the Cowardin approach. The decision to combine the regional HGM subclasses (Cole et al. 1997) into designated HGM management classes was based both on a need to increase sample size and to make IBI classifications intuitive to resource managers, rather than solely wetland specialists (Veselka et al. 2009). We believe our verification of no ecoregion or classification influences resulted in a series of intuitive and scientifically defensible Veg-IBIs that can be used to evaluate the effectiveness of measures aimed at meeting the Clean Water Act objective of biological integrity (Jackson and Davis 1994).

Metric performance by classification scheme

Vegetation indices of biological integrity were composed of 1–5 metrics depending on classification schemes. The most common metric was the adjusted FQAI that was included in three of the six resulting class-specific Veg-IBIs. The formula for this metric was revised (Miller and Wardrop 2006) from other floristic quality indices (Lopez and Fennessy 2002; Mack 2004; Nichols et al. 2006; Rentch and Anderson 2006), but the robustness is not unexpected, as it was essentially based on an established lineage of plant indices. We suggest the adjusted FQAI metric formula (Miller and Wardrop 2006) resulted in increased discrimination effectiveness between reference and stressed sites, potentially because the calculation incorporates a penalty for non-native plant richness.

The floodplain Veg-IBI was the only index significantly related to the disturbance gradient that does not include the adjusted FQAI as a metric. This was not because the adjusted FQAI did not discriminate between reference and stressed sites but rather because the mean Coefficient of Conservatism metric was more effective at discriminating between the reference and stressed sites. We suspect the penalty factor associated with the adjusted FQAI resulted in some of our reference sites scoring similar to that of the disturbed sites. These sites were deemed reference sites because they lacked characteristics of habitat, hydrology, or substrate alterations that can support the proliferation of non-native species in many instances (Drohan et al. 2006; Kercher and Zedler 2004; Galatowitsch et al. 1999). However, due to the nature of floodplains, they are already inherently prone to invasions by non-native species (Planty-Tabacchi et al. 1996). As a result, the mean Coefficient of Conservatism of plant species in each site was a better indicator of disturbed conditions, as it does not overtly penalize for the proportion of non-native richness. However, a separate metric measuring the non-native richness was still included in the floodplain Veg-IBI. This metric was simply the non-native species richness counted in the walk-through of the plant community, without adjusting for the ratio of non-native to native species mean Coefficient of Conservatism.

The forested Veg-IBI was composed of 5 metrics, 3 of them unique to this classification: the relative cover of fern allies, the relative cover of hydrophytic herbaceous herbs, and the relative cover of *Phalaris arundinacae* and other invasive grasses. Forested wetlands are considerably different both structurally, and often hydrologically, than other Cowardin classes; therefore, the majority of the metrics capable of discriminating between reference and stressed conditions would be unique.

Other metrics specific to one classification include the relative cover of monocot species metric for the impoundment Veg-IBI as well as the mean importance value (IV) of the tree stratum for the floodplain Veg-IBI. The relative cover of the monocot species metric increased with disturbance in impoundment wetlands. The impoundment Veg-IBI was not significantly related to the disturbance scores, although it was capable of discriminating between reference and stressed conditions. Impoundment wetlands are inherently products of altered hydrology, so in a sense, they are unique, as they represent a transition somewhere between the gradient of highly disturbed sites and those reaching a stable recovery point until natural hydrology can be restored. Identifying metrics that are significantly related to the disturbance gradient for impoundment wetlands also has been problematic using avian assemblages (Veselka et al. 2009). Therefore, as impoundment wetlands are themselves an anomaly (product of altered hydrology) in comparison to the other wetlands types, it is not altogether surprising that a metric not found in any of the other IBIs would be included in the impoundment Veg-IBI.

The mean IV metric was only used in the floodplain and derived from the tree stratum. Importance values for a tree species was calculated as one half the sum of relative tree basal area (relative basal area = basal area per species/total basal area of all species) plus relative abundance (relative abundance = number of a tree species/ total number of trees) in a community. The resulting measure can equal up to 100 for a single tree species and allows relative comparisons by standardizing the measurement of both tree size and frequency when comparing forest stands (Robertson et al. 1978; Smith 1996). However, the importance of basal area and, as a result, tree size is implicitly weighted because diameter increases basal area at an exponential rate as opposed to relative abundance. If trees were included in our survey of floodplain wetlands, it was generally indicative of a lessening degree of habitat alteration and low surrounding land-use impact, as many floodplains have historically been used for agriculture in West Virginia. These two factors were used in calculating our disturbance score for each wetland, which were used to determine the reference and stressed wetlands resulting in the inclusion of the metric in floodplain Veg-IBIs.

The only other metric that was used in multiple classes in addition to the previously noted FQAI metric was the relative cover of *Carex* species. It was included as a metric in the floodplain, impoundment, scrub-shrub, and forested Veg-IBI. However, the relative cover of *Carex* species as a metric for scrub-shrub Veg-IBI is not intuitively biologically meaningful and may be representative of the transition from emergent wetlands to scrub-shrub and forested wetlands. Nevertheless, the robustness of these metrics, spanning both Cowardin and designated HGM management classes within our study, was not altogether surprising.

The emergent Veg-IBI was composed of only 1 metric able to discriminate between reference and stressed conditions, the adjusted FQAI metric. This sole metric did exhibit a significant response to the disturbance gradient that accounted for a portion of the variation in the scores ($R^2 = 0.14$), although we expected more metrics suitable for inclusion into the emergent Veg-IBI. One explanation could lie in the variability of emergent wetlands. In our study, emergent wetlands were composed of high-elevation fens, high- and low-order floodplains, mitigated impoundment cells, and areas of poor drainage as a result of road or railroad tracks. We postulate that the variation in plant communities in the above-described wetlands throughout West Virginia was the primary reason that more candidate metrics did not adequately identify the stressed and reference conditions in emergent wetlands throughout the entire state.

Hybrid capacity of the Veg-IBI

With the exception of emergent wetlands, all other Veg-IBIs exhibited an increased sensitivity to the disturbance gradient by combining metrics from the alternate classification scheme. By combining metrics from the Cowardin class-specific and the designated HGM management class Veg-IBI, the number of metrics increased; however, the emergent Veg-IBI was comprised of only 1 metric, the adjusted FQAI metric. This metric was the most common metric discriminating between reference and stressed sites, resulting in the emergent Veg-IBI integrating its sole metric with other adjusted FQAI scores rather than bolstering the other vegetative indices. Regardless, the ability of the entire suite of both the hybrid scrub-shrub and forested Veg-IBIs to respond with greater sensitivity to disturbance supports the use of the approach and the need for continual research into integrating both classification systems from both a biological and regulatory perspective.

Implications for future monitoring programs

Wetland regulations are implemented at the local scale, as the filling and dredging of larger wetlands is generally permitted on a case-by-case basis. The Clean Water Act mandates that these activities should be conducted in a manner that maintains the biological integrity of the wetland as long as the wetland in question meets the jurisdictional requirements of the Army Corps of Engineers (USACOE 1987). The success or failure of mitigation projects resulting from the permitted activities typically hinges on a surrogate of biological integrity, such as the survival rate of a prescribed number of plants per acre. In part, because of the EPA (40 CFR Part 230) advocating mitigation banks as the preferred mitigation alternative, the statewide Veg-IBI may be used as the benchmark to define successful mitigation. The use of the Veg-IBI for this purpose will provide an in-depth level of accountability as to the relative success of a mitigation project, better ensuring "no net loss" of wetlands in West Virginia as it pertains to biological integrity.

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